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Green glass manufacturing: Approaches to sustainable production

Glass sustainability standards | Trinitite: Deciphering the glass born from destruction

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Green glass manufacturing: Approaches to sustainable production

While some green glass manufacturing methods are closer than others to commercial viability, they all contribute to the long-term goal of ensuring glass continues to be a vital, environmentally friendly material in the future.

by Lisa McDonald

Trinitite: Deciphering the glass born from destruction

Trinitite glasses, formed during the Trinity nuclear weapon test, demonstrate the intriguing connection between geochemistry, glass science, and cosmology resulting from humanity's insatiable quest for knowledge.

by S. K. Sundaram

Global sustainability: Toward a unified system of green glass standards

While steps toward developing and implementing global glass sustainability standards are being made, one impediment to adoption could be the sense in some countries that these standards must reflect the unique climate challenges they face.

by Randy B. Hecht

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As seen on *Ceramic Tech Today*...

Credit: Ashley Reese, Smithsonian American Art Museum

Contemporary botanical glasswork: The exquisite flora of Debora Moore

Many artists have used glass to capture the ephemeral beauty of nature. Contemporary glass artist Debora Moore uses her skills to create botanical models of flora she has seen on her travels around the world.

Read more at https://ceramics.org/Debora-Moore

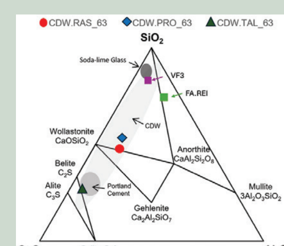
Also see our ACerS journals...

Modeling of physical–chemical and thermomechanical properties of glasses from recycled waste
By R. Ercoli, P. Stabile, G. Giuliani, et al.
International Journal of Applied Glass Science

Preparation of glass-ceramics based on Ti-bearing blast furnace slag and coal fly ash
By K-Q. Cao and G.-H. Zhang.
Journal of the American Ceramic Society

Heat transfer in nuclear waste glasses: Measurements and modeling of thermal radiation properties
By P. Ferkl, J. Marcial, J. C. Rigby, et al.
Journal of the American Ceramic Society

Flexural strength of glass with poly(methyl methacrylate)-silica nanoparticle composite coatings
By S. M. Becerra, H. Özbayraktar, E. Kilinc, and J. C. Mauro
International Journal of of Applied Glass Science



Credit: Ercoli et al., *IJAGS*

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news & trends

'FORGE'-ing ahead to protect critical mineral supply chains in the US

As transformative technology such as artificial intelligence rapidly evolves, these advancements will require the use of critical minerals and rare earths. To help position the United States at the forefront of a global market transformation for these materials, the U.S. government launched the Forum on Resource Geostrategic Engagement (FORGE).

On Feb. 4, 2026, the U.S. Department of State announced the launch of FORGE during the inaugural Critical Minerals Ministerial in Washington, D.C. The event hosted 55 foreign delegations from allied and partner nations, uniting under collaborative efforts for critical minerals security. Although a U.S.-led initiative, FORGE will be chaired by the Republic of Korea until June 2026.

FORGE serves as the successor of the Minerals Security Partnership (MSP), which was a U.S.-led initiative launched in 2022. Comprised of 14 countries and the European Union, the main goal of MSP was to catalyze public and private investment to ensure critical mineral supply chains were diverse and secure, with a focus on minerals and metals critical for clean energy technologies.

FORGE and MSP: What is the difference?

Although these two initiatives may not sound too different on the surface, they vary greatly in structure and strategy.

In 2021, the Biden–Harris administration found that the U.S. heavily relies on foreign sources and adversarial nations for critical minerals and materials. While some focused efforts were made to strengthen supply chains, it was ultimately decided that a widespread collaboration between partnering nations would make more significant strides. So, in 2022, the MSP was launched.

Overall, the Biden-era MSP functioned more like a funding vehicle, in which participating countries coordinated investments to fund mining projects in hopes of reducing reliance on China, which controls most of the market for cobalt, lithium, rare earths and other critical minerals. The MSP partner nations met multiple times throughout 2024, even creating a Minerals Security Partnership Forum to advance discussions with allied countries around the world. However, with the advent of FORGE, the MSP has not been rebranded or restructured—it has been replaced entirely.

FORGE is said to operate more like a preferential trading zone for participating countries rather than a minerals project funding vehicle. The 54 countries will together set reference prices at each stage of the supply chain, from mining, processing, and manufacturing to the consuming of critical minerals. The goal is to strengthen and diversify critical mineral supply chains while avoiding Chinese price dumps on minerals.

How the US plans to forge ahead

The U.S. push for critical minerals partnerships also comes at a pivotal time for the critical minerals and rare earths industry, as China has also begun their own partner initiatives. In November 2025, China began encouraging more countries to join their International Economic and Trade Cooperation Initiative on Green Mining and Minerals. This initiative reportedly has 20 participating countries, with an emphasis on partnering with developing countries such as Africa.

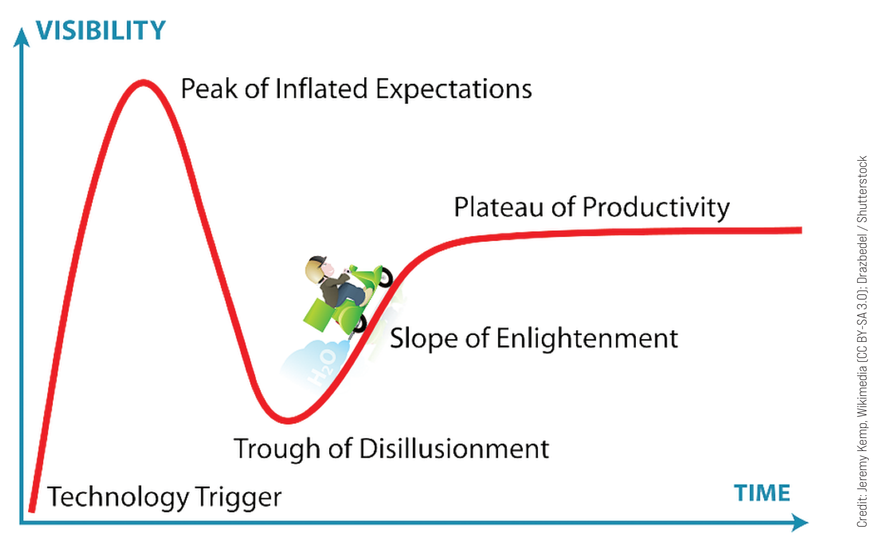
Besides the FORGE announcement, the Critical Minerals Ministerial also included the signing of several other memorandums of understanding and the announcement of a few more plans and agreements between nations. For example, the U.S.–Mexico Action Plan on Critical Minerals will bring the two countries together to "develop coordinated trade policies and mechanisms that mitigate critical mineral supply chain vulnerabilities," such as price ceilings and floors, according to a press release by the Office of the United States Trade Representative. (No bilateral agreement was signed with Canada.)

The U.S., the European Commission, and Japan also intend to develop action plans for critical minerals supply chain resilience, including discussions on border-adjusted price floors. Argentina and the U.S. also signed an Agreement on Reciprocal Trade and Investment.

Full details on FORGE and its functionalities have yet to emerge, but an abundance of partnerships and agreements have created a path for the U.S. to lead in a global market transformation of critical mineral and rare earths supply chains. Coordinated efforts to ensure that these initiatives are well aligned within participating nations will likely become crucial as these efforts develop and expand. ■

Hype cycles: The uphill climb for hydrogen bikes

You may be familiar with the Gartner Hype Cycle, which provides a graphical representation of the maturity and adoption of a technology or innovation over time. Hydrogen bikes are currently somewhere in the Trough of Disillusionment. Will they ever start the climb up the Slope of Enlightenment?



The Gartner Hype Cycle, illustrated above, is a good way to conceptualize the current development of hydrogen bikes.

Technology Trigger: Sparking a sustainable idea

Electric bikes (e-bikes) are not a new concept. As soon as the Rover Safety bicycle made its debut in 1885, offering all the core features of standard modern bicycles, inventors were looking for ways to strap an electric motor on it. In 1895, Ogden Bolton Jr. was awarded a U.S. patent for a DC-motor powered electric bike. But for many years after that, e-bikes remained experimental and heavy due to their lead-acid battery power sources.

The oil crisis of the 1970s prompted additional research into e-bike designs. But e-bike technology did not really take off until the early 2000s when lithium-ion batteries, which became commercially viable in the early 1990s, started being used.

As with electric vehicles, e-bikes have the drawbacks of long charging times and limited ranges. On average, an e-bike battery needs 3 to 6 hours to fully charge, and that charged battery will last a distance of 20 to 50 miles (30 to 80 km), depending on how much the rider pedals.

Hydrogen fuel cells could provide a solution to the challenges of long charging times and limited ranges. Rather than relying on stored electricity, like battery-powered e-bikes do, fuel cells function like an onboard power plant that produces electricity upon demand. Relying on stored fuel rather than stored electricity can allow for faster refueling, greater range, and potentially a longer lifespan.

Hydrogen fuel cells have been used in mass-produced vehicles for almost the last two decades. Compressed hydrogen has an energy density of 120 MJ/kg, approximately three times that of oil, making it an attractive fuel source. In addition, modern hydrogen fuel cells are two to three times as efficient as gas-powered internal combustion engines.

Regarding the use of fuel cells in bicycles, early hydrogen bikes were first prototyped in 2000, but the rapid development of modern hydrogen fuel cells in the 2010s were the true Technology Trigger for hydrogen bike technology. This development accelerated hydrogen bikes into the next stage of the Gartner Hype Cycle: the Peak of Inflated Expectations.

Peak of Inflated Expectations: The rise, fall, and resurgence of Youon Technologies

Chinese cities have leaned hard into hydrogen bike sharing programs, in part because of safety concerns around lithium-ion batteries. But even in such a large market of urban centers as China, hydrogen bikes have struggled to overcome barriers to commercial adoption.

For example, a June 2024 article in *South China Morning Post* detailed the rollout and subsequent recall of shared hydrogen bikes in Shanghai using stock supplied by Youon Technology. This Chinese bicycle systems manufacturer is by far the most established company in the hydrogen bike space, so the recall had an immediate impact.

As of March 2025, however, it appears that Youon Technology's fortunes have reversed. It is under new leadership and new ownership. A subsidiary of Hello, China's largest bike-sharing provider, is becoming the majority shareholder in Youon Technology.

Trough of Disillusionment: Commercial adoption of hydrogen bikes

As with other innovations, the biggest hurdles to hydrogen bike commercialization are infrastructure, technology maturity, cost, and market readiness.

Infrastructure

The biggest hurdle to hydrogen bike commercialization is the currently limited infrastructure for refueling hydrogen vehicles. As of 2025, the only commercial hydrogen refueling stations in the United States are in California. Industrial hydrogen can be purchased from gas suppliers, but those suppliers typically require large bulk purchases. Their hydrogen is also more likely to be a byproduct of fossil fuel production, which negates the point of using so-called clean hydrogen in the first place.

Technology maturity

Each hydrogen fuel cell has a low power capacity (typically less than 1 V), so they are packaged in stacks of multiple fuel cells to supply enough power to the bike. Efforts toward improved power density continue, specifically with the aim of miniaturization. Higher power density makes smaller fuel cells possible, which increases their application in smaller vehicles, such as drones.

Cost

The production cost of green hydrogen (from renewable sources by hydrolysis) is currently much higher than that of hydrogen from steam-methane reforming or biogas reforming. Additionally, most hydrogen fuel cells use a platinum catalyst, which further drives up the technology's cost. Research on nickel or iron catalysts, among other materials, is ongoing. The hydrogen bikes themselves are also expensive in comparison to conventional battery-powered e-bikes.

Market readiness

Even if these other challenges are overcome by innovation, market readiness is difficult to induce. Individual hydrogen bikes for household use remain prohibitively expensive, which keeps demand low and reduces the incentive for further innovation.

Currently, hydrogen bikes seem best suited for niche applications. For example, they could be used in delivery fleets or shared mobility programs (think Citi Bike, Indego, Capital Bike Share, or Divvy) where centralized refueling infrastructure can be more easily managed.

Slope of Enlightenment: The outlook for hydrogen bikes

Adoption of hydrogen power for many types of transport should not be as much of an uphill climb as it is. If hydrogen is produced by renewable energy from electrolysis, it generates no harmful byproducts. Yet significant challenges to green hydrogen production, transport, and storage remain—with efficiency losses at each step.

Given these challenges, what would be required to begin climbing the Slope of Enlightenment? Household-scale domestic hydrogen production from renewable sources would reduce efficiency losses and has been demonstrated as achievable. Hydrogen is already making inroads as a fuel for buses, heavy trucks, and trains, where battery limitations are more of an issue.

Hydrogen bikes may become more common as a complement to, rather than a replacement for, battery-powered e-bikes. Their presence in the market offers diversity and resilience to the e-mobility ecosystem. However, it remains to be seen if these hype cycles will ever make the triumphal ride through the Plateau of Productivity. ■

Corporate Partner news

Alteo Alumina enters long-term partnership agreement with HES Fos

Alteo Alumina signed a long-term agreement with HES Fos, a subsidiary of HES International, to cover the maritime unloading, storage, and downstream logistics of hydrated alumina that is going to Alteo's industrial site in Gardanne, France. The strategy aligns with Alteo's decarbonization strategy. Read more: https://www.hesinternational.eu/en/newsroom

MRF collaborates on advanced materials testing with the University of Arizona

Materials Research Furnaces partnered with the University of Arizona's Department of Materials Science and Engineering to develop a high-temperature, high-vacuum physical testing furnace. The new furnace will support next-generation aerospace innovation, advancing research in hypersonic flight, defense technologies, and additive manufacturing. Read more: https://mrf-furnaces.com/news

Fraunhofer IKTS-coordinated automotive project highlighted as 'exemplary initiative'

The project "BeaT – Renewing Vocational Training for the Automotive Transformation," coordinated by Fraunhofer IKTS and implemented in collaboration with automotive thüringen e.V. and Friedrich Schiller University Jena, was highlighted as an exemplary initiative by the EU Commission's Good Practices Catalog Vol. 1. The BeaT project works to address vocational training concepts that come with preparing the workforce for the electrification of the automotive industry. Read more: https://www.ikts.fraunhofer.de/en/press_media.html

Niterra selected for fifth year as member of S&P Global's Sustainability Yearbook 2026

Japan-based Niterra Co., Ltd., a leading Japanese manufacturer of sparkplugs and sensors, was selected as a member of S&P Global's Sustainability Yearbook 2026. In 2026, 848 companies were recognized for their sustainability excellence out of more than 9,200 companies. This selection marks the fifth consecutive year that Niterra has been recognized. Read more: https://www.niterragroup.com/english/news

Sunrock Ceramics acquired by PPT Group

Illinois-based Sunrock Ceramics, a specialized manufacturer of high-purity refractory ceramics, announced it was acquired by Power Processing and Technology LLC. Doug Thurman, president of Sunrock Ceramics, says in a press release that "This transaction provides Sunrock Ceramics with the capital and strategic support needed to continue scaling the business." Read more: https://www.sunrockceramics.com/blog ■

Green glass manufacturing: Sustainable processing and applications

Glass manufacturing is a carbon-intensive process, and many in the industry are working to reduce the sector's environmental footprint.

