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emerging ceramics & glass technology
AUGUST 2025

Powering a safer future with novel energy solutions

Emerging battery technologies | Nuclear energy developments | USGS Mineral Commodity Summaries 2025

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Cover image: Energy materials sample loading into a thermogravimetric analysis with differential scanning calorimetry setup.
Credit: UL Research Institutes

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As seen on *Ceramic Tech Today*...

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The power of lavender: Good for the mind, body—and batteries

While lavender oil may indirectly contribute to a longer and healthier lifespan, researchers from the Max Planck Institute of Colloids and Interfaces found that linalool, one of the main chemical compounds in this oil, can help actively extend the service life of sodium–sulfur batteries.

Read more at https://ceramics.org/lavender-batteries

Also see our ACerS journals...

Production of 3D ZrO_2 nanofibrous structures by solution blow spinning
By D. dos S. Gomes, M. O. G. Ferreira, B. V. Sousa, et al.
Journal of the American Ceramic Society

Bi_2S_3 nanorods supported on eggshell membrane electrodes for supercapacitor applications
By T. M. Almutairi, M. U. Nisa, S. Ijaz, et al.
International Journal of Applied Ceramic Technology

Flexible hollow Ni/Al_2O_3 fibers: A sustainable and reusable catalyst for efficient dry reforming of methane
By H. Yan, K. Wang, L. Zhao, et al.
Journal of the American Ceramic Society

Influence of point defect concentration on the generalized stacking-fault energy in uranium dioxide
By J. Amodeo and E. Bourasseau
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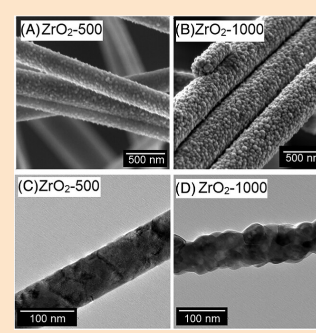

Credit: Gomes et al., *JACerS*

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ACSBA7, Vol. 104, No. 6, pp. 1–64. All feature articles are covered in Current Contents.

Ceramics for a sustainable future: Insights from the 4th Global Ceramic Leadership Roundtable

By B. Venkata Manoj Kumar
Professor and head, Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Roorkee

The ceramics industry requires collaborative initiatives to ensure that sustainability is prioritized throughout the entire sector's operations and supply chain. Such efforts were exemplified by a dedicated session during the 4th Global Ceramic Leadership Roundtable in March 2024.

The Global Ceramic Leadership Roundtable is a conference that aims to bring together both young and experienced researchers and industry personnel to deliberate on recent progress and emerging prospects in the synthesis, processing, characterization, and performance of advanced ceramics.

The fourth edition of the conference, which was organized under the theme "Ceramics for Frontier Sectors: Emerging Advances and Prospects," took place at the Center for Space Science and Technology at the Indian Institute of Technology (IIT) Roorkee from March 11–12, 2024. ACerS International Northeast India Chapter and iHUB DivyaSampark at IIT Roorkee co-organized the event. L. K. Sharma, CEO at Mahamana

Speakers at the "Ceramics for Sustainable Society: Challenges & Path Forward" roundtable discussion. From left: Emmanuel Guilmeau, Valérie Pralong, M. R. Ajith, Jon Binner, Sanjay Mathur, S. Packirisamy, Bikramjit Basu, Sitendu Mandal, and Syam S. Rao.

Credit: Manoj Kumar

Ceramic Development Organization and chairman of ACerS International Northeast India Chapter, served as organizing co-chair and B. Venkata Manoj Kumar, professor at IIT Roorkee and vice chair of ACerS International Northeast India Chapter, served as organizing secretary for the conference.

The 4th Global Ceramic Leadership Roundtable featured an illustrious lineup of plenary, keynote, and invited speakers from esteemed research groups worldwide, including France, the U.K., Slovenia, the U.S., Germany, and various Indian institutions. The presence of distinguished luminaries, such as past presidents of The American Ceramic Society and the European Ceramic Society, as well as the then-president of the Indian Ceramic Society added immense prestige to the gathering. The then-chairman of the Indian Space Research Organization inaugurated the conference.

During the conference, a dedicated roundtable discussion on "Ceramics for Sustainable Society: Challenges & Path Forward" was held on the first evening of the conference. The following sections summarize the key takeaways from this dedicated session.

Ceramic challenges in India

ACerS Past President Sanjay Mathur, professor at the University of Cologne and chair of the roundtable, set the tone for the session by emphasizing the need for brainstorming on ceramics for sustainability. Using India as a model, he highlighted the perennial gap between research and application and cited the country's lack of silicon production facilities as an example.

Bikramjit Basu, professor at Indian Institute of Science Bangalore and moderator of the roundtable, continued the discussion by highlighting India's third position in ceramic research publications. However, he noted that the research funding in India comes mostly from the government, whereas in developed countries, industry funding plays a significant role.

Bhaskar Prasad Saha of ARCI, Hyderabad, highlighted another problem experienced by ceramics researchers in India, notably the nonavailability of domestic processing facilities for nonoxide ceramics. He underscored that these facilities are essential to advance the development of materials for space and defense, such as ultrahigh-temperature ceramics, a point also made by M. R. Ajith of the Vikram Sarabhai Space Center.

To address these challenges, Jon Binner, professor at the University of Birmingham and former president of the European Ceramic Society, provided some possible solutions based on his experience with industry–academia collaborations in Europe. He underscored the crucial role of adequate funding and flexibility in facilitating successful collaborations.

Valérie Pralong of CNRS provided another Europe-based example by sharing her expertise on how the French government supports labs and facilitates access to industry, encouraging collaboration and innovation. Emmanuel Guilmeau from CNRS and and Abhendra K. Singh from Baylor University enriched the conversation with their knowledge of ceramic materials and applications.

Industry–science–innovation

Shyam S. Rao of CUMI Bangalore underlined the industry's shift toward sustainable practices and the need for research-oriented projects with commercial viability. Meanwhile, Sitendu Mandal of CSIR-CGCRI Kolkata highlighted the potential of national labs in producing glass and glass-ceramic products for strategic and societal sectors. He emphasized the need for a suitable policy to encourage small-scale industries and start-ups to adopt these technologies.

Packirisamy of Anabond Limited and former ISRO scientist stressed the importance of innovation in developing sustainable ceramics. He highlighted the crucial role of visionary start-ups in the development of cutting-edge technology, such as polymer-derived ceramics.

In response to a question from a young researcher who was seeking guidance on developing a vision for the bigger picture in ceramics, Mathur emphasized the importance of integrating industry and science from the outset. He encouraged young researchers to explore interdisciplinary approaches, collaborate with experts from various fields, and engage with industry partners to gain practical experience.

Basu added that developing a vision for the bigger picture requires a team effort. He suggested that young researchers should surround themselves with people from diverse backgrounds, including technology and business, to gain a comprehensive understanding of the field.

Ceramics education

Bharat Bhushan Jha of MRIT Bangalore mentioned that the development of technology at academic institutes or in industry should involve the user right from the initial stage to build trust. He also highlighted that there are only a few institutes that give undergraduate degrees in ceramics, whereas there is a huge demand for ceramic engineers. Mathur concurred that a trust deficit exists between academic institutions, research laboratories, and industry, hindering effective collaboration. He said the end goal is fixed, but the steps in between are not well planned.

As the discussion progressed, N. V. Ravi Kumar of Indian Institute of Technology Madras shared his optimistic views on India's progress in ceramics education and research. He noted that establishing a robust foundation in ceramics education and research is essential for driving future advancements and innovation in the field.

Basu also agreed on the point that manpower training and skill development are needed. He stressed the importance of introducing and strengthening ceramic engineering programs in premier institutions, such as within the Indian Institute of Technology system, and other universities. He pointed out that merely a handful of institutes in India produce a limited number of ceramic engineering graduates annually, highlighting a significant shortage and underlining the urgent need to train a larger workforce of skilled ceramic engineers.

Finally, Binner highlighted the importance of achieving gender balance in science and technology, particularly in ceramics research and education. Mathur also supported this view, acknowledging that gender balance is a global issue that requires attention and effort.

Takeaways from the roundtable

The roundtable concluded with a consensus on the need for collaboration, innovation, education, and sustainability in ceramics research and development. The experts recommended the development of ceramic engineering programs, promotion of industry–academia collaboration, support for start-ups, and encouragement of women in science and technology.

Some of the papers presented during the 4th Global Ceramic Leadership Roundtable are published as special issue articles in *International Journal of Applied Ceramic Technology*. A deeper look at the Indian ceramics market is available as part of a recent Confederation of Indian Industry report on advanced materials, critical minerals, and metals: https://bit.ly/CII-2024-report-advanced-materials. ■

Corporate Partner news

Allied Mineral Products opens new facility in Türkiye

On May 9, 2025, Allied Mineral Products celebrated a grand opening of their new manufacturing facility in Izmir, Türkiye. The new facility will help Allied meet the growing demand for refractory products in the region. Read more: https://alliedmineral.com/news

Kyocera and Kyuden Mirai Energy sign memorandum on renewable energy

Following a recent off-site corporate power purchase agreement, Kyuden Mirai Energy began supplying Kyocera facilities with geothermal electricity to help reduce greenhouse gas emissions. The two companies signed a memorandum of understanding to continue collaborating in the renewable energy space. Read more: https://www.kyocera.co.jp/newsroom/news

Saint-Gobain launches lowest carbon glass wool insulation plant in the world

The recent installation of three pressurized biogas tanks at the Saint-Gobain Isover plant in Forssa, Finland, means it is now the lowest carbon glass wool insulation plant in the world. Fifty percent of the site utilizes biogas energy while the other 50% utilizes hydroelectric power. Read more: https://www.saint-gobain.com/en/press/press-releases ■

bccResearch

Renewable energy: Technologies and global markets

The global renewable energy market was valued at $1.25 trillion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 8.7% to reach $2.0 trillion by the end of 2029.

There recently has been a significant increase in government and regulatory support for renewable energy generation to reduce dependency on other nations and on conventional emissions-intensive energy sources. These policies, some of which are described below, have encouraged both energy producers and consumers to embrace renewable energy sources despite higher initial investments.

- **Carbon pricing mechanisms**, such as taxes or cap-and-trade systems, can increase the cost of fossil fuels, making renewable energy more economically competitive.
- **Feed-in-tariffs** are policy mechanisms that guarantee renewable energy providers will receive a fixed price for each unit of energy they generate and feed into the electricity grid. These long-term contracts allow providers to recover costs and realize a return on investment.
- **Renewable portfolio standards** are quotas that require an electricity supply company or sometimes consumers to source a share of their electricity from renewable energy sources. Companies that fail to meet the obligations must pay penalties.
- **Power purchase agreements** are long-term contracts between an electricity generator and a customer, where the customer buys electricity at a prenegotiated price. These agreements help enable investment in alternative or renewable energy plants by guaranteeing the purchase of the electricity they produce.

Table 1. Global renewable energy market, by technology, through 2029 ($ millions)

Technology	2023	2024	2029	CAGR % (2024–2029)
Solar power	356,730.0	418,657.5	962,306.3	18.1
Hydroelectric power	478,332.4	488,177.6	535,342.5	1.9
Wind power	268,288.4	282,799.2	371,268.2	5.6
Bioenergy	145,863.2	147,981.5	167,792.4	2.5
Geothermal energy	8,200.9	8,450.7	9,723.0	2.8
Ocean energy	253.0	315.8	1,158.7	29.7
Total	1,257,667.9	1,346,382.3	2,047,591.1	8.7

Table 2. Global solar photovoltaic market, by technology, through 2029 ($ millions)

Technology	2023	2024	2029	CAGR % (2024–2029)
Crystalline silicon photovoltaics	308,167.3	358,922.6	801,601.1	17.4
Thin-film photovoltaics	32,828.8	39,665.7	105,622.7	21.6
Others	12,166.6	15,073.2	35,836.3	18.9
Total	353,162.7	413,661.5	943,060.1	17.9

Among all the renewable sources, hydroelectric power is currently the largest renewable energy market (Table 1). However, solar photovoltaic technology is poised to become the largest sector due to the technology's scalability and very low operational costs and maintenance requirements (Table 2).

China is expected to contribute 58% of the total growth of the global renewable energy market between 2024 to 2030, followed by the European Union with a 10% share. North America is also ramping up the pace, but this region faces potential challenges in wind energy capacity enhancement.

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 utkantha.srivastava@bccresearch.com.

Resource

BCC Publishing Staff, "Renewable energy: Technologies and global markets," BCC Research Report EGY049F, April 2025. https://bit.ly/April-2025-renewable-energy ■

By James Marra
Guest columnist

Nuclear power: Reliable, clean energy for now and the future

The effects of climate change are evident as the daily news cycle reports on historic high temperatures and severe weather events across our nation and the world. It is now clear that minimizing carbon emissions is paramount to stemming continued changes to our climate.[1]

Our transition to clean and renewable energy, though happening slower than desirable, is steadily progressing. In 2023, renewable electricity, mainly in the form of hydro and wind power, made up nearly 21% of U.S. electricity generation.[2]

While the addition of renewable energy sources to our grid is welcome, we all know the wind does not always blow and the sun does not always shine. Moreover, widespread droughts are also impacting the reliability of hydropower. As such, the basket of clean energy sources that we rely on needs to be expanded.

Nuclear energy is a prime solution to provide clean, consistent power. Not only does it have the highest capacity factor of any energy source—producing maximum power more than 94% of the time—nuclear power plants are extremely land efficient. A 1,000-megawatt nuclear facility needs just slightly more than one square mile to operate, while wind and solar farms require 360 and 75 times more land, respectively, to produce the same amount of electricity.[3]

Support for nuclear energy is gaining renewed traction here in the U.S. and around the world. This approval has led to new nuclear plant builds, life extensions, unretiring idled plants, and government policy shifts, among other activities.

In the last two years, two new nuclear reactors were brought on-line at Southern Nuclear's Vogtle plant right in my backyard near Augusta, Ga. These reactors, which are the first new nuclear builds in the U.S. in more than 30 years, made Vogtle the largest nuclear plant in the U.S. with four operating reactors.

On the other side of the country, California state leaders reversed direction by moving to extend the life of the Diablo Canyon Plant beyond a 2025 planned shutdown date. Diablo Canyon supplies about 10% of California's electricity and accounts for 17% of the state's zero-carbon energy. The proposed legislation could keep the plant open until 2035. Additional efforts are underway to bring back online decommissioned reactors at the Palisades Nuclear Plant in Michigan and at the Three Mile Island nuclear plant in Pennsylvania.

Other states are embracing nuclear, too. Over the past few years, 25 states passed legislation to support advanced nuclear energy implementation in their jurisdictions.[4] Moratoriums on nuclear power construction were lifted in Connecticut, Illinois, Kentucky, Minnesota, Montana, West Virginia, and Wisconsin.

Tech powerhouses Microsoft, Google, and Amazon are also delving into nuclear to power artificial intelligence and data centers. These companies are actively investing in reviving decommissioned sites and developing small modular reactors (SMRs). SMRs are compact nuclear reactors that can be built in a factory and then shipped to the operating site, thus reducing costs and speeding up the time to implementation. Some of the leading SMR companies today include Terrapower, NuScale Power, GE Hitachi Nuclear Energy, Westinghouse Electric Company, X-Energy, Kairos Power, Holtec International, and Oklo.

Other countries around the world are also getting on board the nuclear train. France, Japan, and South Korea are again considering new nuclear after backing away for a decade. The United Kingdom ambitiously has pledged to complete eight new nuclear power plants by 2050. Germany's new government recently changed course and now plans to invest in advanced nuclear technologies as well as explore partnerships with other European countries.

Credit: James Marra

James Marra at an outreach event for Citizens for Nuclear Technology Awareness.

Through the operation of existing reactors and the development of new, advanced technologies, the solution to reliable, clean energy is clear—nuclear!

About the author

James Marra is nuclear technology advisor for Citizens for Nuclear Technology Awareness (CNTA), an Aiken, S.C.-based charitable educational organization dedicated to educating the public on nuclear issues. For more information, call CNTA at 803-649-3456, email cnta@bellsouth.net, or visit https://cntaware.org.

References

[1]"AR6 Synthesis Report: Climate Change 2023," Intergovernmental Panel on Climate Change. Published March 2023. https://bit.ly/4ld1SSW

[2]"FAQs: What is U.S. electricity generation by energy source?" U.S. Energy Information Administration. Updated February 2024. https://bit.ly/4n0ACZE

[3]"Land needs for wind, solar dwarf nuclear plant's footprint," Nuclear Energy Institute. Published 9 July 2015. https://bit.ly/444h3a7

[4]"Status report: State legislation and regulations supporting nuclear energy," Nuclear Energy Institute. Published January 2025. https://bit.ly/4e8uKtg

*All references verified as of May 30, 2025.

By David Holthaus
Industry reporter

The surging demand for energy brings both threats and opportunities

State government workers inspect battery storage enclosures in Texas, the fastest-growing battery storage market in the U.S.

With more than 6,000 data centers already operating around the world, and many more expected to be built, the demand for energy to power them is surging. The revolution in artificial intelligence is also fueling a growing need for electricity, and other factors are contributing to the energy demand, too: growth in advanced manufacturing, uptake in electric vehicles, cryptocurrency "mining," electrification of emerging economies, and an increase in extreme weather events.

Globally, energy demand is projected to grow 11–18% by 2050, according to McKinsey & Co.'s Global Energy Perspective 2024. Electrification is driving that demand, as electricity consumption worldwide could more than double or even triple during that period, according to McKinsey's analysis.

In the United States, electric demand is forecast to increase by 15.8% by 2029, according to a report updated in April 2025 by Grid Strategies, a Washington, D.C.-based consulting firm.

"For the last 20 years, the U.S. has been in an era of flat power demand," says Zach Zimmerman, research and policy manager at Grid Strategies, in an interview. "What we're finding now is that utility forecasts for load demand are increasing significantly across the country."

The firm based its forecast largely on utility data filed with the Federal Energy Regulatory Commission.

"There's a number of factors driving this load growth, but the main one by far is data centers," Zimmerman says. "Over the next five years, we project about 120 gigawatts in growth. About 80 gigawatts of that is from data centers."

Likewise, the North American Electric Reliability Corporation's December 2024 report dramatically increased its forecast from last year.

"The demand growth is now higher than at any point in the past two decades," according to the forecast from the Atlanta-based not-for-profit regulatory authority. Its summer peak demand forecast for the next 10 years is 132 gigawatts, up from over 80 GW in its 2023 report. Its forecast covers the continental U.S., Canada, and northern Mexico.

For manufacturers, these trends will likely mean increased costs for energy, but they also signal opportunities to supply new systems and energy-efficient applications. Cambridge, Mass.-based GE Vernova, a major global energy equipment manufacturer, is a prime example. In the first quarter of 2024, the company, which is one of three companies spun off from General Electric, posted a loss. A year later, it reported a profit of $264 million. The company said in a first-quarter earnings conference call that it expects this growth to continue through 2025.

"To put today's investment super cycle into perspective in terms of energy needs and decarbonization, the scale of load growth we're seeing in North America is the most significant since the post-World War II industrial build-out," GE Vernova CEO Scott Strazik said during the call. "But, unlike then, the growth is global."

As of April 2025, GE Vernova reported that orders for electrification equipment in its first quarter of 2025 grew 44% year-over-year in North America and nearly doubled (92% growth) in Asia. The company also reported that its installed technology base, which includes 7,000 gas turbines and 55,000 wind turbines, helps generate about 25% of the world's electricity.

Clean energy can play a major role in meeting this global demand for energy. With traditional energy sources, it can take many years to bring new power generation systems online due to siting concerns, regulations, costs, and other factors. But today's energy demands require "a paradigm shift in terms of planning, and it's on much faster timelines than the utility industry normally operates on," Zimmerman says. "Trying to build new generation or transmission takes a lot longer than it takes to build a data center."

Sources of clean energy can usually be built more quickly than traditional sources. Specifically, "Wind, solar, and storage right now are the three resources that generally can be built in the next five years," Zimmerman says.

Therefore, it is undeniable that "Clean energy is going to play a role," Zimmerman says. "It's also the most economic energy source currently, and so just in terms of consumers wanting lower-cost energy, I think you have to consider clean energy as part of a portfolio."

Both 2023 and 2024 were very strong years for the deployment of clean energy in the U.S., according to a February 2025 report by the World Resources Institute. The report found that "Clean electricity sources are an increasingly vital part of the U.S. economy and power system, with renewable sources and battery storage making up the vast majority of new additions to the grid."

Solar surpassed 2023's record installations in 2024, adding an estimated 39.6 gigawatts of capacity, the WRI report says. As of the report's release, installed solar capacity in the U.S. totaled about 220 GW, enough to provide more than 7% of the nation's electricity.

Battery storage nearly doubled in 2024, with total installed capacity reaching almost 29 GW—and projected to grow another 47% in 2025, the report says. Onshore wind capacity growth has tapered off, with only 5.3 GW of new generation added in 2024, significantly less than wind installation levels in previous years, the report says.

At the same time, the report also notes that headwinds slowing clean energy growth are getting stronger. Those headwinds include a lack of sufficient grid capacity and system interconnections, siting delays, interest rates, and lingering supply chain issues. The report also notes that the new federal administration has created roadblocks for leasing and permitting wind energy, has frozen or delayed funding, and has opposed incentives in the Inflation Reduction Act and Bipartisan Infrastructure Law that were designed to advance the clean energy sector.

Globally, China is the trendsetter when it comes to manufacturing clean energy technologies, according to the International Energy Agency's World Outlook 2024.

"China's solar expansion is now proceeding at such a rate that, by the early 2030s—less than 10 years from now—China's solar power generation alone could exceed the total electricity demand of the United States today," IEA Executive Director Fatih Birol said in the report's summary.

One approach to meet the demand in the U.S. is to improve and increase electricity transmission capacity so power can be efficiently transferred from one region to another. Investing in large-scale transmission is the lowest-cost way to address load growth, as it is likely to cost less than $300 million per GW, the Grid Strategies report says.

However it is accomplished, meeting the demands for energy in the coming years is likely to require the investment of billions of dollars in the energy supply chain and in power generation and transmission.

About the author

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

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

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

ACerS International Northeast India Chapter Chair gives lecture on 'Ceramics in space technology'

L. K. Sharma (back row, center) with graduate students and teachers from A.K.P. Degree College.

On May 24, 2025, A.K.P. Degree College organized a lecture on "Societal benefits of space, science, and technology" by A. C. Mathur, professor in the Center for Space and Technology at the Indian Institute of Technology, Roorkee, and "Ceramics in space technology" by L. K. Sharma, chair of the ACerS International Northeast India Chapter. Dimple Vij, professor and principal of A.K.P. Degree College, introduced the speakers. Lectures were attended by graduate students and teachers of the college. ■

ACerS International Brazil Chapter attends Brazilian Ceramics Congress

The ACerS International Brazil Chapter strengthened its presence at the Brazilian Ceramics Congress, which took place June 15–18, 2025, at the Praiamar Natal Hotel & Convention, through new initiatives aimed at promoting engagement and supporting researchers. Highlights of the event included

- **ACerS booth:** A dedicated booth at the Congress facilitated interaction between ACerS and the Brazilian ceramics community, encouraging new memberships.
- **English presentation competition:** Young researchers presenting in English competed for free ACerS annual memberships, fostering internationalization.
- ***IJCES* publication incentive:** The top three full papers submitted in English received a publication waiver for *International Journal of Ceramic Engineering & Science*.
- **Complimentary GGRN memberships:** The ACerS International Brazil Chapter has limited free Global Graduate Research Network memberships for 2025. Postgraduate attendees are also encouraged to apply for a free ACerS Associate Membership. ■

FOR MORE INFORMATION:

ceramics.org/spotlight

ACerS International Thailand Chapter to co-host ICAPMA-ICREM 2025

The ACerS International Thailand Chapter and Rare-Earth Minerals Association extend a cordial invitation to participate in the 7th International Conference on Applied Physics and Materials Applications (ICAPMA2025), taking place Dec. 10–13, 2025, in Pattaya, Thailand. ICAPMA2025 serves as a prestigious global platform for the exchange and dissemination of knowledge, fostering the establishment of new collaborations among experts worldwide.

For more information and to submit an abstract, visit https://matscitech-thailand.com/icapma-icrem2025/index.php. ■

Attend your Division business meeting at MS&T25

Five of ACerS Divisions will hold executive and general business meetings at ACerS Annual Meeting at MS&T25 in Columbus, Ohio. General business meetings will be held Monday or Tuesday in the Greater Columbus Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Monday, Sept. 29
Electronics Division: Noon–1 p.m.
Engineering Ceramics Division: Noon–1 p.m.
Energy Materials and Systems Division: 5–6 p.m.

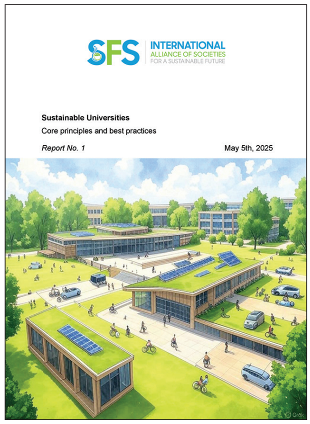
Tuesday, Sept. 30
Glass & Optical Materials Division: Noon–1 p.m.
Basic Science Division: Noon–1 p.m. ■

Do you qualify for Emeritus membership?

If you will be 65 years old (or older) by Dec. 31, 2025, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Vicki Evans at vevans@ceramics.org.

more SOCIETY DIVISION SECTION CHAPTER NEWS

SFS Alliance unveils report on 'Sustainable Universities'



Cover of the "Sustainable Universities" Report No. 1.

The International Alliance of Societies for a Sustainable Future (SFS Alliance) recently announced the publication of its inaugural report, "Sustainable Universities: Core Principles and Best Practices." Released in May 2025, this report serves as an inspiration and guide for higher education institutions worldwide to reimagine sustainability as an integrated part of their missions.

The report was conceived by ACerS Fellow Jürgen Rödel of the Technical University of Darmstadt and developed by an international and interdisciplinary team of contributors, including Yannik Gehlen, Daniel Isaia, and Patrick Breckner from TU Darmstadt; Rishabh Kundu of Case Western Reserve University; Krista Bailey of The Pennsylvania State University; and Till Frömling of Forschungszentrum Jülich. It documents a diverse range of best practices and distilled principles across three key domains: Infrastructure and Operations, Mobility, and Education.

