AMERICAN CERAMIC SOCIETY

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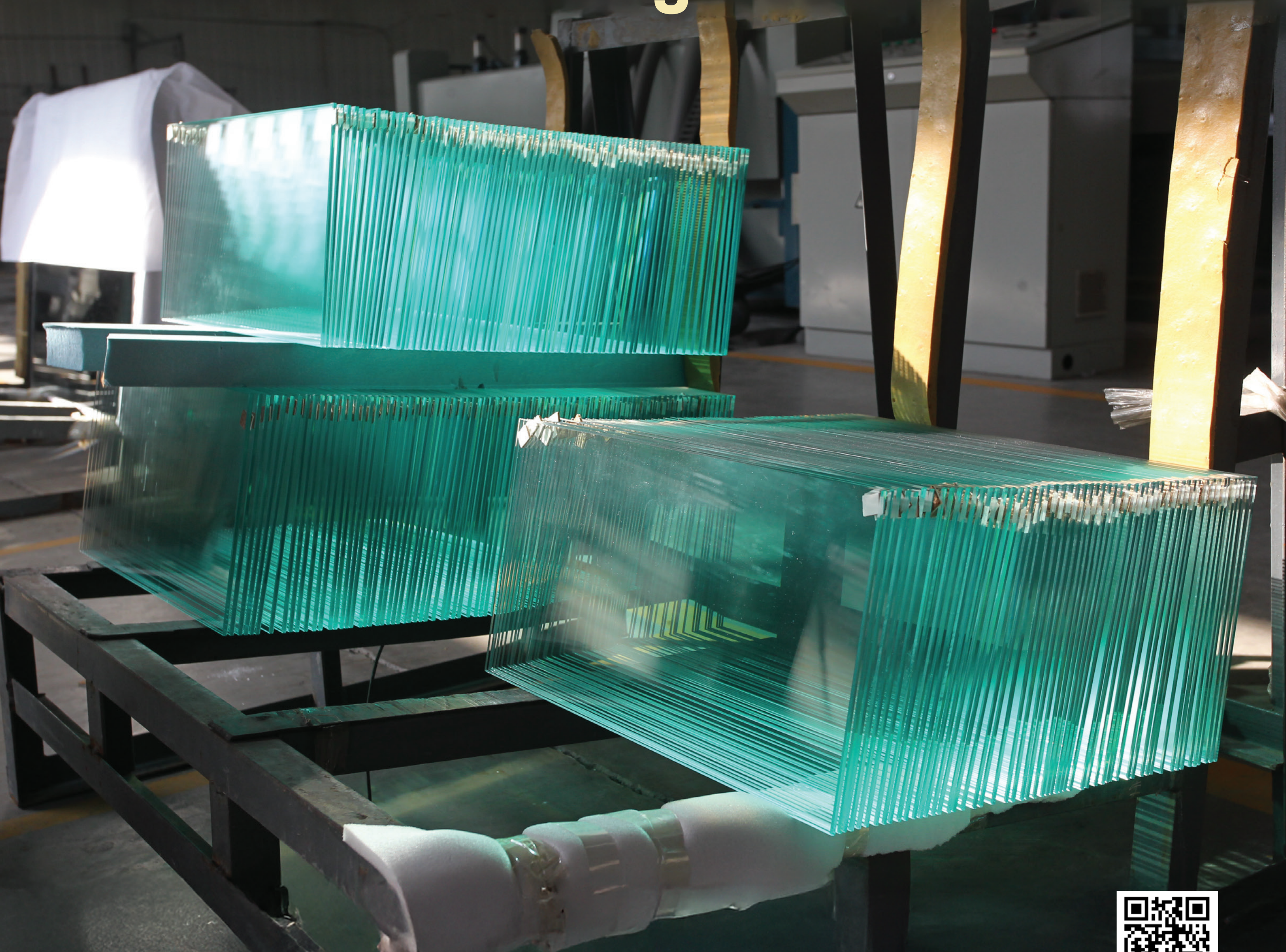
emerging ceramics & glass technology

MAY 2025

Prospects for ion-exchange processing of commercial soda-lime-silica glasses



Evolution of car windshields | History of the glass transition | Value-added glass markets

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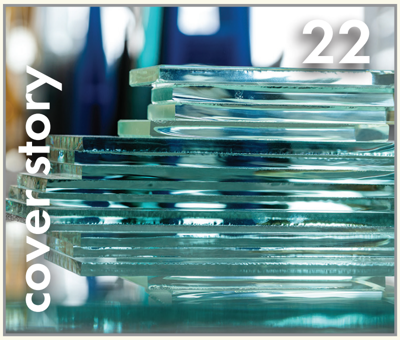

Prospects for ion-exchange processing of commercial soda-lime-silica glasses

Ion-exchange processing has been used to improve the mechanical properties of many specialty glass compositions. But its potential for similar use with commercial-grade soda-lime-silica glasses remains to be explored.

by William LaCourse, Jacob Kaspryk, and Benjamin J. A. Moulton

The evolution and importance of car windshields in automotive design

The history of car windshields reflects significant advancements in automotive design, marked by continuous innovations aimed at improving safety and comfort for both drivers and passengers.

by Lisa McDonald

The untold history of the glass transition

The nature of glass is inextricably tied to its thermal history through the glass transition. But what of the history of the glass transition itself? This article explores the origin of this scientific concept, tracing its beginnings to an unlikely source.

by Sofia F. Mauro and John C. Mauro

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As seen on *Ceramic Tech Today*...

Credit: Nicole Fandel, MIT Lincoln Laboratory

3D-printed glass: Shining a light on recent developments

Developments in glass 3D printing continue to advance slowly, and today's CTT summarizes some recent work done by several groups at Massachusetts Institute of Technology in this area.

Read more at https://ceramics.org/3d-printed-glass-developments

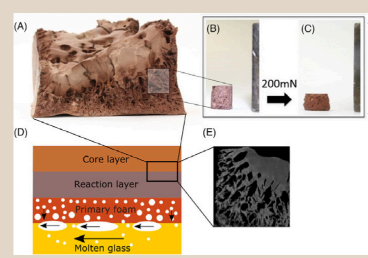
Also see our ACerS journals...

Thermo-rheological snapshot of melter feed conversion to glass
By S. Younk, J. L. George, S. A. Luksic, et al.
Journal of the American Ceramic Society

Structure and durability of opal crystallized glass plates
By L. Brunswic, F. Angeli, L. Gautron, et al.
International Journal of Applied Glass Science

Transparent superhydrophobic and thermal insulating dual-functional coatings fabricated by a rapid thermal process
By C. Ke, C. Zhang, L. Pan, and Y. Jiang
International Journal of Applied Ceramic Technology

Automated tool for cylindrical glass container blow and blow mold design
By O. Fibla-Figuerola, A. Biosca, V. Pedret-Clemente, et al.
International Journal of Applied Glass Science



Credit: Younk et al., *JACerS*

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American Ceramic Society Bulletin is the membership magazine of The American Ceramic Society. It covers news and activities of the Society and its members and provides the most current information concerning all aspects of ceramic science and technology, including R&D, manufacturing, engineering, and marketing. *American Ceramic Society Bulletin* is published monthly, except for February, July, and November. Subscription included with The American Ceramic Society membership. Institutional subscription rates can be found online at www.ceramics.org or by contacting customer service at customerservice@ceramics.org.

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ACSBA7, Vol. 104, No. 4, pp. 1–40. All feature articles are covered in Current Contents.

news & trends

Down in price, up in size: The climate costs of supersized electric vehicles

Thanks to mature technology, expanded options, and federal tax credits, the price for electric vehicles has dropped considerably in recent years, bringing this technology into the realm of affordability for many more consumers. But as the price for EVs has gone down, the size of EVs has started to creep up.

Although supersized EVs are better for air quality than a similar-sized internal combustion engine vehicle during operation, manufacturing the supersized battery and components produces considerable emissions. This fact begs the question—are supersized EVs really better for the planet?

Downsides of supersized vehicles

Simple physics tells us that a heavier object moving at the same speed as a smaller object will have more force upon impact. When applied to cars, this logic indicates that a supersized vehicle will cause more damage to pedestrians, other vehicles, and stationary objects (such as guardrails) during collision.

Furthermore, the increased height and bulk of supersized vehicles can obstruct sightlines, making it harder for drivers to see pedestrians, especially smaller individuals or children. This limitation makes collisions more likely, not to mention that the vehicle's heavier weight will put increased stress on bridges and overpasses. And then there is the increased environmental cost of mining materials for all the supersized components.

In some ways, these downsides are even more acute for supersized EVs.

Concerns for pedestrian safety

EVs are so quiet that they are required to produce an artificial noise at low speed. Their lack of noise can make them difficult for distracted pedestrians or bicyclists to hear. One study found that pedestrian collisions with EVs were almost twice as common as pedestrian collisions with gas cars.

Damage to infrastructure

Like cargo trucks, heavier EVs can place increased stress on road surfaces and bridges. But EVs also have lower centers of gravity than gasoline-powered cars, and this fact has raised concerns that existing highway guardrails may be insufficient to stop many electric vehicles.

Furthermore, many highway repair programs are funded by state gasoline taxes. As EV use goes up, gasoline tax receipts go down. As such, different highway maintenance funding schemes are needed.

Environmental concerns

The environmental benefits of EVs during operation must be offset by the costs of mining and refining the necessary materials. The larger the vehicle, the greater the demand for raw materials.

EV batteries, particularly, present environmental challenges. Batteries rely on many critical minerals and metals, and mining these materials is resource intensive. Additionally, the tailings (leftovers from the mining process) can leach toxic chemicals into the ground, contaminating water sources and causing habitat loss.

The climate costs of supersized electric vehicles

In January 2025, Perry Gottesfeld, executive director of the nonprofit Occupational Knowledge International, published an open-access opinion piece analyzing the tradeoff between climate costs and benefits of supersized electric vehicle production and operation.

Credit: Mr.choppers, Wikimedia (CC BY-SA 3.0)

Example of the 2024 Tesla Cybertruck Foundation Series, which weighs in at 6,669 lbs. Similarly sized gas-powered pickup trucks weight much less. For example, the Ford F-150 has similar dimensions as the Cybertruck but ranges from 4,021 to 5,740 lbs depending on the model, engine, and features.

"To better align car purchasing with the goal of reducing greenhouse gas emissions, we need to educate consumers that replacing a conventional vehicle with an EV may not necessarily be reducing their emissions," Gottesfeld said in an interview with Cosmos.

He concluded that supersized EVs are "failing to substantially reduce greenhouse gas emissions" in comparison to small conventional vehicles, and so improved public policy, incentives, and messaging are needed to drive consumer demand to smaller EVs.

The open-access paper, published in *PLOS Sustainability and Transformation*, is "Super-sized electric vehicles will not solve the climate crisis" (DOI: 10.1371/journal.pstr.0000159). ■

Corporate Partner news

CARBO Ceramics' new Louisiana plant earns ISO certification

In January 2025, CARBO Ceramics' new plant in New Iberia, La., achieved ISO certification, awarded by Perry Johnson Registrars Inc. This new plant specializes in chemical coating, infusing, and drying processes. Read more: https://carbo.tech/newsroom

Sumitomo Chemical appoints new chairman and president

In February 2025, Sumitomo Chemical Nomination Advisory Committee appointed Nobuaki Mito as the company's new president. His inauguration is planned for June 2025. Keiichi Iwata, the current president, will serve as representative director and chairman. Read more: https://www.sumitomo-chem.co.jp/english

Toto Ltd. in top 10% of S&P Global's Sustainability Yearbook ranking

Toto Ltd., a Japanese multinational toilet manufacturer, was selected as one of the top 10% in S&P Global's Sustainability Yearbook for 2025 rankings. S&P Global assessed 7,690 companies worldwide and selected only 780 companies. Read more: https://www.toto.com/en/press

U.S. Borax donates to communities impacted by Los Angeles wildfires

In February 2025, Rio Tinto's U.S. Borax donated $600,000 to organizations to help support the areas impacted by wildfires in the Los Angeles area. The funds will be split evenly between The Kern County Fire Department, the Los Angeles Fire Department Foundation, and the Los Angeles Regional Food Bank. Read more: https://www.borax.com/news-events ■

Global markets and technologies for smart glass

The global market for smart glass was valued at $5.6 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 11.7% to reach $10.8 billion by the end of 2029.

Smart glass, also called switchable glass, is a type of chromogenic material that can change its optical properties to become opaque or tinted in response to various signal types. It can be classified as either active or passive (Table 1). Active smart glass requires electricity to change its properties. Examples of active smart glass technologies include

- **Electrochromic glass**, which consists of electrochromic materials and conductive coatings fitted between two sheets of glass. Electricity causes ions to move between the layers, altering the optical properties.
- **Suspended particle device glass**, which uses rod-like particles suspended in a liquid or film between two layers of glass. Electricity causes the orientation of the particles to vary, thereby regulating the amount of light transmitted.
- **Polymer-dispersed liquid crystal glass**, which uses liquid crystal molecules dispersed in a polymer between two layers of glass. Electricity causes the orientation of the molecules to vary, thereby regulating the amount of light transmitted.

Passive smart glass relies on inherent properties to respond to external stimuli without requiring electricity. Examples of passive smart glass technologies include

- **Photochromic glass**, which contains molecules that darken when exposed to ultraviolet radiation.
- **Thermochromic glass**, which contains materials that change opacity when exposed to heat.

Table 1. Basic comparison of different smart glass technologies

Type	Control mechanism	Common applications	Response speed
Electrochromic	Electric	Office partitions, windows, automotive, residential	Slow (up to several minutes)
Suspended particle devices	Electric	Automotive, aircraft, luxury buildings, skylights	Fast
Polymer-dispersed liquid crystals	Electric	Privacy windows, office partitions	Instant
Photochromic	Sunlight exposure	Exterior building windows, eyewear	Slow (seconds to minutes)
Thermochromic	Temperature sensitive	Building windows, greenhouses, skylights	Slow changes in temperature

Table 2. Global market for smart glass, by end-use industry, through 2029 ($ millions)

End-use industry	2023	2024	2029	CAGR % (2024–2029)
Construction	2,955.4	3,312.7	6,200.5	13.4
Automotive and aircraft	1,861.6	2,036.7	3,371.1	10.6
Electronics	355.0	376.9	533.5	7.2
Power generation	280.6	300.7	443.3	8.1
Others*	166.5	181.9	234.2	5.2
Total**	5,619.0	6,209.0	10,782.5	11.7

*Other segments include consumer products and medical devices.
** Totals in this report's tables might not match exactly because of rounding.

Smart glass finds significant application in the construction industry for purposes such as creating partitions and improving energy efficiency (Table 2). But it is also gaining ground in the automotive sector for use as sunroofs and windows. The electronics industry is exploring the use of smart glass, too, to enable dynamic electronic display features, such as light adjustment and privacy options. Meanwhile, the power generation industry is investigating smart glass integrated with photovoltaic technology to help reduce energy needs for lighting and cooling.

As of 2023, Europe accounted for the highest market share of smart glass (38.7%), followed by North America (30.4%) and Asia-Pacific (21.1%). The European market's interest in smart glass is mostly due to strict government regulations toward energy-efficient buildings.

