AMERICAN CERAMIC SOCIETY

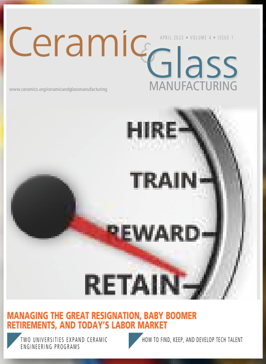
bulletin

emerging ceramics & glass technology

APRIL 2023

Hydrogen firing: UK's Lucideon works with ceramics industry on hydrogen-firing trials

New issue inside:



Hydrogen infrastructure | Green hydrogen markets | High-purity aluminas

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Cover image

A pipe supplying Lucideon's hydrogen kiln with a hydrogen/natural gas blend. *Credit: Lucideon*

AMERICAN CERAMIC SOCIETY

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As seen on *Ceramic Tech Today*...


Credit: Lithoz GmbH, YouTube

Effect of particle size distribution on curing behavior of ceramic-filled photo-thermal resins

To improve the mechanical properties of vat polymerized ceramics, researchers have extensively studied a range of factors that affect the photopolymerization process. In a recent study, two University of Stuttgart researchers elucidated the correlations between particle size distribution and polymerization kinetics.

Read more at www.ceramics.org/particles-in-resins

Also see our ACerS journals...

Research on the preparation of Ni/Al_2O_3 powder by fluidized crystallization granulation–hydrogen reduction
By X. Wang, L. Gui, H. Yang, et al.
International Journal of Applied Ceramic Technology

Recent trends of advanced ceramics industry and Fine Ceramics Roadmap 2050
By H. Takemura and H. Fukushima
International Journal of Applied Ceramic Technology

Flexural strength of a conventionally processed and additively manufactured debased 94% alumina
By D. R. Kammler, D. E. Cillessen, K. R. Ford, et al.
International Journal of Applied Ceramic Technology

A Corning perspective on the future of technical glass in our evolving world
By J. T. Kohli, M. Hubert, R. E. Youngman, and D. L. Morse
International Journal of Applied Glass Science

Read more at www.ceramics.org/journals

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ACSBA7, Vol. 102, No. 3, pp. 1–64. All feature articles are covered in Current Contents.

news & trends

Swedish rare earth discovery calls attention to mining's effects on Sámi reindeer herders

In January 2023, Swedish state-owned mining company LKAB made the striking announcement that it had identified more than 1 million tonnes of rare earth oxides near the town of Kiruna in northern Sweden. This discovery is the largest known such deposit in Europe, and many news articles have debated the impact this deposit may have on reducing reliance on China for rare earths.

But these articles often gloss over why LKAB believes it will take 10–15 years to secure the required permits and begin mining the deposit. Namely, its impact on Kiruna residents and the indigenous Sámi people.

The Sámi are a Finno-Ugric-speaking people who inhabit the region of Sápmi, which today encompasses large northern parts of Norway, Sweden, Finland, and the Murmansk Oblast of Russia. While traditional Sámi livelihoods include fishing, gathering, handicrafts, and hunting, what they are most well known for is reindeer herding.

Traditional herding was based around the natural migration path of reindeer, but Sámi reindeer herding communities were forced into settlement by the colonial acts of the Swedish, Russian, and Finnish nation-states. Now, reindeer are herded into different winter and summer pastures based on the herders' knowledge about food resources, climate, winds, and forest structure.

A community of Sámi reindeer herders lives near Kiruna, and their herding of the reindeer is already being disrupted by an iron ore mine that LKAB operates in the area. The Kiruna mine is the largest underground iron ore mine in the world, and its continued expansion—along with growth in the town of Kiruna—has created a bottleneck for the Sámi herders.

"Reindeer up until 1948 trekked through Kiruna in a path [Sámi reindeer herder Tomas Kuhmunen] described as a bloodline access to pastures," an *EUobserver* article explains. "That path has been closed due to the mine and other infrastructure, including an airstrip … As the mine and town expands, it further squeezes an already narrow

A Sámi reindeer herder in Sweden. Mining in Sweden has had a profound effect on Sámi reindeer herding communities, and the discovery of a new rare earth oxides deposit has the Sámi people concerned.

Credit: Mats Andersson, Flickr (CC BY 2.0)

strip of the district for the reindeer to herd and graze."

The Sámi herders are unable to bypass the bottleneck because the two neighboring districts will not allow the herders to graze on their land. Additionally, a Kiruna sewage treatment facility pumps out warm water into a nearby creek, which keeps it from freezing over in winter and makes passage more difficult.

The expansion of the iron ore mine has also caused subsidence (sinking) in the surrounding area. This caving in of the ground puts the town of Kiruna at risk, and about 6,000 people are moving themselves—and some historic buildings—about three kilometers east to avoid the town being swallowed by the sinking land.

Based on this history, the Sámi herders do not feel comforted by LKAB's promise to conduct fossil-free extraction of the newly discovered rare earth oxides.

"They [LKAB] don't see the whole landscape in the same manner that we do when we're herding our reindeers. And that is of course a major problem," says Sámi reindeer herder Tomas Kuhmunen in the *EUobserver* article. "They see this as an island, in a vast ocean of nothingness. They see it as fragmented." ■

'Invisible' solar roof tiles bring sustainable technology to historical sites

With 2023 marking the halfway point in implementing the United Nations Sustainable Development Goals, which were adopted in 2015, governments around the world feel the pressure to double down on their commitments.

For countries that are home to designated historical sites, the implementation of new sustainable materials and technologies is complicated by the need to preserve the area's historical nature. This complication is especially relevant to Italy, which is home to the largest number of UNESCO world heritage sites, with 58 world heritage locations.

In May 2015, the Italian Ministry of Cultural Heritage, Activities, and Tourism and the National Research Council of Italy signed a 7-year framework agreement to identify and promote research and innovation programs, as well as demonstration and educational programs, in the cultural heritage and tourism sector.

The following March, the two organizations signed an operating agreement to develop an integrated technological solution to improve the safety and sustainability of the Archaeological Park of Pompeii, a UNESCO world heritage site since 1997.

Deemed Smart@Pompei, this pilot project aims to deploy an interconnected array of sensors throughout the site that generate alarms in cases of danger, vandalism, or exceeding limits of environmental and energy impact. The main backbone of the integrated system consists of a fiber-optic network and a wireless network managed by a Milestone Systems XProtect open platform video solution.

"Thanks to the IoT [Internet of Things] technology, the technologically integrated system is scalable and flexible, so that other devices and components, as well as other useful sensors for optimal and sustainable site management, can be added at any moment," the project website explains.

Example of the terracotta-styled Invisible Solar Rooftile panels that are meant to blend into the Archaeological Park of Pompeii while generating power for a new sensor system.

Ideally, this system will serve as a model for protecting and monitoring other historical sites while incorporating sustainable technologies and practices.

While visitor safety is a main goal of the new system, with particular attention given to assisting people with disabilities, it also needs to preserve the artistic and historical elements of the site. That is why, in 2018, the Smart@Pompei project managers teamed up with Dyaqua, a small family-run Italian business that offers a unique type of photovoltaic panel.

In a *Fast Company* article, Dyaqua's spokesperson Elisa Quagliato explains that her father, Giovanni Battista, started Dyaqua to create a solar panel that could be installed on any of the thousands of historic buildings in Italy. Currently, these buildings cannot host solar panels due to laws requiring the buildings maintain their original appearance.

Initially, Battista and his family produced a line of ultra-resistant LED lamps that look like common building materials, such as stones, bricks, and paver tiles. But in 2016, they officially launched Battista's ideal product, which he had been developing since 2009—the Invisible Solar Rooftile.

The Invisible Solar Rooftile is a tile-like module covered in a nontoxic and recyclable polymeric compound that can look like different main building materials, such as terracotta, but it allows light to pass through and feed photovoltaic cells hidden inside.

Though the Invisible Solar Rooftile is not quite as efficient as a standard solar array—it generates only about 25% as much energy as a conventional setup—it can be installed just about anywhere on a building, which potentially dramatically increases the production space.

In a POCITYF article, Gabriel Zuchtriegel, director of the Archaeological Park of Pompeii, says the Invisible Solar Rooftile offered an ideal way to power the new Smart@Pompei integrated system.

"Pompeii is an ancient city which in some spots is fully preserved. Since we needed an extensive lightning system, we could either keep consuming energy, leaving poles and cables around and disfiguring the landscape, or choose to respect it and save millions of euros," he says.

"The [Invisible Solar Rooftile] not only helps us cut the energy bills but it also makes our archaeological park more enjoyable. This is therefore just the beginning. From now on, we will be taking this solution into account for all future renovation and restoration projects," Zuchtriegel adds.

In addition to the Smart@Pompei project, in the coming months, Dyaqua will install Invisible Solar Rooftiles on some public buildings in the towns of Split, Croatia, and Evora, Portugal, according to the POCITYF article. ■

Funding alert: DOE to provide approximately $6 billion to support industrial decarbonization demos

On Dec. 22, 2022, the U.S. Department of Energy's (DOE) Office of Clean Energy Demonstrations (OCED) released a Notice of Intent developed in collaboration with the Office of Manufacturing and Energy Supply Chains to provide up to $6.3 billion to support the advancement of transformational technologies necessary to decarbonize the industrial sector and provide the U.S. with a competitive edge in the race to lead the world in low- and net-zero carbon manufacturing.

The Industrial Demonstrations Program will fund projects that focus on the highest emitting industries where decarbonization technologies can have the greatest impact: iron and steel, cement and concrete, chemicals and refining, food and beverage, paper and forest products, aluminum, other energy-intensive manufacturing industries, and cross-cutting technologies. It will include up to $5.8 billion from the Inflation Reduction Act and $500 million from the Bipartisan Infrastructure Law.

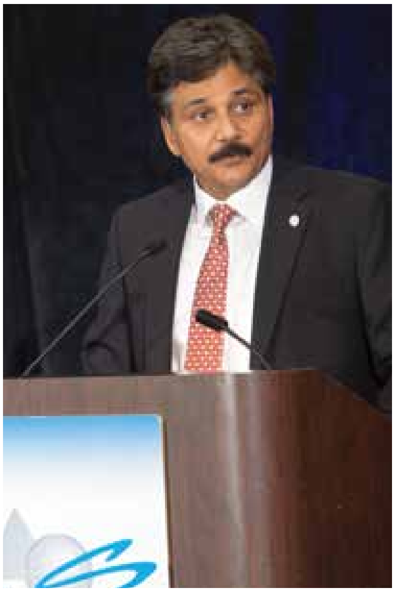
OCED will provide up to 50% of the cost of each project to catalyze impactful, scalable, and replicable demonstrations that maximize emissions reductions, prioritize energy and environmental justice, and create good-paying jobs. To ensure these projects provide benefits to their host communities and neighbors, applicants must submit a community benefits plan related to engaging communities and labor; investing in the U.S. workforce; advancing diversity, equity, inclusion, and accessibility; and implementing the Justice40 Initiative.

On March 8, 2023, DOE issued the Funding Opportunity Announcement. Learn more about this funding opportunity at https://www.energy.gov/oced/funding-notice-industrial-demonstrations.

To watch the recording of the informational webinar held Jan. 24, 2023, visit https://www.energy.gov/oced/industrial-demonstrations-program-notice-intent-informational-webinar.

For more about OCED and its programs, visit https://www.energy.gov/oced/office-clean-energy-demonstrations. ■

SOCIETY DIVISION SECTION CHAPTER NEWS



ACerS Bulletin's digital evolution set for May issue

We announced in the March issue that the *Bulletin* is transitioning to a new digital format beginning with the May issue. Instead of a flipbook, readers will peruse a dynamic website; you can still download a PDF to read offline as well.

Getting the *Bulletin* will be as simple as opening the *Bulletin* Table of Contents email that we send members and subscribers. However, members who receive a complimentary print magazine with their current membership level may opt in to receive a paper copy.

U.S. or Canada members

- Online: Login to your ceramics.org account using your membership credentials. → "Purchase" a $0 subscription at https://myacers.ceramics.org/productdetails?id=a1B3u000006PMp8EAG.
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- Email: customerservice@ceramics.org

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- Online: Login to your ceramics.org account using your membership credentials. → "Purchase" a $0 subscription at https://myacers.ceramics.org/productdetails?id=a1B3u000006PMp9EAG.
- Phone: +1 614-890-4700
- Email: customerservice@ceramics.org

ACerS welcomes new United Arab Emirates Chapter

The January meeting of the ACerS Board of Directors reviewed and approved a petition for a new International Chapter located in Abu Dhabi, United Arab Emirates. ACerS looks forward to working cooperatively with this new Chapter to further promote the local/regional ceramics and glass communities.

The leadership team will be as follows:

Chair: **Ahsan Ul Haq Qurashi**, Khalifa University, Abu Dhabi

Vice-chair: **Yarjan Abdul Samad**, Khalifa University, Abu Dhabi

Secretary: **Kemal Celik**, New York University, Abu Dhabi

Italy Chapter hosts Happy Hour at ICACC'23

The Italy Chapter met on January 23 during ICACC'23 for an informal networking event. ACerS president Sanjay Mathur, ACerS executive director Mark Meckenborg, and Spain Chapter chair Arnaldo Moreno Berto joined the event to meet the Italian participants attending ICACC.

Germany Chapter members attend ICACC'23

Several members of the Germany Chapter attended the 47th International Conference and Expo on Advanced Ceramics and Composites in Daytona Beach, Fla., in late January 2023.

Two members participated in the Winter Workshop, which took place before the conference, to learn about future opportunities in science with other students from Europe, North America, and South America. The young scientists participated in workshops on topics such as writing, effective communication, and work–life balance.

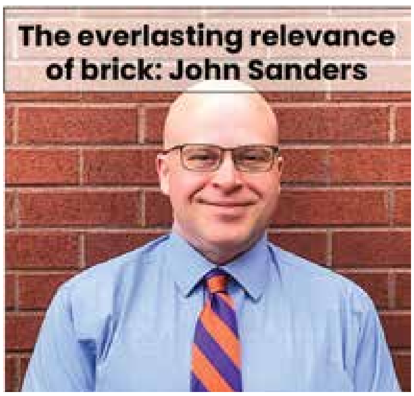
ACerS president Sanjay Mathur and members of the Germany Chapter, pictured above, had the honor to present their research during the conference sessions.

FOR MORE INFORMATION:

ceramics.org

Ceramic Tech Chat: John Sanders

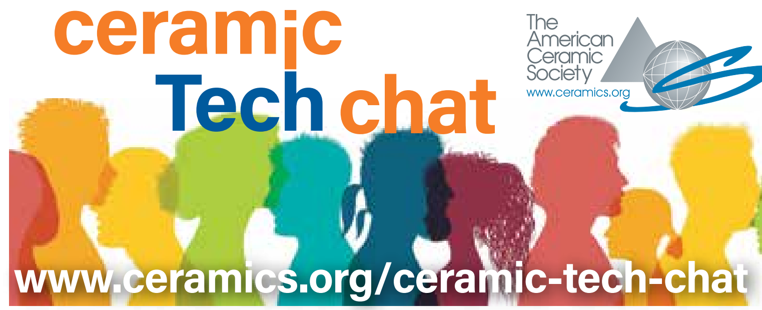
Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the second Wednesday of each month.



In the February episode of Ceramic Tech Chat, John Sanders, director of the National Brick Research Center at Clemson University, shares how he became interested in researching brick and other clay-based construction materials, overviews National Brick Research Center activities, and discusses how brick can help support our sustainable future. Check out a preview from his episode, which features Sanders talking about the potential of using recycled glass in bricks.

"You know, a lot of cities take recycled glass and they don't have a home for it, and so it piles up and then they stop taking it. It's a beautiful material to use as an aggregate in brick. There's no reason with a good clay you couldn't make something 50, 60% recycled glass. So, the beauty of that, it's previously fired, so there are no emissions other than the fuel that it takes to heat it up. And you've got the potential of lowering your firing temperature. And you've got a high recycle content, which goes into the whole sustainability thing, and you're not taking as much raw material out of the ground."

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



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Meet the Strategic Planning for Emerging Opportunities Committee

The Strategic Planning for Emerging Opportunities (SPEO) Committee comprises the leaders of ACerS principal committees and Society member groups, such as the President's Council of Student Advisors, the Young Professionals Network (YPN), and technical interest groups, and several members-at-large. The Committee is responsible for identifying emerging opportunities that the Society should consider as part of its strategic planning process.

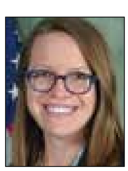
ACerS Board of Directors develops ACerS long- and short-term strategy, which, in turn, is implemented through the Society's committees and member groups. Thus, SPEO serves an important role, complementary to the Board, in setting and achieving the Society's strategic direction.

