AMERICAN CERAMIC SOCIETY

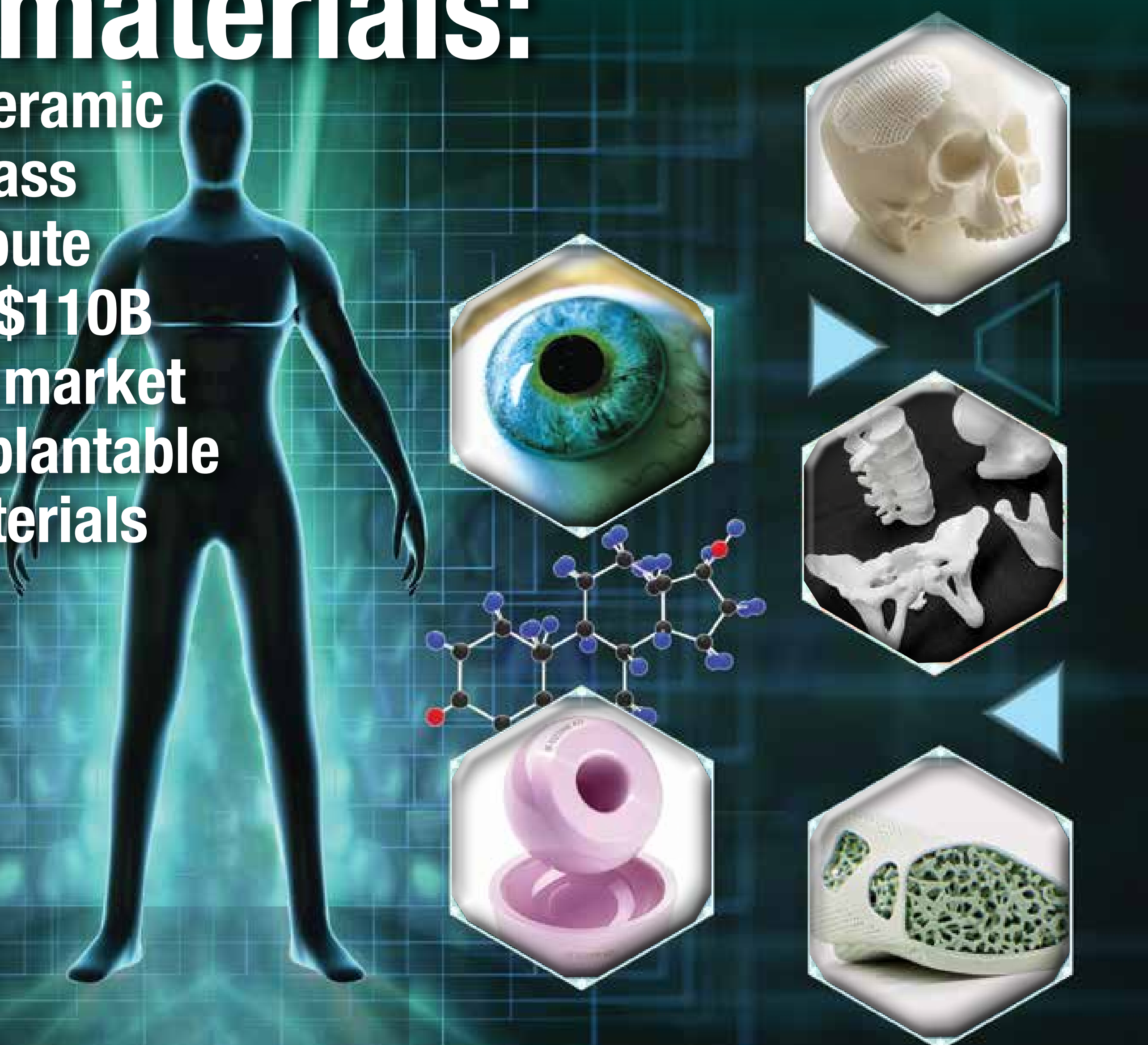
bulletin

emerging ceramics & glass technology

DECEMBER 2020

Better bodies with biomaterials:

How ceramic and glass contribute to the $110B global market for implantable biomaterials



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AND Ceramic & Glass MANUFACTURING

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AMERICAN CERAMIC SOCIETY bulletin

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As seen on *Ceramic Tech Today*...

Credit: University of Oxford Press Office, Flickr (CC BY 2.0)

Pursuing the future of energy: A review on perovskite tandem solar cell development and fundamentals

Perovskite tandem solar cell technologies improved rapidly in the past six years, but there are still challenges keeping them from commercialization. A recent review article by two researchers at the University of Surrey in the U.K. provides an expansive look at this budding industry.

Read more at www.ceramics.org/perovskitereview

Also see our ACerS journals...

A review: Recent advances in sol-gel-derived hydroxyapatite nanocoatings for clinical applications
By G. Choi, A. H. Choi, L. A. Evans, et al.
Journal of the American Ceramic Society

Review on calcium silicate-based bioceramics in bone tissue engineering
By P. Srinath, P. Abdul Azeem, and K. Venugopal Reddy
International Journal of Applied Ceramic Technology

A review of acellular immersion tests on bioactive glasses—influence of medium on ion release and apatite formation
By A. Nommeots-Nomm, L. Hupa, D. Rohanová, D. S. Brauer
International Journal of Applied Glass Science

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ACSBA7, Vol. 99, No. 9, pp 1– 138. All feature articles are covered in Current Contents.

news & trends

Toward an International Year of Glass

Credit: International Year of Glass

Glass helps us live safer and more sustainable lives, from offering a sound disposal method for nuclear waste to improving osseointegration of biomedical implants to allowing for high-speed internet access. Yet this material, which is key to so many applications, is often underappreciated in society and viewed only in terms of windows and kitchenware.

Educating the public about the importance of glass in modern society is a goal for many materials science organizations, but individual efforts only go so far. What if we could bring people together in a global initiative to raise awareness of this influential material?

That is the driving force behind a recent initiative spearheaded by the International Commission on Glass (ICG) to have 2022 declared the International Year of Glass.

Since 1959, the General Assembly of the United Nations designated specific years as United Nations International Years to acknowledge fields of international endeavor and the importance of their contributions to global society. Usually, one or more Member States propose these observances, or on occasion, specialized agencies of the United Nations such as UNESCO and UNICEF may put forth a proposal. The proposal for the International Year of Glass, though, originated from a completely different source.

International Year of Glass: From conception to a thousand endorsements

The idea for an International Year of Glass was first discussed at the 2018 Fall Annual Meeting of ICG in Yokohama, Japan, per a suggestion by ACerS Distinguished Life Member David Pye. In May 2019, ICG, The Corning Museum of Glass, The American Ceramic Society, and The Glass Art Society endorsed the idea in a presentation to the Office of the United States Mission of the United Nations in New York City, which was well received.

ICG president Alicia Durán formally introduced the initiative to the ACerS community in a "Letter to the Editor" published in the September 2019 *Bulletin*. At the time, she noted that "Extensive planning is now underway to inform international art and scientific glass-themed societies and museums of this endeavor to secure the United Nations declaration of the 2022 International Year of Glass."

Since then, more than 1,100 organizations from over 70 countries have expressed support for the initiative. In an email, Durán says they are now forming an international steering committee to continue working and developing the initiative, and "Fundraising campaign, proposals of activities (international and national) and spreading these activities to the planet will be some of the tasks that we can face, and solve!!"

Coming next: November presentation to the United Nations

The next big task on the way to having 2022 designated the International Year of Glass is to receive formal approval from the UN. To do that, the International Year of Glass steering committee is preparing a presentation to be given in early November to the UN General Assembly.

Agustin Santos, the Spanish Ambassador to the UN, has guided the required resolution through the General Assembly, and he will present the proposal in November through a virtual presentation. The presentation will include introducing partner organizations and personalities in the International Year of Glass project, explaining the activities planned and concepts being developed, and how they link to the UN Agenda 2030.

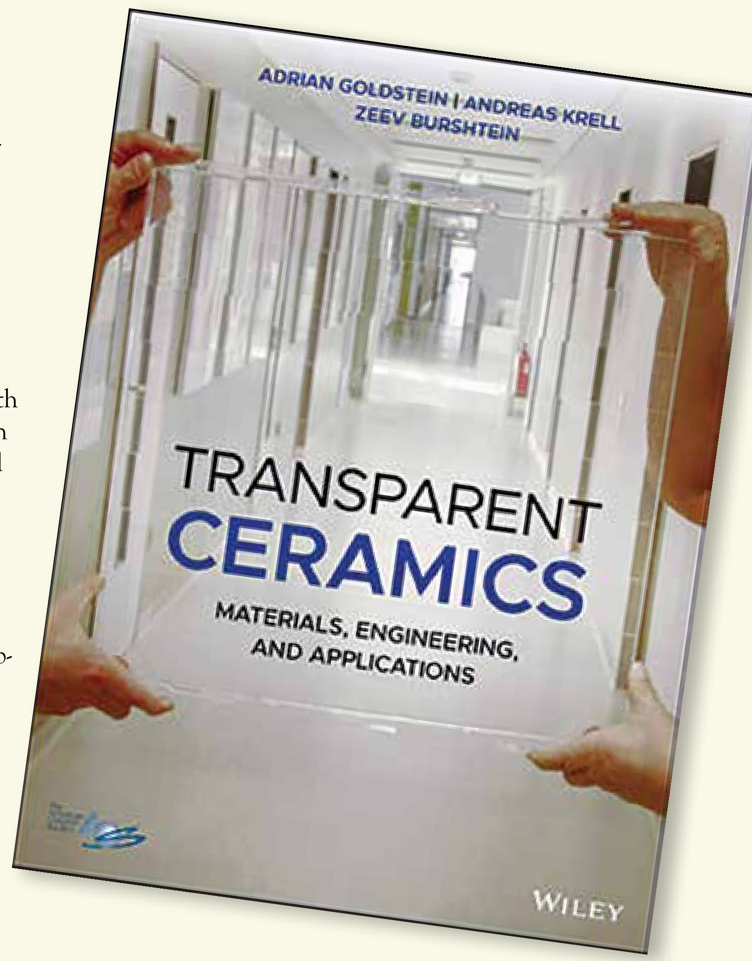
Volkan Bozkir, the Turkish Ambassador and recently installed President of the Assembly, has already expressed his support and will do so during the presentation as well.

After the presentation, the resolution for approving the International Year will be presented at the 75th UN General Assembly planned for December 2020.

If you wish to become a supporting institution, you can register your interest on the official International Year of Glass website at http://iyog2022.org or email the steering committee at manager@iyog2022.org. You can follow updates on the initiative on the official LinkedIn page at https://www.linkedin.com/company/international-year-of-glass-2022. ■

Roni Shneck
Guest columnist

Review of *"Transparent Ceramics: Materials, Engineering, and Applications"*



Over the last two decades and more, a considerable effort has been invested in development of optically transparent ceramic and glass-ceramic materials for functioning as various optical elements. Fabrication techniques of ceramic components has the potential of being highly cost-effective, and exhibit improved uniformity of optical properties compared to their crystalline counterparts. The prospected uses range from transparent optical military armour up to optical laser components.

The book addresses in detail that entire scope, starting with the underlying theoretical basis through technical production details, relevant materials, and current and future prospected applications. Especially, it provides a survey and analysis of currently used and studied materials, and points out some goals for near future developments.

Chapter 1 describes the book rational topic and aims in view of some historic progress, a definition of the spectral regions of interest, definition of transparency factors, and fabrication means and costs.

Chapter 2 describes the basic physics underlying the interaction of light with matter. Fundamental features of light like polarization, interference, and interaction with matter involving reflection, refraction, absorption and scattering are related to the relevant material properties like refractive indices, and acoustic and optical waves. Special attention is devoted to energy states spectroscopy of dopant rare earth and transition metal ions.

Chapter 3 surveys in detail the issue of ceramic materials processing, with attention on those mostly adequate to obtain transparent parts of optical equipment.

Chapter 4 surveys the multitude of materials used and proposed to be used for production of transparent ceramics, all in view of available production techniques and aimed-at applications.

Chapter 5 elaborates on various possible applications of transparent ceramics, mostly for security windows, optical lenses, and laser parts, but also for some, perhaps less appreciated ones like colour filters, scintillation elements, dental parts, and many more.

The book offers the thus-far broadest and deepest account of transparent ceramics. Individuals wishing acquaintance with this still emerging field, for either teaching or performing of scientific research, will definitely benefit from learning and consulting this new book.

Roni Shneck is professor in the Department of Materials Engineering at Ben-Gurion University of the Negev, Israel.

High-strength glass: Global markets

By Margareth Gagliardi

The global market for high-strength glass increased from $28.9 billion in 2018 to $30.9 billion in 2019, and is estimated to reach $31.9 billion in 2020, corresponding to a compound annual growth rate (CAGR) of 5.0% during the two-year period. The market is forecast to rise at a CAGR of 6.1% from 2020 to 2025, reaching global revenues of $42.9 billion in 2025.

High-strength glass is a category of glass characterized by high tensile or compressive strength. Its origins can be traced back to the 1660s, when German-English officer and scientist Prince Rupert of the Rhine, Duke of Cumberland presented the first tempered glass with the shape of a teardrop to King Charles II of England. However, almost 200 years went by before the first industrial process for producing tempered glass was developed.

There are seven main sectors in which high-strength glass finds current and potential applications: aerospace and defense, construction, electronics and optoelectronics, energy, life sciences, mechanical/chemical, and transportation. Applications within the transportation sector currently account for the largest share of the market, at an estimated 53.4% of the total in 2020. High-strength glass for the construction sector represents a relatively smaller share at 21.5%, while electronics and optoelectronics is estimated to account for 7.6%. All the remaining applications represent a combined share of 17.4%.

Laminated and tempered soda-lime-silica glass currently represent the largest segment (85.4%) of the high-strength glass market, with projected sales of $27.2 billion by the end of 2020.

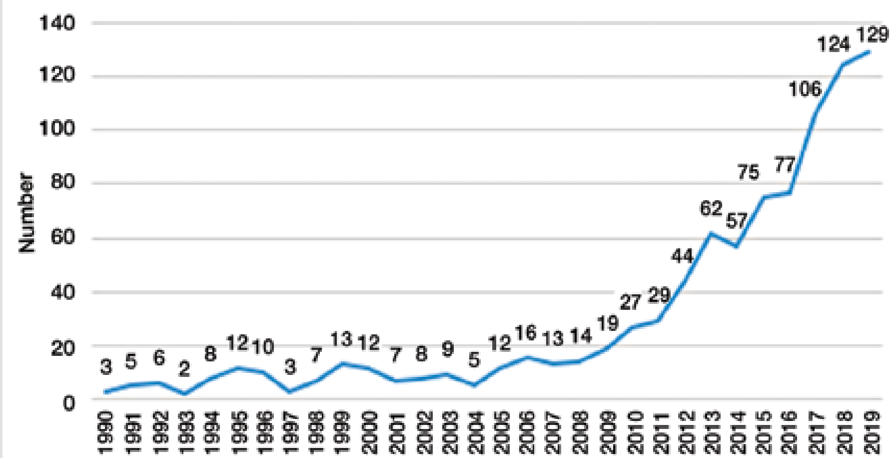


Figure 1. Number of global patent applications and patents issued related to high-strength glass, 1990–2019

Following that, aluminosilicate glass is estimated to be valued at $2.4 billion (7.5%), borosilicate glass at $1.6 billion (5.1%), and magnesium aluminosilicate glass at $632 million (2.0%).

Sales of high-strength glass are expected to continue rising at a single-digit rate during the next five years due to a number of relevant factors, including

- Expected general moderate growth for most industry sectors in which high-strength glass finds application,
- Higher unit price for high-strength glass compared to traditional glass,
- Stronger demand in the construction sector due to architectural trends aimed at emphasizing natural lighting and energy savings,
- Stronger demand in the electronics and optoelectronics sector due to on-going miniaturization and fabrication of devices with very thin profile,
- Larger use in the energy sector driven by the fabrication of solar cells and photothermal devices, and
- Emerging trends, such as higher demand for lightweight materials.

The Asia-Pacific region is currently the largest consumer of high-strength glass, with sales estimated to reach $13.1 billion by the end of 2020, corresponding to a share of 41.1% of the total. The United States represents the second-largest market (25.2%) with estimated sales of $8.0 billion while Europe is expected to reach slightly over $6.7 billion (21.1%).

Table 1. Global market for high-strength glass, by end use, through 2025 ($ millions)

End Use	2018	2019	2020	2025	CAGR% 2020-2025
Transportation	15,692	16,547	17,043	21,855	5.1
Construction	6,121	6,667	6,863	9,671	7.1
Electronics and optoelectronics	2,198	2,329	2,436	3,546	7.8
Energy	2,019	2,266	2,380	3,713	9.3
Aerospace and defense	920	953	977	1,194	4.1
Mechanical/chemical	750	798	822	1,074	5.5
Life sciences	597	640	670	914	6.4
Others	652	690	711	890	4.6
Total	28,949	30,890	31,902	42,857	6.1

About the author

Margareth Gagliardi is a research analyst for BCC Research. Contact Gagliardi at analysts@bccresearch.com.

Resource

M. Gagliardi, "High-strength glass: Global markets" BCC Research Report AVM199A, October 2020. www.bccresearch.com.

acers spotlight

SOCIETY, DIVISION, SECTION, AND CHAPTER NEWS

A Case for continuous membership

You were nominated to be an ACerS Fellow! ...but wait, you have not held continuous ACerS membership. I am sorry, you do not qualify for the Fellows distinction.

What if this situation happened to you? Do you count on renewing your ACerS membership only when you attend meetings? If you miss a meeting one year, you could experience a gap in membership and an interruption of important member benefits, such as the *Bulletin* and online access to ACerS' four peer-review journals and B*ulletin* archives.

It also makes you ineligible to receive distinctions that require continuous membership, such as becoming an ACerS Fellow (five continuous years) or Emeritus member (35 continuous years). To be eligible for Fellow and Emeritus status, ACerS encourages you to renew your membership each year. For more information about Fellows, Emeritus, or other awards eligibility, visit https://ceramics.org/members/awards. ■

Volunteer Spotlight

Brauer

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

Delia Brauer studied chemistry with environmental chemistry at Friedrich Schiller University Jena (Germany) and University of Northumbria at Newcastle (England) before executing a Ph.D. research project on degradable phosphate glasses and glass/polymer composites for medical applications at the Otto Schott Institute, Friedrich Schiller University Jena.

After postdoctoral research projects at the University of California, San Francisco; Imperial College London; Queen Mary University of London; and Nagoya Institute of Technology (Japan), Brauer returned to Friedrich Schiller University Jena as a junior professor in 2012. She was made a full professor of bioactive glasses in 2017.

Brauer leads an international group of students and postdoctoral researchers from various backgrounds. Her research focuses on inorganic glasses as biomaterials and on the interaction between glass and water.

She has edited one book and has contributed several chapters to publications. She is regularly invited to give talks at international conferences.

Brauer served as chair of Technical Committee 04 (Bioglasses) and member of Technical Committee 23 (Education) of the International Commission on Glass. The 2015 winner of the Gottardi Prize of the ICG, she was made a Fellow of the Society of Glass Technology (U.K.) in 2016. In 2020, together with Jessica Rimsza, she served as program co-chair of the first Virtual Glass Summit organized by ACerS.

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

In memoriam

Edward Aitken
David J. Barber
Daniel Reardon
Willard Renner
John Roberts
Stuart Weinland

Some detailed obituaries can also be found on the ACerS website, www.ceramics.org/in-memoriam.

Names in the News

Jain

Himanshu Jain, Lehigh University's T.L. Diamond Distinguished Chair in Engineering and Applied Science and professor of materials science and engineering, was named winner of the 2020 *Journal of Non-Crystalline Solids* N.F. Mott Award, which recognizes a distinguished senior scientist with a history of outstanding contributions to the science of non-crystalline solids.

Wagner

Larry Wagner joined Du-Co Ceramics as automation engineer–electrical. ■

AWARDS AND DEADLINES

ACerS 2020 Award winners

This year's ACerS award winners can be seen on our YouTube channel https://youtu.be/7L9sRTTNVeI. Congratulations to all the winners! ■

Upcoming awards nomination deadlines

For more information about each award, visit www.ceramics.org/awards or contact Erica Zimmerman at ezimmerman@ceramics.org.

Society awards: January 15

ACerS runs a thriving awards program that recognizes the contributions of deserving individuals and companies in the ceramics and glass community. Nominations are encouraged for candidates from groups that are underrepresented in ACerS awards relative to

Awards and deadlines (cont.)

their participation in the Society, including women, underrepresented minorities, industry scientists and engineers, and international members.

We urge you to submit nominations for our many Society and Division awards.

GOMD awards: January 21

The Glass & Optical Materials Division seeks nominations by **Jan. 21, 2021**, for the following awards:

- The Norbert J. Kreidl
- George W. Morey
- L. David Pye Lifetime Achievement
- Stookey Lecture of Discovery
- Varshneya-Mauro-Jain Guru-Chela Travel Fund

Bioceramics Division Awards

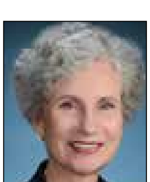
In 2020, the Bioceramics Division received ACerS Board approval for the creation of four awards with a **July 1** nomination deadline:

- Bioceramics Young Scholar
- Global Young Bioceramicist
- Larry L. Hench Lifetime Achievement
- Tadashi Kokubo (sponsored by Nippon Glass Co., Ltd.)

The Division announced the first recipients for two awards.