About the author

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

Resource

BCC Publishing Staff, "Global markets and technologies for smart glass," BCC Research Report AVM065E, January 2025. https://bit.ly/BCC-January-2025-smart-glass ■

By Cory L. Trivelpiece, Xiaonan Lu, Dilpuneet Aidhy, and Collin Wilkinson
Guest columnists

Expanded access: DOE's nuclear waste glass database

Scientists and engineers around the world have worked for decades developing technologies to safely and permanently dispose of nuclear waste. Though these wastes originate from a multitude of processes, they all are highly toxic and extremely harmful to life in any form.

In 1982, borosilicate glass was deemed the preferred waste form for the disposal of high-level nuclear waste.[1] Since then, researchers confirmed glass is an effective waste form for low-activity waste as well.[2]

In the years leading up to and following that 1982 decision, an enormous amount of data has been generated by U.S. national labs, universities, and international institutions relating to the properties of nuclear waste glasses. Until recently, most of this data could only be accessed from isolated reports or institutional databases maintained by scientists who performed the original experiments.

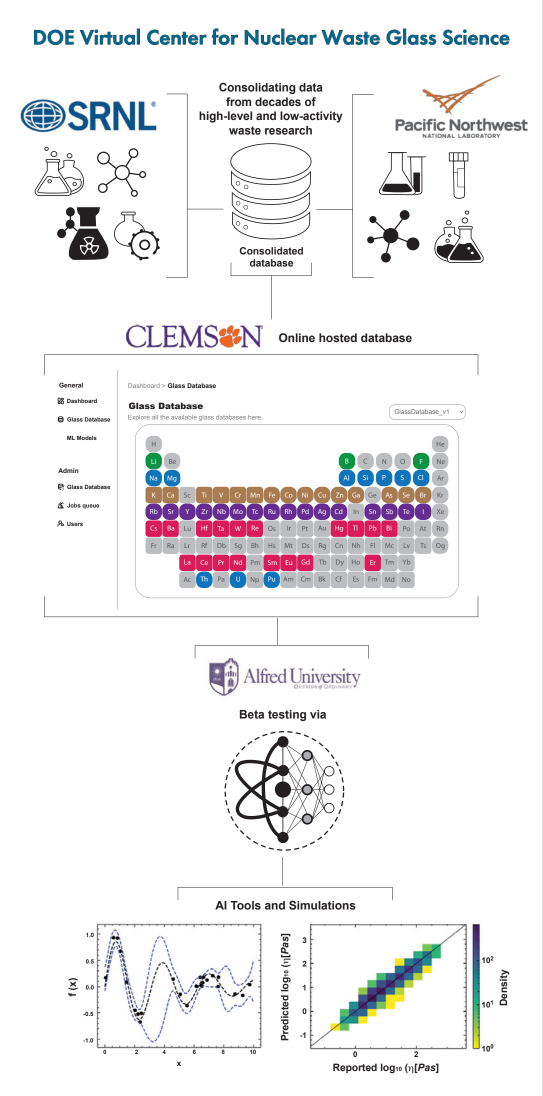
In 2019, researchers from Savannah River and Pacific Northwest National Laboratories joined forces to create the first online, open-access repository of nuclear waste glass data. This effort, which now also includes experts from Clemson and Alfred Universities, is sponsored by the U.S. Department of Energy's Office of Environmental Management.

The primary goal of the database development team is to consolidate the data from these decades of research into a single source that can be used by glass scientists from around the world to study vitrified radioactive waste forms. They have worked to incorporate data from multiple institutions; identify the Nuclear Quality Assurance level for each study; develop a forward-facing "landing page" for the front end of the database; and implement filtering methods to target specific glass properties such as composition, viscosity, and durability.

In 2024, the development team began work to bootstrap the former "SciGlass" database,[3] which contains information on more than 400,000 glasses, to the website. Along with this bootstrapping, which allowed for greater compositional breadth, the developers incorporated machine learning-based predictive models to enhance the database's utility.

The result is the new Virtual Center for Nuclear Waste Glass Science, which currently includes data for more than 6,000 glass compositions with various properties related to processability and product quality. In contrast to other glass databases, the Virtual Center uses statistical mechanics-based estimates to approximate various properties, adding physically meaningful results to the software implementation. These estimates are made possible through using the new Stat Mech Glass Python module.[4]

The Virtual Center for Nuclear Waste Glass Science is undergoing its final rounds of beta testing before being officially launched to the general public. The website can be found at https://srnl.mcdc.cecas.clemson.edu/database.



Credit: Images provided by Savannah River and Pacific Northwest National Laboratories and Clemson and Alfred Universities. Compiled by Cyndy Griffith, ACerS.

About the authors

Cory L. Trivelpiece is principal engineer in the Glass, Cement, and Ceramic Science Group at Savannah River National Laboratory. Xiaonan Lu is a materials scientist at Pacific Northwest National Laboratory. Dilpuneet Aidhy is associate professor of materials science and engineering at Clemson University. Collin Wilkinson is assistant professor of glass science and engineering at Alfred University. All are co-principal investigators on the Virtual Center for Nuclear Waste Glass Science. Contact Trivelpiece at Cory.Trivelpiece@srnl.doe.gov.

References

[1] "EA-0179: Waste form selection for SRP high-level waste," Washington, D.C. (1982). https://www.energy.gov/nepa/ea-0179-waste-form-selection-srp-high-level-waste

[2] J. Marcial et al., "Hanford low-activity waste vitrification: A review," *Journal of Hazardous Materials* 2024, **461**: 132437.

[3] SciGlass Next, https://sciglass.uni-jena.de

[4] C. J. Wilkinson et al., "Statistical mechanical modeling of glass-forming systems: A practical review considering an example calcium silicate system," *Current Opinion in Solid State and Materials Science* 2022, **26**(5): 101018.

By David Holthaus
Industry reporter

Market demands spur development of innovative value-added glass products

Bigger, brighter, louder—as large-scale commercial and residential construction booms alongside growing urban populations, there are ever-increasing demands on buildings to keep occupants insulated from the intrusive sights and sounds of expanding cities. Add in the fact that many nations, states, and municipalities have adopted stricter energy efficiency standards for new constructions, and it is clear the market for value-added glass is prime for growth.

Value-added glass refers to glass that has been enhanced to offer additional functionalities beyond basic transparency. For example, smart or switchable glass, which can change its opacity or tint in response to electrical, thermal, and light signals, provide buildings with both improved solar control and privacy. (Learn more about the market for smart glass on page 6 in this issue.) Other examples include ultraviolet-resistant glass, which helps prevent degradation in museum artwork; water-repellent glass, which improves visibility when driving during rainy conditions; and acoustic glass, which reduces the noise inside buildings and vehicles to acceptable levels without sacrificing daylight.

Glass manufacturers around the world have responded to these market demands, rolling out innovative, value-added glass products that provide benefits such as energy efficiency, privacy, and more. Below are just a few examples of companies innovating in this sector.

North America

Auburn Hills, Mich.-based Guardian Glass has been a leader in the value-added glass sector. Thirty years ago, the company started up its first high-performance glass coater in Carleton, Mich. Today, the company operates 16 glass coaters around the world, producing advanced commercial glass on every continent.

Its SunGuard line of coated glasses offers different levels of solar control and light transmission. It is installed on some of the most ambitious structures in the world, including the world's tallest building Burj Kalifa, which serves as a center for commerce and culture in the desert climate of Dubai, United Arab Emirates.

The company also recently began commercializing a between-the-glass, automated shade technology. The shade is contained within a double- or triple-insulating glass unit, has no mechanical parts, and is activated by passing a small current through the conductive layers, creating an electrostatic attraction between the ultrathin shade and the glass surface. It has licensed the technology to Coral Springs, Fla.-based Privacy Glass Solutions, which will produce and commercialize the product in the U.S.

Guardian has also pioneered bird-friendly glass. More than 1 billion birds die each year from glass impacts in the U.S., according to the U.S. Fish and Wildlife Service, and the American Bird Conservancy and others have pushed for bird-friendly design standards. Guardian's Bird1st UV glass appears transparent to humans under most viewing conditions but features a striped pattern that is visible to birds. It is available in large sheet sizes to permit the design and installation of bird-friendly building façades.

Europe

Paris, France-based global manufacturer Saint-Gobain offers a value-added glass product that helps prevent overheating in buildings. The product, called Cool-Lite, reduces energy needs with an invisible thermal shield that retains the heat inside the building and captures the sun's heat to keep it outside.

The glass façades of Humaniti, a 39-story complex in downtown Montreal, Canada, that houses apartments, a hotel, offices, and restaurants, were made with Saint-Gobain's solar control glass and with its Planitherm glass, a low-emissivity, multipane safety glass.


Credit: Chuck Choi Architectural Photography

Guardian Glass SunGuard products were used in this Boston-area office building to enhance the project's sustainability, for example, by providing thermal insulation.

Mainz, Germany-based Schott AG, whose founder, Otto Schott, is credited with inventing specialty glass resistant to heat and temperature change, has continued its history of glass innovations. Its Pyran Platinum glass product offers high resistance to heat and thermal shock while maintaining a clear, colorless appearance and a smooth surface. It provides fire protection for up to 90 minutes in windows and 180 minutes in doors, the company states on its website.

Asia

Tokyo, Japan-based NSG Group, which owns the Pilkington brand of glass products, introduced a heated, insulating glass solution in 2024 featuring an electrically conductive coating. This HeatComfort technology provides infrared heating, offering a sustainable method for heating and insulating homes. By applying a voltage to the coating, the glass heats up. When incorporated into an insulating glass unit, the heat flow can be directed into the living space.

NSG also offers a Pilkington line of fire-resistant architectural glass, Pyrostop, that it says can provide additional time in an emergency for evacuation and fire extinguishing.

Value-added glass in transportation

The transportation industry also uses value-added glass for, among other things, windshields, sunroofs, and display panels.

Zeeland, Mich.-based Gentex supplies dimmable devices for vehicles, shipping more than 40 million units annually. Its product portfolio includes glare-eliminating interior and exterior rearview mirrors for automobiles and electronically dimmable windows for the aerospace industry. Among its newest products are large-area dimmable devices, such as sunroofs and sun visors.

Asahi India Glass Ltd. also offers a host of value-added glass products for the automotive segment. Examples of their products include heated windshields that automatically melt snow, windshields with in-built sensors to assist during dangerous driving conditions, and water-repellent windshields that prevent water droplets from adhering during downpours.

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. ■

Market forecast for value-added glass

Market research firms forecast solid growth in the value-added glass market in the next few years. New York City-based IMARC Group valued the global advanced glass market (which includes value-added glass) at $76.6 billion in 2024 and estimates it will grow at a compound annual growth rate of 4.3% to reach $114.3 billion by 2033. Ireland-based Research and Markets forecasts faster annual growth. In a 2022 report on advanced glass, it valued the market at $65.9 billion in 2021 and projected it will grow at a compound annual growth rate of 6.7% to reach $117.9 billion by 2030.

Worldwide, demand for value-added glass is strongest in the Asia-Pacific region, according to the IMARC report. Rapid urbanization in the region as well as infrastructure development and the expansion of the automotive and construction industries are credited with the growth. In North America, strong demand from the construction and automotive sectors is behind the growth, partly from an emphasis on sustainable infrastructure and the growth of electric vehicles. In Europe, the expanding aerospace and defense sectors are contributing to the growth of value-added and other advanced glasses. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

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Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partner:

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

ACerS International Türkiye Chapter attends Material Expo

On March 1, 2025, ACerS International Türkiye Chapter members attended the Material Expo, a Material Advantage program at Eskişehir Technical University. The program offered students a unique opportunity to gain firsthand knowledge about careers, industry standards, and emerging developments in the field of materials science and engineering from 12 distinguished speakers from leading businesses in the industry. Students reported a positive experience at the Material Expo, and the ACerS International Türkiye Chapter plans to create similar initiatives to improve the linkage between academia and industry. ■

ACerS International Türkiye Chapter members at the Material Expo.

WEBINARS TO WATCH

Check out these recent additions to the ACerS Webinar Archives:

HYDRATION-INDUCED CRACKING OF REINFORCED CONCRETE STRUCTURES: A EUROPEAN PERSPECTIVE
Original air date: Feb. 24, 2025
Hosted by: Cements Division
Featured speaker: Agnieszka Jędrzejewska

ADDITIVE MANUFACTURING OF CERAMICS and SELF-STANDING, MALLEABLE DOUGHS OF ADVANCED CERAMICS ENABLE LOW-NUMBER PRODUCTION ON A BENCHTOP
Original air date: March 10, 2025
Hosted by: ACerS International Italy Chapter and ACerS International Türkiye Chapter
Featured speaker: Paolo Colombo and Özge Akbulut

ACerS members can view these webinars and other past recordings by visiting the ACerS Webinar Archives at www.ceramics.org/education/webinars

Third São Carlos School welcomes nearly 100 attendees to advance glass science education and research

The Third São Carlos School on Glasses and Glass-Ceramics took place March 10–15, 2025, at the Federal University of São Carlos in Brazil. This prestigious event, which is organized by the Center for Glass Research, Technology and Education in Vitreous Materials (CeRTEV), brought together students and professors from around the world to advance glass science education and research.

The 94 attendees came from 12 countries, including the U.S., France, Germany, Poland, China, Croatia, Nigeria, Türkiye, Japan, India, Colombia, and Brazil. The School featured a carefully balanced program of high-level scientific lectures during the day, complemented by vibrant social activities in the evenings. These activities included a cocktail reception, an international snack party, a capoeira demonstration and tutorial, a glass orchestra performance, a farm visit, and student networking events.

The organizers extend their sincere gratitude to the sponsors who made this event possible: CeRTEV, DEMa-UFSCar, NYSCC Alfred University, ParqTec São Carlos, FAPESP, Şişecam, Corning, and the International Commission on Glass. Special recognition goes to the New York State College of Ceramics at Alfred University, whose exceptional contribution enriched the program significantly. Their delegation of six distinguished faculty members delivered outstanding lectures that inspired intellectual engagement and genuine excitement among participants. Instructors from Wuhan, Warsow, Corning, Şişecam, and AGC further strengthened and crystallized the School's program as well.

Instructors and attendees of the Third São Carlos School on Glasses and Glass-Ceramics (March 2025).

Further details about the School can be found on the CeRTEV webpage at https://bit.ly/Third-Sao-Carlos-School-2025. Glass professors and researchers are encouraged to send their students to the Fourth São Carlos School, which is planned for 2026. ■

MEMBER HIGHLIGHTS

IN MEMORIAM

Murray Schwartz

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Volunteer Spotlight: Delbert E. Day

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

Delbert E. Day is Curators' Distinguished Professor Emeritus of Ceramic Engineering at the Missouri University of Science and Technology (Missouri S&T). Day received a B.S. in ceramic engineering at the Missouri School of Mines and Metallurgy (now called Missouri S&T) and a Ph.D. in ceramic technology from The Pennsylvania State University.

Following his Ph.D., Day returned to Missouri S&T and for the next 50 years taught classes in the ceramic engineering program. He and his students performed ground-breaking research on a variety of glass-related topics, including the mixed alkali effect, nucleation and crystallization phenomena, iron phosphate glasses, and glasses for biomedical applications. The latter work included the development of glass microspheres for radioembolism treatment of liver cancer, and in 1985, Day started the company Mo-Sci to produce the microspheres. The company has now grown to become a worldwide supplier of specialty glasses for healthcare applications and other engineering products.