Two recent BCC Research reports demonstrate solutions to green glass manufacturing in both the processing and application realms.

Industrial furnaces: Electric and hydrogen firing reduces emissions

The global industrial furnaces market was valued at $11.4 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 4.5% to reach $14.7 billion by the end of 2028.

Industrial furnaces are a vital part of major industries for the processing of various materials, such as steel, glass, and chemicals. Advancements in furnace technology are aimed at helping users maximize operational efficiency through preventive maintenance while minimizing the environmental footprint and total cost of ownership.

Heat is generated in a furnace using a variety of methods, including the burning of fuel or the conversion of electricity to heat. Currently, the most common type of furnace is powered by fossil fuels. However, across the world, emissions standards are tightening. The growing popularity of carbon-free furnaces is creating new business prospects in the industrial furnaces market.

Hybrid furnace technology offers a positive route forward for the industrial furnaces market as it holds the promise of significantly reducing carbon emissions. Hybrid technology can cut direct furnace carbon emissions by replacing natural gas with alternative fuels, such as hydrogen, or renewable electricity. Such new developments in furnace technology are taking the industrial sector to the next level. For instance, in December 2022, Encirc, a leading glass manufacturer, announced a hydrogen-powered furnace that helps reduce carbon emissions by 90%.

Green building materials: Glass innovations support healthier living

The global market for green building materials was valued at $332 billion in 2024 and is expected to grow at a CAGR of 14% to reach $709 billion by the end of 2030.

Green building materials are designed to minimize resource consumption, lower carbon emissions, and promote healthier living environments throughout a building's lifecycle. These materials generally include low-carbon cement, recycled or green steel, reclaimed wood, bio-based insulation, solar-integrated materials, and high-performance glazing systems.

There are various ways that glass contributes to the green building landscape:

- **Low-emissivity (low-E) glass** is made to let natural light into buildings while minimizing heat transfer. It usually has a thin layer that reflects infrared light, reducing heat loss in the winter and mitigating heat gain in the summer.
- **Thermochromic glass**, which can adjust transparency based on temperature, also helps with regulating indoor climates by modulating the amount of light that can pass through the glass.
- **Photovoltaic building materials** integrated with glass and roofing tiles directly generate energy from building surfaces.
- **Fiberglass** is a promising structural material for windows and door frames. Thermoset fiberglass is dimensionally stable and about 10 times stronger than conventional vinyl, allowing frames made from fiberglass to withstand higher wind loads and extreme temperatures (from −40°F to more than 350°F).

Additional sustainability approaches

These reports highlight just two of the many aspects of transitioning to a more environmentally friendly economy. Explore additional approaches in these three reports:

- BCC Publishing Staff, "Circular economy: A global outlook," BCC Research Report ENV073A, August 2024. https://bit.ly/August-2024-circular-economy
- BCC Publishing Staff, "Global markets and technologies for smart glass," BCC Research Report AVM065E, January 2025. https://bit.ly/January-2025-smart-glass
- BCC Publishing Staff, "Carbon capture, utilization & storage technologies," BCC Research Report EGY037G, February 2025. https://bit.ly/February-2025-CCUS

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, "Industrial furnaces: Global markets," BCC Research Report ENG011B, February 2024. https://bit.ly/February-2024-industrial-furnaces

BCC Publishing Staff, "Green building materials: Global markets," BCC Research Report AVM239B, July 2025. https://bit.ly/July-2025-green-building ■

By Caio Bragatto
Guest columnist

For the love of borates: Carrying the mantle of Steve Feller

Historically and currently, soda lime silicate is the most common type of glass used globally, serving as the windows and bottles surrounding us in everyday life. While alternative glass compositions sometimes made an appearance throughout the centuries,[1] the emergence and reliance on specialized glasses did not become prevalent until the end of the 19th century with the development of borate glasses.

Borate glasses contain boron oxide (B_2O_3) as one of their main network formers. The boron and oxygen atoms can take two possible arrangements—either a planar trigonal BO_3 unit or a 3D tetrahedral BO_4 unit. The relative concentrations of these arrangements relate to different glass properties, such as the glass transition temperature.[2,3]

Borosilicate is generally recognized as the first, and most significant, type of modern commercial borate glass.[4] English chemist and physicist Michael Faraday created an early version of this glass type in the 1820s, but Otto Schott in Germany ultimately developed it into a commercial formulation for laboratory equipment and pharmaceutical packaging near the end of the 19th century. About two decades later, researchers at Corning in the U.S. developed their own version of borosilicate glass, branded as Pyrex, for use as consumer cookware.

To better understand the borate glass network, Phillip J. Bray and collaborators at Brown University pioneered the use of nuclear magnetic resonance (NMR) in glassy systems, developing different predictive models on the structure of these glasses starting in the late 1950s.[5] Steve Feller was part of Bray's group during his Ph.D. studies in the 1970s, and he helped improve the group's simple mathematical quantitative models using the newly discovered technique of magic angle spinning (MAS).[6]

After graduation, Feller wanted to continue his research on borate glasses, but specifically at an institution that valued his passion for education and mentoring (Figure 1). So, he moved to Iowa to become a physics professor at the small liberal arts institution Coe College, where he stayed his whole career.

Even though Coe is exclusively an undergraduate institution, Feller established a renowned glass research center at the school to continue his passion for glass science. With the help of more than a hundred undergraduate students over his 40 years as a professor, Feller's group uncovered many underlying aspects of the glass structure–property relationship.[7] Many collaborators around the world aided in these discoveries, and one of Feller's last articles reviews what is known about the fraction of three- and four-coordinated boron in borate glasses thanks to the collective's use of various spectroscopy techniques.[8]

However, the boron coordination ratio by itself cannot explain all the property changes observed in borate systems. So, Feller also sought to understand the effects of packing fraction on glass properties for an extensive compositional range.

Feller died on Nov. 19, 2025. He leaves behind not only a substantial body of work but a passion for glass science that resides in his mentees, collaborators, and friends. It is our duty to carry his mantle, both for advancing the understanding and use of borate glasses and his deep care for future generations.

About the author

Caio Bragatto is assistant professor of ceramic engineering at the New York State College of Ceramics at Alfred University. Before, Bragatto was fortunate to work alongside Feller for six years at Coe College. Contact Bragatto at bragatto@alfred.edu.

Credit: Caio Bragatto

Figure 1. Feller holds an alumina crucible containing borate glass made from boric acid melted with a blowtorch. The demonstration took place during a visit to Tuskegee University in Alabama in January 2023.

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[8]O. L. G. Alderman et al., "A review of the fraction of four-coordinated boron in binary borate glasses and melts," *Rep. Prog. Phys.* 2025, **88**: 076501.

By David Holthaus
Industry reporter

How organizations are overcoming challenges in the glass recycling ecosystem

Driven by the potential for cost savings, energy reductions, and fulfilled sustainability goals, glass manufacturers are increasingly incorporating recycled glass into their products.

Glass is theoretically infinitely recyclable, creating a huge potential to use waste glass, or cullet, as raw materials for a variety of glass products, including container glass and flat glass. The savings for manufacturers can be significant, and the practice of using cullet is an area where economic advantage and environmental performance come together.

Recycled glass melts at lower temperatures than virgin raw materials, saving energy costs and reducing wear on furnaces. The industry standard is that for each 10% increase in the use of cullet, energy use is cut by about 3%, says Matthew Kirian, project manager at the regional industry coalition Northwest Ohio Innovation Consortium (NOIC), in an interview. A 10% increase in cullet can also save about 20% in raw material use, he adds.

Beyond the economic advantages, the use of cullet can reduce carbon dioxide emissions and take glass products out of the waste stream, thereby conserving landfill space and making it a proven practice for improving sustainability.

Although the market for recycled glass is expected to continue growing significantly, its growth faces challenges. The most significant is the lack of an efficient ecosystem to enable the collection of cullet of sufficient quality to be recycled into new glass products.

"The volume is not where it needs to be," says Eric Muskovin, laboratory project leader at CelSian, in an interview. CelSian is a Netherlands-based glass industry consulting firm with U.S. offices in Toledo, Ohio.

"Everybody in the glass industry is looking to increase their cullet percentage, lower energy rates, and decrease carbonization across all platforms," Muskovin says. "But there's just not a whole lot of clean cullet out there, and the volumes are very, very small."

A major factor is the widespread use of single-stream recycling, particularly in the United States.[1] Recycling programs typically allow for glass to be recycled with other materials such as plastic and cardboard. That makes it more convenient for consumers and may result in more consumers recycling their goods. But it creates a comingling of materials that can result in the contamination of glass. The result is that only 40% of glass recycling is actually accepted at material recovery facilities, according to the Glass Packaging Institute.[2]

To improve that rate, Kirian says that NOIC is leading two programs in Northwest Ohio to create a framework for a glass circular economy that could be used as a model for other regions to replicate. The consortium has deployed six centralized collection points for residents of two major counties in the region to deposit glass-only products. The discarded glass is then taken directly to a processor to be cleaned and sorted per customer specifications.

NOIC is also conducting a bar and restaurant program to educate employees and owners about keeping glass separate, and it is providing support to implement the recommended practices. The program resulted in the collection of about 120 tons of good glass in six months, Kirian says.

CelSian also launched a project recently to improve the standardization of cullet sampling. As Muskovin explains, "One of the big problems in the industry is some of the ambiguity surrounding effective sampling techniques, making sure you know exactly what is in that pile of material." The project involves using different sampling techniques to maximize the amount of data that can be gathered and make it easier for cullet suppliers to sample more effectively.


Credit: Schott

Figure 1. Glass manufacturers such as Schott are exploring ways to increase the availability of clean cullet for their industrial processes. In this picture, Schott employees examine cullet as part of a pilot project to recycle glass pharmaceutical vials.

Major glass manufacturers are also moving forward with ways to increase the availability of clean cullet for their industrial processes:

- **Schott** (Mainz, Germany) is a specialty glass manufacturer that for decades has used cullet as a raw material for production. It is now exploring ways to return used glass-ceramic cooktop panels and pharmaceutical packaging to the production of new products (Figure 1).[3] According to Schott's calculations, around three million glass-ceramic cooktop panels, equaling 10,000 tons of glass-ceramic, will end up in landfills in Germany in 2030 alone. The scarce metal lithium, needed for electric car batteries, is a component of glass-ceramic cooktop panels, and the project holds the potential to keep lithium in the production cycle.

- **O-I** (Perrysburg, Ohio) operates more than 20 glass recycling programs throughout the U.S. In 2025, the company announced a target of achieving an average of 60% recycled content in its packaging globally by 2030.
- **Ardagh Glass Packaging-North America**, a unit of Luxembourg-based Ardagh Group, announced in April 2025 a long-term partnership with one of the largest U.S. recyclers of glass, CAP Glass (Mt. Pleasant, Pa.), to establish glass recycling services throughout the country.
- **Vetropack** (Zurich, Switzerland), a large manufacturer of glass containers, committed to increasing the proportion of recycled content in its products to 70% by 2030.
- **Solarcycle** (Mesa, Ariz.), a solar panel recycling company, began operations in 2026 at a new facility in Cedartown, Ga. that will more than double the throughput of the company's first-generation recycling lines. The recycling facility is located next to the site of a future solar glass manufacturing plant, which will create an integrated campus to recover and remanufacture solar panels.

Major beverage and consumer brands are also demanding higher recycled content in their packaging. For example, AB InBev (Leuven, Belgium), owner of hundreds of global consumer brands, including Budweiser and Michelob, has a goal of making 100% of its packaging returnable or made from majority recycled content.

As the demand for glass products of all kinds continues to grow—and the calls increase for adopting environmentally friendly production practices—the introduction and expansion of new recycling technologies and processes is likely to continue growing as well.

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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*References verified as of March 6, 2026. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

Introducing the ACerS Innovation Fund

The American Ceramic Society recently launched an Innovation Fund to support bold ideas from ACerS members.* The Fund will subsidize potential revenue-generating products and services that will benefit the ceramics, glass, and materials community. Examples of potential proposals include

- A searchable database of glass properties offered as a paid subscription;
- An expert consultant matching service connecting companies with ACerS member specialists; or
- A new meeting format, such as a learning or networking event at a unique location.

Any ACerS member can submit a proposal individually or as part of a group, such as a Division, U.S. Section, ACerS International Chapter, Committee, Principal Activity Committee, or SPEO. Co-investment from external partners is welcome.

Visit https://ceramics.org/innovation-fund to learn more about the Innovation Fund and submit your proposal.

Key details

- Funding per proposal: $5,000–$25,000 (larger amounts considered case by case)
- Submission deadline: **July 1, 2026** (first round of successful proposals to be announced at ACerS Annual Meeting at MS&T 2026)
- Items to include: Proposals must include a detailed itemized budget and address the financial potential of the idea
- Length of funding: Projects may spend allocated funds over up to three years

**Disclaimer: The Fund is not for research grants, travel funding, complimentary conference registrations, or other forms of individual financial support.* ■

Eastern Tennessee Section sponsors 'Best Poster' at University of Tennessee Student Night

Vincent Garcia, center, receives the Best Poster award from the Eastern Tennessee Section.

ACerS Eastern Tennessee Section members attended the University of Tennessee's Center for Advanced Materials & Manufacturing Student Night on Feb. 12, 2026.

Section members who attended the Student Night included several researchers from Oak Ridge National Laboratory—Steve Bullock, Max Mudugno, Dan Delia, Corson Cramer, and Trevor Aguirre—and University of Tennessee Assistant Professor Dustin Gilmer.