Rather than providing an exhaustive inventory of sustainability projects, the report offers a flexible, need-based framework and living foundation for institutional transformation.

More than a checklist, the report emphasizes the importance of viewing sustainability not as a separate agenda but as a guiding principle that informs how universities operate, teach, and engage their communities. It highlights how campuses can become living laboratories for change, advocating environmental stewardship.

Crucially, the report positions sustainability as a dynamic, collective endeavor—one that demands inclusivity and equitable participation from all campus members. These insights align with global goals, including the United Nations Sustainable Development Goals, and aim to equip the next generation of leaders with the skills and perspectives needed to navigate complex sustainability challenges.

The report is designed as a living document, meaning the SFS Alliance is open to contributions from across the global higher education community, including students, to help shape future versions of the report. The second version is already in development and scheduled for release in August 2025.

Access the full report at https://bit.ly/SFS-Alliance-Report-1

For those who wish to share examples, offer insights, or correspond on the report's content and future editions, please reach out to Yannik Gehlen (gehlen@ceramics.tu-darmstadt.de) and Rishabh Kundu (kundurishabh@gmail.com). ■

About the SFS Alliance

Formally established in December 2023, the SFS Alliance is a joint committee of the German Ceramic Society; The American Ceramic Society; the European Ceramic Society; the German Materials Society; and the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society. It aims to leverage the collective knowledge, resources, and networks of scientists to drive transformative change that benefits all. https://sfs-alliance.org

WEBINARS TO WATCH

Check out these recent additions to the ACerS Webinar Archives:

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

MEMBER HIGHLIGHTS

Volunteer Spotlight: Bikramjit Basu

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

Bikramjit Basu is a faculty member at the Indian Institute of Science (IISc), Bangalore, and director of the Council for Scientific and Industrial Research's Central Glass and Ceramic Research Institute (CSIR–CGCRI). He received his undergraduate and postgraduate degrees in metallurgical engineering from the National Institute of Technology (NIT), Durgapur and IISc, respectively, and a doctorate in engineering ceramics from Katholieke Universiteit Leuven, Belgium. Following a brief post-doctoral stint at the University of California, Santa Barbara, Basu served as a faculty member of the Indian Institute of Technology (IITs), Kanpur, before joining IISc.

Basu's research is at the confluence of ceramic science, biomaterials, additive manufacturing, biological science, and medicine. His research group has developed technologies related to the manufacturing of bioceramics, acetabular liners, customized bone flaps for cranioplasty surgeries, dental implants, and variants of 3D bioprintable hydrogels. These technologies are transferred to multinational corporates or start-ups, and many of the products, after regulatory clearances, are currently used for patient care in India.

Basu has been an active member of ACerS since 2008. During that time, he helped promote the Engineering Ceramic Division's Global Engagement in Ceramic Science and Technology program and ACerS President's Council of Student Advisors at both IITs and IISc. He also organized the ACerS-endorsed conclaves "New Materials for Healthcare" and "ICME Approaches to Innovation in Biomedical Implants" at IISc in 2018, as well as the ACerS-sponsored International Virtual Conference on Biomaterial-Based Therapeutics, Engineering, and Medicine in December 2021.

As principal investigator of the Ceramic and Glass Industry Foundation project "Conventional and Advanced Ceramics Manufacturing for Next Generation of Ceramics and Glass Engineers," Basu coordinated significant outreach activities between 2018 and 2019, which impacted 585 high school students, 62 undergraduates, and 70 postgraduate students through short courses, two workshops, 25 keynote lectures, and four internships at IISc, IITs/NITs and other companies.

Basu previously served as chair of the Kingery Award Committee and is currently serving on the Publications Committee. For the last two years, he has served as chair of the ACerS Panel of Fellows. He previously served as chair of the Bioceramics Division, and he has played a key role in the ACerS Strategic Planning Committee by chairing the International Theme Committee.

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

more MEMBER HIGHLIGHTS

IN MEMORIAM

Rodney Ewing

Raghvendra Pandey

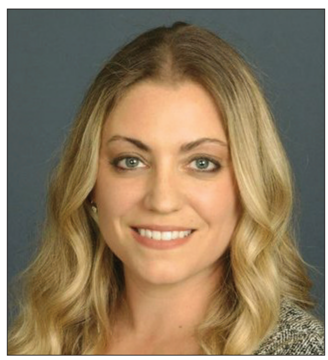
Carlo Pantano

Louis Trostel

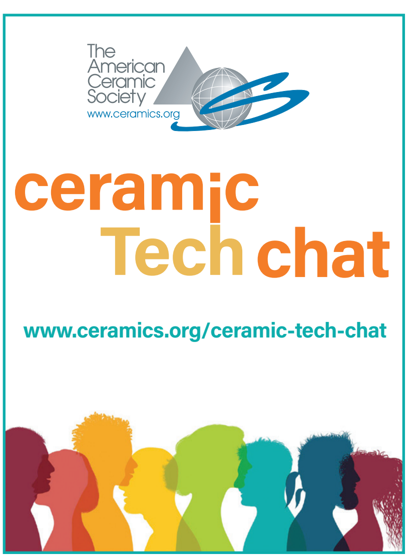
Names in the News

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

Deborah Chung, SUNY Distinguished Professor of mechanical and aerospace engineering at the University at Buffalo, was one of four alumni to receive the 2025 Distinguished Alumni Award at the California Institute of Technology's 88^{th} Annual Seminar Day. Chung received the award for her pioneering work in multifunctional structural materials and smart concrete, as well as her efforts to diversify STEM.



Bryn Snow, applications director for industrial metals and glass industries at HWI, a member of Calderys, received this year's Hotbels BTU award. The award recognizes individuals who have contributed significantly to Hotbels Seminars and to the education of the glass industry. ■



FOR MORE INFORMATION:

ceramics.org/membership

Ceramic Tech Chat: William LaCourse

Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics.

In the May 2025 episode of Ceramic Tech Chat, **William LaCourse**, Emeritus Professor of glass science in the New York State College of Ceramics at Alfred University, shares how several serendipitous encounters with giants in the glass field led to his employment at Alfred, highlights some of the untapped markets for ion-exchanged glass products, and gives some fun anecdotes from his time as the Alfred sports announcer for football and basketball.

Check out a preview from his episode, where he describes the mechanism behind ion-exchange strengthening of glass.

"So, ion exchange, the best word I can come up with is it's stuffing. You take this material, and you take a little tiny chunk of that material out, like a sodium ion. And you say, 'Okay, now I'm going to shove this big atom, potassium, back into the same place that that sodium came from.' As you push it in, it puts stress on the rest of the structure. If there are cracks in the material, then the cracks get closed by the compression that's generated from these larger atoms entering a smaller location than they really want."

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

AWARDS AND DEADLINES

Nomination deadline for Society awards: Sept. 1, 2025

Contact: **Erica Zimmerman** | **ezimmerman@ceramics.org**

Society award	Deadline	Description
Darshana and Arun Varshneya Frontiers of Glass Lectures	September 1	Lectures encourage scientific and technical dialogue in glass topics of significance that define new horizons, highlight new research concepts, or demonstrate the potential to develop products and processes for the benefit of humankind.

Nomination deadlines for Division awards: Sept. 5, 2025

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

Division	Award	Deadline	Contacts	Description
BSD	**Roland B. Snow Award**	September 5	Klaus van Benthem benthem@ucdavis.edu	Presented to the Best of Show winner of the Ceramographic Exhibit & Competition, which is an annual poster exhibit to promote the use of microscopy and micro-analysis in ceramics research.

The CGIF's 'sweet science' candy fiber demos captivate at COSI's Big Science Celebration

By Nathan McIlwaine, PCSA chair

The Ceramic and Glass Industry Foundation (CGIF) proudly participated in the seventh annual COSI Big Science Celebration on Saturday, May 3. Hosted by the Center of Science and Industry (COSI), one of the nation's premier science museums, this exciting event served as the grand finale to the four-day COSI Science Festival and brought a full day of hands-on STEM learning to downtown Columbus, Ohio. The celebration unfolded on the vibrant outdoor plaza just outside the museum.

Widely recognized as one of the largest public STEM events in Ohio, the Big Science Celebration featured more than 100 booths from leading organizations in science, education, and industry. This year's exhibitors included Intel, Honda, NASA, and The Ohio State University, among many others—each offering engaging activities for learners of all ages. Among them, the CGIF's booth— "The Sweet Science Behind Glass Fibers"—stood out as a crowd favorite.

The CGIF's booth offered a lively and interactive introduction to the materials science behind fiberglass and fiber optics. The Candy Fiber Pull demonstration returned as the highlight of the day, capturing the imagination of both children and adults. This well-loved demo uses melted Jolly Ranchers to illustrate how glass fibers are formed.

Located along the bustling Wolfe Drive directly in front of the museum, the CGIF's booth quite literally stopped traffic. Curious attendees often paused as young scientists-in-training pulled long strands of candy fiber, drawing interest even from the event's organizing staff and photographers. Real samples of fiberglass insulation, fiber optic lamps, and fiberglass snowboards were also available for participants to examine, giving families a complete, hands-on understanding of how these advanced materials are made and then incorporated into products from everyday life.

Events such as the COSI Big Science Celebration allow the CGIF to fulfill its mission of inspiring and educating the next generation of ceramic and glass professionals. We extend heartfelt thanks to the volunteers who made this day a success. We look forward to bringing the sweet science of materials back to COSI next year!

CERAMIC AND GLASS INDUSTRY FOUNDATION

Rain did not dampen the excitement around learning about glass fibers. Many families stopped by the CGIF booth to witness the "sweet" demo.

Two siblings aiming to pull the longest candy fiber temporarily halted foot traffic. Volunteers guided passersby around the siblings to protect the delicate fibers.

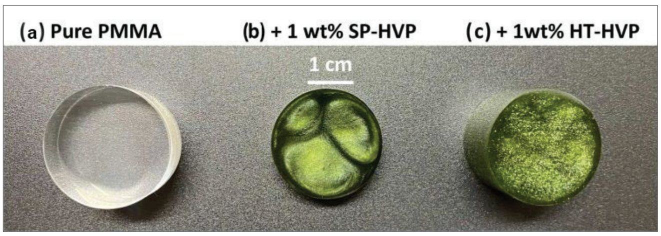
2025 COSI Big Science Celebration volunteers

Allied Mineral Products: Emily Denton and Taylor Murphy

Owens Corning: Tim Powers (retired)

ACerS President's Council of Student Advisors: Emilee Fortier, Tony Annerino, Sevag Momjian, and Nathan McIlwaine ■

Vanadium phosphate demonstrates potential as substrate-free pearlescent pigment



Pictures of HVP pearlescent pigments dispersed in a poly(methyl methacrylate) (PMMA) matrix. a) Pure PMMA. b) PMMA with 1 wt.% HVP (37 μm). c) PMMA with 1 wt.% HVP (147 μm).

Tohoku University researchers investigated the potential of certain vanadium phosphates to serve as single-component platelets for pearlescent pigment design.

Pearlescent pigments consist of plate-like particles called platelets, which reflect and refract light between the various platelet layers. Typically, mica and titanium dioxide are used as the base and surface layer platelets, respectively, but the manufacturing process is costly due to specialized equipment and complex chemical procedures.

Substrate-free pearlescent pigments, which are made of single-component platelets without a base layer, exist as well. But only a few materials are known to crystallize into plate-like particles suitable for use as substrate-free pigments.

Of the various vanadium phosphate compounds, yellow vanadium phosphate dihydrate [$VOPO_4 \cdot 2H_2O$, or VOP] and its hydrated green phase [$H_{0.6}(VO)_3(PO_4)_3(H_2O)_3 \cdot 4H_2O$, or HVP] have plate-like morphologies with a high ability to intercalate, which "indicate its potential as a candidate for substrate-free pearlescent pigments," the Tohoku researchers write.

Analysis of VOP and HVP pigments synthesized via a hydrothermal process revealed they demonstrate high gloss units and striking iridescent colors comparable to commercial mica-based pearlescent pigments.

The open-access paper, published in *Journal of Alloys and Compounds*, is "Synthesis of novel colored substrate-free pearlescent pigments of vanadium phosphates with large-size layered platelet morphology" (DOI: 10.1016/j.jallcom.2024.177735). ■

Materials in the news

New catalyst boosts efficiency of CO_2 conversion

Researchers at Ecole Polytechnique Fédérale de Lausanne developed a ceramic-encapsulated cobalt–nickel alloy that significantly improves the efficiency and durability of high-temperature carbon dioxide conversion. The encapsulation, which was done via a sol-gel process, prevents the metal from agglomerating, a common problem that reduces catalyst effectiveness. The new catalyst maintained an energy efficiency of 90% at 800°C while converting CO_2 into carbon monoxide with 100% selectivity. For more information, visit https://actu.epfl.ch.

Stable triple bond finally achieved between boron and carbon

There have long been stable double bonds between boron and carbon, but only simple transient molecules featuring boron–carbon triple bonds have been experimentally confirmed. In March 2025, researchers from Julius Maximilian University of Würzburg successfully achieved the necessary conditions to form stable triple bonds between boron and carbon.

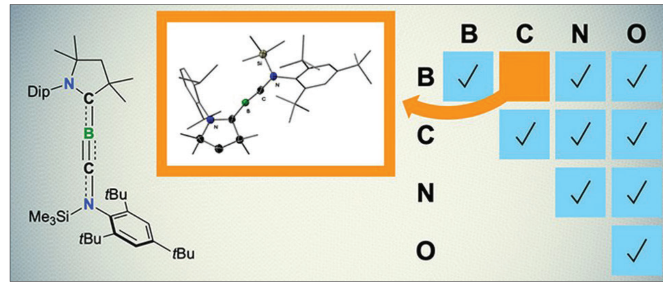
To create the so-called neutral "boryne" (named as such by extension from the term alkyne), the researchers performed a multistep synthesis process starting with bromoborylene, which underwent reductive dehalogenation, isolation of the dimeric dipotassium complex, and then addition of trimethylsilylchloride. This process resulted in an orange solid (the boryne) that was stable indefinitely under argon at room temperature but decomposed in solution at room temperature.

The researchers synthesized several derivates of the boryne in solution, as well as performed quantum chemical calculations, to confirm the boryne's geometry. These experiments revealed the triple bond comprised one σ and two orthogonal π bonds, which is the usual structure for triple bonds.

The researchers write that their study is "a testament to the power of iterative synthetic variation of the substituents in low-valent main-group species," which in this case provided the right balance of steric and electronic factors to "allow the isolation of the title compound as a metastable species en route to a more thermodynamically stable borylene species."

In a press release, first author Maximilian Michel, the doctoral student who made the molecule in the laboratory, notes that boryne's geometry is very uncomfortable for boron atoms, as it puts them in a linear arrangement with the carbon atoms. However, "Compounds in which individual atoms feel 'uncomfortable' often show a very interesting reactivity," he says, and this potential reactivity is what the researchers are now investigating.

The paper, published in *Nature Synthesis*, is "The synthesis of a neutral boryne" (DOI: 10.1038/s44160-025-00763-1). ■



Credit: Rian Dewhurst, Julius Maximilian University of Würzburg

Structure of the world's first molecule with a stable triple bond between boron and carbon.

Proximity effect unlocks ferroelectricity without need for chemical modification

In January 2025, researchers from The Pennsylvania State University announced the ability to turn a nonferroelectric material into one simply through proximity with another ferroelectric material.

Previous studies induced ferroelectricity in nonferroelectric materials through chemical modification. However, this modification can result in tradeoffs with other properties, such as heat dissipation during device operation.

The new study simply involved stacking nonferroelectric layers of aluminum nitride and zinc oxide on top of wurtzite-structured ferroelectrics, specifically boron-substituted aluminum nitride and magnesium-substituted zinc oxide. At the interface between the layers, the local elastic and electric fields in the ferroelectric materials induce ferroelectricity in the nonferroelectric layers.

Because no chemical modification took place in the nonferroelectric layers, these layers retain the desirable properties that are lost during chemical modification. Furthermore, because the proximity effect only requires a ferroelectric layer that is 3% of the total volume of the stack, "the vast majority is material with the most-desired properties," a Penn State press release explains.

The paper, published in *Nature*, is "Proximity ferroelectricity in wurtzite heterostructures" (DOI: 10.1038/s41586-024-08295-y). ■

Materials in the news (continued)

Hygroscopic layer cools solar panels, boosts output by 13%

An international research team led by King Abdullah University of Science and Technology developed a novel composite material made of lithium chloride and sodium polyacrylate. This hygroscopic material absorbs moisture from the air during the night and releases it during the day, providing electricity-free cooling for solar panels. While operating for weeks in the Saudi desert, solar cells covered with this material were 9.4°C cooler than uncovered cells, and they showed an increased power output of more than 12% along with an increased lifespan of more than 200%. For more information, visit https://techxplore.com.

Plant leaves inspire design of improved fuel cell

University of Toronto researchers used plant leaves as inspiration to improve the design of channels, called "flow fields," that direct water inside fuel cells. They showed that, compared to existing designs, the nature-inspired design resulted in a 30% increase in the peak power density that could be reached in the fuel cell. The new design also allowed a more even distribution of water within the cell, with no build up, which meant the fuel cell could use the platinum catalyst more effectively. For more information, visit https://www.lightsource.ca/public/news-landing-page.php.

How porcelain established itself as musical material

Wood, brass, metal, and plastic commonly serve as materials for instruments in the music industry—but what about ceramics and glass?

Clay-based ocarinas, xuns, and similar wind instruments have been found throughout ancient cultures of Asia, Africa, Europe, and even the Americas. Meanwhile, glass has been used as the base of string instruments such as the harp, violin, and cello, in addition to the all-glass armonica created by Benjamin Franklin.

Porcelain is another ceramic material that has found use in the music industry. Its use ties into the history of Jingdezhen, the Porcelain Capital of the world.

The city of Jingdezhen is located in southeastern China in the Jiangxi province. Fine ware for official use started to be produced in the city as early as 6th century CE, and by the 12th century, the city was well-established in the art of ceramics and had significantly increased the amount of porcelain they were exporting.

The city's porcelain industry skyrocketed during the Ming Dynasty (1368–1644) when their fine ware was adopted by the imperial household and the government overall. The development of porcelain in the area helped advance and inspire the development of the material in other countries.

In addition to dinnerware, porcelain was used to create instruments such as chimes, drums, erhu (Chinese fiddle), and flutes. Due to porcelain's durability and resistance to chipping, it worked well as an instrument in addition to its everyday duties as dishes, cups, tiles, and other decorative objects.

The Jingdezhen porcelain instruments have remained a part of the music industry in modern Chinese culture, as demonstrated by the recent project by the China National Traditional Orchestra.

According to a *China Daily* article, musicians of the China National Traditional Orchestra traveled to Jingdezhen about two years ago hoping to get inspired by the porcelain instruments.

Known for its use in dinnerware, traditional Chinese porcelain also has been used to create instruments, a fact that recently captured the attention of the China National Traditional Orchestra.

"These instruments are valued not only for their musical properties but also for their artistic craftsmanship. They represent a fusion of Jingdezhen's porcelain artistry with traditional Chinese musical instruments," says Cui Suxiang, deputy mayor of Jingdezhen, in the article. "The porcelain material contributes to a unique tonal quality, often characterized by a clear, resonant, and sometimes delicate sound that is distinct from wooden or metal instruments."

In September 2024, the China National Traditional Orchestra signed a strategic agreement with the city of Jingdezhen to foster collaboration and spark inspiration using the porcelain instruments. Their goals are to work together on performances, music creation, and musician training, blending traditional culture with modern music elements.

The collaboration comes at a time when Jingdezhen is "brimming with youthful energy, especially young entrepreneurs, artists, and tourists," says Zhao Cong, a veteran pipa (four-stringed Chinese lute) player and president of the China National Traditional Orchestra, in the *China Daily* article.

You can hear the chime-like sounds of porcelain instruments in the video at https://www.youtube.com/watch?v=IZRt3jKK-60, which features a performance of "Right Here Waiting for You in Jingdezhen." ■

Interlocked electrodes push silicon battery lifespan beyond limits

Researchers from Pohang University of Science and Technology and Sogang University developed an in situ interlocking electrode–electrolyte system that forms covalent chemical bonds between the electrode and electrolyte. Cells with the interlocked electrodes demonstrated an energy density of 403.7 Wh/kg and 1,300 Wh/L, representing more than 60% greater gravimetric energy density and nearly twice the volumetric energy density compared to typical commercial lithium-ion batteries. For more information, visit https://www.postech.ac.kr/eng/research/research_results.do.

3D printing of photothermal bioceramic scaffolds

Shandong University researchers developed a stereolithography-based fabrication method for a novel graphene oxide-doped photothermal bioceramic slurry. The conventional debinding process for stereolithography-printed components is conducted in air, but graphene oxide is susceptible to decomposition at elevated temperatures in an oxygen-rich atmosphere. This study employed the principle that polysiloxane can be pyrolyzed to produce SiOC ceramics under oxygen-free conditions, thereby circumventing the decomposition of graphene oxide. For more information, visit https://www.eurekalert.org/news-releases/1088263. ■

Navigating restrictions on Ukrainian clay: Researchers appraise the potential of European and Middle Eastern alternatives

Since the 1990s, Ukrainian clay gained a reputation around the world for its purity and good consistency. There are currently around 40 recognized refractory and ball clay deposits in Ukraine amounting to more than 600 million metric tons in resources, with most deposits concentrated in the Donbas region, near Donetsk, eastern Ukraine, according to an IMFORMED article.

When Russia invaded Ukraine in February 2022 and the country could no longer export its clay, tile manufacturers rushed to find alternative sources of clay. But as explained in a May 2022 *Ceramic Tech Today* post, finding new sources was extremely challenging given the special qualities of Ukrainian clay, which led to shortages of very white and large-format tiles.

With sky-high demand for high-quality clay, some manufacturers are considering reformulating their tiles based on clay in local deposits. Below are two studies that investigated alternative clays in Europe and the Middle East.

Investigating the potential of red clays in porcelain stoneware production

Researchers from the University of Modena and Reggio Emilia and the Institute of Science, Technology, and Sustainability for the Development of Ceramic Materials in Italy conducted a comprehensive characterization of two Italian clays to determine their suitability for porcelain stoneware production.

The clays come from quarries located near the town of Sassuolo, which lies at the heart of the Italian ceramic industry. The clays here are iron-rich (~7% Fe_2O_3), which can lead to well-known issues in ceramic tile production, such as warping and bloating during firing.

The researchers used wavelength-dispersive X-ray fluorescence spectrometry to reveal the clays' mineralogical composition. They then used methods such as thermogravimetric and thermo-differential analyses to fully characterize the clays during each step of tile production, from milling to firing.

They compared the results to those from a conventional iron-rich (~3% Fe_2O_3) German red clay. For context, the most widespread and commercially available iron-rich ball clays come from Westerwald, Germany, which is the second largest supplier of clays for the Italian ceramic tile industry. The researchers explain that this comparison "will help in distinguishing between the effect due to the presence of iron and to the different mineralogical compositions."

The mineralogical characterization revealed that the Italian clays did not contain any organic matter and had only a low amount of sulfur. These findings are "particularly important" because organic matter can cause undesired effects in tiles properties, such as color changes, reduced mechanical strength, and increased fire loss, while the presence of sulfides can lead to unwanted gas emission during firing, the researchers explain.

Credit: David von Diemar, Unsplash

Red may become the new "white" for ceramic tiles if Ukraine remains unable to export its high-quality clay.

The data collected during tile production showed that partially substituting the iron-rich Italian and German clays for classic ball clays in porcelain stoneware did not cause severe technological bottlenecks, though it did affect the process. The grindability worsened when using 20–35% of the low-plasticity German clay, while the rheological behavior of the slip worsened when using 10–20% of the highly plastic Italian clays.

"Both drawbacks can be easily overcome by increasing the milling time and the amount of deflocculant, respectively," the researchers write.

Using iron-rich clays noticeably affected the firing behavior, however. The German clay required an increase of the sintering temperature, while the Italian clays required a reduction of the firing temperature. The researchers note that "a study of the role of iron in the vitrification path and sintering kinetics is necessary" to fully understand why the clays had this effect.

While all previously described effects can be accounted for by modifying the processing parameters, the effect that cannot be easily overcome is the change in color. The iron-rich clays resulted in darker and reddish tiles, in contrast to the bright white tiles that are produced using Ukrainian clay.

But with the current constraints on the supply chain, it is likely that red will need to "become the new 'white'," says Brendan Clifford, co-CEO of Portugal-based Mota Ceramic Solutions, in the IMFORMED article.

The paper, published in *Applied Clay Science*, is "Reappraisal of red clays in porcelain stoneware production: Compositional and technological characterization" (DOI: 10.1016/j.clay.2024.107291).

Turkish clay demonstrates potential for white tile manufacturing

Researchers from Spain and Türkiye investigated the potential of clay sourced from the Afyon region of Türkiye as a possible alternative to Ukrainian clay.

Commercially known as "Afyon clay," this material is located around the village of Alanyurt, near the city of Afyonkarahisar. The clay here comes in three forms: white colored (mostly illite clays), beige and creamy (kaolinite-dominated clays), and green-pale or green (contains smectitic clays). Supply companies usually operate all the clay groups together, marketing them as a single product of Afyon clay.

Studies exist on the origin and geological structure of these deposits. But practically no works consider the physico-chemical characterization of this clay nor its possible application in tile manufacturing.

In the recent study, the researchers used commercial samples of Afyon and Ukrainian clays supplied by Çanakkale Seramik, the company known for being the first Turkish ceramic tile manufacturer, to determine Afyon clay's potential as a replacement.

First, they characterized the Afyon and Ukrainian clays using chemical (X-ray fluorescence spectrometry) and mineralogical (X-ray diffraction) methods, followed by laser diffraction to determine the particle size distribution. They also performed thermal analysis to obtain the thermogravimetric curves and the differential scanning calorimetry curve.

Then, they investigated the Afyon and Ukrainian clays' rheological behaviors by determining the deflocculation curve at a given solids content using a twist wire viscometer. They also determined the Atterberg plastic index via indentation, as well as assessed the clays' behaviors during pressing and firing.

The researchers found that although some properties of the Afyon clay differed from those of the Ukrainian clay, its behavior during the different stages of processing, milling/deflocculation, pressing, and firing were similar to that of the Ukrainian clay.

In addition, when they substituted Afyon clay into a tile composition traditionally based on Ukrainian clay, the fired body demonstrated only a slight decrease in whiteness. However, the researchers attributed this effect to the presence of Istanbul clay in the composition rather than the Afyon clay.