Day is a Distinguished Life Member and past president of The American Ceramic Society. He is a recipient of the Glass & Optical Materials Division's George W. Morey Award for glass research (1998), the Phoenix Award for the Glass Person of the Year (2010), and the International Commission on Glass President's Award (2013), among his many other honors. He is also a member of the National Academy of Engineers and a fellow of the National Academy of Inventors.

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

ACerStudent Engagement: Aaron Bossen

Aaron Bossen is a Ph.D. candidate studying materials science and engineering at The Pennsylvania State University. He serves as a member of the ACerS President's Council of Student Advisors (PCSA) Communications Committee.

"The PCSA has been a great professional resource within this exciting field, and has also connected me with new friends and experiences I wouldn't have had otherwise."

You can take advantage of these opportunities as well by becoming a student member of ACerS. Visit https://ceramics.org/membership/types-of-membership to learn more. ■

Ceramic Tech Chat: Holly Shulman

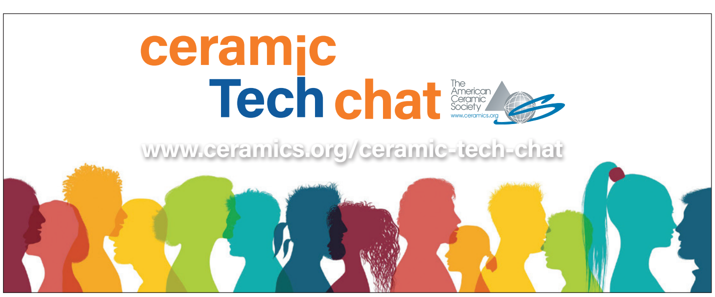
Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the third Wednesday of each month.

In the March 2025 episode of Ceramic Tech Chat, **Holly Shulman**, research professor at Alfred University, shares how she became interested in microwave sintering, describes its benefits compared to conventional sintering processes, and explains how it could support the development of future lunar colonies.

Check out a preview from her episode, where she describes the difference between microwave and conventional sintering.

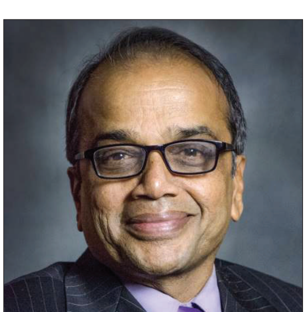
"What's happening is instead of just driving heat from the surface inward, if you can apply the energy volumetrically instead of just from the surface, then you're able to absorb energy in larger volumes, right? … Now, microwaves are not the most efficient way of creating a heat source. But once you have that microwave energy impinging on your product, your product is able to absorb it immediately and completely in the whole volume."

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



Names in the News

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



S.K. Sundaram, FACerS, Inamori Professor of materials science and engineering in The New York State College of Ceramics at Alfred University, was elected a Fellow of Optica. Sundaram received this distinction for his contributions to the development of the structure–terahertz properties relationship, ultrafast laser modification of glasses, and ceramics and optical materials education. ■

AWARDS AND DEADLINES

Call for YPN+1 Division Liaisons

The YPN+1 program offers Young Professionals Network (YPN) members a way to become involved in leadership roles within ACerS and their Divisions. Being a YPN Division Liaison provides YPN members the opportunity to connect in a meaningful way with their Division, learn how it operates, contribute to Division decisions, help promote engagement with other young professionals, and more.

Applications are now open for YPN Division Liaisons for the 2025–2026 term. To review the expectations for YPN Division Liaisons and to apply, visit www.ceramics.org/ypn1-program. The deadline to apply is **July 20, 2025.** ■

Nomination deadlines for Division awards: May 15, July 1, or Aug. 1, 2025

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	Christina Rost cmrost@vt.edu	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	Christina Rost cmrost@vt.edu	Recognizes academic interest and excellence among undergraduate students in ceramics/materials science and engineering.
ECD	Mrityunjay Singh Bridge Building Award	July 1	Amjad Almansour amjad.s.almansour@nasa.gov	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	Federico Smeacetto federico.smeacetto@polito.it	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	Jie Zhang jiezhang@imr.ac.cn	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 Diversity 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	Charmayne Lonergan clonergan@mst.edu	Recognizes exemplary student research related to the mission of ACerS Energy Materials and Systems Division.

Teachers dive into materials science at the CGIF's Ohio workshop

Teachers huddle around lab tables, the blue flames of the torches casting a soft glow across their focused faces. With steady hands, they dip copper wires into small piles of borax powder, then carefully return the coated wires to the flames. "Look at that!" exclaims one teacher as the powder melts and begins to transform into a clear, glass-like bead. Excited conversations fill the room as these simple materials transform before their eyes, demonstrating core scientific principles in engaging, visual ways.

This scene captures the essence of the Ceramic and Glass Industry Foundation's (CGIF) Magic of Materials Science Workshop, which took place at the Summit County Educational Service Center in Cuyahoga Falls, Ohio, on Feb. 28, 2025.

CGIF staff spent the day with 28 middle and high school teachers, many from a STEAM cohort that takes a multidisciplinary approach to teaching. The workshop equipped these educators with the knowledge and tools to inspire the next generation of ceramic and glass professionals.

The seven-hour professional development session allowed teachers to perform all nine hands-on experiments from the CGIF Materials Science Classroom Kit. Throughout the day, educators gained confidence in demonstrating principles of materials science that they can immediately implement in their own classrooms.

In addition to the hands-on experimental work, teachers had the opportunity to network with ceramic and glass industry professionals from Saint-Gobain NorPro, Momentive Technologies, GrafTech International Holdings Inc., and Owens Corning during an industry luncheon. These connections help teachers learn about the diverse careers available in the ceramic and glass industries so they can better guide students interested in materials science career paths in their local communities.

"These workshops create a direct connection between classroom learning and real-world applications in the ceramics and glass industries," says Marcus Fish, director of development at the CGIF. "When teachers understand the exciting career opportunities available in materials science, they become powerful advocates who can inspire students to explore these fields."

CGIF CERAMIC AND GLASS INDUSTRY FOUNDATION

Participants in the Magic of Materials Science Workshop at the Summit County Educational Service Center on Feb. 28, 2025.

Each participating teacher received a complete Materials Science Classroom Kit (valued at $250) to take back to their classroom, allowing them to immediately implement what they learned. Teachers also received supplemental resources highlighting career pathways in materials science, helping students connect these engaging experiments with real-world professional opportunities in ceramic and glass industries.

The workshop was made possible through the generous sponsorship from Saint-Gobain NorPro, along with additional funding from donations to the CGIF that support educational programming. Missi Zender-Sakach of the Summit County Educational Service Center played a crucial role in coordinating local logistics, recruiting participants from area schools, and facilitating engaging discussions throughout the workshop. This combined support enabled the CGIF to provide this valuable training opportunity to local educators.

For more information about the Magic of Materials Science Workshop or to inquire about bringing a teacher training program to your area, visit foundation.ceramics.org or contact foundation@ceramics.org. ■

Inside the world of brood parasitic birds: The role of grain boundaries in eggshell strength

An international group of researchers used imaging techniques and conceptual frameworks from the field of grain boundary engineering to understand how structural features affect eggshell strength.

To date, scientists have typically inferred eggshell strength based on the shell's thickness. But these inferences "underestimate and trivialize the complex eggshell ultra- and microstructure and its specific functional performances," the researchers write in an open-access paper.

They investigated the eggshells of a wide range of brood parasitic birds. Brood parasitic birds lay their eggs in the nests of others, sparing themselves the expense of rearing their own young. When the eggs hatch, the parasitic chicks compete with the host babies for food and nest space.

Host birds have developed various defense strategies against brood parasites, which the brood parasites then evolve to counter, as explained on the webpage of Georgia-based natural history museum Fernbank Science Center. For example, since at least the late 1800s, scientists have reported that parasitic eggshells are often stronger than the host eggs to prevent host birds from puncturing them in rejection.

The researchers of the recent study determined that eggshells featuring longer and more complex grain boundary paths were stronger and tougher than eggshells of similar thickness without those characteristics. However, not all parasitic eggshells demonstrated this extra strengthening mechanism. It depended on the specific parasitic species and host pair, which determined the likelihood of eggshell puncturing being used as a defense strategy.

The open-access paper, published in *iScience*, is "Avian obligate brood parasitic lineages evolved variable complex polycrystalline structures to build tougher eggshells" (DOI: 10.1016/j.isci.2023.108552). ■

Credit: Birds of Gilgit-Baltistan, Flickr (CC BY-SA 2.0)

The common cuckoo (pictured above) is a brood parasitic bird, meaning they lay their eggs in the nests of others. A recent study explored the structure–strength relationship in brood parasitic eggshells.

Materials in the news

Vehicle-integrated PV modules based on glass fiber-reinforced composites

Researchers at AGH University of Krakow and the Eko-Energia AGH student group developed an approach to lightweight, vehicle-integrated photovoltaic modules. The modules employ glass fiber-reinforced sheets on both the front and rear sides of the modules, thus making the modules bifacial and resulting in slightly higher energy output for a given area. For more information, visit https://www.pv-magazine.com/2025/03/17. ■

Exploring alternative aggregates: Coral sand could offset use of sea sand in cementitious composites

In a recent paper, researchers from Wuhan University of Technology in China investigated the potential of using coral sand as an aggregate in cementitious composites.

Coral sand is a type of carbonate sand originating in tropical and subtropical marine environments. Despite its name, coral is not the main component of coral sand. Instead, this sand comes primarily from the bioerosion of limestone skeletal material of marine organisms such as foraminifera, calcareous algae, mollusks, and crustaceans.

In their study, the researchers sourced coral sand as well as siliciclastic (silicate-rich) sea sand from the South China Sea. Scanning electron microscopy revealed the coral sand had slightly smaller average particle sizes than the sea sand (120 μm vs 140 μm), and the coral sand exhibited abundant pore structures on its surface.

To create the cementitious composites, the researchers mixed varied ratios of coral sand and sea sand with low-calcium fly ash and ground granulated blast-furnace slag. A solution of sodium hydroxide and sodium silicate was employed as the alkaline activator for the composite's matrix. Additionally, the composite contained a modified polycarboxylate-based superplasticizer to improve mixture workability as well as polypropylene fibers to improve tensile ductility and crack control.

Testing revealed that as coral sand replaced sea sand in the composite, flowability and drying shrinkage decreased while compressive strength experienced an initial rise followed by a decline. Overall, a 20 wt.% coral sand mixture yielded optimal results, with a compressive strength of 54.4 MPa and tensile strain capacity of 2.397% after 28 days.

The paper, published in *International Journal of Applied Ceramic Technology*, is "Sea/coral sand in marine engineered geopolymer composites: Engineering, mechanical, and microstructure properties" (DOI: 10.1111/ijac.14874). ■

US fusion code breakthrough slashes stellarator design time to under 10 seconds

Princeton Plasma Physics Laboratory researchers unveiled a groundbreaking computer code, QUADCOIL, that could greatly accelerate the design of stellarator fusion reactors. Stellarators use complex magnetic fields to confine superheated plasma. Unlike tokamaks, stellarators can operate in a steady-state mode, which is crucial for commercial power generation. However, they rely on intricate, 3D magnetic fields generated by external coils to confine the plasma. QUADCOIL can rapidly evaluate potential magnet design complexity in a mere 10 seconds, helping save time and resources early in the development cycle. For more information, visit https://interestingengineering.com/energy ■

Ultraviolet-emitting glass prevents biofilm formation in marine environments

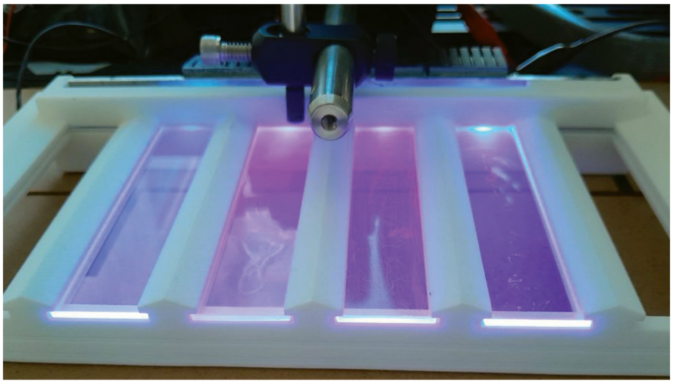
Researchers led by the University of Massachusetts Amherst, with funding from the U.S. Office of Naval Research, developed a new long-lasting coating to prevent biofouling.

Biofouling is a big problem for the U.S. Navy, costing them $180–260 million per year in added fuel use and cleaning costs, according to a study in 2011. Chemical agents are often used to kill fouling organisms, but this method can have negative effects on the ecosystem.

The new coating is based on an ultraviolet-emitting glass. Using ultraviolet radiation to disinfect surfaces and air entered the mainstream during the COVID-19 pandemic when it proved very effective at inactivating the SARS-CoV-2 virus. However, employing this method underwater is more challenging.

"We cannot use traditional light sources to distribute light evenly on the surface," says lead author Leila Alidokht, postdoctoral research associate at UMass Amherst, in a UMass Amherst press release. Murkiness in the surrounding water can disrupt the ultraviolet waves, and this uneven distribution of the light gives biofilm-forming microorganisms a foothold—thus leaving the whole surface vulnerable when it spreads.

The team's solution was to embed light-scattering silica nanoparticles into the glass's surface. When an ultraviolet LED is connected to the glass, the light waves bounce off the nanoparticles and throughout the glass interior, which enables an evenly "glowing" glass surface.



Credit: Mariana Lanzarini-Lopes, University of Massachusetts Amherst

A new ultraviolet-emitting glass can reduce visible biofilm growth by 98%.

To test the glass's effectiveness, the UMass Amherst researchers submerged the ultraviolet-emitting glass in the waters of Port Canaveral, Fla., for 20 days. Compared to untreated glass, the modified glass reduced visible biofilm growth by 98%.

The team is now testing long-term applications of the glass and exploring the creation of larger surface areas. They already received a provisional patent for their discovery.

The open-access paper, published in *Biofilm*, is "UV emitting glass: A promising strategy for biofilm inhibition on transparent surfaces" (DOI: 10.1016/j.bioflm.2024.100186). ■

Uncovering hidden dangers: Fiberglass boats contribute to microplastic contamination in bivalve mollusks

Researchers at the Universities of Brighton and Portsmouth in the U.K. investigated the extent to which fiberglass boats contribute to microplastic contamination in bivalve mollusks.

Fiberglass boats became popular in the 1960s, but they are less durable and heavier than aluminum boats. Because of the high disposal costs, some owners will choose to abandon their old fiberglass boats in public waters instead. The abandoned boats will eventually degrade, leaking microplastics and other toxic chemicals into the surrounding environment.

To gather more exact data on the levels of contamination resulting from this illegal dumping, the U.K. researchers gathered oysters and mussels from several areas in Chichester Harbor, downstream of an active boatyard. They collected the mollusks during both the winter months (coinciding with seasonal boat maintenance) and in May (start of a busy schedule for water sport activities). They then used micro-Raman spectroscopy to identify the chemical composition of glass fibers found in the mollusks.