A best poster award was granted to Vincent Garcia for his work on "Synthesis of compositionally complex rare earth aluminum garnets (CCREAGs)." Garcia received a $300 gift card. ■

FOR MORE INFORMATION:

ceramics.org/spotlight

ACerS Dayton/Cincinnati/Northern Kentucky Section participates in TechFest 2026

The ACerS Dayton/Cincinnati/Northern Kentucky Section participated in TechFest 2026 on Feb. 14–15, 2026, at Sinclair Community College in Dayton, Ohio.

TechFest is Ohio's premiere STEM event and brings more than 90 exhibitors and presenters together for K–12 students and their families. More than 2,500 people attended the event this year and experienced robotics, computers, engineering, and unmanned aerial systems.

The local ACerS Section demonstrated thermal shock resistance of various types of glass, the effect of heat treatment on the mechanical properties of bobby pins, and the principle of light guiding in optical fibers. For the two-day event, students from the University of Cincinnati and scientists from AeroVironment, the Air Force Research Laboratory, and Arctos volunteered for booth setup and demonstrations. Section members plan to participate in the event again next year to introduce the world of ceramics to future ceramists. ■

Volunteers from the University of Cincinnati at TechFest 2026.

ACerS Section members interacting with booth visitors.

MEMBER HIGHLIGHTS

Volunteer Spotlight: Fumie Iizuka and Federico Smeacetto

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

Fumie Iizuka is assistant professor of anthropology at the University of Wisconsin-Madison and an affiliated researcher in the Center for Northeast Asian Studies at Tohoku University, Japan. She received her M.A. in anthropology from the University of California, Santa Barbara, and her Ph.D. in anthropology from the University of Arizona. Prior to joining UW-Madison, she was affiliated as a researcher with institutions including the Research Reactor Center and the Department of Anthropology at the University of Missouri; the University of California, Merced; and Tokyo Metropolitan University. She also taught at a variety of institutions including the University of California, Merced; the University of California, Los Angeles; and California State University, Fullerton.

Iizuka uses geochronology and reconstructed ceramic technology to investigate decisions made by hunter–gatherers and early farmers who adopted pottery and associated technologies in response to climate and ecosystem changes. Her current geographical foci are Japan and Mongolia, with primary research conducted on Tanegashima Island in southern Japan, where there is an excavation site bearing Ice Age pottery. Her research has been funded by the National Science Foundation, Japan Society for Promotion of Science, and Smithsonian Institution.

Iizuka was chair of the Art, Archaeology & Conservation Science Division (AACS) in 2024–2025. Through AACS, she chaired a symposium at the 16th Pacific Rim Conference in 2025 and co-chaired symposia at the Pan-American Ceramics Congress in 2022 and 2024. She is a recipient of the Claude C. Albritton Jr. Award from the Geological Society of America.

Federico Smeacetto is full professor of materials science and technology at Politecnico di Torino, Italy. He received his M.S. in chemistry from the University of Torino and Ph.D. in materials science and technology from Politecnico di Torino. Following his doctorate, he worked as a researcher at Imperial College, London; the University of Hertfordshire, United Kingdom; and AGH-UST, Poland before moving to Politecnico di Torino.

Smeacetto leads a research group of eight-plus tenure-track postdoctoral researchers and Ph.D. candidates to develop engineering solutions for the design, development, and characterization of functional glass and ceramics as joining and coating materials for hydrogen conversion, with a focus on integration and recycling strategies. He is principal investigator on several European Union-funded projects and contracts mainly related to hydrogen technologies, namely GriNHy, NewSOC, HyP3D, 24_7 ZEN, Solstice, Ecolefins, H2Shift, H2START, and DESIREE.

Smeacetto has been a member of the Engineering Ceramics Division since 2004. He is currently chair-elect of the Engineering Ceramics Division (2025–2026) and served as program chair of the Golden Jubilee Celebration of the 50th ICACC in January 2026. Smeacetto has been awarded the prestigious ACerS Global Ambassador designation and was elevated to ACerS Fellow in October 2025.

We extend our deep appreciation to Iizuka and Smeacetto for their service to our Society! ■

FOR MORE INFORMATION:

ceramics.org/membership

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.

Cato T. Laurencin, FACerS, the Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopaedic Surgery and professor of chemical and biomolecular engineering, materials science and engineering, and biomedical engineering at the University of Connecticut, received the Blaise Pascal Medal for his "transformative" contributions to biomaterials and regenerative engineering during the European Academy Annual Symposium and Ceremony held in Geneva, Switzerland, in December 2025. ■

Ceramic Tech Chat: Mario Affatigato

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.

In the February 2026 episode of Ceramic Tech Chat, **Mario Affatigato**, the Fran Allison and Francis Halpin Professor of Physics at Coe College, shares how his initial experiences with glass research as a student at Coe came full circle when he returned to Coe as a professor, describes the fundamental and applied glass science that his research group conducts, and discusses his plans and goals as president of ACerS this year.

Check out a preview from his episode, where he talks about the benefits of doing research as an undergraduate student.

"One [benefit] is that undergraduate students are rarely exposed to high-tech, high-end, research-grade equipment. What you want is for the students to begin to discover the world of high-end instrumentation, but at the same time also get over the fear of using high-end instrumentation. Many undergraduates, when they find out that the instrument they are learning is worth half a million, quarter million, three quarters of a million, there are a lot of nerves: They are nervous about damaging it. But that's a fear you must get over because you often cannot do materials research without utilizing these research-grade instruments."

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

AWARDS AND DEADLINES

Nomination deadlines for Division awards: May 15, July 1, or August 1

Contact: **Vicki Evans | vevans@ceramics.org**

Division	Award	Deadline	Contacts	Description
GOMD	Alfred R. Cooper Scholars Award	May 15	Steve Martin swmartin@iastate.edu	Recognizes undergraduate students who demonstrated excellence in research, engineering, and/or study in glass science or technology.
EDIV	Edward C. Henry Award	May 15	Eric Patterson eric.patterson@nrl.navy.mil	Recognizes an outstanding paper reporting original work in *Journal of the American Ceramic Society* or the *Bulletin* during the previous calendar year on a subject related to electronic ceramics.
EDIV	Lewis C. Hoffman Scholarship	May 15	Eric Patterson eric.patterson@nrl.navy.mil	Recognizes academic interest and excellence among undergraduate students in ceramics/materials science and engineering.
ECD	Mrityunjay Singh Bridge Building Award	July 1	Federico Smeacetto federico.smeacetto@polito.it	Recognizes individuals outside of the United States who have made outstanding contributions to engineering ceramics, international collaboration, and outreach
ECD	Global Young Investigator	July 1	Yuki Nakashima nakashima-yuki@aist.go.jp	Recognizes the outstanding young ceramic engineer or scientist whose achievements have been significant to the profession and to the general welfare of the community around the globe. Nominations are open to candidates from industry, academia, or government-funded laboratories around the world.
ECD	James I. Mueller Lecture	July 1	Amjad Almansour amjad.s.almansour@nasa.gov	Recognizes the accomplishments of individuals who made similar contributions as James I. Mueller to the Engineering Ceramics Division and to the field of engineering ceramics.
ECD	Jubilee Global Excellence Award	July 1	Michael Halbig michael.c.halbig@nasa.gov	Recognizes exceptional early- to mid-career professionals who are women and/or underrepresented minorities (i.e., based on race, ethnicity, nationality, and/or geographic location) in the area of ceramic science and engineering.
EMSD	Outstanding Student Researcher	August 1	Sepideh Akhbarifar sepideha@vsl.cua.edu	Recognizes exemplary student research related to the mission of ACerS Energy Materials and Systems Division.

FOR MORE INFORMATION:

ceramics.org/awards

Bringing materials science to BOCES teachers in Alfred, NY

The Ceramic and Glass Industry Foundation (CGIF) recently collaborated with Alfred University's Inamori School of Engineering to bring materials science classroom activities to educators in Belmont, N.Y., through a professional development workshop hosted by the New York Board of Cooperative Educational Services (BOCES). Led by CGIF Program Manager Nathan McIlwaine, the session introduced 11 elementary and middle school science teachers to hands-on lessons from the CGIF's Mini Materials Kit and online lesson resources designed to make complex science concepts accessible across the K–12 level.

The workshop was organized in collaboration with Professor Benjamin Moulton, outreach coordinator Amelia Overbye, and Ph.D. candidate Grace Dunham. These volunteers presented on the background of materials science, glass, and ceramic engineering, and they showed workshop attendees how the CGIF's outreach resources connect to different pathways that students can pursue after high school, from university programs such as at Alfred to careers in the field.

Belmont sits within a unique corridor of materials innovation, positioned between Rochester's photonics industry, Corning's global leadership in glass manufacturing, and the long-standing ceramics manufacturing presence in Buffalo and throughout New York State. Supporting STEM outreach in this region, with a leading ceramics and glass science university just down the road, helps connect classrooms directly to the industries shaping the local economy.

Rather than simply observing demonstrations, teachers practiced facilitating the lessons themselves using activities from the CGIF's Mini Materials Kit and online resources. These lessons are designed specifically for K–12 educators to bring interactive materials science learning into their classrooms. The kits introduce students to foundational concepts in ceramics, metals, polymers, composites, and glass through experiments aligned with core STEM standards.

One of the most popular activities was the "How Strong Is Your Chocolate?" lesson, which explores how material structure and processing affect strength. Teachers tested and compared samples while discussing how engineers evaluate material properties, processing, and performance. Teacher Jillian Filbert from Wellsville Central School shared afterward that "The chocolate experiment was super easy and super fun."

Participants also explored the "Candy Fiber Pull" activity, which uses simple materials to demonstrate deformation and materials behavior, making it especially useful for classrooms with limited lab equipment. Another highlight was the Nitinol wire lesson, which introduces students to shape memory alloys and phase transformations.

Throughout the workshop, teachers also discussed practical strategies for adapting activities across grade levels, integrating lessons into existing units, and connecting experiments to science standards. Michelle Sullivan, an elementary STEAM teacher from Prospect Elementary School, says her favorite part of the workshop was "seeing all of the great lessons that I can bring back and use with my students."

CGIF CERAMIC AND GLASS INDUSTRY FOUNDATION

Elementary and middle school science teachers listen as members of Alfred University's Inamori School of Engineering explain some of the hands-on activities in the CGIF's Mini Materials Kit.

Workshop participants testing the strength of different chocolate bars during the "How Strong Is Your Chocolate?" activity.

Jolly Ranchers being melted in a beaker for the "Candy Fiber Pull" activity.

A teacher, left, helps demonstrate the Nitinol wire activity alongside CGIF Program Manager Nathan McIlwaine, right.

The CGIF's teacher training workshops are part of a broader suite of teacher resources that include free lesson plans, video demonstrations, and opportunities for educators to request classroom science kits. These resources help teachers bring materials science concepts, from thermal processing to mechanical testing, into everyday instruction.

By equipping educators with both the tools and confidence to teach materials science, the CGIF expands access to hands-on STEM learning while supporting teachers in their ongoing professional growth.

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

Colors of history: Four studies paint a picture of past pigment use and development

Color is a fundamental element of our biological and cultural experiences of the world. Knowing the history of different pigments can give us deep insight into past societies, as demonstrated by the four studies summarized below.

World's first synthetic pigment recreated

Blue is considered the most popular color globally in modern times even though this color is rarely found in nature. The prevalence of blue in human culture changed about 2500 BCE following the development of a synthetic blue dye by ancient Egyptians.

Egyptian blue became popular around the Mediterranean region for more than 3,000 years, but the pigment went out of use during the Renaissance (14th–17th centuries). However, renewed interest in Egyptian blue due to its unique optical, magnetic, and biological properties inspired a team of researchers led by Washington State University, in collaboration with Carnegie Museum of Natural History and the Smithsonian's Museum Conservation Institute, to recreate the pigment.

Egyptian blue is a calcium copper silicate material, with the main coloring agent being cuprorivaite. The pigment can be quite heterogeneous, however, and commonly includes other materials such as silicate glass, the minerals cristobalite and tridymite, and sometimes wollastonite. These inclusions affect the final tone of the pigment, allowing it to range from deep blue to dull gray or green.

To better understand the effect of these inclusions on the final blue tone, the researchers created 12 different recipes of Egyptian blue. Comparison with ancient Egyptian blue pigments found in artifacts at Carnegie Museum of Natural History and in the literature confirmed that a multiphase mixture was the "rule rather than the exception," the researchers write in the paper describing their experiments.

The open-access paper, published in *npj Heritage Science*, is "Assessment of process variability and color in synthesized and ancient Egyptian blue pigments" (DOI: 10.1038/s40494-025-01699-7).

Oldest blue pigment ever discovered in Europe

Sometimes the greatest discoveries are hiding right under our noses. That was the case for a group of archaeologists from Denmark's Aarhus University when they were reexamining a purported Paleolithic oil lamp housed at Mühlheim City Museum in Germany.

As explained in a *Smithsonian* magazine article, the archaeologists originally examined the artifact for traces of animal fat to confirm its use as a lamp. But they noticed small dots of blue pigment on the concave part of the bowl-shaped object.

The archeologists initially thought modern ink had gotten on the artifact, but further analysis revealed the spots are one of the oldest blue pigments in the world at around 13,000 years old. (The oldest blue pigment was found on figurines in Siberia, dated between 19,000 and 23,000 years ago.)

X-ray fluorescence and microscopic imaging tests showed the synthetic pigment was created from azurite, a mineral native to the area in Germany where the artifact was originally found. Because the blue spots were only found on the concave part of the artifact, the archaeologists hypothesis it may have been used as a palette or a mixing tool rather than a lamp.

"The presence of azurite shows that Paleolithic people had a deep knowledge of mineral pigments and could access a much broader color palette than we previously thought," says Izzy Wisher, postdoc at Aarhus University, in a press release.

The open-access paper, published in *Antiquity*, is "The earliest evidence of blue pigment use in Europe" (DOI: 10.15184/aqy.2025.10184).

Deep-sea worm creates toxic yellow pigment used by artists throughout history

Orpiment is a naturally occurring arsenic sulfide mineral used to create a vivid yellow pigment with a golden sheen. Despite its toxicity, artists throughout history made use of this material, including 17th-century Dutch painter Rembrandt and 19th-century French painter Paul Cézanne.

Materials in the news

Data center cooling method decreases electricity use

Researchers in the New York University Tandon School of Engineering proposed a zeolite-based thermal battery for enabling electricity-free cooling data centers. Zeolites are crystalline materials riddled with microscopic pores, giving them a remarkable ability to soak up water vapor. The plan is to use zeolites to adsorb water vapor from the server room and then transport the water-filled materials to an industrial facility. At the facility, waste heat will be used to dry the zeolite, so it can then be returned and reused at the data center. The team estimates this approach can reduce total electricity used by the data center for cooling and the industrial facility by more than 75%. For more information, visit https://engineering.nyu.edu/news.