Raj Bordia 2022–23
Chair and president-elect
Clemson University

Monica Ferraris 2022–23
President-elect nominee
Politecnico Di Torino, Italy

David Poerschke 2018–24
Publications Committee chair
University of Minnesota

Jessica Rimsza 2022–24
Meetings Committee chair
Sandia National Laboratories



Lisa Rueschhoff 2020–24
Member Services Committee chair
Air Force Research Laboratory

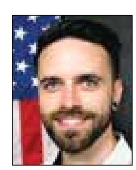
Victoria Blair 2020–23
Member-at-large
U.S. Army Research Laboratory

Clive Randall 2021–24
Member-at-large
The Pennsylvania State University

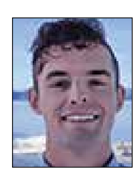
Surojit Gupta 2022–25
Member-at large
University of North Dakota

Claire Xiong 2022–25
Member at-large
Boise State University

Ashley Hampton 2021–23
YPN co-chair
Allied Mineral Products, LLC.



Christopher Kassner 2022–24
YPN co-chair
UES, Inc.



Fox Thorpe 2022–23
President's Council of Student Advisors chair
University of California, Davis

Mathieu Bauchy
SPEO standing guest, Technical Interest Group leader
Focus: Computational design of ceramics and glasses
University of California, Los Angeles

Gurpreet Singh
SPEO standing guest, Technical Interest Group leader
Focus: Products arising from polymer-derived ceramics
Kansas State University

Volunteer spotlight

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

Amanda Krause is assistant professor of materials science and engineering at Carnegie Mellon University. She received her B.S. and M.S. in materials science and engineering from Virginia Tech, and her Ph.D. in materials science from Brown University. Before joining Carnegie Mellon University in 2022, she was assistant professor at the University of Florida (2019–2022) and a post-doctoral research associate at Lehigh University.

Krause's research focus is engineering grain boundaries and microstructures for improving the mechanical performance and degradation response of ceramics used in extreme environments. She is a recipient of the NSF CAREER award (2022).

Krause is currently vice chair of ACerS Basic Science Division. Additionally, she was a member of the organizing committee for the Electronic Materials and Applications conference in 2022 and 2023, as well as a symposium co-organizer for each year.

We extend our deep appreciation to Krause for her service to our Society! ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

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. The deadline is the 30th of each month.

▲ ACerS DLM Arun Varshneya (furthest right in left back row) visited middle school girls at the St. Thomas School New Delhi, along with officials from the All India Glass Manufacturers' Federation, in November 2022. Students received glass bottles commemorating the International Year of Glass. The group posed with a bust of Mahatma Gandhi, who used to exhort students to "Keep the earth clean," to which Varshneya added, "Use glass." ■

Carol Handwerker, Reinhardt Schuhmann, Jr. Professor of Materials Engineering, was named Fellow of the American Association for the Advancement of Science.

Alexandra Navrotsky, ACerS Distinguished Life Member, was named Regents Professor by Arizona State University, where she directs ASU's Navrotsky Eyring Center for Materials of the Universe. ■

AWARDS AND DEADLINES

Nomination deadlines for Division awards: May 15, May 30, or July 31

Contact: Karen McCurdy | kmccurdy@ceramics.org

Division	Award	Nomination Deadline	Contacts
GOMD	**Alfred R. Cooper Scholars**	May 15	Steve Martin swmartin@iastate.edu
EDiv	**Edward C. Henry**	May 30	Reeja Jayan breeja@cmu.edu
EDiv	**Lewis C. Hoffman Scholarship**	May 30	Reeja Jayan breeja@cmu.edu
EMSD	**Outstanding Student Researcher**	July 31	Charmayne Lonergan charmayne.lonergan@pnnl.gov

FOR MORE INFORMATION:

ceramics.org/members/awards

MEMBERSHIP SPOTLIGHT

Distinguished Life Member Martin Harmer on his boat Cheeky Monkey III in Florida.

Description
Recognizes undergraduate students who demonstrated excellence in research, engineering, and/or study in glass science or technology.
Recognizes an outstanding paper reporting original work in the *Journal of the American Ceramic Society* or the *Bulletin* during the previous calendar year on a subject related to electronic ceramics.
Recognizes academic interest and excellence among undergraduate students in ceramics/materials science and engineering.
Recognizes exemplary student research related to the mission of the Energy Materials and Systems Division of ACerS.

STUDENTS AND OUTREACH

Your dream job is out there—find it on the Ceramic and Glass Career Center

Online recruitment continues to gain support from organizations looking for top talent. Over the past several years, companies have spent thousands of dollars raising brand awareness on the Ceramic and Glass Career Center to attract more interested job seekers, like you, to fill their open positions. Visit the online Ceramic and Glass Career Center at https://careers.ceramics.org to view current openings, explore a myriad of career resources, and post your resume for employers to find you. ■

Are you ready to P.A.C.K. your bags? Apply for the P.A.C.K. international research fellowship!

P.A.C.K. is an international research fellowship opportunity for graduate students funded by the National Science Foundation to conduct research at University of Kiel in Germany.

The fellowship provides support for travel, lab fees, and boarding. In addition to research, selected students will have an opportunity to attend relevant courses at University of Kiel, get exposure to entrepreneurship training, and participate in professional development activities. For more information, visit http://packfellowship.org. ■

Opportunities delivered to your inbox each month

Current student members, faculty, and other interested ACerS members may receive the ***Ceramic & Glass Scope***, a monthly e-newsletter with a focus on student opportunities and interests. Be sure to check your inbox for updates on contests, scholarships, travel grants, student-authored articles, webinars, podcasts, and more! ■

While you are at it, follow GGRN for updates

Visit and follow the **ACerS Global Graduate Researcher Network** on Facebook for posts relevant to grad student life, current opportunities, and more.

Visit https://www.facebook.com/acersgrads to check it out. ■

FOR MORE INFORMATION:

ceramics.org/students

CERAMICANDGLASSINDUSTRY FOUNDATION

Winter Workshop 2023: A successful professional development weekend

Winter Workshop 2023 was a resounding success as it brought together 42 students from Europe, North America, and South America for a weekend of professional development and networking in Daytona Beach, Fla.

Throughout the weekend, students had the opportunity to hear from a variety of professionals in the ceramic and glass community. These sessions covered topics such as writing, effective communication, and the importance of work–life balance, all of which are essential skills for success in today's job market.

Winter Workshop provided invaluable networking opportunities for students to connect with one another as well as with the professionals who led the workshops and sessions. These opportunities gave the students a chance to learn from the experiences and insights of others and to make lasting, personal connections.

One of the highlights of Winter Workshop was an exhilarating trip to the Kennedy Space Center, where students learned about NASA science, technology, and engineering.

Here is what a student had to say about this year's workshop:

"Winter workshop was an incredibly valuable experience and set the gold standard for a day-long professional development workshop. Well worth the time!"

– Nathan McIlwaine
Penn State University

WINTER WORKSHOP 2023 GUEST SPEAKERS

Elizabeth Dickey, head of the materials science and engineering department, Carnegie Mellon University

Eva Hemmer, associate professor of materials chemistry, University of Ottawa

Jamesa Stokes, materials research engineer, NASA Glenn Research Center

Tim Powers, senior engineering design lead, Owens Corning

Charmayne Lonergan, materials scientist, Pacific Northwest National Laboratory

Emmanuel Malliet, technology manager, GE Research

PLUS: **Andrea Caloiaro**, **Angela Brown**, and **Emily Bald** from the University of Florida's Writing Program

Group photo of Winter Workshop 2023 students at Daytona Beach, Fla., in January 2023.

Green hydrogen: Global market outlook

By BCC Publishing Staff

Hydrogen fuel is seen as vital for decarbonizing the economy, through replacing fossil fuels in the industrial and transportation sectors as well as aiding in the storage of clean energy (Figure 1).

According to the International Energy Agency, since 1975, the demand for hydrogen fuel has tripled, reaching almost 70 million tons in 2018. According to the World Bank, in 2020, the global demand for hydrogen fuel reached 87 million tons and is anticipated to reach 500 to 680 million tons in 2050. Significant disruptions in the oil and gas sector due to the Russia–Ukraine war have further propelled the need for energy security in the global economy, mainly in Europe.

There are three primary ways to produce hydrogen fuel.

- **Grey hydrogen** is produced by steam reforming of natural gas. This process emits about 9–11 kg of CO_2 per kg of hydrogen production.
- **Blue hydrogen** is also produced by steam reforming of natural gas, but the carbon emissions are captured and stored.
- **Green hydrogen** is produced through water electrolysis. This process emits no CO_2 if renewable energy sources, such as wind and solar power, provide the electricity.

In 2021, green hydrogen accounted for less than 0.1% of worldwide hydrogen production. The cost of electricity is the most crucial variable influencing the financial viability of green hydrogen. It is imperative that energy-efficient electrolyzers be developed. As the prices of renewable energy fall, the production cost of green hydrogen delivered via renewable energy will also decrease.

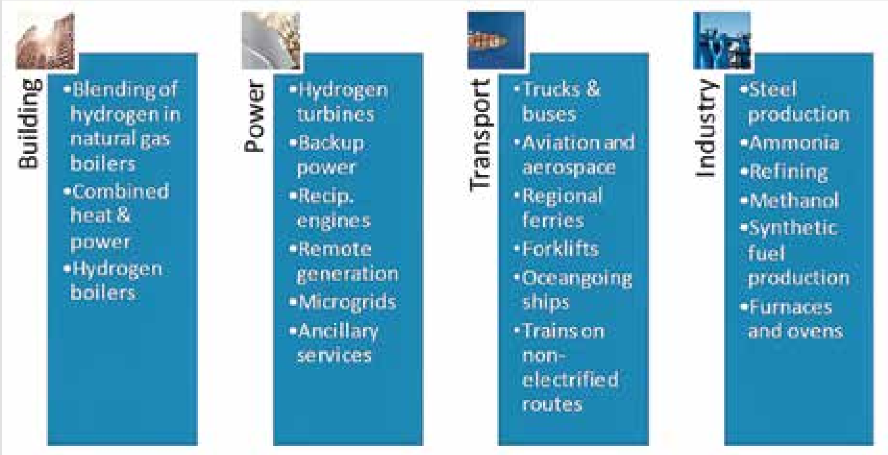


Figure 1. Applications of hydrogen across various end-user sectors.

Among the total installed capacity for green hydrogen production in 2021, nearly 70% was based on alkaline water electrolyzers, while most of the remaining capacity was based on proton exchange membrane (PEM) electrolyzers. Among other technologies that held a minority share, anion exchange membranes and solid oxide electrolysis cells were common; however, they are less mature than alkaline and PEM electrolyzers.

Currently, most hydrogen is consumed at the same location where it is generated. It can be transported by trucks, tankers, and trailers within pressurized gas containers and in cryogenic liquid tanks. But transportation is a cost-intensive process due to the costs of liquefaction, regasification, and refrigeration.

In the global green hydrogen market (Table 1), Europe has emerged as the dominant region, contributing 57% of the market by volume in 2021. While Europe is expected to maintain its dominance throughout the forecast period, the Asia-Pacific region is expected to register the highest compound annual growth rate (CAGR) of 26.0%.

Table 1. Global market volume of green hydrogen, by region, through 2027 (kilotons)

Region	2021	2022	2027	CAGR % (2022–2027)
Europe	535.8	638.0	1,829.2	23.4
Asia-Pacific	319.6	388.2	1,232.1	26.0
North America	57.5	69.4	212.4	25.1
Rest of the world	27.1	32.5	97.4	24.5
Total	940.0	1,128.0	3,371.1	24.5

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, "Green hydrogen: Global market outlook" BCC Research Report ENV060A, February 2023. www.bccresearch.com. ■

ceramics in biomedicine

Time for removal: A review of erbium laser-assisted ceramic debonding for dental restorations and appliances

Though some dental restorations last for well over 10 years in ideal circumstances, there are numerous situations that necessitate the removal of a restoration sooner.

Fortunately, there are various methods for removing dental restorations. Which method is used depends on factors such as the crown and bridge material, the luting cement (material that secures the restoration to a tooth), location of the restoration, and status of the underlying tooth.

Traditionally, the safest and least traumatic way to remove a restoration is by destroying it. Methods that conserve or semi-conserve the restoration often risk harming the underlying tooth. However, continued research on conservative methods helps mitigate the risk of tooth damage and makes such procedures more desirable options.

Erbium lasers are a conservative method being explored for removing both ceramic restorations and ceramic appliances (e.g., braces). These lasers emit light in wavelengths that can be transmitted through a translucent ceramic and then absorbed by the water molecules and residual monomers in the luting cement. This absorption results in vaporization of the molecules and debonding of the cement.

The main concern with using erbium lasers to remove dental ceramics is the possibility of thermal injury to the adjacent tissues. An increase in pulpal temperature by 5.5°C can cause irreversible damage to the pulp tissue, while an increase in osseous temperature by 10°C can cause bone damage; increasing temperatures by 6°C can damage periodontal ligaments.

In a recent open-access paper, researchers from Virginia Commonwealth University and Wroclaw Medical University (Poland) reviewed the current literature on erbium laser-assisted ceramic debonding to identify the parameters needed for safe application of this method.

They conducted a comprehensive search of seven databases and, after a multistep narrowing process, selected 38 articles for inclusion in the study. Among the 38 articles, 15 reported on experiments conducted with orthodontic brackets (braces), nine reported on veneer removal, five studies reported research findings using ceramic disks, six reported on all-ceramic crown removal from natural teeth, and three studied the removal of crowns from various implant abutments.

Notably, all 38 articles involved ex vivo or simulated experiments. As such, the findings "may not be reflective of clinical situations where the patient's oral structures, tongue and cheek, as well as optimal access to the laser intraorally, can present challenges in manipulating the laser handpiece and application," the researchers acknowledge.

Some key findings from the review paper are given on the following page.

Material effects on debonding time

Based on the data in these studies, type of luting cement played an important role in debonding time. For example, one study showed that lithium disilicate crowns debonded from titanium implant abutments in only 97.5 seconds when secured with a resin-modified glass-ionomer cement, while crowns secured with a resin cement required 196.5 seconds.

On the other hand, translucency of a given ceramic appeared to have little influence on debonding. For example, "No significant difference in debonding veneers from bovine incisors was reported among feldspathic ceramics with different translucency," the researchers write.

However, the type of ceramic did influence debonding time. For example, previous studies reported that it takes longer to debond a zirconia crown (226–312 seconds) compared to a lithium disilicate crown (190 seconds) from a human molar.

Laser effects on debonding time

Five studies compared the efficiency of debonding between erbium,chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG) and erbium-doped yttrium aluminum garnet (Er:YAG) lasers. Though time for removal was not always statistically different, debonding times generally were shorter for the Er:YAG laser than the Er,Cr:YSGG laser.

Power and duration of the laser depended on the type of restoration or appliance being removed. For example, one study found removal of an orthodontic bracket required a power of 3 watts, 10 seconds in the scanning mode with energy density 22–28 J/cm^2, and pulse duration of 100 μs. In contrast, another study found crown removal required laser settings to be in the range of at least 3.5–4 watts of power with 25 Hz pulse rate.

Laser effects on surrounding tissue and irradiated ceramics

Though thermal injury to adjacent tissues is the main concern when using laser-assisted ceramic debonding, no study reported a significant increase in pulpal temperature beyond the physiological limit of 5.5°C during irradiation with any erbium laser. Pulpal temperature changes typically ranged between 0.71°C to 4.28°C.

Additionally, most studies reported successful removal of restorations or appliances with no detectable physical damage to the irradiated ceramic. Scanning electron microscopy was the most common method used to examine the debonded ceramics, with energy dispersive spectroscopy, secondary electron imaging, or backscattered electrons sometimes applied as well.

Ultimately, "Results from all studies showed that erbium lasers are effective in debonding all ceramic restorations with no damage to abutment teeth/implant and with none or minimal alterations to the ceramic restorative/orthodontic appliance surfaces," the researchers conclude.

Future directions for research

The researchers write that there is a real need for clinical studies so the in-vivo-based debonding time can be assessed, as well as a patient's compliance and acceptance of the laser-assisted ceramic debonding.

Additionally, though this review found similar applications of laser settings across studies, researchers need to develop a consensus for this procedure for both Er:YAG and Er,Cr:YSGG lasers.

The open-access paper, published in *Journal of Prosthodontics*, is "Erbium laser-assisted ceramic debonding: a scoping review" (DOI: 10.1111/jopr.13613). ■

ceramics in the environment

Utilizing stored emissions: A review of molten salt electrochemical conversion to recycle carbon dioxide

In an open-access paper, researchers from the University of Science and Technology Beijing summarize the successes and challenges of using molten salt electrochemical conversion to extract pure carbon products from stored carbon dioxide emissions.