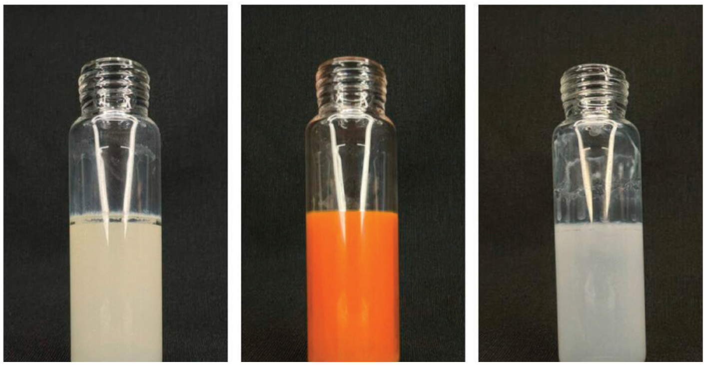
The researchers found the highest fiberglass concentrations during the winter months, with up to 11,220 fiberglass particles per kilogram in oysters and up to 2,740 particles per kilogram in mussels. This contamination can have severe consequences for the mollusks' health, as explained in a University of Portsmouth press release.

"Bivalves, being stationary filter feeders, are highly susceptible to accumulating these particles, which can severely impact their health. The ingestion of GRP [glass-reinforced plastic] can interfere with their digestive systems, leading to physiological stress and even death," the press release states.

More research is needed to understand the full scope of effects resulting from this contamination. But regardless, "Creating a better ethos around end-of-life boat management is crucial to minimize further exposure and spread of these contaminants," says first author Corina Ciocan, principal lecturer in marine biology at the University of Brighton, in the press release.

The open-access paper, published in *Journal of Hazardous Materials*, is "Glass reinforced plastic (GRP) boats and the impact on coastal environment—Evidence of fiberglass ingestion by marine bivalves from natural populations" (DOI: 10.1016/j.jhazmat.2024.134619). ■

MOF-coated glass vials enable simple, reusable water contaminant testing



Credit: Taima-Mancera et al., *Advanced Functional Materials* (CC BY 4.0)

Example of MOF-coated glass vials developed by researchers at the University of La Laguna in Spain.

Researchers from the University of La Laguna in Spain demonstrated a new way to fabricate stable metal-organic frameworks (MOFs) that are integrated directly into practical devices.

MOFs are an emerging material system for water treatment applications. These porous hybrid materials consist of metal ions or clusters interconnected by organic “linker” molecules to form highly ordered hollow structures.

Synthesizing MOFs in bulk is challenging. These materials have less robust thermal and mechanical properties than ceramics, so they do not hold up well during traditional processing techniques, thus limiting their adoption in commercial applications.

In the new method, MOFs are grown directly onto the inner walls of ordinary glass vials. This process allows the vial to double as both the sample container and extraction device for testing water contaminants.

Previous studies attempting to grow MOF coatings inside glass vials were unsuccessful because they relied on conventional polymer linkers that degraded when exposed to common organic solvents. In contrast, the new method uses carboxylate anchoring points rather than polymeric binders to encourage growth of MOF crystallites.

The researchers tested their technique using three zirconium-based MOFs known for their stability and tunable pore structures. The MOF coatings successfully extracted trace contaminants from water stored in the vial, with the best result being 90% of contaminants captured in one hour. After capture, the contaminants could be released from the MOFs in minutes using a simple solvent wash, allowing the preconcentrated substances to be easily analyzed.

Rigorous shaking of the vial is typically needed to encourage extraction, but the researchers showed the MOF coating captured contaminants even with only mild or no agitation. In addition, performing the extraction and desorption process dozens of times did not significantly affect the coating’s extraction efficiency.

The open-access paper, published in *Advanced Functional Materials*, is “Metal–organic framework-coated glass vials: A step forward in analytical platforms” (DOI: 10.1002/adfm.202402517). ■

Dome-shaped organic photovoltaic cells show high efficiency

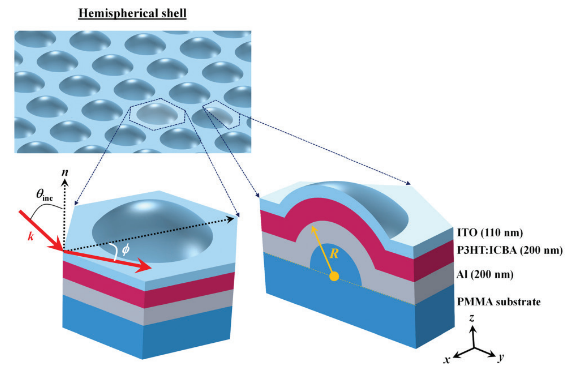
In an open-access article, Abdullah Gül University Assistant Professor Dooyoung Hah analyzed the absorption efficiency of hemispherical-shaped, or "domed," organic photovoltaic cells.

Hah previously investigated solar cell structures based on shell-shaped organic active layers with semicircular and triangular cross sections. These cells, which featured a circular shape in two dimensions, showed improvements in adsorption and angular coverage compared to a rectangular, flat shape. However, because these cells still appeared rectangular in the *xz* plane, Hah believed that completing the circle in all directions (i.e., making a hemisphere) would improve the absorption performance.

His proposed hemispherical-shell-shaped cell consists of an organic polymer called P3HT:ICBA as the active layer placed on a layer of aluminum and a substrate of the synthetic polymer PMMA. The cell is capped off with a transparent protective layer of indium tin oxide.

Hah modeled his proposed hemispherical-shell-shaped cell on the computer and investigated its potential using 3D finite element analysis. The results showed

- Absorption improvements of 66% and 36% when incoming light is transverse electric (TE) and transverse magnetic-polarized (TM), respectively, compared to a flat-structured device. (Electric and magnetic fields are perpendicular to the direction of propagation.)



Credit: Hah, *Journal of Photonics for Energy* (CC BY 4.0)

Proposed photovoltaic cell structure. Top left: Bird's-eye view of a solar cell array with hemispherical-shell-shaped active layers. Bottom left: Unit cell of the dome-shaped device. Bottom right: Cross-section view of the dome-shaped device.

- Absorption improvement is as high as 13% (TE) and 21% (TM) when compared to the semicylindrical shell structure, depending on the polarization of the light.
- Angular coverage reached 81 degrees (TE) and 82 degrees (TM), allowing light to enter from a wider range of directions than a flat surface.

"With the improved absorption and omnidirectionality characteristics, the proposed hemispherical-shell-shaped active layers will be found beneficial in various application areas," Hah concludes.

The open-access paper, published in *Journal of Photonics for Energy*, is "Hemispherical-shell-shaped organic photovoltaic cells for absorption enhancement and improved angular coverage" (DOI: 10.1117/1.JPE.14.018501). ■

Honeycomb-shaped bladeless generators for urban wind harvesting

The size of wind turbines has grown dramatically in the past two decades, in terms of both height and blade length. While this size increase means each turbine can produce more electricity, it also makes transportation and installation of turbines more difficult, thus hindering their deployment in certain locations.

Some companies have developed smaller, alternative devices for harvesting wind energy that can be more easily deployed in urban areas. For example, Spanish technology startup Vortex Bladeless SL offers bladeless wind generators that range in height from 1–13 meters (3.3–42.6 feet), in contrast to the 98-meter (322-feet) height of current utility-scale land-based wind turbines.

Recently, news outlets have reported on the development of another bladeless wind generator design by Scottish technology startup Katrick Technologies. In contrast to the generators offered by Vortex Bladeless, which consist of a single vibrating column, the generators by Katrick Technologies embrace a honeycomb-shaped design.

Within each quadrant of Katrick's compact hexagonal generator are airfoils that oscillate independently when exposed to wind. These mechanical oscillations are converted to energy, making the approach more efficient in less windy conditions.

Credit: Katrick Technologies, YouTube

A rendering showing how Katrick's honeycomb-shaped bladeless wind generators could be installed in urban settings.

On Dec. 14, 2023, Katrick announced that the honeycomb-shaped generator, which was developed in partnership with The Manufacturing Technology Centre, had completed the first stage of alpha testing at the University of Strathclyde and was validated to technology readiness level (TRL) 5. Katrick aims to have the generator validated at TLR 6 during the next stage of testing. ■

Credit: iStock

Prospects for ion-exchange processing of commercial soda-lime-silica glasses

By William LaCourse, Jacob Kaspryk, and Benjamin J. A. Moulton

Ion-exchange processing has been used to improve the mechanical properties of many specialty glass compositions. But its potential for similar use with commercial-grade soda-lime-silica glasses remains to be explored.

Bioactive glass, smartphone cover glass, solid-state glass batteries—these cutting-edge materials and innovative applications implicitly announce "Welcome to The Age of Glass!"[1]

Glass is certainly not a new material—it has helped advance the quality of life for millennia in the forms of containers, windows, and adornments. But our ability to design and produce specialty glasses for applications spanning healthcare, communications, and astronomy, among others, has led us into an epoch where glass plays an integral role in transforming society for the better.

Novel glass compositions, such as LionGlass (see page 40 in this issue), are one core component of advancing the Glass Age. But so, too, is the development of state-of-the-art processing techniques and technologies, which can help improve the carbon footprint and material properties of existing glass compositions.

Chemical strengthening, or ion exchange (IOX), is one processing approach that can alter the mechanical, optical, and electrical properties of a formed glass. While the technique has largely been applied to specialty glass compositions (more on that below), this article considers the potential of using IOX to improve the production of commercial-grade soda-lime-silica (SLS) glasses and identifies factors that could either accelerate or slow future advances.

Kinetics and mechanics of the IOX process

IOX strengthening of glass results from the interdiffusion-controlled removal of a small radius ion (typically sodium, Na^+, radius ~0.10 nm) and replacement with a larger ion (typically potassium, K^+, radius ~0.12 nm). This exchange is achieved by placing the glass in an IOX bath containing a source of K^+ ions, usually liquid KNO_3.[2]

When the potassium ion comes to occupy the sodium ion site, the site must expand to accommodate the larger ion. Because the glass is a solid during this process, it cannot easily

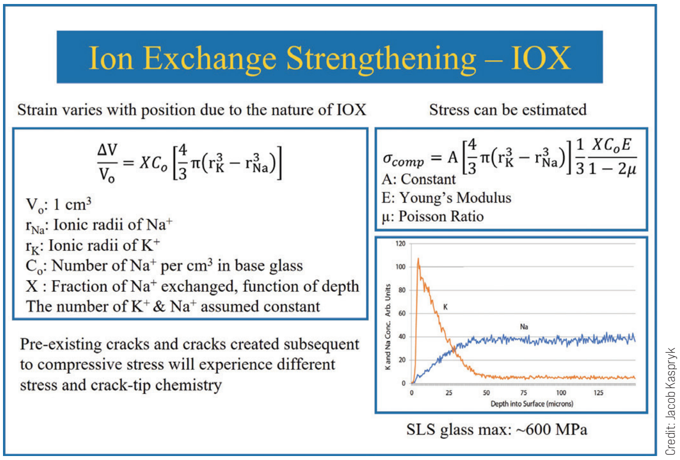


Figure 1. (Upper left) General equation for strain due to IOX. (Upper right) Equation for surface compressive stress due to IOX. The correction factor, termed "A," recognizes that the sites occupied by the two ions may not be spherical. (Bottom right) Example maximum diffusion distance and relative concentration of sodium and potassium ions in IOX SLS glass, determined using energy dispersive X-ray spectroscopy. Adapted from Reference 3.

change structure, so expansion of the smaller ion site causes compression of the structure between the two ions. The equation modeling this compressive stress can be seen in Figure 1.[3] Compressive stresses as high as 1,200 MPa have been obtained in aluminosilicate glasses and as high as 800 MPa in SLS glasses.

Because the IOX process puts significant strain on the glass, IOX is best carried out at least 50°C below the glass's strain point (i.e., the temperature where the viscosity of the glass is $10^{13.5}$ Pa•s). If the glass was processed at the strain point, it would take about four hours to fully relax any IOX-induced stress. The strain point for commercial SLS glasses is near 500–510°C, whereas alkali aluminosilicates are much higher, in the range of 570–650°C.

The depth of layer (DOL), i.e., the depth from the surface at which the ion exchange process occurs, can be determined using Equation 1. It relates DOL to a single diffusion coefficient D, which describes the effective diffusion coefficients of the two mobile ions, and the time dependence of the penetration as described by the root mean square penetration distance, d_{rms}.

$$\mathrm{DOL} = \sqrt{3}\, d_{rms}, \text{ where } d_{rms} = (2D \bullet t)^{0.5} \qquad \text{Equation 1}$$

In general, a deeper DOL leads to improved mechanical properties and fracture resistance.

IOX successes with non-SLS glasses

As noted in the introduction, IOX to date has largely been applied to specialty glass compositions. Cover glasses such as DragonTail (Asahi, Japan), Gorilla Glass (Corning Inc., U.S.), and Panda Glass (Tungshu Group, China) are examples of IOX sodium aluminosilicate glasses, while the cover glass Xensation (Schott, Germany) is an example of an IOX lithium boroaluminosilicate glass.

The success of these products lies with the ways composition affects structure. Specifically, two important changes occur when Al_2O_3 and/or B_2O_3 are added to the base sodium silicate composition.[4] First, the weak NBO bonds are replaced by much stronger Al–O–Si or B–O–Si bonds. Typically, the aluminum (Al^{3+}) or boron (B^{3+}) ions share four oxygens, each of which form four strong "bridging" oxygens (Al–O–Si). Second, following IOX, alkali ions no longer bond to nonbridging oxygen ions. Instead, they bond less strongly to negatively charged structures associated with $(Al–O_4)^-$ tetrahedra, which leads to increased mobility of the alkali ions. Thanks to these two changes, the IOX cover glasses demonstrate increased scratch and drop resistance.

The one major downside of IOX specialty glasses is their more energy-intensive manufacturing process. The reduced NBO content in aluminosilicate and boroaluminosilicate glasses causes these compositions to have increased viscosities, which requires the glass to be processed at noticeably higher temperatures—which translates to much higher production costs.

For example, melting temperatures for Gorilla Glass, DragonTrail, and Xensation are roughly 100–200°C higher than for SLS glasses. Gorilla Glass windshields for a Jeep Wrangler can reach $1,000,[5] for example, about three times more expensive than a conventional SLS glass windshield.

Despite the increased production costs, superior properties such as scratch resistance and compressive strength reaching 1,200 MPa justify the expenditure for certain applications.

Challenges with IOX processing of SLS glasses

The sale of and market for IOX glass products have grown since Gorilla Glass's debut in the original iPhone in 2007.[6] However, IOX and other specialty glass compositions, such as fiberglass, still only account for approximately 10% of the global glass market—the other 90% is taken up by SLS glasses in the form of float glass and containers.

There are surprisingly few differences in SLS composition across different products and companies, as shown in Table 1.[3,7] The major compositional difference between float glass and container glass is a lower MgO content compensated for by increased CaO in container glass.

Obviously, there are cost benefits to using a single, base glass composition to mass produce multiple products. But the current base SLS composition and form factor presents some challenges to processing SLS glass using chemical strengthening.

Modern float ("flat") glass is made by floating molten glass on a bath of molten tin. As the name "flat" implies, float glass factories produce limited shape variations, with the major difference being glass thickness. The process can produce plates as thin as 0.4 mm and up to 25 mm thickness, allowing a wide range of products to be produced using the same composition.