Lepry

2020 Global Young Bioceramicist Awardee: **William Lepry,** McGill University



Primus

2020 Larry L. Hench Lifetime Achievement Awardee: **Carolyn Primus,** Primus Consulting ■

STUDENTS AND OUTREACH

Register today for ACerS Annual Winter Workshop

ACerS Winter Workshop, hosted by the Ceramic and Glass Industry Foundation, will be held in conjunction with the ICACC 2021 virtual meeting on Thursday, Jan. 28 and Friday, Jan. 29, 2021. The Winter Workshop provides a combination of technical and professional development sessions designed specifically for students and young professionals. For more information and to register, visit https://ceramics.org/winter-workshop-2021. ■

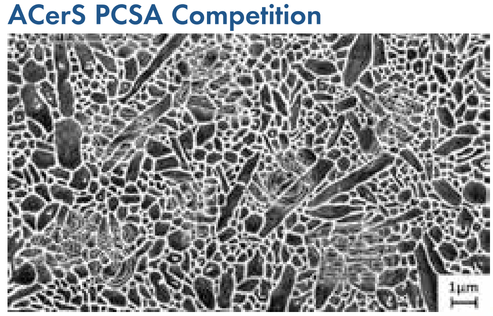
ACerS Global Distinguished Doctoral Dissertation Award

This award recognizes a distinguished doctoral dissertation in the ceramics and glass discipline. The awardee must have been a member of the Global Graduate Researcher Network and have completed a doctoral dissertation as well as all other graduation requirements set by their institution for a doctoral degree within 12 months prior to the application deadline. The nomination deadline is **Jan. 15, 2021**. For more information, visit www.ceramics.org/doctoraldissertationaward. ■

PCSA student competition awardees

Congratulations to the following awardees from the 2020 PCSA student competitions:

ACerS PCSA Competition



◀ **2020 Artistic Creativity and Viewer's Choice Award**
Macro innovations from micro observations
by **Rachel Eckert,**
Iowa State University

2020 Scientific Award ▶
Promethean Sierpinski
by **Zach Abrams,**
Charles E. Smith Jewish Day School

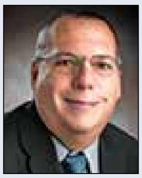
ACerS PCSA Lab Blooper Competition

◀ **2020 Artistic, Scientific, and Viewer's Choice Award**
Murphy's Law always obey
by **Anna De Marzi,**
University of Padova

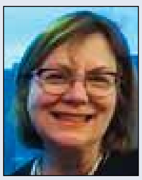
CERAMICANDGLASSINDUSTRY FOUNDATION

CGIF welcomes new board members

The Board of Trustees of the Ceramic and Glass Industry Foundation welcomed four new Board members at its recent meeting.



Alex Cozzi
Manager, applied materials research
Savannah River National LaboratoryAiken, S.C.



Leslie Fenwick Beiter
Regional account manager–ceramics
U.S. & Canada, Almatis, Inc.
Leetsdale, Pa.

Jeff Kohli
Director of glass research
Corning Incorporated
Painted Post, N.Y.

Nola K. Pearce
Vice president/Account executive
ETS Tech-Ops
Rochester, N.Y.

John Kieffer
Professor, University of Michigan
Ann Arbor, MI

CGIF Board of Trustee Officers for 2020–2021 are chair **Mary Stevenson**, president of Deltech, Inc.; chair-elect **Todd Steyer**, chief engineer for materials & technologies at The Boeing Company; immediate past chair **Thomas Arbanas**, president of Du-Co Ceramics; treasurer **Steve Houseman**, president of Harrop Industries; and secretary **Mark Mecklenborg**, executive director of The American Ceramic Society.

There can be no doubt that this year was a rough one for all of us. Despite that, the CGIF has remained diligent in finding new ways of reaching students—the future of our industry. Now more than ever, your gift to the Ceramic and Glass Industry Foundation is vital to our success in attracting students to the ceramics and glass fields as we fill the talent pipeline for industry. Please visit our website at https://foundation.ceramics.org/give or donate via your cell phone by texting the word "give" to 614-914-2685. ■

Titanium-reinforced bioceramic implant induces cranial regrowth in sheep

Researchers from several Swedish universities and institutes described in a recent paper a synthetic ceramic implant they created that could regenerate bone in large cranial defects in sheep.

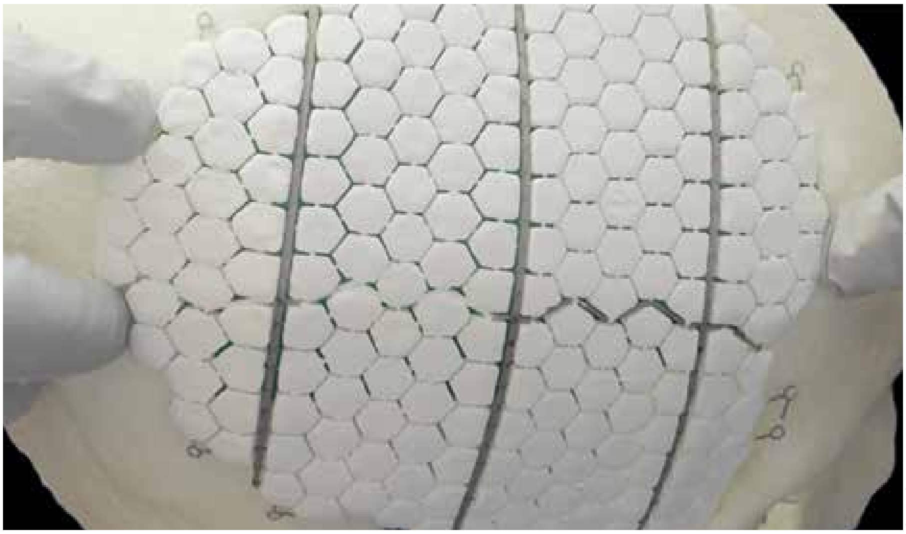
Cranioplasty, or the surgical reconstruction of a defect in the skull, is a practice stretching back hundreds of years, but the technique only became common during the second half of the 20th century, due largely to warfare providing an impetus to improve our ability to cover large cranial defects.

To date, autologous bone grafts, or grafts made from bone obtained from other areas of the patient, are the standard for reconstructive treatment. Yet this approach is associated with frequent complications, in particular relatively high resorption, protrusion, and infection rates and a high rate of donor-site morbidities.

In the past few decades, researchers have extensively investigated alloplastic materials, or synthetic materials that substitute for tissue, as another option for cranioplasty grafts. Calcium phosphate ceramics are one group of materials that have played a central role in modern alloplastic cranioplasty research due to their biocompatibility and osteoconductivity, i.e., the ability of bone-forming cells in the grafting area to move across a scaffold and slowly replace it with new bone.

Calcium phosphate cements in particular have gained an edge over granular calcium phosphates because of advantages afforded by the cements' self-hardening properties, which make molding the brittle ceramic into a desired shape easier. Often, the cements are combined with or overlaid on other materials such as bioresorbable fibers or titanium mesh, respectively, to augment strength of the graft.

In recent years, several studies showed calcium phosphate ceramics that consist of several phases, such as beta-tricalcium phosphate (ß-TCP) and hydroxyapatite, exhibit improved or new properties compared to ceramics with a single phase. For example, high protein adsorption and osteoinduction, or the ability to stimulate cells to change into bone-forming cells. More researchers are now exploring mixed-phase calcium phosphate ceramics, such as the collaborative group of researchers in Sweden.



Researchers in Sweden developed this experimental bioceramic implant, which is composed of calcium phosphate tiles reinforced and interconnected by an additively manufactured titanium frame.

For their study, the researchers from the University of Gothenburg, Uppsala University, and Karolinska University Hospital and Karolinska Institutet chose a powder mixture of ß-TCP/dicalcium pyrophosphate and monocalcium phosphate monohydrate for their ceramic, which they mixed with glycerol to form a paste. They molded this bioceramic paste in the form of hexagonal tiles around an additively manufactured titanium frame and then left it to set overnight in sterile water, a process that also eliminated the glycerol.

The titanium-reinforced bioceramic implant and a control implant made only of titanium were placed in sheep skulls for testing. Following analysis of observations recorded at three months and 12 months, the researchers drew several notable conclusions, including

- **Soft tissue adaption:** The bioceramic implants revealed defect restoration and soft tissue adaptation in sheep cranial defects. In contrast, soft tissue contraction was apparent around titanium implants, with visible metal on the skin and dura sides.
- **Bone growth:** In the sheep skull, the bioceramic implant promoted a higher degree of bone formation, remodeling, and osseointegration compared to the titanium implant, leading to enhanced repair of the cranial defect. Outside the skeletal envelope, only the bioceramic implant promoted bone formation and maintained bone. Regardless of the location, the regenerated bone from the bioceramic had a composition similar to that of the native bone.

In the discussion section, the researchers note two main limitations of the study: the absence of a mechanical evaluation after bone regeneration, and the absence of cellular and molecular techniques to shed light on the underlying ceramic-to-bone transformation mechanisms. Despite these limitations, the researchers say the study provided proof-of-concept for this bioceramic's potential to promote in situ bone regeneration and osseointegration.

The open-access paper, published in *Proceedings of the National Academy of Sciences*, is "In situ bone regeneration of large cranial defects using synthetic ceramic implants with a tailored composition and design" (DOI: 10.1073/pnas.2007635117). ■

Thermal scanning probe lithography allows precise nanocutting of 2D materials

Researchers at École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland explored using thermal scanning probe lithography to fabricate nanostructures in 2D materials.

To date, top-down approaches to nanostructure construction are used extensively in the semiconductor industry to fabricate integrated circuits, among other things. Specifically, lithographic techniques—or techniques by which a pattern is transferred onto a surface—are typically used.

Common lithographic techniques involve using beams of light, electrons, or ions to etch patterns onto a surface. However, though these techniques work well for fabricating nanostructures on most surfaces, they run into some challenges when used to pattern 2D materials, such as causing structural damage.

Scanning probe lithography (SPL) is one type of lithography that holds potential for effectively fabricating nanostructures in 2D materials. Instead of using a focused beam of particles to etch patterns in a sample, SPL methods use a physical tip to modify the surface through various physical and chemical interactions, such as scratching, nanoindentation, or heating.

Among SPL methods, thermal scanning probe lithography (t-SPL) has gained much attention in recent years. This method involves using a heated nanotip to modify the surface of a sample, and it has now reached a high level of technical maturity, with several dedicated tools to perform reliable t-SPL.

In the recent open-access study on t-SPL, the researchers made a significant change to the setup of their experiment to fully harness the thermal component of t-SPL.

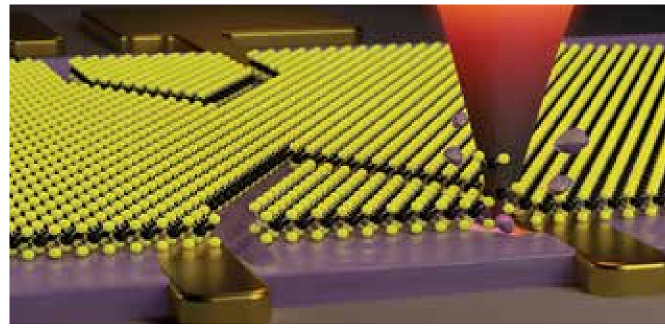
Instead of placing the 2D materials directly on an inelastic substrate, they placed a polymer layer between the 2D layer and substrate. "The polymer we use is polyphthalaldehyde (PPA) with a glass transition temperature of ≈150°C. Above this temperature, ... PPA does not melt but directly sublimates," they write in the paper.

When they pressed the heated tip into the 2D material, sublimation of the underlying polymer layer allowed the tip to achieve a deeper indention, thus making it easier to cut through the 2D material's chemical bonds.

The researchers used the t-SPL method to create square patterns in a variety of molybdenum-based 2D materials, with pattern sizes ranging from 20 to 200 nm. "The smallest feature we were able to cut is about 20 nm, which is the smallest reported for a direct cutting method and is similar to the resolution in [electron beam lithography]," they write.

They also note their method is not limited to cutting monolayers but also can be used to cut certain multilayers and, "most interestingly," heterostructures. They acknowledge graphene, even at monolayer thickness, could not be fractured "as the intra-layer bonding exceeds the force that can be applied with the t-SPL tool," but they say this limitation "could be eventually overcome with a t-SPL cantilever that can apply larger contact forces."

In an EPFL press release, first author Xia Liu, researcher and postdoc in the School of Engineering's Microsystems Laboratory, says their technique could prove quite useful to the semiconductor industry.



Credit: Case Western Reserve University

Researchers in the U.S. and Italy found infiltrating metalenses with liquid crystals may allow dynamic control of the lenses' optical properties.

"This generic technology will be very useful in nanoelectronics, nanophotonics, and nanobiotechnology, as it will help to make electronic components smaller and more efficient," she says.

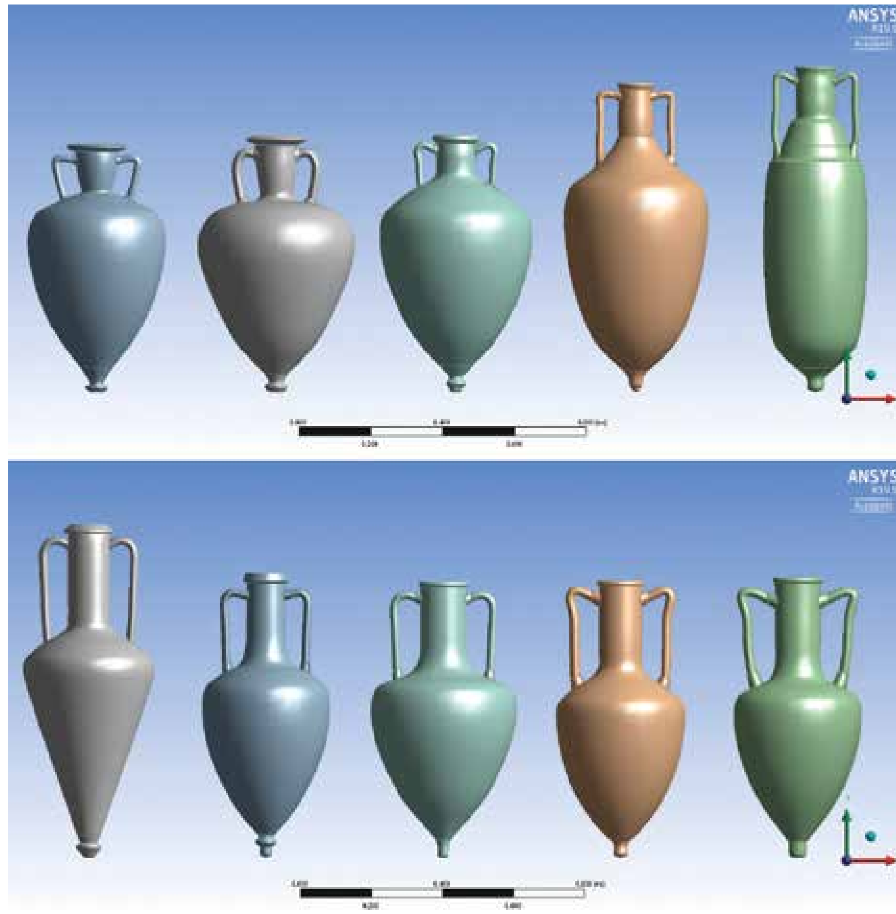
The open-access paper, published in *Advanced Materials*, is "Thermomechanical nanocutting of 2D materials" (DOI: 10.1002/adma.202001232). ■

Modeling illuminates properties of ancient ceramics

When master artisans passed down recipes for historic pottery from generation to generation, they determined correct firing and other processing conditions by relying on senses and experiences that could in no way be captured, even when records were kept. So it is no wonder some of the beauty and utility of historic pottery is difficult to replicate today, even by skilled artisans and engineers.

As archeologists find more artifacts, archeometrists seek to unlock the secrets of ancient civilizations and their engineers and artisans. But how can these scientists uncover key mechanical and chemical information from such priceless, irreplaceable items? How can they figure out how they were produced? Examining shards is helpful when the tests can be destructive, but it only goes so far. Instead, scientists use models to estimate and attempt to reproduce such items.

Two recent open-access articles in *International Journal of Ceramic Engineering & Science* discuss models that were used to better understand ceramics from different parts of the world designed for very different purposes: commerce and decoration.



3D models of amphorae from Kos (top) and Rhodes (bottom).

Amphorae: Understanding mechanical properties of standard transport containers

With the advent of regional trade, merchants needed containers in which to store and transport goods over long distances, especially by boat. And one type of ceramic container used often in antiquity for this purpose was amphorae.

Amphorae are bullet-shaped vessels, typically with long necks and handles that are affixed near the mouth of the vessel on one end and attached to the body at the other. They are specifically designed to be stacked inside cargo holds of ships in multiple layers.

While the amphorae itself had some value, the real value lay in the vessel's

Research News

Flash graphene rocks strategy for plastic waste

Rice University researchers advanced a new technique to make graphene from waste with a focus on plastic. Instead of raising the temperature of a carbon source with direct current, as in the original process, the lab first exposes plastic waste to around eight seconds of high-intensity alternating current, followed by the DC jolt. The products are high-quality turbostratic graphene, a valuable and soluble substance that can be used to enhance electronics, composites, concrete, and other materials. They estimate that at industrial scale, the process could produce graphene for about $125 in electricity costs per ton of plastic waste. For more information, visit https://news.rice.edu/category/news-releases.

Mini perovskite solar panels with 18.4% efficiency

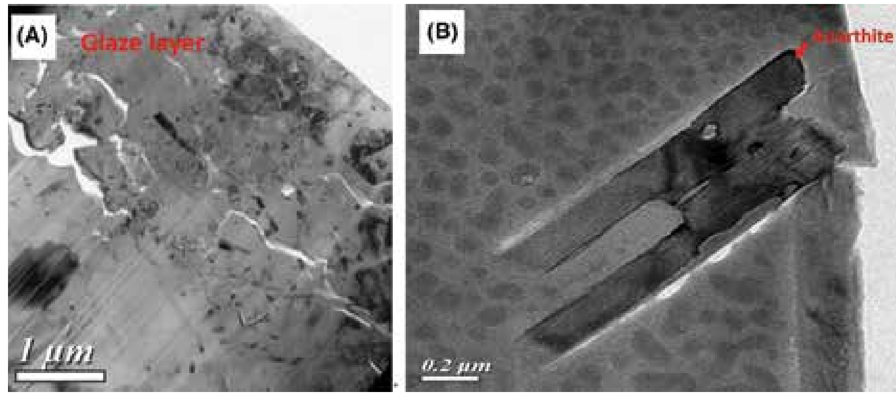
Researchers from Singapore's Energy Research Institute at Nanyang Technological University developed a mini solar module based on thermally evaporated perovskites with an efficiency of 18.4% and a geometric fill factor of around 91%. The module, which has an active area of 6.4 cm^2, is based on thermally evaporated methylammonium lead iodide with an optimized thickness of 750 nm. The perovskite films were used to build solar cells with an "n-i-p" layout on fluorine-doped tin oxide glass substrates. For more information, visit https://www.pv-magazine.com.

contents. As such, if the container broke and the contents of that vessel were lost—and potentially damaged other goods in the cargo hold as well—it could result in substantial losses to the producer and the ship owner.

In the first open-access paper, Anno Hein and Vassilis Kilikoglou from the Institute of Nanoscience and Nanotechnology in Greece assessed specific design features of different amphorae for their performance (e.g., failure potential), particularly during transport. Furthermore, they used simulations to provide information to help interpret typical damages observed in archaeological finds.

The researchers ran nondestructive testing such as X-ray tomography to determine wall thicknesses while performing mechanical testing on shards to get insights into mechanical strength, tangent moduli, and plastic deformation.

They used the limited experimental information as inputs and boundary conditions for finite element modeling of the stresses that build up at the contact points of the amphorae due to static vertical loading (e.g., the weight of one layer on the next), dynamic vertical loads (ships travel over waves), and dynamic horizontal loads (ships rocking side-to-side).



Credit: Sorensen et al., *Science Advances* (CC BY 4.0)

TEM micrographs of the shard of Ru celadon porcelain, including (A) the glaze layer of Ru celadon porcelain, and (B) anorthite surrounded by the dual-phasic glass matrix.

The results of the modeling include compressive and tensile stresses on the exterior and interior walls of the amphorae. Excessive compressive loads are found, but the authors surmise these loads result in elasto-plastic deformation, which is not catastrophic. Tensile stresses on the outer surfaces, on the other hand, can lead to crack initiation and eventual failure. Failed amphorae artifacts show damage in the areas predicted by the modeling.

The open-access paper, published in *International Journal of Ceramic Engineer-*

ing & Science, is "Digital modeling of function and performance of transport amphorae" (DOI: 10.1002/ces2.10056).

Ru celadon: Investigating the coloring of a masterwork of Chinese ceramics

Celadon is a pottery term that refers to both a transparent, greenish glaze and the wares to which the glaze is applied. Though the term is purely European, celadon originated in China, and today notable kilns such as the Longquan kiln in Zhejiang province are renowned for their celadon glazes.

Celadons come mostly in some shade of green, but shades of pale blue—notably Ru celadon—are highly valued, and in historical times were reserved more or less exclusively for use in the Chinese Imperial court.

In the second open-access paper, Yen-Yu Chen (Chinese Culture University) and Yi-Wun Bai and Wen-Cheng J. Wei (National Taiwan University) investigated methods to reproduce the unique color and milky opalescence of ancient Ru celadon glazed ceramics.

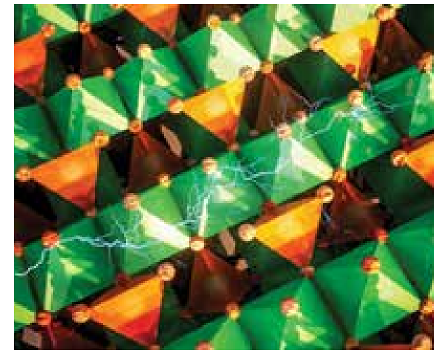
The color of celadon is generated by two mechanisms: chemical coloring by iron species in calcium aluminosilicate compositions; and structural coloring by inhomogeneities, specifically crystallites and voids in the celadon glass. While there is some information available about the material composition of ancient celadon—both from analysis of ancient shards and from prior studies—the fabrication methods are not well understood. For example, it is believed the porcelain was fired in a reducing environment, but there is no way of knowing the composition of the gases or their temperature—the technology simply did not exist for those measurements 1,000 years ago.

In this article, the researchers created their own celadon by varying a range of experimental conditions, including composition relative to phase stability data for the complex chemical system and firing temperatures, environments, and holding times. They measured the model systems they created against a shard of ancient celadon ceramic for color, microstructure, and chemical content of the glass and crystallites.