Hydrogen production using wastewater

University of Wyoming researchers explored the potential of wastewater usage for the hydrogen economy. Wastewater treatment is traditionally an energy-intensive process, often resulting in significant thermal loss. Meanwhile, hydrogen production via hydrocarbon reforming requires both water and intense heat. By using wastewater as a feedstock, industries can both recycle the waste heat that would otherwise be lost and repurpose it for hydrogen generation. The research was inspired by a U.S. Department of Energy-funded project that integrates thermal desalination technology for produced water with autothermal or steam methane reforming. For more information, visit https://www.uwyo.edu/news/index.html.

Historically, orpiment was mined in places such as Türkiye, Macedonia, Hungary, and Syria. It is generally considered to form as a sublimation product in volcanic fumaroles, low-temperature hydrothermal veins, and hot springs. It can also be formed as a byproduct when realgar, another arsenic mineral, decays.

In a surprising twist, researchers from the Center of Deep-Sea Research in the Chinese Academy of Sciences' Institute of Oceanology discovered that orpiment can also be formed organically as part of the defensive mechanisms of the deep-sea worm *Paralvinella hessleri*.

P. hessleri lives in deep-sea hydrothermal vents in the western Pacific Ocean. To withstand the extreme environment, the worm accumulates microscopic particles of arsenic on its outer skin cells and internal organs. These particles react with sulfide from the hydrothermal vent to form small clumps of orpiment, creating an "armor" around the worm that protects it from the hot, toxic vents.

The open-access paper, published in *PLOS Biology*, is "A deep-sea hydrothermal vent worm detoxifies arsenic and sulfur by intracellular biomineralization of orpiment (As_2S_3)" (DOI: 10.1371/journal.pbio.3003291).

First comprehensive scientific dataset of Indian pigments

Individual studies on pigments are valuable, but being able to access all that information in a single, centralized location makes using the knowledge gained from each study possible. That is the goal of Mapping Color in History, a project led by Harvard University Professor Jinah Kim to create a searchable database of pigment analyses in Asian paintings.

The project was launched in 2018, with a pilot database released in late 2022. In summer 2025, ACerS member Celia Chari and her colleagues made a noteworthy expansion to the database with the addition of a comprehensive dataset of traditional and contemporary Indian pigments, which they described in an open-access paper.

The open-access paper, published in *npj Heritage Science*, is "Characterization of Indian pigments: Investigating the color palette of a traditional Jaipuri workshop" (DOI: 10.1038/s40494-025-01729-4). ■

Lead-free quantum dots for eco-friendly technologies

Researchers led by the National Institute of Metrology in China used lead-free $CsMnBr_3$ quantum dots and introduced Eu^{3+} to establish an $Mn^{2+} \rightarrow Eu^{3+}$ energy-transfer pathway, thereby strengthening radiative emission and reducing defect-related losses to improve luminescence efficiency. In addition, borosilicate glass encapsulation was employed to isolate the quantum dots from water and oxygen, suppressing surface reactions and ion migration and thus markedly enhancing long-term stability. As a result, the sample achieved a quantum yield of 43.45% and retained about 97% of its emission intensity after 450 days of storage in water. For more information, visit https://www.eurekalert.org/news-releases/1121686. ■

Designer hybrid 2D materials: Platform chemically combines fundamentally different materials

Researchers led by Rice University created a genuine 2D hybrid material by chemically integrating graphene and silica glass—two fundamentally different materials—into a single, stable compound called glaphene.

In glaphene, "The layers do not just rest on each other—electrons move and form new interactions and vibration states, giving rise to properties neither material has on its own," explains first author Sathvik Ajay Iyengar, doctoral student at Rice University, in a press release.

Graphene is a semi-metal (zero-bandgap semiconductor) with long-range ordering, whereas silica glass is an insulator (bandgap ~9.0 eV) with short-range ordering. Glaphene, on the other hand, has an experimental bandgap of 3.6 eV, similar to the wide bandgap semiconductor gallium nitride (3.4 eV).

To create the material, the Rice-led team developed a one-pot, liquid-precursor chemical vapor deposition process. Tetraethyl orthosilicate served as the main precursor because it is a source of both carbon and silica. The precursor thermally decomposes and catalytically forms methane and ethane gases, which drives graphene growth on copper substrates. It also produces silica as one of its thermal decomposition products, but it can also form silica via hydrolysis.

The process, which is scalable to several centimeters, involves two steps:

1. Graphene grows under low pressure (10^{-3} Torr) at elevated temperatures in an argon/hydrogen atmosphere.
2. Oxygen is slowly introduced to promote water formation and thus silica growth via hydrolysis.

High-quality growth of graphene saturated the substrate before silica growth dominated. Further analysis showed the oxygen content played a role. If too little oxygen was present, amorphous silica formed on high-quality graphene. If too much oxygen was present, amorphous silica formed on amorphous carbon.

The authors used various microscopy and spectroscopy methods to characterize the final material:

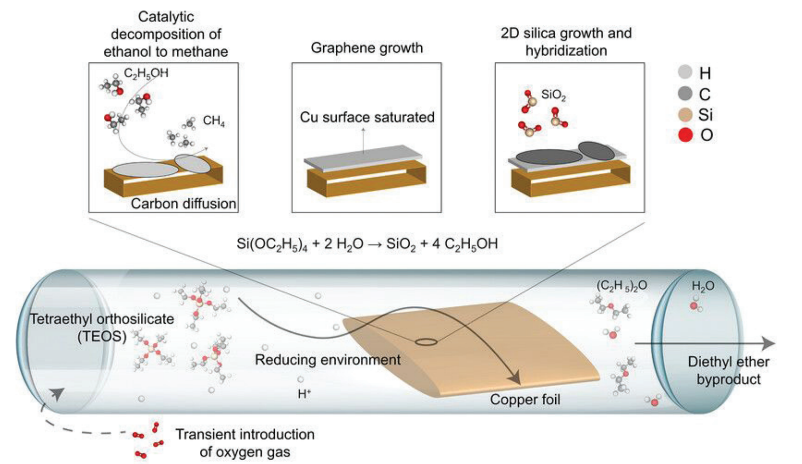

Illustration of the one-pot, liquid precursor-mediated, low-pressure chemical vapor deposition process that creates genuine 2D hybrid materials consisting of graphene and silica glass.

- Low-magnification transmission electron microscopy and energy-dispersive X-ray spectroscopy indicated layered ordering.
- The interlayer structure was chemically validated using optical and electron spectroscopy, mass spectrometry, and atomic-resolution electron microscopy.
- Spectroscopic analysis also showed that effective charge transfer resulted in interlayer hybridization, resulting in a structure that was more stable than the sum of its layers.
- Depth-dependent time-of-flight secondary-ion mass spectrometry indicated interlayer interaction between silicon in the silica glass layer and carbon in the graphene layer.
- Both Raman spectroscopy and X-ray photoelectron spectroscopy verified that no competing species formed during chemical vapor deposition.
- Qualitative stoichiometric X-ray photoelectron spectroscopy analysis indicated a close agreement between the theoretical model (SiO_3C_2) and experimental values ($SiO_{2.1}C_{2.1}$).

Based on these results, the authors proposed a hybrid metastable structure with a larger unit cell and a lower biaxial lattice mismatch (0.3%). This result contrasts with a previous study that reported a 7% lattice mismatch between 2D silica glass on graphene. Further analysis predicted a metastable structure accommodates the lower strain by slight out-of-plane bending of silicon–oxygen bonds.

A unique feature of the hybrid glaphene was its disordered crystalline structure, which is not observed in other known phases of 2D silica. This structure consisted of bond distortions in silica (from hybridization), while maintaining the overall lattice.

The authors conclude, "With 2D materials serving as a creative sandbox for studying emergent properties, demonstrating such one-pot, large-area growth processes to construct 2D hybrids from the bottom up opens new doors to true materials discovery with scalability."

Although Rice University led this study, in the press release, Iyengar emphasizes that it "was a cross-continental effort" involving colleagues from The Pennsylvania State University (U.S.), University of Sussex (U.K.), and Federal University of Minas Gerais (Brazil).

The open-access paper, published in *Advanced Materials*, is "Glaphene: A hybridization of 2D silica glass and graphene" (DOI: 10.1002/adma.202419136). ■

Credit: zedspider / Shutterstock

Green glass manufacturing: Approaches to sustainable production

By Lisa McDonald

Glass is a core material in modern society, but there are various aspects of its production and usage that remain less than ideal.

Global glass manufacturing produces at least 86 million metric tons of carbon dioxide annually.[1] Two aspects of the production process account for most of these emissions. One, soda–lime–silica glass accounts for roughly 90% of all manufactured glass products, and this composition relies on carbonate raw materials that release carbon dioxide when processed. Two, traditional glass processing methods require high temperatures to melt the raw materials, and these high temperatures are mainly achieved through the burning of fossil fuels, which generate even more carbon emissions.

Using cullet (waste glass) as a raw material can significantly improve the environmental friendliness of glass production. The Glass Packaging Institute reports that for every 10 wt.% increase in cullet usage, furnace energy consumption decreases by about 2–3% and greenhouse gas emissions decrease by about 4–10%.[2] Unfortunately, the logistics of using cullet as a raw material—from establishing robust transport networks to implementing effective sorting and cleaning processes—limit the economic feasibility of this solution.

Despite these challenges, glass scientists and manufacturers have embraced green manufacturing practices in recent years. Green manufacturing refers to production methods that minimize environmental impact, conserve resources, and reduce waste from industrial processes. Despite short-term complications, implementing green manufacturing practices can result in lower long-term operational costs as well as meet rising consumer demand for eco-friendly products.

Glass scientists and manufacturers are approaching green manufacturing from several angles. While some approaches are closer than others to commercial viability, all contribute to the long-term goal of ensuring glass continues to be a vital, environmentally friendly material in the future.

Raw material innovation: Cut emissions at the source

The raw materials conventionally used for soda–lime–silica glass production account for roughly 15–25% of process-related carbon emissions. Using different raw materials or developing entirely new compositions can help cut emissions from this source.

Using cullet as a raw material can be a straightforward solution because its composition is familiar to manufacturers and it takes less energy to melt than conventional first-use raw materials. However, the logistics of collecting and cleaning cullet for reuse is complicated, as explained in the cover story of the September 2024 *ACerS Bulletin*.[3] Fortunately, organizations such as the Northwest Ohio Innovation Consortium are working to overcome these challenges in the glass recycling ecosystem, as explained in the "Industry Insights" column on page 10.

Using alternative sources for the various components of soda–lime–silica glass is another option to reduce carbon emissions. For example, the "Deciphering the Discipline" column on page 40 explores using wollastonite as a source of calcium oxide rather than calcium carbonate because it does not release carbon dioxide during the decomposition process.

Developing entirely new, noncarbonate glass compositions that can match or surpass the performance of soda–lime–silica glass is an idealistic approach to cutting carbon emissions due to the raw materials. Yet researchers at The Pennsylvania State University have made great strides in this area with

The growing carbon footprint of construction materials

The construction industry has a significant carbon footprint, accounting for 33% of global greenhouse gas emissions in 2022 (Figure 1a,b). Previously, the emissions from nonmaterial sources, such as transport and on-site activities, were roughly comparable with emissions from materials-related sources. However, over the past 30 years, emissions from materials-related sources grew rapidly, and they have now surpassed the emissions from nonmaterial sources (Figure 1c).

The rapid growth of materials-related emissions indicates that the industry has grown more dependent on materials over the years, particularly cement and steel (Figure 1d). Reducing emissions in this sector will thus require a paradigm shift in how materials are produced and used in this industry, and stakeholders all along the industry's value chain will have a role to play in this shift.

NOTE: All information and figures in this sidebar come from Li et al.'s paper "Carbon footprint of the construction sector is projected to double by 2050 globally" (*Communications Earth & Environment* 2025, **6**: 831).

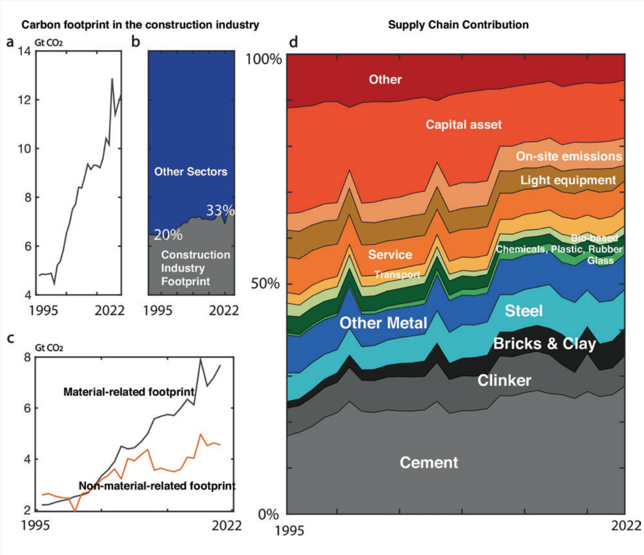

Figure 1. a) Total carbon footprint growth from the construction industry from 1995 to 2022. b) Share of the construction industry's carbon footprint in total global carbon emissions. c) Materials- and nonmaterial-related footprints in the construction industry. d) Evolution of different factors contributing to the construction industry's carbon footprint from 1995 to 2022. Carbon emissions from glass, chemicals, plastic, rubber, and bio-based materials comprise approximately 6% of the industry's total carbon footprint.

LionGlass™, a family of aluminosilicophosphate glasses that do not contain any carbonate constituents and melt at a lower temperature than conventional soda–lime–silica glass.

LionGlass has been in development for several years, and the "Deciphering the Discipline" columns in the past three May issues of the *ACerS Bulletin* track the history of this development (Figure 1).[4–6] The researchers have now developed this glass family to the point that they are working with major glass companies Verallia (France),[7] Bormioli Luigi (Italy),[8] and Vitro Architectural Glass (U.S.)[9] to create commercial products out of LionGlass spanning food and beverage packaging, cosmetic packaging, and flat glass applications, respectively.