Some factories can produce 800–1,200 tons per day of SLS glass. Different lengths and widths can be cut from the standardized sheets, and different colors are obtained in-house by performing post-forming surface treatments. Other post-forming treatments, such as thermal tempering or IOX processing, take place in secondary manufacturing facilities.

Prospects for ion-exchange processing of commercial soda-lime-silica glasses

Glass ID	Composition (Mol %)						Depth 24 (h)	Time (h) To reach DOL = 50 µm	Total Alkali Arb. Units
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O			
Float 1	71.6	0.06	9.3	5.7	13.2		29	72	5.4
Float 2	71.6	0.97	9.1	5.0	13.2	0.2	36	48	2.8
Float 4	71.0	0.85	8.3	5.7	13.3	0.6	39	39	2.8
Container 6	73.4	0.95	11.0	0.1	14.5		40	38	5.6
Float 8	71.9	0.83	8.8	5.2	12.6	0.2	33	54	2.1
Float 10	71.2	0.36	9.3	5.6	13.1	0.1	33	54	3.7
Float 17	71.7	0.35	9.1	5.2	13.0	0.1	27	85	5.1
Float 16	67.0	2.00	8.5	4.6	17.4	0.4	51	24	6.5
DOE	69.8	0.25	5.3	8.0	15.2	1.5	67.4	14	---
DOE	69.0	0.25	5.8	7.5	14.5	3.0	70.6	13	7.0
DOE	70.0	0.50	5.8	7.8	15.5	0.5	57.4	19	6.2
Gorilla® Glass 3 CODE 2318					Treated at 430°C, 2 h, DOL of 75 µm				

Credit: Jacob Kaspryk

Table 1. Composition and properties of some commercial and experimental SLS glasses. Includes maximum depth of layer (DOL) for a 24-hour ion exchange period at 450°C; the time required to achieve a 50 µm DOL; and chemical durability as measured by the amount of sodium leached per gram of glass in one hour. For float samples, the DOL was measured on the air side of the floating glass because glass on the molten tin side exhibits a lower diffusion rate that varies with thickness due to the different contact times of the glass and molten tin. Adapted from Reference 3.

The mixed alkali effect in IOX SLS glass processing

When comparing the change in DOL between compositions A and B in Table 2, it is evident composition B, which had no K_2O in the base starting glass, showed much smaller effects. We attribute the larger effects in composition A to the mixed alkali effect.[a]

In terms of ionic conductivity, a simple definition of the mixed alkali effect is that the conductivity decreases upon substitution of a second alkali. While this definition is technically correct, it does not explain why this decrease occurs.

The reason for this decrease is that ionic conductivity is controlled by the fastest-diffusing ion, i.e., sodium, while interdiffusion of the ions is controlled by the slowest diffusing ion, i.e., potassium. As more potassium ions are substituted for sodium ions, the potassium diffusion coefficient increases while the sodium diffusion coefficient decreases due to blocking by the potassium ions.

As we know from Equation 1, the diffusion coefficient D is based on the effective diffusion coefficients of the two mobile ions. Because this value is larger in composition A, which contained K_2O in the base starting glass, the ions can achieve a deeper DOL than in composition B.

Reference

[a]B. J. A. Moulton and G. S. Henderson, "Glasses: Alkali and alkaline-earth silicates," *Encyclopedia of Materials: Technical Ceramics and Glasses* 2021, 2: 462–482.

As stated earlier, a deeper DOL during IOX processing typically leads to greater resistance to cracking and fracture. But as seen in Table 1, the DOL for all commercial SLS compositions is extremely low, ranging from 24–51 µm after a 24-hour treatment at 450°C. In contrast, Gorilla Glass (last line in Table 1) develops a DOL of more than 50 µm following treatment for two hours at 430°C.

Achieving a DOL of 50 µm in commercial SLS compositions requires exposure times between 24–85 hours. And even then, surface compression strengths of 800 MPa or more cannot be reached consistently.

Because most SLS glass applications do not require high strength, some may assume IOX processing of SLS glass is not a worthwhile pursuit. However, there is one big advantage to subjecting SLS glass to IOX processing: lightweighting.

Lightweighting involves making an object weigh less without compromising its mechanical properties or performance. Successful lightweighting reduces raw material requirements, which translates to reduced manufacturing and shipping costs, among other benefits.

High-volume markets for lightweight glass products include energy (e.g., solar panels) and transportation (e.g., windshields for cars, aircraft, and boats). In the former case, reducing solar panel thickness from 3 mm to 2 mm would reduce its weight by more than 30%, making installation easier and reducing the need for structural reinforcement. In the latter case, a 10% reduction in vehicle weight can improve fuel economy by 6–8%.[8]

Lightweighting also has benefits in commercial and residential construction. The U.S. Department of Energy estimates that drafts, leaks, and inefficiencies cost U.S. households at least $25 billion dollars each year.[9] By lightweighting glass windows, new three- and four-pane windows can be fabricated that are comparable in thickness to typical double-pane windows but with highly improved insulation capabilities.[10]

Both thermal and chemical processing treatments can be used for lightweighting. However, thermal tempering becomes dramatically less effective at glass thicknesses less than 3 mm, while IOX maintains its strengthening ability—thus making it the preferred approach for certain energy and construction applications.

IOX specialty glasses are starting to be used for these lightweighting applications, for example, the Gorilla Glass automotive windshields mentioned earlier. But if SLS glasses could achieve DOLs of 50 μm within exposure times only 20–30% longer than aluminosilicates—rather than the current 10 times or more—they could offer similar benefits at a more affordable cost due to the lower melting temperature. Thus, there is a strong incentive to overcome the challenges with IOX processing of SLS glasses.

Current successes and possible solutions to IOX SLS glass processing

In Table 1, commercial composition Float 16 came close to achieving the threshold 50 μm DOL within an exposure time only 20–30% longer than aluminosilicates. However, that composition is no longer produced.

Some modified SLS compositions have reached the threshold 50 μm DOL in less than 20 hours. For example, the three experimental compositions created as part of a U.S. Department of Energy project (labeled DOE in Table 1) achieved the required threshold in 14, 13, and 19 hours, respectively.

We also achieved the desired threshold in experiments conducted at Alfred University.[11] As seen in Table 2,[3] composition A (X = 4, 6, or 8) achieved the threshold 50 μm DOL when processed for 16 hours at 450°C. (Additional interesting findings in the Alfred experiment are detailed in the sidebar "The mixed alkali effect in IOX SLS glass processing.")

Though the experimental glasses (DOE compositions in Table 1 and composition A in Table 2) achieved sufficiently deep DOLs in much shorter times, the successful compositions are noticeably different from commercial SLS glasses. Because mechanical–property relationships in IOX glass surfaces can be quite complicated, tweaking compositions to provide improvement in one property may not benefit other properties.

For example, Figure 2 shows the DOL versus compressive strength for some standard and IOX SLS glasses based on composition A in Table 2.[3,11] While IOX processing generally results in higher compressive strength, surprisingly, initial four-point bending tests found the commercial float glass composition had the highest compressive strength despite having the lowest DOL value (25 μm). The commercial float glass composition's compressive strength did decrease dramatically after abrasion, however, and came in last upon retesting.

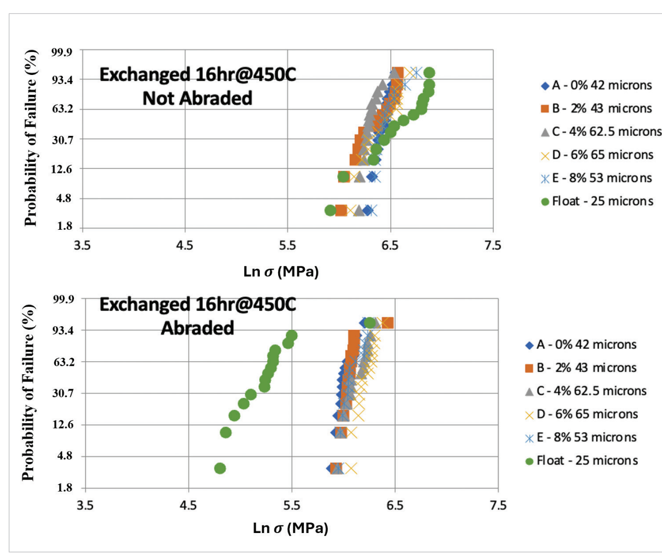
Because of the different properties between standard SLS glass and IOX SLS glass, manufacturers would need to process IOX SLS glass separately from the standard SLS glass to avoid contamination. But unfortunately, constructing a new facility for IOX SLS glass would be a costly addition that could only be justified by a large market for IOX SLS glass.

Instead of an entirely new facility, it may be possible to adopt a production strategy used for colored container glasses: multiple forehearths on a single melter. Currently, float glass is produced using a single melter and a single forehearth, i.e., a reservoir for holding the molten material before it is poured or withdrawn for further processing. In contrast, colored container glass production involves directing the molten material into multiple

Glass A: $11Na_2O$-$4K_2O$-$(10–X)CaO$-$XMgO$-$3Al_2O_3$-$72SiO_2$				
X (MgO)	Maximum Exchange Depth (μm)			
	16 h 400°C	25 h 400°C*	16 h 450°C	25 h 450°C*
0	23	29	42	53
2	28	35	43	54
4	29	36	62	78
6	32	40	65	81
8	31	39	53	66
Glass B: $15Na_2O$-$(10-X)CaO$-$XMgO$-$75SiO_2$				
	16 h 400°C	25 h 400°C*	16 h 450°C	25 h 450°C*
0	16	20	31	39
2	19	31	35	44
4	23	29	38	48
* Data for 25 h calculated from 16 h data assuming $t^{1/2}$ dependence				

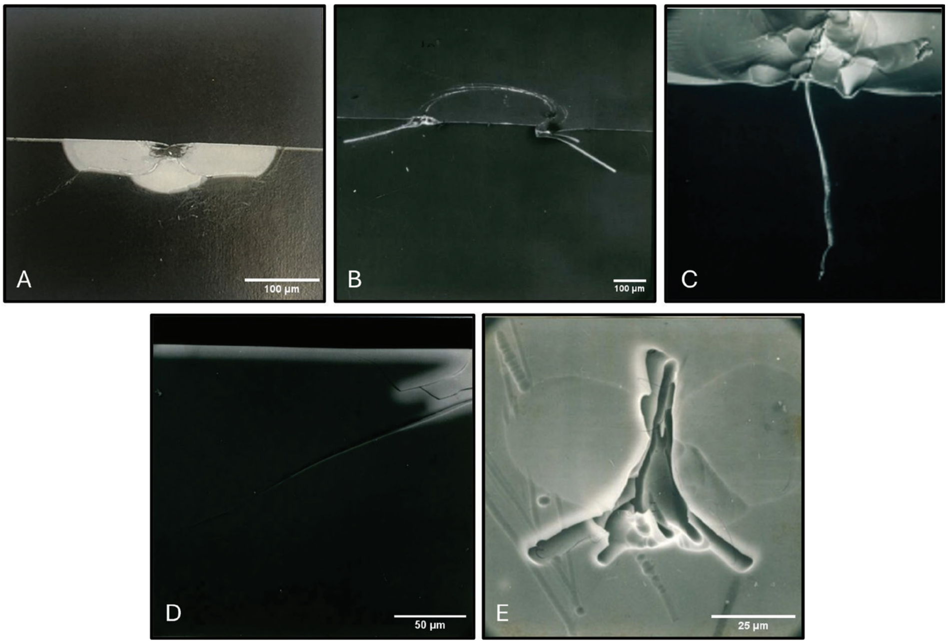
Credit: Jacob Kaspryk

Table 2. Depth of layer for two compositions of MgO-containing SLS glasses. Adapted from Reference 3.



Credit: Jacob Kaspryk

Figure 2. Weibull statistics (probability of failure) versus load. Combined strengthening effects using the mixed alkali glass with 11 mol% Na_2O and 4 mol% K_2O and substitution of up to 8 mol% Mg^{2+} for Ca^{2+} samples of composition A from Table 2. An increase in the Mg^{2+} concentration caused a rapid increase in DOL and a corresponding increase in abrasion resistance. The commercial SLS glass (green data points) showed excellent strengthening (top curves) but poor abrasion resistance due to the low DOL. Other studies at Alfred suggest that DOL levels of 40 μm or more are required to avoid large strength decreases by impact or scratching. Adapted from Reference 3.



Credit: A–D: Ruth[17]; E: Vitch[18]

Figure 3. A–D: Various surface flaws in SLS glass after IOX treatment in $AgNO_3$. (A) Vickers indentation, 2 kg; (B,D) blunt indentation, 60 kg; (C) scratch, 200x magnification. White highlighted part is indicative of the presence of silver via scanning electron microscopy backscatter imagery of the cross section. E: Top-down view of acid-etched SLS to demonstrate the complexity of surface flaw geometry. The flaw was caused by dropping a 1-mm-diameter silicon carbide ball on the glass. Republished with permission from References 16 and 17.

forehearths, which permits changes to the glass in small batches rather than committing the entire melt to a single color.

If this multi-forehearth setup was used for float glass, it would permit changes in the bulk composition without committing the entire melt to the modified SLS composition. Conversations with people familiar with coloring forehearths suggest that compositional modifications on the order of 5–8% would be "easy" and that larger changes might be possible. A lecture on the potential of this multi-forehearth approach was given at the 84th Conference on Glass Problems,[12] and the presentation is available upon request.

Such an approach to flat glass production may seem a bit far out, but as the market demand for lightweighting SLS glass products grows, it will be essential to consider this and other approaches to making IOX SLS processing economically feasible. Below are two more approaches that could help in realizing this market opportunity.

Suggestion 1: Noncompositional methods for accelerated IOX processes

Methods that do not require significant compositional modifications to achieve accelerated IOX processing times are important to consider. Even simple approaches, such as using a programed nonisothermal IOX process,[13] could allow rapid diffusion by starting at a high temperature (450–475°C) followed by programed cooling to avoid relaxation effects.

Ultrasound-assisted diffusion could also help increase diffusion rates.[14,15] Theory indicates that the probability of ion diffusion increases more in the direction of increasing tension than it decreases in the direction of increased compression. The effect is small for a given cycle, but at high frequencies, the effect will be magnified.

There is, however, a possible negative effect—the extra energy of the vibrations might cause relaxation at lower temperatures than predicted, resulting in a loss of the stress-induced diffusion. It is known that both effects can occur, but the importance of the effects and the temperature dependences are not known. These factors need to be investigated.

Suggestion 2: Effects of preexisting flaws in IOX glass

Most discussions regarding IOX processing focus on improving the glass to avoid scratches and impact damage. But what if it is too late? What if the glass was scratched or damaged during removal from the production line or in transit to the secondary manufacturing facility?

While some surface flaws cannot be strengthened by IOX, such as half-penny cracks caused by Vickers indentation, others can benefit from the IOX process. For example, some surface crack geometries are such that the IOX bath is drawn into the crack by capillary action and by interdiffusion along the remaining distance to the crack tip. Figure 3 shows a few cases in which the ion-exchange liquid, doped with $AgNO_3$ to increase visibility under scanning electron microscopy, shows penetrations of as much as 100 µm.[16,17] As the IOX process progresses, the crack opening may narrow due to the IOX-induced glass expansion.