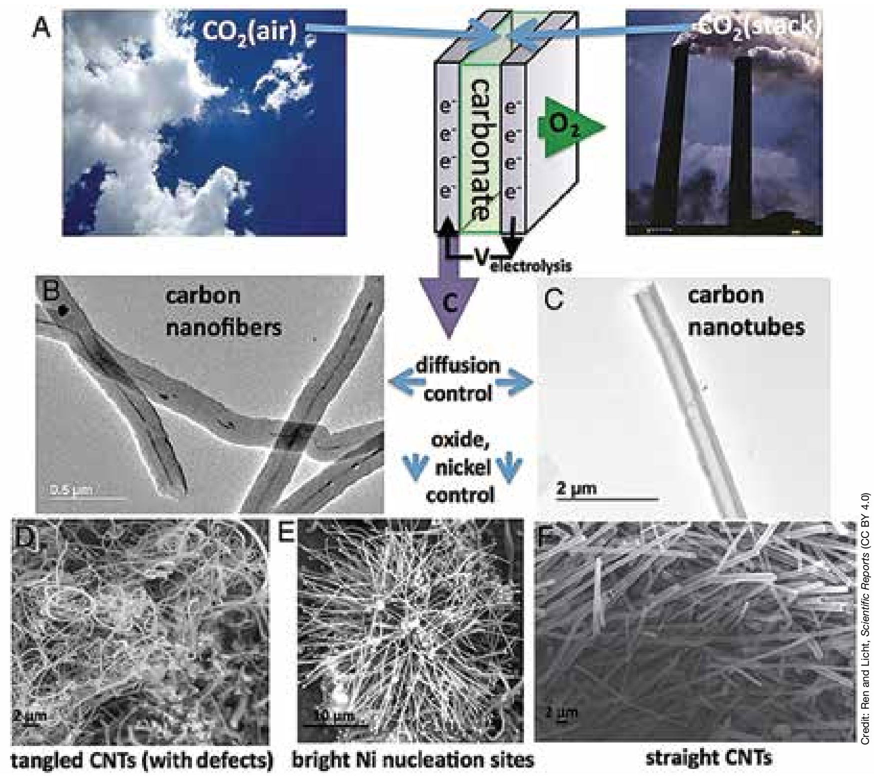
Carbon dioxide typically separates into carbon monoxide and oxygen when split. Extracting pure carbon is traditionally an energy-intensive process that relies on burning fossil fuels.

Recent studies have shown that molten salt electrochemical conversion may offer an economic and relatively clean way to extract pure carbon products from carbon dioxide. In this process, carbon dioxide gas is readily absorbed by dissolved O^{2-} ions in a molten salt, and the subsequently formed CO_3^{2-} ions can then be reduced into solid carbon and oxygen gas following application of sufficient voltage.

Below are some highlights from the 17-page review.

Molten salts for electrochemical reduction of CO_2

Molten carbonates and molten chlorides are typically used in the molten salt electrochemical conversion process because of their high solubility of O^{2-} ions.



(A) High yield electrolytic synthesis of carbon nanostructures from dissolved air or smokestack concentrations of carbon dioxide in molten lithium carbonates. During CO_2 electrolysis, transition metal deposition controls the nucleation and morphology of the carbon nanostructure. (B,C) Diffusion controls the formation of either nanotube (C: as grown from natural abundance CO_2) or nanofiber (B: from 13C) morphologies. (D–F) Electrolytic oxide controls the formation of tangled (D: high Li_2O) or straight (F: no added Li_2O) nanotubes.

For molten carbonates, most studies use molten alkali metal carbonates, lithium carbonate, sodium carbonate, and potassium carbonate due to their superior stabilities under high working temperatures.

For molten chlorides, most studies use calcium-chloride-based and lithium-chloride-based salts due to the relatively high solubility of O^{2-} ions in these systems.

Managing the competing carbon monoxide evolution reaction

For the reduction of CO_3^{2-} ions into solid carbon, there are generally two accepted pathways: single-step reduction and two-step reduction.

The single-step reduction involves a direct four-electron transfer, splitting CO_3^{2-} ions directly into solid carbon and O^{2-} ions.

The two-step reduction involves the reduction of CO_3^{2-} ions to CO_2^{2-} ions and subsequent reduction of CO_2^{2-} ions to solid carbon and O^{2-} ions. However, the CO_2^{2-} ions are unstable and may decompose into carbon monoxide gas and O^{2-} ions.

The evolution reaction of carbon monoxide competes with the reaction for carbon deposition in molten salts. The carbon monoxide evolution reaction is thermodynamically easier than the carbon deposition reaction when working temperature is higher than 970°C in molten Li_2CO_3. Thus, conducting the molten salt electrochemical conversion process at lower temperatures is beneficial to minimizing carbon monoxide evolution.

The reduction of carbon dioxide in molten salt can also be tuned by regulating the activity of O^{2-} ions. For example, Hu et al. (2020) reported the “buffer effect” provided by borate (BO^{2-}) ions in molten LiCl–Li_2CO_3. The added BO^{2-} ions can absorb O^{2-} ions to form BO_3^{3-} ions, which significantly decrease the activity of O^{2-}. The formed BO_3^{3-} ions can then react with CO_2 to regenerate BO^{2-} and release CO_3^{2-}. The decreased activity of O^{2-} positively shifts the potentials of carbon deposition and carbon monoxide evolution, which allows the reactions to occur at low temperatures.

Transforming amorphous carbon products into graphitic carbon materials

The molten salt electrochemical conversion process results in carbon products containing large amounts of amorphous carbon. To convert the amorphous carbons into graphitic carbons (e.g., nanotubes, nanofibers), small amounts of additives or catalysts typically are used, but these additions may contaminate the final products.

Recently, a strategy was proposed for transforming amorphous carbons into graphitic carbons without using any catalysts. This electrochemical graphitization process involves two steps: the electrochemical removal of oxygen through cathodic polarization, and the rearrangement of carbon atoms into a graphite crystal lattice.

The electrochemical graphitization process is applicable to various amorphous carbon feedstocks, from “soft carbons” to “hard carbons.” The typical “hard carbon,” carbon black, which cannot be graphitized by the conventional high-temperature treatment, was successfully converted into nanoflake graphite by cathodic polarization.

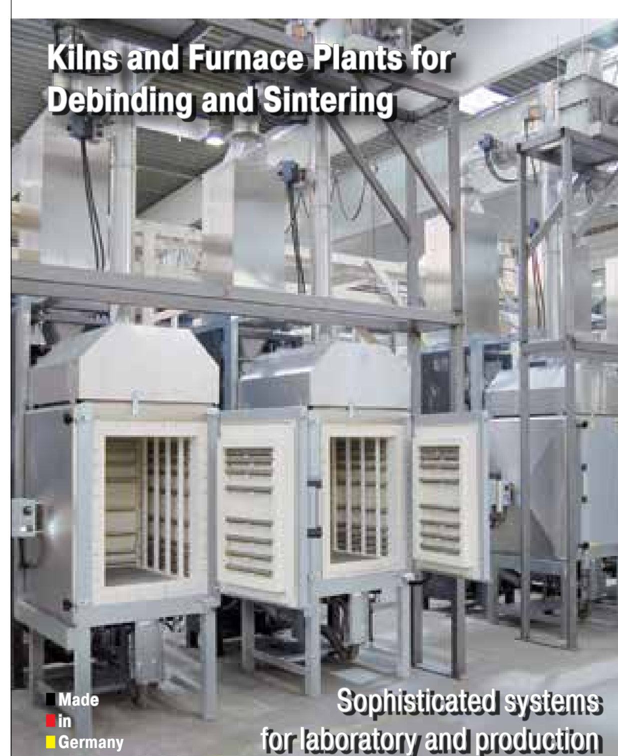
Various studies have shown that the graphitic carbon materials prepared in molten salts exhibit excellent electrochemical performance when tested as electrode materials for energy storage (e.g., batteries and supercapacitors).

Future directions for research

If molten salt electrochemical conversion is to be scaled-up for commercial production of graphitic carbons, the energy consumption of the process and the quality of the carbon products need to be compared to other synthesis routes.

Additionally, more needs to be learned about the reduction mechanisms that turn carbon dioxide into solid carbon and oxygen gas. Very limited information can be obtained in situ by present electrochemical techniques (e.g., cyclic voltammetry and square wave voltammetry tests). So, in-situ techniques designed for high-temperature molten salts, such as high-temperature Raman and computed tomography, need to be further developed.

The open-access paper, published in *Exploration*, is “Molten salt electro-preparation of graphitic carbons” (DOI: 10.1002/EXP.20210186). ■



Doing double duty—novel metalenses offer both spatial and spectral control of light

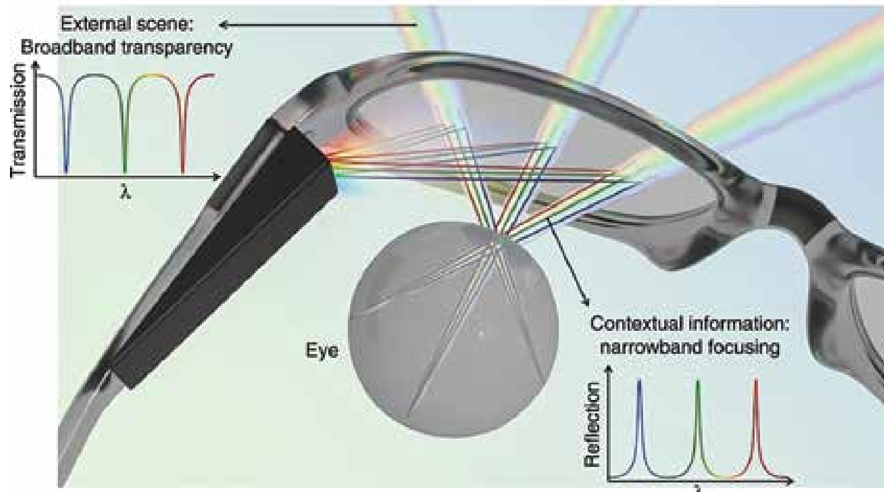


Illustration showing the operation of an augmented reality headset based on new multifunctional nonlocal metalenses developed by Columbia University and City University of New York researchers.

A new metalens developed by researchers from Columbia University and the City University of New York offers both spatial and spectral control of light.

Metalenses are flat, engineered lenses constructed of nanoscale arrays of columns or fin-like structures. This design allows a metalens to focus light without causing image distortion, and so a single metalens can focus light in lieu of multiple curved glass lenses.

Traditionally, metalenses offer either spatial or spectral control of light, not both, based on the structure of the nanoscale arrays.

In "local" metalenses, each metaunit (nanoscale array) operates independently. Such localization allows for good spatial control of light, but it limits spectral control because the wavefront deformation inevitably extends over a wide frequency range.

In "nonlocal" metalenses, each metaunit works together to support a collective mode that governs the device response. So, nonlocal metalenses can produce sharp spectral features, but they typically cannot spatially tailor the optical wavefront.

In a recent open-access paper, the Columbia-led researchers explain how previous theoretical work they published in 2020 indicated that spatial control with nonlocal metalenses should be possible. The new study aimed to experimentally confirm this possibility.

The operating principles of their nonlocal, wavefront-shaping metalenses are rooted in the physics of photonic crystals. Photonic crystals are periodic dielectric structures that either allow or forbid the propagation of electromagnetic waves of certain frequency ranges.

Within photonic crystals, a phenomenon called bound state in the continuum (BIC) may occur. BICs refer to areas of the crystal where, at the right angle, a specific wavelength of light will get "trapped" (confined) to the crystal's surface while the rest of the light freely passes through. By manipulating the crystal's structure, the wavelength and angle of this special state can be readily engineered.

The researchers hypothesized that introducing BICs into a nonlocal metalens would allow them to spatially tailor the optical wavefront.

To create BICs in a metalens, the researchers showed in their previous theoretical work that breaking the in-plane inversion symmetry of metaunits may create a quasi-BIC. Through modeling, they created a "library" of quasi-BICs based on introducing different perturbations into a lattice called the *p2* plane group.

In the new study, they used this library to guide fabrication of metalenses made of amorphous silicon on a glass substrate. Their metalenses allowed for both spectral and spatial control of light in the near-infrared spectrum. Plus, stacking the metalenses led to versatile multispectral wavefront shaping.

To demonstrate the utility of the new multifunctional nonlocal metalenses, the researchers simulated their use in augmented reality glasses (see image above). The metalenses could reflect contextual information to the viewer's eye at selected narrowband wavelengths while permitting an unobstructed broadband view of the real world. As such, it did not require extra polarizers or beam-splitters to attenuate real-world light, thus reducing the size and weight of the headset.

A Columbia University press release says the researchers' next steps are to experimentally demonstrate the metalenses' ability to control light in the visible spectrum. They are also exploring the possibility of including more than two perturbations in a single metalens.

Research News

Researchers create ultrathin nanosheets of MgB_2 that increase hydrogen storage capacity

A collaboration including scientists from Lawrence Livermore National Laboratory, Sandia National Laboratories, the Indian Institute of Technology Gandhinagar, and Lawrence Berkeley National Laboratory created 3–4 nanometer ultrathin sheets of magnesium diboride that increase hydrogen storage capacity significantly. High-pressure hydrogenation of these multilayers at 70 MPa and 330°C followed by dehydrogenation at 390°C reveals a hydrogen capacity of 5.1 wt%, which is about 50 times larger than the capacity of bulk magnesium diboride under the same conditions. For more information, visit https://www.greencarcongress.com/2023/02.

The open-access paper, published in *Light: Science & Applications*, is "Multifunctional resonant wavefront-shaping meta-optics based on multilayer and multi-perturbation nonlocal metasurfaces" (DOI: 10.1038/s41377-022-00905-6). ■

Relict no more—inclusion of lime clasts gives Roman concretes self-healing properties

Researchers led by Massachusetts Institute of Technology demonstrated that aggregate-scale lime clasts in Roman concretes were likely purposefully included to provide the concretes with self-healing properties.

These distinctive bright white clasts, also called remnant lime or lime lumps, are a ubiquitous and conspicuous feature of both land-based and maritime Roman concretes. Traditionally, researchers have considered these clasts "relicts" of the concrete fabrication process, which results from incomplete or over-burning during the calcining of lime, carbonation before concrete preparation, incomplete dissolution during setting, or insufficient mixing of the mortar.

This "relict" characterization of the lime clasts bothered ACerS member Admir Masic, professor of civil and environmental engineering at Massachusetts Institute of Technology.

"If the Romans put so much effort into making an outstanding construction material, following all the detailed recipes that had been optimized over the course of many centuries, why would they put so little effort into ensuring the production of a well-mixed final product?" he says in an MIT press release.

Spurred on by this question, Masic and colleagues at MIT and Harvard University, along with researchers at laboratories in Italy and Switzerland, took a closer look at the clasts. Their study focused on 2,000-year-old Roman concrete samples sourced from the masonry mortar of the city wall at the archaeological site of Privernum, Italy.

Spectroscopic examination of the samples provided clues that the concrete was formed at extreme temperatures. This finding is significant because it suggests the Romans employed a hot mixing technique—introducing quicklime directly into the mixture—rather than slaking, i.e., first hydrating the quicklime before introducing it. Such an approach would "create an environment where high surface area aggregate-scale lime clasts are retained within the mortar matrix," the researchers write.

But why would the Romans want to use an approach that purposefully retains lime clasts within the mortar matrix? The researchers suggest these clasts may provide the concrete with a self-healing ability.

"The recent discovery of calcite-filled cracks in Roman concrete suggested a potential long-term healing process that requires a Ca-rich source," the researchers write. "Considering the ubiquity of relict lime clasts in Roman concrete and their high surface area due to their particulate microstructure, these

Credit: Seymour et al., Massachusetts Institute of Technology

A large-area elemental map (calcium: red, silicon: blue, aluminum: green) of a 2-cm fragment of ancient Roman concrete (right) collected from the archaeological site of Privernum, Italy (left). A calcium-rich lime clast (in red), which is responsible for the unique self-healing properties in this ancient material, is clearly visible in the lower region of the image.

inclusions might provide the requisite Ca reservoirs for these processes."

To test this hypothesis, the researchers created cementitious formulations based on the Roman concretes. After curing the modern samples, they fractured the samples and then flowed water over them for 30 days.

Compared to the clast-free control samples, water stopped flowing through the clast-containing samples within a month. Examination of the cracked surface revealed it had filled completely with a newly precipitated mineral phase.

Following these successful tests, the MIT press release reports that the researchers are working to commercialize this Roman-inspired concrete.

"It's exciting to think about how these more durable concrete formulations could expand not only the service life of these materials, but also how it could improve the durability of 3D-printed concrete formulations," Masic says in the press release.

The open-access paper, published in *Science Advances*, is "Hot mixing: Mechanistic insights into the durability of ancient Roman concrete" (DOI: 10.1126/sciadv.add1602). ■

Two-step sintering process improves electrical properties of lead-free piezoelectric

In a recent paper, researchers at Changzhou University in China improved the electrical properties of a lead-free piezoelectric by identifying the optimum temperature and dwell time for the first step of a two-step sintering process.