Developing these solutions to the raw materials challenge can be a slow process due to the nearly infinite range of possible glass compositions. But in recent years, artificial intelligence (AI) and machine learning (ML) systems have enabled a new paradigm for materials design, one based on rapid data-driven discovery rather than lengthy trial-and-error experimentation. Past *ACerS Bulletin* Editor Eileen De Guire discussed the progress in computer-aided glass design with ACerS members John C. Mauro and Mathieu Bauchy in the May 2022 *ACerS Bulletin*.[10]

Furnace strategies: Reduce energy-related emissions

The combustion of fossil fuels to heat glass furnaces accounts for roughly 75–85% of process-related carbon emissions. Using alternative fuels or energy sources to power the high-temperature process can help cut emissions from this source.

Oxy-fuel glass furnaces are one of the most established alternatives to traditional glass furnaces. Conventionally, gas and air are injected into a furnace and ignited to produce a high-temperature flame. The oxygen within the air serves as the oxidizing agent during combustion, but the nitrogen component lowers combustion efficiency by absorbing heat (as well as forms toxic nitrogen oxides).

In oxy-fuel furnaces, pure oxygen is used as the oxidant rather than air. As a result, the furnace avoids heating atmospheric nitrogen, which results in higher temperatures, higher thermal efficiency, lower exhaust gas volumes, and lower fuel consumption. Oxy-fuel glass furnaces started gaining traction in the early 1990s, and more than 300 commercial glass furnaces worldwide have since converted to oxy-fuel.[11]

Although oxy-fuel furnaces lower emissions, they still largely rely on the combustion of natural gas derived from fossil deposits. There are several feasible substitutions for natural gas that are low in fossil carbon or are derived from sources with no net increase in atmospheric CO_2. For example,

- **Biofuels** are produced from organic materials such as plants, agricultural waste, and algae. They are considered carbon neutral because the CO_2 emitted to the atmosphere during combustion is the same as was taken in by the source material through photosynthesis.
- **Synthesis gas**, or syngas, is a combustible mixture of hydrogen and carbon monoxide generated by heating a solid fuel in a low-oxygen environment. It provides a way

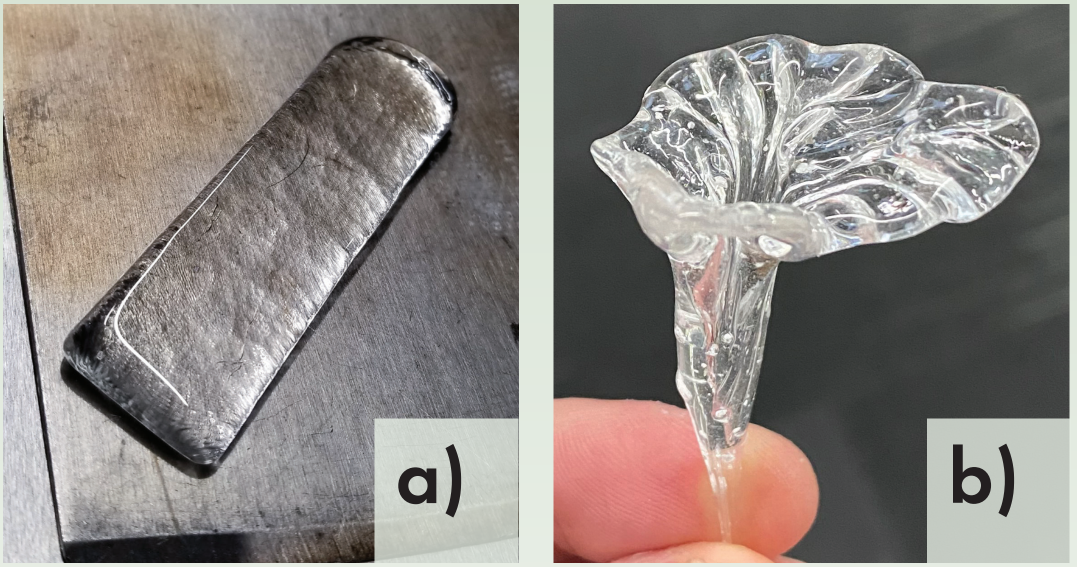

Figure 1. a) Bar of LionGlass made at The Pennsylvania State University for mechanical testing and b) handblown flower created from LionGlass.

to convert municipal solid waste, plastics, and organic waste into valuable energy, reducing the environmental impact of landfills.

- **Hydrogen** is a highly combustible gas that emits no CO_2 when burned. Currently, most hydrogen is produced from natural gas through steam methane reformation ("grey" hydrogen), which perpetuates the reliance on fossil fuels. But it can also be produced through water electrolysis ("green" hydrogen), which is a much more environmentally friendly, albeit expensive, option.

Among these alternatives, green hydrogen is considered the superior long-term, scalable alternative, and many glass manufacturers are conducting trials on its potential. *Ceramic Tech Today* first reported on some small-scale pilot projects in 2023,[12] and as of 2025, the European Union-funded H2GLASS project is conducting full-scale trials at various sites across Europe.[13]

In contrast to physical fuels, glass manufacturers are also exploring electric heating, which offers higher energy efficiency and removes combustion-related emissions compared to traditional glass furnaces. In 2024, the Glass Manufacturing Industry Council was awarded a three-year, $3-million U.S. Department of Energy grant to advance electric melting technology, and it is working with partners at CelSian Glass USA, TECO, RoMan Manufacturing, and Pacific Northwest National Laboratory on the project.[14]

Additional information on these various novel furnace strategies can be found in the May 2023 *ACerS Bulletin* cover story "Deep decarbonization of glassmaking."[15]

Data-optimized manufacturing: Address wasteful processing steps

From material preparation to firing parameters to maintenance schedules, there are dozens of distinct, highly controlled steps within each stage of the glass manufacturing process. Each of these steps feature numerous interrelated variables, and ideally all must be accounted for to reduce waste and improve production efficiency.

The advancement of AI and ML technologies in recent years has not only supported the design of new glasses, as noted earlier, but it has also aided in optimizing each stage of glass production. The "Journal Highlights" column in the September 2025 *ACerS Bulletin* demonstrated several ways in which researchers have harnessed data-driven modeling for this purpose.[16] An April 2025 *ACerS Bulletin* feature story by CelSian Glass researchers provided a detailed case study of leveraging computational fluid dynamics to optimize bubbling and fining (Figure 2).[17]

The Federal Institute for Materials Research and Testing (BAM) in Berlin, Germany, is playing a crucial role in the development of data-optimized manufacturing solutions for glass production. BAM has a one-of-a-kind robotic facility for melting oxide glasses, which was designed and constructed by researchers at Fraunhofer Institute for Silicate Research.

In 2021, BAM launched a collaborative academic–industry research project called GlasDigital to implement an automated infrastructure for the facility.[18] The project also involved developing and implementing a glass ontology and ML tools to facilitate property-driven compositional optimization of glasses, as described in detail in a 2025 open-access paper.[19]

BAM launched a follow-up project called GlasAgent in 2025.[20] The goal of this project is to expand the glass ontology developed during the original GlasDigital project and use it to develop a software program that will control the integration of all the various glass manufacturing stages. Test melts will be carried out to determine the effectiveness of the software-controlled workflow.

Over in the United States, the Northwest Ohio Innovation Consortium established the Northwest Ohio Glass Innovation Hub in 2024 to accelerate innovation and job growth in both

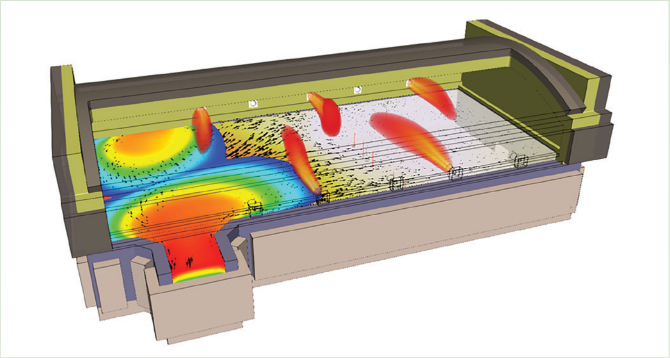

Figure 2. Oxy-fuel combustion furnace modeled in GTM-X, CelSian's advanced computational fluid dynamics software. Raw materials enter through the chargers on the left, flow under the burners, and exit on the right.

the glass sector and solar industry.[21] In December 2025, partners in the Hub announced a new three-year, academic–industry research project that aims to integrate AI and ML into the glass-melting process by developing a multiobjective optimization tool that balances energy efficiency, nitrous oxide emissions, control input constraints, and boundary-condition robustness.[22]

Sustainability standards: Establish a framework for responsible glass production

As the various approaches to green glass manufacturing mature, the next step will be to develop industry standards, which help ensure that companies around the world can successfully understand and adopt green manufacturing methods.

Currently, few sustainability standards exist for the glass industry, and the ones that do tend to vary greatly by region. The establishment of a new multistakeholder organization called ResponsibleGlass in December 2025 marks an attempt to take global standardization from theory to practice, and the resource roundup on page 32 explores how this initiative may spark increased interest in strengthening sustainability performance.

The future of glass manufacturing

As countries around the world strive to accomplish their climate goals, carbon-intensive industries have a role to play as well in limiting their emissions. By investing in green manufacturing practices, the glass industry is doing its part to achieve these objectives, and it sets the stage for glass to remain a relevant and transformative material choice for years to come.

About the author

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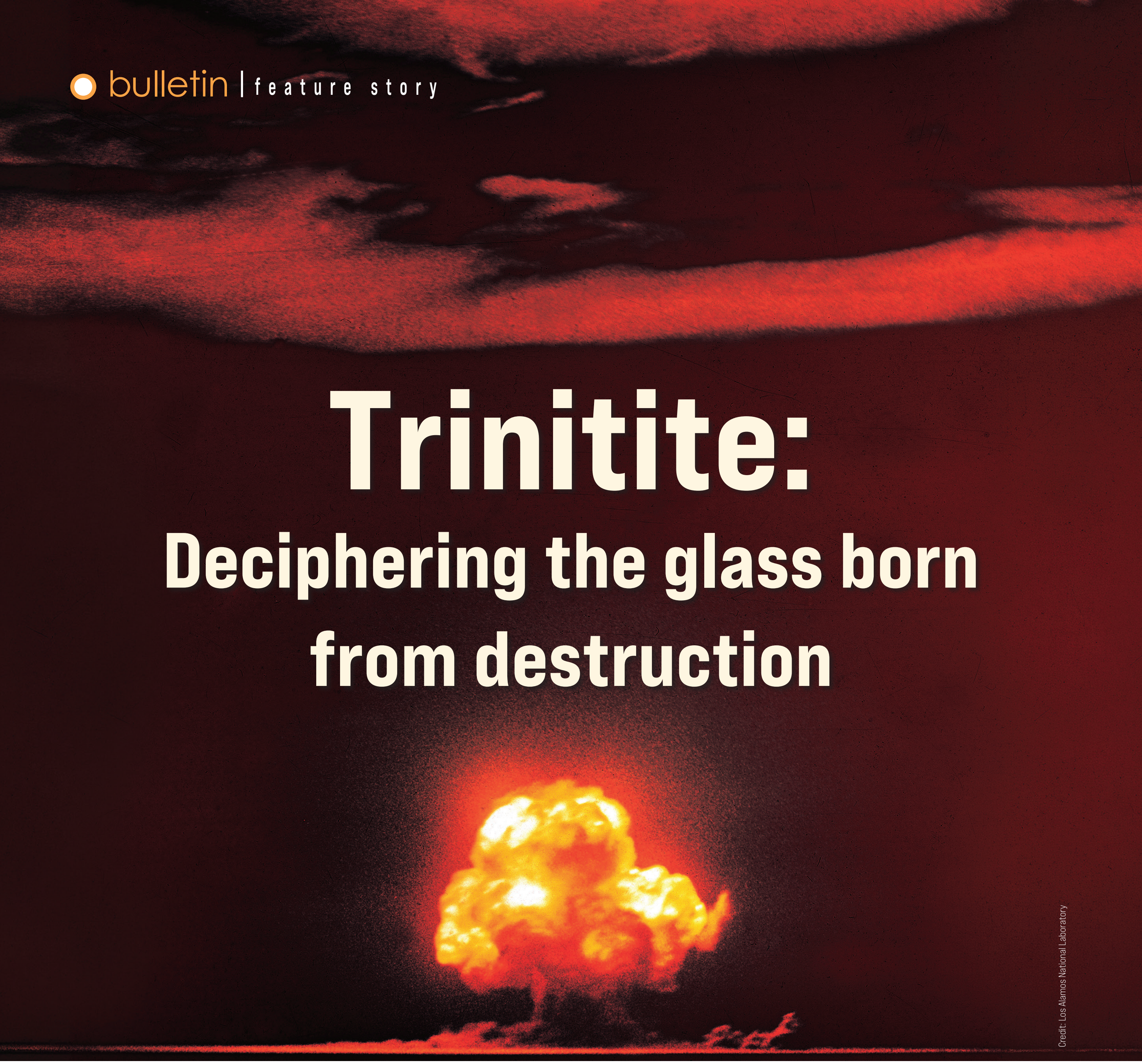
Trinitite: Deciphering the glass born from destruction



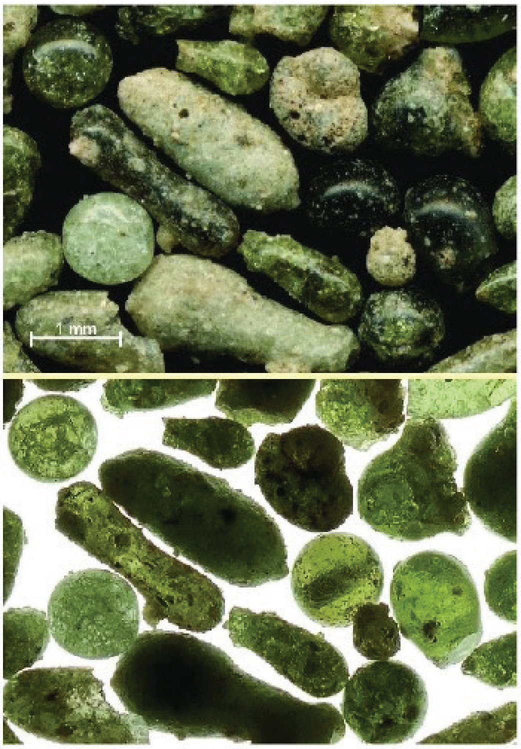
The only existing color photo of the Trinity nuclear weapon test. A unique glassy residue called trinitite was formed during the blast.

By S. K. Sundaram

When the "father of the atomic bomb," J. Robert Oppenheimer, recalled the famous Hindu scripture quote "*Now I am become Death, the destroyer of worlds*" after the Trinity nuclear weapon test on July 16, 1945, little did he know that from the immense destruction something new would be born as well—a unique glassy residue called trinitite.