There are still a lot of unknowns regarding how preexisting flaws affect the IOX process. Studies that provide more information would be worthwhile.

Ultimately, there is much to be learned—and, conversely, much opportunity to be lost—when it comes to IOX processing of SLS glass. By engaging researchers in academia, government, and industry, we can successfully identify factors that could either accelerate or slow IOX SLS glass advances and ideally open the door to the commercial success of new chemically strengthened glass products. We can then introduce and welcome everyone to the new (and more advanced) Glass Age.

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References

[1]J. Ballato et al., "Affirmation of The Age of Glass," *Am. Ceram. Soc. Bull.* 2024, **103**(9): 4–5.

[2]G. Macrelli, J. C. Mauro, and A. K. Varshneya, "Coupling of diffusion and chemical stress: The case of ion exchange in glass," *Journal of the American Ceramic Society* 2021, **104**(11): 5599–5613.

[3]W. C. LaCourse, "Design of SLS compositions for accelerated chemical strengthening," *Ceramic Engineering and Science Proceedings* 2018, **39**: 181–189.

[4]K. J. Rao, *Structural Chemistry of Glasses*. Elsevier Science: New York, 2002. p. 568

[5]"Corning Gorilla Glass for automotive exteriors," Corning. Accessed 3 April 2025. https://bit.ly/Corning-Gorilla-Glass-automotive-exteriors

[6]S. Berneschi, G. C. Righini, and S. Pelli, "Towards a glass new world: The role of ion-exchange in modern technology," *Applied Sciences* 2021, **11**(10): 4610-4646.

[7]C. W. Sinton, W. C. LaCourse, M. J. O'Connell, "Variations in K^+–Na^+ ion exchange depth in commercial and experimental float glass compositions," *Materials Research Bulletin* 1999, **34**(14–15): 2351–2359.

[8]"Lightweight materials for cars and trucks," U.S. Department of Energy. Accessed 1 April 2025. https://www.energy.gov/eere/vehicles/lightweight-materials-cars-and-trucks

[9]"Why energy efficiency matters," U.S. Department of Energy. Accessed 3 April 2025. https://www.energy.gov/energysaver/why-energy-efficiency-matters

[10]C. Mims, "A piece of glass thinner than a credit card could solve America's $25 billion energy problem," *The Wall Street Journal*. Published 21 March 2025. Accessed 3 April 2025. https://www.wsj.com/business/corning-window-gorilla-glass-4f443b07

[11]M. J. O'Connell, "The effects of MgO replacement of CaO on the ion exchange behavior." M.S. thesis, Alfred University, 1998. Supervised by William C. LaCourse.

[12]W. C. LaCourse, D. Swiler, M. Choudhary, A. Cormack, and S. K. Sundaram, "Accelerated melting and homogenization for single melter and multi-forehearth processes." Presented at the 84th Conference on Glass Problems, November 2023, Columbus, Ohio. Contact LaCourse at lacourse@alfred.edu for a shortened version of this material.

[13]J. Shen and D. J. Green, "Variable temperature ion-exchanged engineered stress profile glasses," *Journal of the American Ceramic Society* 2003, **86**(11), 1979–1981.

[14]H. Wang, "Sonic strengthening effect on soda-lime silicate glass," M.S. thesis, Alfred University, 1991. Supervised by William C. LaCourse.

[15]V. Geyer, "Ultrasonic-assisted ion exchange in commercial float glass," M.S. thesis, Alfred University, 1994. Supervised by William C. LaCourse.

[16]S. M. Vitch, "The effect of flaw origin on the ion-exchange strengthening of glass," M.S. thesis, Alfred University, 1988. Supervised by William C. LaCourse.

[17]K. Ruth, "Direct observation of ion exchange in flaw damaged glasses," M.S. thesis, Alfred University, 1991. Supervised by William C. LaCourse. ■

The evolution and importance of car windshields in automotive design

Credit: Collections of The Henry Ford (Gift of Ford Motor Company)

An early safety feature adopted by car manufacturers was laminated windshield glass. Introduced in the late 1920s, laminated glass kept glass shards in place after impact. This 1931 photograph shows the shattered laminated windshield of a Ford Model A.

By Lisa McDonald

The car windshield is a fundamental component of modern vehicles, providing essential visibility for drivers while safeguarding against environmental elements.

While modern drivers may take the car windshield for granted, the history of this component reflects significant advancements in automotive design, marked by continuous innovations aimed at improving safety and comfort for both drivers and passengers.

Early windshields and potential dangers

During the first decade of automotive production in the 1890s, cars were essentially open carriages without any form of glass protection. But as cars became faster and more widely used, the need for a barrier to protect drivers and passengers from wind, road debris, and inclement weather became evident.

The first car windshields debuted near the turn of the 20th century as an optional add-on for cars.[1] U.S. automobile brand Oldsmobile became the first car manufacturer to make windshields a standard feature in 1915,[2] and other car manufacturers followed soon after.

These early windshields were far from perfect—they were constructed out of standard plate glass, and their propensity to shatter upon impact could lead to severe injuries for drivers and passengers alike.

Development of laminated glass

Laminated glass is a type of safety glass consisting of two or more glass layers held together with a transparent adhesive interlayer. This interlayer prevents the glass from breaking into large, sharp pieces.

In 1903, French chemist and painter Edouard Benedictus made the accidental discovery that a thin layer of cellulose nitrate can keep glass from shattering when he knocked a bottle off the shelf and the broken pieces held together. While initially he did not think anything more about this curious accident, reports of drivers and passengers harmed by broken glass in cars caused Benedictus to investigate the bottle further, leading him to discover the cellulose nitrate coating the broken pieces. He then used this knowledge to develop an early form of laminated glass.

As reported in an article by Rasmussen,[3] Benedictus received a patent for his laminated glass in 1909, three years after fellow inventor John C. Wood of England patented an early form of laminated glass in 1906. However, Wood's invention languished due to technical difficulties in its fabrication, and so Benedictus's invention became the basis for the first commercial laminated glass products.

In 1912, Reginald Delpech founded the English Triplex Safety Glass Company to produce laminated glass based on Benedictus's invention. The production cost of the brand name Triplex glass initially limited its market reach, but the outbreak of World War I in 1914 created significant demand for Triplex glass in military applications, such as airplane and automobile windshields, bulletproof glass for tanks, glass for submarines, battleship-bridge windows, and lenses for gas masks and aviator goggles.[3]

Advancements in windshield design

Though laminated glass started being used in windshields during World War I, it was not until 1927 that it became a standard feature in cars with the introduction of the Ford Model A.[3] This first version of safety glass still had drawbacks, however, as explained by ceramic engineer Fred Dimock in a Model T Ford Forum discussion.[4]

"In medium accidents, the glass broke and the plastic acted like a balloon as the occupant was thrust into it. The result was that the balloon effect acted somewhat like an air bag or cushion as the person hit it," he explains. "The problem was with more severe accidents, where the broken inner glass acted like a knife and it cut the plastic liner. The occupant was then thrust through the resultant hole, and the edges of the glass shredded him. If the person was unlucky enough to only go part way through the windshield, he was caught in a Chinese finger puzzle and received significant lacerations."

In the early 1930s, five companies joined forces to research and develop an improved interlayer material for automotive laminated glass. By the end, only DuPont and Monsanto remained as development partners, and their innovative polyvinyl butyral (PVB) resin interlayer had improved visibility and penetration resistance compared to the traditional celluloid interlayer.[5] PVB is now the most common interlayer used around the world in laminated glass.

Alongside developments in laminated glass, advancements in tempered glass for automobile applications took place. Tempered glass is a type of safety glass that undergoes a thermal or chemical treatment process so that it will break into small, rounded chunks rather than sharp, jagged shards. In 1938, Pittsburgh Plate Glass introduced the tempered glass product Herculite to the automobile market.[6] Today, tempered glass is mainly used for side and rear windows while laminated glass remains the top choice for windshields.

The 1960s and 1970s marked a pivotal period for the automotive industry, with the introduction of various safety standards and regulations for windshields.[7] It also saw the rise of value-added glass products for cars. Value-added glass offers additional functionalities beyond basic transparency. Early value-added automotive glass products included tinted windshields for glare reduction and ultraviolet protection. Recently, windshields with in-built sensors are taking value-added glass products to the next level. (Learn more about value-added glass products on page 8 in this issue.)

Recycling laminated windshields

Though the use of laminated windshield glass has greatly improved the safety of contemporary vehicles, the polymeric interlayer in this glass complicates the recycling and reuse of end-of-life windshields. Fortunately, more companies are starting to invest time and resources in developing improved recycling schemes for used windshields.

One company working to recycle used windshields is Maltha Glass Recycling, a Netherlands-based subsidiary of waste-to-product company Renewi (Milton Keynes, U.K.). The company recently developed a technology that extracts 99.5% of glass from used windshields while also recovering the binding resin PVB.[8] This technology enables circularity in the production of new products, which previously would have been disposed of as waste.

In conclusion, the history of car windshields exemplifies the evolution of automotive design. With ongoing advancements in materials and technology, car windshields continue to be a crucial element in ensuring the safety and comfort of both drivers and passengers on the road.

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References

[1]"The history of the windshield," Alfa Auto Glass. Accessed 2 April 2025. https://alfaautoglass.com/the-history-of-the-windshield

[2]C. Florea, "20 ways Oldsmobile revolutionized the car industry," Auto Evolution. Published 17 Sept. 2023. Accessed 2 April 2025. https://www.autoevolution.com/news/20-ways-oldsmobile-revolutionized-the-car-industry-221159.html

[3]S. C. Rasmussen, "Art and inspiration: Edouard Benedictus and the invention of laminated safety glass," *ChemPlusChem* 2025, **90**(1): e202400572.

[4]"Forum 2011: A brief windshield glass history with a Model T tie in," Model T Ford Club of America. Accessed 2 April 2025. http://www.mtfca.com/discus/messages/179374/187215.html

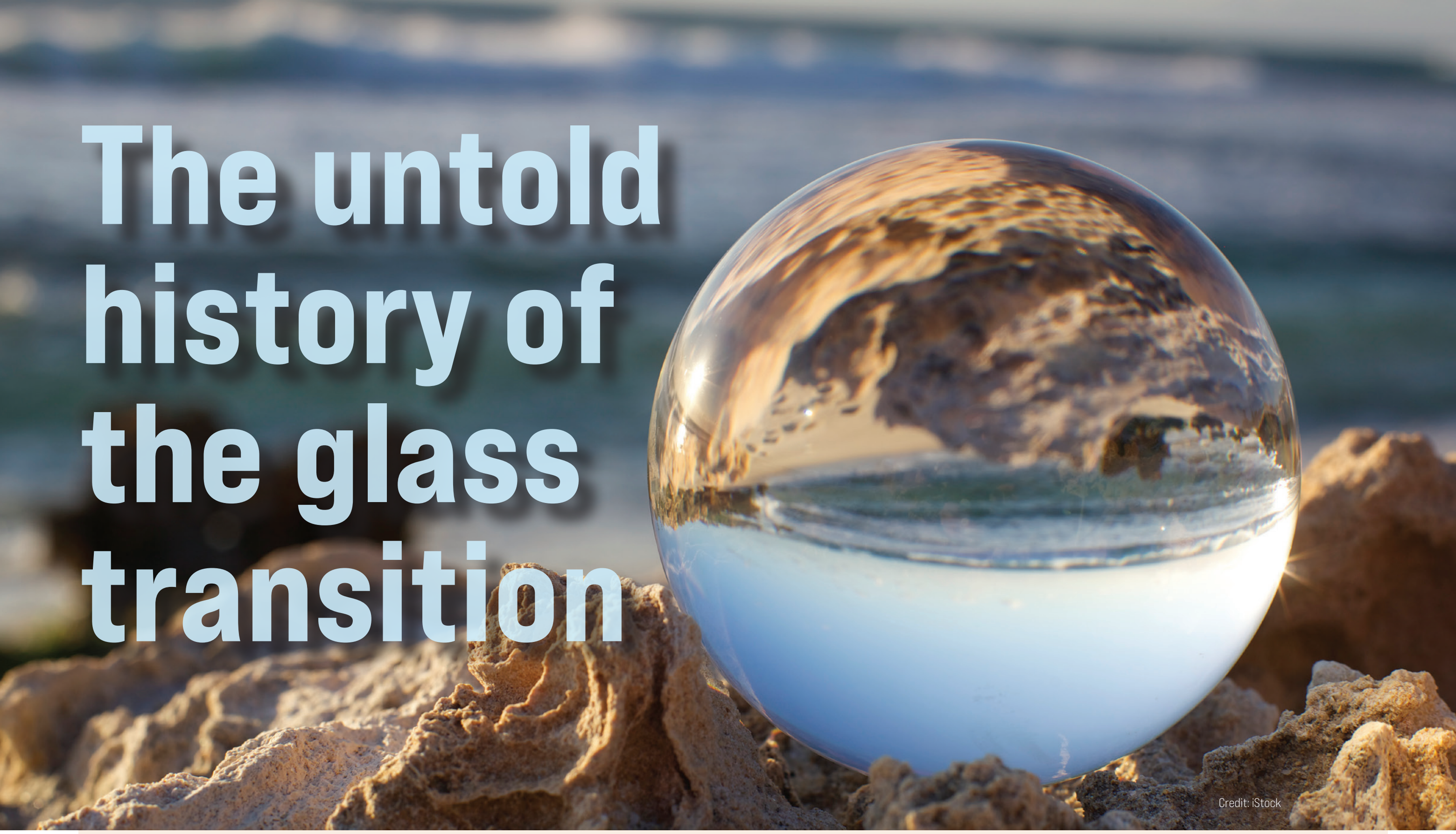
[5]L. Moeyersons, "History of (PVB) laminated glass in automotive," *GlassonWeb*. Published 1 March 2023. Accessed 2 April 2025. https://www.glassonweb.com/article/history-pvb-laminated-glass-automotive-luc-moeyersons

[6]"Herculite glass test with automobile," Historic Pittsburgh. Accessed 2 April 2025. https://historicpittsburgh.org/islandora/object/pitt:20170227-hpichswp-0048

[7]R. Contreras, "Innovations in the 1960s and 1970s," Tucson Auto Tint & Glass. Accessed 2 April 2025. https://www.tucsonsbestautotint.com/innovations-in-the-1960s-and-1970s

[8]"Maltha Glass Recycling invests in laminated glass recycling," Maltha Glass Recycling. Published 16 Jan. 2025. Accessed 2 April 2025. https://www.maltha-glassrecycling.com/en/news/maltha-glass-recycling-investeert-in-recyclage-gelaagd-glas ■

The untold history of the glass transition


Credit: iStock

By Sofia F. Mauro and John C. Mauro

The nature of glass is inextricably tied to its thermal history through the glass transition. But what of the history of the glass transition itself? This article explores the origin of this scientific concept, tracing its beginnings to an unlikely source.

The glass transition is the cornerstone of glass science, essential for the existence of the glassy state and responsible for its defining characteristics. In fact, "glass transition" is the second-most popular keyword used in publications related to glass science and technology.[1]

Despite the fundamental importance of this phenomenon in advancing glass science and technology, the origin of the glass transition as a concept is not well known. This article takes readers on a journey through the glass transition literature starting in the mid-20th century and going back to the late 19th century, with the goal of discovering which scientist can be credited with the earliest accurate description of the glass transition phenomenon.