In the end they came close to the ancient celadon color and opalescence, giving insight into ancient firing protocols. Their work supports the combination of the chemical coloring and structural coloring mechanisms. Specifically, the dual-phase nature of the glass contributes to Rayleigh scattering while crystallites and voids contribute to the "milky" color, while the ratio of Fe^{2+} and Fe^{3+} oxidation states of iron contribute to chemical coloration.

The open-access paper, published in *International Journal of Ceramic Engineering & Science*, is "Analysis of structural effects on coloring mechanism of Ru celadon porcelain" (DOI: 10.1002/ces2.10058). ■

Updated small-polaron transport model accounts for complex oxide systems



Credit: Robinson et al., Cornell University

An updated ceramic conduction model may help researchers custom-tailor the properties of metal oxides in energy technologies such as lithium-ion batteries, fuel cells, and electrocatalysts.

An interdisciplinary collaboration between Cornell University and Technion–Israel Institute of Technology (Israel) updated a model for ceramic conduction to more accurately calculate small-polaron transport in complex oxides.

For the past 60 years, researchers described the movement of polarons through a material using a small-polaron transport model developed by Heikes and Ure in the 1960s. However, Heikes and Ure developed the model based on binary compounds. When this model is used to describe conduction in higher-order oxides with multiple cations, it quickly runs into problems, as the researchers describe in their paper.

"For instance, in the binary spinel Fe_3O_4, all of the charge-conducting octahedral (Oh) sites are occupied by Fe cations, and charge transport occurs along pathways having an alternating arrangement of Fe^{2+}/Fe^{3+}," they explain. "On replacing an Fe^{2+} cation with a Mn^{2+} cation, although the donor/acceptor pair arrangement is still present, the charge transport may be affected by the differences introduced by the hopping barriers or different spinstates between the Fe^{3+}/Mn^{2+} cation pairs."

To update the conventional small-polaron transport model, the researchers investigated conduction in a tightly defined sample of epitaxial thin films of the spinel $Mn_xFe_{3-x}O_4$ grown by molecular-beam epitaxy.

Experiments on the $Mn_xFe_{3-x}O_4$ spinels confirmed what the researchers suspected—that charge cannot hop between manganese and iron cations. "This creates a requirement for a contiguous elemental path and leads to an additional condition for charge transport to occur: separate, decoupled percolation networks need to be formed by both Fe and Mn cations," they write.

They also observed a preference for polarons to travel along the manganese pathways rather than the iron pathways, and the presence of asymmetric hopping barriers between cross-hopping pairs. "To account for these observations, we introduce a percolation parameter, a polaron distribution parameter, and a cross-hopping parameter to the conventional electronic conductivity equation that correct the model for higher-order spinels," they write.

The updated model with these additional parameters showed "excellent overlap" with the experimental trends, thus "confirming the role of percolation pathways and cross-hopping in describing the charge transport in ternary spinels."

The paper, published in *Advanced Materials*, is "Breakdown of the small-polaron hopping model in higher-order spinels" (DOI: 10.1002/adma.202004490). ■

Ceramic matrix composites contain corrosive materials in thermal energy storage

In the recent September/October 2020 issue of the *International Journal of Applied Ceramic Technology*, two articles from different research groups in Germany explore creating carbon/carbon-silicon carbide (C/C–SiC) ceramic matrix composites (CMCs) for use as container materials in thermal energy storage systems.

Thermal energy storage systems offer an alternative to batteries and pumped hydro for storing energy generated from renewable sources. However, the molten salts and other closely related materials that are at the center of such systems are difficult to contain due to the highly corrosive nature of the liquid materials, moderately high operating temperatures, and substantial expansion during the transition from solid to liquid.

Producing container materials that can withstand the high temperatures, thermal expansion stresses, and corrosive materials for decades of operation are key to adoption of large-scale thermal energy storage. And as the research groups in Germany showed, C/C–SiC CMCs have the potential to serve as good container materials.

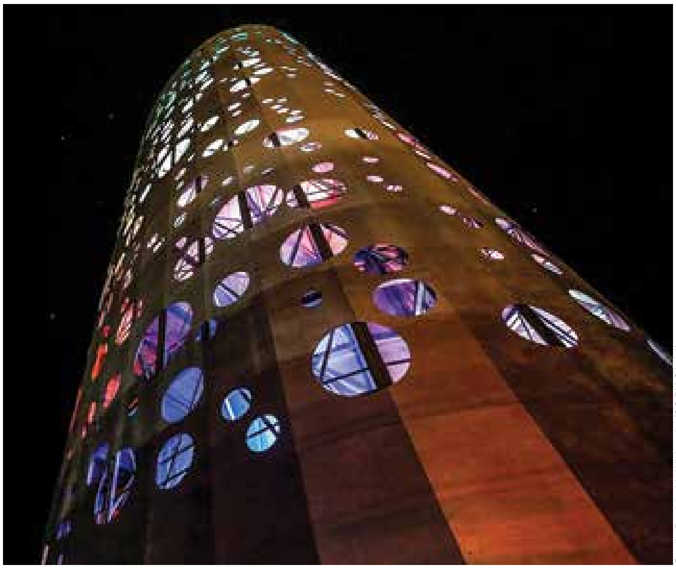
In the first open-access article, researchers from the German Aerospace Research Center and the University of Augsburg in Germany describe the design, fabrication, and characterization of a C/C–SiC container for an aluminum-silicon phase change alloy.

The first stages of their study focused on fabrication and compatibility testing of C/C–SiC test bars. They found the bars withstood the liquid aluminum-silicon alloy and maintained their physical properties with no discernable interactions, such as penetration of the alloy into the test bars. Though there are potential chemical reactions between the alloy and the CMC, the researchers found no evidence of substantial reactions, which echoes the findings of other researchers.

Following the test bars, they continued with the design and fabrication of the container. They decided on low-cost, scalable techniques for fabricating the four main components of their annular container and then used these techniques as boundary conditions for finite element analysis. They used finite element analysis to determine container wall thickness by balancing the strength needed to withstand stresses that arise during phase changes against heat conduction requirements to allow efficient energy transfer.

Unfortunately, pressure testing of the container revealed cracks at the interface of two of the parts, which most likely occurred during fabrication. Though the flaw prevented the full regimen of performance testing, and several issues require further experimentation, the researchers believe the container shows promise for thermal energy storage application.

The second article, by researchers from Chemnitz University of Technology in Germany, describes a different path to low-cost fabrication of C/C–SiC composites. The researchers prepared C/C–SiC using carbon fiber reinforced polymers as the starting material. The moldable precursor polymers are shaped and cross-linked, then pyrolyzed to C/C composites under argon atmosphere. Conversion to C/C–SiC is achieved by either liquid silicon infiltration or internal siliconization, the latter of which is accomplished by mixing silicon powder into the original polymer.



Thermal energy storage tower inaugurated in 2017 in Bozen-Bolzano, South Tyrol, Italy. Ceramic matrix composites hold promise as container materials for high-temperature and corrosive materials integral to thermal energy storage.

The researchers explored the effects of carbon fiber fraction (weight %), silicon fraction, and silicon loading method by measuring the processing parameters of mass loss, shrinkage, and porosity, and performance parameters of strength and elongation. The results are complex, but in short, the researchers concluded that the best mechanical properties were found to be at a fiber mass content of 40%, and a silicon amount higher than 14 wt% negatively influences the whole process.

Their results show that molding C/C–SiC composites from preceramic polymer-based mixtures has the potential to be a cost-effective method for fabrication of complex structures. Further research to optimize properties and processing parameters should improve the end-product performance and allow this method to compete with the more conventional fabrication methods, such as those employed by the authors of the first open-access paper.

The first open-access paper, published in *International Journal of Applied Ceramic Technology*, is “C/C–SiC component for metallic phase change materials” (DOI: 10.1111/ijac.13570).

The second paper, published in *International Journal of Applied Ceramic Technology*, is “Properties of C/C–SiC composites produced via transfer moulding and inner siliconization” (DOI: 10.1111/ijac.13548). ■

Polar rather than conductive battery cathodes lead to long-term cycling stability

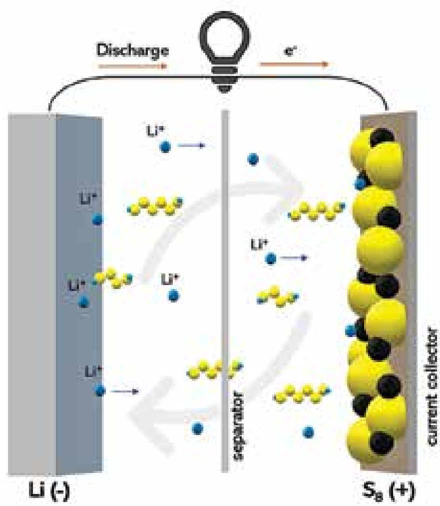
An international team led by Jong-Su Yu from Daegu Gyeongbuk Institute of Science & Technology (Korea) and Khalil Amine from Argonne National Laboratory conducted a recent study to determine the respective importance of two key properties—polarity and conductivity—in improving the cycling stability of lithium-sulfur batteries.

Li-S batteries have a theoretical specific energy of more than 2,500 Wh/kg, which is much higher than the average specific energy of 100–265 Wh/kg for current Li-ion batteries. However, to date the experimental values of Li-S battery specific energy have been far below theoretical values.

The main mechanisms hindering Li-S battery performance are irreversible loss of sulfur from the cathode (the polysulfide "shuttle" effect) and unstable lithium deposition on the anode. These mechanisms are not the only challenges, however. Sulfur also has low electrical conductivity (5×10^{-30} S/cm at room temperature), which hinders the cycling efficiency of Li-S batteries.

To improve conductivity, researchers have experimented extensively with placing the cathode's sulfur within highly conductive carbon host materials, such as hollow porous carbon, graphene, mesoporous carbon, and microporous carbon. Unfortunately, long-term cycling stability continues to be a problem because of the nonpolar covalent bonds that carbon forms with itself, which prevent polysulfides on the carbon surface from attaching strongly, and instead they diffuse away—leading to the notorious polysulfide "shuttle" effect.

Researchers have investigated employing oxide additives, polymers, or other inorganic materials on the carbon framework to enhance polysulfide confinement and mitigate the polysulfide shuttle effect. But these methods often require complicated and expensive synthesis processes, plus they limit the accommodation of sulfur by reducing available surface area.



Credit: Egibe, Wikimedia (CC BY-SA 4.0)

Shuttling of polysulfide compounds (shown as yellow and blue chains) impairs the performance of lithium-sulfur batteries. Polar host materials for the cathode's sulfur can mitigate this effect, and researchers found this ability makes up for the materials' low conductivity.

Based on these challenges, the question of the best host material for sulfur in Li-S batteries remains wide open.

In the recent study, the researchers wanted to determine if it is better to pursue polarity or conductivity in the cathode to improve cycling if only one of these two properties can be maximized. To answer this question, they designed two cathodes, one made from platelet ordered mesoporous silica (pOMS) and one made from platelet ordered mesoporous carbon (pOMC).

"The two cathodes were designed to be exact replicas of one another apart from the use of either silica or carbon," Amine says in an Argonne press release. "This way, we could determine whether a more polar cathode or a more conductive cathode improved the longevity of the battery."

Upon testing, the researchers found that while the conductive carbon host with a higher specific surface area of 1,597 $m^2 g^{-1}$ showed better initial capacity, "the polar [silica host] with a lower surface area of 844 $m^2 g^{-1}$ reveals much more stable performance for long cycles and eventually outperforms the conductive counterpart after 500 cycles."

In addition, the silica host also demonstrated outstanding low fading rates, even at high current density, and comparable and improved areal and volumetric capacities, respectively, compared to carbon hosts.

"These outstanding areal and volumetric capacities, as well as cycle stability, which have not been achieved by even state-of-the-art carbon hosts, clearly indicate that the polar [silica] host, despite nonconductivity, has high promising potential for energy storage in [Li-S batteries]," the researchers write in the paper.

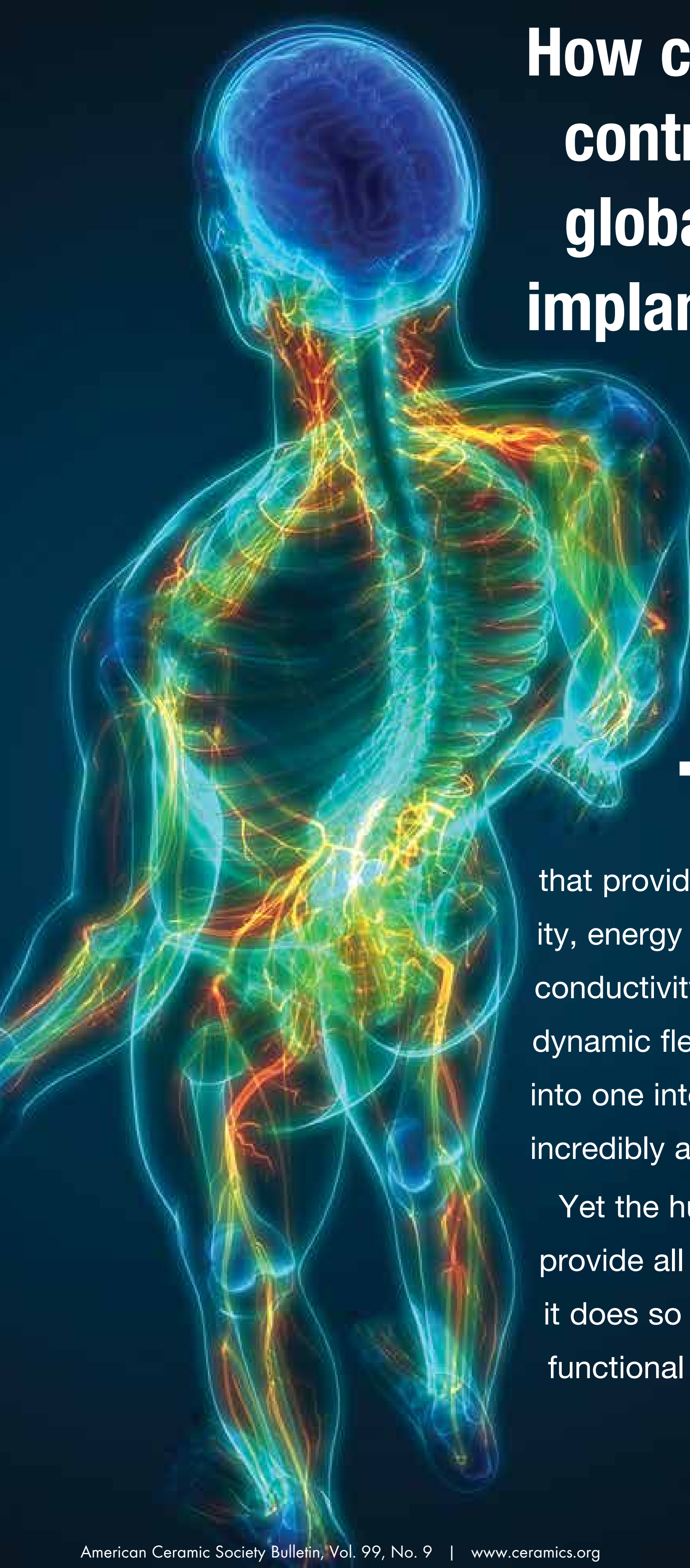
Of course, electrical conductivity is still necessary to achieve good electrochemical performance. "However, the conductivity is not a big issue in the host itself since the poor conductivity of the host can be compensated by the conducting agent involved as a required electrode material during electrode preparation," the researchers add.

In the conclusion, the researchers note they are currently investigating ways to improve electron pathways in the silica host while maintaining the high surface polar properties, such as by adding a thin conductive carbon coating to the silica to enhance conductivity.

The paper, published in *Advanced Energy Materials*, is "Revisiting the role of conductivity and polarity of host materials for long-life lithium–sulfur battery" (DOI: 10.1002/aenm.201903934). ■

BETTER BODIES WITH BIOMATERIALS:

How ceramic and glass contribute to the $110B global market for implantable biomaterials



By April Gocha and Lisa McDonald

Ceramic and glass biomaterials integrate with the human body in diverse ways to support human health. As aging populations and evolving healthcare approaches shift the medical landscape, increasing opportunities for both established and innovative technologies predict a strong future for ceramics and glass.

There are few systems that can efficiently incorporate materials that provide structural support, filtration capacity, energy generation, energy storage, electrical conductivity, gas exchange, processing power, dynamic flexibility, and regenerative potential into one integrated, highly functional, and incredibly adaptable self-contained system.

Yet the human body is a system that can provide all those functions and many more, and it does so through a unique collection of highly functional materials.

Better bodies with biomaterials

Collectively those materials enable everything our bodies do, and they often retain functionality throughout the human lifespan, which worldwide is an average of 73.2 years.[1] However, the materials are not always perfect and sometimes fail due to overuse, injury, disease, or genetics—circumstances that are becoming more common as worldwide populations age due to population dynamics and increasing life expectancies.

Globally, the number of individuals over 65 years old surpassed that of children under 5 years old for the first time in history in 2018. And while an estimated one in 11 individuals (9%) around the world were over 65 years old in 2019, the older population is expected to increase to one in six (16%) by 2050.[2]

These trends affect nearly every aspect of life, perhaps most notably healthcare. Individuals are living longer and are remaining active until later years of life, demanding enhanced strategies to maintain longer functionality of the body's materials.

Humans have long turned to biomaterials in diverse forms to repair, replace, or enhance bodily materials (Figure 1), establishing a global market for implantable biomaterials that was estimated to be worth nearly $110 billion in 2019.[3] While metals, polymers, ceramics, and glass all are used for biomaterial applications, ceramics and glass have a particular advantage, says Frank Anderson, vice president of Global Research and Development at CoorsTek (Golden, Colo.). "Many technical ceramics are inherently biocompatible, chemically-resistant, and inert, which gives them a unique advantage over other implantable materials," he says.

The global market for bioceramics was valued at $14.5 billion in 2016 and is predicted to reach a value of $20.2 billion by 2021, growing at a 6.9% compound annual growth rate (CAGR).[4] The market is mainly dominated by alumina and zirconia, which account for 75% of the market due to primary use of these materials in bone and dental implants. Other bioceramics frequently found in implantable devices include hydroxyapatite and tricalcium phosphate, and bioactive glass also has clini-

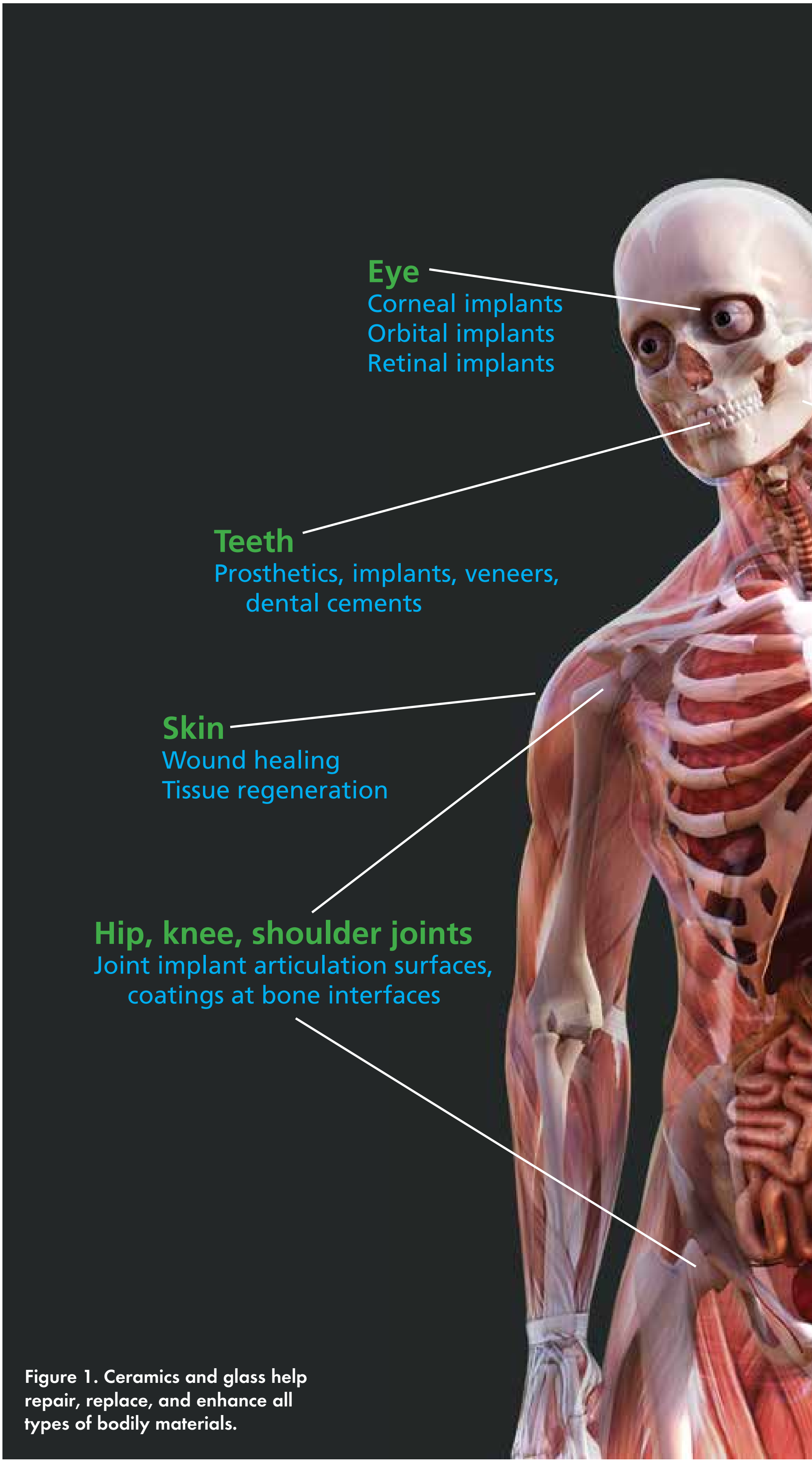
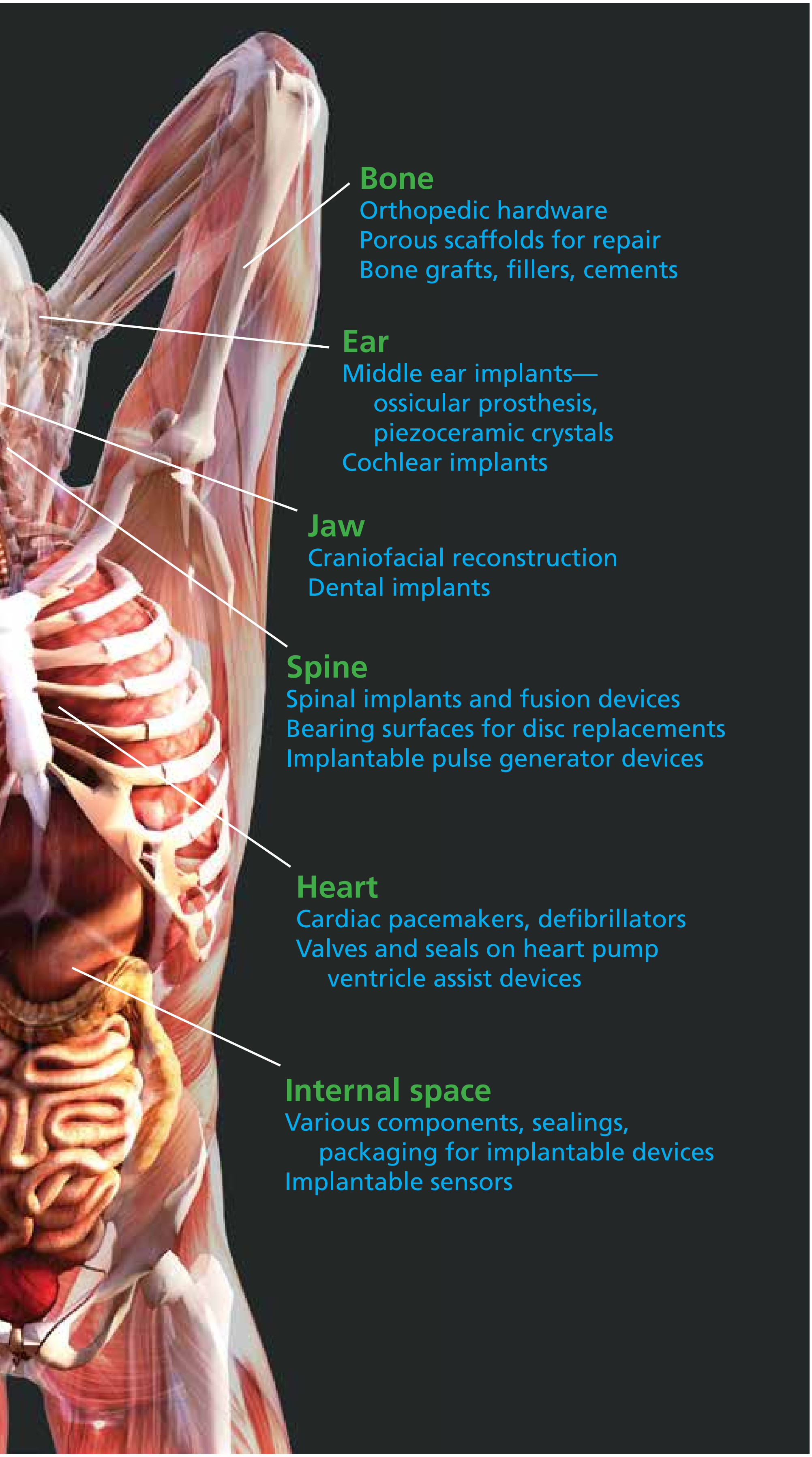