"Consequently, it can be concluded that a porcelain tile composition can be designed using Afyon clay as the major clayey component, adapting adequately to the requirements demanded in industrial practice," the researchers conclude.

The open-access paper, published in *Boletín de la Sociedad Española de Cerámica y Vidrio*, is "On the use of Afyon clay in Ukrainian clay-free compositions for porcelain tile manufacture" (DOI: 10.1016/j.bsecv.2024.05.002). ■

Vibrating-rod viscometers help rapidly assess and control clay slips

Researchers from the Instituto de Carboquímica and the University of Zaragoza in Spain, along with a colleague from viscometer manufacturer Sofraser in France, investigated the potential of using a resonance vibrating-rod viscometer (VRV) as a process control device in clay manufacturing.

As noted in the "Navigating restrictions" story on the previous page, variability in clay composition can greatly affect the processing parameters, for example, requiring higher firing temperatures or more intense grinding procedures. Thus, to minimize potential technological bottlenecks during processing, manufacturers must have a deep understanding of the materials they are using and effective quality control systems.

Viscometers are instruments used to measure a fluid's viscosity. Because clays are typically processed in concentrated aqueous dispersions called slurries or slips, viscosity measurements are a key parameter in quality control.

Compared to other vibrational viscometers, VRVs offer several advantages, including excellent tolerance to variations in fluid level and minimal sensitivity to external vibrations. Additionally, VRVs operate at around 300 Hz, which ensures a limited influence of shear rate on viscosity data.

For this study, the researchers used a VRV to monitor the viscosity of a concentrated clay dispersion during stirring and during its conformation inside a plaster mold. The VRV results were compared with data obtained from a widely used rotational viscometer.

The results showed that VRVs can accurately assess rapid changes in a dispersion's viscosity, thus underscoring its potential for real-time process control in slip tanks.

So, even though rotational viscometers are widely used in various industries, the adaptability of VRVs to different process conditions and environments "makes it a versatile tool for process control in the ceramics industry, in particular for slip conditioning and casting in sanitaryware production," the researchers conclude.

The open-access paper, published in *Applied Clay Science*, is "Controlling clay slips with a process vibrational viscometer" (DOI: 10.1016/j.clay.2024.107447). ■

Glass art exhibition explores the history and implications of genetic food modification

Glass can be used as a medium to engage with difficult topics, such as understanding the virus that causes COVID-19 (https://ceramics.org/COVID-glass) and offering a way to handle the grief resulting from so many losses (https://ceramics.org/glass-grief). For farmer and artist Michael Meilahn, he uses glass to explore the history of a topic that is very contentious in modern times: genetic food modification.

Born into a Wisconsin farm family, Meilahn originally entered the University of Wisconsin-River Falls to study agriculture. However, after realizing agribusiness was not his passion, he switched his major to art, which introduced him to the world of glass blowing. He subsequently spent a quarter abroad in Germany working with glass legend Erwin Eisch, considered a founder of the studio glass movement in Europe.

After graduation, Meilahn volunteered with the Peace Corps and spent a year in Bolivia learning the agricultural traditions of indigenous cultures. He then returned to the U.S. and earned an M.S. in art from Illinois State University.

Meilahn finally made his way back to the family farm to work the land. But he also built a studio there so he could continue glass blowing as time allowed.

According to Meilahn's website, his interest in genetic food modification began in 1996, when he planted his first genetically modified seed on the farm. This interest culminated in the creation of Primordial Shift, an exhibition that explores the history and implications of genetic engineering through 32 hand-blown glass ears of corn. Meilahn chose corn as the focus because "corn is broadly iconic these days in terms of food, agribusiness, and culture," according to his website.

Credit: Milwaukee PBS, YouTube

Michael Meilahn stands next to some of the glass corn used in his Primordial Shift exhibition about genetic food modification.

Since 2022, the Primordial Shift exhibition has been touring around the U.S. The next stop will be Rochester Art Center (Rochester, Minn.) from June 1–Sept. 30, 2025.

Learn more about Michael Meilahn and the Primordial Shift exhibition in the video at https://www.youtube.com/watch?v=yxd5-R8GPho. ■

Stabilizing earth-based concrete: Food additive effectively modifies kaolinite rheology

Columbia University researchers led by ACerS member Shiho Kawashima investigated the potential of the common food additive xanthan gum as a stabilizer for earth-based concrete.

Xanthan gum stands out among bio-based stabilizers for its exceptional effectiveness in enhancing soil durability and mechanical performance. It also possesses a notably lower market price compared to other commonly used biopolymers, such as gellan gum, agar, and guar gum.

Despite its well-known effects on soil mechanics, however, "the impact of [xanthan gum's] interaction on the rheological performance of clay suspensions and its subsequent implications for advanced applications like 3D printing of earth-based materials remain largely unexplored," the Columbia University researchers write in the recent paper.

To bridge this gap in understanding between microscopic clay–polymer interactions and macroscopic rheological and printing behavior, the researchers used a mixture consisting of kaolinite clay, Ottawa test sand, water, and xanthan gum. First, they conducted microstructural characterizations of the sample composition, and then they varied the xanthan gum concentrations and different water/clay ratios to observe how these changes affected key rheological properties. They correlated these findings with the identified microstructural interactions.

A main takeaway was that both xanthan gum and kaolinite share high negative surface charges, leading to electrostatic repulsion between them in suspension. So, xanthan gum did not directly bind to the kaolinite particles, but its presence impeded the free movement of kaolinite particles, "thereby obstructing their ability to form flocs and consequently leading to delayed sedimentation and promoting dispersion," the researchers write.

Following these tests, the researchers investigated the extrudability and buildability of the sample earth-based concrete using syringe pump extrusion tests and 3D printing experiments. They determined that at 0.6 wt.% xanthan gum, there begins a gradual rise in yield stress and viscosity due to polymer network formation, which enhances buildability. At 5 wt.% xanthan gum, the mixture's yield stress and viscosity reach a state that is ideal for 3D printing.

The paper, published in *Cement and Concrete Research*, is "Rheology, 3D printing, and particle interactions of xanthan gum-clay binder for earth concrete" (DOI: 10.1016/j.cemconres.2024.107551). ■

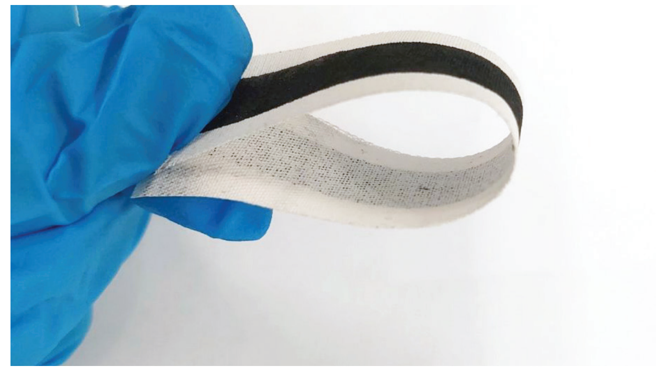
Biodegradable smart textiles provide both sustainability and functionality

Researchers led by the University of Southampton and UWE Bristol developed a new biodegradable smart textile that demonstrates sustainability does not have to come at the cost of functionality.

As described in the open-access paper, their SWEET technology, which stands for "Smart, Wearable, and Eco-friendly Electronic Textiles," consists of the following components:

1. **Sensing layer** consisting of either inkjet-printed graphene or a biodegradable conductive polymer called PEDOT:PSS. The ink-jet printing process is environmentally friendly because it deposits the exact amount of functional materials required with almost no material waste, as well as uses less water and energy compared to conventional screen printing. Furthermore, the graphene ink was prepared using a solution of graphite powder and deionized water because water-based inks are typically nontoxic and less detrimental to human health.
2. **Interface layer** consisting of an insulator paste, which was applied to the base fabric before inkjet printing of the sensing layer. This layer allowed successful printing of continuous conductive tracks.
3. **Base fabric** consisting of a textile called Tencel, which is made from biodegradable wood with appropriate softness, breathability, and flexibility. This textile is considered renewable because it is fabricated using a closed-loop production method with a higher resource efficiency (99% recovery rate for water and solvent) and little negative environmental impact.

To test the sensing capabilities of this smart textile, SWEET was integrated with gloves using double-sided adhesive tape, ensuring a secure and stable connection between the sensor and glove materials. Five human subjects wore these gloves to measure their electrocardiogram signals and skin temperature. Results confirmed the material can effectively and reliably measure both heart rate and temperature at the industry standard level.


Credit: Marzia Dulal, University of Southampton

Strip of the inkjet-printed, biodegradable smart textile.

To measure the smart textile's biodegradable properties, the SWEET sensors were buried in an incubator in 150 mm of soil with a 6.5 to 6.8 pH, a temperature of 29°C (84°F), and a relative humidity of around 90%. After four months, the fabric had a 48% decrease in weight and 98% decrease in strength, which indicated a relatively rapid and effective decomposition.

Furthermore, a laboratory-scale life cycle assessment, based on ISO 14040 and 14044 standards, revealed the graphene-based electrodes had up to 40 times less impact on the environment than standard electrodes and were three times less impactful than the PEDOT:PSS ones.

The open-access paper, published in *Energy & Environmental Materials*, is "Sustainable, wearable, and eco-friendly electronic textiles" (DOI: 10.1002/eem2.12854). ■

The intricate sample loading process shown here is required when using thermogravimetric analysis with differential scanning calorimetry for the thermal characterization of battery and energy storage materials.

Credit: UL Research Institutes

Powering a safer future with novel energy solutions

By Wan Si Tang

Global energy demand rose by 2.2% in 2024,[1] and it is projected to increase by 15% more by 2050 as the world population grows to 10 billion.[2]

Because modern energy services are crucial to individual human well-being and to a country's economic development, reliable and affordable access to electricity is paramount. However, because electricity is increasingly produced by renewable intermittent sources, such as hydro, wind, and solar,[1] it is essential to develop efficient and safe electrochemical conversion and storage devices.

Today, rechargeable batteries and electrification technologies have become ubiquitous. In 2022, 91.4% of the world had access to electricity,[3] and global electric car sales exceeded 17 million in 2024, reaching a sales share of more than 20%.[4]

A battery cell is made up of several main components (Figure 1a): anode (negative electrode), cathode (positive electrode), liquid electrolyte (ion conductor), and porous separator (electrically nonconductive, ion-permeable membrane).[5] The first battery ever developed, the voltaic pile, consisted of alternating discs of zinc and silver separated by paper soaked in salt water.[6] More recent battery advances follow the progress of secondary lithium-ion batteries (LiBs), with the first commercial cell produced by Sony Group Corporation in 1991.[7]

In modern rechargeable batteries, lithium ions shuttle internally between the anode and cathode through the porous separator during charge and discharge cycles, facilitated by the liquid electrolyte. The anode active material is graphite, which can reversibly accept and release lithium ions. The cathode is a lithium-rich ceramic oxide-based material, typically lithium iron phosphate ($LiFePO_4$, LFP) or layered lithium metal oxides ($LiMO_2$). In the latter case, the M encompasses single metals, such as cobalt ($LiCoO_2$), or multiple metals in stoichiometric ratios, typically nickel, manganese, and cobalt (e.g., $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$, NMC811). The electrolyte solution

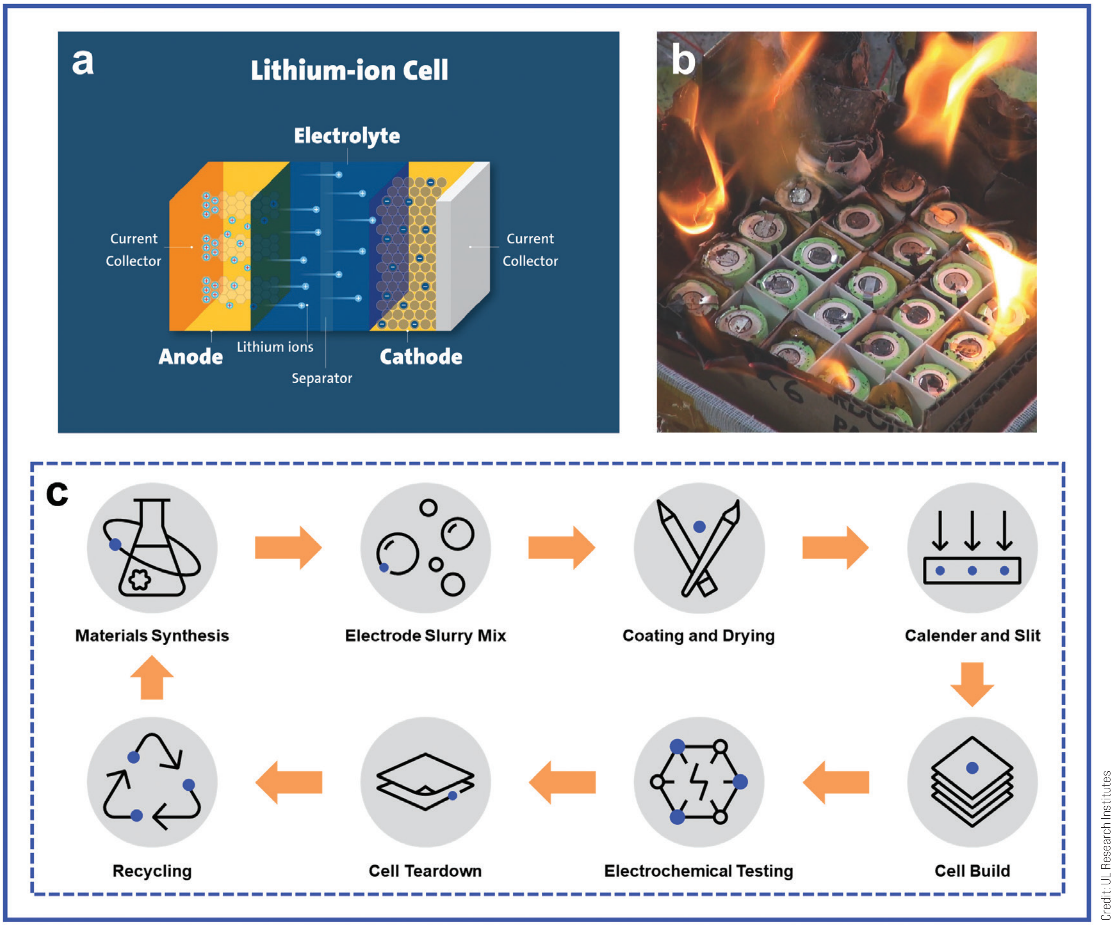


Figure 1. a) Basics of a LiB cell, b) battery fire resulting from thermal runaway, and c) LiB cell manufacturing process.

contains lithium salts such as lithium hexafluorophosphate ($LiPF_6$) dissolved in carbonate-based solvents, for example, ethylene carbonate, ethyl methyl carbonate, or dimethyl carbonate. The separator is a polymeric membrane made from polyethylene and polypropylene.

Although LiB energy storage products are widely used in many commercial markets, a complete understanding of their hazards is still lacking; as a result, safety considerations have often been neglected.[8] In 2018, the U.S. Consumer Product Safety Commission reported more than 25,000 accounts of overheating or fire incidents that occurred within a span of five years in more than 400 different consumer products powered by lithium batteries.[9] More recently, specific databases have been initiated to record and track incidents related to battery energy storage systems failure,[10] as well as trends occurring in aviation.[11]

These incidents have made the term "thermal runaway" common in current public lexicon. It refers to the phenomenon in which a LiB enters an uncontrollable, self-heating state, which can result in eventual battery failure through extremely high temperatures, violent cell venting, smoke, and fire (Figure 1b).[12]

Thermal runaway can be caused by internal cell failure, such as an internal short circuit, which is an unintentional electrical connection between the anode and cathode.[12] Because battery manufacturing is a multistep process (Figure 1c), stringent requirements are necessary at every stage to fabricate high-quality cells. The lack of quality controls can create defects with cascading catastrophic effects that compromise the overall integrity of the cell, manifesting as internal failure during use.[8]

Thermal runaway can also be caused by external conditions, including electrical, mechanical, or thermal faults, or when the battery's use is beyond the boundaries of its nominal specifications provided by the manufacturer for current, voltage, and temperature. Such usage can trigger unintended but detrimental side reactions and products.[8,12] In addition, the failure of the battery management system and thermal management system, which are safety mechanisms designed to monitor and control circuitry and temperature, respectively, can lead to catastrophe.[8]

Hence, to better understand the electrical and thermal safety hazards, it is necessary to identify and mitigate the potential risks through scientific methods.

Working toward a safer world at ESRI

At the Houston-based Electrochemical Safety Research Institute (ESRI), a unit of UL Research Institutes (ULRI), we are advancing the safer design and deployment of energy storage and energy generation technologies through rigorous fundamental and applied scientific studies. Understanding the science behind the causes of safety risks in electrochemical energy provides relevant and accurate solutions that reduce or eliminate potential hazards posed by high-energy and high-power energy storage and energy generation systems.

Powering a safer future with novel energy solutions

Our discovery-driven research explores the performance and safety of energy technologies to mitigate risks.[13] It centers on gathering data throughout the whole design process, from materials and cells to commercial battery packs and modules. To investigate the potential risks of current and future battery chemistries, the Novel Materials and New Energy Forms team at ESRI focuses on the research and development of both materials and low-capacity, cell-level technologies by studying new chemistries and novel systematic engineering methods related to energy storage and conversion with early-technology readiness levels through a safety lens.

Besides strong technical expertise, ESRI also has the facilities to study the performance and safety of energy-related materials. These facilities include multiple dry boxes with low water- and oxygen-controlled environments for sample manipulation, as well as instruments for various types of measurements, synthesis, cell fabrication, and testing (Figure 2).

In the race for safer batteries, the continual expansion of ESRI's capabilities, including both equipment and talent, allows us to be on the cutting edge of safety science research and development. But what constitutes safety research at a materials level?

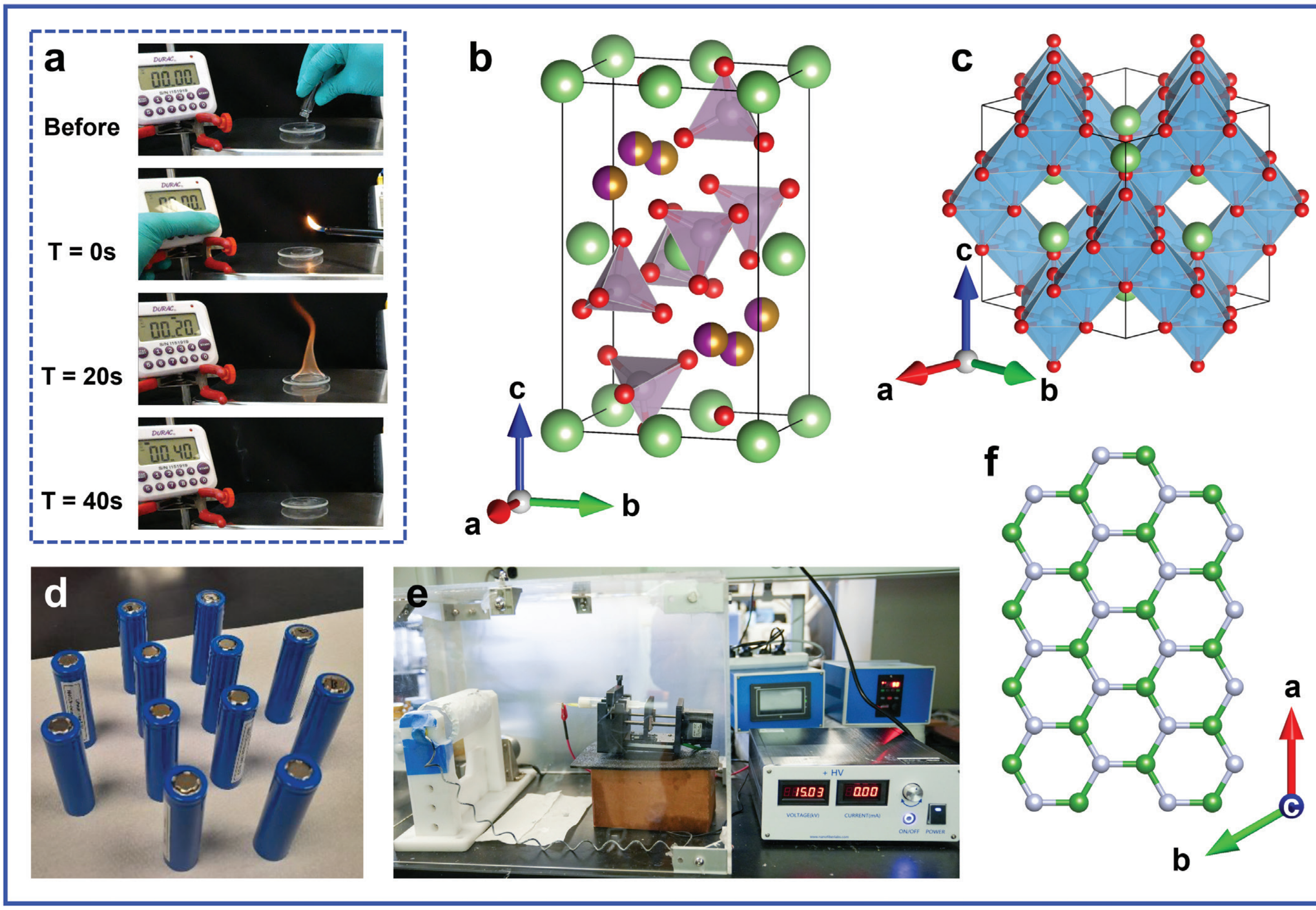
First, the intrinsic and fundamental thermal properties describe how materials respond to temperature. Thermal conductivity indicates the ability of a material to transfer heat. The specific heat capacity, which can be measured from differential scanning calorimetry, is the amount of thermal energy absorbed or released to raise the temperature of a unit mass of a substance by one degree Kelvin.

Second, flammability parameters describe how materials respond to an ignition source.[14] Flash point is defined as the lowest temperature at which a volatile substance evaporates to form an ignitable mixture with air in the presence of an ignition source. The self-extinguishing time describes the ability of a material to cease burning after the removal of an ignition source.

Third, hazardous and gaseous species characterization allows the understanding of unfavorable products harmful to human health during the manufacturing process or from undesirable battery failure reactions. Thermogravimetric analysis elucidates a material's weight loss as a function of temperature, and Fourier-transform infrared spectroscopy and gas chromatography with mass spectrometry identify chemical bonds and chemical species, respectively. When these techniques are

Credit: UL Research Institutes

Figure 2. Some examples of the research and development capabilities at ESRI for materials performance and safety: a) in-house fabricated coin cell assembled in the dry box, b) powder X-ray diffraction sample loading, c) sample loading for thermogravimetric analysis with differential scanning calorimetry, d) calendering of in-house fabricated electrode, e) Karl Fischer moisture analysis titrator sample loading, f) vacuum sealing of in-house fabricated pouch cells, g) connecting pouch cells in pressure stacks for electrochemical testing, and h) placing an 18650 cylindrical cell in a temperature chamber for electrochemical characterization.



Credit: a,b,c,f) UL Research Institutes; e) Xiaonan Shan; d) Palani Balaya

Figure 3. a) Still images taken from the self-extinguishing time experiment for electrolyte studies at different times. b) The crystal structure of orthorhombic LMFM′P (green, red, purple/gold, and lilac balls represent lithium, oxygen, manganese/iron/magnesium, and phosphorous, respectively, with lilac [PO_4] tetrahedra). c) The crystal structure of cubic LTO (green, red, and blue balls represents lithium, oxygen, and titanium, respectively, with blue [TiO_6] octagons). d) Lab-fabricated 18650 cylindrical cells. e) The electrospinning setup. f) The structure of an hBN layer (green and silver balls represent boron and nitrogen, respectively).

coupled together, the data can provide in-depth information about the possible reaction pathways and products formed among battery materials during thermal runaway, especially when these safety science techniques are applied to simulate a full cell with combined battery components.

Innovations in lithium-ion battery technology

At ESRI, efforts to address the issue of thermal runaway in current LiB technology center around various cell components, including electrolyte additives, LiB cathode and anode active materials, and separator membrane material modifications.

Flame-retardant ions as electrolyte additives

To improve the performance of LiBs, small amounts of additives are included in the electrolyte to enhance the battery's performance, cyclability, thermal stability, safety, and various physical properties. Because the highly volatile and flammable organic electrolyte becomes an unstable component when a LiB goes into thermal runaway, flame-retardant additives that reduce burning time and increase the electrolyte solution's flash-point temperature can improve its safety during this phenomenon.

A project with John Protasiewicz, Hurlbut Professor of Chemistry at Case Western Reserve University (Cleveland, Ohio), focuses on the enhanced performance and safety of novel flame-retardant ions (FRIons) with fire-retardant properties as safer electrolyte additives. Electrolyte formulations with and without the presence of these FRIon salts are compared.

Other than ensuring chemical and electrochemical stability, flammability parameters are particularly important to the safety of liquid electrolytes. For example, Figure 3a shows the self-extinguishing time experiment on the baseline electrolyte sample of 1.2 M $LiPF_6$ in an ethylene carbonate–ethyl methyl carbonate (3:7 wt.% ratio). When 1 gram of the electrolyte was ignited in open-air, the time required for the flame to extinguish was recorded: The baseline electrolyte exhibited a burning duration of approximately 40 seconds after ignition. By comparison, the modified electrolytes containing the FRIon additives showed significantly shorter flame durations due to the formation of thermally stable protective layers, which prevented the combustion of the baseline electrolyte.

New lithium-ion battery electrode active materials

Battery active materials beyond the typical ones used in commercial LiBs, such as graphite anodes and LFP or $LiMO_2$ cathodes, are also explored through the scaling-up of in-house synthesized magnesium-doped lithium manganese iron phosphate ($LiMn_{1-x-y}Fe_xMg_yPO_4$, LMFM′P, Figure 3b) cathode for pairing with lithium titanate ($Li_4Ti_5O_{12}$, LTO, Figure 3c) anode. These electrodes are being used to fabricate cells similar to commercial 18650 cylindrical cells (Figure 3d) for fast-charging and high-power applications in collaboration with Palani Balaya, associate professor of mechanical engineering at the National University of Singapore.