Defining the glass transition

Many theories regarding the nature of glass have been proposed over the years. These notions vary from glass as a fourth state of matter, a colloidal "jelly" containing suspended microcrystals, a mesomorphic state,[2] an agglomeration of quartz crystals,[3] and the result of a second-order thermodynamic phase transition.[4]

By modern understanding, glass is neither a solid nor a liquid but instead a phase beyond these equilibrium states. This rather unintuitive phase is defined by the concept of the glass transition.[5]

The glass transition is the "continuous transformation of a supercooled liquid into a glassy state upon cooling to sufficiently low temperatures," which must be accomplished at a sufficiently rapid rate to avoid crystallization.[6] In other words, a glass is formed when the atomic structure of a liquid is frozen in without the time to rearrange itself into a crystal.

Based on this definition, it is clear that the glass transition is not a thermodynamic phase transition but rather a kinetic transition with an intrinsic dependence on time. Hence, the temperature at which a supercooled liquid becomes a glass cannot be pinpointed to a single critical temperature. Rather, a glass may be described by the temperature range over which it vitrifies (transforms into a glassy state) and the associated quenching rate.

Even once a supercooled liquid has transformed into a glassy state, this state is not thermodynamically stable. In other words, the material will continually drive toward equilibrium by gradually relaxing back toward the supercooled liquid state. Eventually, it will undergo a first-order thermodynamic phase transition as it crystallizes to a stable equilibrium. For many common glasses, the relaxation and crystallization processes occur at infinitesimal rates at room temperature, too slow to observe on a human time scale.

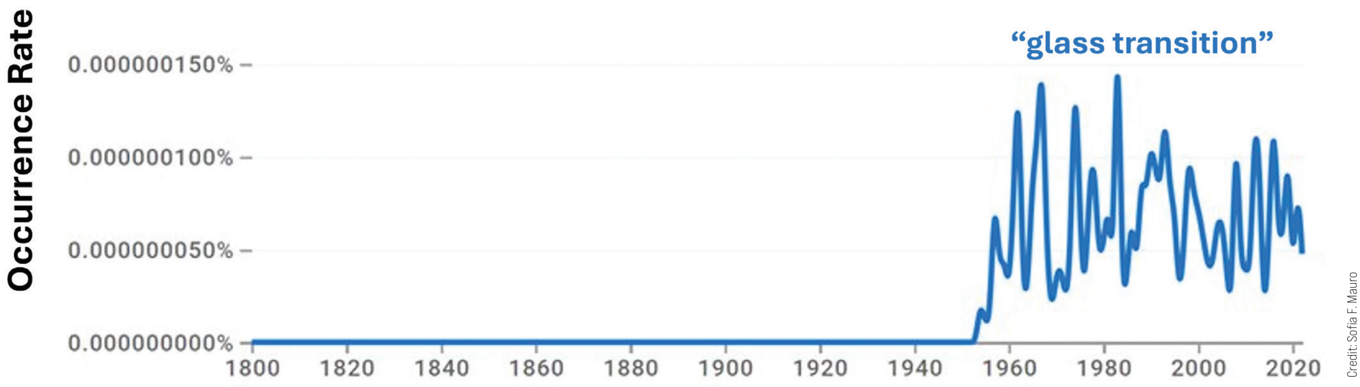


Figure 1. This plot shows the usage of the term "glass transition" in published works, based on the Google corpus of printed sources, which consists primarily of books. The first peak corresponds to the year 1952.

History of the glass transition

According to an *n*-gram analysis using Google's Ngram Viewer (Figure 1), a tool that tallies the frequency of words in the Google corpus of printed sources (primarily books), the term "glass transition" began a dramatic increase in usage around 1952. This increase immediately follows the publication of Walter Kauzmann's landmark 1948 paper, "The nature of the glassy state and the behavior of liquids at low temperatures." While controversial, the paper accurately describes the glass transition as a continuous process that "occurs too slowly at low temperatures to permit thermodynamic equilibrium to be established."[7]

Although the phrase "glass transition" was popularized following the publication of Kauzmann's paper, the phenomenon of the glass transition was described and discussed decades before the term was formally coined and in common use. For example, 15 years before Kauzmann's work and one tick prior on the timeline in Figure 2, Jesse Littleton published the 1933 paper "Critical temperatures in silicate glasses." In that paper, he states that "there seems to be no positive evidence of any critical temperatures existing on the thermal expansion curves of glasses," and that any critical temperature would be more accurately described as a "transformation 'zone' or 'region,' where the equilibrium process is retarded by the high viscosity of the material."[8]

One year earlier, W.H. Zachariasen's 1932 paper, "The atomic arrangement in glass," established a foundation for glass science by examining how glass forms on an atomic level. He describes the structure of glass as one infinitely large unit cell due to the lack of periodicity in the material. He then gives an atomic explanation for why glasses have a seemingly continuous transition between liquid and solid—whereas many sources from the same period give only empirical justifications—and concludes with: "…it is impossible to say at which temperature a given glass passes from the solid to the liquid state."[9] However, his discussion of the glass transition is brief because his work focuses on the rules governing the noncrystalline structure of glass.

Moving back in time to 1927, Parks and Huffman state that "the transition between the glass and liquid is more indefinite. Instead of a mere point, there seems to be a transitional range of temperature in which there occurs a relatively great and rather abrupt change in specific heat, viscosity, coefficient of expansion, [and] dielectric constant."[2] They label the glass transition as a softening temperature and propose glass to be a fourth state of matter with characteristics of a liquid and a crystal. Although viscosity does not exhibit an abrupt change at the glass transition,[6] and the term "state" as used in their work inaccurately implies thermodynamic equilibrium, the authors were correct in clarifying that glass is different from a supercooled liquid—its origin—and from a crystalline solid, which bears a similar outward resemblance and mechanical properties.

Earlier, in 1903, Gustav Tammann wrote a widely circulated textbook called *The States of Aggregation*, translated to English in 1925. Unlike Parks and Huffman, Tammann does not distinguish glass from the supercooled liquid state, claiming that it is "justifiable to consider glasses as undercooled liquids." However, he proposes that any liquid can be supercooled—and, according to his logic, become a glass—if quenched rapidly enough: "Therefore, if a substance be cooled rapidly…it should then be possible to obtain the substance in the form of a glass… It must therefore be possible to obtain all substances in the form of glass."[10]

Conceptual origin of the glass transition

Tammann was closely acquainted with another noted scientist who wrote extensively about condensed matter: Walther Nernst.[11] Nernst was a Nobel Prize laureate in chemistry who developed the Nernst heat theorem in 1906, which became known as the third law of thermodynamics.

Nernst published the 1893 textbook *Theoretical Chemistry from the Standpoint of Avogadro's Rule & Thermodynamics*. This edition makes little mention of glass and considers the idea that "amorphous solid substances are composed of crystal fragments too small for detection."[12] However, at some point

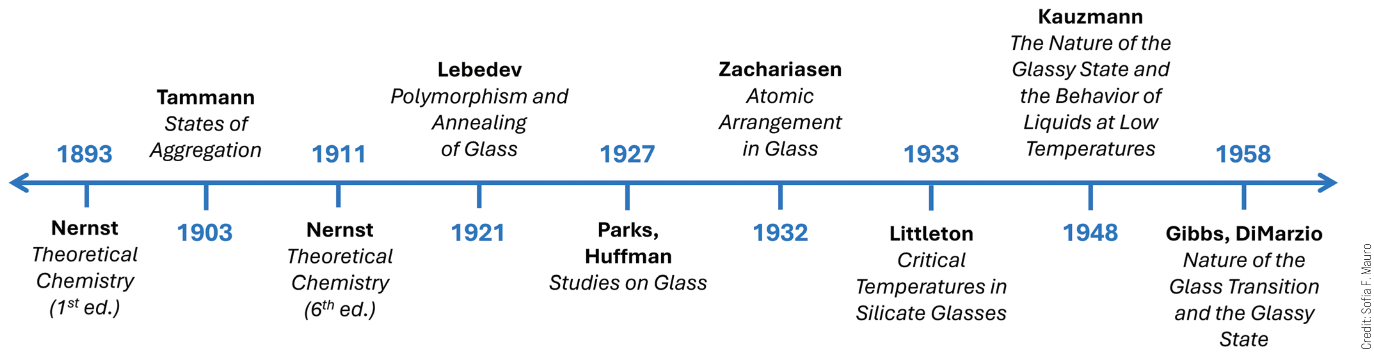


Figure 2. Timeline of sources discussing the glass transition phenomenon.

between the publication of the first edition and the sixth edition (translated to English in 1911), Nernst developed his own viewpoint on glasses, which he classifies as amorphous solids.

In the sixth edition of *Theoretical Chemistry from the Standpoint of Avogadro's Rule & Thermodynamics*, Nernst describes a continuous transition from the unstable (non-equilibrium) amorphous state to the liquid state. He cites Tammann's *The States of Aggregation* in the development of the view of amorphous solids as distinct from crystalline solids; however, he deviates from Tammann's ideas related to the origin of glass. Whereas Tammann considers the glass and supercooled liquid states to be identical, Nernst understands that there is a glass transition connecting these two distinct states.

Nernst writes that the rate of crystallization of a liquid diminishes with "great undercooling" and may "go so far that [it] sinks practically to nothing, so that the undercooled liquid loses its capacity of crystallization and remains of a glassy character,"[13] which is the definition of a glass. This statement can be considered the earliest accurate description of the glass transition, even if the distinction between glasses and amorphous solids was not understood at that time.

Despite the importance of the glass transition as the foundation of glass science, the conceptual development of this phenomenon was previously unknown. Ultimately, the glass transition originated with the same scientist who proposed the third law of thermodynamics: Walther Nernst. We argue that, although the focus of Nernst's research was not glass, he should be given credit as the first scientist to publish a conceptually accurate description of the glass transition and be appropriately recognized for this important contribution to materials science.

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References

[1]Mauro, J. C. and Zanotto, E. D., "Two centuries of glass research: historical trends, current status, and grand challenges for the future," *International Journal of Applied Glass Science* 2014, **5**(3), 313–327.

[2]Parks, G. S. and Huffman, H. M., "Studies on glass. I. The transition between the glassy and liquid states in the case of some simple organic compounds," *The Journal of Physical Chemistry* 1927, **31**(12), 1842–1855.

[3]Lebedev, A.A., "The polymorphism and annealing of glass," *Transactions Opt. Inst. Petrograd* 1921, **2**(10), 1–20.

[4]Gibbs, J.H., and DiMarzio, E.A., "Nature of the glass transition and the glassy state," *The Journal of Chemical Physics* 1958, **28**(3), 373–383.

[5]Zanotto, E.D. and Mauro, J.C., "The glassy state of matter: Its definition and ultimate fate," *Journal of Non-Crystalline Solids* 2017, **471**: 490–495.

[6]Mauro, J.C., *Materials Kinetics: Transport and Rate Phenomena* (1st edition). Elsevier: 2021, pp. 295.

[7]Kauzmann, W.J., "The nature of the glassy state and the behavior of liquids at low temperatures," *Chemical Reviews* 1948, **43**(2), 219–256.

[8]Littleton, J. T., "Critical temperatures in silicate glasses," *Industrial & Engineering Chemistry* 1933, **25**(7), 748–755.

[9]Zachariasen, W.H., "The atomic arrangement in glass," *Journal of the American Chemical Society* 1932, **54**(10), 3841–3851.

[10]Tammann, G., *The States of Aggregation: The Changes in the State of Matter in Their Dependence upon Pressure and Temperature* (R. F. Mehl, Translated). Constable: 1925, pp. 231–247. (Original work published 1903)

[11]"Professor Gustav Tammann (to 140th birthday anniversary)," *Russian Journal of Applied Chemistry* 2001, **74**: 1610–1615.

[12]Nernst, W., *Theoretical Chemistry from the Standpoint of Avogadro's Rule & Thermodynamics* (C.S. Palmer, Translated). Macmillan: 1895, pp. 65–66. (Original work published 1893)

[13]Nernst, W., *Theoretical Chemistry from the Standpoint of Avogadro's Rule & Thermodynamics* (6th edition; H. T. Tizard, Translated). Macmillan: 1911, pp. 72–588. ■

Jonathon Foreman
ACerS journals managing editor

Toward more sustainable soda-lime glass

Soda-lime silicate glass, more commonly known as soda-lime glass, is the composition of choice in many glass applications, particularly for windows and containers. The raw materials are plentiful, and production methods are well known.

Unfortunately, soda-lime glass has a large carbon footprint arising from both the energy required for high-temperature processing and the release of carbon dioxide from firing carbonate raw materials. Reducing energy usage and adopting alternative raw materials with lower embodied carbon are keys to improving the sustainability of soda-lime glass.

Recent articles by Deng et al. explore the relationships among glass composition, raw materials, and processing parameters to help drive future research toward improved sustainability.[1,2] One of their most interesting analyses in Reference 1 shows the contributions of various factors to the overall energy usage. The factors they considered in this analysis include carbonate raw materials versus reuse of cullet and processing temperatures versus composition.

It is commonly held that reducing the processing temperature will reduce the energy usage because the energy to heat glass to the melting temperature scales essentially linearly with that temperature. However, other contributions to the total theoretical processing energy include energy to decompose the carbonates into oxides, energy consumed by heating the released gases to the melt temperature, and reaction energy (for transformation from the individual oxides to the glass composition).

Deng et al.'s analysis in Reference 1 shows that reducing the processing temperature has a relatively small effect on the total theoretical energy. In contrast, using materials other than the carbonates has a much more substantial effect. Such raw materials include cullet, as explored by Somogyi et al.,[3] and oxides from biomass ash, as explored by Dias et al.[4] and Deng et al.[5] Interestingly, Deng et al. found that washed particles of ash that are a minimum of 2 mm contain very low amounts of contaminants such as sulfur, chlorine, and carbon.

Credit: Picryl

Though Deng et al. showed that theoretical processing energy is relatively unaffected by processing temperature, the actual energy usage is highly influenced due to, among other things, thermal energy lost to the environment during the processing. They cite that reducing the melt temperature by 30°C can reduce heat lost from the furnace crown by 2.5%.

Expanding on the variable of processing temperature, Deng et al.[2] and Kilinc et al.[6] explore the relationships between composition, processing temperatures, processing speeds, and properties from both historical and phase perspectives. Briefly, processing temperatures should be sufficiently high to minimize recrystallization, the temperature of which is dependent on the composition. The amount of calcium oxide has a strong influence such that more calcium oxide leads to a higher liquidus temperature. Kilinc et al. conclude that the differences between commercial processing and liquidus temperatures, particularly for low-calcium glasses, can be reduced through reformulation. Unfortunately, from a sustainability perspective, recent changes to compositions of commercial glasses have been more focused on improving throughput and chemical durability and, for some glasses, raw materials cost than on reducing furnace temperature.

In conclusion, multiple efforts are needed to improve sustainability of soda-lime glass production. Increasing recycling and use of alternative raw materials reduce both carbon dioxide output and energy consumption. Concurrent optimization of both composition and processing temperature aimed at reducing thermal losses during processing are also needed.

References

[1]W. Deng et al., "A survey of commercial soda–lime–silica glass compositions: Trends and opportunities I—Compositions, properties and theoretical energy requirements," *IJAGS* 2025, **16**(1): e16691.