Figure 1. Ceramics and glass help repair, replace, and enhance all types of bodily materials.



cal applications with rapidly expanding potential throughout the human body.

It should be noted that while these materials predominate many implantable applications within the human body, mainly due to their acceptance and time on the market, other ceramic and glass compositions are also suitable for many of these applications, and we might expect their purview to expand in future markets.

Collectively, ceramic and glass materials enable many different kinds of implantable medical products that not only significantly contribute to human health but also constitute robust industries with rich economic impact. Table 1 provides a sample of some companies that manufacture ceramic and glass biomaterials or implantable products.

The following sections highlight a handful of applications for ceramics and glass in the human body. Although the listed applications are not exhaustive, the diversity highlighted here should provide a flavor of the vast potential of ceramics and glass within the human body.

PACKAGING: GLASS PROTECTS BOTH BODY AND DEVICE

Ceramic and glass materials are incorporated into or play supporting roles in many electronic devices implanted into the human body, such as neurostimulators and pacemakers. In these applications, a bioinert and long-lasting barrier between the device components and the harsh environment of the body is imperative to protect both—precisely a job for ceramics and glass.

For instance, glass-sealed feedthroughs and packaging often encase the batteries for implantable pacemakers, where a hermetic seal preserves both function of the device and safety of the patient.

"Glass is used to seal the terminals of pacemaker batteries. It acts as an electrical insulation material for the metal conductors. At the same time, glass creates a reliably gas-tight barrier when hermetically sealed with the electrical contact pins," says Jochen Herzberg, medical program manager of Schott's Electronic Packaging business unit (Landshut, Germany). "Specially selected glass types are resistant to the highly corrosive environment in the battery. And it doesn't deteriorate or get brittle over time like polymers or epoxies. It enables a higher reliability and a longer device lifetime."

To manufacture the glass-to-metal sealed packages and feedthroughs, Schott presses finely ground glass powder into a ring shape that is then sintered and assembled with the metal conductors inserted in the middle of the ring and an outer metal casing. The three components then undergo a sealing process in a belt furnace to bond the materials together.

Although this manufacturing technique provides a hermetic seal for battery feedthroughs, there is another glass technology that comes into play when miniaturization or encapsulation of heat-sensitive components is required. For those applications, Schott has another solution with its Primoceler glass micro-bonding technology. This wafer-scale technology uses a laser to precisely and locally bond glass to glass, creating a vacuum-tight bond with no additional materials.

"If you want to encapsulate, for example, a miniature sensor inside of a glass package, this is possible by stacking base wafers with spacer glass and cover or etched lid wafers, thereby creating a cavity in which the sensor device will be encapsulated," Herzberg says. "The stacked glass wafers are then laser-sealed, resulting in a gas-tight all-glass sensor package. One major advantage of Primoceler laser bonding technology is that it all happens at room temperature. So even if the sensor is very heat sensitive, which is usually the case, it can be packaged using the Schott Primoceler process. The extremely precise laser fuses

Table 1. Select companies that manufacture ceramic and glass implantable medical products or components*

Company (location)	Annual revenue (millions)*	Website	Role in value chain
Johnson & Johnson	$82,100	www.jnj.com	Develops, manufactures, and supplies diverse healthcare products, including medical devices such as orthopedic products
Stryker	$14,900	www.stryker.com	Develops, manufactures, and supplies diverse healthcare products, including medical devices such as orthopedic products
Kyocera Corp. (Kyoto, Japan) • Life & Environment Group, business segment that includes medical and healthcare	$15,404 $760	http://global.kyocera.com	Develops, manufactures, and supplies advanced materials to diverse markets; medical application is mainly ceramic hip implants
Zimmer Biomet (Warsaw, Ind.)	$7,982	www.biomet.com	Develops, manufactures, and supplies orthopedic products, including artificial joints and dental prostheses
Schott AG (Mainz, Germany)	$2,568	www.schott.com	Develops and manufactures diverse glass and ceramic products, including dental materials, medical device electronic components, implant packaging
The Straumann Group (Basel, Switzerland)	$1,746	www.straumann.com	Develops and manufactures diverse dental solutions, including implants, prostheses, technologies, and biomaterials
Morgan Advanced Materials Plc (Windsor, U.K.)	$1,356	www.morganadvancedmaterials.com	Develops and manufactures ceramic components for medical applications, such as feedthroughs for implantable devices
Wright Medical Group NV (Middlesex, U.K.)	$921	www.wright.com	Medical device, especially orthopedic surgical solutions and biologics
CoorsTek (Golden, Colo.)	$1,000‡	www.coorstek.com	Develops and manufactures technical ceramics for numerous industries, including orthopedic and implantable ceramics, (including ceramic hip implants), medical device components, and pharmaceutical components.
Ceramtec Gmbh (Plochingen, Germany) • Medical products	$727 $304	www.ceramtec.com	Develops and manufactures ceramic orthopedic components (including ceramic hip implants), dental implants, and medical engineering devices
Nobel Biocare (Zürich, Switzerland)	$629‡	www.nobelbiocare.com	Manufactures and supplies diverse dental solutions, including implants, prostheses, technologies, and biomaterials
Rauschert GmbH (Pressig, Germany)	$67‡	www.rauschert.com	Manufacturer of technical ceramics, including ceramic medical components
DSM Biomedical (Exton, Pa.)	$65‡	www.dsm.com/biomedical	Develops and manufactures biomaterials including bioceramics for diverse healthcare industries
Collagen Matrix Inc. (Oakland, N.J.)	$15‡	www.collagenmatrix.coc	Manufactures collagen and mineral-based medical products for dental and orthopedic applications, including ceramic and bioglass bone grafts
Mo-Sci (Rolla, Mo.)	$6‡	www.mo-sci.com	Develops and manufactures high-tech glass, including bioactive glass for medical applications
Lithoz GmbH (Vienna, Austria)	$5‡	www.lithoz.com	Develops and manufactures additive manufacturing technologies, particularly with ceramic materials, for diverse industries including medical applications
CAM Bioceramics (Leiden, The Netherlands)	$3.5‡	www.cambioceramics.cco	Develops and manufactures calcium phosphate biomaterials and coatings for orthopedic and dental applications
Berkeley Advanced Biomaterials Inc. (Berkeley, Calif.)	$0.6‡	www.hydroxyapatite.com	Develops and manufactures calcium-based biomaterials for medical industry, particularly bone grafts

*Conversions per Google as of October 16, 2020. All financial data obtained from company reports unless otherwise noted.

‡Private company or data not available; revenue estimated from dnb.com or google.com.

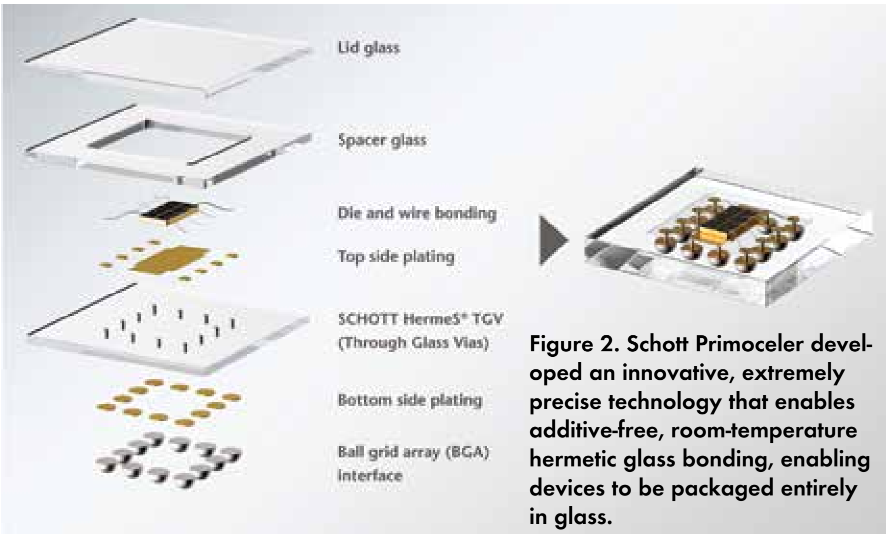


Figure 2. Schott Primoceler developed an innovative, extremely precise technology that enables additive-free, room-temperature hermetic glass bonding, enabling devices to be packaged entirely in glass.

Credit: Schott Primoceler Oy

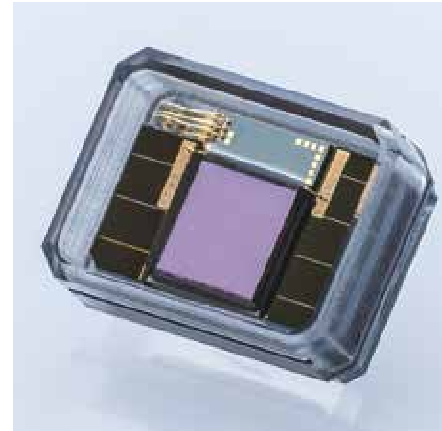


Figure 3. NanoRetina NR600 retinal implant with glass encapsulation.

Credit: Schott

and melts only the very small interface area where the glass wafers meet—an area of just some tens of microns—while leaving all other surfaces untouched." (Figure 2)

The possibilities of such technology are wide-reaching even within implantable device applications, but one of the first to see clinical application is in the eye.

For patients with reduced or lost sight due to retinal degradation, a company called NanoRetina (Herzliya, Israel) pioneered an artificial retina device. NanoRetina's NR600 implant, which is designed to mimic the functionality of the eye's highly sensitive photoreceptor cells, is a tiny chip containing an imager, 3D neural interface, and embedded photovoltaics to provide power. The device is completely encased in glass using Schott Primoceler technology (Figure 3).

"Without our glass-to-glass laser bonding technology, this would not have been possible because the encapsulated sensor inside is very heat sensitive. Only with our technology could we encapsulate it at room temperature," Herzberg says.

Enabled by glass, NanoRetina's NR600 implant entered a small clinical trial of 20 patients in Europe and Israel in early 2020 and already shows promising results. "The device was activated for the first time, and the result was amazing: this patient had been completely in the dark for five years, and she immediately reported seeing an image in the center of her visual field when the device was activated, and could show with her hands the size of the image that she saw," professor Peter Stalmans, who implanted the trial device and is one of Europe's leading retinal specialists, says in a Schott press release.[5] "I am very impressed by this experience. I have been working for more than 20 years as an ophthalmologist, but this is the first time I witnessed a completely blind patient being given back a visual perception."

Akin to maturation in the smartphone industry[6]—where shrinking of components has enabled enhanced functionality in smaller devices—miniaturization is an important reason why implantable devices such as NanoRetina's NR600 are possible today, and it can be traced back to advances in ceramics and glass, as well as other materials.

The consequences of miniaturization are not limited to better performing and more innovative devices, however—it also affects the ultimate bottom line in modern heathcare: cost.

"It starts with the surgery itself," Herzberg says. "Imagine the pacemaker—30 years ago it was very bulky, so hospitalization time of patients was really long, increasing healthcare costs. People cannot go to work, they are on sick leave,

THE SCIENCE AND ART OF GLASS OCULAR PROSTHESES

Credit: glasseyes view; Flickr CC BY-SA 2.0

Although ocular prostheses are often called "glass" eyes, many modern such prostheses are actually made of acrylic.

However, prosthetics fashioned from glass—true glass eyes—still exist and are especially prevalent in Germany, Austria, and Switzerland, where more than 90% of ocularists manufacture custom glass ocular prosthetics.

These glass ocular prosthetics are individual works of glass art, handmade by an ocularist to specifically match a patient's need. Ocularists train for about six years, gaining practical experience in addition to their education, to be able to master their art.[1]

Glass ocular prosthetics are uniquely made of cryolite glass, a silicate glass containing the mineral cryolite to provide a white hue that matches the look of a natural eye. The prosthetic is usually bowl or shell shaped.

Ocularists custom match a prosthetic to the patient's other eye, using colored class to embed details such as iris color and drawn blood vessels onto the eye, rather than painting them on, thus reducing the potential for reaction with the body. All details are part of the 100% glass prosthetic and are fired into the finished product.

Firing produces a very polished uniform surface on the prosthetic to prevent irritation within the eye socket. And unlike the hydrophobic surface of acrylic prosthetics, which can leave a feeling of dryness for the patient, glass's hydrophilic surface provides a uniform tear film that keeps the prosthetic moist.

A video of the custom manufacturing process is available at https://doi.org/10.3791/60016. ■

[1]Kunstaugen-Institut Leipold, http://www.augenprothesen-essen.de/en/wiki/augenprothese-aus-glas. Accessed Oct. 29, 2020.

and this is very costly for insurance companies. Today pacemakers are getting smaller and smaller because technology is getting better and better." Smaller devices allow more minimally invasive procedures, translating to faster recovery times and shorter hospital stays, which ultimately help reduce care-related costs.

Technologies and advances that continue to allow implantable devices to assume smaller forms with enhanced performance, as well as parallel medical developments that permit minimally invasive procedures and improved surgical outcomes, are critical components of future healthcare strategies to sustainably and effectively promote the health of growing, aging populations.

JOINT IMPLANTS: CERAMICS EXTEND IMPLANT LIFE

Our joints, the connections between the skeleton's more than 200 bones, provide our bodies with an incredible capacity for movement.

This ability is perhaps most appreciated in the face of reduced or lost mobility in the joints, often due to stiffening caused by conditions such as arthritis. Osteoarthritis, the most common form of arthritis, represents the single most common cause of disability in aging bodies, affecting an estimated 10%–15% of adults over 60 years old.[7]

As such, it is no surprise that the global market for joint replacement, implants, and regenerative product devices is expected to grow—reaching a value of $33.6 billion by 2023, growing at a CAGR of 4.8% during 2018–2023.[8]

Knee replacements constituted the largest share of the $26.5 billion joint replacement market (by value, not number) in 2018, accounting for 33% of the market, or $8.8 billion. Hip replacements were the next largest share, accounting for 28% of the market or $7.4 billion, followed by spinal implants (20%; $5.2 billion) and then extremities reconstruction, which comprises implant devices for the shoulder, elbow, wrist, digits, and ankle joints.

At all of these locations, ceramic implants compete with those made of polymers, metals, and combinations thereof. Due to length of time in the market, ceramics' successful infiltration into joint replacements is most notable for hip replacements.

"Though implantable ceramics have been in the market for decades, the adoption of these materials has really happened in the last 15 years," says Lucian Strong, vice president of CoorsTek Bioceramics (Grand Junction, Colo.), which manufactures ceramic femoral heads and acetabular liners for total hip arthroplasty, among other bioimplantable ceramic components. "The adoption is coming from the transition away from metals to ceramics due to the superior wear properties of ceramics, as well as patients' demands for longer and more active lifestyles after joint replacement."

Wear of polymer and metal joint implants can generate debris particles that cause inflammation around the joint, loosening the implant and potentially leading to its failure. Potential allergic reactions to metals as well as toxicity from release of metal ions from an implant into the body are also considerations.

These considerations are creating a favorable landscape for ceramic implants, and that shift is evident in data from the 2019 annual report of the American Joint Replacement Registry, a database of more than 1.5 million knee and hip arthroplasty procedures performed in the U.S. during 2012–2018. Registry data show that for total hip arthroplasty, the number of implants with ceramic heads is increasing and first surpassed those with cobalt chromium heads in 2015.[9]

This data, however, presents only a limited picture, as the registry captures an estimated 25%–30% of the volume of annual procedures in the U.S. Other estimates indicate that adoption of ceramic hip implants is already much higher in some parts of the world—more than 50% of hip implants performed in European countries like Austria, France, Germany, Italy, and Switzerland use a ceramic ball head, while 72% of total hip replacements in Asian countries such as South Korea have an alumina ball head.[10]

A large proportion of total hip replacement ceramic implants are historically alumina, although zirconia is used as well. Acceptance of zirconia was severely hindered by the 2001 recall of millions of Prozyr brand zirconia ball heads, prompted by high fracture rates in patient implants. Subsequent failure investigation of the manufacturer, Saint Gobain Ceramiques Desmarquest, determined that a switch in the type of furnace used to manufacture the implants caused an unanticipated change in temperature kinetics, resulting in insufficiently densified zirconia.[11] Although the problem was traced back to a manufacturing error, the recall significantly marred zirconia's reputation in the market.

Many modern ceramic hip joint implants now combine the best of both worlds with composites that offer improved properties of strength, toughness, and scratch resistance, for example, ones based on zirconia toughened alumina (Figure 4).

Beyond material-based considerations, additional factors also are coalescing to create a favorable landscape for ceramics implants. "Medical care has seen many transitions over time, but the latest big trend is the move to outpatient care due to rising costs," Strong says.

Similar to how miniaturization of components allowed pacemakers to shrink in size, resulting in shorter hospital stays and lower care-related costs, parallel evolu-

Credit: CoorsTek Bioceramics

Figure 4. Femoral head and acetabular liner cup for total hip arthroplasty, manufactured by CoorsTek Bioceramics. The implant is made of CeraSurf-p, an alumina zirconia matrix composite that incorporates advanced toughening mechanisms to improve the material's performance.

tions also occurred for joint replacements.

"Generally speaking, technical ceramics are a component of a larger medical implant. Modern ceramics are engineered to be so strong that they are allowing for design changes to the entire device," Strong explains. "They have been optimized to the point where they are impacting the surgical procedures, which are now quicker and more efficient. In total hip arthroplasty, ceramics are a critical part of the overall device, which has been designed around the next generation in surgery. With the current trend toward robotics, these designs allow for faster and more accurate outpatient surgical procedures that previously would require significant time in hospital recovery."

These advancements not only improve patient outcomes but also help reduce healthcare costs, factors that are intimately intertwined.

SPINAL IMPLANTS: SECURING WITH GLASS OR SILICON NITRIDE

Because the spine provides a critical balance of flexibility and stability to the body, any modifications to the spine ideally also must balance those same properties.

Spinal implant devices stabilize and strengthen the spine in various ways, often by securing vertebral elements and inserting implants to shore up the intervertebral space (Figure 5). But that need for flexibility and stability makes spinal devices challenging to design.