Currently, lead-based ceramics are the most widely used piezoelectric materials because of their excellent piezoelectric properties. However, in the past two decades, awareness of the environmental and health concerns related to lead's toxicity drove research on alternative lead-free piezoelectric materials.

Main challenges in developing lead-free piezoelectrics include

1. Decoding the fundamental mechanisms underlying the piezoelectric response,
2. Overcoming the temperature sensitivity of the piezoelectric response, and
3. Developing simplified chemical compositions that are easily fabricated.

With these challenges in mind, oxides based on $(Na_{1-x}K_x)NbO_3$, or KNN, appear to be the most suitable replacements for lead-based piezoceramics. These oxides display good piezoelectric properties, high Curie temperature, and environmental compatibility.

Densification of KNN-based piezoceramics through a traditional high-temperature sintering process can inadvertently deteriorate the ceramic's piezoelectric response because of the volatility of the potassium and sodium ions.

Instead, researchers found a two-step sintering process (TSS) can reduce volatilization of the alkali metals. TSS involves first heating the ceramic at a high temperature for a short time and then rapidly cooling to a lower temperature for a longer dwell.

Several recent studies extensively studied the effects of temperature and dwell time during the second step of the TSS process on the final ceramic's properties. Now, the Chinese researchers looked at the effects of temperature and dwell time during the first step.

For this study, they used the doped KNN composition $0.95(Li_{0.02}Na_{0.50}K_{0.48})(Nb_{0.95}Sb_{0.05})O_3$–$0.05AgTaO_3$. Then, they conducted the TSS process as follows.

1. Samples were heated to 500°C at a heating rate of 3°C/min
2. Samples were further heated to a high sintering temperature (either 1,130°C, 1,140°C, 1,150°C, or 1,160°C) at a heating rate of 5°C/min for a short dwelling time (either 15 min, 30 min, 45 min, or 1 hour).
3. Samples were rapidly cooled to 1,050°C with a cooling rate of 15°C/min and dwelled for 8 hours.
4. Samples were cooled to room temperature within the muffle furnace with the power off.

A sample was conventionally sintered at 1,120°C for 2 hours for comparison. For piezoelectric property measurements, the ceramics were poled under different direct current electric fields (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 kV/mm) at room temperature for 5 min.

Analysis of the samples revealed that the bulk density of all TSS ceramics was higher than that of the conventionally sintered ceramic, with the highest bulk density (4.58 g/cm^3) achieved for samples sintered at 1,140°C for 30 min during the first step. However, the bulk density of the TSS ceramics decreased when sintering temperature was higher than 1,140°C or dwell time was longer than 30 min, apparently due to alkali metal volatilization.

Likewise, the TSS ceramics demonstrated improved piezoelectric properties compared to the conventionally sintered ceramic. As with the bulk density, samples sintered at 1,140°C for 30 min during the first step demonstrated the best piezoelectric properties, with the relative permittivity equal to 5,957 at 1 kHz (compared to 5,205 for the conventionally sintered sample).

Based on these findings, the assertion that "introduction of the TSS process can improve the dielectric and piezoelectric properties of" KNN-based ceramics is further supported, the researchers conclude.

The paper, published in *Journal of the Korean Ceramic Society*, is "Enhancing densification and electrical properties of KNN-based lead-free ceramics via two-step sintering" (DOI: 10.1007/s43207-022-00215-y). ■

Ceramics processing—are we using the correct sintering and creep models?

By Shen Dillon, University of California, Irvine

The notion that sintering is not diffusion rate limited will likely garner some consternation. Ubiquitous diffusion-rate-limited kinetic models have been used to understand, interpret, and engineer sintering for more than a half century.

Less controversial would be the suggestion that the models for grain-boundary-mediated creep at low stresses do not conform to existing models. The low-stress, nonlinear creep response has often been attributed to some combination of point defect emission and absorption kinetics, grain boundary sliding, and/or lattice plasticity, but much experimental data does not fit well any existing models.

Sintering of powders larger than about 100 nm typically occurs at average sintering stresses well within the regime associated with nonlinear grain boundary creep, as seen in the schematic below. This disparity between sintering and creep has largely been overlooked within the literature.

There are, furthermore, many persistent questions in the sintering literature related to heating rate effects, field effects, shear stress effects, residual stress evolution, cold sintering, and two-step sintering, among other effects. These unknowns might lead one to question whether the phenomena are being interpreted within the appropriate framework.

What grain boundary processes are necessary for grain-boundary-mediated sintering and creep?

Densification and grain boundary creep require the removal and/or addition of atomic planes at the boundary. This process necessitates three fundamental components:

1. A diffusional flux of point defects to and from sinks and sources,
2. The absorption and emission of those point defects at sinks or sources, and
3. The presence of or nucleation of sinks and sources that climb in response to the flux.

Disconnections serve as the primary grain boundary sources or sinks when they have Burgers vectors lying out of the grain boundary plane. Preexisting disconnections can only mediate a limited amount of strain, which is much less than typical of sintering densification. The stresses necessary to nucleate climb-mediating disconnections should be several orders of magnitude larger than the average sintering stresses or applied stresses in which these processes become facile.

What observations motivate the need for a new model?

Recent small-scale bicrystal creep experiments revealed that the applied and sintering stresses necessary to induce grain boundary strain are quite large, consistent with predictions for disconnection nucleation. They also revealed that grain boundary strain during sintering and creep is intermittent and can induce rotation, consistent with disconnection nucleation phenomena.

A challenge has been rationalizing the discrepancies between bicrystal and polycrystalline sintering and creep, both in terms of the relative magnitudes of the required stresses and the proposed rate limiting mechanisms.

What assumptions in classical sintering models could lead to the wrong conclusions?

Classical sintering models often begin with geometric assumptions of constant volume grains. Such models predict a rapid decay in the sintering stress toward relatively small values.

When coarsening occurs, however, sintering stress can increase as some grains shrink. In the limit of no densification, a shrinking particle will de-sinter, at which point sintering stress reaches the value necessary to overcome the work of adhesion. Coarsening powders can thus access a broad range of sintering stresses between zero and the failure stress, making it possible for the boundary to sample sintering stresses large enough to nucleate disconnections that mediate densification.

A new sintering model was recently developed to account for the way coarsening can drive disconnection nucleation, which facilitates densification. This new model cannot be distinguished from the classical model by considering isothermal sintering power law exponents; however, it does make unique predictions about the temperature dependence of sintering kinetics and residual stress evolution.

Credit: Shen Dillon

In-situ sintering of alumina (bright phase) and zirconia (dark phase) particles that happened to be aligned. Note the shrinking of the neck indicated by the red arrow increases the sintering stress and precedes rigid body motion, densification, and particle rotation. Similarly, shrinkage of the alumina grain highlighted by the blue arrow, via coarsening, drives densification of the overall length of the structure.

What is missing in classical treatments of grain boundary creep?

The discrepancy between applied stress and local stress has already been considered in numerous studies in the context of creep cavitation. These treatments typically assume singularities at triple junctions, second phase particles, or grain boundary steps act as stress concentrators.

A just-published study demonstrates that applying these stress concentration models to disconnection nucleation kinetics do well predicting the stress, temperature, and grain size dependencies of creep for a broad range of systems. The nucleation rate limited sintering and creep models provide good agreement between all four sets of data, i.e., bicrystal and polycrystalline creep and sintering.

Does the model really matter?

Both the classical models and the new proposed models fit isothermal kinetic data well. Such data and their fitting have often been used to infer grain boundary properties, and using the wrong model could lead to the wrong conclusions.

In addition to fitting the experimental data well, the new models make useful predictions and provide new avenues to understand and design materials and processing. For example, the new sintering model naturally predicts that high heating rates favor densification over coarsening, which is observed in practice.

The model also predicts grain size density evolution well for a variety of starting conditions based on a small number of sintering or creep data points. This knowledge can help researchers improve their master sintering curve type approaches, which are typically developed for a single starting particle size.

The new model also predicts residual stress evolution that qualitatively differs from classical models because the nucleation process is discrete and large local stresses can be stabilized below some threshold value. The physical properties of grain boundaries should also depend on their disconnection content, providing a path toward engineering their properties.

The open-access sintering paper, published in *Acta Materialia*, is "Interface nucleation rate limited densification during sintering" (DOI: 10.1016/j.actamat.2022.118448)

The creep paper, published in *Acta Materialia*, is "A nucleation rate limited model for grain boundary creep" (DOI: 10.1016/j.actamat.2023.118718). ■

Hydrogen firing: UK's Lucideon works with ceramics industry on hydrogen-firing trials

By Andrew Norwood

Hydrogen fuels can help the energy-intensive ceramics industry drive to net zero emissions. U.K.-based Lucideon started using hydrogen fuel mixes in its test kiln.

Burning fossil fuels such as natural gas releases carbon dioxide and other greenhouse gases into the atmosphere, causing climate change. To mitigate these changes, the world will need to reach an equilibrium between greenhouse gases emitted and removed from the atmosphere, a state referred to as reaching "net zero" emissions.

The Net Zero World initiative[1] stresses the importance of transitioning to global net zero by 2050, and meeting this deadline will require countries around the world to work in partnership. Organizations such as Lucideon, a testing, characterization, and consultancy company headquartered in the U.K. and with additional sites in the United States, bring a global presence and expertise across multiple regions, which will be crucial to the collaborative effort required.

Hydrogen fuel is expected to play a significant role in achieving net zero. Hydrogen fuel is a cost effective, highly sustainable, clean source of energy, provided it is manufactured using non-polluting energy sources.

The world has witnessed a significant increase in announced and planned national hydrogen policies in the last couple of years. Countries' geographical locations factor critically in the development of national hydrogen strategies. The local availability and ease of access to hydrogen are vital for assessing potential supply. Demand will be dictated by a country's industrialization, energy needs, and dependencies. Together, these factors will dictate the potential opportunities and challenges that a country may face.

Careful study and anticipation may allow for a potential strategy that leads to success in becoming a large-scale energy exporter or importer. The legislation circulating around the world in the global push to net zero means that, while challenges are present, there can be opportunities for organizations that are able to rise to the task.

Global ambitions

The German Hydrogen National Strategy, for example, recognizes that a large portion of its hydrogen demand targets will have to be met by imports. Likewise, the Netherlands identified the potential for hydrogen imports into the Dutch and European markets as part of its hydrogen strategy. It foresees the Port of Rotterdam playing a key role in facilitating the supply of imports and distribution of hydrogen across the continent.

Chile has the most ambitious plans for embedding hydrogen in its future energy mix. It aims for 25 GW of green electrolysis by 2030 and 25 million tonnes of green hydrogen per year by 2050. Chile's National Green Hydrogen Strategy also calls for the country to become a major exporter of green hydrogen and its derivatives.

One angle of approach for using hydrogen to support existing energy networks is to transition the current natural gas network toward implementing a blend of hydrogen gas and natural gas. As hydrogen is a clean source of energy, this approach could significantly reduce greenhouse gas emissions—especially if the hydrogen is produced from renewable energy sources such as wind or solar. Table 1 details projects currently underway on the feasibility of hydrogen and natural gas blends.[2]

Proposals currently under consideration in the United States could see hydrogen blended into the existing natural gas pipeline network as a means of increasing the output of renewable energy systems, such as large wind farms. If implemented, initial concentrations would start at 5–15% of hydrogen by volume.

This strategy would go some way toward solving the issue of effectively and efficiently storing and delivering renewable energy to markets, and it appears to be viable without significantly increasing risks associated with the use of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network.[3]

More significant issues must be addressed for higher blends in the range of 15–50%, for example, conversion of household appliances or an increase in compression capacity along distribution mains serving industrial users.[4] Blends of more than 50% face more challenging issues across multiple areas, including pipeline materials, safety, and modifications required for end-use appliances or other uses.

The manufacturing capabilities and costs of hydrogen must also be considered, as there are no high-volume production facilities in place. These capabilities will inevitably take time to develop. That said, hydrogen can be deployed on a small scale immediately, and it can be produced on manufacturing sites, ideally using renewable energy. The MyKonos[5] and Iris group[6] developed such a capability by installing a 2.5-MW photovoltaic plant, an electrolyzer, and sufficient hydrogen storage.

The ceramics industry, as a large consumer of energy, will need to adapt as many countries begin to transition toward hydrogen/natural gas blends in their supply networks. Both challenges and opportunities will be presented by this change; for example, as part of the industry-wide reaction to the 2050 Net Zero initiative, the potential use of hydrogen to fuel kilns for the ceramics industry would significantly reduce CO_2 emissions. However, the industry will also need to understand the safety implications and any effects it may have on product performance, aesthetics, or other key quality considerations.

Table 1. Hydrogen blending projects currently underway[2]

No.	Project	Country	Blended Hydrogen [%]
1	HyDeploy	UK	20%
2	Fort Saskatchewan Hydrogen Blending Project	Canada	5%
3	H21	UK	100%
4	Hyblend	US	-
5	GRHYD	France	20%
6	Snam	Italy	10%
7	HyP SA	Australia	5%
8	Enbridge and Cummins	Canada	2%
9	Hy4Heat	UK	100%
10	Hydrogen injection in the gas grid	Denmark	15%
11	Cleangas Turkey	Turkey	20%
12	EN-H2 (Portugal National Hydrogen Strategy)	Portugal	15%

Prototype trials

Phases one and two of HyDeploy,[7] a U.K. program that aims to blend hydrogen in the U.K. natural gas network, have been completed successfully. The initial phase was conducted on Keele University's (Keele, U.K.) campus natural gas network from November 2019 to March 2021, where 20% hydrogen by volume was mixed with natural gas. This test led to the second phase,[8] where a larger trial was conducted between August 2022 until June 2022 using the U.K. Northern Gas Network for a larger volume. This trial supplied 668 houses, a school, several businesses, and a church and provided further evidence to support the safety of blended hydrogen in a gas network. The outcome of this work will assist the U.K. government in forming hydrogen/natural gas blending policies for the wider U.K. network.[8, 9]

Successful trials have also been conducted at Pilkington Glass (Lathom, Lancashire, U.K.) and Unilever (London, U.K.). If deployed at scale, hydrogen blending at 20% concentration could unlock 29 TWh per year of decarbonized heat, which could provide a roadmap for deeper savings. The carbon savings of a national roll-out of a 20% concentration hydrogen blend would be equivalent to removing 2.5 million cars from the road. Further details regarding these blending trials are available.[9]

For industrial applications, a series of in-depth trials will need to be completed to ensure safety at the points of production and consumer use. To this end, HyDeploy worked with Lucideon to demonstrate how 20% blended hydrogen can be used in the ceramics industry safely and to determine the performance of safety-critical ceramics when firing using a hydrogen/natural gas blend (Figure 1).[10]

The trial used Lucideon's state-of-the-art kiln (Figure 2), capable of blending up to 20% hydrogen with natural gas by volume.[10] The kiln has a temperature rating of 1,750°C and is capable of reduction firing. The kiln's burner system and flame velocity are very important, as is the adiabatic flame temperature.

Figure 1. A pipe supplying Lucideon's hydrogen kiln with a hydrogen/natural gas blend.

Credit: Lucideon

Figure 2. Lucideon's hydrogen kiln at Stone, North Staffordshire.

Credit: Lucideon

Lucideon–HyDeploy trial results

As part of the trial, a representative variety of safety-critical ceramic products were fired, including bricks; roof tiles; shaped refractories; and ceramic cores and shells used for metal alloy casting, for example, turbine blades, water purification filters, flame arrestors, and filters for metal casting. A range of standards testing was conducted and compared to existing production standards. The results showed some variation with regards to density, hot modulus of rupture, pore size, and creep, although generally the results were found to be within acceptable tolerance.

Notably, there was increased cristobalite formation with increased water vapor, volatilization of silica during sintering, increased propensity of carbon monoxide attack in reducing conditions, and reduction of iron oxides to metallic iron in reducing conditions. Firing with 20% hydrogen concentration used 86.4% of the energy for the same total volume of combustion gas, and an additional 15% total gas volume was used to match expected heat energy of natural gas. Additionally, the nitric oxide, nitrogen dioxide, and sulphur dioxide emissions were higher when firing with a 20% hydrogen blend when compared to natural gas; however, CO_2 emissions were higher during natural gas firing.

Though significant progress has been made, additional R&D is needed to address issues such as autoignition, flashback, thermoacoustics, mixing requirements, aerothermal heat transfer, materials issues, turndown/combustion dynamics, NO_x emissions, and other combustion-related phenomena. In addition, when hydrogen concentration exceeds 75%, there is a significant change in combustion behavior, requiring new combustor designs, different sensor locations, and new control schemes.

These enhancements will allow for limiting NO_x emissions to single digit (ppm) levels, improved flame detection, and monitoring for flashback and thermoacoustic instabilities. NO_x emissions control while firing hydrogen requires micromixer combustor technology, which is a refinement of today's premixed dilution technologies for low NO_x natural gas firing. Higher flame temperatures and increased water content could also reduce the lifetime of metal and ceramic parts exposed to hot gases, thereby increasing the need for new materials and thermal barrier coatings as well as improved cooling schemes.