[2]W. Deng et al., "A survey of commercial soda–lime–silica glass compositions: Trends and opportunities II—Principal component analysis (PCA) of glass compositions," *IJAGS* 2025, **16**(1): e16689.

[3]A. Somogyi and V. Chesnot, "Glass packaging and its contribution to the UN Sustainable Development Goals," *IJAGS* 2024, **15**(4): 342-349.

[4]T. S. S. Dias et al., "Glass-ceramic: Controlled crystallization of glasses obtained from biomass ash," *IJCES* 2023, **5**(6): e10191.

[5]W. Deng et al., "Alternative raw material research for decarbonization of UK glass manufacture," *IJAGS* 2023, **14**(3): 341-365.

[6]Kilinc et al., "Dynamic high-temperature crystallization and processing properties of industrial soda–lime–silica glasses," *JACerS* 2024, **107**(4): 2242–2259.

POTENTIAL AND PRACTICAL EFFECTS OF AI DRIVE DISCUSSION AT 60TH ANNUAL SYMPOSIUM ON REFRACTORIES

All photos credit: ACerS

Though relatively few in numbers, the 60th Annual Symposium on Refractories co-hosted by the ACerS Greater Missouri Section and Refractory Ceramics Division was truly a global event. Approximately 220 attendees from 15 countries gathered at the Hilton Airport Hotel in St. Louis from March 25–27, 2025, to discuss an increasingly impactful technology in industry: artificial intelligence.

GROWING THE WORKFORCE THROUGH DIGITALIZATION

Recruitment and retainment of personnel are two perennial challenges for manufacturers. Determining why there is such high turnover with younger workers is a pressing question, and the symposium's first speaker, Yakup Bayram of PaneraTech, Inc., had an answer.

His company recently interviewed glass manufacturing executives and engineers from around the world to find out why workers leave the industry after only a few years. While the executives believed this behavior was due to the perception of glass manufacturing as a "dirty, low-profile industry," the engineers explained it was the constant need to solve rather than prevent emergencies that caused discouragement.

The PaneraTech report suggested that digitalization could help alleviate worker burnout in the glass and other heavy industries, such as steel and refractories, by supporting optimized operations and preventative maintenance. Of course, data on processes and equipment are only useful when people engage with the information. Bayram described some best practices for doing so, including the need for human oversight because no data collection setup is infallible.

HARNESSING CONVENTIONAL AND AI-DRIVEN MODELS AND SIMULATIONS IN INDUSTRY

Bayram's opening talk served as the perfect introduction to the rest of the presentations, which demonstrated the many ways that refractory, steel, and other manufacturers in related industries are making use of conventional and AI-driven models and simulations to improve their operations.

Across all talks, the limitations as well as benefits of digitalization were discussed in depth. Many of the featured techniques are emerging science, after all, and seeing how manufacturers such as RHI Magnesita, MiNTEQ, and Almatis accounted for and adjusted to these restrictions in real time provided invaluable insights for other attendees considering using these techniques in their operations.

CELEBRATING NEW AND PAST RCD AND GREATER MISSOURI SECTION AWARD WINNERS

Two awards are traditionally given at the Refractories Symposium: the Refractory Ceramics Division's biennial Alfred W. Allen Award, which recognizes the author(s) of the best technical paper on refractory ceramics published in the last two years, and the Greater Missouri Section's Theodore J. Planje Refractories Award, which recognizes individuals who show excellence in the field of refractories.

This year's Allen Award recipients were Somnath Mandal and Manoj Mahapatra of the University of Alabama at Birmingham and James G. Hemrick of Oak Ridge National Laboratory for their 2023 paper "Impact on aggregate/matrix bonding when a refractory contains zinc aluminate instead of spinel and magnesia-chrome."

Regarding the Planje Award, instead of a new recipient, the Greater Missouri Section decided to recognize all past Planje recipients in honor of it being the 60th Annual Symposium.

See more photos from the 60th Annual Symposium on Refractories on the ACerS Flickr page at https://bit.ly/Refractories-Symposium-2025. The 61st Annual Symposium on Refractories will take place in March 2026. ■

Current Refractory Ceramics Division Vice Chair John Waters, left, presents RCD Chair Austin Scheer with the outgoing chair certificate to recognize his leadership.

Ruth Engle, left, presented this year's Allen Award to Somnath Mandal, James Hemrick, and Manoj Mahapatra. Mandal presented the award lecture, and he said winning this award was his "dream" because his work has now achieved the same level of recognition as some of his mentors.

Dilip Jain gives Kent Weisenstein (red jacket) a hug during the session recognizing past Theodore J. Planje Refractories Award recipients. Weisenstein gave a speech reflecting on his years in the refractories industry and as an ACerS member.

Past Theodore J. Planje Refractories Award recipients, from left: Andus Buhr, Dilip Jain, David Tucker, Ruth Engel, James Hemrick, Jeffrey Smith, Nancy Bunt, and Kent Weisenstein. Everyone shared their memories of Weisenstein and what it means to be a Planje recipient.

UPCOMING DATES

SEPT. 28–OCT. 1, 2025
Save the date!

GREATER COLUMBUS CONVENTION CENTER,
COLUMBUS, OHIO

Join us in Columbus for the annual Materials Science & Technology technical meeting and exhibition series. MS&T is a long-standing, recognized forum for fostering technical innovation at the intersection of materials science, engineering, and application.

JAN. 25–30, 2026
Save the date!

HILTON DAYTONA BEACH OCEANFRONT RESORT,
DAYTONA BEACH, FLA.

Join us in Daytona Beach for the Golden Jubilee Celebration of the 50th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2026).

APRIL 12–16, 2026
Save the date!

HYATT REGENCY BELLEVUE ON SEATTLE'S EASTSIDE
BELLEVUE, WASH., USA

Six ACerS Divisions are collaborating to host the first-ever ACerS Spring Meeting in Bellevue, Wash. Each of the six Divisions will create its own programming, though collaborative sessions will take place as well. One registration fee will allow you access to all programming and events.

MAY 31–JUNE 5, 2026
Save the date!

SHERATON SAN DIEGO HOTEL & MARINA,
SAN DIEGO, CALIF., USA

Join us in San Diego for the combined 12th International Conference on High Temperature Ceramic Matrix Composites and 3rd Global Forum on Advanced Materials and Technologies for Sustainable Development.

calendar

Calendar of events

April 2025

15–June 20 ★ Properties of Refractories – Virtual; https://ceramics.org/course/homeny-properties-of-refractories

May 2025

4–9 16th Pacific Rim Conference on Ceramic and Glass Technology and the Glass & Optical Materials Division Meeting – Hyatt Regency Vancouver, Vancouver, Canada; https://ceramics.org/pacrim16

20–22 ★ A Technician's Guide to Ceramics – Virtual; https://ceramics.org/course/carty-technician-guide-ceramics

June 2025

9–11 ACerS Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Birmingham, Ala.; https://ceramics.org/clay2025

11–13 15th Advances in Cement-Based Materials – Boulder, Colo.; https://ceramics.org/cements2025

11–27 ★ Foundations of Ceramic Processing – Virtual; https://ceramics.org/course/carty-ceramic-processing

July 2025

8–11 ➡ The 8th International Conference on the Characterization and Control of Interfaces for High Quality Advanced Materials – Highland Resort Hotel & Spa, Fujiyoshida, Japan; https://ceramics.ynu.ac.jp/iccci2025/index.html

16–18 ★ Properties and Testing of Refractories – Westerville, Ohio; https://ceramics.org/course/homeny-properties-and-testing-refractories

September 2025

16–Dec. 4 ★ Refractory Manufacturing – Virtual; https://ceramics.org/course/homeny-refractory-manufacturing

17–18 ★ Tools for Visualizing and Understanding the Structure of Crystalline Ceramics – Virtual; https://ceramics.org/course/sparks-crystalline-ceramics

28–Oct. 1 ACerS 127th Annual Meeting with Materials Science and Technology 2025 – Greater Columbus Convention Center, Columbus, Ohio; https://www.matscitech.org/MST25

October 2025

5–9 ➡ International Symposium on Green Processing of Advanced Ceramics (IGPAC 2025) – Ise-Shima/Mie, Japan; https://igpac2025.com

27–30 ➡ Unified International Technical Conference on Refractories – JW Marriott Cancún Resort & Spa, Cancún, Mexico; https://unitecr2025.com

January 2026

25–30 Golden Jubilee Celebration of the 50th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2026) – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; https://ceramics.org/icacc2026

March 2026

24–26 ➡ ceramitec 2026 – Trade Fair Center Messe, München, Germany; https://ceramics.org/event/ceramitec-2026

April 2026

12–16 ACerS Spring Meeting — Bellevue, Wash.; http://ceramics.org/acersspring

May 2026

31–June 5 12th International Conference on High Temperature Ceramic Matrix Composites (HTCMC 12) and Global Forum on Advanced Materials and Technologies for Sustainable Development (GFMAT 2026) – Sheraton San Diego Hotel & Marina, San Diego, Calif.; https://ceramics.org/htcmc12_gfmat2026

June 2026

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

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

August 2026

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

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Entries in **BLUE** denote ACerS events.

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

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deciphering the discipline

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

By Elif Pınar Akman Özay
Guest columnist

LionGlass recycling: Preparing for the industrial transition

Glass is an integral part of modern life, but the environmental impact of glass production is significant, contributing approximately 86 million metric tons of carbon dioxide (CO_2) annually—about 0.3% of total global CO_2 emissions.[1] Addressing these emissions is critical for achieving the sustainability goals outlined by the United Nations.[2]

While 75–85% of the emissions in glass production are due to fuel combustion, 15–25% result from the decomposition of carbonate batch materials.[1] Soda-lime silicate (SLS) glass specifically is the primary contributor to these emissions as the most widely produced glass type.

Credit: Mehmet Arda Özay, The Pennsylvania State University

Figure 1. LionGlass contaminated with soda-lime silicate glass being poured into a mold.

A promising alternative to SLS glass is LionGlass™, a novel phosphate-based glass family developed by researchers at The Pennsylvania State University. LionGlass eliminates the need for carbonate batch materials and has a significantly lower melting temperature, reducing carbon emissions from manufacturing by 50–60%.[3] Plus, LionGlass exhibits remarkable mechanical properties, including enhanced crack resistance and chemical durability.[4]

Given these advantages, LionGlass has the potential to revolutionize the glass industry by providing a sustainable alternative for various applications, including glass packaging and architectural glazing. However, transitioning from SLS glass to LionGlass is not a straightforward process. The glass industry is built around well-established manufacturing and waste disposal processes, and companies cannot overhaul their production lines to accommodate the new composition overnight.

Glass recycling is a major factor in transitioning LionGlass to market. In theory, glass is indefinitely recyclable without losing its properties. But in practice, not all glass compositions are recyclable on an industrial scale. Borosilicate glasses and glass-ceramics, for example, are not recycled as extensively as SLS glass due to their lower production volumes, higher melting temperatures, and longer lifespan in consumer use. As a result, most recycling facilities are optimized specifically for SLS glass, with furnaces designed to melt its composition efficiently.

Because LionGlass is not yet mass-produced, it is not economically feasible to establish separate recycling streams just for this glass. But then how will LionGlass be sorted from SLS glass at recycling facilities to prevent contamination?

Research indicates that LionGlass can be optically sorted from SLS glass based on differences in their ultraviolet absorbance spectra, ensuring that it does not interfere with existing recycling streams. But even with efficient sorting, some degree of cross-contamination between LionGlass and SLS glass is inevitable, whether at recycling facilities or within manufacturers' own production lines.

This mixing of LionGlass and SLS glass raises an important question: What happens when LionGlass cullet contaminates SLS cullet, and vice versa? If even small amounts of LionGlass alter the properties of SLS glass beyond acceptable limits, manufacturers may be reluctant to adopt it. Similarly, understanding how SLS cullet affects LionGlass properties is crucial for ensuring product consistency.

Addressing these concerns is a key focus of my research at The Pennsylvania State University (Figure 1). In addition to determining acceptable contamination thresholds and their impact on final glass properties, I am also working to develop an SLS-compatible version of LionGlass. By designing a composition that minimizes the effects of cross-contamination, manufacturers can integrate LionGlass into existing production lines with fewer risks—thus encouraging industry adoption.

LionGlass represents a major step toward a more sustainable glass industry, offering significant environmental benefits while maintaining the performance required for commercial applications. By addressing challenges related to sorting, contamination, and compatibility, we can pave the way for a future where LionGlass coexists with and eventually replaces traditional SLS glass, fostering a more sustainable and efficient glass industry.

References

[1]W. Deng, E. Wakelin, E. Kilinc, and P. A. Bingham, "A survey of commercial soda–lime–silica glass compositions: Trends and opportunities I—Compositions, properties and theoretical energy requirements," *Int. J. Appl. Glass Sci.* 2025, **16**(1): e16691.

[2]"The Sustainable Development Goals Report 2024 | DESA Publications," United Nations. Published June 2024. Accessed 23 Feb. 2025. https://desapublications.un.org/publications/sustainable-development-goals-report-2024

[3]S. Astle and S. Traugh, "LionGlass: A phosphate-based approach to carbon-neutral glass manufacturing," *Am. Ceram. Soc. Bull.* 2023, **102**(4): 40.

[4]J. Chen, "A carbon-neutral future with Penn State's pride, LionGlass," *Am. Ceram. Soc. Bull.* 2024, **103**(4): 40.

Elif Pınar Akman Özay is a Ph.D. student in materials science and engineering at The Pennsylvania State University. Her research focuses on the recycling and cullet compatibility of LionGlass. In her free time, Elif enjoys journaling, cooking, practicing yoga, and trying different flavors of ice cream. ■

WELCOMING NEW FACULTY

Caio Bragatto, Ph.D.

Alfred University welcomes Assistant Professor of Ceramic Engineering Dr. Caio Bragatto. Bragatto earned his B.S. degree in Industrial Chemistry from the Universidade de São Paulo (São Paulo, Brazil), and his master's and Ph.D. degrees in Materials Science and Engineering from the Universidade Federal de São Carlos (São Paulo, Brazil).

Bragatto worked as a research assistant at the Otto-Schott Institut für Materialwissenschaft at the University of Jena (Thüringen, Germany) and as a physics professor at Coe College (Cedar Rapids, Iowa). He specializes in the ionic conductivity of glasses, like those used for batteries and sensors focusing especially on unveiling the mechanisms behind the phenomena and working on a universal model to predict this property. During his time at Coe College, he was the principal investigator (PI) for an NSF-MRI (National Science Foundation Major Research Instrument) grant for an electrochemical impedance spectrometer, co-PI for another NSF-MRI for a differential scanning calorimeter as well for the institution's NSF-RUI (Research at predominantly Undergraduate Institutions). This research was done in direct collaboration with the undergraduates at Coe College, which led to two of his students being awarded runner-up prizes for the Glass and Optical Materials Cooper Awards ('19 & '22).

Dr. Bragatto has also been deeply involved with student life, advising multiple clubs, including the chapter for the Society of Physics Students. His involvement led to his election as a congressman in the national society, a role he will keep for another two years. He is also involved with ACerS, and is a member of multiple committees, chairing sessions during conferences. He is excited to bring this experience to Alfred University.

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