For instance, the articulation surface for a total disc arthroplasty must not only be functional, it must be designed to account for an estimated device life of more than 40 years. Considering the estimated number and amplitude of load cycles a lumbar disc undergoes annually—based on an average adult bending an estimated 125,000 times and taking 2 million steps in that year—a disc implant is expected to endure some 85 million cycles of loading during its lifetime without wearing down.[12]

So these devices demand incredibly high-performance and long-lasting materials. While the usual biomedical materials have long been used in spinal implant devices—metals such as stainless steel, titanium, and cobalt-based alloys offer strength; high-performance

Figure 5. Due to excellent their wear rates, ceramics can also be found in cervical disc bearing surfaces for spinal total disc replacements. This one, by CoorsTek Bioceramics, is made of alumina zirconia matrix.

polymers such as polyetheretherketone (PEEK) provide good value—these materials do not offer perfect solutions in the spine, where integration with existing tissue is particularly desirable for preserving functionality of the spine and maintaining longevity of the device.

"Overall, the need of the hour is to develop materials that demonstrate both biomechanical applicability and biocompatibility while being user friendly in a surgical environment," according to a 2017 article on trends in spinal surgery materials.[13] So it is not surprising that this field is also starting to realize the potential of ceramics and glass.

For instance, Mo-Sci (Rolla, Mo.) is developing multicomponent bioresorbable spinal bone grafts from bioactive glass—containing one bioactive glass formulation that dissolves more quickly and contains compounds to stimulate vasculature growth (e.g., copper and zinc elements) in early stages of healing, and another bioactive glass formulation that forms a porous silicate glass scaffold that dissolves more slowly to provide support while natural bone formation gradually replaces the graft.

"This bone graft has shown really nice improvements in spinal fusion rates, and it actually isn't even on the market yet," says Steve Jung, chief technology officer of Mo-Sci. "Mixing to get this benefit from this material and this benefit from this material is sometimes a better option than trying to find this one material that could do it all. Sometimes you have to accept that there are just two really great materials you can put together and get what you want from each."

Beyond bioactive glass, other materials also have their sights set on the spinal

Figure 6. Silicon nitride spinal devices manufactured by SINTX.

market. Silicon nitride spinal fusion devices manufactured by SINTX (Salt Lake City, Utah)—the only FDA-registered and ISO-certified silicon nitride medical device manufacturer in the world—and sold through CTL Amedica are working their way into this market (Figure 6). Silicon nitride is not only bioactive, antiviral, and antibacterial but also promotes bone growth, providing an effective orthopedic solution.

Although the material currently constitutes a small portion of the overall market for spinal fusion devices, data indicates silicon nitride has significant potential, as the company reports there were fewer than 30 FDA-reported adverse events despite more than 35,000 human spine implantations over 10 years.[10]

SINTX anticipates many additional orthopedic applications for silicon nitride, such as dental and craniofacial applications as well as joint replacements. "There's a lot of concerns that metals corrode in the body. As you're putting hips into younger and younger patients who are going to live longer, you're not looking at 20-year outcomes. You're interested in 30- and 40-year outcomes, and there ceramics have a very special role," says Sonny Bal, president and CEO of SINTX.

For craniofacial applications, customized repair of defects with 3D-printed patient-specific implants is a possibility that SINTX has in mind, according to Don Bray, vice president of business development at SINTX. "If someone has a severe accident and you need to rebuild the facial bones and structure, you would want to do a CAT scan and make an exact fit. In the spine you can use some standard sizes. But because of the shape of the face, you can't—and we think 3D printing there with our silicon nitride is key," Bray says.

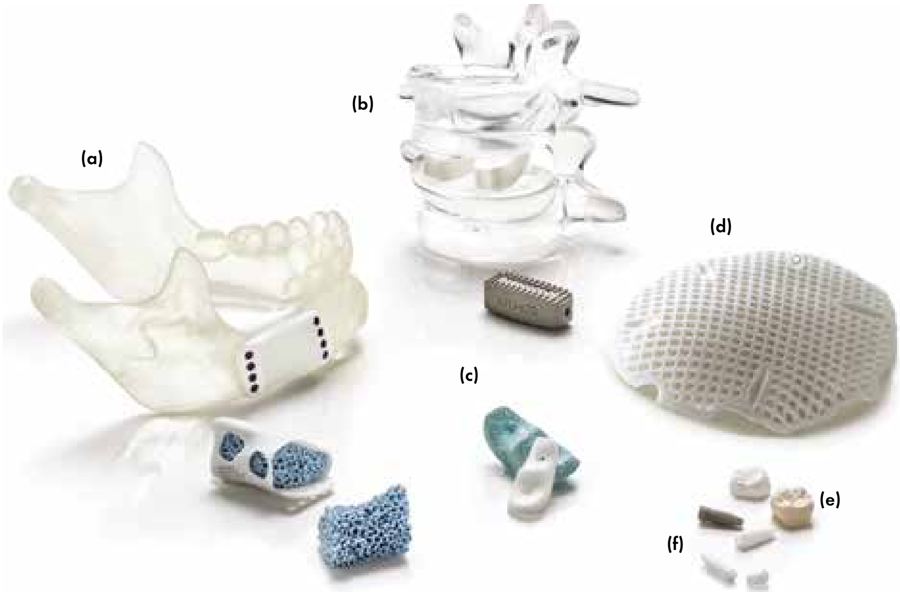


Figure 7. 3D-printed medical devices manufactured with Lithoz CeraFab System printers. From left to right: a) Mandibular implant (white: zirconia, blue: hydroxyapatite), b) spinal implants (grey: silicon nitride, white: tricalcium phosphate), c) front jaw bone augmentation (blue: hydroxyapatite, white: bioactive glass), d) cranial implant (tricalcium phosphate), e) zirconia crowns (native and colored), f) dental implants and abutment (grey: silicon nitride, white: zirconia).

"It's a very critical area, so having an antibacterial implant that would you could make exactly for the person is where we think this is going to go," Bray adds. "And we don't think it's that far off."

Because of silicon nitride's favorable antibacterial and biological properties, SINTX also is developing techniques to incorporate silicon nitride into devices and products made of other materials as well. For example, silicon nitride can be mixed into polymer-based products or coated onto titanium devices to enhance biocompatibility of those surfaces, promote healing, and prevent infection and spread of viral diseases, according to Bal. "We are looking at 3D processing procedures that we can commercialize, in which we put a very tenacious micron-level coating of silicon nitride that supercharges the metal and makes it antibacterial," he says.

3D PRINTING: A TECHNOLOGY WITH LAYERED MEDICAL POTENTIAL

Multimaterial implants

At the intersection of medical care and additive manufacturing lies tremendous promise to completely change how we approach health strategies to replace, enhance, and restore function of the human body.

According to the annual Wohler's report, the 2019 additive manufacturing industry was worth some $11.867 billion. Medical and dental applications account for about 11% of that market, and dental in particular represents a large growth segment in the latest report.[14]

Additive manufacturing company Lithoz GmbH (Vienna, Austria) is familiar with the potential of the technology for medical and dental applications. Lithoz's lithography-based ceramic manufacturing technology 3D prints complex structures layer-by-layer using a photocurable polymer–ceramic slurry. After printing, green parts are debinded and sintered to remove the polymer, leaving fully dense ceramic parts.

Lithoz developed both the expertise and the custom printers to additively manufacture a diverse array of ceramic materials, everything from piezoceramics to regolith, and certainly including ceramics with medical applications such as alumina, zirconia, silicon nitride, hydroxyapatite, and tricalcium phosphate. Daniel Bomze, head of the Lithoz's medical business unit, says the company also has success printing with bioactive glass. "We have produced several parts and some slurries already successfully with bioglass. So we know it works," he says. Now, Bomze says Lithoz is waiting for a commercial partner who is interested in making the investment to further develop applications for additively manufactured bioactive glass.

Lithoz's technologies can print complex geometries such as high-resolution lattice structures with openings just several hundred microns wide—optimal scaffolds to promote interaction and integration with living tissues—so medical applications are one promising direction (Figure 7). For instance, such bioceramic scaffolds could be used to repair bone defects due to injury or disease.

While ceramic and bone are a perfect match materially speaking, design of bioceramic scaffold structures is challenging because they must provide both porosity and mechanical strength, properties that often come at a tradeoff. Fortunately, natural bone can provide some inspiration. Bone's structure consists of an outer layer of dense cortical bone filled with porous and spongy inner trabecular bone, a multimaterial strategy that uses two different forms to provide two different components of bone's function.

Lithoz is developing multimaterial 3D-printed implants that provide both porosity to promote tissue regeneration and mechanical stability to support a bone defect. These multimaterial implants incorporate a strong outer layer for structural support during the initial healing phase, composed of a ceramic material with good mechanical stability such as zirconia, with a porous inner scaffold of bioresorbable ceramic substrate such as tricalcium phosphate or hydroxyapatite. The inner material more closely matches the inorganic component of bone, and its porosity permits cell attachment and penetration of blood vessels, allowing the body to heal and replace the bioresorbable substrate with natural tissues over time.

Such multimaterial implants could be used to repair many types of bone defects, such as those in the jawbone. Critically, Bomze says, the material's resorption rate can be tuned to the area of the body being targeted. "The ideal would be that the regrowth, the new tissue forms at the same speed as the implant is being resorbed. So you have the overall volume and stability, and the whole healing time is the same by tuning this artificial material and the natural material," he says.

Although the individual components of these implants were implanted into a small number of human patients, with good results so far, the multimaterial implant is currently a proof-of-concept. And although the current design is printed into two separate steps, Lithoz has bigger plans for the future.

"The future will be printing it simultaneously, in one single step—you could print the cage and the inner part at the same time and then sinter them together," Bomze says. "You can probably make even more sophisticated materials, for example a sandwich structure with an inner part of hydroxyapatite, then a shell of zirconia, and then a tiny outer coating or a third layer again of hydroxyapatite to facilitate ingrowth of the of implant. And here we're making really rapid progress."

In that vein, Lithoz released in September 2020 a new multimaterials 3D printer called the CeraFab Multi 2M30. The printer is similar to the company's other offerings but now includes two vats to provide the ability to simultaneously print with two different raw materials (Figure 8). This ability affords new functional applications, such as printing multiple materials in a single layer and allowing gradual compositional variation from one material to the next.[15]

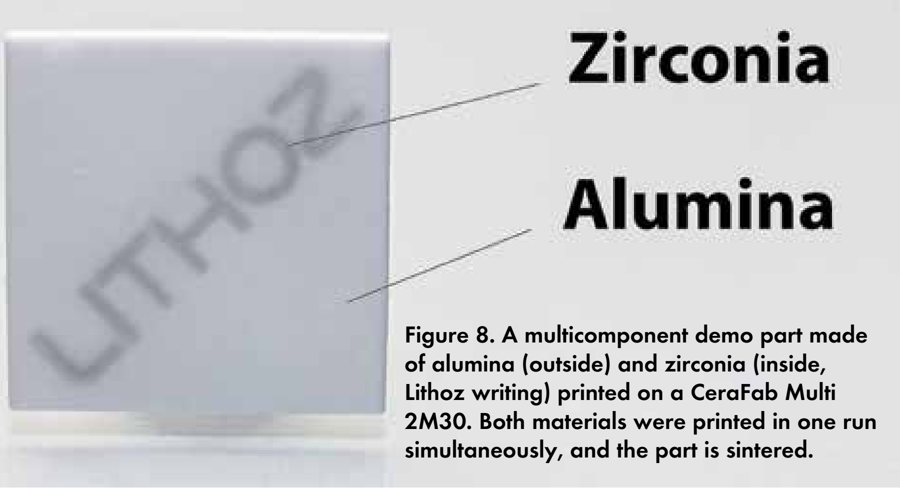


Figure 8. A multicomponent demo part made of alumina (outside) and zirconia (inside, Lithoz writing) printed on a CeraFab Multi 2M30. Both materials were printed in one run simultaneously, and the part is sintered.

Credit: Lithoz

3D-painting

Additive manufacturing is a diverse technology, so Lithoz's lithography-based technique is one of many different approaches.

Another company, Dimension Inx (Chicago, Ill.), is innovating with printing ceramic-based biomaterials at room temperature, with no additional post-processing sintering steps required—affording the ability to incorporate organic molecules such as proteins, drugs, and antibiotics into the materials themselves before printing.

As noted in a May 2019 *Bulletin* article,[16] "3D-painting is a materials-centric advanced manufacturing technology that permits nearly any material to be transformed into a 3D-printable '3D-paint' via simple, room-temperature extrusion without the need for support materials,

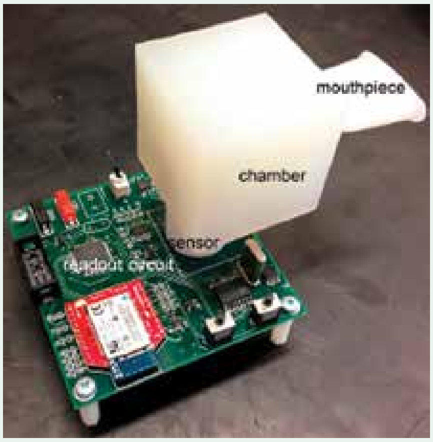
BREATHALYZERS: ANOTHER WAY TO DETECT COVID-19

In the fight against COVID-19, the main technique used to collect samples is a deep nasal swab, a procedure doctors describe as moderately uncomfortable but some patients describe as "being stabbed in the brain."

Testing methods that are more comfortable and more easily administered would certainly be appreciated by patients and physicians alike, and researchers have explored saliva testing as an alternative, with some promising results. However, according to Edward Orton, Jr., Chair in Ceramic Engineering Pelagia-Iren (Perena) Gouma at The Ohio State University, breathalyzers may be an even easier and readily accessible way to administer tests.

Breathalyzers use selective gas sensing elements to detect certain biomarkers in breath that signal disease. Compared to swab-based testing methods, breathalyzers are noninvasive, nonintrusive, and can deliver a result in dozens of seconds.

Gouma has explored the use of breathalyzers for medical diagnostics since 2003. She started investigating the development of breathalyzers aimed specifically at detecting infectious diseases a few years ago, and she has worked extensively the past few months to use that knowledge to design a breathalyzer that detects COVID-19.



Credit: Perena Gouma and M. Stanacevic.

The portable, battery-operated breathalyzer prototype to detect COVID-19 developed at The Ohio State University.

The in-development COVID-19 breathalyzer uses ceramic sensors to target biomarkers that give a response specific to that infection, and it includes advances on nanomaterials for detecting specific breath gases at concentrations that can make a diagnosis.

Gouma says her team initially tested the new breathalyzer by using gas canisters that were mixed to simulate the breath gas mixture as a result of COVID-19 infection. However, they have since moved to conducting human testing and have been testing at various COVID-19 testing sites around Columbus, Ohio.

In mid-September, they reported initial results from the ICU-focused human testing at the Ohio State Wexner Medical Center. The results showed the breathalyzer could detect acute cases of COVID-19 and can monitor the severity of the disease.

The researchers currently are seeking FDA emergency-use authorization for the breathalyzer.

For more information on Gouma's study, as well as other breathalyzer studies taking place at Northeastern University, check out a recent *Wired* story on the topic at https://www.wired.com/story/could-breathalyzers-make-covid-testing-quicker-and-easier. ■

Figure 9. Anatomical structures display a handful of possible structures that were 3D printed by Dimension Inx with Hyperelastic Bone: (clockwise, from top left) spine, femoral head, mandible, and pelvis.

Figure 10. A sheet of Dimension Inx's 3D-printed Hyperelastic Bone, which is flexible despite being 90% ceramic.

powder-beds, resin-baths, cross-linking, or curing."

In the 3D-painting technique, a powder-based material is mixed with elastomer and solvents; after extrusion through a nozzle, the finished printed product requires only rinsing and sterilizing. The flexibility of the technique means that in addition to 3D printing structures out of 3D-paints, the same strategy could also be used to coat products manufactured via other techniques and out of other materials.

Importantly, 3D-painting can be applied to almost any material, including ceramics. "3D-painting is materials agnostic. It's not dependent on what you're making or what material you're using," says Adam Jakus, cofounder and chief technology officer at Dimension Inx.

As one example of the 3D-painting technology, Dimension Inx's bone-specific 3D-paint formulation, called Hyperelastic Bone®, is primarily ceramic yet still incredibly flexible, offering significant potential for bone implants. Hyperelastic Bone can be printed in specific structures (Figure 9) as well as porous scaffolds and sheets that could be cut and custom-fit in the operating room (Figure 10).

"The really interesting thing about Hyperelastic Bone is that it's 90% ceramic, which is technically more ceramic than is in our actual bones," Jakus explains. Human bones contain 60%–70% dry weight of crystalline hydroxyapatite, bound by collagen and other structural and functional proteins. "But the end result is actually flexible and cuttable and shapeable, which you wouldn't really expect for a something that's mostly ceramic."

That flexibility is because of Hyperelastic Bone's unique microstructure, which forms as evaporants vaporize from the printed material after it is extruded through a printer nozzle. The rate of evaporation tunes precipitation of the elastomer, forming an optimized structure in the printed material.[17]

"A very specific microstructure really allows the different components of the composite, the ceramic and the resorbable polymer, to play off each other and move around and then return to their original form without breaking," Jakus says.

Hyperelastic Bone also is microporous, which provides excellent osteoconductivity and biocompatibility. "If it's intended to regrow bone, the body tissue needs to be able to access that material on the microstructure level and transform it," Jakus says, although the porosity can have a drawback. "But it's a balance if you want structural integrity and you want bioactivity. Those things are in conflict all the time."

Since the technology is relatively well-established at this point, Jakus says Dimension Inx is now working on quality control aspects of the process, showing that it can demonstrate consistent results. "So a lot of our efforts throughout 2020 have been establishing new quality control systems and quality manufacturing systems around design and synthesis of these new materials as well as the 3D-painting process itself," he says.

That includes establishing consistent and detailed manufacturing processes and identifying and mitigating risks—all part of the company's preparations toward seeking FDA approval for Hyperelastic Bone devices.

3D printing inherently conjures ideas of patient-specific printed implants. And while that is an eventual direction for Dimension Inx, the company is starting with a more practical pathway—and one common for biomedical innovations—by targeting mass-produced implants of Hyperelastic Bone, a collection of standard shapes like "strips or squares or blocks," Jakus says. "We are introducing a new material in a new manufacturing process. So I think it's important to get the regulatory agencies, the FDA, surgeons, everybody comfortable with the material and the process first so they are then willing to take that next step to patient-matched implants."

That acceptance is a considerable issue in the medical industry—you not only have to prove that a device or technology works (see sidebar: *Regulating the pace of medical innovation*), but you also have to convince medical professionals to use it as well. And that can be a major barrier, especially for new medical innovations.

"The technology is the easy part," Jakus says. "And even after you identify a technology that addresses an actual need, getting surgeons to venture out their comfort zone is very hard." If an existing clinical solution is trusted and works relatively well, medical professionals often are not keen to change a process, especially if the solution does not offer additional profit or patient benefit or it requires the professional to master a new technique. Introducing a new product also comes with some inherent risk, which medical care is designed to minimize, for good reason.

One sector, however, where medical professionals are often more willing to take modest risks is the craniofacial space—which is why medical innovations often target this site.

In particular, additively manufactured medical technologies often focus on craniofacial applications because these defects are non-load bearing and highly individualized. In addition, there are few existing off-the-shelf products to treat craniofacial defects, so these medical professionals are often more willing to take a slight risk with innovative new solutions.

Infiltrating a site like the craniofacial space can then be a strategic initial target application of a new technology to gain acceptance before expanding to additional sites and applications.

Another consideration that makes the craniofacial segment attractive for innovation in additive manufacturing, especially with bioresorbable materials, is that these surgeons treat many pediatric defects. "So they're most excited to use new materials, ceramic or not, that transform over time and grow with the patient," Jakus says.

TISSUE REGENERATION: THE SOFTER SIDE OF BIOMATERIALS

In terms of the body's natural materials, ceramics and glass are most analogous to bone and tooth enamel—so it is not surprising that there are so many orthopedic and dental applications for ceramics and glass (see sidebar: *Ceramics used in dentistry*).

But modern developments in nanotechnology, particularly the ability to engineer nanosurfaces, nanoparticles, and nanoscaffolds, as well as more nuanced understanding of cell biology are together reshaping how we think about the potential of biomaterials.

Biomaterials were once designed to minimize interactions with the body and to eliminate any potential adverse reactions. But starting with Larry Hench's discovery of bioactive glass 50 years ago,[18] a more modern perspective for biomaterials no longer attempts to eschew cell biology.

"Design of a new biomaterial should always consider the need of the cells, because the cells are the engineers of our body," says Aldo Boccaccini, professor of biomaterials and head of the Institute of Biomaterials in the Department of Materials Science and Engineering at University of Erlangen-Nuremberg (Erlangen, Germany).

Many biomaterials now aim to not only stand in for living tissues when they need to be repaired or replaced, but the materials play a more supportive role in actually helping the body perform its own healing—more like an assist rather than a complete substitution. That guidance can be used to mediate processes such as wound healing and to rebuild damaged or missing tissues, broadly contributing to the overall field of tissue engineering, or regenerative medicine.

In terms of the future of healthcare, regenerative medicine is a big business. The global market for tissue engineering

REGULATING THE PACE OF MEDICAL INNOVATION

While there is no shortage of innovative ideas for medical applications, bringing such innovations to the market is a whole different story.

"The medical market is slow and steady in terms of innovation," says Lucian Strong, vice president of CoorsTek Bioceramics (Grand Junction, Colo.). "While new applications or processes may demand new materials, there is a well-defined process that is governed through the regulatory bodies around the globe. There is no simple introduction of a new material that will be implanted into a patient. Clinical data, proven over numerous years and multiple patients, is necessary for any new material to gain acceptance."

Collecting such data takes considerable time, but it is a critical component of the regulatory processes to ensure that biomaterials and devices are safe and effective once implanted into human patients. And even before the clinical data, much additional time must be first devoted to testing and documenting effectiveness and safety in both lab settings and in animal models.

In the U.S., where the FDA regulates the approval process, bringing a medical device to market takes on average 3–7 years.[1] Although this process unavoidably slows the pace of innovation, these pathways are critical to maintain safety and minimize potential harm to human health.

Yet even once clinical data does provide acceptance for a material, the story is still not over.

"The increasing longevity of the human race, younger patients undergoing surgical interventions, all points to a future in which we as scientists need to understand the long-term interaction of the implant with the body," says B. Sonny Bal, president and CEO of SINTX.