Lucideon continues to support the ceramics industry and the journey to net zero by developing new capabilities that enable up to 100% hydrogen firing, eschewing natural gas entirely while also addressing effects it may have on kilns, products, and safety considerations during production.

An industry-wide effort

Everywhere you look, it is becoming clear across the entire ceramics industry that the challenge of adapting to a net zero world is being accepted with ambition and enthusiasm. For example, Michelmersh (Michelmersh, U.K.) has its Hybrick project to conduct a feasibility study to replace natural gas with hydrogen in the brick-making process, aiming to produce "the world's first 100% hydrogen-fired clay bricks."[11] The Italian Iris Ceramica Group, mentioned previously, is also working to adapt their processes to create a production site that, in the long term, is designed to run on 100% hydrogen, using a blend of green hydrogen with natural gas as an intermediary solution. Schott, the German speciality glass manufacturer, reported successful trials of using 35% hydrogen for industrial-scale glass production, with plans to use 100% hydrogen in future lab-scale tests.[12]

The efforts of the ceramics industry demonstrate that even energy-intensive industries may have opportunities to cut emissions. What might be considered marginal gains percentage-wise can be leveraged to achieve significant actual carbon savings, and business incentives are aligning to reward and assist the pursuit of net zero. We are confident that the entire ceramics industry will be able to take the initiative to meet the challenge ahead of us, and we are ready to help.

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Credit: Almatis

ALMATIS PREMIUM ALUMINA expands its calcined aluminas into a higher purity range

By Nils Rosenberger and Marius Schustereder

Emerging and developing technical applications require improved purity levels of specialty alumina. To address the increasing need for higher purity alumina, Almatis has focused on generating cost-effective alumina powders with alumina content purities greater than 99.9%.

Alumina is the most extensively used ceramic material.

A major reason for the success of alumina over other technical ceramic materials is its excellent material properties in combination with its lower price, which is due to the use of the Bayer process for synthesis.

For the vast majority of alumina applications, a purity range of 99.6–99.8% is sufficient to achieve the desired properties. However, some specialty applications, such as lithium-ion batteries, require higher purities to achieve the desired properties.

The demand for higher purity alumina has been increasing recently due to new emerging applications, such as 5G, as well as the advancement of existing applications, such as semiconductor processing equipment.

An increase in purity to more than 99.9% typically comes at a significantly higher cost—i.e., by an order of magnitude—caused by either more expensive feed that must be used or complex processing steps to remove impurities from the alumina. For example, purities of 99.99% or greater are typically produced by methods that use ammonium alum, aluminum metal, or aluminum salts as feed instead of the cost-effective Bayer feed from a refinery.

To address the increasing need for higher purity alumina, Almatis focused on improving the purity levels of Bayer-based materials to generate cost-effective alumina powders with alumina content purities greater than 99.9%.

In previous work,[1–3] it was reported how impurities and dopants such as Na_2O, SiO_2, CaO, and MgO affect the sintering behavior and microstructure evolution in specialty aluminas derived from the Bayer process. However, limited work has been done on how impurities in this concentration range affect properties of alumina.

For applications in semiconductor processing and 5G, the dielectric loss tangent is an important property, and it is reported that the impurity concentration in the alumina has a major impact on it.[4–6] Therefore, we investigated the dielectric loss tangent of alumina with different purity levels and impurities.

This work led to the development of a proprietary process that allows us to selectively remove impurities from a Bayer-based feedstock and reach purity levels of 99.9–99.99%.

Higher purity specialty calcined aluminas produced at Almatis

Table 1 shows the overall purity of five alumina powders and the concentration of their impurities. The five powders are chosen to cover the purity range of 99.78–99.97%. Note that MgO is typically not considered an impurity due to its use as a sintering aid. MgO was intentionally added to powders 1, 2, and 5 for this reason. The physical parameters of the five powders are shown in Table 2.

Microstructures and densities of higher purity Bayer alumina

Figure 1 shows microstructures of samples prepared from Bayer process alumina with purities of A) 99.78% (powder 1) and B) 99.97% (powder 3). The samples were prepared by freeze granulation, uniaxial pressing of freeze granulated powder at 90 MPa, and firing at 1,600°C for 1 hour.

It can be seen that the impact of the overall purity on the microstructure of the samples investigated here is small. The grain size and shape of samples with a purity level of 99.78% (A) are similar to samples with a higher purity level of 99.97% (B). After investigating a larger sample area, a higher number of facetted grains similar to the grain in the center of image (A) in Figure 1 was observed in the alumina with lower purity.

The formation of a small amount of second phases, most likely sodium aluminate, calcium aluminate, and spinel phases,[2–3,7] was observed in samples with the lower purity of 99.78%. No second phase formation was observed in the sample with a higher purity of 99.97%.

Table 1. Purity levels of five alumina powders used for dielectric measurements. Credit: Almatis

in ppm	Na_2O	Fe_2O_3	B_2O_3	SiO_2	MgO	TiO_2	CaO	Li_2O	% Al_2O_3
Powder 1	790	184	12	204	761	34	241	2	99.78
Powder 2	80	133	14	214	563	15	105	2	99.89
Powder 3	150	67	11	60	14	4	19	20	99.96
Powder 4	70	193	10	79	16	34	59	2	99.95
Powder 5	80	187	8	83	595	34	63	2	99.89

Table 2. Particle size values by laser diffraction and specific surface are measured by the BET method. Credit: Almatis

	d10 (µm)	d50 (µm)	d90 (µm)	d100 (µm)	BET (m2/g)
Powder 1	0.12	0.5	2.11	10	6.56
Powder 2	0.09	0.45	2.08	12	7.92
Powder 3	0.1	0.49	1.62	12	4.80
Powder 4	0.08	0.43	1.84	10	8.57
Powder 5	0.08	0.43	1.93	10	8.28

To determine the impact of the purity on the sintered density, 10 pellets of each powder were uniaxially pressed at 90 MPa and sintered at 1,600°C for 1 hour in an electric kiln. The samples made from the powder with a purity of 99.78% had an average density of 3.91 g/cm^3 (standard deviation = 0.01 g/cm^3), whereas the samples made from the powder with a purity of 99.97% had an average density of 3.93 g/cm^3 (standard deviation = 0.01 g/cm^3). The difference in the sintered density can be attributed to the effects of impurities on sintering mechanisms, as described in the literature.[1–3,7]

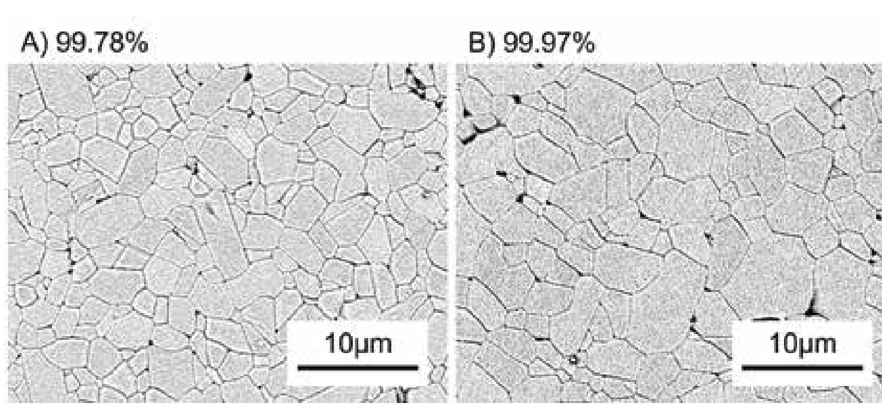
Effects of impurities on properties: Example dielectric loss tangent

Figure 2 shows the dielectric loss tangent of samples that were prepared from the five alumina powders described in Tables 1 and 2. The dielectric loss tangent was determined at 10 GHz using split-cylinder resonator measurements as described by Janezic and Baker-Jarvis.[8] We estimate the accuracy of this measurement to be about 10%.

It can be seen that the dielectric loss tangent decreases with increasing purity. The sample prepared from powder 1 (99.78% purity) has a dielectric loss tangent of 3.5 x 10^{-3}, whereas the samples prepared from powders with a purity of 99.89% or higher have dielectric loss values that are one order of magnitude lower.

However, it can also be seen that the dielectric loss tangent does not solely depend on the overall purity of the alumina. In other words, it is not the purest sample (made from powder 3) that has the lowest dielectric loss tangent. This observation indicates that the type of impurities present is more important for the dielectric loss than the total amount of impurities.

Powder 3 has the lowest overall impurity concentration and the lowest impurities for every individual impurity, except for Na_2O and Li_2O. This finding indicates that Na_2O and Li_2O have a more severe impact on the dielectric loss tangent than other impurities. Powder 1



Credit: Almatis

Figure 1. Microstructures of alumina samples with purities of A) 99.78% and B) 99.97%.

Almatis expands its calcined aluminas into a higher purity range

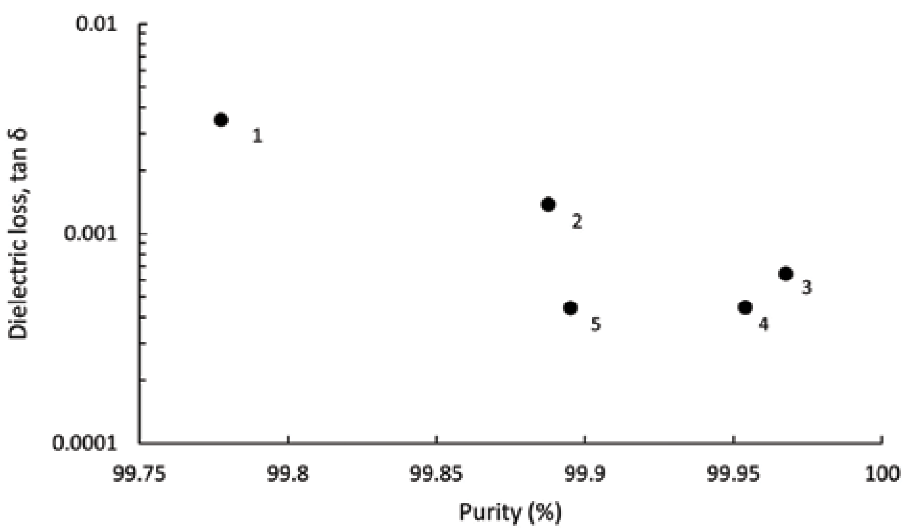


Figure 2. Loss tangent and purity of the alumina samples. The numbers indicate the powders used to prepare the samples.

has the highest Na_2O concentration with 790 ppm and also shows the highest loss tangent, which further supports the claim that Na_2O has a significant impact on the dielectric loss tangent.

It is also apparent that Na_2O and LiO_2 are not the only impurities that affect the dielectric loss. Samples from powders 1 and 2 have a higher SiO_2 and CaO concentration than samples from powders 3, 4, and 5. This finding indicates that higher SiO_2 and CaO concentrations led to higher dielectric loss tangents as well.

Powders 4 and 5 have similar impurity levels, except for the MgO concentration. Powder 5 was intentionally doped to the reported MgO level, as it is common practice for reactive aluminas due to the positive effect of MgO on the sintering behavior and microstructure development of alumina (Figure 1A). Powder 4 was not doped with MgO, and the difference in MgO concentration did not affect the dielectric loss tangent at 10 GHz for these samples. This finding contradicts the observation by Molla et al.,[4] who reported a negative effect of MgO on the dielectric loss tangent of alumina. However, further investigations are necessary to understand this discrepancy.

The data analyzed in this study shows no indication that Fe_2O_3, TiO_2, or B_2O_3 have any impact on the dielectric loss tangent at 10 GHz within the impurity ranges (see Table 1).

Summary

The data presented here suggests that Na_2O, CaO, SiO_2, and Li_2O are the main impurities that affect the dielectric loss tangent at 10 GHz. The dielectric loss tangent can be reduced from 3.5×10^{-3} to 4.4×10^{-4} by avoiding/removing the mentioned impurities.

However, more detailed investigations are necessary to fully understand the effects of single impurities and cross-effects of different impurities with each other and how they influence the dielectric loss tangent over a wider range of frequencies of alumina.

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States are vying for money to start ‘hydrogen hubs’—what are they?

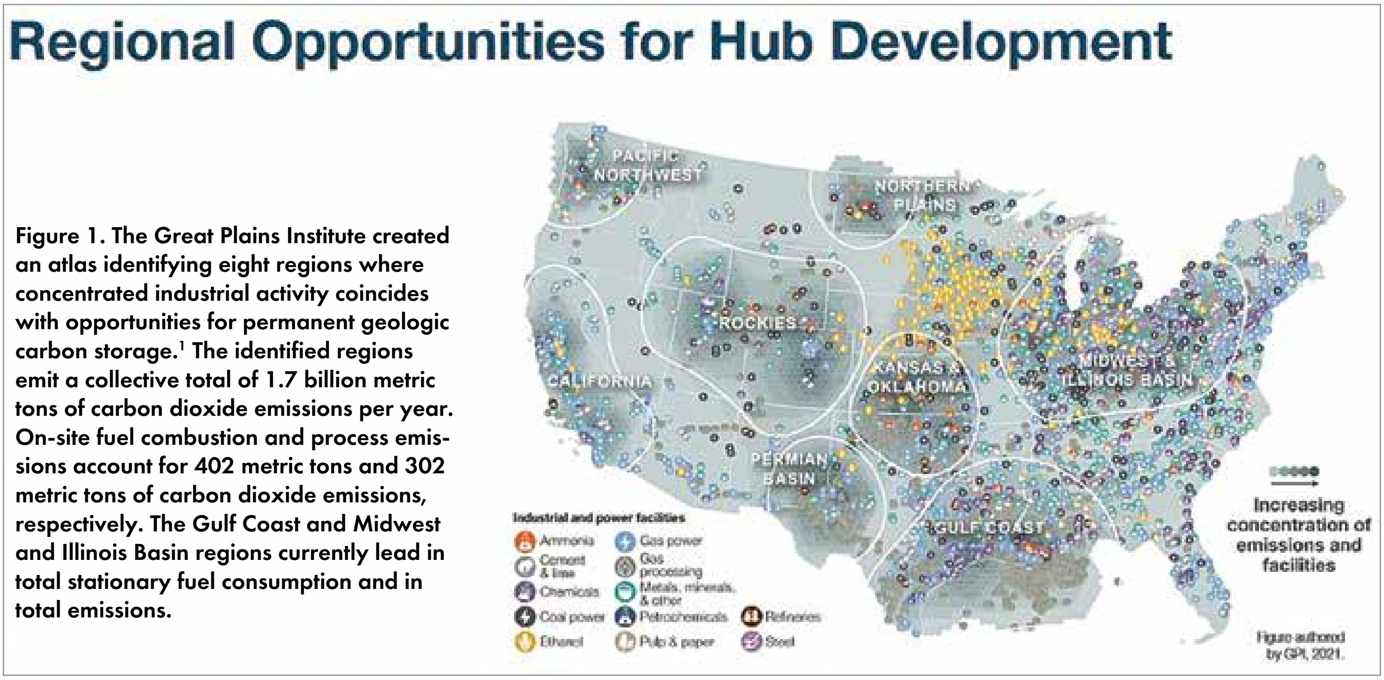


Figure 1. The Great Plains Institute created an atlas identifying eight regions where concentrated industrial activity coincides with opportunities for permanent geologic carbon storage.[1] The identified regions emit a collective total of 1.7 billion metric tons of carbon dioxide emissions per year. On-site fuel combustion and process emissions account for 402 metric tons and 302 metric tons of carbon dioxide emissions, respectively. The Gulf Coast and Midwest and Illinois Basin regions currently lead in total stationary fuel consumption and in total emissions.

By Robert Zullo

Across the United States, states are vying for federal funding to set up hydrogen infrastructure. However, how broad a role hydrogen will play in decarbonizing the U.S. economy is a matter of debate.

Across the country, states are inking agreements with neighbors or striking out on their own to pursue billions in federal funding to set up “hydrogen hubs” (Figure 1),[1] clustered centers for production, storage, and use of the gas that many see as a crucial piece of the puzzle for decarbonizing the U.S. economy.

How broad a role it should play, however, is a matter of debate.

The U.S. Department of Energy is looking to dole out $7 billion from last year’s bipartisan infrastructure law that could fund up to 10 regional clean hydrogen hubs (Figure 2),[1] defined as “a network of clean hydrogen producers, potential clean hydrogen consumers and connective infrastructure located in close proximity” to be sited across the country.[2]

“The H2Hubs will be a central driver in helping communities across the country benefit from clean energy investments, good-paying jobs and improved energy security—all while supporting President Biden’s goal of a net-zero carbon economy by 2050,” the department said in a news release in September 2022, calling the federal cash infusion one of the largest in the DOE’s history.[3]

That pool of money joins provisions in the Inflation Reduction Act—which created a clean hydrogen production tax credit[4] and enacted big changes in carbon capture tax credits[5]—that could also boost hydrogen.