Olivine LMFM'P, which is isostructural to LFP, has a similar theoretical specific capacity (170 mAh/g) but offers a higher voltage for lithium intercalation to achieve increased energy densities. Although spinel LTO has a lower theoretical specific capacity (175 mAh/g) than graphite, it is highly stable with zero volume expansion and contraction during the lithium interaction process; these properties allow it to handle faster charge and discharge rates for high-power-density applications.

Besides assessing the battery performance in small capacity coin cells, Balaya and his group fabricated cells in a commercial 18650 cell configuration to better understand the scale-up requirements of this chemistry pairing. Moreover, the safety of these materials and cells through thermal properties, flammability parameters, and hazardous and gaseous species characterization will be further examined.

Hexagonal-boron-nitride-doped polyvinylidene-fluoride separator membrane

The polymeric separator, which is located between the anode and cathode in a cell, plays an integral role in battery safety. Because separator failure such as puncture or shrinkage can cause internal short circuits, advances in separator materials (e.g., enhanced thermal stability, shutdown mechanisms, and flame-retardant coating) are crucial for safer battery operation.

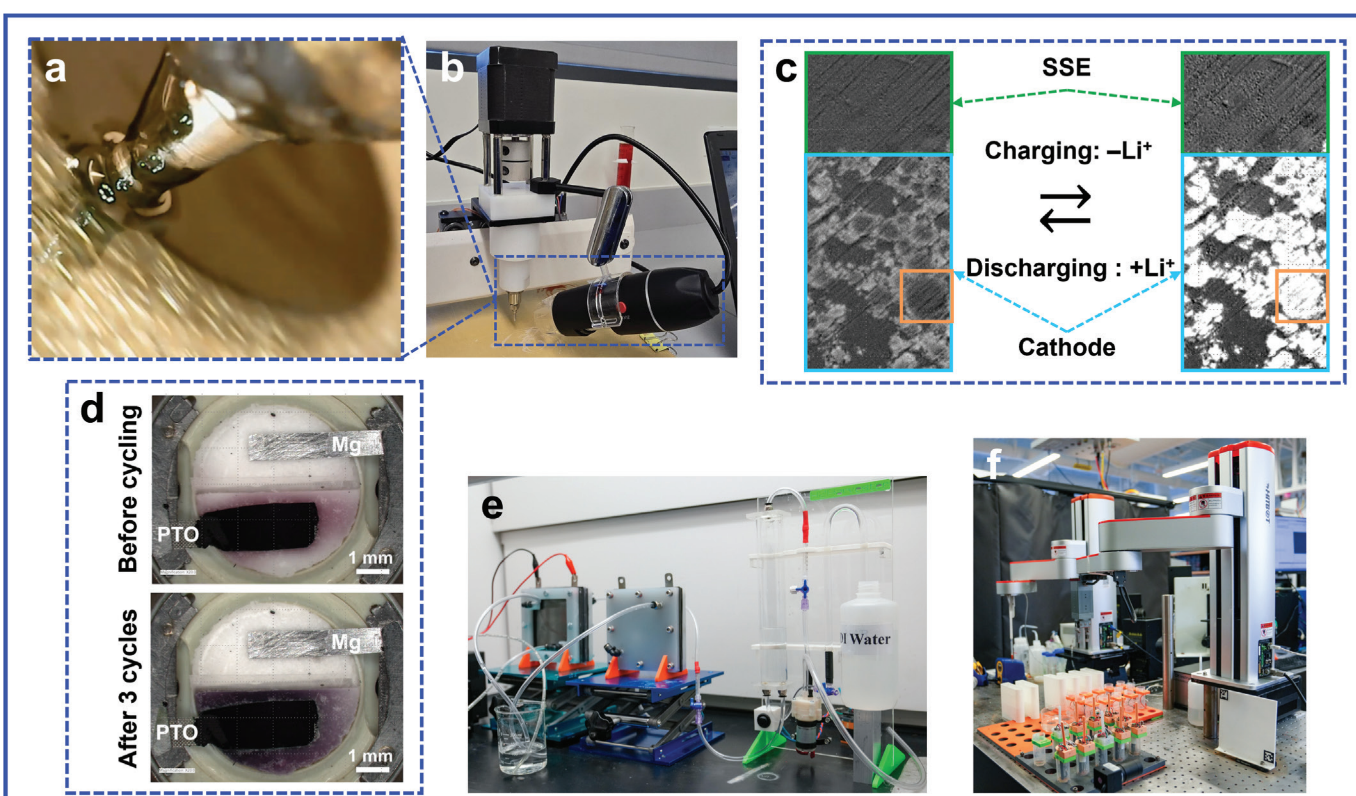
At ESRI, research scientist Bicy Kottathodi is using electrospinning, a method to produce micro- and nanofibers from polymer solutions, to synthesize polyvinylidene-fluoride (PVDF) membranes. These porous, flexible membranes exhibit high mechanical integrity and ion transport capability (Figure 3e), making them a promising polymer separator candidate for LiBs.

In addition, hexagonal boron nitride (hBN, Figure 3f) is a thermally conductive and electrically insulating material. When incorporated into the PVDF membrane, it can improve localized heat dissipation to reduce the risk of hot spots and mitigate thermal runaway.

The aim of this study is to design a thermally stable hBN-PVDF composite separator by optimizing the electrospinning conditions and evaluating the membrane through materials characterization, electrochemical performance, and safety properties. Its enhanced wettability, ionic conductivity, flame retardancy, and mechanical and thermal stability are compared with conventional polyolefin-based separators.

Alternatives beyond the lithium-ion battery paradigm

Moving beyond present-day, state-of-the-art LiB research, ESRI is also investigating unique battery fabrication methods, potentially safer solid-state batteries (SSB) and



Credit: a,b) Zheng Fan; c,e,f) Xiaonan Shan; d) Reprinted with permission from Ren et al., *ACS Nano*.[15] Copyright 2025 American Chemical Society

Figure 4. a) Still image of the 3D printing process. b) Modification of the 3D-printer setup with a camera attachment to capture the process in Figure 4a. c) Optical response of NMC cathode particles in a solid-state battery (Li-In anode | Li_6PS_5Cl electrolyte| NMC cathode) during operando microscopy. d) Operando optical characterization of a magnesium battery (Mg anode | MBF electrolyte | PTO cathode) with Mg-SPEEK separator.[15] e) The electrolyzer setup for catalytic water-splitting and gas collection. f) The robotic platform.

magnesium-based batteries, and alternative green hydrogen production as part of a broader strategy to enable safe and sustainable energy solutions.

3D printing of anode-free solid-state batteries

SSBs are constructed by substituting the highly volatile and flammable organic electrolyte and polymer separator in conventional LiBs with a single layer of solid electrolyte, which is an ionic conductor and electrically insulating material. In addition, anode-free refers to the absence of an anode during the initial battery assembly, with the lithium-rich cathode instead being the lithium source.

Together with Zheng Fan, assistant professor of mechanical engineering technology at the University of Houston, the goal of this collaboration is to investigate 3D printing as an alternative cell manufacturing technique to fabricate viable anode-free SSBs. 3D printing or additive manufacturing is a method that can enable thinner battery layers and potentially achieve higher density cells as compared to those from conventional battery manufacturing.

The primary development of this technology is optimizing slurries for the 3D-printed solid-state electrolyte and interlayer (between the copper current collector and solid-state electrolyte), which will be paired with a tape-casted cathode for full cell electrochemical characterization. Figure 4a shows the printed interlayer using a modified 3D printer setup with a camera attachment to capture the process (Figure 4b).

Concurrently, we are also teaming up with another institute at ULRI, the Chemical Insights Research Institute (Marietta, Ga.), which specializes in the toxicological assessment of hazardous chemical emissions, to further evaluate the detection of any unfavorable and undesirable products emitted during the 3D printing process for human health safety improvements.

Operando studies of solid-state batteries

The first collaboration with Xiaonan Shan, associate professor of electrical and computer engineering at the University of Houston, revolves around understanding the performance and safety of the emerging SSB technology through operando investigations, which are critical to identifying the interfacial reactions and resistances between the battery layers during electrochemical cycling. In this study, specialized setups are developed for operando optical microscopy and Raman spectroscopy techniques. Other than room-temperature experiments, cycling at high temperature to understand the thermal behavior at the electrode–electrolyte interface will help identify thermal instabilities and failure mechanisms.

Figure 4c follows a full SSB cell undergoing electrochemical testing with two optical images zoomed in on the layers of the solid-state electrolyte (green boxes) and cathode (cyan boxes) at different states of charge. To guide the eye, the same NMC cathode particle is also highlighted in orange boxes. The left image shows the pristine cell.

During charging, as lithium ions are extracted from the NMC cathode, the optical response of the cathode particles changes: The particles get brighter, starting a gradient from the edges until the whole particle is radiating light, as shown on the right image. The opposite is observed during discharge: As the lithium ions are reinserted into the NMC, the particles become less bright. This observation illustrates that the reversible optical changes correlate well with the movement of lithium ions during cycling and, therefore, suggests brightness is a good tool to provide visualization and evidence of lithium ion diffusion and migration under various conditions.

Selective membranes for magnesium batteries

Compared to lithium technology, magnesium-based batteries have the potential to provide higher energy density and improved safety due to reduced dendrite formation. The investigations to identify, characterize, and optimize membrane separators with good magnesium-ion conductivity and selectivity for an established system (magnesium anode, magnesium alkoxyl fluorinated borate electrolyte, and pyrene-4,5,9,10-tetraone organic cathode) were successfully examined with Yan Yao, the Hugh Roy and Lillie Cranz Cullen Distinguished Professor of electrical and computer engineering at the University of Houston.

The PTO cathode can accept two stoichiometric magnesium ions to form Mg_2PTO through a two-step electrochemical reaction with an intermediate cathode species, Mg_1PTO, which is soluble and has a distinct purple color. This reaction allows optical microscopy to be an effective technique for studying its diffusion evolution.

Figure 4d demonstrates that the fluorine-free magnesiated sulfonated poly(ether ether ketone) (Mg-SPEEK) selective membrane facilitated magnesium ion conduction while effectively rejecting soluble organic species during full cell cycling through operando optical characterization. Because there is no bleeding of color into the magnesium anode side, Mg_1PTO is effectively confined to the PTO cathode region, indicating that the Mg-SPEEK membrane was instrumental in preventing the cathode–anode crosstalk.[15]

Because this technology is nascent, next steps include understanding the mechanisms of the stripping-induced magnesium pulverization and evaluating the safety performance of this promising battery chemistry.

Green hydrogen generation from sea water using alternative catalysts

Hydrogen is a promising energy carrier that can effectively store and deliver energy. It is produced through various methods, though so-called "green" hydrogen is the most environmentally friendly, as it is produced by renewable energy sources with near-zero greenhouse gas emissions.

Water electrolysis is a clean process to generate green hydrogen and oxygen. Platinum metal is a typical high-performance catalyst used in the hydrogen evolution reaction cathode process. However, it is an expensive, rare, and precious metal.

This research project is ESRI's second collaboration with University of Houston Professor Shan to develop cheaper substitutes as alternative catalysts for the hydrogen evolution reaction process to effectively generate green hydrogen during the (sea) water-splitting reaction. Figure 4e shows the lab-scale electrolyzer setup used for synthesis and characterization of the catalysts, as well as to understand the lab-based viability, scalability, and safety requirements relating to electrolysis. Because the alternative catalysts under investigation include phosphorus-based alloys with multiple metals, replacing the traditionally labor-intensive, trial-and-error experimentation process with an automatic robotic platform (Figure 4f) allows the compositions of the catalysts to be optimized within a shorter time. A video showing the different elements of this project in action is available at https://www.youtube.com/watch?v=LeZGXjKqr_U.

Documentation and database building

The impact of science and engineering lies not only in research and development but also in the essential collection and dissemination of data. At ESRI, we are ensuring that documenting safety information and database building are a part of our discovery-driven research.

Electric Vehicles for American Low-Carbon Living program

Together with Sandia National Laboratories, the University of Maryland, Purdue University, as well as six other collaborators, ESRI is a part of the Electric Vehicles for American Low-Carbon Living (EVs4ALL) program, under the Department of Energy Advanced Research Projects Agency–Energy.[16]

One of the aims of this program is to perform failure mode and effects analysis (FMEA) on current and prospective, precommercialized battery technologies through a combination of experimental methodology and modeling framework regarding their thermal properties, and to produce a multiscale safety testing manual report. “Failure mode” refers to the way in which something might fail, and “effects analysis” studies the results of those failures. Together, the FMEA is a structured approach to identify and assess potential failures in a system, product, or process.

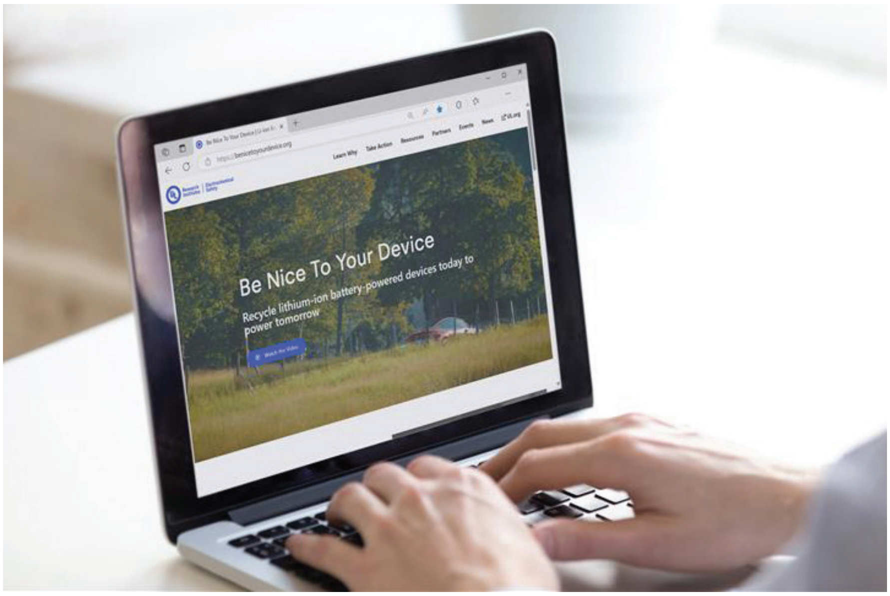
In this program, ESRI is applying the risk assessment tool toward a variety of battery technologies by combining experiments, literature, and knowledge to proactively anticipate potential issues, assess their impact, and develop strategies to mitigate or prevent them. This engagement highlights the need to ensure that safety, performance, and reliability of new battery chemistries are prioritized throughout the whole development process. The FMEA document facilitates informed decision-making for stakeholders, ultimately contributing to the successful deployment and adoption of advanced electric vehicle technologies.

Library (for) Battery Research and Reference (Internal ESRI)

Although our interests lie in pushing the envelope for safer novel battery technologies, in parallel, it is also essential to produce high-quality data in our research studies through optimized processes on well-established systems as a baseline comparison for new chemistries. The **Li**brary (for) **B**attery **R**esearch **a**nd **R**eference (**I**nternal **E**SRI) program, with the acronym LiBRaR(IE), is an internal project at ESRI with the goal of documenting a wide range of our laboratory standard operating procedures. This project includes

- Establishing a systematic database regarding battery materials and best practices;
- Developing and optimizing repeatable and reliable chemistry and engineering processes (e.g., electrode engineering, coin- and pouch-format cell fabrication, testing benchmarks, destructive physical analysis, design of experiments, and results analysis); and
- Generating in-house characterization data from various instruments on a commercial battery technology to serve as a reference for future studies.

Furthermore, our intention for this library goes beyond gathering data. The purpose is also to release and report the relevant information to other battery researchers through meetings (conferences and summits) and publications (peer-reviewed scientific journals and ULRI white papers).



Credit: UL Research Institutes

Figure 5. ESRI’s Be Nice To Your Device campaign promotes safe and sustainable LiB recycling. Learn more about the program by visiting benicetoyourdevice.org.

Prospective research projects and other ESRI endeavors

ESRI is interested in pursuing new projects as part of our expanding portfolio on safety, science, and engineering, and we look forward to research and development growth in more areas. Other pending projects include various collaborations on sodium-ion battery technologies (cathodes, liquid electrolytes, solid-state electrolytes, bipolar cell design) and upcoming internal investigations committed to developing the next-generation of sulfur and SSB chemistries, chemistry-specific material- and cell-level safety characterizations, and other energy storage and conversion materials related to hydrogen.

Other than the investigations into novel materials and new energy forms, ESRI also performs research on recycling, battery and hydrogen safety, and modeling.[13] It is also important to communicate our research findings outside the scientific community through outreach activities. One example of our public education and engagement initiatives is the Be Nice To Your Device campaign, which promotes safe and sustainable LiB recycling (Figure 5).

Driving energy research for a safe and sustainable future

As the world moves further into electrification and toward net-zero emissions, understanding the performance and safety of energy storage, conversion, and generation devices and systems is imperative.

At ESRI, our interest lies in energy safety across all points of the energy technology development process, from materials and cells to scaling commercially viable applications of lithium-ion batteries, future battery chemistries, and other renewable energy technologies. The multipronged scientific research taking place at ESRI and through various partnerships exemplifies the need to recognize the risks and drive solutions to reduce potential hazards.

Acknowledgments

The author deeply recognizes ESRI colleagues (J. A. Jeevarajan, V. R. Rikka, B. Kottathodi, T. Mullee, F. S. Gray, M. S. Ng, and M. R. Trujillo) and collaborators (P. Balaya, J. D. Protasiewicz, Z. Fan, X. Shan, and Y. Yao) for their review and suggestions.

About the author

Wan Si Tang is director of research for novel materials and new energy forms at the Electrochemical Safety Research Institute, a unit of UL Research Institutes (Houston, Texas). Contact Tang at wansi.tang@ul.org.

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Founding and future goals

Founded in 1894, UL Research Institutes (Evanston, Ill.) is a nonprofit research organization dedicated to advancing public safety through scientific discovery. From fire mitigation and air quality to safe energy storage and digital privacy, the UL Research Institutes team conducts rigorous independent research, analyzes safety data, and partners with experts to uncover and act on existing and emerging risks to human safety. Learn more about the organization and its research by visiting UL.org.

The Electrochemical Safety Research Institute (Houston, Texas), a unit of UL Research Institutes, was founded in 2015 and is led by Judy Jeevarajan, vice president and executive director. This unit specializes in advancing the safer design and deployment of energy storage and energy generation technologies. Learn more about the research being conducted at ESRI at UL.org/ESRI.

References

[1]International Energy Agency, "Global Energy Review 2025." Published March 2025. https://www.iea.org/reports/global-energy-review-2025

[2]ExxonMobile, "ExxonMobil Global Outlook: Our View to 2050." Published August 2024. https://corporate.exxonmobil.com/sustainability-and-reports/global-outlook

[3]World Bank, International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, and World Health Organization, "Tracking SDG 7: The Energy Progress Report 2024 (English)." Published 31 Dec. 2024. http://documents.worldbank.org/curated/en/099031225175211404

[4]International Energy Agency, "Global EV Outlook 2025." Published May 2025. https://www.iea.org/reports/global-ev-outlook-2025

[5]UL Research Institutes, "What are lithium-ion batteries?" Published 14 Sept. 2021. https://ul.org/research-updates/what-are-lithium-ion-batteries

[6]A. Volta, "XVII. On the electricity excited by the mere contact of conducting substances of different kinds. In a letter from Mr. Alexander Volta, F. R. S. Professor of Natural Philosophy in the University of Pavia, to the Rt. Hon. Sir Joseph Banks, Bart. K.B. P. R. S.," *Philosophical Transactions of the Royal Society of London* 1800, **90**: 403.

[7]A. Dhage, "SONY Lithium-ion batteries: World's first commercialized LiB 1991," Battery Design. Published 12 March 2023. https://www.batterydesign.net/sony-lithium-ion-batteries-worlds-first-commercialized-lib-1991

[8]J. Lamb et al., "New developments in battery safety for large-scale systems," *MRS Bulletin* 2021, **46**: 395.

[9]U. S. Consumer Product Safety Commission, "Status report on High Energy Density Batteries Project." Published 12 Feb. 2018. https://www.cpsc.gov/s3fs-public/High_Energy_Density_Batteries_Status_Report_2_12_18.pdf

[10]Electric Power Research Institute, "BESS failure incident database." Updated 17 March 2025. https://storagewiki.epri.com/index.php?title=BESS_Failure_Incident_Database&oldid=5702

[11]UL Standards and Engagement, "Advancing battery safety in aviation." https://mytripportal.org

[12]UL Research Institutes, "What causes thermal runaway?" Published 20 Aug. 2021. https://ul.org/research-updates/what-causes-thermal-runaway

[13]UL Research Institutes, "Ongoing research." https://ul.org/institutes-offices/electrochemical-safety/ongoing-research

[14]S. Hess et al., "Flammability of Li-ion battery electrolytes: Flash point and self-extinguishing time measurements," *Journal of The Electrochemical Society* 2015, **162**(2): A3084.

[15]W. Ren et al., "Fluorine-free ion-selective membrane with enhanced Mg^{2+} transport for Mg-organic batteries," *ACS Nano* 2025, **19**(5): 5781.

[16]A. Bates et al., "A multi-scale framework for advancing battery safety through early calorimetric analysis of materials and components," *The Electrochemical Society Interface* 2024, **33**(3): 69.

*All references verified as of June 23, 2025. ■

Processing limits of cermets for nuclear waste form application

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By Nathaniel Marrero, Samuel Gross, and S. K. Sundaram

In recent years, nations around the world have shown increasing interest in deploying advanced nuclear reactors by 2030 to meet rising energy needs and counter the environmental impacts of fossil fuels.[1]

The radioactive waste from commercial nuclear reactors and legacy weapons programs continues to be a concern, however. Scientists have investigated various waste treatment approaches and waste immobilization forms over the past several decades. Waste forms of interest include hydrocarbon-based materials, polymers, metals, cement or concrete, glasses, ceramics, and glass-ceramics.[2,3]

Currently, the most commercially viable methods for nuclear waste immobilization are cementation (mixing with cement) and vitrification (converting into glass).[2,3] Both of these forms can be easily tailored to contain a range of different waste streams, but they have some drawbacks. While cement waste forms are low cost and can be fabricated with water at ambient conditions, they have low waste loading percentages due to chemical and thermal limitations and can only handle low-level waste.[2] On the other hand, glass waste forms can immobilize both low- and high-level waste streams,[3,4] but manufacturing them requires high melting temperatures. Mixing the glass-forming constituents with radionuclides can decrease the melting temperature, but it also lowers the waste loading percentage.[4]

Understanding the benefits and limitations of these various waste forms allows for innovation and discovery of new material systems for nuclear waste immobilization. For example, cermets, or the family of ceramic–metal composites often used in cutting tools and electronics, could combine the best qualities of both ceramics and metals.

Ceramic waste forms have been the focus of many studies due to their stable crystal structures, which mimic natural minerals with proven stability over extended geological time scales. However, ceramic waste forms are not commonly used due to high processing temperatures comparable to or in excess of those required for glass waste forms, and they require long-term testing to determine their viability.[1,2] On the other hand, metal waste forms are uncommon because metallic wastes are prone to reacting with environmental stimuli, such as water and oxygen, resulting in corrosion and leakage of the toxic wastes within a short time frame.

Cermets consist of both ceramic and metallic phases.[5–8] This structure gives cermets the high melting point and wear resistance of ceramics along with the toughness and ductility of metals. Thanks to these unique properties, cermets are a promising candidate to contain both low- and high-level waste streams from different advanced reactor types in a single waste form.[9]

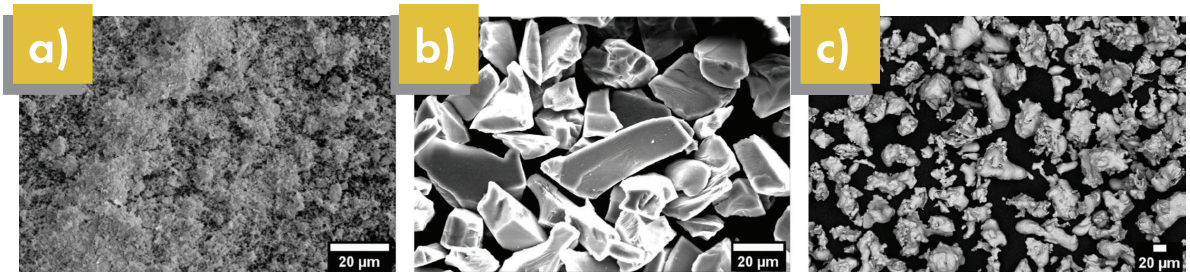


Figure 1. Scanning electron microscopy images of a) zirconia, b) silicon carbide, and c) 316 stainless steel starting powders.

To fabricate cermets, hot pressing techniques are commonly used because they can maximize the material's densification while decreasing the porosity of the system.[10,11] However, hot pressing is typically done in batches, which complicates the goal of continuous processing of nuclear wastes. It also complicates scaling up the process due to limited size and geometry options.

Spark plasma sintering (SPS) is an alternative sintering technique that could offer a potentially better way to densify cermets. SPS applies an electrical current, either pulsed or direct, to induce Joule heating along with some plasma effects between particle surfaces, which leads to consolidation of the particles in minutes. In contrast, other traditional and advanced sintering techniques generally take multiple hours or days to produce dense compacts.[12]

We recently explored the potential of SPS processing of cermets in our lab at Alfred University. We used 316 stainless steel (SS316) powder and either oxide (zirconia, ZrO_2) or non-oxide (silicon carbide, SiC) ceramic powders to fabricate the model cermet system. These powders were sintered using either hot uniaxial pressing (HUP) or SPS to determine the processing limits of densification, which is critical information for scaling up commercial production of advanced cermet waste forms.

Experimental procedure

Zirconia powder and silicon carbide powder were combined with 316 stainless steel powder to produce the model cermet samples (Table 1). A FCT Systeme GmbH SPS and Thermal Technology hot press were used to sinter the samples.

The zirconia powder's maximum particle size of 5 µm (Figure 1a) makes its agglomeration much easier in ambient conditions compared to the larger particle sizes of the silicon carbide (37 µm) and SS316 (45 µm) powders. Regarding the latter powders, the silicon carbide powder is elongated and angular (Figure 1b) while the SS316 powder is relatively spherical (Figure 1c). These form factors are important in compaction and sintering of the powder, where optimum particle size and distribution promote high densification. Due to the ductility of metals, the SS316 powder can deform and encase the ceramic powders to create a continuous metal phase. The change in metal-to-ceramic ratio also allows for a range of densities and microstructural changes, with the benchmark goal of more than 95% density and less than 5% porosity.