Of course, it is not feasible to wait decades while collecting long-term outcomes for every new device—such observation trials would completely stifle innovation and prohibit entrance of any new product on the market.

Instead, to develop materials for the future, we need robust short-term outcome proxies that can predict long-term behavior, Bal says. "That's the Holy Grail."

Bal made the analogy to how NASA uses algorithms and modeling to predict the outcomes of its missions. There are no practice runs when sending a rocket to Mars—NASA incorporates knowledge and modeling to maximally reduce the margin of error. And that, he envisions, is where biomaterials need to go.

"Instead of experimenting with humans, we need to be able to predict how a biomaterial will behave in the body just like NASA does—because there's no room for mistakes. You do it once, and that patient has to live with it. You can't have failures," he says. ■

[1]G. A. Van Norman, "Drugs, devices, and the FDA: Part 2: An overview of approval processes: FDA approval of medical devices," *JACC: Basic to Translational Science*, **1**[4] 277–87 (2016). DOI: 10.1016/j.jacbts.2016.03.009

and regeneration was valued at $24.7 billion in 2018 and is predicted to reach $109.9 billion by 2023, representing an impressive CAGR of 34.8%.[19] While bone is a significant focus of this market, it encompasses soft tissues as well, such as strategies to repair damaged cardiac and gastrointestinal tissues or engineer vascular, muscle, neural, and skin tissues.

Likewise, there is potential for many different types of materials in this broad field. "In the field of regenerative medicine and tissue engineering, there is no one material that is going to tackle all the problems," Boccaccini says. And many of the ceramic- or glass-based strategies to heal tissues actually combine them with organic materials, in polymer composites or hydrogels, for example.

Although bioactive glasses were discovered half a century ago, their potential within regenerative medicine is still being realized today. When in contact with body fluids, bioactive glasses dissolve and release ionic dissolution products such as biologically active ions within the body. Cells, in turn, respond to these ionic products, some of which stimulate growth of new blood vessels in the tissue, a process called angiogenesis. Blood vessels nourish developing tissue with oxygen and nutrients and remove waste products, so the angiogenic response is part of what makes bioactive glass so attractive for tissue repair.[20]

But ionic dissolution products also do more than stimulate angiogenesis—these products alter gene expression patterns in nearby cells, shifting signaling pathways that orchestrate every cellular function, such as cell migration, proliferation, and differentiation.

Although we are just beginning to unravel some of these biomolecular mechanisms, the potential exists for bioactive glass compositions and properties to catalyze a diverse array of cellular responses, precisely tuned to the target tissue and the desired effect in that tissue—whether that is modulating an immune reaction, prompting tissue regeneration, or stimulating release of growth factors to guide stem cell differentiation.

"Understanding genetic upregulation and activation by ionic stimuli released from bioactive glasses offers the possibility of developing patient-specific therapies, a huge challenge for the aging population," per a 2015 *Bulletin* article on bioactive glasses.[21]

One of the more familiar and clinically approved applications of bioactive glasses for soft tissues is in wound repair, with products such as a cotton candy-like borate bioactive glass fiber matrix to heal advanced wounds.[22]

CERAMICS USED IN DENTISTRY

Ceramics are ubiquitous in the $10.7 billion U.S. dental industry,[1] with applications in prosthetics, fillings, orthodontic appliances, cosmetic products, process materials, preventive products, toothpaste, and more. Below are some highlights of the roles that ceramics play in this industry.

Dental caries: From prevention to treatment

Dental caries, commonly known as tooth decay, is the most common bacterial disease of children and adults worldwide.[2] Formerly, tooth loss due to bacteria attacking the tooth enamel was inevitable, but advances in dental materials and techniques during the last few decades have greatly reduced chances of this outcome.

Plaque removal and teeth cleaning at home and by hygienists is the first line of defense against these bacteria. Toothpastes contain many ceramic powders ranging from stannous fluoride, potassium nitrate, and several calcium phosphate compounds. Bioactive glass is also present in some toothpastes, to promote remineralization of the enamel. Sodium bicarbonate is often used by hygienists to more thoroughly remove plaque, and pumice is sometimes used as well.

When bacterial attack progresses into the enamel, a dentist will seek to remove the softened tissue and restore tooth anatomy. Small to medium bacterial lesions (cavities) are treated with ceramic composite filling[a] material or glass polyalkenoate cement[b] material to restore the tooth form.

When the disease progresses into the pulp, a medication that induces the pulp tissue to build a protective barrier of reparative dentine is needed. Calcium hydroxide-containing materials used to be the standard material used for this purpose, but now tricalcium silicate cements, which are based on the same materials as white Portland cement, are the "gold standard." (These cements are set with a matrix that includes calcium hydroxide.)

If the pulp becomes irreversibly infected, a root canal procedure is required. In this procedure, the pulp is removed and is replaced by a combination of rubber points shaped like a root canal and sealed with another material. The trans-polyisoprene rubber points are usually filled with zinc oxide and barium sulfate. The sealing material comes in a variety of polymer and ceramic matrices, ranging from epoxy to zinc oxide–eugenol. The newest sealers are based on tricalcium silicate powders. Sometimes, glass fiber-reinforced composite posts are inserted in a root canal after a root canal procedure to help restore tooth function.

When a majority of the anatomy of a tooth is lost, the anatomy is restored with a crown. Gold foil and its alloys were the materials traditionally used for crowns, but in the 1950s, porcelain enameled crowns and bridges became the standard tooth restoration for severely damage teeth because of their greater durability and more natural aesthetic. Today, all-ceramic crowns—such as alumina, lithium disilicate, and yttria-stabilized tetragonal zirconia—are the most common crown type because of their strength, ease of fabrication, and aesthetics. Tetragonal zirconia with 3% yttria dominates this market due to its high strength, but zirconia with higher yttria formula are also in use due to better aesthetics, despite their diminished strength.

Whenever a temporary or permanent crown or bridge is placed, dental cements are needed. Numerous ceramic- and glass-containing dental cements are used in dentistry, but the original cements were all based on zinc oxide. More recently, glass-ionomer cements evolved from the original silicate filling materials in the mid 20th century and remain popular because of their temporary fluoride release, which deters caries from forming under a crown. Resin-modified glass-ionomer cements and compomers are also advantageous, by combining light-curable polymers from composites with limited fluoride ion release from the glass ionomers.

Tooth extractions: Replacing the missing teeth

Periodontal diseases and tooth fractures may lead to tooth extraction. Dental implants, or posts surgically placed into the jawbone, are increas-

[a]Urethane polymers filled with about 40–70% by weight of ceramic powders, which may include radiopaque glasses, fumed silica, or quartz in combination. Requires bonding agents such as silane and a polymer primer to induce adhesion.

[b]In other words, glass-ionomer, composed of fluoroaluminosilicate glass powder reacted with a polyacrylic acid liquid, which bonds to tooth structure. Used for restoring tooth anatomy plus permanent cementation of crowns, bridges, inlays, onlays, posts, and orthodontic appliances.

"But you can also think of internal wounds, such as adhesives with hemostatic ability for coating internal wounds where there is a lot of bleeding," Boccaccini says. "Here I think yet is an open area for the applications of [bioactive glass], either as a fiber or mesh or in composites."

As research continues to characterize how cells respond to the unique materials as well as the underlying biomechanisms of these responses, soft tissue applications of bioactive glass will also continue to expand.

Mo-Sci's Steve Jung says that bioactive glass is experiencing increasing integration in medical products due to the material's recognition as a "premium material" and its ability to intimately interact with tissues. Bioactive glasses are being combined with other materials to make new products as well as being integrated into existing products already on the market. "They're making these products better by the addition of bioactive glass," Jung says.

Jung says that in veterinary medicine, there also have been some indications that bioactive glass can also repair tendons and ligaments. "To me, that kind of outcome is really what gets you thinking about sports injury-type situations—if you blow a ligament, could we develop a technology to help to heal that back together?" he says.

Beyond being implanted within the human body to aid tissue regeneration, ceramic and glass materials can also be similarly used to grow tissues outside of the body, with the vision that these tissues could eventually be harvested and implanted into or on the body as appropriate.

"The possibilities for ceramic technologies for improving the health and wellbeing of mankind are vast," says Randel Mercer, chief technology officer at CoorsTek. "One exciting avenue CoorsTek has been working on is the use of engineered ceramic cell culturing devices. Our product, Cerahive, is used to grow human tissue cells in an environment that mimics the growth environment in the human body." These porous ceramic substrates line the bottom of a cell culture dish to support 3D cell cultivation, allowing in vitro growth of cell spheres (Figure 11). "The future potential to 'manufacture' specific tissues in the laboratory could be used as a source for repairing damaged tissue in humans," Mercer says.

LOOKING FORWARD—A GLIMPSE OF FUTURE HEALTHCARE

So what does the future of medical care look like, and how do biomaterials fit into that future?

---

ingly used to replace single teeth and to support bridges and dentures. Implants used to be exclusively titanium, sometimes with a hydroxyapatite (ceramic) coating. However, tetragonal zirconia is gaining popularity despite its higher cost due to its improved biocompatibility.

When implants are not possible, a partial or full denture may be made for a patient. Today, most dentures are composed of pressure formed acrylic base with injection molded acrylic teeth. However, in some regions of the world, porcelain teeth in an acrylic base remain popular. (Porcelain was the standard denture material in the early 20th century.)

Other applications: Brackets, abrasives, equipment

Orthodontic brackets are commonly made of stainless steel, but sapphire, tetragonal zirconia, and polycrystalline alumina (with no glass bonding) are also used to manufacture orthodontic brackets because of their aesthetic appeal (they make the brackets less obvious). Ceramic coatings such as rhodium oxide are also used on orthodontic wires to disguise the orthodontic device.

Diamonds, tungsten carbide, and alumina and silica abrasives are essential for dentistry to remove tooth structure and to polish or adjust any dental restorative or denture. Some abrasives are bound in rubber; others are used in paste form.

"Of course, most of the equipment used in dentistry would not be possible without ceramics, from microscopes and cameras to curing lights to air turbines handpieces; from piezoelectric devices, to general electronic devices, to office scheduling and case record software and computers," says Carolyn Primus, medical device consultant and the 2020 Larry Hench awardee for Bioceramics.

Future of dental ceramics

Biocompatibility is a top priority for medical devices, and ceramics excel in biocompatibility compared to polymers and metals. On the other hand, durability is a key concern for ceramic restoratives in dentistry, particularly composite ceramics. Current research on zirconia, for example, looks to optimize the strength and appearance of zirconia by exploring variations in the stabilizers for the tetragonal phase. Ceramic nanoparticles are another subject of much research, as nanoparticles offer a way to provide unique biological responses. Nanoparticles are not new in dentistry, however—silica nanoparticles have been used for decades in composites and toothpastes.

Compared to other fields, manufacturing in dentistry happens at a small scale. As such, "Dentistry often follows the innovations in other industries or adopts materials used in other fields," Primus says.

For example, computer-aided design and computer-aided manufacturing (CAD/CAM) are examples of innovations from other industries adopted for dental applications beginning in the 1980s.[3] CAD/CAM dentistry is becoming a widespread method for making ceramic dental crowns in a dental office.

Additive manufacturing is also being adopted for dentistry. Fabrication of dentures and temporary restorations are leading the way for additive manufacturing. Lithoz GmbH (Vienna, Austria) is helping to lead the adoption of additive manufacturing for dental purposes with their lithography-based CeraFab 7500 Dental and CeraFab System Series ceramic manufacturing machines. Ivoclar Vivadent (Schaan, Liechtenstein) is also exploring additive manufacturing with their PrograPrint PR5, a digital light processing-based stereolithography printer.

As these technical innovations allow people to retain more teeth, the dentistry field will continue to grow, and the opportunities for ceramic and glass materials along with it. ■

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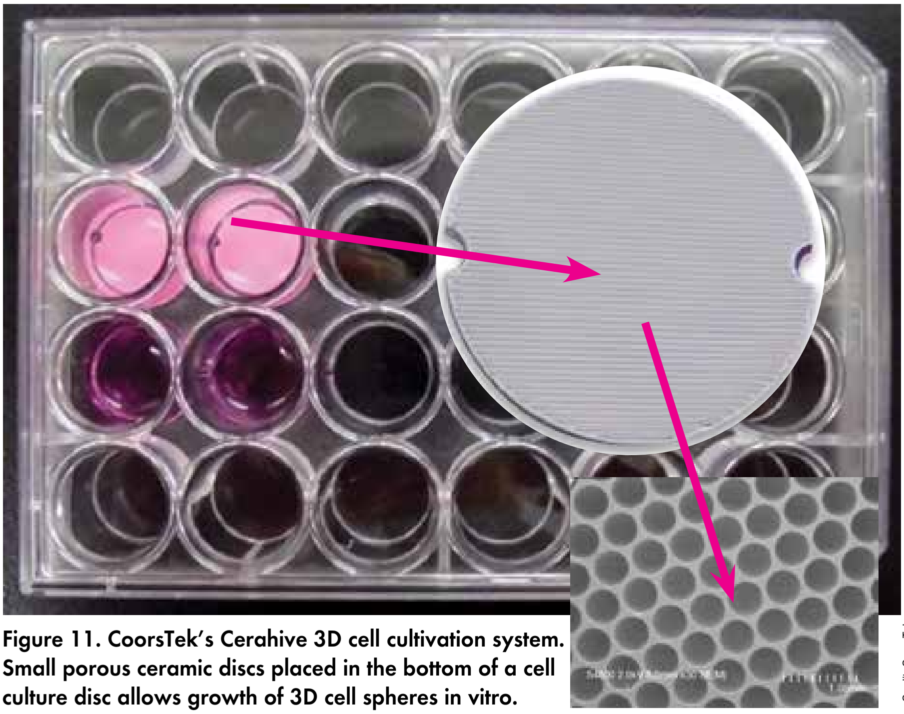

Figure 11. CoorsTek's Cerahive 3D cell cultivation system. Small porous ceramic discs placed in the bottom of a cell culture disc allows growth of 3D cell spheres in vitro.

Credit: CoorsTek

"The medical industry is constantly searching for new, better, and more cost-effective solutions, and advancements in the medical industry are moving at a pace so much faster than just a few years ago due to the introduction of advanced materials. With climbing healthcare costs combined with the move from inpatient to outpatient procedures, there is a pull from the market for better materials," says CoorsTek's Lucian Strong.

Ceramics and glass clearly fit into that future vision not only because of the role of established products such as joint implants but also due to entirely new forms and functionalities of the materials that are just starting to be discovered, realized, and matured.

"I absolutely believe that ceramics and bioactive glass have a really strong future, and their areas of use are going to diversify in a big way," says Mo-Sci's Steve Jung. "Bioactive glass is 50 years old, but we're still finding new ways to use it all the time. Old materials used in new ways or in combination with new techniques I think is the wave of the future."

Some of those new ways, combinations, and techniques are highlighted in this article, but potential extends much, much further as well.

One particular area ripe for future innovation is technologies that address multiple different tissues simultaneously. Although an isolated tissue-specific approach often guides biomaterial developments, components of the human body operate together in systems on several different scales.

"If you look at everything in isolation, there are solutions that already exist. They may not be the best solutions, but there are ways to treat individual tissues," says Dimension Inx's Adam Jakus. However, most injuries or conditions involve multiple tissues, so more complex solutions are often required.

"This has been a driving force for our technology for a long time, and we set up a manufacturing technology where all the materials are complementary to each other," Jakus says about Dimension Inx's 3D-painting platform. "So we can manufacture a bone material with a muscle material and with a ligament material, so that in the future you could make a multitissue implant."

Such strategies will inevitably need to leverage properties and strengths from multiple different materials. "This could be partially ceramic, partially polymer, partially biological, even partially things like graphene and graphite for electrical conductivity," Jakus adds. "So manufacturing different material types together to match the really different material types in the body."

Another systems-level approach that will certainly shape the future of healthcare is smart implants.

Miniaturization of devices, enabled by advances in the materials themselves, provided the feasibility for tiny sensors that can be implanted within the body to track an array of biological parameters on-demand. Such sensors provide the ability to track those parameters continuously, rather than sporadic measures taken at a doctor's office or hospital, and monitor for any changes that could signal a potential health problem. Such rich data provides a more comprehensive view of a patient's health as well as the ability to respond immediately to a potential disturbance in that health.

According to Schott's Jochen Herzberg, smart implants have a prominent place in the future of medical care not only because they provide better monitoring but also in terms of reducing healthcare spending, by reducing trips to the doctor or hospital and by informing more strategic medical intervention when necessary.

"A trend that is very visible right now is smart implants and remote monitoring of patients to reduce hospitalization. For example, in-line measurements of vital signs like blood pressure inside of your body, with smart computers inside your body communicating with your doctor without being hospitalized," Herzberg says.

Glass is already used in several different components of such devices, including hermetic seals, but its optical transmissivity offers compatibility in terms of data transmission (see sidebar: *Could future bandages not only be smart, but also made of glass?*).

Yet tiny implantable devices also can do more than just sense and monitor—they can also be designed with the capability to intervene as well, for instance by delivering a therapeutic.

"This is very fast moving technology. The idea is to replace conventional medical therapies with active implants so that you avoid overmedicating your whole body, for example by replacing

COULD FUTURE BANDAGES NOT ONLY BE SMART, BUT ALSO MADE OF GLASS?

Credit: Schott North America; YouTube

"The materials of the future must be smarter than ever," states a video from Schott's Opportunity lab.

The company is clearly giving top marks to ultrathin glass, as the video depicts a transparent glass bandage being directly applied to a cut in the skin.

In this concept, thin-film sensors are integrated into a small sheet of ultrathin glass, which can be applied directly to a wound to not only treat the wound and help it heal but also to transmit health data in real time.

Although the smart bandage is a concept idea, it plays into current medical trends toward connected devices and data-driven monitoring of health, with increasing use of sensors in and on the body to continuously measure diverse health parameters.

Yet although thin glass is flexible, it is still breakable—meaning that damaging this bandage could result in additional wounds beyond what the bandage was originally intended to treat.

However, according to Schott's website,[1] the company is not discounting the concept's potential. "Sounds utopian perhaps, but due to the special properties of glass, it could soon be a reality," the website says.

Watch the video at https://youtu.be/aSiJsGchvbw. ■

[1]Schott, https://www.us.schott.com/innovation/smart-glass

chronic pain relievers with very smart implants that are active only where the pain is created rather than influencing the whole body," Herzberg says.

Smart implants play into an overall health ecosystem increasingly focused on early detection and proactive intervention, before health conditions because problems and require more involved treatment.

These data-based monitoring strategies extend beyond implants as well, according to a Deloitte Insights report on the future of health.[23] "Medical products might no longer be limited to pharmaceuticals and medical devices. They could also include software, applications, wellness products, even health-focused foods. The home bathroom of the future, for example, might include a smart toilet that uses always-on sensors to test for nitrites, glucose, protein, and pH to detect infections, disease, even pregnancy. A smart mirror equipped with facial recognition might be able to distinguish a mole from melanoma," the report says.

Ultimately, the entire landscape of how we approach, monitor, manage, and mitigate human health is shifting. While these changes will not come without challenges to the market for biomaterials, they also offer incredible opportunity—and ceramics and glass are certainly well-positioned to capitalize on such opportunities as well as integrate critical function into the human body. ■

ACKNOWLEDGEMENTS

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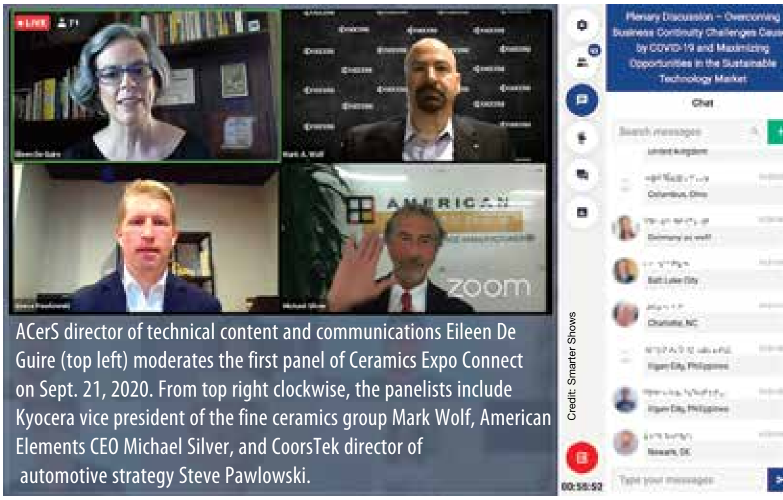
ceramics expo

Connect covers wide range of new and emerging ceramic applications



ACerS director of technical content and communications Eileen De Guire (top left) moderates the first panel of Ceramics Expo Connect on Sept. 21, 2020. From top right clockwise, the panelists include Kyocera vice president of the fine ceramics group Mark Wolf, American Elements CEO Michael Silver, and CoorsTek director of automotive strategy Steve Pawlowski.

How are manufacturers handling business during the COVID-19 pandemic? That question was at the core of many discussions during Ceramics Expo Connect, the virtual version of Ceramics Expo. The industry exposition, which typically takes place in the spring, took place instead from Sept. 21–25, 2020, and it welcomed more than 1,500 virtual event attendees and more than 150 exhibitors.

Each day of the exposition featured panels, interviews, and roundtables focused on different themes, including clean and electrified technology (Monday), additive manufacturing (Tuesday), aerospace applications (Wednesday), and quality and testing (Thursday).

The exposition kicked off Monday with a panel on overcoming business continuity challenges caused by COVID-19. The manufacturers on the panel say while there are still difficulties, overall some of the necessary workarounds enacted to handle the pandemic could prove useful in the future, such as facilitating business electronically and working from home.

On Tuesday, manufacturers again were future focused in their discussions of additive manufacturing. However, they did caution that additive manufacturing should not be treated as a solution to all processing challenges but rather as just another forming process.

With all the talk of future potential, Wednesday discussions focused on one area in which ceramics are already making a difference: aerospace. The first jet engines based on ceramic matrix composites were commercially deployed in 2016, and panelists suggested more aerospace opportunities for ceramic materials in the future, including in shrouds, liners, nozzles, and blades.