"Some states are going to be motivated by climate goals. Hydrogen is an important tool for achieving those climate goals," says Bryan Willson, a professor of mechanical engineering and executive director of the Energy Institute at Colorado State University. "Others are really motivated by economic development and hydrogen represents a tremendous new business opportunity."

Willson is also the director of the Rocky Mountain Alliance for Next Generation Energy,[6] which is made up of universities and national labs from four western states that are providing technical support to the effort to create the Western Interstate Hydrogen Hub,[7] a collaboration between Colorado, New Mexico, Utah, and Wyoming, two red states and two blue ones.

Matt Fry, a senior policy manager focusing on carbon management at the nonprofit Great Plains Institute[8] and a former adviser to Republican Wyoming Gov. Matt Mead, says even conservative states have come around on the need to capture carbon and the obvious effects of a changing climate.

"We know that this is what we're going to have to do," he says. "We'll utilize hydrogen as we bridge from a more fossil-fuel-based economy to a more electrified economy."

Similar hub agreements have been made between Louisiana, Oklahoma, and Arkansas[9]; Minnesota, Montana, North Dakota, and Wisconsin[10]; and Connecticut, Massachusetts, New Jersey, and New York.[11] Minnesota and Wisconsin also have a separate memorandum of understanding with Illinois, Indiana, Kentucky, Michigan, and Ohio aimed at "accelerating and improving" clean hydrogen production.[12] And Oregon and Washington are also collaborating to create a Pacific Northwest hub.[13]

Other states, like Pennsylvania[14] and Georgia,[15] have launched efforts to create hubs on their own.

"The hubs are trying to focus on areas where you have resources to produce it, resources to use it and resources to balance that supply and demand," says Jeffery Preece, director of research and development at the Electric Power Research Institute.

"We're still working on where and how to deploy hydrogen in a decarbonized future. It's important to bring stakeholders together … to figure this out. Getting it focused in hubs helps to really find those ways where we're challenged with limitations on infrastructure today."

Why hydrogen?

There is a consensus that hydrogen, which releases no carbon emissions when burned,[16] could be a major part of addressing hard-to-decarbonize portions of the economy in which electrification is not feasible (Figure 3),[17] including shipping;[18] aviation;[19] heavy ground transportation, such as rail;[20] and industry, such as steelmaking[21] and cement. Hydrogen fuel cells can power heavy vehicles such as long-haul tractor-trailers,[22] which need greater range than batteries can currently provide, or hydrogen can be used to produce fuels compatible with existing internal combustion engines.[23]

It can also be blended—up to a certain point currently[24]—with natural gas to burn in gas turbines for electric generation. In what it called the largest test of its kind, Georgia Power reported in June that it was able to burn a 20% hydrogen blend in one of the turbines at its Plant McDonough-Atkinson natural gas power

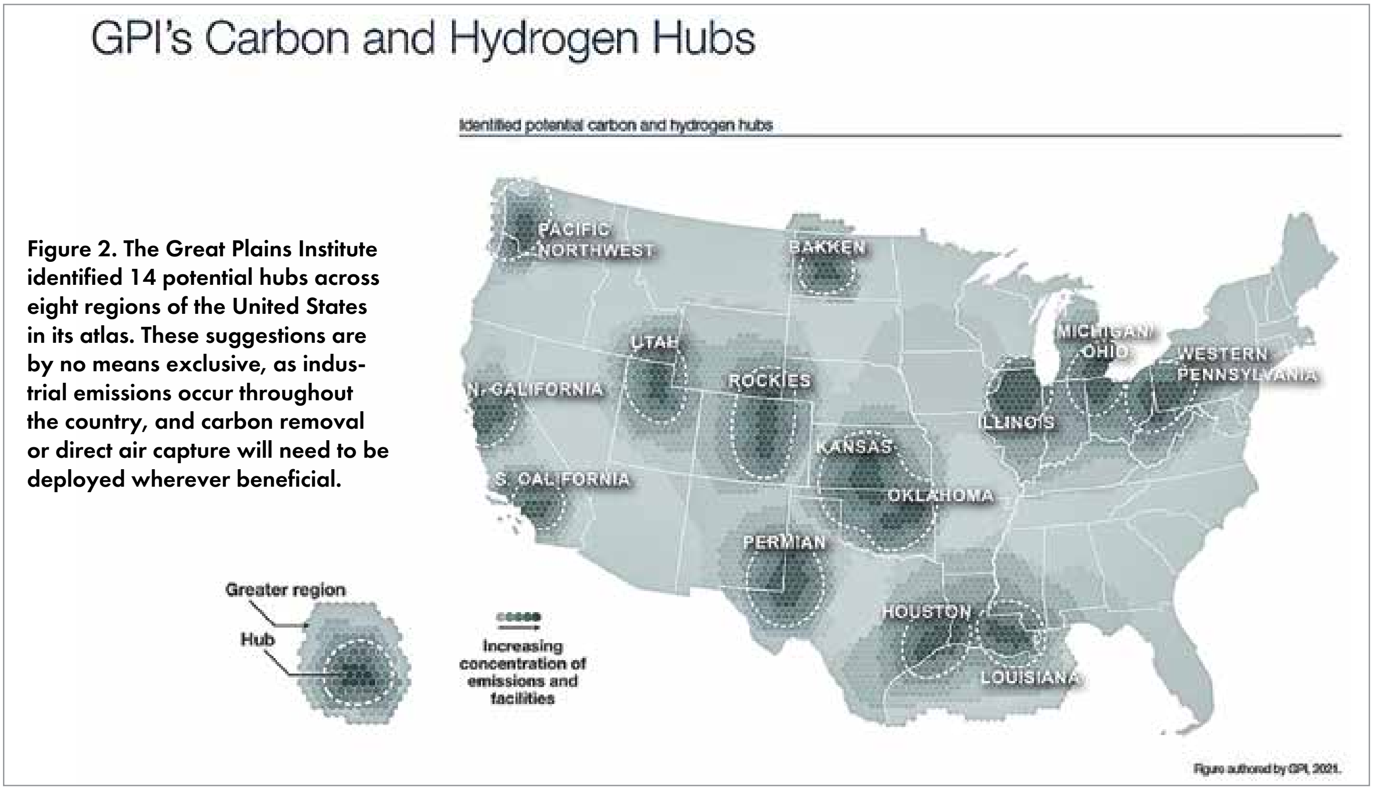
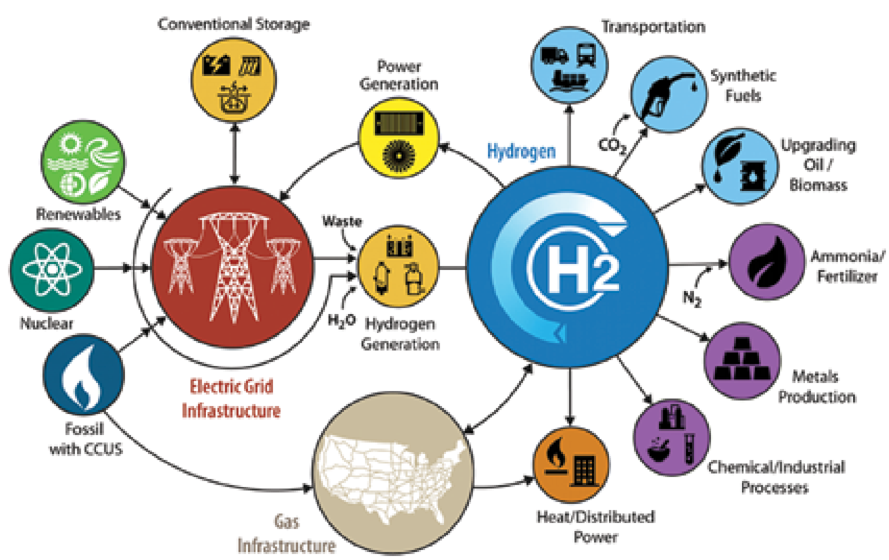


Figure 2. The Great Plains Institute identified 14 potential hubs across eight regions of the United States in its atlas. These suggestions are by no means exclusive, as industrial emissions occur throughout the country, and carbon removal or direct air capture will need to be deployed wherever beneficial.

Credit: Great Plains Institute

States are vying for money to start 'hydrogen hubs'—what are they?



Credit: U.S. Department of Energy

Figure 3. Illustration showing how clean hydrogen could help decarbonize the U.S. economy.[17]

plant outside Atlanta, achieving a 7% reduction in CO_2 emissions.[25]

"We are probably the most aggressive state in terms of decarbonization. Along with that we have increasing needs for storage and hydrogen basically gives the ability to fill in the gaps when the wind doesn't blow and the sun doesn't shine," Willson of Colorado State University says.

But how clean hydrogen is depends on how it is produced. Right now, most hydrogen in the U.S. is produced using steam-methane reforming via natural gas,[26] so-called "grey" hydrogen.[27] "Green" hydrogen is produced by an electrolysis process with clean energy. "Blue" hydrogen is fossil-fuel derived but coupled with carbon capture,[28] in which CO_2 that would normally go up a smokestack or flue is filtered out of emissions and stored underground,[29] though there are increasingly more efforts to find beneficial uses for that carbon.[30]

There is precious little green or blue hydrogen being produced at the moment, but Willson says the money for hydrogen hubs, production tax credits, and the Department of Energy's Hydrogen Shot,[31] an initiative to reduce the cost of hydrogen produced from renewable energy from the current cost of about $5 per kilogram to $1 per kilogram over the next decade, could change that.

"Right now there's no question that hydrogen from fossil resources is cheaper," he says. "But as the cost of renewables continues to drop and the cost of hydrogen continues to come down, the case for green hydrogen becomes pretty compelling."

Given that dynamic, though, environmental groups worry that pushing to use hydrogen in scenarios in which renewable power and electrification (such as for home heating[32] and appliances like stoves) make more sense could wind up prolonging the life of fossil fuels, particularly natural gas.

"In general when it comes to hydrogen we feel that there are some good opportunities there and there are also some very bad possibilities depending on how this is implemented," says Patrick Drupp, the Sierra Club's deputy legislative director for climate and clean air.

Drupp notes that the political wrangling over the infrastructure bill produced some constraints for the Department of Energy as it evaluates hydrogen hub proposals.

"Certain things were mandated in the legislation that we don't agree with," he says. "The DOE should focus on things where hydrogen has the best possible outcomes."

For example, at least one hub must demonstrate the production of hydrogen from fossil fuels (with carbon capture), one must be from nuclear, and one must be from renewable energy. They must also be located in different regions of the U.S. "and shall use energy resources that are abundant in that region, including at least two H2Hubs in regions with abundant natural gas resources," DOE documents state.[33]

Building out a large hydrogen economy, with its unique storage and transportation requirements, Drupp notes, will require expensive infrastructure such as new pipelines to handle high concentrations of hydrogen being blended into the natural gas system.

As of March 2022, natural gas and electric utilities had proposed more than two dozen pilot projects related to producing and distributing hydrogen for electric generation, heating buildings, or other uses, according to a report by Energy Innovation, Policy & Technology,[34] a nonpartisan energy and climate policy think tank. Blending hydrogen with natural gas for those purposes would do little to curb greenhouse gas emissions and might "thwart more viable decarbonization pathways while increasing consumer costs, exacerbating air pollution and imposing safety risks," the report warns.

"There's a lot of money out there," Drupp says. "The gas industry sees the writing on the wall and sees this as an opportunity to prolong their industry."

About the author

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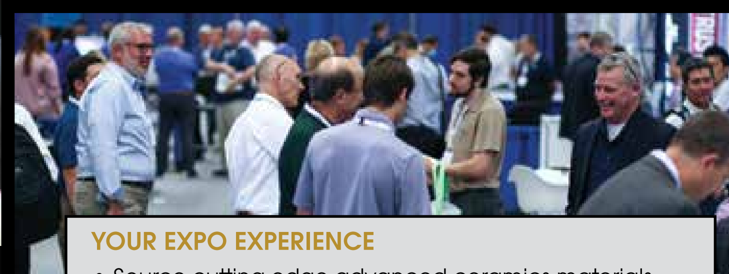

The free pass also provides access to an unmissable two-day conference program. The key focus is on the latest advancements and innovations in materials and technology, where 30+ speakers will address the unique and most pressing challenges in the industry. Sessions will be delivered by technical experts from industry leaders including Bruker AXS, Sierra Space, Kyocera, General Electric Aviation, and Lockheed Martin.

Do not forget, included in the free pass is entry to the co-located Thermal Management Expo, which is now heading into its second year! This co-located exhibition and conference provides thermal management professionals with the chance to solve the unique challenges faced by high-tech applications and stakeholders up and down the supply chain. ■

YOUR EXPO EXPERIENCE

- Source cutting-edge advanced ceramics materials and technologies from 275+ leading suppliers & manufacturers.
- Understand the latest industry developments from 30+ expert speakers and game-changers.
- Gain a 360° view of the ceramic materials market.
- High-level conference program spanning two days.
- Locate new solutions to technology development and implementation, cost reduction, and scaling-up of manufacturing processes.
- Evaluate the use cases of the latest products and services thanks to the live demos and showcases.
- Network with your peers from across the advanced ceramics value chain, from manufacturers and suppliers to major end-users in the aerospace, automotive, energy, medical, and electronics sectors.

CERAMICS EXPO CONFERENCE AGENDA*

Gain insight and expertise into the current trends and challenges facing the advanced ceramics industry through a series of panel sessions.

Day 1 – Tuesday, May 2

Keynote Presentation

The Current Market Landscape for Ceramics and Charting a Path Forward

Ceramics in Critical Environments

Advanced Ceramic Manufacturing Methods: Producing Complex Ceramic Shapes through Ever-evolving, Automated Production Processes

Ceramic Powder Processing and Forming Methods: Engineering Microstructure Control in High Performance Ceramics

Day 2 – Wednesday, May 3

Evaluating New Advancements and Innovations in Ceramic Materials

Ceramic Additive Manufacturing: Latest Advancements in Applications and Materials

Overcoming Raw Materials & Quality Control Challenges in a Dynamic Global Landscape with an Increasing Focus on Sustainability

Mechanical Properties and Failure Analysis of Ceramic and Glass Material

*Correct at time of publishing. Visit ceramicsexpousa.com for live information.

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Contact **Marcus Fish** at mfish@ceramics.org or 614-794-5863 to learn more.

UPCOMING DATES

HOTEL MONTELEONE, NEW ORLEANS, LA.

ACerS Glass & Optical Materials Division will hold its annual meeting and conference in New Orleans, La., from June 4–8, 2023.

HYATT REGENCY BELLEVUE, BELLEVUE, WASH.

If your research seeks sustainable energy solutions on a global scale, you should attend this conference.

GREATER COLUMBUS CONVENTION CENTER, COLUMBUS, OHIO

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

GREATER COLUMBUS CONVENTION CENTER, COLUMBUS, OHIO

The Conference on Glass Problems is organized by the Glass Manufacturing Industry Council and Alfred University. It is endorsed by The American Ceramic Society. *Glass Worldwide* is the official journal.

Calendar of events

March 2023

28–30 58th Annual St. Louis Section/ Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo.; https://ceramics.org/event/58th-annual-st-louis-section-refractory-ceramics-division-symposium-on-refractories

28–30 IMFORMED Mineral Recycling Forum 2023 – Dubrovnik, Croatia; http://imformed.com/get-imformed/forums/mineral-recycling-forum-2023

May 2023

1–3 8th Ceramics Expo co-located with Thermal Technologies Expo – Suburban Collection Showplace, Novi, Mich.; https://www.ceramicsexpousa.com

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

30–June 1 MagForum 2023 – Grand Hotel Dino, Baveno, Lake Maggiore, Italy; http://imformed.com/get-imformed/forums/magforum-2023

June 2023

4–8 ACerS Glass & Optical Materials Division Annual Meeting (GOMD 2023) – Hotel Monteleone, New Orleans, La.; https://ceramics.org/gomd2023

5–8 ACerS 2023 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Austin Hotel Downtown, Austin, Texas; https://ceramics.org/clay2023

14–16 13th Advances in Cement-Based Materials – Columbia University, New York, N.Y.; https://ceramics.org/cements2023

July 2023

2–6 XVIIIth Conference of the European Ceramic Society (ECerS) – Lyon, France; https://www.ecers2023.org

August 2023

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

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

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

September 2023

12–15 China Refractory Minerals Forum 2023 – InterContinental, Dalian, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2023

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

October 2023

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

November 2023

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

January 2024

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

February 2024

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

July 2024

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

Dates in **RED** denote new event in this issue.

Entries in **BLUE** denote ACerS events.