Trinitite, also known as atomsite or Alamogordo glass, is the greenish glassy material found near Alamogordo, N.M., following the detonation of the implosion-design plutonium bomb. The intense heating followed by rapid cooling of the desert sand at the site produced the radioactive silica-based substance.

Quite a few studies on trinitite have taken place over the past eight decades. This research has not only revealed the chemical and structural complexity of various trinitite glasses but also the intriguing connection between geochemistry, glass science, and cosmology resulting from humanity's insatiable quest for knowledge.



Credit: Eby et al., *Geology Today*

Figure 1. Optical microscopic images of trinitite beads and dumbbells using reflected (top) and transmitted (bottom) light. Republished with permission from Reference 1.

Table 1. Geological makeup of the Trinity test site. Data from References 1 and 2.

Type of material	Specific compounds
Carbonates	Aragonite ($CaCO_3$), calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)
Chlorides	Bischofite ($MgCl_2 \cdot 6H_2O$), halite (NaCl), and sylvite (KCl)
Clays	Illite ($(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$) and kaolinite ($Al_2Si_2O_5(OH)_4$)
Silica	Quartz (SiO_2) and sand
Silicates	Albite plagioclase feldspars ($NaAlSi_3O_8$)
Sulfates	Anhydrite ($CaSO_4$), bassanite ($2CaSO_4 \cdot H_2O$), blöedite ($Na_2Mg(SO_4)_2 \cdot 4H_2O$), gypsum ($CaSO_4 \cdot 2H_2O$), hexahydrite ($MgSO_4 \cdot 6H_2O$), mirabilite ($NaSO_4 \cdot 10H_2O$), selenite ($CaSO_4 \cdot 2H_2O$), and thenardite ($Na_2SO_4$)
Others	Augite ($(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$), ilmenite ($FeTiO_3$), hornblende ($(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH,F)_2$), magnetite ($Fe_3O_4$), olivine ($(Mg,Fe)_2SiO_4$), and both meteoritic and volcanic dust

The chemical and structural complexity of trinitite

Although trinitite glasses are composed mainly of silica, the complex local mineralogy of the Trinity test site means the glasses contain notable amounts of many other materials as well (Table 1).[1,2] In addition, anthropogenic elements from the test—such as copper wire, lead bricks, and the steel tower and bomb casing—along with the aerodynamics and material transport after the test resulted in unique chemical and structural complexity at submicron and micron scales in the formed glasses.

Eby et al. used scanning electron microscopy, backscattered electron imaging, and energy dispersive spectroscopy to describe four varieties of trinitite glasses in two comprehensive papers[1,2] published in 2010 and 2015:

- **Pancake trinitite** consists of a green glass layer (~1–5 cm) on top of embedded mineral grains.
- **Red trinitite**, found to the north of ground zero, contains metallic chondrules made of lead, iron, and copper, with the last component being the source of the glass's red color.
- **Green trinitite**, found throughout the immediate vicinity of ground zero, consists mainly of partly resorbed quartz grains but also notable concentrations of iron and calcium.
- **Bead and dumbbell-shaped trinitite**, which formed in the rising cloud of hot gases, were transported downwind and spread over a wide area (Figure 1). However, these glasses are often found around the tops of anthills due to being moved there by ants as they excavate their tunnels.

Among the studies on the radioactive nature of trinitite, a unique one by Fahey et al. used scanning electron microscopy and electron probe microanalysis with X-ray florescence to discriminate between alpha and beta radioactivity and then used this information to map the location of radiation sources in a trinitite sample (Figure 2 and Table 2).[3] They identified a correlation between uranium and plutonium abundance in the vitrified calcium-rich regions, which had the most intense alpha activity. These findings indicate that the uranium came from the nuclear explosion and not from environmental uranium-bearing minerals.[4] Further research on the chemistry, structure, and radioactivity of trinitite glasses will increase our understanding of their complex nature.

Geochemistry–glass science–cosmology connection

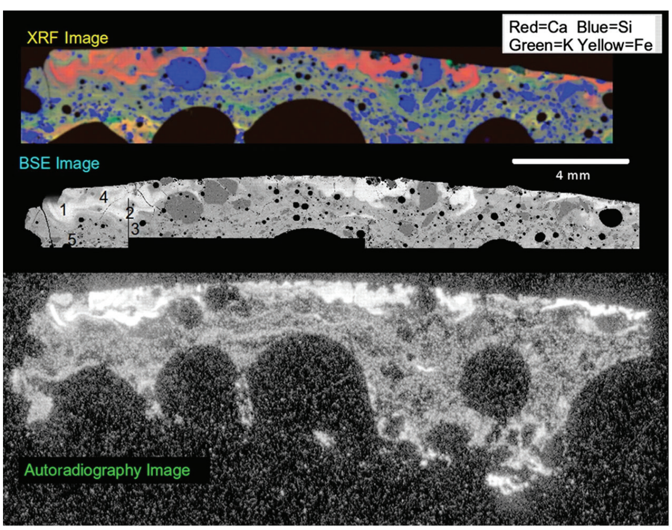
Although the explosion that triggered the formation of trinitite was an anthropogenic event, there are many parallels between trinitite and naturally formed glasses. For example, extensive mineralogical and geochemical data collected during and after the Trinity test suggest that following the roughly 20 kiloton explosion, the fireball reached temperatures of more than 8,000 K and the shock wave caused intense, rapid air compression. These effects occurred within a fraction of a second, and so the conditions did not support equilibrium melting, as evidenced by the metallic globules found in some trinitite glasses.

Trinitite: Deciphering the glass born from destruction

Table 2. Electron probe microanalysis data from the regions marked in the backscattered electron images in Figure 2.[3] All values are in weight percentage; oxygen calculated by assumed stoichiometry; integrated spectrum 0.1 keV to 20 keV: ~ 5 × 10^6 counts.

		Elemental makeup (wt.%)							
Probed region number	O (stoichiometrically assumed)	Sodium	Magnesium	Aluminum	Silicon	Potassium	Calcium	Titanium	Iron
1	44.0	0.77 ± 0.01	0.70 ± 0.01	8.45 ± 0.01	24.0 ± 0.02	1.23 ± 0.01	18.8 ± 0.02	0.29 ± 0.01	1.78 ± 0.01
2	45.1	0.75 ± 0.01	0.86 ± 0.01	7.96 ± 0.01	26.2 ± 0.02	1.10 ± 0.01	15.6 ± 0.02	0.33 ± 0.01	2.13 ± 0.02
3	46.4	0.99 ± 0.01	0.66 ± 0.01	5.97 ± 0.01	30.3 ± 0.02	1.77 ± 0.01	11.8 ± 0.02	0.26 ± 0.01	1.87 ± 0.01
4	44.4	0.71 ± 0.01	0.96 ± 0.01	9.73 ± 0.01	23.7 ± 0.02	0.72 ± 0.01	17.0 ± 0.02	0.30 ± 0.01	2.46 ± 0.02
5	46.3	1.27 ± 0.01	0.97 ± 0.01	6.55 ± 0.01	29.8 ± 0.02	2.30 ± 0.01	10.1 ± 0.02	0.35 ± 0.01	2.47 ± 0.02
6	53.2	ND	< 0.02	< 0.05	46.67 ± 0.02	ND	< 0.01	< 0.01	< 0.01

Credit: Data from Fahey et al., *PNAS*; layout by ACerS



Credit: Fahey et al., *PNAS*

Figure 2. X-ray fluorescence, backscattered electron, and audiography images across about 20 mm of the trinitite glass. Republished with permission from Reference 3.

Similar extreme temperature and pressure conditions on very short time scales can lead to the formation of natural glasses, such as fulgurites formed by lightning strikes and tektites formed by meteorite impacts. Therefore, analysis methods and datasets for natural glasses can be used for comparison to understand trinitite glasses.

Scatter plot, immiscibility, and redox

Harker diagrams are a type of bivariate scatter plot used by petrologists to illustrate the chemistry of rocks. The weight percentage of minor and major constituents are plotted against the main ingredient, generally silica.

Glass scientists have also used Harker diagrams to show the chemical makeup and formation of different glasses. These diagrams can then be combined with other scatter, correlation, or spider plots to correlate the glass chemistry with material properties, such as immiscibility.

Immiscibility is the inability of two or more substances to form a homogenous mixture. Knowing whether substances are immiscible is crucial for controlling chemical, industrial, and natural processes.

Trinitite glasses consist of two primary liquid phases: a viscous silicon-rich phase (essentially silica) and a less viscous low-silicon glass of varying composition.[2] Red trinitite glasses have additional glasses that are rich in copper, iron, and lead along with the two liquid phases.

Early immiscibility studies on trinitite glasses were reported in the 1940s,[5] but there is still a lot to learn about this physical property. Fortunately, the diagram developed by Kamenetsky et al.[6] for iron-rich basaltic magma can be used to highlight immiscibility in trinitite glasses. As seen in Figure 3, there is a partitioning between iron-rich and silicon-rich melts, and this partition can be used to explain the immiscibility between the iron-rich and normal silicate melts in red trinitite glasses as well even though they contain very little phosphorous.

Speaking of the iron-rich melts in red trinitite glasses, iron with Fe^0, Fe^{2+}, and Fe^{3+} states is commonly used in determining the redox reactions of numerous materials, minerals, and glasses. Recently, various forms of spectroscopy have been applied to study redox in both fulgurites and trinitites.[7] The study showed that impact of high-temperature and pressure events can induce redox variations and metamorphism in these materials.

Ternary diagrams

Ternary diagrams are commonly used in glass science to illustrate compositional space, phase boundaries, crystallization paths, and glass formation regions.

Bonamici et al. created various ternary diagrams for trinitite glasses using large datasets of scanning electron microscopy, electron probe microanalysis, digital autoradiography, and laser Raman spectroscopy data of glass debris within aerodynamic fallout from the Trinity test.[8]

The phase maps created using qualitative electron probe microanalysis data showed variations in spectral intensity of elements present in the debris. Activity maps produced using the autoradiograph data showed that the radioactivity is mainly from the volumetrically dominant calcium–magnesium–iron (CaMgFe) glass phase. Considering diffusion, mass transport, and viscosity of the materials and melts, Bonamici et al. determined that the silica- and alkali-rich trinitite glasses are melting products equivalent to local minerals and anthropogenic materials, while the CaMgFe trinitite glasses are a condensation product of evaporated volatile materials (Figure 4).

The ternary volatility space diagram seen in Figure 5 illustrates the dynamic balance among refractory, transitional, and volatile elements of trinitite glasses, compared with natural glasses and minerals (e.g., natural silicate rock, basalt and volcanic felsic rocks). Bonamici et al. state that the morphological phase assemblage is generally interpreted as the interplay between melting of refractory elements versus the condensation of silica and alkalis via active solid–liquid–vapor interfacial transitions.

Macroscopic models

Macroscopic glass formation and transition are generally represented as a schematic plot of volume versus temperature showing many cooling paths, as pressure is not a significant variable in commercial glass production.

Geochemical macroscopic models of trinitite fallout formation created by Bonamici et al.,[8] schematically plotted in Figure 6, shows three main variables—temperature, pressure, and time—critical to capture the dynamics. The sequence of events shown on the temperature curve are

1. Condensation of calcium–aluminum-rich, silicon-poor melts;
2. Convection and turbulence delivering topsoil material into the cloud and condensation accelerating; and
3. Condensation continues with more silicon- and alkali-rich condensates until fallout ends.

Macroscopic changes continue past this event.

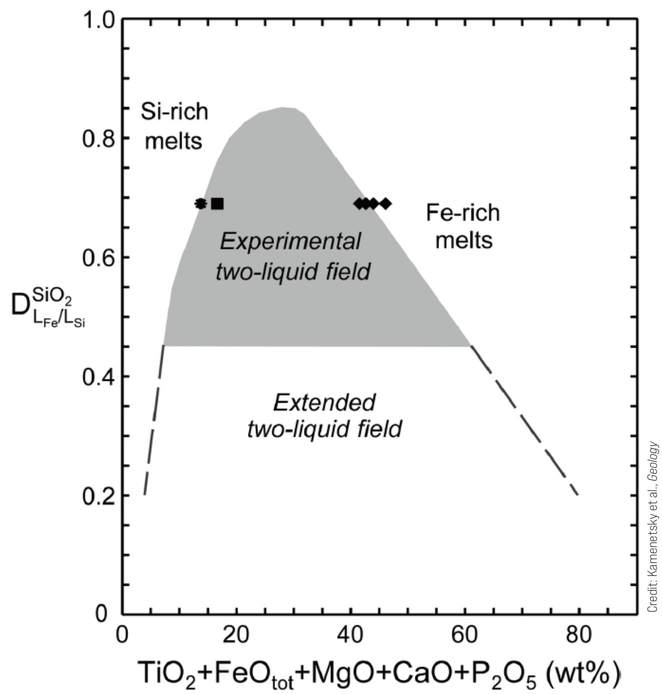


Figure 3. Immiscibility diagram at about 980°C. Republished from Reference 6 with permission from The Geological Society of America.