Because of differences in the heating schedule between SPS and HUP, two sets of processing schedules were created to sinter oxide and nonoxide cermets. Both processes use lower temperatures than other waste form synthesis methods, specifically glass-based waste forms, which typically require temperatures around 1,150°C.[4] The sintering profiles for both SPS and HUP can be seen in Figure 2.

Table 1. Raw powder characterization. Powders and particle size information for silicon carbide and zirconia from Sigma Aldrich and for 316 stainless steel from Goodfellow. Specific surface area and density calculated using an AccuPyc II TEC pycnometer and Gemini VII surface area analyzer, both from Micromeritics.

Materials	Specific surface area (m^2/g)	Density (g/cm^3)	Max particle size (µm)
SiC	0.4972 ± 0.0142	3.22	37
ZrO_2	5.0993 ± 0.0736	5.80	5
SS316	0.0914 ± 0.0059	7.89	45

Credit: Nathaniel Marrero

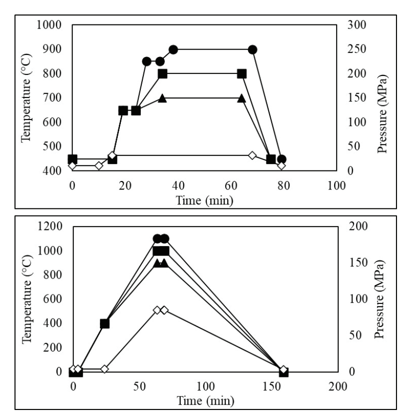


Figure 2. Heating and pressure profiles for SPS (top) and HUP (bottom). Heating profiles are the filled markers, and pressure profiles are the hollow markers.

An initial mix of metal and ceramic powders in different volume percent ratios was packed in a graphite die assembly. Graphite foil served as both a high-temperature lubricant for the graphite pressing rod to compress the sample and as an encapsulating material to prevent interaction between the samples and the graphite die.

As known from the literature, the metallic phase functions as a binder (or continuous) phase around the ceramic particles by way of liquid phase sintering (LPS).[6,13,14] LPS is a common technique used to enhance densification by introducing a phase with a lower melting temperature than the other phases. Once this former phase melts, the resulting liquid provides a faster diffusion path for rapid sintering.[11,15]

LPS is useful for nuclear waste processing because as sintering temperatures go higher, the chance of volatility of radioactive species increases as well. Volatility temperatures range for different species, but in general, temperatures above 1,000°C can cause volatility unless the radioactive species are suitably incorporated into the waste form. By employing LPS, the sin-

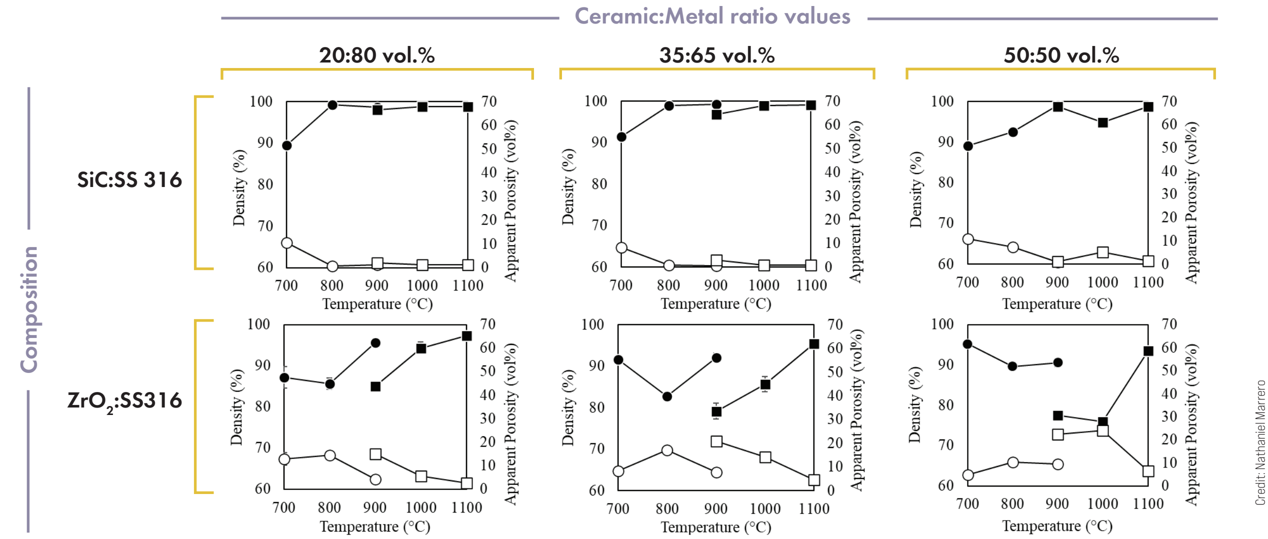


Figure 3. Cermet sample density and apparent porosity. Black markers indicate density values and white markers indicate apparent porosity.

tering temperature of cermets can be lowered to a maximum of 1,100°C in hot pressing and 900°C in SPS.

After sintering, samples were ground and polished using silicon carbide disks (60 to 800 grit) and then further polished using diamond suspensions (15 μm to 0.25 μm). Surface oxidation of the samples was observed after polishing, and this oxidation was removed by a 1 M citric acid solution and subsequent deionized water bath. The samples were then placed in a drying oven at 100°C for at least 24 hours to remove any water trapped in the sample. After drying, scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS) was used to analyze the microstructure of the cermet samples.

Finally, each sample was cut into four sections using a diamond blade saw for density and apparent porosity measurements by the immersion method (ASTM C373-18).[16] The four measurements for each sample were averaged to get the final porosity and density values of each cermet composition.

Results and discussion

Density and porosity analysis

In general, density values of more than 95% with less than 5% porosity could be achieved for all the cermet samples under certain processing conditions (Figure 3). Issues with mixing the initial powders created some variations in the data, particularly at higher ceramic volume percents, which caused some inconsistency in the trends of the data. Regardless, the results still provide a guideline for achieving high densities and low porosities, meaning that an added short mixing step would ideally solve the issue of the mixed trends in the data.

For 20:80 volume percent samples, both oxide and nonoxide cermets achieved the density and porosity benchmarks. However, for the ZrO_2:SS316 samples below temperatures of 900°C and 1,000°C in SPS and HUP, respectively, the density and porosity did not meet the desired benchmarks. For SiC:SS316 samples, the density values during HUP processing are about the same at all temperatures, while 700°C in SPS is not high enough for desirable densification.

The 35:65 volume percent oxide cermets presented mixed trends over the temperature range in SPS but showed linear trends in HUP (i.e., density increased with temperature). Ultimately, the only optimum temperature for these samples was 1,100°C in HUP. Meanwhile, the 35:65 volume percent SiC:SS316 samples showed a similar trend to the 20:80 volume percent samples.

For the 50:50 volume percent cermet samples, mixed trends indicated that at this ratio, the temperature range was adequate for sintering the cermets. At the higher temperatures, the cermet samples are sufficiently densified to achieve the benchmark set for these samples.

Microstructural characterization

Using SEM-EDS images, maps of both the oxide and nonoxide cermet microstructures were analyzed. SiC:SS316 systems showed limited interaction between the ceramic and metallic phases; however, some overlap suggests the formation of secondary carbides. Additionally, the microstructural analysis and elemental distribution in the ZrO_2:SS316 system show there was a higher intensity of elemental chromium and molybdenum, the alloying elements in SS316, at or near the ceramic–metal interface. The intensity is greater when combined with zirconia compared to silicon carbide, as shown in Figures 4 and 5.

<u>Carbide cermets</u>

In SiC:SS316 samples, the elemental distribution of the metallic species can be seen as a continuous phase surrounding grains of silicon carbide. Overlayed EDS elemental maps show coexistence of metallic species, such as iron with nickel and chromium with molybdenum, in the microstructure (Figure 4).

Further inspection reveals that all four main components of SS316 are contained in the metal binder phase with minimal growth of a native oxide film on the SS316 particles. At the highest processing temperature, the SEM-EDS images show evidence of dissolution of the metallic species into the silicon carbide grains. This dissolution supports our observation of possible secondary carbide formation in the cermet samples.

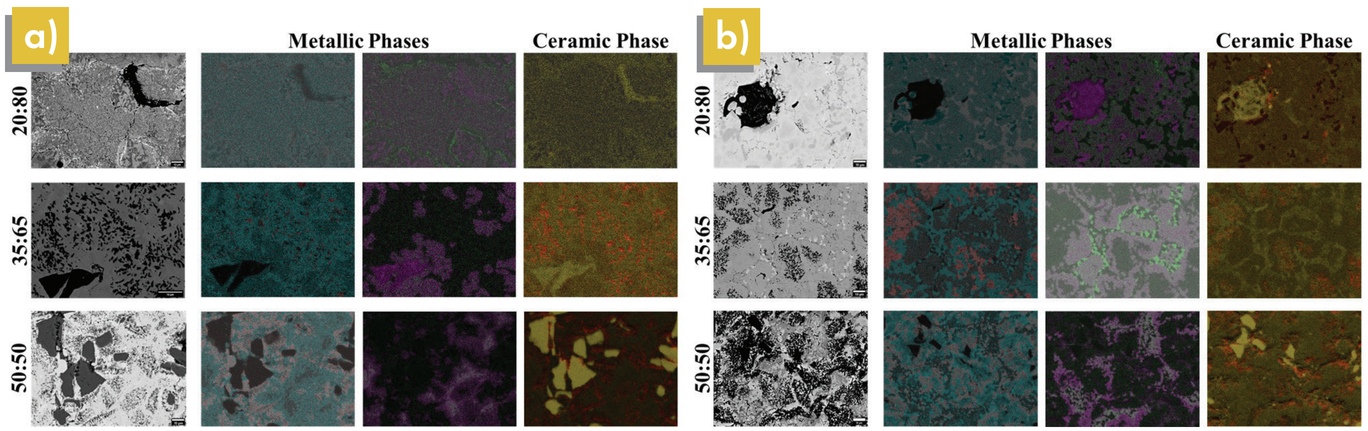


Figure 4. SEM images (left-most greyscale columns) and EDS maps (colored columns) of a) SiC/SS316 samples at 900°C in SPS and b) SiC/SS316 samples at 1,100°C in HUP. In metallic phases: Blue = iron, Red = nickel, Green = molybdenum, Purple = chromium. In ceramic phases: Red = carbon, Yellow = silicon.

Although silicon carbide grains can be seen as black regions in the metallic phases of the SEM images, the metallic species can form eutectics, leading to potential carbide formation. These eutectics lower the melting temperature of the SS316, which is beneficial for reducing processing requirements for producing dense cermet samples.

Oxide cermets

In the SPS EDS maps (Figure 5), elemental chromium and molybdenum can be seen with great intensity both in the metallic binder phase and at the edge of the ceramic–metal interfaces. However, in HUP EDS images, the intensity of chromium and molybdenum at ratios of 35:65 and 50:50 do not have as distinct of lines as their counterparts in SPS or at a ratio of 20:80.

As mentioned before, the electric current applied in SPS imparts enough energy into the cermet system to allow for preferential arrangement of metallic species in the binder phase. At 1,100°C in HUP, there is not enough thermal energy for this rearrangement to happen at higher volumetric ratios of ceramic-to-metal powders. This constraint is due to the difference in how heat is applied to both systems, with induction being the heat source in HUP and the resistivities of materials determining the current and heat applied in SPS.

Native oxide film growth

It is well known that the addition of chromium and molybdenum in SS316 promotes corrosion resistance by reacting to form a beneficial passivation oxide layer on the steel. But while chromium and molybdenum typically form an oxide layer quite readily, that formation can be impeded by the iron present in stainless steel.[17,18] By packing the samples in an open-air environment, the native oxide on these steels remains.

EDS mapping of the 35:65 and 50:50 ZrO_2:SS316 samples showed limited growth of the passivation oxide layer (Figure 5). The reduced oxide layer formation results from a higher oxide content, relatively short dwell time, and induction heating.

Although it is difficult to measure precise partial pressures in a cermet sample, Ellingham diagrams can offer insights into the formation of oxides in our samples. Figure 6 shows an Ellingham diagram of common oxides and carbides that could form in our cermet samples.[19]

As the constituent elements interact in the cermets during sintering and processing, the slope of the lines in the diagram will change significantly, leading to their intersection within the temperature range. Thermodynamically, chromium oxide is energetically favorable to be formed during sintering. Iron oxide and molybdenum oxide can also be formed at lower energies than carbide formation.

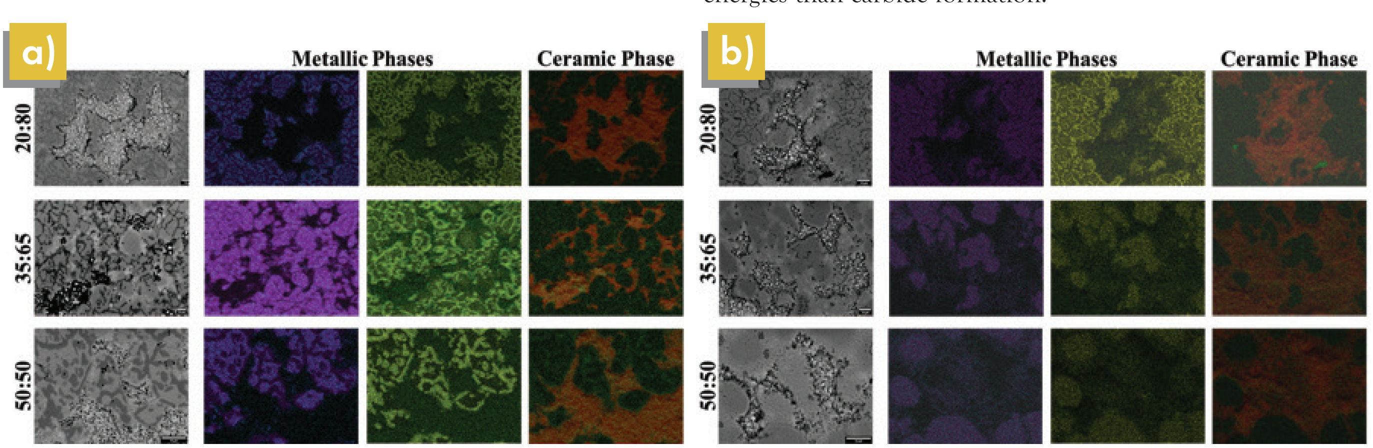


Figure 5. SEM images (left-most greyscale columns) and EDS maps (colored columns) of a) ZrO_2/SS316 samples at 900°C in SPS and b) ZrO_2/SS316 samples at 1,100°C in HUP. In metallic phases: Blue = iron, Purple = nickel, Green = molybdenum, Yellow = chromium. In ceramic phase: Red = zirconium, Green = oxygen.

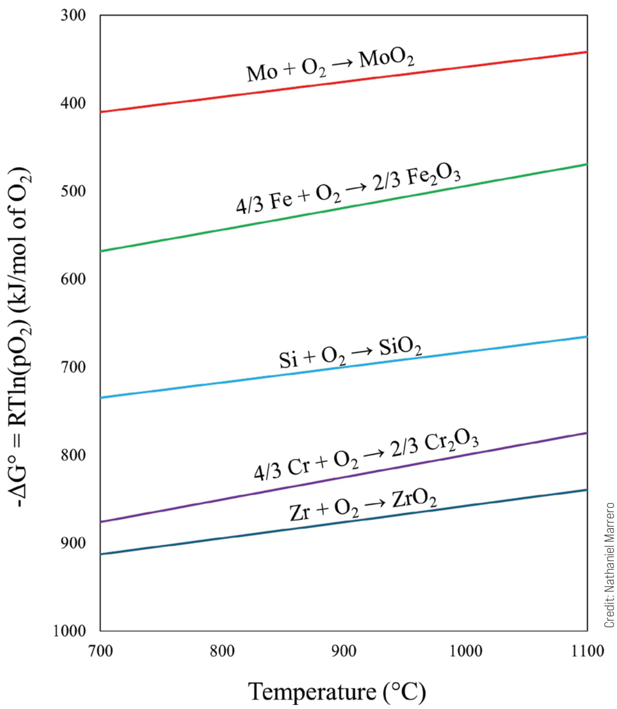


Figure 6. Ellingham diagram of oxide formation in current cermet samples. Diagram plotted using the ΔG of formation values found in Reference 19.

Further testing on the cermet samples is required to determine how the oxide layer affects the chemical durability of the cermets and their ability to immobilize advanced nuclear wastes.

Factors affecting native oxide film growth

Oxygen vacancies in the oxide cermet may aid in the formation of an oxide layer. This possibility can be inferred from the work of De Souza and Appel,[20] who used density functional theory simulations to study oxygen vacancies in zirconia as candidates for carbon dioxide capture. They found vacancy formation was an energetically taxing process in zirconia without any dopants. When zirconia was doped with a 2+ cation such as calcium, however, the dopant eliminated an oxygen atom to account for the charge imbalance. This elimination allowed for an oxygen vacancy at a lower energy cost to the system, thus opening the door to a more thermodynamically stable zirconia surface.

Although this research was for a different application, these interpretations could be extended to the oxide cermet samples. If a 2+ cation allows for the creation of oxygen vacancies, this phenomenon likely could be applied to the metallic components of the SS316 to create a passivation layer. Barring differences in atomic differences between calcium and the metallic species of SS316, the surface oxygen vacancies and ejected oxygen could be a source of oxygen for the oxide layer in addition to the native oxide film.

This interpretation of oxygen vacancy formation supports our argument as to why the intensities of chromium and molybdenum were much less in the SPS case than the HUP case. A detailed density function theory analysis of this cermet system—or of a chromium-doped zirconia sample—would further validate this theory. For the purpose of this paper, however, it is presented as potential supporting evidence.

Another factor to consider in the oxide layer formation is the radius dependence on atomic movement. Fu et al. previously investigated this phenomenon in oxide ceramics,[21] and one can apply the same argument to cermets. A radii mismatch can be calculated using the equation $100 \times (r_a - r_b)/r_a$, where r_a = solute radii and r_b = solvent radii.

As seen in Table 2,[22] chromium and molybdenum have two of the lowest radii mismatches with zirconium, suggesting these ions have a higher probability of migrating in the metallic phase toward zirconium sites to enhance the native oxide layer. This layer can aid in the corrosion resistance of these waste forms, which is beneficial for storage in deep geological repositories.

The migration of chromium in these samples can be another indication of cermets' ability to offer high oxidative corrosion resistance for nuclear waste forms. That is because given adequate oxygen vacancy formation, chromium can create an energetically favorable surface between the 316 stainless steel and zirconia grains to create a passivation layer, assuming the same phenomenon proposed by De Souza and Appel applies.[20]

Our SEM-EDS data show that for a given area, elemental chromium and molybdenum are present in similar amounts, but chromium shows the most prominent migration. As chromium migration is observed above 800°C, the higher end of the processing window is more favorable in SPS no matter the ceramic-to-metal ratio. However, with HUP, the 20:80 vol.% mixture showed chromium migration similar to that of the SPS samples, while the other two mixtures had less evident chromium migration. This behavior may be attributed to the electrical current in the SPS, allowing for an enhanced migration of metallic ions.

The EDS maps in Figure 5 shows oxide film growth as a function of metallic content, supporting our suggestion that the same phenomenon proposed by De Souza and Appel applies.[20] This growth allows more chromium to migrate toward existing oxygen vacancies with higher alloy compositions.

In addition to oxide film growth, our interpretation of the migration phenomenon also explains the absence of chromium migration in the carbide cermet sample within the limits of the SEM-EDS. Strong covalent bonding between silicon and carbon requires higher energy and affinity for chromium to migrate from stainless steel into the chrome-free silicon carbide.

Besides the migration phenomenon, the Acheson process, a common formation method for silicon carbide that uses silica and carbon, and various kinetic models have been developed to understand the mechanics driving oxidation of silicon carbide.[23,24] Though a silica layer can be present on the surface of silicon carbide powder, this layer is typically minimal and would not enhance the oxide layer on SS316.

Finally, secondary silicide and carbide formation are more probable due to the resistance heating in SPS, forcing the breakdown of silicon carbide at lower temperatures. The inert atmospheres used in both sintering processes prevent additional oxygen incorporation and limit oxide interactions with SS316. Consequently, fewer oxide species in carbide cermets restrict the formation of oxide growth in nonoxide cermets.

Conclusions

Cermets offer a unique solution for containing both low- and high-level waste streams in a single waste form, thus allowing safe storage of these materials and decreasing the need for multiple repositories. Based on our study, cermet systems can be successfully sintered using SPS under a less energetically taxing and faster process compared to hot pressing.

Furthermore, microstructural analysis of the cermet samples identified a metallic binder phase with the growth of an oxide layer at the ceramic–metal interfaces in oxide cermets, which may enhance the corrosion resistance in cermet waste forms. These secondary phases were formed through LPS of the binder phase.

Ultimately, our findings support further investigation of cermets as a viable candidate for nuclear waste forms. Further research into the chemical durability of these cermets and radiation stability is required to classify cermets as an effective nuclear waste form.

About the authors

Nathaniel Marrero, Samuel Gross, and S. K. Sundaram are graduate student, undergraduate student, and professor, respectively, at the Inamori School of Engineering in The New York State College of Ceramics at Alfred University. Contact Sundaram at sundaram@alfred.edu.

Table 2. Radii mismatch data using calculated radius data from Gosh et al.[22]

Solute (Å)	Solvent (Å)	Radii mismatch (%)
Zr^{4+} (0. 747)	Fe^{3+} (0.609)	18.5
Zr^{4+} (0. 747)	Ni^{2+} (0.59)	21.0
Zr^{4+} (0. 747)	Cr^{3+} (0.615)	17.7
Zr^{4+} (0. 747)	Mo^{3+} (0.69)	7.6
Si^{4+} (0.33)	Fe^{3+} (0.609)	84.5
Si^{4+} (0.33)	Ni^{2+} (0.59)	78.8
Si^{4+} (0.33)	Cr^{3+} (0.615)	86.4
Si^{4+} (0.33)	Mo^{3+} (0.69)	109

Credit: Nathaniel Marrero

References

[1]"GEN IV International Forum Annual Report 2023," Nuclear Energy Agency. Updated 17 June 2025. https://www.gen-4.org/resources/annual-reports/2023-gif-annual-report

[2]N. C. Hyatt and M. I. Ojovan, "Special Issue: Materials for nuclear waste immobilization," *Materials*, 2019.

[3]M. I. Ojovan and W. E. Lee, *An Introduction to Nuclear Waste Immobilisation* (2nd edition). Elsevier, 2014. p. 362.

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

[5]S. A. Jose, M. John, and P. L. Menezes, "Cermet systems: Synthesis, properties, and applications," *Ceramics* 2022, **5**(2): 210–236.

[6]S. Liu and D. Liu, "Effect of hard phase content on the mechanical properties of TiC-316L stainless steel cermets," *International Journal of Refractory Metals and Hard Materials* 2019, **82**: 273–278.

[7]I. Sulima, "Consolidation of AISI316L austenitic steel–TiB_2 composites by SPS and HP-HT technology." Published in *Sintering Techniques of Materials*, 2015.

[8]Y. Pristinskiy, N. Peretyagin, and N. W. Solis Pinargote, "Comparative studies on mechanical properties of WC-Co composites sintered by SPS and conventional techniques," *MATEC Web Conf.* 2017, **129**: 02028.

[9]J. D. Vienna et al., "Closed fuel cycle waste treatment strategy," Idaho National Laboratory. Published February 2015. https://inldigitallibrary.inl.gov/sites/sti/sti/6410770.pdf

[10]J. Binner and T. S. R. C. Murthy, "Structural and thermostructural ceramics." Published in *Encyclopedia of Materials: Technical Ceramics and Glasses*, 2021. pp. 3–24.

[11]A. Leriche, S. Hampshire, and F. Cambier, "Control of the microstructure in ceramics." Published in *Encyclopedia of Materials: Technical Ceramics and Glasses*, 2021. pp. 349–366.

[12]M. Suarez et al., "Challenges and opportunities for spark plasma sintering: A key technology for a new generation of materials." Published in *Sintering Applications*, 2013.

[13]S.-J. Zhou et al., "Enhanced densification of ultrafine Ti(C, N)-based cermets based on grain-growth induced liquid-phase pore filling mechanism," *Journal of Alloys and Compounds* 2024, **986**:174141.

[14]J. D. Bolton and A. J. Gant, "Phase reactions and chemical stability of ceramic carbide and solid lubricant particulate additions within sintered high speed steel matrix," *Powder Metallurgy* 1993, **36**(4): 267–274.

[15]R. M. German, P. Suri, S. J. Park, "Review: Liquid phase sintering," *J. Mater. Sci.* 2009, **44**(1): 1–39.

[16]"Standard test methods for determination of water absorption and associated properties by vacuum method for pressed ceramic tiles and glass tiles and boil method for extruded ceramic tiles and non-tile fired ceramic whiteware products," ASTM International. Updated 3 March 2023. https://www.astm.org/c0373-18r23.html

[17]Z. Wang et al., "Mechanisms of Cr and Mo enrichments in the passive oxide film on 316L austenitic stainless steel," *Frontiers in Materials* 2019, **6**: 232.

[18]X. Huang et al., "Oxidation behavior of 316L austenitic stainless steel in high temperature air with long-term exposure," *Materials Research Express* 2020, **7**(6): 066517.

[19]M. W. Chase, "NIST-JANAF Thermochemical Tables, Fourth Edition." Published in *J. Phys. Chem. Ref. Data Monograph*, 1998.

[20]E. F. De Souza and L. G. Appel, "Oxygen vacancy formation and their role in the CO_2 activation on Ca doped ZrO_2 surface: An ab-initio DFT study," *Applied Surface Science* 2021, **553**: 149589.