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

Ceramic & Glass MANUFACTURING

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www.ceramics.org/ceramicandglassmanufacturing

MANAGING THE GREAT RESIGNATION, BABY BOOMER RETIREMENTS, AND TODAY'S LABOR MARKET

TWO UNIVERSITIES EXPAND CERAMIC ENGINEERING PROGRAMS

HOW TO FIND, KEEP, AND DEVELOP TECH TALENT

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Ceramic & Glass MANUFACTURING

Vol. 4, Iss. 1

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INDUSTRY NEWS

KYOCERA PLANS RECORD INVESTMENTS IN JAPAN

Kyocera Corp. plans to build a manufacturing plant in Isahaya City, Japan, and plans to acquire about 37 acres in the Minami Isahaya Industrial Park there. The company says its capital investment in Japan is expected to reach a record high in the current fiscal year, mainly due to strong demand for components related to advanced semiconductors. Kyocera is planning even higher levels of investment in fiscal year 2024 and beyond, in addition to increasing production capacity in both Japan and internationally.

Kyocera says its existing campuses have little or no room to expand.

Shinagawa plans to strengthen its nonrefractories business globally.

SHINAGAWA ACQUIRES SAINT-GOBAIN BUSINESS UNITS

Shinagawa Refractories Co., Ltd. completed the acquisition of Saint-Gobain's Brazilian refractories business and its alumina-based, wear-resistant ceramics business in the United States. Shinagawa has supplied technology for Saint-Gobain's manufacture of iron and steel refractory products in Brazil since 1991. The acquisition of the wear-resistant ceramics business represents a new non-refractories product offering for Shinagawa in the U.S.

NGK ADDS SOLAR POWER TO MANUFACTURING PLANTS

NGK Insulators, Ltd. will install photovoltaic equipment with a total capacity of 40 MW at its manufacturing sites in Japan, Poland, Thailand, and elsewhere by fiscal year 2025. The renewable energy plan will cut its annual carbon dioxide emissions by 22,000 tons, the company says. NGK plans to achieve net zero CO_2 emissions by 2050. The group is also developing technology for manufacturing ceramics using clean energy sources that do not emit CO_2, such as hydrogen and ammonia.

NGK produces ceramic products for the automotive, energy, telecommunications, and other industries.

AMI's new innovation center in Houston, Texas.

NEW R&D CENTER OPENED BY AMI

Active Minerals International opened a state-of-the-art research and development innovation center in Houston, Texas. AMI produces air float kaolin and gellant attapulgite, and the company says the new center will lead technical innovations in products, processes, and application developments. Research includes particle morphology study, mineral phase analysis, particle size measurement, and rheology study. The center will be run under the direction of AMI vice president of research and development Bo Wang.

RHI MAGNESITA ACQUIRES REFRACTORY PRODUCER IN CHINA

RHI Magnesita acquired a majority share of Jinan New Emei Industries Co., Ltd., a leading producer of refractories in China. Jinan New Emei produces refractory slide gate plates and systems, nozzles, and mixes for use in steel flow control. It employs more than 1,300 people and is headquartered in Shandong province. RHI Magnesita says it expects to realize substantial synergies from the combination of Jinan New Emei with its existing refractory business in China.

The acquisition will allow RHI Magnesita to increase the supply of refractories in both China and the wider East Asia region. *Photo: RHI Magnesita*

The EU plans to install more than 320 GW of new solar photovoltaic capacity by 2025. *Photo: Guillaume Périgois on Unsplash*

EU FORMS SOLAR MANUFACTURING ALLIANCE

The European Commission launched the European Solar PV Industry Alliance to secure diversification of supplies through more diverse imports and scale up solar photovoltaic manufacturing in the European Union. The Commission says the alliance is an essential component of the REPowerEU plan, which aims to scale up and speed the production of renewable energy in Europe to gain independence from Russian fossil fuels, and make the EU's energy system more resilient.

SCHOTT OPENS US FACILITY FOR LIFE SCIENCES PRODUCTS

Schott opened its first facility in the U.S. to increase capacity to develop and manufacture diagnostics and life sciences products. The multimillion-dollar investment in a 40,000-square-foot facility in Phoenix, Ariz., will focus on production of custom DNA and protein biosensors and other microarrays on glass, semiconductors, and polymer microfluidic consumable devices. The expansion will create 150 new jobs over the next few years.

Phoenix mayor Kate Gallego, center, and Schott senior executives celebrate the opening of the Phoenix facility. *Photo: Schott*

Pittsburgh-based HWI is the largest refractory products and services supplier in North America.

PRIVATE INVESTMENT FIRM ACQUIRES HWI

HarbisonWalker International (HWI), a provider of refractory products and services, announced that it agreed to be acquired by investment firm Platinum Equity. Financial terms were not disclosed. In 2022, Platinum Equity acquired Imerys S.A.'s high-temperature solutions (HTS) business, a provider of refractory solutions serving more than 6,000 customers in Europe and Asia. Platinum Equity says it plans to combine HWI and HTS into a global business. Founded in 1995 by Tom Gores, Platinum Equity has approximately $36 billion of assets under management and a portfolio of approximately 50 operating companies.

MANAGING THE GREAT RESIGNATION, BABY BOOMER RETIREMENTS, AND TODAY'S LABOR MARKET

By David Holthaus

Spurred on in part by the pandemic, more than 47 million people quit their jobs in 2021, a mass exodus from the workforce that has become known as The Great Resignation. The unprecedented movement exacerbated an already severe labor shortage that employers have been coping with for years.

The post-pandemic exodus was not merely a one-time phenomenon but was the continuation of a long-term trend. For a decade, each year from 2009 to 2019, the percentage of people leaving the workforce increased, according to the Bureau of Labor Statistics. That number declined in 2020, as the uncertainties surrounding the pandemic caused workers to hang on to their jobs and paychecks. But it returned in a big way in 2021, as people reevaluated their lives, their work, and their purpose.

With post-pandemic U.S. unemployment already well below the traditional "full employment" threshold since December 2021, and at low levels not seen in decades, employers have turned to new strategies to not only find workers but to keep them.

CoorsTek is a global manufacturer of engineered ceramics, with more than 6,000 employees at more than 30 facilities across three continents. Maintaining a pipeline of well-trained talent is critical to its ongoing success, and the company has developed connections with engineering and technical schools so it can provide feedback on industry needs and help develop curricula to train the future workforce of advanced manufacturing, says Emily Lundi-Mallett, CoorsTek's vice president of talent management.

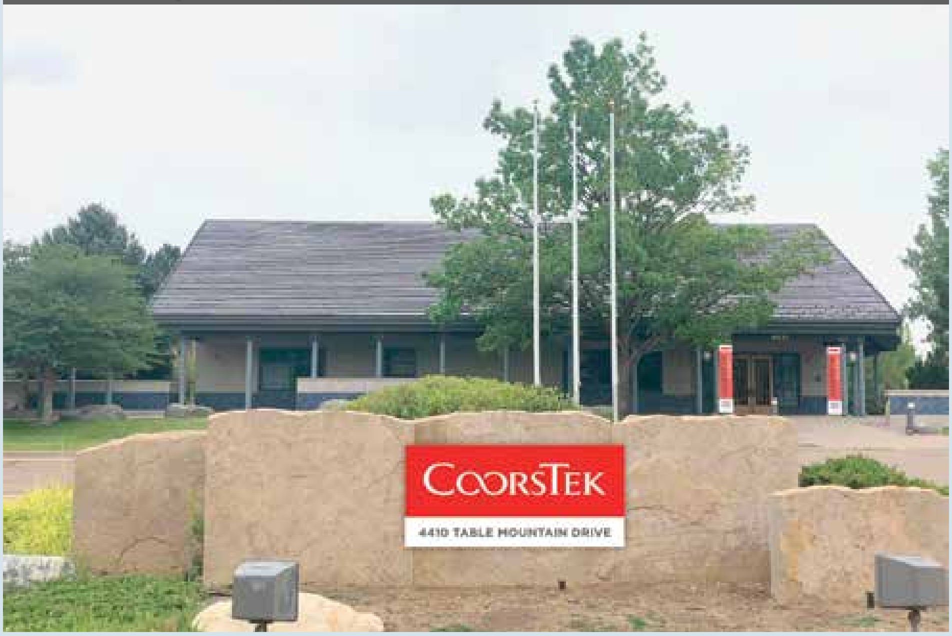
A teaching session in progress at CoorsTek Academy. *Credit: CoorsTek*

The company is working with a career and technical education center in Benton, Ark., for example, on developing ceramic materials courses. CoorsTek operates a manufacturing facility there that has been expanded in recent years.

The company will be closely involved in the development and implementation of the courses.

"We'll bring the ceramics piece to it," Lundi-Mallett says. "We can start to ignite and spark some interest in their students."

CoorsTek Academy in Golden, Colo. *Credit: CoorsTek*



The Golden, Colo.-based company has a longstanding relationship with Colorado School of Mines in Golden, a partnership that has included funding the CoorsTek Center for Applied Science and Engineering, a 95,000-square-foot facility that supports a range of academic and research activities on the Mines campus. The company is also partnering with other engineering-centric schools across the country, including Alfred University in New York and Kettering University in Flint, Mich.

"Part of our reach outward is to make sure we have those schools tapped, we have relationships built, we're partnering with them with education and providing internships and entry into CoorsTek," she says.

Finding and hiring qualified talent is just part of the workforce puzzle today. Keeping them is the other part. To help foster long-term employee engagement, CoorsTek started CoorsTek Academy, a two-week, immersive onboarding experience for new employees. In the first week, new hires learn about the company, its history, its culture, its markets, and hear from different representatives across the company's disciplines and functions. In the second week, new employees begin to get introduced to their roles, learning through job shadowing, mentoring, and training.

Technical trainers help with skills assessments and instruction so new employees can start their jobs feeling ready and supported. The Academy experience also serves to improve productivity.

"We give them a deep understanding of what will be expected of them," Lundi-Mallett says. "When they start on the job, they hit the ground running. It helps accelerate their productivity."

Last year was the first full year of implementation for the Academy, and all new employees now take part in the process. The reception has been very good, Lundi-Mallett says, as new employees feel engaged and welcomed.

"They are a little bit blown away," she says. "They love that we are investing that much time in them."

She adds, "It sets them up for success because in the second week they get to actually experience and see what it's going to be like when they're standing in front of the machine or working inside of a plant."

The company also helps employees envision a future for themselves, as it conducts skills assessments and helps develop career opportunities within the company.

"We want to build our technical acumen internally so people can see the multiple career paths they have within CoorsTek," Lundi-Mallett says.

At Corning Inc., the New York-based glass and ceramics technology company that employs more than 60,000 people, tapping into next-generation talent is critical. The company has a well-established, competitive internship program that expands its access to science and engineering students.

The company receives thousands of applications each year for 300 internships in the U.S. On average, science and engineering internships account for 75% to 80% of Corning's total summer intern hires in the U.S., the company says. The company also offers similar internship opportunities globally.

Students are assigned to projects that align with their coursework, help solve some of the company's challenges, and provide experiences they can apply in future careers. Students are also assigned to a manager and paired with a mentor who is available to help guide the student and frame the deliverables for each summer project. At


Stevanato Group is expanding production of its EZ Fill vials and syringes in Italy, China, and the U.S. *Credit: Stevanato Group*

the end of the summer, students present their project, key findings, and lessons learned during a poster session for Corning's Technology Community.

Typically, approximately a third of interns in the U.S. transition to full-time positions after graduation, Corning says. If the student is a rising junior or decides to move into a graduate or doctorate program, Corning will often invite students back for a second, or possibly a third internship.

The program is one of the largest sources for identifying early-stage talent for Corning's technology community.

Finding and keeping talent is also essential to the growth of Stevanato Group, a leading global provider of drug containment, drug delivery, and diagnostic solutions to the pharmaceutical, biotechnology, and life sciences industries. The company employs more than 5,000 people globally and is rapidly expanding, with new manufacturing facilities now under way in Latina, Italy; Zhangjiagang, China; and Fishers, Ind.

So far, the company has navigated the talent marketplace partly by being competitive with compensation, but that is not its only approach, says Riccardo Butta, president of Stevanato's Americas division.

"We are not trying to steal people from other companies simply over pay; that's not a good practice," he says.

Rather, the company fosters long-term engagement with its employees, partly through training.

"We want to add stability to the organization," Butta says. "It's knowledge that you want to retain. We want to invest in the long term."

The company also promotes its culture and history as a firm started by the Stevanato family in the 1940s and now traded on the New York Stock Exchange.

"We talk about and live our values and guiding principles," Butta says. "That helps people to engage and see the value of the company and create the environment that you need to have if you want to retain people over time."

The company is also very conscious of promoting diversity in its hiring, he says, as a diverse management and workforce improves competitiveness.

"Not only gender and race, but also cultural diversity," he says.

Colleagues from the company's operations in Mexico, Brazil, and China rotate into positions at the home office in Italy, and have been added to the core team that is beginning to staff the new plant in Indiana.

"It's something that will create value for the company in the long run," Butta says.

Two universities expand ceramic engineering programs

By David Holthaus

How times have changed.

A few decades ago, 14 U.S. colleges offered undergraduate degrees in ceramic engineering. That's now down to two.

Beginning this year, make it three.

The Colorado School of Mines this fall will formally launch a bachelor of science degree program in ceramic engineering, helping to fill a growing demand.

Brian Gorman

"There's a huge need for ceramic engineers, and demand is significantly outpacing supply," says Brian Gorman, professor of metallurgical and materials engineering at Mines.

Additionally, at South Dakota School of Mines, a minor in ceramic engineering was added to that school's curriculum last fall semester.

"We were looking at some of the roles that our students were getting into, and we saw that there was a knowledge gap in those materials," says Michael West, head of the materials and metallurgical engineering department at South Dakota.

The coursework could develop into a ceramic engineering major in the future, he says.

The additions at the two schools are in response to feedback from industry.

"We actually brought some of our industrial partners to campus and asked them, 'What do you need from our graduates? What skills do you want them to have?'" Gorman says. "And so we built the program around those interactions."

Those partners include CoorsTek Inc., one of the largest manufacturers of technical ceramics, which is headquartered just a few blocks away from the school in Golden, Colo., and Johns Manville, the Denver-based maker of insulation and other industrial materials.

The ceramic engineering program at Colorado will build on the university's expertise in materials science and engineering, as well as make use of its ceramics research facilities, including an on-campus glass hot shop. Students will be prepared to work in industries including semiconductors and electronics, defense, renewable and traditional energy, household goods, automotive, aerospace, and more.

South Dakota has good relationships with companies in the steel industry, and other sectors that have a demand for specialties in refractory science, West says. After attending trade shows, including Ceramics Expo and the annual Materials Science & Technology exhibition, West and his colleagues came away with a better understanding of industry needs, he says.

Colorado Mines actually had a "soft kickoff" of its new program in the 2023 winter semester, as 10 juniors majoring in metallurgy switched to ceramic engineering and will graduate with that degree in 2024. The first full class of ceramic engineering majors will start in the fall.

The undergraduate students will receive hands-on training in ceramic processing; sintering; glass science; and thermal, mechanical, and electrical properties, Gorman says. Four core laboratory classes starting in the students' second year will provide hands-on experience with the materials, and students will also have access to undergraduate research opportunities and makerspaces.

Students at Colorado School of Mines will have access to research opportunities and makerspaces, including Mines' on-campus glass hot shop. *Credit: Colorado School of Mines*

The graduates from these programs are sure to be welcome in industries that have a need for such specialty talent in engineering.

"That's our number-one goal as educators, to put out a well-educated, capable workforce," Gorman says.

HOW TO FIND, KEEP, AND DEVELOP TECH TALENT

By Sven Blumberg, Ranja Reda Kuba, Suman Thareja, and Anna Wiesinger

The full version of this McKinsey article was originally published on McKinsey.com on April 14, 2022. It can be found at mckinsey.com/capabilities/mckinsey-digital. Republished with permission.

Editor's note: While this article focuses on coders, developers, and engineers in the tech industry, we felt the information translates equally to other industries reliant on technical talent to drive innovation, such as the ceramic and glass industry.

The Great Attrition is being felt in many companies as tech talent streams out the door to pursue better opportunities. Being able to work remotely has made it even easier for people to leave because geography is less of a barrier to poaching talent.

For many companies, these moves come with a big warning: there is a massive push happening to grab talent, and you may be missing out.

These seismic shifts come at a time when the shortfall for tech talent is already acute. Our analysis shows that significant skill gaps exist in seven areas, and we expect them to become more severe over time.

Business leaders are feeling the heat. According to a McKinsey survey of more than 1,500 senior executives globally, some 87% say their companies are not adequately prepared to address the skill gap. And according to another McKinsey survey, 61% of HR professionals believe hiring developers will be their biggest challenge in the years ahead.

Despite the formidable challenges in finding tech talent, incumbent companies cannot expect to succeed in the digital world without being technologically strong, which is simply not possible without a deep bench of tech talent. In fact, developing robust people and talent strategies are among the highest-value actions a business can take. Tech talent, therefore, should be a CEO's top priority.