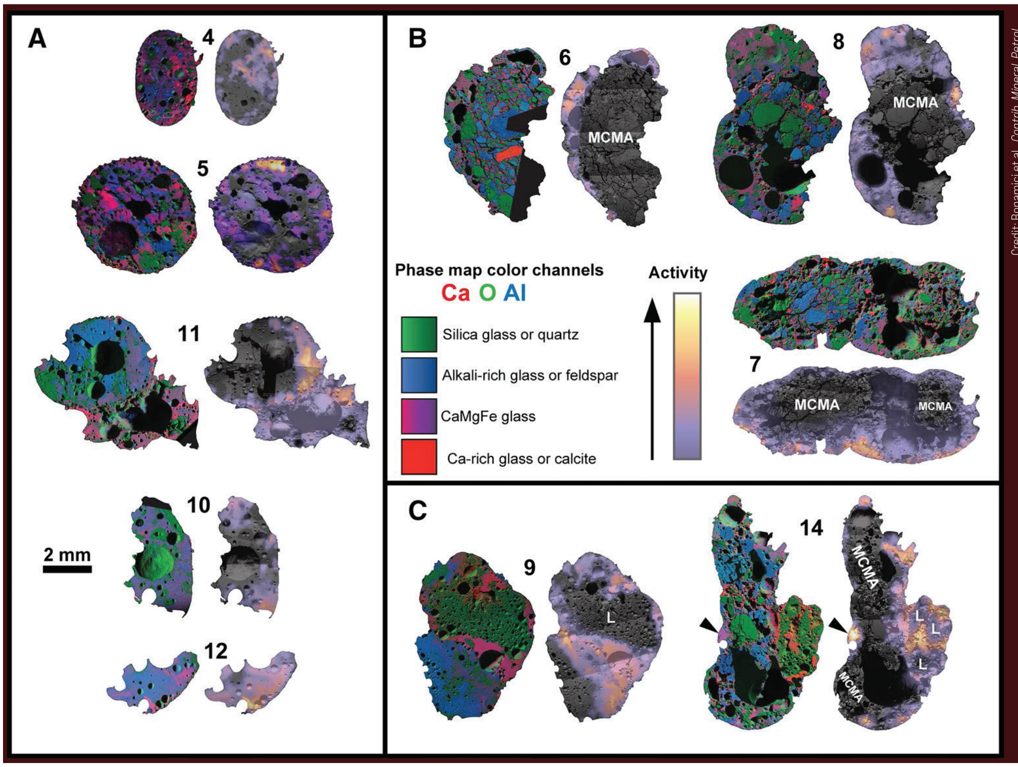


Figure 4. A) Phase maps of smooth spheroidal beads and fragments. B,C) Activity maps of irregular beads with B) mineral aggregates and C) lechatelierite (amorphous SiO_2). Republished from Reference 8 with permission (courtesy Bonamici).

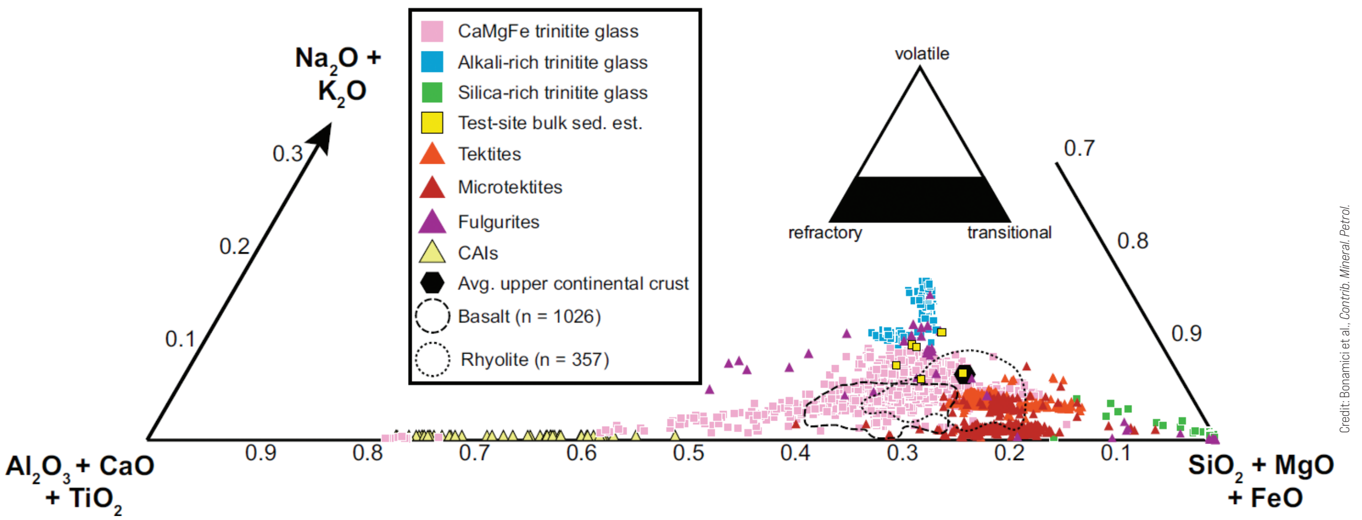


Figure 5. Ternary volatility space diagram. Black hexagon corresponds to average composition of the upper continental crust shown as reference. Republished from Reference 8 with permission (courtesy Bonamici).

The glass transition temperatures shown in Figure 6 are estimated using viscosity versus temperature data calculated for CaMgFe trinitite glasses using a viscosity model and experimental data of a quartz melt at 1 atmosphere pressure. Various phenomena, such as impact and shock wave, rapid expansion, oxidation, diffusion, and viscous flow of melt, in less than 10 seconds of detonation and over orders of magnitude of time scale have resulted in the range of physical and textural features recorded in the fallout debris.

The model highlights a key observation—despite some similarities, fulgurite and microtektite glasses are not perfect analogues for trinitite formation. Rather, the CaMgFe and corresponding end members—Al_2O_3+CaO+TiO_2 and SiO_2+MgO+ FeO, shown in the ternary diagram in Figure 5—are closer to condensed materials from the formation of the early solar nebula, such as the calcium–aluminum-rich inclusions shown in Figure 4.

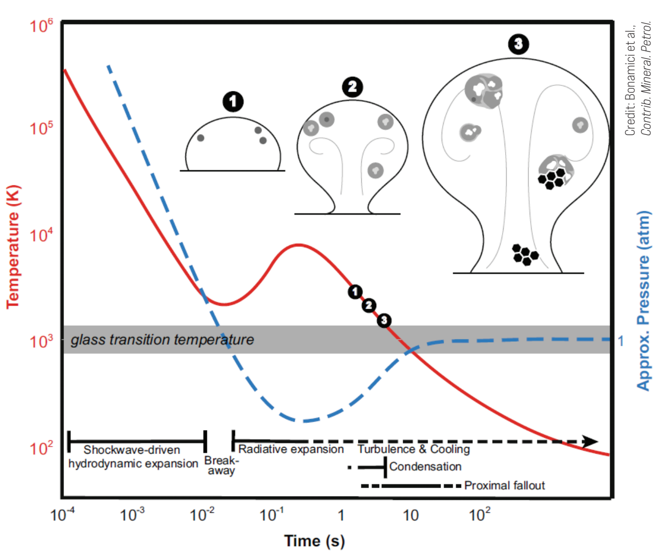


Figure 6. Macroscopic model of trinitite glass fallout formation. Republished from Reference 8 with permission (courtesy Bonamici).

As in the case of the inclusions, the condensation via volatilization is the dominant process in CaMgFe melt and trinitite glass formation. Liquid phase interactions have not had significant impact on primary condensation and compositions. Similarity between calcium–aluminum-rich inclusions and trinitite formation ultimately connects these processes to a singular cosmic event—the Big Bang.

Novel approaches to understanding trinitite

Researchers continue to unravel the mystery of trinitite formation, emphasizing the merging of geochemistry, glass sciences, and cosmology through the use of newer glass analysis techniques.

For example, Bailey et al. used synchrotron X-ray spectroscopy to collect titanium K-edge X-ray absorption spectroscopy data and titanium pre-edge X-ray absorption near-edge structure data on trinitite glasses.[9] Combining this information with scanning electron microscope, inductively coupled plasma mass spectrometry, and gamma spectroscopy data allowed them to determine the ratio of nonbridging oxygens to tetrahedrally coordinated cations and titanium coordination, which describe the network connectivity of the glass.

Meanwhile, Mercer et al. used the novel technique of decay energy spectroscopy to gather more forensic details on trinitite.[10] Another report by Bindi et al. revealed that extreme pressure–temperature transient conditions during the test are favorable for the discovery of new materials, such as quasicrystals.[11]

Continued explorations of trinitite formation

With the 75th anniversary of the Trinity test in 2020, more documentation of the test was made public.[12] With this new information and the development of novel analysis techniques, we can continue to unravel the mystery of trinitite formation.

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*All references verified as of April 2, 2026.

Credit: Dilok Klaisataporn / Shutterstock

Global sustainability: Toward a unified system of green glass standards

By Randy B. Hecht

What would it take to establish a global sustainability standard for glass manufacturing, materials sourcing, and recycling?

Historically, the glass sector has lagged the aluminum and steel industries in establishing sustainability standards.[1,2] Of the standards that do exist, they typically vary greatly by region.

In March 2026, the board of a new multistakeholder organization called ResponsibleGlass proposed a framework for developing global glass sustainability standards. While this initiative marks an important step toward developing and implementing global standards, one impediment to adoption could be the sense in some countries—from Canada to Singapore—that sustainability standards must reflect the unique climate challenges they face.

RESPONSIBLEGLASS: TAKING RESPONSIBILITY FOR SUSTAINABLE GLASS

ResponsibleGlass, headquartered in London, was founded in December 2025 to "bring together the entire glass value chain, from raw material suppliers to manufacturers, glass users, and recyclers, alongside civil society organisations" and adopt a global standard for glass production, sourcing, and recycling (https://responsibleglass.org).

The organization's vision and mission document, which is available at https://bit.ly/ResponsibleGlass-2026, lays out the overriding standard: for all glassmaking materials to be produced responsibly and without causing death or injury. It calls for the industry and all participants in its supply chain to respect worker and human rights and the rights of communities in which they operate. The environmental practices it champions include biodiversity, water stewardship, near-zero and net-zero greenhouse gas emissions, and recovery/recycling of all glass after its use.

The vision statement acknowledges that these objectives are aspirational and can be converted into practice only through the use of new technologies, processes, policies, and partnerships. To achieve its mission, ResponsibleGlass commits to "creating value for responsible businesses" in the sector and "working with affected stakeholders and rightsholders" to develop "international standards and certification and related tools where required."

The board approved and published two additional documents in March 2026: International Standards Development Procedures (https://bit.ly/4lKrbxg) and International Standard for Glass Making Terms of Reference (https://bit.ly/4dFzyYQ).

The organization is recruiting sponsors and founding members through December 2028. Beginning in January 2029, it will require new business members to hold ResponsibleGlass certificates, for which they will be charged a license fee.

EUROPE'S PERSPECTIVE ON GLASS STANDARDS

Efforts to establish a global sustainability standard for glass will have to account for existing and emerging local, national, and regional standards.

Glass for Europe, the Brussels-based trade association for Europe's flat glass sector, is one of eight associations that in November 2025 co-published a paper titled "Making environmental performance declarations work: European construction industries call for practical and effective rules to declare the environmental performance of their products" (full paper available at https://bit.ly/3NyhipT). The organization's objectives include contributing to "the development of EU and international product standards adapted to market needs and legal obligations" (https://glassforeurope.com/mission).

In January 2020, Glass for Europe announced "2050 Flat Glass in a Climate-Neutral Europe," a vision document that highlights the flat glass sector's role in Europe's decarbonisation goals "but also identifies how a virtuous decarbonisation cycle can be triggered on the journey towards climate-neutrality." Learn more: https://bit.ly/Flat-Glass-Neutral-Europe

Subsequently, the organization presented its recommendations for the Clean Industrial Deal, a European Commission initiative that launched on Feb. 26, 2025. The deal "outlines concrete actions to turn decarbonisation into a driver of growth for European industries" by focusing on affordable energy, boosting demand for clean products, financing the clean transition, integrating circularity, building reliable global partnerships, and supporting skills training and quality jobs. Learn more: https://commission.europa.eu/topics/competitiveness/clean-industrial-deal_en

APAC COUNTRIES ACT INDEPENDENTLY

There are 18 national member institutions within the World Green Building Council's Asia Pacific Network (https://worldgbc.org/asia-pacific). Sustainable glass concerns are integrated within building standards in the region and have developed at the country level.

Green Building Council Australia founded Green Star in 2003 and describes it as "an internationally recognised rating system setting the standard for healthy, resilient, positive buildings and places." Learn more: https://new.gbca.org.au/green-star/exploring-green-star

Green Building Council New Zealand has adopted its own version of Green Star. Learn more: https://nzgbc.org.nz/green-star-buildings-nz

The Green Building Council Indonesia is developing a certification program called GREENSHIP Net Zero "as part of the global initiative for total sector decarbonization by 2050." Learn more: https://gbcindonesia.org/netzero/greenship

Green Building Japan promotes the LEED certification standard. Learn more: https://www.gbj.or.jp

The Korea Green Building Council promotes "best practices in green building certification, industrial advancements, and technological innovations." Learn more: https://www.koreagbc.org/english

Singapore's Green Mark Certification Scheme launched in January 2005. Its Green Mark 2021 is the "internationally recognised green building certification scheme tailored for the tropical climate." Learn more: https://www1.bca.gov.sg/sustainability/greenmark

The Thai Green Building Institute advocates for "innovative design, construction practices, and local wisdom to promote sustainability in Thailand's construction, engineering, and architectural industries." Learn more: https://tgbi.or.th/en/home-en

NORTH AMERICA'S GREEN GLASS GOALS

In 2025, the Canadian Glass Standards Board was dissolved as work on and technical support for glass standards were integrated into the National Building Code of Canada.[3]

Features of the 2025 Code include expansion of efforts to address greenhouse gas emissions, introduction of a harmonized framework intended to reduce residential and commercial buildings' operations greenhouse gas emissions, and new energy efficiency requirements for the alteration of existing buildings. The Code also calls for "inclusion of projected climatic data, which anticipates climate trends over the next 50 years, so buildings are better prepared for future climate conditions in Canada. Learn more: https://cbhcc-cchcc.ca/en/current-codes

In the U.S., the National Glass Association "works with standards and codes bodies to promote and defend the use of glass in the built environment." It tracks the latest in industry standards (https://bit.ly/NGA-industry-standards) and building codes (https://bit.ly/NGA-building-codes) at the international, national, and state levels and also publishes resources on topics such as window recyclability and sustainability terminology.

The National Institute of Building Sciences oversees the High-Performance Buildings Guide (previously managed by the U.S. General Services Administration) as a "resource for creating efficient, healthy buildings...and making sustainable and resilient purchasing choices" (https://hpb.wbdg.org). An affiliated learning page covers topics such as building energy use, building energy security and efficiency, grid-interactive efficient buildings, and net-zero energy.

The Glass Packaging Institute published "A circular future for glass: A ten-year roadmap to increase US glass recycling," which details plans to increase the U.S. glass recovery and recycling rate by 19%. Learn more: https://bit.ly/4rMmCUx

It remains to be seen how well a global standard can incorporate national priorities, but attempts to take global standardization from theory to practice should spark increased interest in strengthening sustainability performance.

ABOUT THE AUTHOR

Randy B. Hecht is founder and owner of Aphra Communications (Brooklyn, N.Y.). She works extensively with clients in Europe, Asia, and the Americas on materials science content produced for global audiences. She has written The American Ceramic Society's annual report on international ceramics and glass markets since 2009. Contact Hecht at rbhecht@aphra.com.