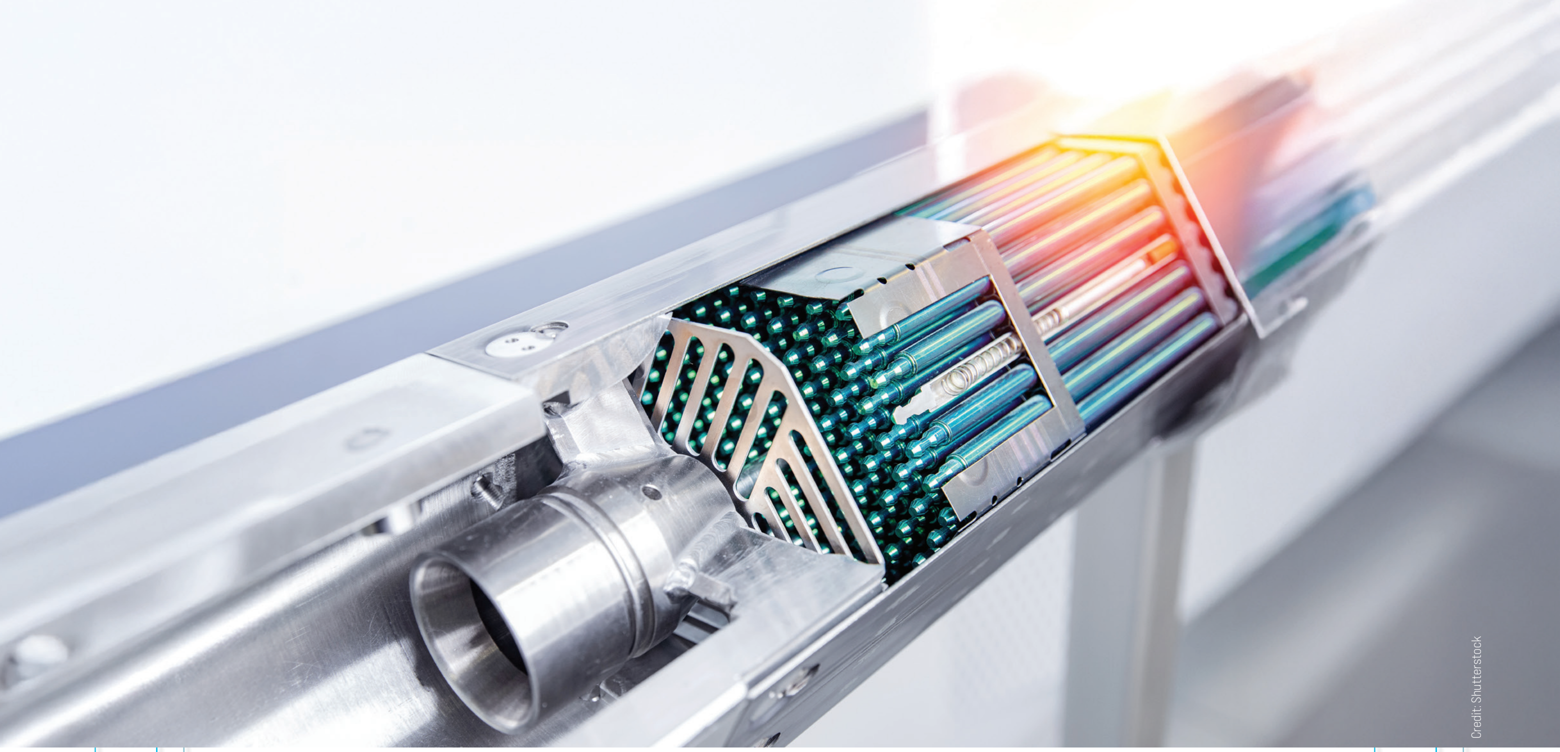
[21]L. Fu et al., "Liquid-phase sintering of ZrO_2-based nanocrystalline glass–ceramics achieved by multielement co-doping," *J. Am. Ceram. Soc.* 2023, **106**(4): 2702–2715.

[22]D. C. Ghosh and R. Biswas, "Theoretical calculation of absolute radii of atoms and ions," *International Journal of Molecular Sciences* 2003, **4**(6): 379–407.

[23]C. Raynaud, "Silica films on silicon carbide: A review of electrical properties and device applications," *Journal of Non-Crystalline Solids* 2001, **280**(1–3): 1–31.

[24]H. Tanaka, "Silicon carbide powder and sintered materials," *J. Ceram. Soc. Japan* 2011, **119**(1387): 218–233.

*All references verified as of June 17, 2025. ■



Nuclear fuel market: Current trends and research opportunities

By Margareth Gagliardi

Nuclear energy is experiencing a revival as countries aim to reduce their dependence on fossil fuels while ensuring enough energy supply to support the future needs of a growing population and human activities.

Currently, approximately 10% of the world's electrical energy is provided by nuclear power plants, according to the World Nuclear Association.[1] During the 2023 United Nations Climate Change Conference, a group of 22 countries set a goal to triple their nuclear power capacity by 2050. Accomplishing this goal, however, will depend heavily on securing a steady supply of the materials used as fuel in nuclear reactors.

Uranium: Current champion of the nuclear fuel market

Today's commercial nuclear power plants all rely on fission to generate electricity. This process entails the irradiation of a fissile material with neutrons to split the heavy nucleus of the material's atoms into smaller nuclei. The thermal energy produced during fission is used to produce steam to drive a turbine and a power generator.

Until now, uranium, more specifically the isotope 235U, has been the most common fissile material globally. However, the 235U isotope is present in nature at very low concentrations, just 0.7% by mass versus 99.3% for 238U. Because the 238U isotope is not as fissile as the 235U isotope, the two isotopes must be separated using a process called "enrichment" before being used in a nuclear power plant. The flow diagram in Figure 1 provides a high-level look at the enrichment process and subsequent application of the enriched uranium-based fuel.

Low-enriched uranium (LEU) contains less than 20% 235U and is utilized in commercial applications, whereas highly enriched uranium (HEU) contains more than 20% 235U and is reserved for nuclear weapons, submarines, and nuclear research. At present, 95% of all nuclear power plants rely on LEU with 2% to 5% enrichment.[2] Canada is the only country that has introduced nuclear reactors based on nonenriched uranium, called CANDU reactors.

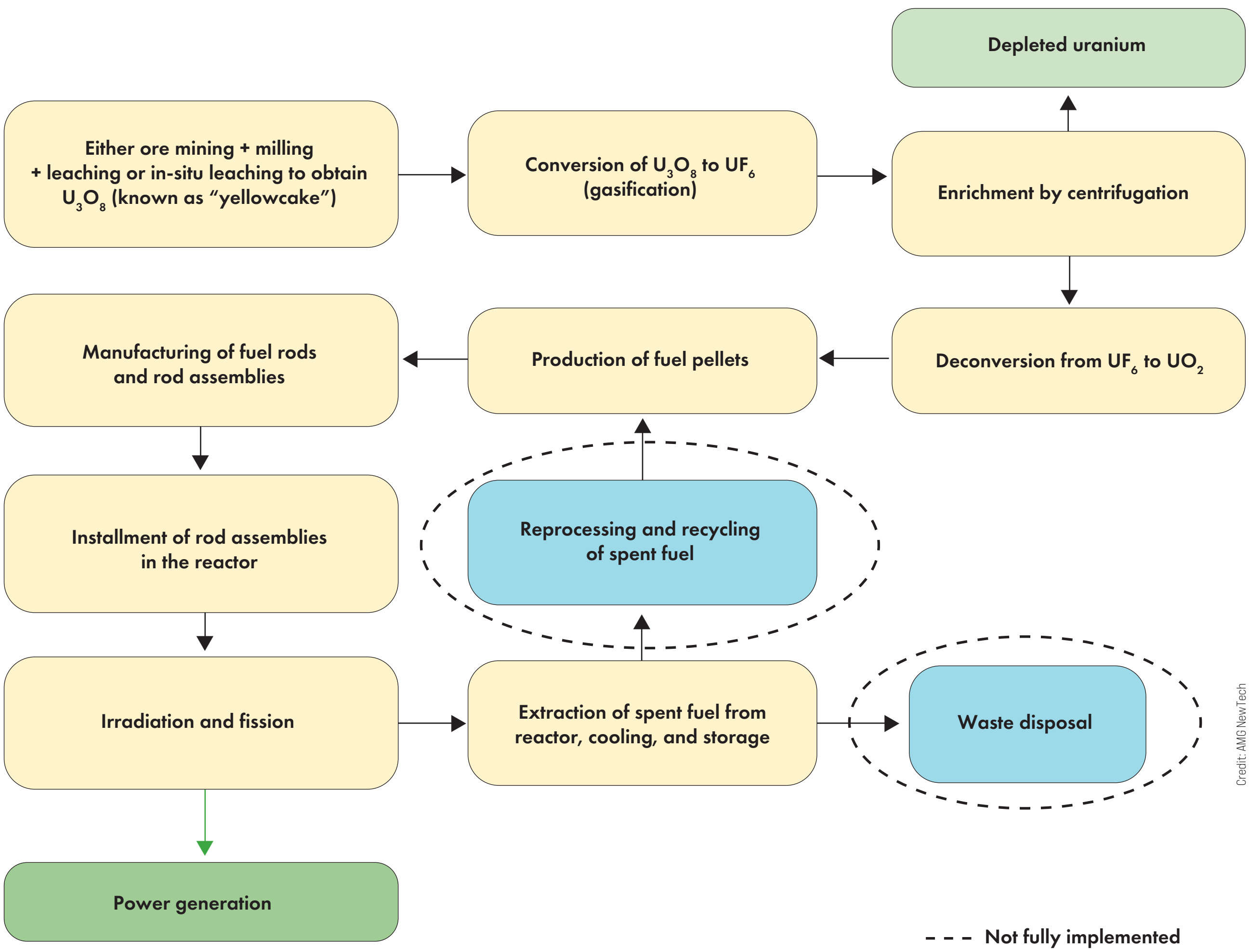


Figure 1. Enrichment and application of uranium-based nuclear fuels.

Recently, countries have become interested in the possibility of high-assay, low-enriched uranium (HALEU), which is uranium enriched to between 5% and 20%. HALEU is expected to provide benefits such as longer fuel life, less downtime, fewer operational costs, and less nuclear waste.

Currently, only Russia and China are capable of manufacturing HALEU in high volumes. In the U.S., Centrus Energy (Bethesda, Md.) is the only commercial producer of HALEU, and it is ramping up capacity to approximately 1 ton per year. Analysts project it will take at least another four years to achieve production of commercial quantities of HALEU in the U.S.

Barriers to enriched uranium production

Besides challenges in sourcing uranium (see sidebar: "Uranium supply and demand"), there are various barriers to entry that limit production of enriched uranium, including complexity of technology, expensive capital investments, high production costs, and international limits aiming at avoiding proliferation of nuclear weapons. Consequently, there are only a handful of suppliers globally (Table 1).[3]

Among the suppliers, China National Nuclear Corp. primarily serves the domestic market. So, there are really only three major suppliers worldwide, the largest of which is Rosatom (Russian State Atomic Energy Corp.), which produces 43.1% of all enriched uranium, according to the World Nuclear Association.[3] Currently, the U.S. can only fill less than 5% of its needs.[4] By comparison, Europe is in a better position because the domestic suppliers Urenco and Orano supply two thirds of the region's enriched uranium demand. (Though Europe-based, Urenco and Orano also have plants in the U.S.)

After the invasion of Ukraine in February 2022, many countries implemented measures to reduce their reliance on imports from Russia. These policies contributed to a rapid increase of activities aimed at boosting the national supply of nuclear fuels. For example, four U.S. companies recently were issued contracts by the Department of Energy to produce HALEU: Louisiana Energy Services (Eunice, N.M.), Orano Federal Services (Federal Way, Wash.), General Matter (San Francisco, Calif.), and American Centrifuge Operating (Piketon, Ohio). Additionally, six companies were

Uranium supply and demand

According to the latest report from the Nuclear Energy Agency,[a] in 2023, total recoverable uranium resources of economic interest exceeded 7.9 million metric tons (Table I). Australia, Kazakhstan, Canada, Russia, and Namibia are the top five countries, accounting for a combined 61.3%, while the U.S. is ranked #13 at 1.5% of the total.

Table I. Uranium recoverable resources, 2023.

Country	Metric tons of U	%
Australia	1,935,200	24.4
Kazakhstan	873,400	11.0
Canada	852,200	10.7
Russia	652,500	8.2
Namibia	550,800	7.0
Niger	454,000	5.7
South Africa	436,400	5.5
China	291,300	3.7
India	252,500	3.2
Ukraine	184,800	2.3
Brazil	177,800	2.3
Mongolia	144,600	1.8
U.S.	121,400	1.5
Czech Republic	119,100	1.5
Denmark	114,000	1.5
Botswana	87,200	1.1
Uzbekistan	63,600	0.8
Tanzania	57,700	0.7
Jordan	49,000	0.6
Others	517,000	6.5
Total	**7,934,500**	**100.0**

Credit: Nuclear Energy Agency

In 2023, Kazakhstan, Canada, and Namibia were the three top producers of uranium (intended as uranium before enrichment), accounting for 71.9% of the total (Table II). Globally, 54,345 metric tons of uranium (tU) were mined and leached, corresponding to a 9.8% increase year-over-year. In recent years, the gap between production and demand was filled up by existing stockpiles and spent fuel reprocessing.

Table II. Uranium production, 2023.

Country	Metric tons of U	%
Kazakhstan	21,112	38.8
Canada	10,986	20.2
Namibia	6,985	12.9
Australia	4,658	8.6
Uzbekistan	4,000	7.4
Others	6,604	12.1
Total	**54,345**	**100.0**

Credit: Nuclear Energy Agency

The Nuclear Energy Agency states that there are currently 438 commercial nuclear reactors operating worldwide and 58 under construction.[a] In 2025, these reactors will consume 59,779 tU at a minimum. At this rate, existing resources will last 132 years (Table III).

Considering that consumption of uranium for power plants is projected to grow significantly through 2050, and that uranium finds application in other fields besides nuclear power stations, such as medicine, space exploration, naval propulsion, and defense, analysts expect that uranium reserves will be more likely depleted within the next 90 years. However, this projection may be extended if nuclear energy becomes more reliant on alternative materials (e.g., thorium), recycling, and new generations of advanced reactors that make a more efficient use of nuclear fuels.

Table III. Uranium demand, 2025–2050 (metric tons).

	2025		2030		2040		2050	
Region	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
North America	17,088	17,138	17,120	17,267	18,445	19,670	14,123	22,603
European Union	11,703	14,252	14,851	16,303	14,746	20,016	13,390	21,900
East Asia	18,125	22,953	20,060	25,448	26,736	40,624	33,936	56,624
Others	12,863	13,385	15,640	17,534	25,964	35,382	28,596	41,504
Total	**59,779**	**67,728**	**67,671**	**76,552**	**85,891**	**115,692**	**90,045**	**142,631**

Credit: Nuclear Energy Agency

References

[a]Nuclear Energy Agency and International Atomic Energy Agency, "Uranium 2024: Resources, Production, and Demand." Published 23 April 2025. Accessed 24 June 2025. https://www.oecd-nea.org/jcms/pl_103179/uranium-2024-resources-production-and-demand

Table 1. Global suppliers of enriched uranium.

	Capacity (1,000s SWU/yr)		
Company (Country)	**2022**	**2025**	**2030**
Rosatom (Russia)	27,100	27,100	27,100
Urenco (U.K.)	17,900	17,900	17,900
China National Nuclear Corp. (China)	8,900	10,000	17,000
Orano (France)	7,500	7,500	7,500
Others (INB – Brazil, JNFL – Japan)	100	400	800
Total	**61,500**	**62,900**	**70,300**

Credit: World Nuclear Association[3]

Note: SWU = Separative Work Unit. This standard unit to measure enriched uranium is not a unit of mass but a measure of the separation process.

awarded contracts to convert HALEU to oxides or metal fuel: Framatome (Lynchburg, Va.), BWXT (Lynchburg, Va.), Centrus (Bethesda, Md.), GE Vernova (Cambridge, Mass.), Orano (Bethesda, Md.), and Westinghouse (Cranberry Township, Pa.).

Alternative, more efficient, and cost-effective enrichment technologies are also being introduced, such as a laser enrichment process called SILEX that Global Laser Enrichment (Wilmington, N.C.) is working to develop and commercialize.

Alternative nuclear fuels

Since the early prototypes were introduced in the 1950s, nuclear reactor design has evolved (Table 2),[5,6] though light water reactors (LWRs), which are moderated and cooled by water, remain the most popular category. In fact, all the 94 reactors currently operating in the U.S. are LWRs. In contrast, nuclear fuel has remained virtually unchanged for decades. Most reactors still utilize UO_2, though newer fuels started to emerge near the end of the 20th century.

MOX

A new fuel chemistry called MOX was introduced in the 1980s, consisting of mixed uranium and plutonium oxides. MOX was developed with the purpose of reprocessing and recycling depleted uranium and spent nuclear fuel from both commercial reactors and weapon programs. Spent nuclear fuel contains plutonium generated from the decay of uranium during fission. All plutonium isotopes are fissionable, i.e., they can still undergo fission when irradiated with fast neutrons. The main advantage of MOX is that it does not require further enrichment.

Some reactors were built to be compatible with MOX, but they continued to use just UO_2. As a result, MOX-fed reactors became operational only in the late 1990s and early 2000s, with the commercialization of Gen III reactors.

Accident-tolerant fuels

Accident-tolerant fuels (ATFs) were introduced after the 2011 Fukushima Daiichi nuclear disaster in Japan. These uranium-based fuels aim to improve the safety of reactors through the use of additives and cladding designs. Additives such as chromium, magnesium, and titanium are used to increase grain size and fuel plasticity in ATFs, which ideally will help with optimizing the retention of fission gases, achieving higher conductivity, and preventing fuel pellet failure.

Among the various ATF types, chromia-based UO_2 is of particular interest because it has been demonstrated to enhance grain growth during sintering, enabling retention of gaseous fission products.[7] This property is important in newer light water reactors, as it allows them to reach burn-ups of up to 70 GWd/tU. (Higher burn-up extends the life of the nuclear fuel from 12–18 months to 24 months, thus reducing the amount of spent fuel.)

An example of a commercial ATF is the Advanced Doped Pellet Technology (ADOPT) by Westinghouse (Cranberry Township, Pa.). This fuel pellet contains uranium doped with chromia and alumina and features higher burn-up, gas retention capability, thermal stability, and enhanced corrosion resistance.

TRISO

TRISO, which stands for tri-isotropic-layered particles, was invented in Germany in the 1980s for very high-temperature reactor applications. This fuel consists of very small spherical particles (less than 1 mm in diameter) comprising a UO_2/UC_2 kernel that is coated with three layers via chemical vapor deposition. The first layer is a porous carbon that retains fission gases; the inner layer is made of silicon carbide to hold fission products; and the external layer is made of carbon to improve particle strength.

This fuel, which can withstand temperatures as high as 1,800°C, is produced in the U.S. by BWX Technologies (Lynchburg, Va.). It was recently selected for the first high-temperature gas cooled reactor (HTGR) under development by X-Energy (Rockville, Md.).[8]

Thorium-based fuels

Thorium-based fuels are considered to be more proliferation resistant than uranium-based fuels because they do not generate plutonium, an essential component of nuclear weapons. Additionally, during decay, thorium becomes a highly radioactive material that is complex to handle, which acts as a deterrent for thieves.

Table 2. Advancements in nuclear reactor and fuel technology.

Period	Reactor technology	Reactor type/Examples	Fuel type
1950s–1960s	Generation I	Early prototype reactors: • Atomic Power Station 1 (Russia) • Shippingport (U.S.) • Dresden (U.S.) • Fermi I (U.S.) • Magnox (U.K.)	UO_2
1970s–1990s	Generation II	Light water reactor (LWR): • Pressurized water reactor (PWR). Example: VVER (Russia) • Boiling water reactor (BWR). Example: General Electric BWR (U.S.)	UO_2
		Light water graphite reactor (LWGR): • RBMK (Russia)	UO_2
		Heavy water reactor (HWR): • CANDU	Nonenriched UO_2
Mid-1990s to present	Generation III and III+	Advanced LWRs and evolutionary reactors: • Advanced boiling water reactor (ABWR). Example: Toshiba ABWR (Japan) • Advanced PWR: Example: Westinghouse System 80+ (U.S.) • Small footprint reactor: Example: Westinghouse AP1000 (U.S.) • Advanced, multifuel HWR reactor: Example: CANDU-6	UO_2, MOX, UO_2/Thorium, Accident-tolerant fuels
Mostly still under development with just a few reactors operative since 2020	Generation IV	Gas-cooled fast reactor (GCFR). It uses helium as a coolant and generates electricity and hydrogen.	UO_2
		Lead-cooled fast reactor (LCFR). It uses lead or lead/bismuth as a coolant and generates electricity and hydrogen.	UO_2
		Molten salt fast reactor (MSFR). It is a fast reactor that utilizes fluoride or chloride salts as a coolant and generates electricity and hydrogen	Uranium-based salt
		High-temperature molten salt reactor (HTMSR). It is a thermal reactor that utilizes fluoride or chloride salts and is designed for hydrogen production.	UO_2 particles in prism
		Sodium-cooled fast reactor (SFR). It is a fast reactor that uses liquid sodium as a coolant and generates only electricity. Example: BN-800 (Russia)	UO_2, MOX, U+Pu nitride, uranium alloys
		Supercritical water-cooled reactor (SWR). It can be a thermal or fast reactor and is cooled by water. It is designed for power generation.	UO_2
		Very high-temperature reactor (VHTR). It is a thermal reactor with helium coolant and is designed to generates both hydrogen and electricity.	TRISO
Under development and projected to become operational after 2030	SMR and MNR	Small modular reactors (SMRs) and micro nuclear reactors (MNRs) for industrial applications. Example: eVinci (Westinghouse)	TRISO, HALEU

Credit: U.S. Department of Energy;[5] World Nuclear Association;[6] AMG NewTech

There are large resources of thorium worldwide, estimated at 6.4 million metric tons.[9] Thorium can be found in rare earth-rich minerals such as monazite and heavy mineral sand deposits. China and India have an abundance of these minerals and are actively pursuing the use of thorium as a nuclear fuel. China has already built an experimental thorium molten salt reactor that reached full power in 2024.

Fuels for Generation IV and other future reactors

Reactors for Gen IV and beyond are being designed to provide enhanced safety, lower capital and production costs, minimal waste, and proliferation resistance. Although they are still being developed primarily on uranium-based fuels, their design does not exclude the possibility of using different fuel types. A variety of materials are being developed to help future reactors reach their objectives. The most relevant ones are summarized in Table 3.

Proliferation risks

As countries plan to significantly increase their consumption of nuclear fuels during the next few decades, there is a more urgent need to find a way to permanently dispose of waste fuel. According to the International Atomic Energy Agency, since the 1950s, approximately 430,000 metric tons of spent fuel has been generated globally, of which only 30% has been reprocessed.[10]

At present, spent fuel is usually stored onsite at the nuclear plant. In the U.S., 92,500 metric tons of waste is stored at 100 sites across the nation. Some countries are taking action to find locations for permanent disposal, such as underground geological repositories. Many activities are also in progress aimed at increasing the amount of fuel that is reprocessed and recycled.

Some experts believe that disposal and reutilization of fuel containing plutonium, together with the trend of using more

Table 3. Emerging materials for nuclear fuels.

Material	Description
Uranium hydrides	Hydride fuel consists of metallic uranium dispersed in a zirconium hydride matrix. This fuel allows for the fabrication of smaller rods with high burn-up and thermal conductivity, resulting in less stored energy, more efficient use of fuel, and fewer fission products. They are suitable for gas-cooled fast reactors, other fast neutron reactor designs, small modular reactors, and micro modular reactors.
Uranium nitrides	Uranium nitrides are considered more efficient and safer than traditional UO_2. Nitrides are expected to become a feature of gas- and lead-cooled fast reactors as well as microreactors.
Uranium carbides	Uranium carbides are characterized by very high thermal conductivity, melting point, and uranium density, and are of interest for fast reactors, high-temperature gas-cooled reactors, and VHTRs.
Thermal propulsion fuels	General Atomics Electromagnetic Systems (GA-EMS – San Diego, California) is developing an undisclosed fuel composition for nuclear thermal propulsion in collaboration with NASA. The purpose is to create a fuel that can withstand harsh space conditions and decrease the flying time to Mars from six months to one.
Uranium alloys and cermets	Uranium alloys and cermets, such as those containing molybdenum, tungsten, silicon, and erbium to act as neutron absorbers, are being tested to increase the efficiency of new power plants.
Fluorides and chlorides	Fuels made from fluorides and chlorides of uranium as well as thorium and their mixtures are being developed for use in molten salt reactors.

Credit: AMG NewTech

HALEU, may increase proliferation risks because these activities create more opportunities for "bad actors" to seize materials suitable for production of weapons. Proliferation concerns cannot be underestimated, and the U.S. National Nuclear Security Administration recently announced a new study to address these concerns for new high-tech reactors.[11]

Conclusions

With renewed interest in nuclear energy as an alternative source of energy to support human activities and to replace fossil fuels, production of uranium at current levels and existing reserves may not be able to meet future demand during the next century. Considering that processing and use of uranium as well as disposal of spent fuel pose quite complex issues, there is a need to accelerate research and development activities in this field, especially in relation to the materials science of alternative fuels and their recycling.

About the author

Margareth Gagliardi is owner of AMG NewTech (Charlottesville, Va.), a firm focusing on custom market research, technical studies, and consulting in advanced materials and emerging technologies. Contact Gagliardi at margarethg@earthlink.net.

References

[1]World Nuclear Association, "World energy needs and nuclear power." Updated 6 Jan. 2025. https://world-nuclear.org/information-library/current-and-future-generation/world-energy-needs-and-nuclear-power

[2]S. Patel, "Nuclear fuel: The unseen barrier ahead," *Power*. Published 19 Nov. 2024. https://www.powermag.com/nuclear-fuel-the-unseen-barrier-ahead

[3]World Nuclear Association, "Uranium enrichment." Updated 21 March 2025. https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment

[4]World Nuclear Association, "US nuclear fuel cycle." Updated 20 Nov. 2024. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle

[5]H. Khalil et al., "The Generation IV Nuclear Energy Systems Technology Roadmap," Nuclear Energy Association Presentations. Published 4 Nov. 2002. https://www.oecd-nea.org/science/rd/presentations/2-2-doc.pdf

[6]World Nuclear Association, "Generation IV nuclear reactors." Updated 30 April 2024. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors

[7]A. Milena-Pérez et al., "Raman spectroscopy coupled to principal component analysis for studying UO_2 nuclear fuels with different grain sizes due to the chromia addition," *Journal of Nuclear Materials* 2021, **543**: 152581.