Based on our work on more than 80 technology-talent transformations, we have identified a set of 10 realities companies need to face and what they can do to address them.

YOU CAN'T BE GOOD AT JUST ONE ASPECT OF TALENT MANAGEMENT AND EXPECT TO SUCCEED

Fulfilling your tech-talent needs is increasingly a multifaceted contest. Finding great talent does not help if the talent does not want to work for you, and hiring great talent does not matter if the talent leaves quickly. Companies have to invest simultaneously across the entire "hire-to-retire" life cycle.

That starts with developing a digital-talent engine, a focused team dedicated to managing the entire employee experience, from hiring and onboarding to creating new career paths and continuously building skills.

The key activities of this more holistic approach to talent can be broken down into three areas.

- **Workforce.** Develop a clear and surgical understanding of your talent gaps, a practical plan to fill them, and a hiring approach centered on candidate experience.
- **Work model.** Put in place a work model that enables small teams of engineers to work on the most interesting problems unfettered by layers of management.
- **Workplace.** Create a work environment that nurtures talent through diversity and a supportive culture, which is especially important within the context of hybrid and remote models.

This environment includes providing different career paths that help talent develop their most valued asset: their skills.

WORKFORCE

Close your talent gap—it's wider than you think

The most effective talent strategies are grounded in a clear view of what capabilities the business needs to generate value compared with those it already has, especially in the area of cloud talent. While 58% of organizations analyze their skill gaps, our experience shows that companies typically underestimate their size. That is often because companies' talent analysis stops at the role level rather than probing what skills their people actually have.

Workforce planning also needs to happen much more frequently than the typical once or twice a year to keep pace with changing demands and shifts in the makeup of the organization.

Think candidate experiences, not recruiting process

To improve recruiting, HR departments and hiring managers tend to focus on improving their recruiting processes and introducing efficiencies. A more effective approach is to "think like a recruit" and focus on the candidate experience. That includes improving the virtual candidate experience because 70% of companies in a recent survey said their recruiting and onboarding was at least half virtual. Ways of doing that include the following.

- Tech talent wants to meet other technologists, so make sure that engineers and other relevant roles are part of your interview team. Bring your best people to interviews, online events, and conferences.
- Good candidates are ambitious and have many options. Develop an interview and evaluation approach that can lead to a decision in as little as one day. Before candidates even come through the door, assess their skills with tools such as HackerRank.
- Post and pray is not a strategy. Tech talent is not just going to job sites, so be active in nontraditional channels, such as hackathons, open-source channels, and specific curated sites for different skills. For some companies, GitHub is their best recruiting channel.
- Top talent is eager to get going, so when new hires show up to start work, make sure there is an onboarding point of contact to help them navigate the company. The onboarding process should be streamlined so that, by the end of week one, developers are able to commit code.

Top talent is interviewing you, not the other way around

Why would tech rock stars want to work for you? While money is important, top candidates care about working with newer technologies, building up their skills, being part of a culture that values technology, connecting with a purpose they find meaningful, and, most importantly, working on interesting and inspiring problems.

You can't hire or outsource your way out of your talent problems

The problem with relying on hiring is that often there is a significant lag time before someone becomes productive as well as there being a general shortfall of qualified talent. Similarly, core capabilities need to remain in house to enable the business to move quickly, so outsourcing cannot be the main answer either. The reality is that much of the talent you need will have to come from within the organization. Your workforce planning should identify the appropriate balance between building skills internally, hiring externally, and outsourcing. To build up skills internally, top companies move past traditional and subscale programs to make training both continuous (through ongoing learning journeys) and tailored (with learning programs created for specific roles and job families.

WORK MODEL

Build small, empowered teams with a clear mission, and let them execute

An expert developer is more than 10 times more productive than a novice. But many of these top engineers cannot work in traditional organizations where a surfeit of managers and bureaucratic process-

es inhibit them from doing good work at pace. In many organizations, the ratio of engineers to management and coordination and support people is 30:70; that needs to be flipped.

Tech leaders reshape their IT organizations around small squads to create highly motivated, self-managing, agile teams. Instead of managing the team day to day or simply telling them what to do, successful leaders focus on clearing organizational roadblocks, enabling team-level decision making, and setting vision and direction.

Eliminate meaningless toil and bad practices—top talent won't put up with it

You cannot hire virtuoso jazz pianists and have them just practice scales all day. In the same way, top tech talent needs a work environment where they can fully practice their craft. Leading organizations focus on eliminating as many barriers as possible for their top coders. They invest, for example, in developing high-quality, reusable code and provide world-class planning and development tools to make engineers' work lives easier. They strive to make more than 80% of testing automated and continuous—with development done only after test cases are written.

WORKPLACE

Focus on developer happiness, and productivity and performance will follow

Retaining top talent requires an environment where developers are treated like innovators, not code writers, and are active participants in the business. McKinsey's Organizational Health Index research, however, has shown that IT functions overall score well below the average in terms of organizational "health" (the ability to align around and execute strategic goals).

Business leaders can reverse this situation by making the quality of the developer experience a primary metric of success and using data to closely track job satisfaction.

Growth is also essential in building an engineering culture, and it can take many forms. Top engineers do not want to just bang out features; they want to experiment with new code, become better developers, and follow passion projects, such as reducing tech debt or optimizing systems.

Stop turning great engineers into bad managers

Do not expect your engineers to aspire to become people managers. More than two-thirds of developers, in fact, don't want to. These experts instead prefer to keep their craft sharp and pursue ever more sophisticated digital challenges.

For this reason, digital organizations often have both managerial and nonmanagerial career paths for tech talent. Leading companies use lateral career moves to promote career growth and exciting career options.

Diversity, equity, and inclusion (DEI) are strategic necessities, not special initiatives

Gender-diverse companies are 25% more likely to financially outperform less diverse companies, while ethnically diverse companies are 36% more likely to do so. By the same token, technology talent expects a diverse work environment. We have found, in fact, that prized digital talent will often refuse a job offer or even refuse to apply to companies it perceives as noninclusive. One-third of recruiters say applicants are inquiring about DEI. It is worth asking: Does your leadership team reflect sufficient diversity?

It is virtually impossible to imagine a business today succeeding without a strong base of tech talent. Only by accepting that overriding reality and making an all-out push to acquire the right tech talent can companies expect to capture the value that digital promises.

Sven Blumberg is a senior partner in McKinsey's Istanbul (Türkiye) office, Ranja Reda Kouba is an associate partner in the Vienna (Italy) office, Suman Thareja is a partner in the New Jersey office, and Anna Wiesinger is a partner in the Düsseldorf (Germany) office.

FEMTOSECOND LASER BURSTS DRILL CRACK-FREE HOLES IN GLASS

By Lisa McDonald

Femtosecond lasers have led to great advances in micromachining capabilities.

Recently, a modification of femtosecond micromachining called "burst mode" is attracting much attention. Rather than releasing single pulses at a fixed repetition rate, burst-mode lasers will emit bursts (or groups) of pulses at a fixed repetition rate. Compared to single pulses, the energy of each individual pulse within a burst is smaller. Thus, the peak fluence of each pulse (i.e., energy delivered per unit) can be nearer the optimum value, thereby increasing the removal rate.

So far, most burst-mode laser studies have involved metals and silicon. However, in April and December 2022, researchers from the University of Bordeaux and laser equipment supplier Amplitude Systems (Pessac, France) published two open-access papers exploring the use of femtosecond laser GHz-bursts to conduct top-down percussion drilling in glass.

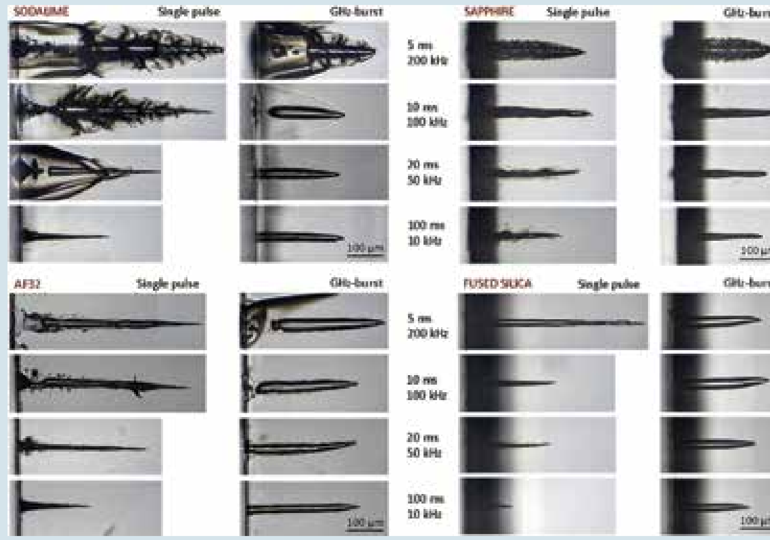


Figure 1. Microscope images of drilled holes for four different repetition rates (10 kHz, 50 kHz, 100 kHz, and 200 kHz) in four different materials (sodalime, sapphire, alkali-free alumina-borosilicate [AF32], and fused silica). The images on the left side correspond to single pulse drilling and on the right side to GHz-burst drilling with 50 pulses at an intraburst repetition rate of 1 GHz. The drilling time corresponds to 1,000 single pulses (fluence of 289 J/cm^2 per pulse) or 1,000 GHz-bursts (fluence of 300 J/cm^2 per burst), respectively. *Credit: Lopez et al.,* Optics Express *(CC BY 4.0)*

In the first paper, the researchers investigated the interaction dynamics of a GHz-burst mode femtosecond laser beam with different types of glasses during the drilling process (Figure 1). They found that single-pulse and GHz-burst percussion drilling removed material in fundamentally different ways, leading to substantially different hole morphologies. In single-pulse drilling, matter was continuously ejected, leading to conical holes with a rough internal surface. In contrast, GHz-burst mode ejected matter in a discontinuous way, resulting in quasi-cylindrical holes with a smooth internal surface.

In the second paper, the researchers further explored using a GHz-burst femtosecond laser to perform top-down percussion drilling in sodalime and fused silica glass. Analysis of the drilling process in sodalime and fused silica glass revealed three stages in hole formation.

1. **The first stage** corresponds to surface ablation. The ablation plume can expand freely in the ambient air above the target, and the drilling rate is high.
2. **The second stage** corresponds to deep ablation. The ablation plume is confined by the inner walls, leading to a decrease in ablation efficiency and a lower drilling rate (0.70 µm/burst for surface ablation versus 0.15 µm/burst for deep ablation).
3. In **the third stage**, the drilling process is over as the fluence value at the hole bottom is below the ablation threshold.

Similarly to hole length, the burst fluence and number of bursts influenced the size of the hole's diameter. When drilling begins, the diameter increases rapidly with increasing burst number. Later, it reaches a saturation value that increases with the burst fluence.

Interestingly, the effect of fluence on inner hole surface quality differed for sodalime and fused silica glass. While increasing fluence decreased the quality of the sodalime's inner hole surface, neither fluence nor burst number affected the quality of the fused silica's inner hole surface.

This difference in fluence's effect on surface quality helped explain why the researchers measured similar hole lengths in sodalime and fused silica glass even though fused silica has a higher ablation threshold, as explained below.

"The difference of the inner surface quality induces different scattering losses of the beam during the drilling process in these two materials," the researchers write. "The glossy surface of fused silica allows for low-loss reflections and therefore a more efficient beam transmission towards the tip of the hole increasing its depth. This results in a compensation for the larger energy amount needed for drilling due to the higher ablation threshold of this material. This is the reason why we measure similar lengths in sodalime and in fused silica."

Based on this knowledge, the researchers optimized the drilling conditions and reached aspect ratios up to 37 in sodalime and 73 in fused silica.

"These impressive results of percussion drilling in femtosecond laser GHz-burst mode allowing for extreme hole geometries may pave the way for future applications in photonics devices or microelectronics," they conclude.

The first open-access paper, published in *Optics Express*, is "Percussion drilling in glasses and process dynamics with femtosecond laser GHz-bursts" (DOI: 10.1364/OE.455553).

The second open-access paper, published in *International Journal of Extreme Manufacturing*, is "Crack-free high-aspect ratio holes in glasses by top-down percussion drilling with infrared femtosecond laser GHz-bursts" (DOI: 10.1088/2631-7990/acaa14).

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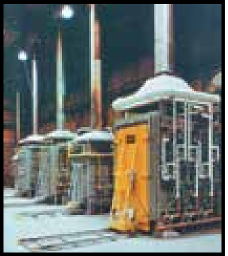

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deciphering the discipline

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

Ian Wells
Guest columnist

Harnessing hydrogen: The need for further research

Hydrogen is the most abundantly found chemical element in the universe. It is found both all around us and in us—hydrogen accounts for roughly 62% of the atoms in a human body.[1]

Though hydrogen is so abundant, it generally does not appear by itself in nature. Instead, it appears within compounds. For example, hydrogen is so plentiful in the human body because of its existence within water molecules.

Currently, hydrogen is mainly used as a fuel source in the form of hydrocarbons (fossil fuels). When combusted, these compounds of hydrogen and carbon release toxic greenhouse gases into our atmosphere.

If pure hydrogen is used as a fuel, carbon-based greenhouse gases are not formed during combustion. Instead, the only byproduct is water, thus making it a much cleaner source of fuel.

While use of hydrogen fuel is making headway, it is far from simple to obtain. Sourcing hydrogen from coal or other fossil fuels using current technologies often produces more carbon emissions than simply using that fuel for energy directly. Sourcing hydrogen from water through electrolysis is a better option, but only if the process is powered through renewable energy sources.[2]

Once hydrogen is produced, storing and transporting it is another challenge. Hydrogen is usually stored as a liquid because this form has a higher density—and therefore more energy per kilogram—than the compressed gas form. However, liquid hydrogen still takes up a significant amount of space due to hydrogen's low volumetric energy density.* Additionally, cooling hydrogen to its liquid state is challenging because it must reach −252.9°C (−423.2°F). Current cooling and storage solutions are far from perfect, often requiring large amounts of energy for liquefaction and then double-walled vacuum jacketed containers resistant to diffusion for storage.

Many research groups are investigating new designs and materials for storage containers to overcome these challenges. For example, a hydrogen and cryogenics research lab at Washington State University is working on a thin polymer collapsible hydrogen storage bladder that uses origami geometry for aerospace applications (Figure 1).[3] This tool mitigates many of the problems with vacuum jacketed containers, but it is still in the laboratory testing stage. This same lab also developed novel liquid hydrogen containment tanks that are 3D printable.[4]

Finally, actually using hydrogen fuel once it is sourced, transported, and stored faces material challenges. Hydrogen fuel is typically used in two ways: in fuel cells (for vehicles) and in combustion reactions (for industry processes). Work is being done to improve fuel cell safety and efficiency through use of ceramic materials in the anodes, cathodes, and/or electrolytes.[5] As for hydrogen combustion, hydrogen burns hotter and more rapidly than traditional fossil fuels, necessitating the development of new refractory materials within the furnace.[6]

Put simply, research on the production, transport, storage, and use of hydrogen fuel is growing, but it still faces many challenges. As the world transitions toward more renewable and clean energy options, this technology will be crucial for meeting emission targets.

Hydrogen is crucial to life as we know it. It is only fitting that harnessing it is essential to the continuation of this life.

Credit: Bob Hubner, Washington State University

Figure 1. A collapsible hydrogen storage bladder in liquid nitrogen demonstrates its ability to repeatedly bend and fold in cryogenic conditions.

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Ian Wells is an undergraduate student at Washington State University studying mechanical engineering with an emphasis in materials science engineering. He previously led a WSU liquid cryogen dusting team in producing a lunar dust mitigation solution for spacesuits. He now works in the Nuclear, Optical, Magnetic, and Electronic Materials Lab on millimeter-wavelength sensing during vitrification. In his free time, he enjoys making images through photography and drawing.

*Hydrogen's low volumetric density is counterbalanced by the fact that hydrogen has a significantly higher specific energy, i.e., energy that can be obtained per unit mass, than any other currently known energy storage options.

WELCOMING NEW FACULTY

Dr. Collin Wilkinson

Alfred University would like to introduce you to our latest faculty member Dr. Collin Wilkinson has been hired as Assistant Professor of Glass Science. Collin earned a Bachelor's in Physics at Coe College followed by a Ph.D. in Material Science at the Pennsylvania State University. He served as director of research and development and CTO of small startups focusing on next-generation recycling technology through material informatics. Collin is the inventor or co-inventor of several new glass compositions for green applications ranging from reducing greenhouse gases to improved glasses for renewable energy applications. Collin joined the faculty at Alfred University in 2022 and his current research revolves around building computational tools for simulations of extreme conditions, understanding the fundamental physics of glassy materials, and engineering better solutions for sustainable glass technology. Collin is the author of over 50 peer-reviewed publications and 4 patents. He is additionally the chair of the undergraduate research committee at Alfred University where he has created a research program for undergraduates from around the world in glass and ceramics.

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