In contrast to the other three days, Thursday wrapped up the exposition with a focus on current processes and how to ensure material quality and testing. Experts from multiple fields offered their expertise, including representatives from vehicle manufacturing, scientific instruments for molecular research, and clay brick making. ■

First-ever

CERAMIC MANUFACTURING SOLUTIONS CONFERENCE looks at latest trends in ceramic manufacturing industry

Andrea Ross (above) presents Dana Goski and Matthew Lambert (below) with this year's John E. Marquis Memorial Award.

Credit: ACerS

Current trends, applications, and processes in the ceramic manufacturing industry were the focus of the first-ever Ceramic Manufacturing Solutions Conference, which took place on Sept. 29, 2020. Originally scheduled to take place alongside Ceramics Expo in the spring, CMSC was rescheduled as a virtual event for the week after Ceramics Expo Connect in light of the ongoing pandemic.

Sixty-nine registrants from 13 countries, including 10 students, registered to attend the one-day event, which was organized into three main sessions: Testing, Quality, and Health & Safety; Ceramic Processing; and Raw Materials.

The day kicked off with a keynote presentation by Doug Freitag, technical director for government affairs at the United States Advanced Ceramics Association. Freitag spent time describing the history and current status of research on transparent ceramic armor and ceramic fiber reinforced ceramic matrix composites for gas turbines.

Following Freitag's presentation, ACerS director of meetings and marketing Andrea Ross presented Allied Mineral Products vice president of research & development Dana Goski and manager of special projects Matthew Lambert with this year's John E. Marquis Memorial Award, in recognition of their paper "Engineering resilience with precast monolithic refractory articles."

During the three main sessions, several topics were discussed in regard to each theme, including

• Occupational Safety and Health Administration citations and ASTM test methods for powder characterization under **Testing, Quality, and Health & Safety**.

• Failure modes & effects analysis, additive manufacturing considerations, silicon nitride production, and specific volume diagrams under **Ceramic Processing**.

• Electric arc fusion of mullite ceramics and the role of alumina in various applications under **Raw Materials**.

"Working in the manufacturing environment, the CMSC event exceeded expectations; the speakers and the content of their talks were both excellent. I'm excited for this event to continue," says coorganizer Keith DeCarlo of Blasch Precision Ceramics. ■

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Electronic Materials and Applications 2021 (EMA 2021) is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, biological and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society, EMA 2021 will be a virtual event on the same planned dates, Jan. 19–22, 2021.

EMA 2021 is designed for scientists, engineers, technologists, and students interested in basic science, engineering, and applications of electroceramic materials. Participants from across the world in academia, industry, and national laboratories exchange information and ideas on the latest developments in theory, experimental investigation, and applications of electroceramic materials.

Students are highly encouraged to participate in the meeting. Prizes will be awarded for the best oral and poster student presentations.

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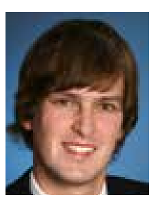

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SCHEDULE OF EVENTS

WEDNESDAY, JANUARY 20, 2021

Plenary session 1	9:45 – 11 a.m.
Concurrent technical sessions	11 a.m. – 4 p.m.
Networking session	4 – 5 p.m.

THURSDAY, JANUARY 21, 2021

Plenary session 2	10 – 11 a.m.
Concurrent technical sessions	11 a.m. – 5 p.m.
Student & Young Professionals networking session	5:30 – 6:30 p.m.

FRIDAY, JANUARY 22, 2021

Concurrent technical sessions	11 a.m. – 5 p.m.
Failure: The greatest teacher	5 – 6 p.m.

TECHNICAL PROGRAM

S1 – Characterization of Structure-Property Relationships in Functional Ceramics

S2 – Advanced Electronic Materials: Processing Structures, Properties, and Applications

S3 – Frontiers in Ferroic Oxides: Synthesis, Structure, Properties, and Applications

S4 – Complex Oxide Thin Films and Heterostructures: From Synthesis to Strain/Interface-engineered Emergent Properties

S5 – Mesoscale Phenomena in Ferroic Nanostructures: From Patterns to Functionalities

S6 – Emerging Semiconductor Materials and Interfaces

S7 – Superconducting and Magnetic Materials: From Basic Science to Applications

S8 – Structure-Property Relationships in Relaxor Ceramics

S9 – Ion-Conducting Ceramics

S10 – Point Defects and Transport in Ceramics

S11 – Dislocations in Ceramics: Processing, Structure, Plasticity, and Functionality

S12 – Evolution of Structure and Chemistry of Grain Boundaries and Their Networks as a Function of Material Processing

S13 – 5G Materials and Applications Telecommunications

S14 – Agile Design of Electronic Materials: Aligned Computational and Experimental Approaches and Materials Informatics

S15 – Functional Materials for Biological Applications

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Due to uncertainty surrounding the current global pandemic, meeting organizers, along with the meetings team at The American Ceramic Society, have decided to move the 45th International Conference & Exposition on Advanced Ceramics & Composites meeting to a fully virtual format for 2021, running live sessions containing pre-recorded talks on a new date: Feb. 8–12, 2021. This conference will be the first-ever Virtual ICACC organized by ACerS Engineering Ceramics Division, and we would like for you to be a part of it.

This conference has a strong history of being the preeminent international meeting on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies, and this year is no different.

The technical program will reflect the growth and success of ICACC by featuring 18 symposia, five focused sessions, one special focused session, and the 10th Global Young Investigator Forum. These technical sessions, consisting of both oral and poster presentations, will provide an open forum for scientists, researchers, and engineers from around the world to present and exchange findings on recent advances on various aspects related to ceramic science and technology. The technical program reflects critical areas of interest within ceramics and advanced composites, with a particular emphasis on current trends in research, development, engineering, and application of advanced ceramics.

Hisayuki Suematsu
Program chair, ICACC 2020
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Focused Sessions

- ❖ Special Focused Session on Diversity, Entrepreneurship, and Commercialization
- ❖ 10th Global Young Investigator Forum

FS1: Bio-Inspired, Green Processing, and Related Technologies of Advanced Materials

FS2: Materials for Thermoelectrics

FS3: Molecular-level Processing and Chemical Engineering of Functional Materials

FS4: Ceramic/Carbon Reinforced Polymers

FS5: Fractography of Ceramics

Symposia

S1: Mechanical Behavior and Performance of Ceramics and Composites

S2: Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications

S3: 18th International Symposium on Solid Oxide Cells (SOC): Materials, Science, andTechnology

S4: Armor Ceramics – Challenges and New Developments

S5: Next Generation Bioceramics and Biocomposites

S6: Advanced Materials and Technologies for Rechargeable Energy Storage

S7: 15th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental, and Health Applications

S8: 15th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT15)

S9: Porous Ceramics: Novel Developments and Applications

S10: Modeling and Design of Ceramics and Composites

S11: Advanced Materials and Innovative Processing Ideas for Production Root Technologies

S12: On the Design of Nano-laminated Ternary Transition Metal Carbides/Nitrides (MAX Phases) and Borides (MAB Phases), and Their 2D Counterparts (MXenes, MBenes)

S13: Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems

S14: Crystalline Materials for Electrical, Optical, and Medical Applications

S15: 4th International Symposium on Additive Manufacturing and 3D Printing Technologies

S16: Geopolymers, Inorganic Polymers, and Sustainable Materials

S17: Advanced Ceramic Materials and Processing for Photonics and Energy

S18: Ultra-High Temperature Ceramics

Antonia Ressler
Guest columnist

Biomimetic approach—the role of ions in bone regeneration

The challenge of bone tissue engineering (BTE) is to develop bone scaffolds that allow good integration with the surrounding tissues. Systems of particular interest are scaffolds based on calcium phosphates (CaP), mainly hydroxyapatite (HAp), due to its chemical and structural similarity to the inorganic matrix of natural bone and its excellent bioactivity.

Scientists have used growth factors in combination with CaP to enhance bone regeneration, but negative side effects such as ectopic or unwanted bone formation throw the safety of this approach into question.[1] An alternative way to adjust properties of synthetic materials is a biomimetic approach, in which various trace elements with a beneficial effect for bone formation are incorporated in CaPs.[1] The introduction of even small quantities of these ions may cause changes or improvements in the biological, physicochemical, or mechanical properties of scaffolds.

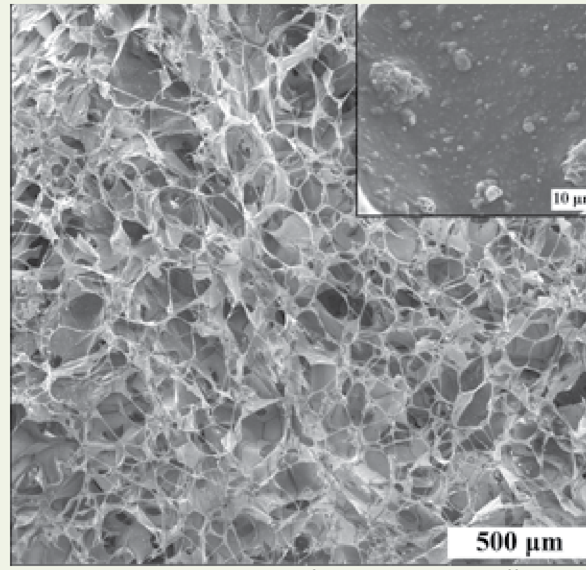
Researchers have extensively investigated CaPs substituted with strontium, magnesium, zinc, selenium, and carbonate ions.[1,2] Findings concerning each of these ions include

- **Strontium** (Sr^{2+}) stimulates bone formation by decreasing resorption activity and differentiation of osteoclasts, while at the same time increasing osteoblast proliferation and differentiation.
- **Magnesium** (Mg^{2+}) acts as a growth factor, especially in the early stage of bone formation, where it plays a key role in bone metabolism. It influences the osteoblast and osteoclast activity.
- **Zinc** (Zn^{2+}) is thought to have the same influence on osteoblast and osteoclast activity as strontium and magnesium. Furthermore, it has antimicrobial and anti-inflammatory properties. Due to that, zinc-substituted CaPs could be used as a coating for metal implants to reduce inflammatory response.[1,2]
- **B-type carbonate** (CO_3^{2-}) substitution is characteristic for biological apatite and thus is a highly interesting substitution in synthetic HAp. Furthermore, the CO_3-substitution enhances bioresorption and therefore osteogenic performance of synthetic material.[3]
- **Selenium** is an essential element for the proper functioning of bone tissue, with strong antioxidant properties. Selenium can induce tumor cell apoptosis while at the same time enhance the proliferation of healthy bone cells.[4] As such, many experiments involve selenium oxyanions (SeO_3^{2-} or SeO_4^{2-}), especially in bone cancer studies.

Though these results show the benefits of introducing trace elements in CaPs, scaffolds based on HAp still face some disadvantages, such as poor mechanical properties. To overcome these disadvantages, HAp has been combined with polymers to obtain composite scaffolds for bone regeneration.

The ongoing University of Zagreb research project "Development of biocompatible hydroxyapatite-based materials for bone tissue engineering applications" supported by the Croatian Science Foundation investigates highly porous scaffolds based on biopolymer chitosan and multisubstituted HAp (Figure 1). Initial results show multisubstituted scaffolds have better osteogenic properties compared to nonsubstituted scaffolds, confirming the importance of trace elements in BTE.

Currently, I am one of the researchers involved with this research project. In the future, we plan to investigate the efficacy of selective laser sintered bioinspired scaffolds for bone tissue engineering as well.



Credit: Antonia Ressler

Figure 1. SEM micrographs of highly porous scaffold based on biopolymer chitosan and hydroxyapatite multisubstituted with Sr^{2+}, Mg^{2+}, Zn^{2+}, Na+, CO_3^{2-}, and SeO_3^{2-} ions.

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Antonia Ressler is a recent doctoral graduate from and now researcher in the Faculty of Chemical Engineering and Technology at the University of Zagreb, Croatia. Her research focuses on biomimetic scaffolds for bone tissue regeneration. She is currently a committee member of the Young Ceramists Network, an initiative of the European Ceramic Society sponsored by the JECS Trust.

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DECEMBER 2020 • VOLUME 1 • ISSUE 5

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SETTING THE STANDARDS: HOW STANDARDS ENHANCE QUALITY AND PROMOTE RELIABILITY

JAPAN FINE CERAMICS ASSOCIATION AND ITS INTERNATIONAL STANDARDIZATION ACTIVITIES FOR FINE CERAMICS

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INDUSTRY NEWS

ENPRO AGREES TO BUY OPTICAL FILTER AND COATINGS MAKER

Charlotte, N.C.-based EnPro Industries, Inc. agreed to acquire Alluxa, Inc., a privately held, Santa Rosa, Calif.-based company. Alluxa is an industrial technology firm that provides optical filters and thin-film coatings for applications in the industrial technology, life sciences, and semiconductor markets. EnPro is financing the transaction with cash and rollover equity from Alluxa executives. The purchase price is $255 million, including rollover equity. EnPro says it has a strategy to grow by acquisition in attractive markets.

North Carolina-based EnPro employs about 6,000 people.

The latest transaction follows two agreements Total signed in February to develop nearly two gigawatts of solar projects in Spain.

TOTAL AGREES TO BUILD SOLAR PROJECTS IN SPAIN

French energy company Total SE reached an agreement with Spanish developer Ignis to build 3.3 gigawatts of solar projects in Spain. The first projects are scheduled to start in 2022, with the rest expected to be in production by 2025. The transaction will bring Total's portfolio of solar projects under development in Spain to more than five gigawatts by 2025, contributing to Spain's goal of generating 70% of its electricity from renewables by 2030 and 100% by the middle of the century.

ALTONA ENERGY ACQUIRES MAJORITY STAKE IN RARE EARTH PROJECT

Australia-based Altona Energy, a mining exploration company with a focus on rare earth element projects in Africa, signed an agreement with Leadway Group Ltd. to acquire a 70% interest in a greenfield project in Uganda, the Nankoma Rare Earth Project. Altona says it wants to build a portfolio of rare-earth sites in Eastern and Central Africa. When the agreement is final, Altona will be responsible for completing a feasibility study on establishing a commercial-scale, rare-earth mining and processing operation at the site. Altona will also be the manager and operator of the project.

The Nankoma Rare Earth Project is located in Eastern Uganda.

SIEMENS, UNIVERSITY OF NEW MEXICO COLLABORATE ON RENEWABLE ENERGY

Siemens Industry and the University of New Mexico signed an agreement to collaborate on integrating renewable energy systems and microgrids. The agreement is centered around a University-owned microgrid. The microgrid assets include facilities such as a cooling tower, thermal storage tank, battery energy storage system, fuel cell, photovoltaic system, and a natural gas generator. The university is part of a statewide consortium that received a five-year, $20 million grant in 2018 to modernize the electrical grid. Its microgrid facilitates research into power system modernization, renewable energy systems, smart grids, and smart cities.

The university's microgrid was built partly to test new smart-grid technologies.

MORE INDUSTRY NEWS

BERLIN PACKAGING ACQUIRES NETHERLANDS-BASED COMPANY

Berlin Packaging announced the acquisition of Vinkova B.V., a Netherlands-based glass packaging supplier with expertise in the food and beverage sectors. The transaction is Berlin's eighth acquisition in Europe since 2016. "Continued expansion in Europe is a central tenant of Berlin Packaging's overall growth strategy," says Bill Hayes, CEO and president of the Chicago-based company. The company says all Vinkova employees and locations would be retained. Financial details were not disclosed.

Berlin Packaging maintains more than 130 sales and warehouse locations, and design and innovation centers on two continents.

SANDVIK JOINS GE ADDITIVE BETA PROGRAM

GE Additive announced that Sandvik Additive Manufacturing joined its Binder Jet beta partner program. Sandvik has a broad alloy program for additive manufacturing on the market, marketed under the Osprey brand. The GE program uses its industrialized additive technology with technical partners to grow its Binder Jet technology. GE says the first phase involves developing the beta system into pilot lines, and eventually into a commercially available factory solution in 2021.

Sandvik is a Stockholm, Sweden-based company with about 40,000 employees.

GUARDIAN GLASS COMPLETES STARTUP OF PLANT IN POLAND

Guardian Glass completed starting up its second float glass facility in Częstochowa, Poland, to help meet the demand for high-performance coated and fabricated glass products in Eastern Europe. The plant hosts two float lines, two coater lines, and a lamination line. Headquartered in Auburn Hills, Mich., Guardian Glass has six float glass plants in the United States and one in Mexico, as well as many fabrication facilities and warehouses. Guardian Glass companies also operate ten float glass plants across Europe and Russia.

The Częstochowa plant represents Guardian's biggest greenfield capital investment in its history, the company says.

The Made In Space ceramics manufacturing module team.

CERAMIC MANUFACTURING MODULE HEADED TO SPACE STATION

Made In Space plans to launch a ceramic manufacturing module to the International Space Station. The technology is a commercial, in-space manufacturing device designed to provide proof-of-potential for single-piece, ceramic turbine blisk (blade and disk) manufacturing in microgravity for terrestrial use. This project marks the first ceramic facility on the ISS. Made in Space says the module will demonstrate the viability of manufacturing with preceramic resins in an additive, stereolithography environment. Made In Space is developing the technology with technical partners HRL Laboratories of Malibu, Calif., and Sierra Turbines of San Jose, Calif.

SETTING THE STANDARDS: HOW STANDARDS ENHANCE QUALITY AND PROMOTE RELIABILITY

By David Holthaus

Standards in manufacturing are essential to ensuring quality products and to improving the accuracy and reliability of the materials used to make them.

They are also critical to promoting the safety of those who use the products, and sometimes it can literally be a matter of life and death.

In 2018, after two years of work, a committee of ASTM International, one of the world's largest standards-developing organizations, published requirements for bullet-resistant doors on police vehicles.

The standard called for door panels to be made from a combination of ceramic and fabric, with the ceramic material acting as the strike face to break bullets that were made with steel cores. Such ammunition was increasingly being used in the high-powered weaponry that police were encountering on the streets, according to ASTM. Panels made with basic, armored steel often would not stop bullets with steel cores.

The new specification standardized protection levels and included language to help public safety agencies retrofit their vehicles or buy new ones with the safer ceramic-fabric panels.

It was a dramatic example of how standards evolve to keep up with new technology, materials, and processes.

Perhaps not as dramatic, but equally important in terms of safety and reliability, is the development and evolution of standards used to make refractories, the materials used to build structures routinely subjected to high temperatures.

The ASTM International Committee C08 on Refractories was founded in 1914. Over its history, the committee has defined what a refractory is, clas-

ASTM International's headquarters in West Conshohocken, Pa.
Credit: ASTM International

sified them by type and function, and defined tests to determine their suitability for specific applications.

In the early decades of the committee's existence, refractories were used to build the linings of fireplaces, kilns, and stills, among other applications. By the end of the 20th century, refractories were used to line nuclear reactors and in the manufacturing of reentry heat shields for space shuttles.

The new uses demanded standardized tests to benchmark performance and to help evaluate and develop new materials.

Bill Headrick has been involved with creating and refining ASTM standards for more than 30 years, and he is currently working with Committee C08 as the chair of the technical subcommittee on monolithics.

Standards for the production of refractories have evolved since 1914. *Credit: RHI Magnesita*

Headrick is head of research and development for aluminosilicate products for the Americas at RHI Magnesita, the world's largest refractories company.

There are more than 100 standards relating to refractories alone, and the manual on refractory standards is nearly an inch thick, Headrick says. Committee members are engaged in a continuous process of evaluating and reviewing the standards to make sure they are up to date. In August alone, Headrick says the committee reevaluated six standards.

"The biggest thing is making sure we're using the best available methods," he adds.

For example, for years, the only method for determining the chemistry of materials was wet chemistry, and the relevant standards only addressed those methods. "Now, we have X-ray fluorescence, X-ray diffraction, mass spectroscopy, and we've had to rewrite our standards to take into account these better methods that give better results," he says.

The committee is currently doing a lot of work to make standards safer, Headrick says, and to have them align with the health and safety requirements of employers.

Bill Headrick
RHI Magnesita

Some of the standards for measuring chemistry use materials that are considered hazardous to health, leading the committee to look for alternative materials that are safer and can produce similar results.

"That's the biggest evolution going on," he says. "We're going through all the standards and making sure they're as safe as possible."

It is a deliberative process.

Every five years, ASTM standards must be reviewed and reapproved by the appropriate subcommittee and then by the main committee. Any negative comment about the proposed standard must be resolved before the standard can be approved.

"To pass a standard, you have to eliminate every single negative," Headrick says. "Once everyone is in full, 100 percent agreement, then the standard is published. That can take a matter of months to a number of years."

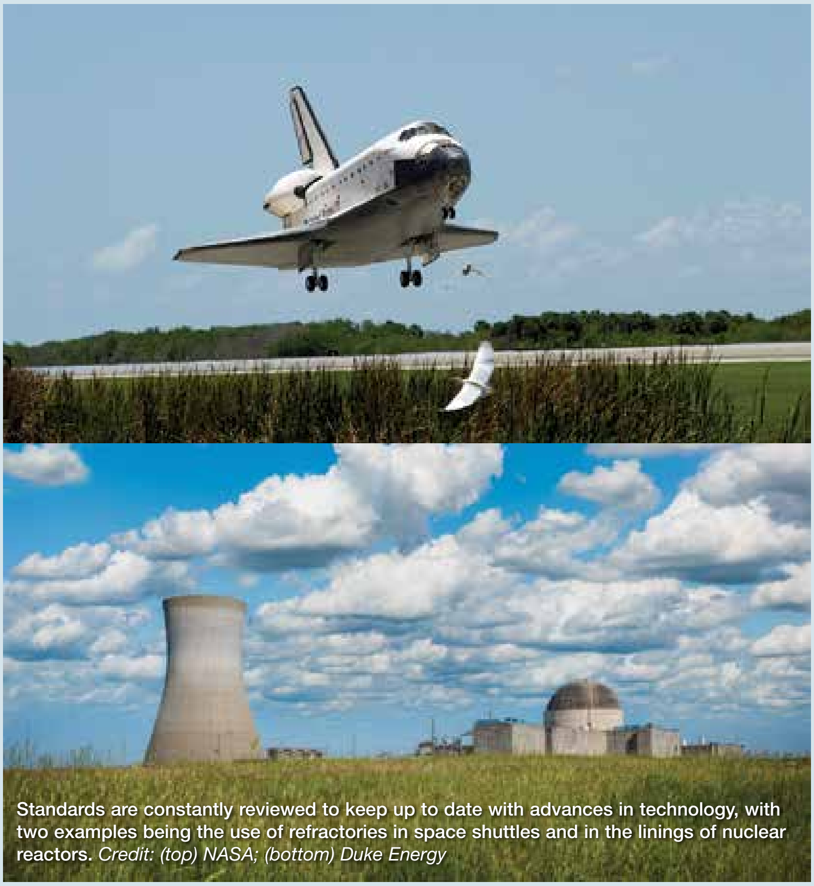
For several years now, ASTM committees and subcommittees have worked on the standardization of the growing and developing field of additive manufacturing, the process of fabricating parts and components layer by layer using computer-aided design rather than traditional manufacturing methods.