[8]D. Dalton, "US / X-energy chooses Geiger Brothers for key $40 million work at Triso-X nuclear fuel facility," *Independent Nuclear News*. Published 20 Dec. 2024. https://www.nucnet.org/news/x-energy-chooses-geiger-brothers-for-key-usd40-million-work-at-triso-x-nuclear-fuel-facility-12-5-2024

[9]World Nuclear Association, "Thorium." Updated 2 May 2024. https://world-nuclear.org/information-library/current-and-future-generation/thorium

[10]M. Abbà, "Finland could be the first country in the world to bury nuclear waste permanently," *Wired*. Published 23 April 2025. https://www.wired.com/story/finland-is-developing-a-permanent-way-to-deal-with-spent-nuclear-fuel

[11]T. Gardner, "US to study proliferation risk of HALEU nuclear fuel, after warning by scientists," *Reuters*. Published 9 Jan. 2025. https://www.reuters.com/business/energy/us-study-proliferation-risk-haleu-nuclear-fuel-after-warning-by-scientists-2025-01-08

*All references verified as of June 24, 2025.

US government expands domestic supply chain efforts amid trade strains

By Helen Widman

A burgeoning trade war with China has led the U.S. government to continue investing in domestic production of certain minerals and materials, as reported in the annual United States Geological Survey *Mineral Commodity Summaries.*[1]

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

In 2024, the total value of nonfuel mineral production in the United States was estimated to be $106 billion, an increase of nearly 1% from $105 billion in 2023. The total value of industrial minerals production was $72.1 billion, which is no change from the revised total of 2023. Of this total, $38 billion came from construction aggregates production, including construction sand, gravel, and crushed stone. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2024 with 24%.

Continuing the trend from last year, the metals sector saw significant decreases in production due to global oversupply. Metals such as cobalt, lithium, and nickel saw decreases of 40–60% compared to 2023 as many other metal-producing countries reduced prices. On the other hand, the industrial minerals sector again saw increased production values for aggregates due to higher prices.

As a continuation of the U.S. government's goals to expand the domestic mining sector, several congressional acts, investments, and projects were passed or launched in 2024. For example, the Department of Defense (DOD) awarded more than $400 million through the Defense Production Act Investments program to U.S.-based projects that aim to establish domestic manufacturing capacities for critical minerals production. The DOD also announced awards of more than $40 million to Canadian companies to support the United States–Canada Joint Action Plan on Critical Minerals.

Even with these developments, the U.S. still relies heavily on foreign sources for certain raw and processed mineral materials. In 2024, the U.S. was 100% reliant on 12 out of 50 individually listed critical minerals, as well as more than 50% net import reliant on 28 more critical mineral commodities. The recycling of antimony, bismuth, chromium, germanium, magnesium metal, tin, tungsten, and vanadium served as the only source of domestic supply for these materials.

The five-year period of 2020–2024 showed declined consumption for many mineral commodities. This decline indicates some substitutions may be in use for certain materials or that less products are being produced with raw mineral commodities. The largest decreases of more than 25% were seen with thallium, asbestos, bauxite, bismuth, industrial diamond (stones), and strontium.

Considering these trends, the U.S. Department of Energy announced a $75 million project in April 2024 to construct a Critical Minerals Supply Chain Research Facility funded by the Bipartisan Infrastructure Law.[2] Moreover, legislation such as the Critical Minerals Security Act of 2024[3] and National Critical Minerals Council Act[4] were introduced to help keep track of all global critical mineral and rare earth element activities and implement a national critical minerals strategy, respectively.[4]

Regarding the ongoing trade war with China, in May 2024, President Joe Biden raised tariffs on electric vehicles, solar cells, steel, aluminum, and metal equipment from China.[5] That December, China issued export bans on antimony, gallium, and germanium.[6] In response, the United States Trade Representative began a Section 301 investigation on China regarding their dominant role in the semiconductor industry.

The next two pages contain a table summarizing some of the statistics and trends for a variety of mineral commodities that serve the ceramic and glass industries. Access the complete USGS report at https://doi.org/10.3133/mcs2025.

References

[1]*Mineral Commodity Summaries* 2025, U.S. Geological Survey, Reston, Va., 2025.

[2]"DOE's top clean energy accomplishments in 2024," Department of Energy, 23 Dec. 2024. https://bit.ly/4jZI4lg

[3]"S.3631–118th Congress (2023–2024): Critical Minerals Security Act of 2024." *Congress.gov*. Published 21 Nov. 2024. https://bit.ly/4eaVidy

[4]"S.5030–118th Congress (2023–2024): National Critical Minerals Council Act." *Congress.gov*. Published 12 Sept. 2024. https://bit.ly/409gqei

[5]S. Mistreanu, "A timeline of US-China tit-for-tat tariffs since Trump's first term," *AP News*. Published 10 Feb. 2025. https://bit.ly/4ldp8jF

[6]A. Lv and T. Munroe, "China bans export of critical minerals to US as trade tensions escalate," *Reuters*. Published 3 Dec. 2024. https://bit.ly/4nog25Q

*All references verified as of June 19, 2025.

Background image credit: Maksim Safaniuk, Shutterstock

2025 USGS MINERAL COMMODITY SUMMARIES

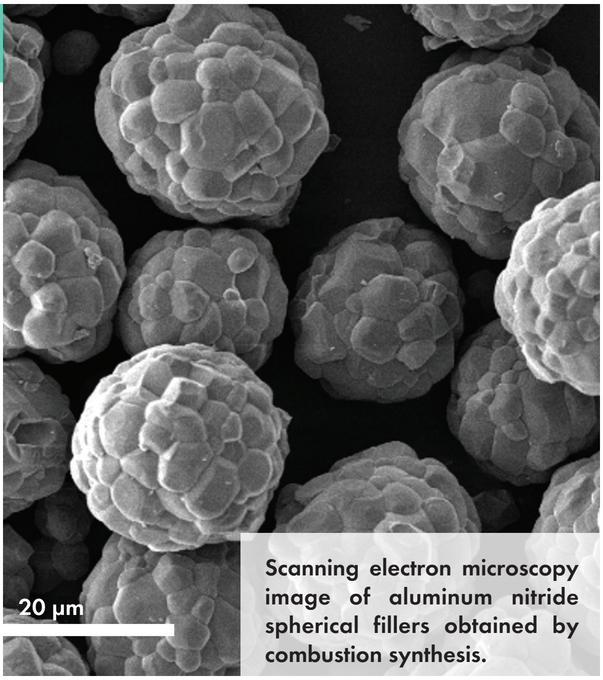
Leading producer highlights

	END-USE INDUSTRIES	TREND GLOBAL PRODUCTION	US PRODUCTION	US IMPORT/ EXPORT	WORLD RESERVES	LEADING PRODUCER
ABRASIVES (fused aluminum oxide and silicon carbide)	Bonded and coated abrasive products	No change for either fused aluminum oxide or silicon carbide	25,000 metric tons fused aluminum oxide; 45,000 metric tons silicon carbide	>95% net import reliance for fused aluminum oxide; 69% net import reliance for silicon carbide	Fused aluminum oxide: adequate in the Western Hemisphere; Silicon carbide: adequate domestic supply	Fused aluminum oxide: China Silicon carbide: China
BAUXITE AND ALUMINA	Bauxite: refined for alumina or aluminum hydroxide, abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills Alumina: used in production of aluminum, abrasives ceramics, chemicals, refractories	2.7% increase for bauxite; 0.7% increase for alumina	Bauxite production information withheld; 720,000 metric tons alumina	>75% net import reliance for bauxite; 59% net import reliance for alumina	Between 55 billion and 75 billion metric tons bauxite	Bauxite: Guinea Alumina: China
CEMENT	Construction	2.4% decrease in cement production; no change for clinker capacity	86,000 metric tons cement; 73,000 metric tons clinker	22% net import reliance	Reserves of lime and stone (crushed) are very large and plentiful, respectively	China
CLAYS	Tile, absorbents, fillers and extenders, binders, drilling mud, construction, paper coating, brick	3.4% increase bentonite; 2.4% increase Fuller's earth; no change for kaolin	26,000 metric tons (50.0% common clay, 17.3% kaolin, 18.5% bentonite, 9.2% Fuller's earth, 6.4% other)	Net exporter	Extremely large	Bentonite: United States Fuller's earth: United States Kaolin: India
FELDSPAR	Glass, ceramic tile, pottery	1.2% increase	450,000 metric tons (marketable production)	33% net import reliance	More than adequate	Turkey

	END-USE INDUSTRIES	TREND GLOBAL PRODUCTION	US PRODUCTION	US IMPORT/EXPORT	WORLD RESERVES	LEADING PRODUCER
GALLIUM	Integrated circuits and optoelectronic devices, including laser diodes, light-emitting diodes, photodetectors, and solar cells	20.1% increase	None (primary)	100% net import reliance	Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and significant quantities could be contained in zinc. Less than 10% of gallium in bauxite or zinc is potentially recoverable.	China
GRAPHITE (natural)	Batteries, brake linings, lubricants, powdered metals, refractory applications, and steelmaking	4.6% increase	None	100% net import reliance	>800 million metric tons	China
INDIUM	Flat-panel displays, alloys and solders, compounds, electrical components and semiconductors, and research	6.0% increase	None	100% net import reliance	Estimate unavailable	China
IRON and STEEL	Construction, automotive, machinery and equipment, appliances	0.76% decrease pig iron; 0.53% increase raw steel	22 million metric tons pig iron; 81 million metric tons raw steel	13% net import reliance	N/A	Iron and steel: China
KYANITE	Refractories, abrasives, ceramic products, foundry products, and precision casting molds	Cannot be calculated	80,000 metric tons	Net exporter	Significant	Kyanite: United States Andalusite: South Africa
LITHIUM	Batteries, ceramics and glass, lubricating greases, air treatment, mold flux powders, medical uses	17.6% increase	Withheld	>50% net import reliance	Substantial increase worldwide to total ~115 million tons	Australia
MICA (scrap and flake)	Joint compound, oil- well-drilling additives, paint, roofing, rubber products	0.3% increase (scrap and flake)	23,000 metric tons sold and used; 52,000 metric tons ground	100% net import reliance	More than adequate	Madagascar
RARE EARTHS	Catalysts, ceramics, glass, metallurgical applications, alloys, polishing	3.7% increase	45,000 metric tons mineral concentrates	80% net import reliance for compounds and metals; net exporter for mineral concentrates	Relatively abundant in Earth's crust, but minable concentrations less common	China
SODA ASH	Glass, chemicals, distributors, flue gas desulfurization, soap and detergents, pulp and paper, water treatments	6.1% increase	12,000 metric tons	Net exporter	About 47 billion metric tons of identified natural soda ash resources; synthetic soda ash is practically inexhaustible but costlier to produce	United States
TITANIUM DIOXIDE (pigment)	Paints, plastics, paper, catalysts, ceramics, coated fabrics and textiles, floor coverings, printing ink, and roofing granules	N/A	850,000 metric tons	Net exporter	Data not available for pigment	China
YTTRIUM	Catalysts, ceramics, electronics, lasers, metallurgy, phosphors	Estimated to be between 15,000 to 20,000 metric ton	N/A	100% net import reliance	Global reserves are adequate, but high-demand, changes in economic conditions, environmental issues, and trade restrictions may affect availability and pricing	Burma China
ZEOLITES (natural)	Animal feed, odor control, wastewater treatment, gas absorbent, fertilizer carrier, pet litter, oil and grease absorbent, fungicide or pesticide carrier, desiccant, and catalyst	5.7% increase	81,000 metric tons	100% net import reliance	Estimate not available but likely sufficient	Slovakia

Bulletin | Application note

Cost-effective synthesis of aluminum nitride for thermal and light management applications



Scanning electron microscopy image of aluminum nitride spherical fillers obtained by combustion synthesis.

Credit: Chen and Miyamoto

By Weiwu Chen and Yoshinari Miyamoto

Efficient thermal management is essential to prevent functional degradation and energy loss in modern electronic devices.

Thermally conductive and electrically insulating ceramic powders—such as alumina, aluminum nitride, and boron nitride—are commonly used as fillers in polymer-based thermal interface materials (TIMs), including thermal gels and sheets, to enhance heat dissipation in electronic circuits. Among these ceramic powders, alumina is widely used because of its low cost and high chemical stability, despite its relatively low thermal conductivity (20–30 W/m·K). In contrast, aluminum nitride and boron nitride powders offer much higher thermal conductivities—approximately 170–220 W/m·K and about 60 W/m·K, respectively—but their commercial use remains limited due to higher production costs.

Aluminum nitride in particular has attracted significant attention as a versatile material thanks to its excellent thermal, electrical, and mechanical properties. Demand for aluminum nitride has thus steadily increased in the electronics industry during the past 40 years.[1]

In the context of TIM applications, the recent rapid growth of information and communication technology, electric vehicles, artificial intelligence, and other power electronics has led to increased demand for aluminum nitride powders and substrates. As a result, dedicated research has improved the mechanical and thermal properties of aluminum-nitride-filled gels and sheets, and thermal conductivity now exceeds 10 W/m·K.

These materials are now essential components in 5G base station antenna modules, insulated gate bipolar transistor devices, data center servers, and related applications. In 2024, the global market size for aluminum nitride fillers was estimated at US$78.9 million, with a compound annual growth rate of 6.3%.[2]

Currently, there are two major industrial processes employed to synthesize aluminum nitride powders:

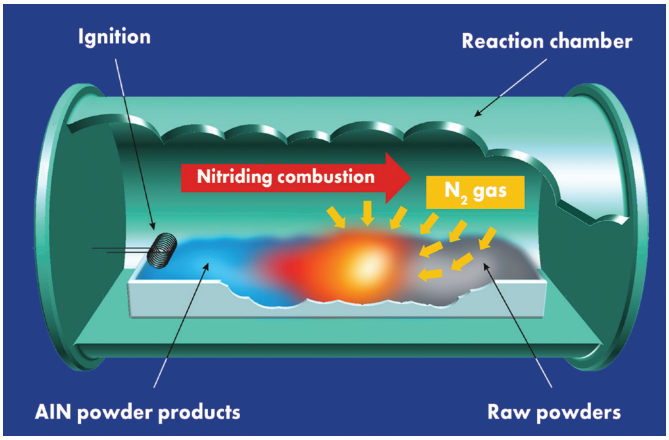
1. Carbothermal reduction and nitridation of alumina using carbon, under a nitrogen atmosphere at around 1,700°C.
2. Direct nitridation of aluminum metal powders in nitrogen gas under a precisely controlled heating rate between 500°C and 1,300°C.

The resulting aluminum nitride powders are ground, surface-treated to prevent hydrolysis with silane coupling agents or other coatings, and supplied as commercial-grade fine powders with low oxygen content.

An alternative synthesis approach is combustion synthesis.[3] This simple and more cost-effective method relies on a highly exothermic reaction between aluminum and nitrogen, which self-propagates after ignition and completes within minutes.

Because combustion synthesis requires no external heating—the temperature at the reaction front can reach nearly 2,000°C due to the heat of formation—the method significantly reduces costs associated with high-temperature furnaces, electricity, and processing times. However, the reaction is extremely difficult to control. A pressurized nitrogen atmosphere is essential to sustain the reaction, but even then, it often results in unreacted or agglomerated products with poor uniformity. Considerable research has been conducted worldwide to optimize this reaction, but industrial applications remain limited.

The authors have studied the combustion synthesis of aluminum nitride for decades,[4–8] and they recently succeeded in producing soft, nonagglomerated aluminum nitride powders. In their process, raw aluminum powders are blended with an appropriate amount of preformed aluminum nitride powder via combustion synthesis to moderate the reaction temperature. This mixture is placed in a graphite tray, and the nitridation is initiated by passing a short current with a few tens of amperes through a carbon heater. The entire reaction occurs in a high-pressure chamber filled with nitrogen gas at less than 1 MPa (Figure 1). The resulting aluminum nitride is pulverized and classified by conventional methods according to application needs.



Credit: Chen and Miyamoto

Figure 1. Schematic illustration of the nitriding combustion reaction of aluminum nitride synthesis in a high-pressure reaction chamber.

Table 1. Comparison of commercial aluminum nitride fine powders synthesized by three different methods. All powders have an average particle size of approximately 1 μm, with oxygen contents around 1 wt.%.

Process	Particle size	Particle morphology	Oxygen content	Purity	Cost
Reduction & nitridation	☆	☆	☆	○	△
Direct nitridation	○	○	○	○	○
Combustion synthesis	○	△	○	☆	☆

Quality : ☆ excellent , ○ good, △ poor

Credit: Chen and Miyamoto

From powder loading to product retrieval after cooling, the total process time is under two hours. Analysis shows this combustion synthesis method is 30–50% less expensive than the conventional aluminum nitride fabrication processes. Table 1 summarizes and compares the properties of the combustion synthesized aluminum nitride powders to ones produced through the conventional routes.

Considering the advantages and benefits of this new combustion synthesis method, commercial production of aluminum nitride using this method began through a joint startup program with Shanghai Toyo Tanso Co. Ltd., a subsidiary of Toyo Tanso Co. Ltd., a Japan-based global leader in graphite, carbon-based materials, and coated substrates such as silicon carbide- and tantalum carbide-coated graphite. The goal is to expand the use of aluminum nitride synthesized via this cost-effective process in thermal, light, and energy management applications.

For example, spherical aluminum nitride powders are widely used as fillers for TIMs. To produce spherical fillers, fine aluminum nitride powders—mixed with a few percent of yttrium oxide as a sintering aid—are spray-dried and sintered at around 1,800°C. The resulting particles are sieved to sizes ranging from 20–100 μm. Fine aluminum nitride powders (~1 μm) are also suitable for sintering into substrates and structural components, such as electrostatic chucks.

These fine and pure aluminum nitride powders can also be used in the synthesis of red phosphors (e.g., $CaAlSiN_3{:}Eu^{2+}$) for LEDs—an increasingly vital component in energy-saving lighting technologies. We also produce pure porous aluminum nitride crucibles without any sintering additives. These crucibles are ideal for heat-treating aluminum-nitride-based products in clean environments and offer a cost-effective alternative to boron nitride crucibles with less than half the cost.

While our current production scale is limited and our market remains primarily within China, we aim to expand our distribution worldwide in 2026 by scaling up the process.

Acknowledgments

The authors would like to express their sincere gratitude to their late colleague T. Sakurai for his invaluable contributions to this project. Our deepest condolences for his passing in 2017.

About the authors

Weiwu Chen is director of the R&D Division at Shanghai Toyo Tanso Co. Ltd. in China. Yoshinari Miyamoto is Professor Emeritus at Osaka University in Japan and senior advisor at Shanghai Toyo Tanso. Contact Miyamoto at yoshinari1027@yahoo.co.jp.

References

[1]L. M. Sheppard, "Aluminum nitride: A versatile but challenging material," *Am. Ceram. Soc. Bull.* 1990, **69**(11): 1801–1812.

[2]"Global Aluminum Nitride Filler (AlN) Market Research Report 2025," Valuates Reports. Published March 2025. Accessed 6 June 2025. https://reports.valuates.com/market-reports/QYRE-Auto-15T19189/global-aluminum-nitride-filler-aln

[3]A. G. Merzahnov and I. P. Borovinskaya, "A new class of combustion process," *Combustion Sci. & Tech* 1975, **10**: 195–201.

[4]K. Tanihata and Y. Miyamoto "Reaction analysis on the combustion synthesis of aluminum nitride," *Int. J. of Self-Propagating High-Temperature Synthesis* 1998, **7**(2): 209–217.

[5]Y. Morisada, T. Sakurai, and Y. Miyamoto, "A new water-resistant coating for AlN powders," *Int. J. Appl. Ceram. Technol.* 2004, **1**(4): 347–380.

[6]T. Sakurai, O. Yamada and Y. Miyamoto, "Combustion synthesis of fine AlN powder and its reaction control," *Mat. Sci. & Eng.* 2006, **415**(1–2): 40–44.

[7]M. Radwan and Y. Miyamoto, "Growth of quasi-aligned AlN nanofibers by nitriding combustion synthesis," *J. Am. Ceram. Soc.* 2007, **90**(8): 2347–2351.

[8]Z. Shi, M. Radwan, S. Kirihara, Y. Miyamoto, and Z. Jin, "Morphology-controlled synthesis of quasi-aligned AlN nanowhiskers by combustion method: Effect of NH_4Cl additive," *Ceram. Int.* 2009, **35**: 2727–2733. ■

High-temperature gas sealing properties of sericite-based self-expansion compression seals

By Seiichi Suda

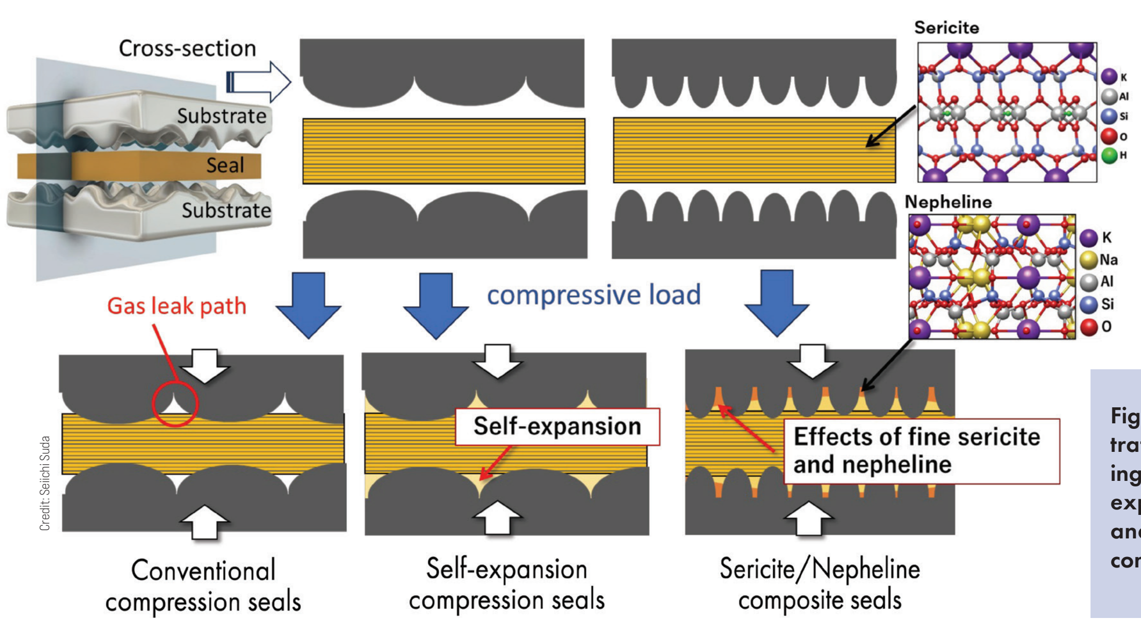


Figure 1. Schematic illustration of the promising advantages of self-expansion compression and sericite/nepheline composite gas seals.

Both solid oxide fuel cells (SOFCs) and solid oxide electrolysis cells (SOECs) require reliable gas seals that are durable at high temperatures and stable in hydrogen environments.

Glass-based materials typically exhibit excellent gas sealing properties at elevated temperatures. However, they encounter significant durability challenges under rapid thermal cycles and vibrations, both of which pose barriers to the installation of glass-sealed SOFCs in mobile systems.

In contrast to traditional glass-based gas seals, glass-free gas seals made from clay materials perform well under vibrations due to their high elasticity. Thus, the development of advanced clay-based gas seals represents a promising research area for rapid start/stop working systems and vehicles.

To ensure an adequate gas barrier, gas seals must handle both a substantial load and achieve a high degree of contact with adjacent materials. My group is developing self-expanding sericite-based compression seals to fulfill both requirements.

Benefits of clay minerals for self-expansion compression seals

Clay minerals with layered structures are increasingly recognized as critical raw materials for compression seals. These minerals exhibit significant anisotropy and irreversible expansion during processing, as the interlayers open widely when dehydrated during heating.[1] For example, vermiculite irreversibly expands multiple times in the vertical direction of each layer when heated to 700°C.

Compression under moderate tightening loads tends to create small gaps at the interface between adjacent materials and the seals due to the uneven material surfaces. The self-expansion inherent to clay minerals effectively fills these gaps within the seals, significantly reducing gas leakage at the interface.

The processing conditions of clay materials greatly influence the degree of irreversible expansion. Proper calcination at temperatures lower than the operating temperatures of SOFCs/SOECs achieves a balance between excellent elasticity and self-expansion during heating at the operating temperature.[2]

Sericite-based compression seals

We focused on using the layered clay sericite ($KAl_3Si_3O_{10}(OH)_2$) as a compression seal for two reasons: its promising insulating properties in a reducing atmosphere and its fine particle sizes.

Sericite contains lower concentrations of transition metal elements compared to other clays. These low concentrations mean that sericite can maintain high electrical insulation even in a highly reducing atmosphere at elevated temperatures.

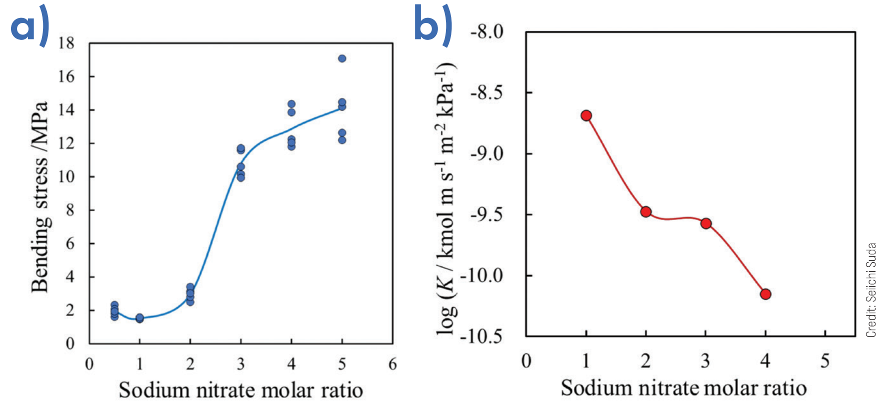


Figure 2. Impacts of nepheline formation on a) mechanical strength (estimated by the three-point bend test) and b) gas permeability (0.46 MPa compression load at 700°C).

As noted in the previous section, the self-expansion of clay minerals allows the seal to conform to microscopic surface irregularities. Clay minerals that feature fine particles enhance the sealing properties because the layered fine particles will help fill the very small gaps (Figure 1).