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Brittney Hauke
ACerS journals managing editor

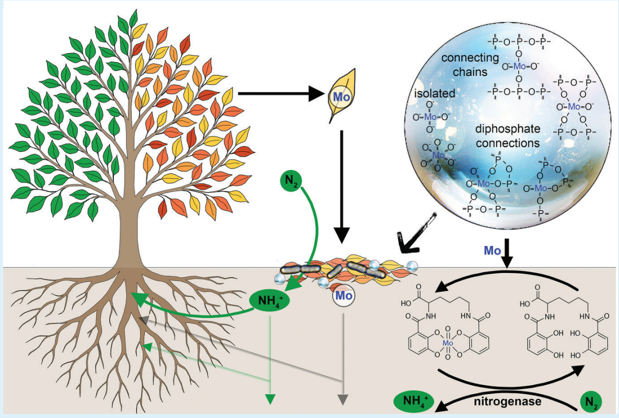
Glass innovations for a more sustainable environment

Although glass is generally considered an eco-friendly material due to being infinitely recyclable in theory, the overall environmental cost of glass is high when you consider the required energy cost and subsequent carbon emissions during manufacturing. Industry, academic, and government researchers have all devoted a lot of effort to decarbonizing the industry, both in terms of the manufacturing process itself and in terms of how the energy required for glass melting is obtained. But more work needs to be done to achieve true carbon neutrality.

Developing alternative compositions to the emissions-heavy soda lime silicate glass (SLS) that currently dominates the market is one way to improve the sustainability of glass manufacturing. The first example in this vein that comes to my mind is The Pennsylvania State University's LionGlass™ (I am biased considering I was a member of the group working on this material). LionGlass is an emerging low-carbon alternative to SLS glass. Unlike traditional SLS glass production, which involves the melting of carbonate batch materials that release a significant amount of CO_2, LionGlass is an aluminosilicophosphate glass that aims to address these issues by both decreasing the temperature required for melting and using batch components without carbonates. The open-access paper "LionGlass™: A low-melting, carbonate-free alternative to soda lime silicate glass" by Clark et al. provides a closer look at this patent-pending glass compositional family.[1]

Lowering the melting temperature of common glass compositions is another way to reduce the environmental footprint of glass. This goal can be accomplished by using fining agents, which assist with the bubbling of gases that are released during the melting process, thus ensuring that the final glass is clear and free of bubbles. Bubble-free production is especially important for aluminosilicate and boroaluminosilicate glasses, which are used for display glasses, vaccine vials, and fibers.

In the open-access paper "Redox behavior of tin in aluminosilicate melts: Implications for the fining process," Donatini et al. used Raman and X-ray absorption fine structure spectroscopy to investigate how tin ions from an SnO_2 fining agent impact the local structure of sodium aluminosilicate (NAS) glass.[2] They found that tin(IV) is octahedrally coordinated in NAS glasses and that the tin redox state at room temperature is dependent on the total tin concentration, where it is oxidized at higher concentrations.



Credit: Franziska Scheffler, J. Am. Ceram. Soc. (CC BY 4.0)

Figure 1. Illustration of the terrestrial molybdenum cycle and its role in plant nutrition.

Glass can also support environmentally friendly processes, such as being used as fertilizer. A fully inorganic glass can help mitigate issues related to releasing nutrients at a specific rate and not leaving behind organic residues. This property is useful as it prevents overfertilization and conserves phosphorus, saving this limited resource and keeping it from poisoning nearby bodies of water due to run off. It can also reduce the environmental impact by requiring less raw materials and potentially reducing greenhouse gases during application.

The ability to tailor specific glass compositions allows not only precise control of the solubility and nutrient delivery but also the option for multinutrient delivery. However, the main issue currently with glass fertilizers is their inability to provide nitrogen. To this end, Scheffler et al. investigated incorporating molybdenum into the glass fertilizer mix in the open-access paper "Functional glass-based fertilizer implementing bacterial nitrogen fixation."[3] They hypothesized that molybdenum could potentially enhance the growth of nitrogen-fixing bacteria, which would provide a natural nitrogen source for the plants (Figure 1). They demonstrated that a phosphate-based glass with 5 mol.% molybdenum can promote the growth of the *Azotobacter vinelandii* bacteria. This bacterium uses an enzymatic reaction to transform ambient nitrogen into ammonia that can be used by plants, thus reducing the need to integrate nitrogen into the glass itself.

These papers are just some examples of the green glass manufacturing research that is being conducted and reported in ACerS journals. To read more, visit the ACerS journals homepage at https://ceramics.onlinelibrary.wiley.com.

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UPCOMING MEETINGS

MAY 31–JUNE 5, 2026

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Save the date!

calendar

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May 2026

★ ACERS COURSE

26–June 4 Foundations of Ceramic Processing – Virtual; https://ceramics.org/course/carty-ceramic-processing

★ ACERS COURSE

31 Testing of Materials in Extreme Environments – Sheraton San Diego Hotel & Marina, San Diego, Calif.; https://ceramics.org/course/hypersonic-testing-htcmc-gfmat

ACERS EVENT

31–June 5 12th International Conference on High Temperature Ceramic Matrix Composites and Global Forum on Advanced Materials and Technologies for Sustainable Development – Sheraton San Diego Hotel & Marina, San Diego, Calif.; https://ceramics.org/htcmc12_gfmat3

June 2026

★ ACERS COURSE

1–Aug. 15 Ceramic Essentials: A Technician Workshop – On-site at companies requesting the training; https://ceramics.org/course/greschuk-ceramics-essentials

ENDORSED EVENT

7–12 Solid State Studies in Ceramic Science Gordon Research Conference – Mount Holyoke College, South Hadley, Mass.; https://www.grc.org/solid-state-studies-in-ceramics-conference/2026

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8–10 Structural Clay Products Division & Southwest Section Meeting 2026 – DoubleTree by Hilton Canton Downtown, Canton, Ohio; https://ceramics.org/clay2026

ACERS EVENT

10–12 16th Advances in Cement-Based Materials – University of Miami, Coral Gables, Fla.; https://ceramics.org/cements2026

ENDORSED EVENT

15–25 CIMTEC 2026 – Perugia, Italy; https://ceramics.org/event/cim-tec-2026

● ENDORSED EVENT

24–26 Electronic Materials Conference – University of Michigan, Ann Arbor, Mich; https://2026.emc-conference.org

July 2026

ENDORSED EVENT

8–10 International Conference on Self-Healing Materials – Drexel University, Philadelphia, Pa.; https://icshm2026.org

ENDORSED EVENT

12–16 American Conference on Neutron Scattering 2026 – Detroit Marriott at the Renaissance Center, Detroit, Mich.; https://ceramics.org/acns2026

★ ACERS COURSE

14–18 Properties and Testing of Refractories – Westerville, Ohio; https://ceramics.org/course/homeny-properties-and-testing-refractories

August 2026

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

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, Penn.; https://ceramics.org/annual-meeting2026

January 2027

● ENDORSED 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

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deciphering the discipline

A regular column showcasing the expertise of emerging ceramic and glass scientists, organized by the ACerS President's Council of Student Advisors

By Ebele Ahizi

Guest columnist

Decarbonizing glass through raw material innovation

The glass industry has a unique presence in modern society, as this material serves a wide variety of purposes in construction, packaging, electronics, and renewable energy systems. However, glass manufacturing remains an energy-intensive process (consumes about 220 TWh/yr) and contributes significantly to industrial carbon dioxide emissions (emits about 50–60 MT/yr of CO_2 as of 2020).[1]

Efforts toward greener glass production typically focus on the processing side, with research aimed at improving furnace efficiency, increasing cullet content, adopting oxy-fuel combustion, and exploring electrification. However, not all carbon emissions from glass manufacturing arise from fuel combustion—an equally important, yet sometimes overlooked, source of CO_2 is the raw materials themselves.

In conventional commercial soda–lime–silica (SLS) glass production, three major oxides are present. One is calcium oxide (CaO), which is introduced from the decomposition of the raw material calcium carbonate ($CaCO_3$) at elevated temperatures above 600°C. This decomposition reaction releases CO_2 and occurs regardless of whether the furnace is powered by natural gas, hydrogen, or electricity. Hence, these emissions are chemically embedded in the batch formulation.

Research shows that the decomposition of $CaCO_3$ is strongly endothermic, meaning the process absorbs heat from its surroundings. Thus, additional thermal energy is required for complete decomposition. Furthermore, when the CO_2 is released, initially it becomes trapped within the viscous melt as bubbles. The melt must thus be held at high temperatures for longer periods to allow the bubbles to escape, thereby increasing the energy burden during the refining stage.

A more comprehensive decarbonization strategy includes the consideration of alternative raw materials to create the glass, such as naturally occurring minerals that exist as prereacted silicates.[2] Wollastonite ($CaSiO_3$) is one such alternative raw material. Unlike $CaCO_3$, the decomposition of wollastonite into CaO does not release CO_2. The reaction is also less endothermic, thereby decreasing the overall enthalpy demand of the melting process,[3] and it results in the formation of fewer bubbles, which could reduce the refining burden by allowing for shorter high-temperature residence times.

Traditionally, refining efficiency has focused on bubble removal through furnace temperature profile optimization, redox control, and the use of refining agents. In other words, these methods have focused on correcting rather than preventing gas generation from batch decomposition. From a thermodynamic perspective, avoiding gas evolution is inherently more energy efficient than driving the formation and then the removal of gas bubbles from the melt. The use of $CaSiO_3$ as a raw material thus supports this preferrable solution to refining efficiency.

Figure 1. Container-type soda–lime–silica glasses produced with incremental substitution of the calcium-bearing raw material $CaCO_3$ with $CaSiO_3$, from 0 wt.% (left) to 100 wt.% (right).

The sustainability benefits of using $CaSiO_3$ are evident, and these benefits may be extended to furnace throughput, which could increase due to enhanced production stability. Nevertheless, factors such as availability, cost, compatibility with existing furnace operations, and product performance must all be considered. So, incremental substitution or partial replacement strategies may offer a more realistic and technically feasible pathway toward greener glass manufacturing.

My present research monitors the impact of incremental introduction of $CaSiO_3$ to replace $CaCO_3$ in the melting of a standard SLS glass (Figure 1). So far, it has shown linear-like energy saving in the reduction of decomposition temperatures during melting.

In conclusion, the drive toward more sustainable SLS glass production demands a broader perspective that integrates raw material innovation with process optimization. Substituting carbonate-based raw materials with alternative sources, such as wollastonite, offers a proactive strategy to reduce CO_2 evolution and energy requirements.

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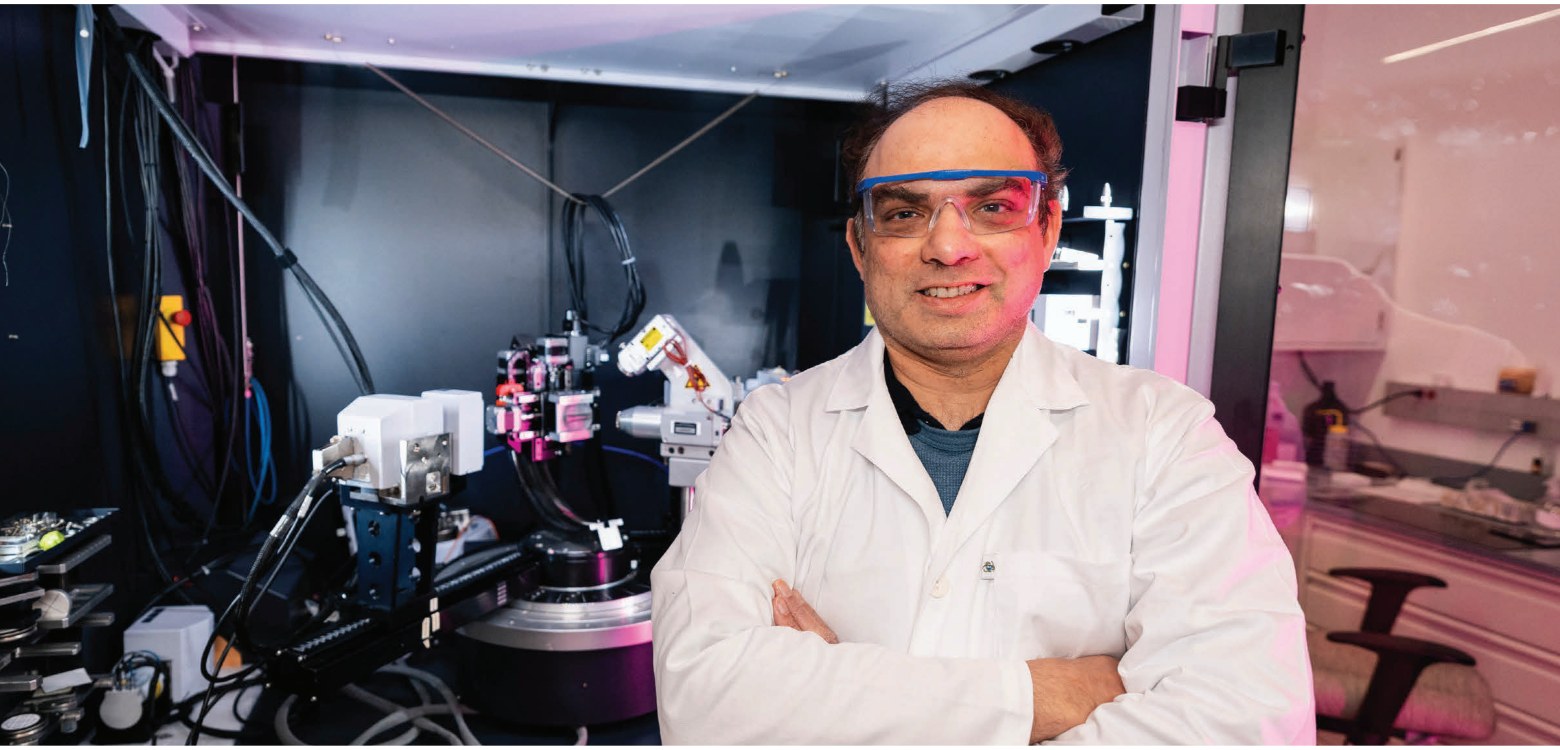
Ebele Ahizi is a Ph.D. candidate in Professor Paul Bingham's group at Sheffield Hallam University in the United Kingdom. Her research focuses on energy reduction and emissions control in glass manufacturing. In her free time, she loves to travel. ■

Welcoming new faculty in Ceramic Engineering at Alfred University.

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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