Layered clays typically consist of coarse particles, and pulverization processes are necessary to obtain fine particles with layered structures. This pulverization significantly reduces the irreversible expansion and self-expansion properties of the clay because it disrupts the layered structure. Fortunately, high-purity sericite naturally forms under hydrothermal conditions and contains fine particles. Only deagglomeration processes that maintain the layered structure are necessary to obtain fine sericite particles.[3]

Sericite, like other layered clays, demonstrates irreversible anisotropic expansion during processing. This irreversible expansion is essential for achieving high gas sealing performance. However, clay minerals may also experience reversible thermal expansion during thermal cycling in operation, and this behavior plays a vital role in the long-term durability of the sealing material.

To evaluate the reversible thermal expansion of sericite, we measured the temperature dependence of the lattice constant using high-temperature X-ray diffraction.[4] The linear expansion coefficient indicated that the reversible thermal expansion of sericite closely correlates with that of typical SOFC electrodes and electrolyte materials, meaning adequate contact will be maintained between the seal and adjacent materials during cycling. Thus, sealing materials primarily composed of sericite can be used for SOFC and SOEC applications.

Potential of sericite/nepheline composites

Despite its advantages, the low mechanical strength of sericite poses a significant challenge to its use as a novel compression seal. Fortunately, the addition of sodium salt to sericite-based seals can notably improve mechanical strength due to the formation of nepheline.

Nepheline is a type of silicate mineral that forms in sericite when heated with sodium salts. It acts as an adhesive between sericite particles and layers, significantly enhancing mechanical strength. Nepheline can also help enhance gas sealing properties at high temperatures because it forms after undergoing a liquid phase. This transient liquid phase allows it to fill the remaining interfacial gaps that were missed by the self-expansion of sericite. Figure 2 shows the impacts of nepheline formation on mechanical strength and gas permeability of the sericite-based compression seals.[4]

In addition to conventional evaluation of the seal's gas permeability (Japanese Industrial Standards R 1761), we separately evaluated the seal's internal gas permeability coefficient, which is derived from the gas permeation path inside the sealing material, and the interfacial gas permeability coefficient, which is derived from the gas permeation path along the interface with the adjacent materials. We determined that the formation of nepheline improved both internal gas permeation and interfacial gas permeation.

The optimization of nepheline is essential to enhance the gas sealing properties of the sericite/nepheline composite. Fortunately, the properties of nepheline can be regulated by substituting alkaline metals contained in the nepheline with other cations via solid solution methods. We found that the addition of potassium significantly improved gas permeation not only from the inside of the seal material but also at the interface.

Future of sericite-based compression seals

Reliable gas seals are needed for next-generation SOFCs and SOECs. This study showed that the thermal properties of sericite-based compression seals are suitable for this purpose. Additionally, the formation of nepheline in sericite-based compression seals via sodium salt doping enhances the sealing properties. Future studies will explore how the sealing performance can be further improved by combining it with suitable additives that modify the properties of the base sericite and nepheline.

About the author

Seiichi Suda is professor of materials science and engineering at Shizuoka University, Japan. Contact Suda at suda@shizuoka.ac.jp.

References

[1]M. Rautanen et al., "Effects of the first heat up procedure on mechanical properties of solid oxide fuel cell sealing materials," *Journal of Power Sources* 2015, **284**: 511–516.

[2]J. Xu and S. Suda, "Effects of composite ratio of vermiculite/talc seal material on gas leak properties," *Proc. 42nd Int. Conf. on Adv. Ceram. Composites* 2019, **39**(2).

[3]"Sanshin Mining's sericite products," Sanshin Mining Ind. Co., Ltd. Accessed 17 June 2025. https://www.sanshin-mica.com/english

[4]Y. Abo and S. Suda, "High-temperature gas sealing properties of sericite-based self-expansion compression seals." Poster presented at the 49th International Conference and Exposition on Advanced Ceramics and Composites, January 2025. ■

Jonathon Foreman
ACerS journals managing editor

Ceramic electrochemical catalysts enable advanced energy and environmental remediation

Electrochemical catalysts, or substances that speed up the rate of a chemical reaction, are the focus of extensive research for advanced energy applications, including production and storage of hydrogen and electricity, along with remediation of pollutants.

Catalytic materials work by adding electrons to (reduce) or removing them from (oxidize) the target reactant. The catalytic potential is determined by the magnitude of its band gap, i.e., the distance between the native upper electron energies (the valence band) and the conduction band, where the electrons are mobile. When electrons gain sufficient energy to move into the conduction band, a positively charged "hole" that can capture electrons is created (Figure 1).

In metals, carbon, and other conductors, the valence and conduction bands are close or overlapping. For insulators, the band gaps are large. Semiconductors have band gaps too large for direct conduction, but they are small enough that adding energy to the system—such as from environmental vibrations, light, and chemical potential—can lead to electrons entering the conduction band.

Catalysts must conform to a common set of requirements: high functionality and selectivity, resilience within the operating environment, longevity (or renewability), and low cost, among others. Maximizing input energy usage while maintaining catalytic activity and minimizing costs are the driving forces for catalyst research.

One way to fulfill these requirements involves reducing the effective band gap via doping or other methods. The article "Principles, mechanism, and identification of S-scheme heterojunction for photocatalysis: A critical review" by Molaei provides an in-depth discussion of this topic.[1] In essence, structural mismatches caused by dopants can, in some cases, reduce the effective band gap. This smaller band gap causes the doped material to have a greater electronic response with a lower energy input compared to the original (undoped) material.

Increasing the amount of energy absorbed is another route for improving catalyst performance. Titanium oxide (TiO_2), a common photocatalyst, can only absorb ultraviolet light energy due to its band gap; the energy from the visible light spectrum goes unused. In the paper "Influence of Al-doped $SrTiO_3$ cores on hydrogen evolution from $SrTiO_3/TiO_2$ core–shell catalysts," Song et al. improved the catalytic activity by fabricating core-shell structures with TiO_2 coated onto aluminum-doped strontium titanate cores.[2] The authors found that the cores absorb broader ranges of light and are responsible for generating and separating the electron–hole pairs for photocatalytic hydrogen generation. While the TiO_2 shell is less important catalytically, it can still serve to protect the core from degradation.

As noted earlier, electrolysis is of great interest in the field of hydrogen production, especially for making good use of excess electricity generated by wind, solar, nuclear, and even traditional power plants. The hydrogen produced through this process can be used as a fuel in fuel cells or internal combustion engines for electricity generation, transportation, and other purposes.

For this application, there are design benefits to having a single (bifunctional) catalyst for both electrodes. In the paper "Bifunctional $MnCo_2Se_4$ nano-cubes directly grown on nickel foam for effective water oxidation," Shah et al. demonstrate that nanocrystalline manganese cobalt selenide grown on nickel foam is a promising bifunctional electrolysis catalyst.[3] It performs well for both the hydrogen and oxygen evolution reactions at the two electrodes and maintains good stability over time. The authors show that their material's performance is comparable to that of the expensive noble metal ruthenium, which is a benchmark for electrolytic catalysts.

These few examples only scratch the surface of the full range of research into ceramic electrochemical catalysts. Visit the ACerS journals homepage at https://ceramics.onlinelibrary.wiley.com to begin your search for new materials and technologies that will help improve global sustainability.

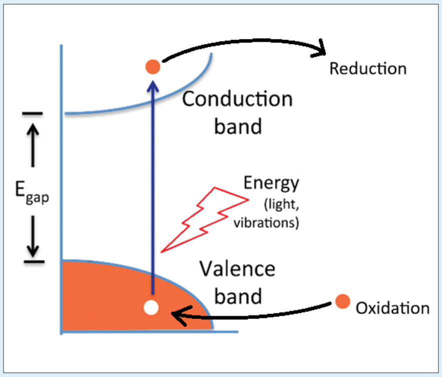


Figure 1. Schematic of atomic-level valence and conduction bands and energy-driven formation of electron–hole pairs.

References

[1]M. J. Molaei, "Principles, mechanism, and identification of S-scheme heterojunction for photocatalysis: A critical review," *J. Am. Ceram. Soc.* 2024, **107**(9): 5695–5719.

[2]W. Song, P. A. Salvador, and G. S. Rohrer, "Influence of Al-doped $SrTiO_3$ cores on hydrogen evolution from $SrTiO_3/TiO_2$ core–shell catalysts," *J. Am. Ceram. Soc.* 2025, **108**(8): e20542.

[3]S. I A. Shah et al., "Bifunctional $MnCo_2Se_4$ nano-cubes directly grown on nickel foam for effective water oxidation," *J. Am. Ceram. Soc.* 2024, **107**(12): 8256–8268. ■

CERAMICS EXPO

CERAMICS EXPO 2025: A DECADE OF INNOVATIONS DRIVEN BY INCREASINGLY URGENT MARKET DEMANDS

All photos credit: ACerS

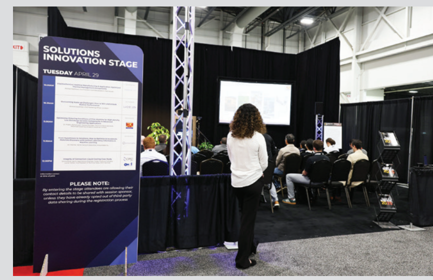
This year's Ceramics Expo took place April 29–30 at the Suburban Collection Showplace in Novi, Mich. It kicked off Monday night with a VIP networking event, followed by two days of exhibiting and conference talks that ran alongside the co-located Thermal Management Expo.

As the milestone 10th anniversary of this conference, the presentations and panel discussions at Ceramics Expo 2025 focused largely on market factors that have shaped the ceramic and glass industry over the past decade. Sessions on sensor miniaturization, high-temperature materials fabrication and application, and scale-up of ceramic additive manufacturing processes helped first-time attendees appreciate some of the key challenges facing the industry today.

These sessions also made it evident, however, the increasing urgency to develop solutions to some of these challenges—such as raw material supply chains, the lifeblood of manufacturing.

Many critical minerals are "asymmetric commodities," a term American Element CEO Michael Silver uses to describe the concentration of critical mineral deposits or processing facilities in a single nation. Such concentrated production gives that nation significant control over pricing, and as discussed in the first two presentations of the conference, the recent tariff actions taken by the U.S. government have revealed the significant economic impacts of upsetting this delicate market balance.

This year's bags given to Ceramics Expo attendees recognized the conference's 10th anniversary.



The Solutions Innovations Stage offered more in-depth insights into specific products and solutions to complement the presentations on the main stage.

The second presentation on the first morning of Ceramics Expo 2025 focused on shoring up resilience in the technical ceramics supply chain. It was moderated by Keith DeCarlo of Blasch Precision Ceramics (left) and featured insights from Jose Martin of Allied Mineral Products (center) and Claire Theron of STC, a unit of IDEX Corporation (right).

During the ACerS Corporate Partner and Manufacturing Division breakfast, the John E. Marquis Award was presented to postdoctoral fellow Marco Pelanconi for his paper "High-strength Si–SiC lattices prepared by powder bed fusion, infiltration-pyrolysis, and reactive silicon infiltration," published in *Journal of the American Ceramic Society*.

As a result, innovations in materials and processing methods can help address supply chain challenges by shifting reliance away from critical minerals toward more accessible materials and reducing waste during production, for example.

To showcase some of these developments, Ceramics Expo 2025 included a new Solutions Innovation Stage alongside the main conference presentations. This stage featured expert-led discussions and technical presentations on some cutting-edge products and solutions by several leading ceramic suppliers and manufacturers, such as Fabric8Labs, Lucideon, Hindalco Industries Ltd., Uncountable Inc., and Colder Products Company and Omni Services.

Of course, successfully developing such innovations requires an educated workforce, and during the ACerS Corporate Partner and Manufacturing Division breakfast on Wednesday, Robocasting Enterprises founder and president Joe Cesarano reported on a survey that ACerS is conducting to better understand the industry's most pressing workforce needs. The results of that survey will release later this year.

Overall, this year's conference served as a welcoming review of the market since the first edition in 2015. Next year, Ceramics Expo will begin the new decade with a fresh start by returning to its hometown of Cleveland, Ohio, May 5–6, 2026.

See more pictures from Ceramics Expo 2025 on the ACerS Flickr page at https://bit.ly/CEX-2025. ■

ATTENDEES MAKE INCREDIBLE MEMORIES DURING THE COMBINED PACRIM 16/GOMD 2025 IN VANCOUVER

In a year marked by challenges to international travel, hundreds of people successfully came together in the heart of Vancouver, Canada, from May 4–9, 2025, to share their love for ceramic and glass materials at the 16th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM).

PACRIM is a biennial conference held in collaboration with the ceramic societies of the Pacific Rim countries: The American Ceramic Society, Chinese Ceramic Society, Ceramic Society of Japan, Korean Ceramic Society, and Australian Ceramic Society. As a benefit of the 2025 conference taking place in North America, the annual meeting of ACerS Glass & Optical Materials Division took place alongside the PACRIM programming as well.

The more than 700 attendees at this year's combined conference came from 33 countries and included 114 students. They enjoyed talks on a wide range of established and emerging ceramic and glass technologies across more than 40 symposia, organized by PACRIM chair Yiquan Wu and co-chair Brian Huey and GOMD co-chairs Madoka Ono and Collin Wilkinson.

"I truly felt that the 16th PACRIM was a beautiful testimony to the wonderful international ceramics community. We gathered at the conference not only as scientists and researchers but also as individuals committed to creating a better world—by fostering stronger friendships, broader collaborations, and a deeper sense of humanity among participants," Wu says.

Ono also expressed excitement for the turnout and engagement at this year's meeting, saying that she sees GOMD 2025 as "just the beginning."

"As these kinds of interactions become more common, I expect glass research will emerge more prominently—even within the broader ceramics field, where glass has long been a part but often overlooked," Ono says.

Highlights from PACRIM 16/GOMD 2025 are below.

PLENARY LECTURES DIVE INTO THE STRUCTURES THAT UNDERLIE OUR WORLD

The PACRIM programming featured six plenary talks by experts who specialize in understanding the microstructures that make up our beloved ceramic and glass materials. The first four plenaries were presented on Monday, and the last two were presented on Tuesday.

Martin Harmer of Lehigh University presented the first plenary on complexions, or complex 3D structures found within the internal interfaces of ceramics. This concept has gone by many different names over the years, and Harmer advocated that scientists adopt a unified terminology to help streamline research on this phenomenon.

Yuichi Ikuhara of the University of Tokyo presented the second plenary on the behavior of grain boundaries in ceramics, focusing on fracture mechanics as well as diffusion and migration of atoms, among other dynamic phenomena.

Jian Luo of the University of California, San Diego presented the third plenary on using flash sintering to control the microstructure in ceramics. He also briefly mentioned the use of blacklight and plasma sintering, as well as opportunities for controlling the microstructure in high-entropy ceramics.

Haiyan Wang of Purdue University presented the fourth plenary on designing functional ceramics by harnessing complex hybrid metamaterial systems. Her main example described vertically aligned nanocomposites films for use in memristors, batteries, and fuel cells.

Seungbum Hong of Korea Advanced Institute of Science & Technology presented the fifth plenary on using various imaging methods to investigate ion behavior and polarization in piezo- and ferroelectric materials. Understanding this behavior can open new pathways in battery design.

Liangbi Su of Shanghai Institute of Ceramics, Chinese Academy of Sciences was the sixth and final plenary speaker. Unfortunately, he was unable to attend the conference, so his colleague gave the talk—which focused on local structure tailoring of rare-earth-doped optical materials—on his behalf.

Besides the plenary lectures, Wu also recognized this year's recipients of the Samuel Geijsbeek PACRIM Internal Award: Dileep Singh of Argonne National Laboratory and Junichi Tatami of Yokohama National University. This award recognizes individuals who are members of the PACRIM societies for their contributions that have resulted in significant industrial and/or academic impact, international advocacy, and visibility of the ceramic and glass field.

AWARD TALKS SHOWCASE NOVELTIES IN GLASS SCIENCE

The GOMD programming featured five award talks by experts conducting research on the cutting-edge of glass science.

Daniel Neuville of the Paris Institute of Earth Physics presented the George W. Morey Award lecture on the fundamental relationships between glass compositions and their properties. He demonstrated how advanced spectroscopic techniques can elucidate these critical structure–property relationships, providing valuable insights for both theoretical understanding and practical applications in glass science and technology.

Jayani Kalahe of the University of North Texas presented the Norbert J. Kreidl Award lecture on her doctoral research, which involves understanding structure–property relationships in iron phosphate nuclear waste glasses through computer simulations. More details about her research can be found in the June/July 2025 *Bulletin*, available online at https://bulletin.ceramics.org.

Timothy Gross of Corning Incorporated presented the Stookey Lecture of Discovery on understanding the mechanisms that prevent catastrophic fracture in damage-resistant glasses. His examples included Corning's famous Gorilla Glass and recently released Fusion5 windshield.

This year's recipients of the Darshana and Arun Varshneya Frontiers of Glass Lectures were John Mauro of The Pennsylvania State University and Stephen Elliott of the University of Oxford. Mauro was unable to attend the conference, but he provided a recording of his Frontiers of Glass Technology lecture on LionGlass, a novel glass family that could someday replace soda lime silicate glass in many applications. Elliott presented the Frontiers of Glass Science lecture on so-called "bad" glasses, or ones that readily crystallize. He showed these glasses could find application as good phase change materials, however.

Besides the award lectures, Delbert Day of Missouri University of Science and Technology was also

All photos credit: ACerS

recognized with the L. David Pye Glass Hall of Fame Award. Day was unable to attend the conference, so fellow Missouri S&T professor Richard Brow accepted the award in his stead.

NEW SESSIONS AND NETWORKING EVENTS HELP ATTENDEES 'MERGE AND EMERGE'

For GOMD co-chair Ono, she saw this conference as an opportunity for attendees to "merge" their shared knowledge and personal networks and subsequently "emerge" with a new appreciation and research directions for ceramic and glass science and technology.

To support this goal, the GOMD programming included a special symposium on Emerging Frontiers: Glasses in New Technology. The meeting co-chairs also organized an informal Fun Run (walk around Vancouver) and Student Mixer to help attendees build new networks with their peers.

"It seems that both the audience and presenters are truly enjoying and appreciating this effort," Ono says.

The ACerS-organized Conference Mentor Program also took place at PACRIM 16/GOMD 2025, and this time 19 mentors and 24 mentees participated.

APPRECIATING THE NATURE AND CULTURE OF VANCOUVER

Having a conference in one of the most beautiful cities in the world is a waste if no one has time to explore it. For this reason, the PACRIM/GOMD organizers graciously left Wednesday afternoon open with no scheduled sessions so attendees could enjoy the breathtaking views offered by the Pacific Ocean and North Shore Mountains.

Vancouver is also known for its cultural diversity, and during the banquet on Thursday night, members of the Squamish First Nations performed several traditional dances for attendees.

View more images from the conference on ACerS Flickr page at https://bit.ly/PACRIM-16-GOMD-2025.

Next year, GOMD will take place alongside five other Division meetings at the new ACerS Spring Meeting in Bellevue, Wash., in April 2026. ■

ACerS President Monica Ferraris, right, presents PACRIM chair Yiquan Wu with a certification of appreciation for his efforts organizing the conference.

At the end of his plenary lecture, Martin Harmer surprised attendees with shirts featuring a diagram of complexions as well as a list of terms used to describe this concept in the literature.

Squamish First Nations dancers performing during the Thursday banquet.

Attendees at the GOMD student mixer on Monday night.

Grouse Mountain is one of the North Shore Mountains near Vancouver. It is known for the challenging Grouse Grind Trail, which several members of the ACerS staff successfully completed on Wednesday afternoon. From left: Mark Mecklenborg (who met up with the hikers at the top of Grouse Mountain), Lisa McDonald, Andrea Ross, Madilyn Paul, and Kameron Haines.

GOMD co-chairs Madoka Ono (far left) and Collin Wilkinson (far right) stand with Arun Varshneya (second from left) and other past recipients of the Frontiers of Glass Lectures.

UPCOMING DATES

GREATER COLUMBUS CONVENTION CENTER,

COLUMBUS, OHIO

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

HILTON DAYTONA BEACH OCEANFRONT RESORT,

DAYTONA BEACH, FLA.

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

HYATT REGENCY BELLEVUE ON SEATTLE'S EASTSIDE,

BELLEVUE, WASH.

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

SHERATON SAN DIEGO HOTEL & MARINA,

SAN DIEGO, CALIF.

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

Calendar of events

August 2025

19–20 ★ Thermal Measurement Workshop – Westerville, Ohio; https://ceramics.org/course/orton-thermal-measurement-workshop

21 ★ Ultrahigh-Temperature Ceramics for Hypersonic Applications — Livermore, Calif.; https://ceramics.org/course/mccormack-opila-uhtc-hypersonic-applications

September 2025

2–11 ★ Sintering of Ceramics – Virtual; https://ceramics.org/course/castro-sintering-course

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

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

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

October 2025

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

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

29 ★ Hypersonic Workshop – Washington, D.C.; https://ceramics.org/course/hypersonic-workshop-dc

November 2025

30–Dec. 3 ➡ The 14th International Conference on High-Performance Ceramics — Haikou, China; https://cicc14.ceramsoc.com

January 2026

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

March 2026

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

April 2026

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

May 2026

5–6 ➡ Ceramics Expo 2026 – Cleveland, Ohio; https://ceramics.org/event/ceramics-expo-2026

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

June 2026

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

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

August 2026

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

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

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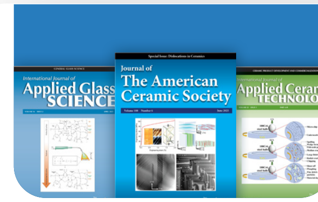

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deciphering the discipline

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

By Hugh Smith
Guest columnist

Raw material considerations for next-generation energy storage technologies

Energy storage technologies touch many aspects of our lives, from powering our personal handheld devices to boosting the reliability of intermittent renewable energy sources. While many types of energy storage technologies exist to meet these market demands, batteries have emerged as the most popular option due to their scalability.

Lithium-ion batteries (LIBs) specifically dominate the energy storage space due to their high energy density and long life. Since their commercialization in the 1990s, continuous developments improved LIB technology to the point that production costs are dominated by raw materials prices themselves.[1]

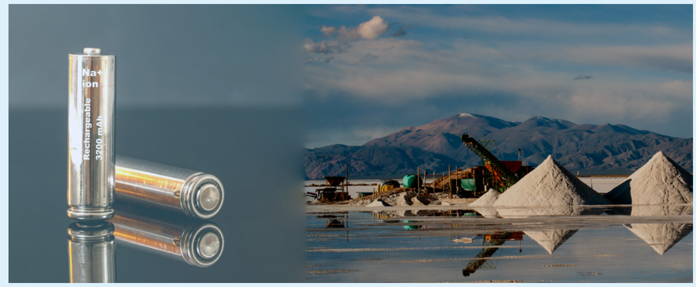
LIB cathode materials typically have high concentrations of elements such as nickel, cobalt, and, of course, lithium. These elements are relatively scarce compared to other metals, and they are concentrated in geographic areas that often are the site of political turmoil or unstable trade relations with the United States. These geopolitical factors lead to LIB cathode materials being expensive and susceptible to price fluctuations.

An alternative to LIBs is sodium-ion batteries (NIBs). These batteries have a similar working mechanism to LIBs and could be manufactured using existing LIB infrastructure. Most importantly, the most energy-dense category of LIB or NIB cathode materials—layered transition metal oxides—can be designed with high amounts of abundant elements such as manganese and iron in NIBs; the same is not true for LIBs. Additionally, sodium is 1,000 times more abundant than lithium in the Earth's crust (Figure 1), leading to considerably lower raw materials prices.[2] NIBs therefore have the potential to be very cost-effective alternatives to LIBs.

Considering these advantages, why have we not yet adopted NIBs on a large scale? The issue lies in performance. A battery derives its capacity from how many ions shuttle between electrodes. Sodium is heavier than lithium, which leads to more mass for the same capacity and lower inherent energy density for NIB cathode materials.

While the highest energy density NIB cathode materials are on par with lower performing but widely commercialized LIB cathode materials (most notably $LiFePO_4$, or LFP), they are not suitable for applications where the weight of the battery matters more than the cost (e.g., cell phones and smartwatches). In terms of energy density, however, they are suitable for the same applications as LFP (e.g., electric vehicles and stationary storage).

Furthermore, while manganese- and iron-based materials are cheaper, they tend to degrade quicker due to structural instability. This behavior means your battery needs to be charged more frequently. Plus, these materials have issues with transition metals migrating from their stable site, and they undergo a lot of phase changes in their crystal structure throughout charging and discharging. The stresses and strains these changes cause lead to deterioration of the material.[3]



Credit: Shutterstock

Figure 1. Sodium is sourced from many different salt flats around the world. Pictured is the Salinas Grandes, a salt desert in the Jujuy Province of Argentina.

My Ph.D. research centers around improving the structural stability of manganese and iron-based NIB cathode materials at different scales. On the atomic scale, I focus on switching individual atoms with other elements or vacancies to improve stability and energy density.[4] On the microscale, I focus on preventing changes in the crystal structure during cycling.

NIBs are a few decades behind in development compared to LIBs, but they are receiving lots of attention and will quickly catch up. A few NIB startups have emerged recently, and earlier this year, CATL, the largest battery manufacturer in the world, launched an NIB brand for electric vehicles.[5]

The raw material advantages of NIBs promise a bright future for this technology. Once the material issues are resolved, I believe we will see its widespread implementation very soon.

References

[1]A. Yao, S. M. Benson, and W. C. Chueh, "Critically assessing sodium-ion technology roadmaps and scenarios for techno-economic competitiveness against lithium-ion batteries," *Nat. Energy* 2025, **10**: 404–416.

[2]M. Munjal et al., "Process cost analysis of performance challenges and their mitigations in sodium-ion battery cathode materials," *Joule* 2025, **9**(5): 101871.

[3]Q. Liu et al., "Recent progress of layered transition metal oxide cathodes for sodium-ion batteries," *Small* **15**(32): 1805381.

[4]Smith HB, Lee G-H, Kumar BS, et al. "Elucidating the role of Fe substitution on structural and redox stability of $Na_2Mn_3O_7$," *J. Mater. Chem. A* 2025, **13**(16): 11466–11474.

[5]"China's CATL launches new sodium-ion battery brand," *Reuters*. Published 21 April 2025. https://reut.rs/4kmWKf2

Hugh Smith is a fourth-year Ph.D. candidate in materials science and engineering at Massachusetts Institute of Technology working on cathode materials for lithium- and sodium-ion batteries. In his free time, he likes to go fishing and explore the city of Boston. ■

WELCOMING NEW FACULTY

Caio Bragatto, Ph.D.

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

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

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

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