Improved technology, advanced equipment and sensors, and more suitable materials are driving the productivity and reliability of additive manufacturing production, yet the rapid change has pointed up the need for standardization, says Mohsen Seifi.

Seifi is ASTM's director of global additive manufacturing programs, responsible for additive manufacturing programs that support standards development and other products and services at the organization. He also oversees its Additive Manufacturing Center of Excellence, which has the mission to bridge the gap between standardization to research and development.

By 2008, the nascent additive manufacturing industry had reached the point where standards were needed.

"Without standards, it's going to be the Wild West," Seifi says. "Industry needs standards for rapid implementation of this technology for critical applications."



Standards are constantly reviewed to keep up to date with advances in technology, with two examples being the use of refractories in space shuttles and in the linings of nuclear reactors. *Credit: (top) NASA; (bottom) Duke Energy*

Additive manufacturing's shortened development cycle and more efficient process means products can be designed and produced more quickly, but standardization is necessary to create consistency and reliability, and to serve as a foundation for continued growth.

"Innovation is inevitable, but without having standards in place, you can't really drive this technology forward in terms of full implementation and adoption to satisfy regulation," Seifi says.

"The reason is very clear," he adds. "You need to make sure we're all communicating the same language and making products in a repeatable and reliable fashion."

Mohsen Seifi,
ASTM International

ASTM's committee on additive manufacturing technologies has met since 2009 and now has more than a thousand members from more than 35 countries who have developed standards that support the application and adoption of additive manufacturing for diverse materials and processes across various industry sectors.

In 2011, ASTM International and the International Organization for Standardization (ISO) signed an agreement paving the way to create joint additive manufacturing standards in order to increase collaboration and minimize duplication of efforts.

"If you are a user of this technology interested in fabricating parts and components, are you going to receive the same results if you produce a part at a service provider in the U.S. versus Europe versus Asia?" Seifi says. "That's where standards play a critical role to make sure we manufacture products in a consistent, reliable, and repeatable manner."

Another key reason for standards is to facilitate certification of additively manufactured parts from regulatory bodies such as the Federal Aviation Administration, NASA, Department of Defense, Food and Drug Administration, and many others.

"Once a standard is out, it has the potential to become part of regulatory frameworks and can get into federal codes and referred to in federal contracts," Seifi says.

One of the key trends on additive manufacturing standardization is understanding the challenges the technology brings in regard to data management and schema, Seifi says. The 3D printers and their sensors can generate gigabytes, sometimes terabytes, of data. "The question is, what data to collect according to what standard and format and why?" he says. "Is that data you collect findable, accessible, and reusable? Does it make sense to capture that data, and using what standard method? What kind of intelligence can we generate from the data to improve the process?"

"There are major standard gaps in this space that ASTM is trying to fill," he adds.

In the cases of newer technologies such as additive manufacturing, and older processes such as refractory production, standards have helped advance processes, improve quality, and enable those production methods to be used reliably in a growing range of industries and applications.

A short list of standards-developing organizations

There are many organizations in the U.S. and around the world that work to develop standards for their industries. Here are some that apply to manufacturing:

- **The Association for Manufacturing Technology**
  Based in McLean, Va., the association promotes the interests of American manufacturing machinery and equipment, including the standardization of technology used to run machines. www.amtonline.org

- **The American Nuclear Society**
  Based in LaGrange Park, Ill., the Society advances the development of nuclear science, engineering, and technology, and maintains a standards committee and board. www.ans.org

- **The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)**
  Based in Atlanta, Ga., the Society focuses on building systems, energy efficiency, indoor air quality, refrigeration, and sustainability through research, standards writing, publishing, and continuing education. www.ashrae.org

- **American Society of Mechanical Engineers**
  Based in New York City, N.Y., the Society enables collaboration and skills development across engineering disciplines through programs in continuing education, training and professional development, codes and standards, research, and conferences and publications. www.asme.org

- **ASTM International**
  Formerly known as American Society for Testing and Materials, ASTM International is an international standards organization that develops and publishes consensus technical standards for a range of materials, products, systems, and services. It is headquartered in West Conshohocken, Pa., outside of Philadelphia. www.astm.org

- **International Code Council**
  Based in Washington, D.C., the Council is an association of building safety professionals and a source of model codes and standards that establish baselines for building safety. www.iccsage.org

- **The International Organization for Standardization (ISO)**
  Headquartered in Geneva, Switzerland, ISO is an international standard-setting body composed of representatives from various national standards organizations. It promotes worldwide proprietary, industrial, and commercial standards. www.iso.org

- **The International Committee for Information Technology Standards (INCITS)**
  Based in Washington, D.C., this committee is a standards development organization composed of information technology developers. www.incits.org

- **The International Society of Automation**
  Based in Research Triangle Park, N.C., the Society is a technical society for engineers, technicians, businesspeople, educators, and students, and it sets standards for industry professionals in automation. www.isa.org

- **National Institute of Standards and Technology (NIST)**
  Headquartered in Gaithersburg, Md., NIST is a nonregulatory federal agency within the U.S. Department of Commerce that develops and disseminates standards that allow technology to work seamlessly and business to operate smoothly. www.nist.gov

- **NSF International**
  Based in Ann Arbor, Mich., NSF International has developed more than 80 public health and safety standards, and tests and certifies products to verify they meet those standards. www.nsf.org

- **SAE International**
  Previously known as the Society of Automotive Engineers, Warrendale, Pa.-based SAE International is a standards-developing organization for engineering professionals in various industries. Its principal emphasis is on global transport industries, such as aerospace, automotive, and commercial vehicles. www.sae.org

- **UL**
  Formerly known as Underwriters Laboratories, UL is a global safety certification company headquartered in Northbrook, Ill. It is approved to perform product safety testing by the U.S Occupational Safety and Health Administration. www.ul.com

JAPAN FINE CERAMICS ASSOCIATION AND ITS INTERNATIONAL STANDARDIZATION ACTIVITIES FOR FINE CERAMICS

By Hirofumi Takemura

Japan Fine Ceramics Association (JFCA) was established in 1986 with a mission to promote the development of the fine ceramics/advanced ceramics industry. To take advantage of the most advanced technologies of fine ceramics, overall collaboration of manufacturers, users, universities, and research laboratories is required, together with the fusion of other materials.

The members of JFCA are 104 companies from different industries, such as ceramics, chemicals, metals, automobiles, electronics, power supply, and service. Through various activities, JFCA brings together and promotes cooperation among government, industry, academia, and overseas countries for the further expansion of the fine ceramics industry. The United States Advanced Ceramics Association (USACA), European Ceramics Center (PEC), and Ceramics Application are cooperating members of JFCA.

There are technical committees and consortiums in JFCA. Committees operate research groups such as Solid Oxide Fuel Cells, Power Electronics, GaN, LED, Bioceramics, Optical Ceramics, Material Function Predictive Simulation, Advanced Coating Alliance, and Ceramics Matrix Composites Consortium. In September, Fine Ceramics Roadmap 2050 Study Group was launched, which will publish the latest Roadmap in both Japanese and English versions in December 2021.

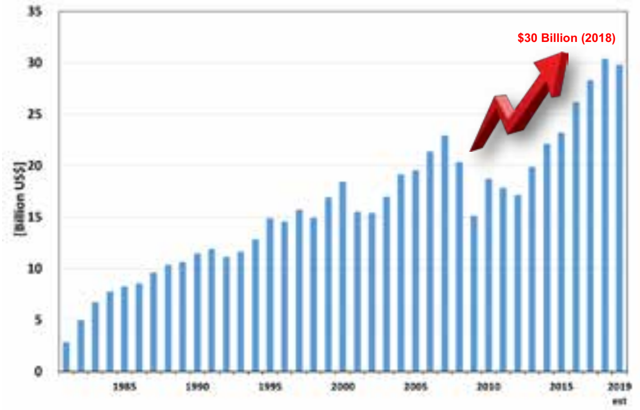


Figure 1. Fine ceramics production in Japan.
Credit: Japan Fine Ceramics Association

Figure 1 shows the amount of fine ceramics production in Japan, which reached $30 billion in 2018.[1]

The benefits of standards for worldwide industries are extensive.[2] Standards help manufacturers reduce costs, anticipate technical requirements, and increase productive and innovative efficiency. Standards make trade across international borders easier and promote global competition, having a positive impact on economies.

Standards provide consumers with confidence in the quality and safety of products and services. In a global economy of rapidly emerging new technologies and markets, standards help set the rules and establish the frameworks, making it easier to innovate successfully.

ISO international standards help businesses of any size and sector reduce costs, increase productivity, and access new markets. Standards can help to

- Build customer confidence that the products are safe and reliable;
- Meet regulation requirements, at a lower cost;
- Reduce costs across all aspects of a business;
- Gain market access across the world;
- Improve quality, safety, and lead time of products and services;
- Lower research and development costs and improve speed to market by building on previously standardized technology or systems; and
- Provide uniformity of units measurement, enabling accuracy and confidence in commercial transactions locally and globally.

THE ROLE OF JFCA

JFCA conducts surveys and research to promote the international standardization of fine ceramics. JFCA, as a drafting organization in the field of fine ceramics, is making international standards for high-quality, safe, secure, and highly reliable fine ceramic materials.

JFCA holds the secretariat of ISO/TC206 (Fine Ceramics) and ISO/TC150/SC7 (Tissue-engineered Medical Products) under the Japanese Industrial Standards Committee. In addition, as a national committee for ISO/TC206 and ISO/TC150 (Implants for Surgery) in Japan, we are engaged in deliberating proposals for new work items, development of projects in Japan and other countries, and maintenance and management of issued ISO standards.

Figure 2. Conventional standardization model. *Credit: Japan Fine Ceramics Association*

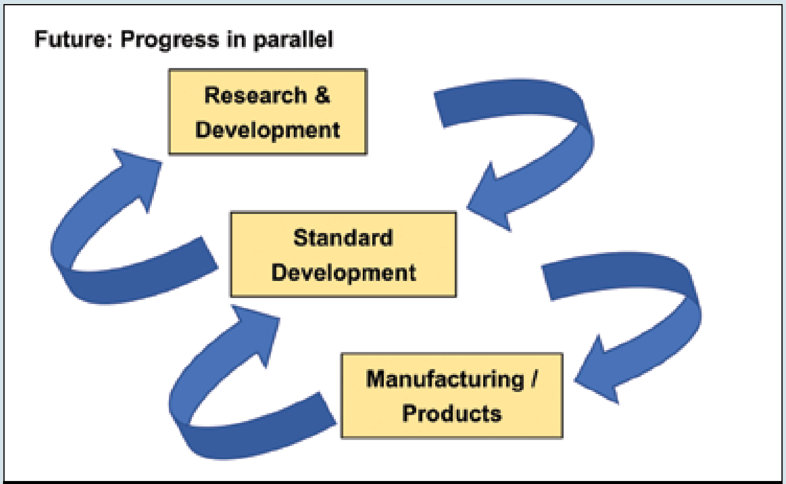


Figure 3. Future standardization model. *Credit: Japan Fine Ceramics Association*

ACCELERATION OF STANDARDIZATION SPEED

The speed of technological development increases to popularize new technologies globally. The conventional model shown in Figure 2, "Research & Development-Standard Development-Manufacturing / Products," cannot catch up with its speed.

It is necessary to proceed with R&D and standard development at the same time and connect it to global manufacturing.

As shown in Figure 3, loop-shaped parallel development becomes the most effective way to establish standardization.[3]

ABOUT INTERNATIONAL STANDARDS ORGANIZATION

International standards are published by international standardization bodies; three organizations are the representative. International Organization for Standardization (ISO) establishes international standards in a wide range of fields, except the fields of electricity, electronics, and communications. International Electrotechnical Commission (IEC) establishes international standards in the fields of electricity and electronics, and International Telecommunication Union (ITU) establishes international standards in the fields of communication, broadcasting, and information technology.

ISO is currently divided into 333 technical committees that deliberate and manage international standardization. The international standards for fine ceramic materials mainly belong to two committees: ISO/TC206 (Fine Ceramics) and ISO/TC150 (Implants for Surgery).

ISO/TC206 standardizes various forms and functions of fine ceramics. Japan is the secretariat of this committee and has a committee manager. The chair is from South Korea. The ISO/TC206 scope states as follows[4]: Standardization in the field of fine ceramics materials and products in all forms: powders, monoliths, coatings and composites, intended for specific functional applications including mechanical, thermal, chemical, electrical, magnetic, optical, and combinations thereof. The term "fine ceramics" is defined as "a highly engineered, high performance, predominantly non-metallic, inorganic material having specific functional attributes."

Note: Alternative terms for fine ceramics are advanced ceramics, engineered ceramics, technical ceramics, or high-performance ceramics.

The ISO/TC206 strategic business plan has the following description[4]:

World demand for fine ceramics is projected to expand to $75 billion in the year 2020.

In order for the fine ceramics industry to further grow to contribute to the 21st century as a new materials industry, the following issues have to be overcome.

- Further promotion of research and development in terms of the material itself, development of new uses and application technologies.
- Research on manufacturing processes, and cost-reduction through corporate efforts.
- Establishment of testing and evaluation methods and standardization of the methods to prepare a basis for research and development, application, and utilization.
- Promoting international cooperation in the fields of research and development, and standardization.

Table 1 shows the composition of ISO/TC206, the number of ISO registrations, and the number under development. ISO/TC206 is divided into more specialized working groups (WGs) from WG1 to WG12. Since the committee's inception in 1992, 136 standards have been issued. In recent years, about 10 new standards were published each year. In addition, there are 18 items under development.

WG	Title	Published Standards	Standards under development
WG1	Terminology/Classification	2	1
WG2	Powders	16	0
WG3	Chemical analysis	4	3
WG4	Composites	22	2
WG5	Porous ceramics	4	0
WG6	Monolithic ceramics/Mechanical properties	20	0
WG7	Monolithic ceramics/Physical and thermal properties	10	1
WG8	Joining	4	0
WG9	Photocatalysis	28	3
WG10	Coatings	16	2
WG11	Electrical and optical applications	6	3
WG12	Engineering applications	4	3
ISO/TC206		136	18

Table 1. ISO / TC206 structure, number of published standards and standards under development

SC/WG	Title	Published Standards	Standards under development
SC1	Materials	37	7
SC2	Cardiovascular implants and extracorporeal systems	33	11
SC4	Bone and joint replacements	36	5
SC5	Osteosynthesis and spinal devices	26	9
SC6	Active implants	16	2
SC7	Tissue-engineered medical products	4	0
WG1-15		14	5
ISO/TC150		166	39

Table 2. ISO/TC150 structure, number of published standards and standards under development

New work-item proposals are deliberated by experts in the relevant working groups depending on the technical field. After approval of new business-item proposals, deliberation and approval proceed by passing through the stages of working draft, committee draft, draft international standard, and final draft international standard, to the goal of being published. It takes about three years to complete the process.

ISO/TC206 is currently composed of Participating Members from 14 countries (nine countries in Europe; five countries in Asia) and Observer Members from 20 countries. Participating Members have the right to vote and can elect experts to actively participate in the proposed project.

ISO/TC206 holds a plenary meeting once a year where member countries can participate. This year, it was scheduled to be held in Brussels, Belgium, but due to the COVID-19 pandemic, the face-to-face conference was canceled, and a web conference was held by Japan. The plenary meeting is a valuable opportunity for experts on global standardization to gather once a year, but it was a shame it was canceled. It is scheduled to be held in France in 2021 and in Belgium in 2022. Japan took the role as host country in the first, tenth, and twentieth plenary meetings. 2023 will be the thirtieth meeting, and we would like to hold the meeting in Kyoto, Japan.

ISO/TC150 is a committee related to surgical implants. It includes bioceramics such as artificial bones and dental implants, which overlap with the field of fine ceramics. Germany is the chair of TC150, and Japan holds the secretariat of TC150/SC7.

The ISO/TC150 scope states as follows[5]:

Standardization in the field of implants for surgery and their required instrumentation, covering terminology, specifications, and methods of tests for all types of implants, and for the materials both basic and composite used in their manufacture and application.

The ISO/TC150 configuration is divided into specialized fields: subcommittee (SC) from SC1 to SC7, and working groups from WG1 to WG15. Since its inception in 1971, the technical committee has issued 166 standards, and 39 standards are under development.

ISO/TC150 currently consists of Participating Members from 29 countries, and Observer Members from 17 countries.

RECENT INTERNATIONAL STANDARDIZATION ACTIVITIES

New work-item proposals were made from Japan to ISO/TC206 in 2020. Two proposals were made regarding the thermal characteristics evaluation method for ceramic substrates for power modules, and one proposal was made regarding the evaluation method for power generation characteristics of piezoelectric materials. One new work-item proposal was approved for a ceramic substrate for a power module, and it is currently at working draft stage.

The market size of power modules was 420 billion yen in 2019, and it is projected to be 570 billion yen in 2025 (140% of 2019). The core technology for ensuring the long-term reliability of power modules is the high-temperature resistance of power semiconductors. More specifically, it is heat that controls the change over time, and the ambient temperature and heat generated by driving the element contribute as heat sources.

We have strategically promoted the world's first international standardization of the method for measuring the thermal properties of ceramic substrates for power electronics, which is a key element of next-generation power semiconductors.

In addition, JFCA is promoting a research project to develop international standardization of fine ceramics as a preliminary step to propose new work-item proposals to ISO. We are working on about six projects a year. Each project takes three years to research, prepare a standardization draft, and make a new proposal to ISO.

The following projects are underway as ongoing research and research projects.

- Test method for GaN crystal surface defects.
- Strength reliability test method for ceramic materials for solid oxide fuel cells (SOFC).
- Corrosion-resistant test method for fine ceramic thin films.
- Optical characteristic evaluation method for ceramic phosphors for white LEDs.
- Test method for thermal characteristics of insulating substrates for power electronics.
- Mechanical property test method for bioceramics.

All of these projects cover advanced technological fields where the market for fine ceramic materials is expected to expand, and they are developments for standardization related to property test methods for fine ceramic materials. We are aiming for international standardization to ensure high-quality, safe, secure, and highly reliable fine ceramic materials.

To secure the competitiveness of the fine ceramics industry and to develop the industry, it is necessary to differentiate products by improving functionality, strengthen price competitiveness by innovation in manufacturing processes, enhance product revolution by innovation of materials, develop new markets, and lead with speed. We hope that the international standardization promoted by JFCA will contribute to the further expansion of the fine ceramics industry.

OTHER JFCA ACTIVITIES

CMC International Cooperation: CMC International Cooperation was established in 2020 for developing reliability assurance technology for ceramic matrix composites. This consortium consists of the CMC center at Tokyo University of Technology, Ultra High Temperature Materials Research Center, and JFCA.

CMC International initiated development of the international standard inspection method that can overcome the problems of the conventional test method for ceramic matrix composite reliability. The method of guaranteeing reliability for use by taking advantage of the "damage tolerance" is not established yet. The first step is to prepare SiC/SiC test pieces that are damaged and defective inside. Then, we will conduct an evaluation test (round robin test) using common test pieces by overseas joint research partners of the University of Birmingham and the University of California, Los Angeles.

Giant Micro-photonics Research: The Giant Micro-photonics Project was established in 2020 by RIKEN Spring-8 Center (RSC), National Institute for Materials Science (NIMS), Mitsubishi Electric Co., Kounoshima Chemical, and JFCA to achieve dramatic sophistication of extremely high-power, solid-state lasers and terahertz generation by new transparent ceramic materials, or so called giant micro-photonics. Based on these research results, the project is expected to prototype and develop a compact ultrahigh output, power density laser and develop wavelength conversion technology, which was difficult until now. It is also designed to convert to other important wavelengths and apply laser driven particle accelerators.

Japan Ceramics Expo: JFCA is the coorganizer of Japan Ceramics Expo, which is one of the world's largest exhibitions alongside Ceramitec in Munich and Ceramics Expo in Cleveland, Ohio. Japan Ceramics Expo is organized by the Reed Exhibitions Japan and gathers all kinds of highly functional ceramics, materials, forming/processing equipment, burning/heating equipment, evaluation/testing/analysis equipment. It is held every year in Osaka and Tokyo.

Japan Ceramics Expo is chosen by advanced materials industry players worldwide as the best gateway to the Japanese and Asian markets. For more information, please go to

https://www.ceramics-japan.jp/en-gb.html.

Osaka Expo
Dates: Wednesday, June 23 to Friday, June 25, 2021
Venue: INTEX Osaka, Japan

Tokyo Expo
Dates: Wednesday, December 8 to Friday, December 10, 2021
Venue: Makuhari Messe, Japan

ABOUT THE AUTHOR

Hirofumi Takemura is director of Japan Fine Ceramics Association.

REFERENCES

[1]JFCA Fine Ceramics Industrial Trend Survey (2019)

[2]ISO-Benefits of standards (https://www.iso.org/benefits-of-standards.html)

[3]METI Standardization Seminar (2020)

[4]ISO/TC206-Fine ceramics (https://www.iso.org/committee/54756.html)

[5]ISO/TC150-Implants for surgery (https://www.iso.org/committee/53058.html)

Japan Ceramics Expo in 2018. *Credit: Japan Fine Ceramics Association*

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December 2019	Globalization: Doing business in China, Vietnam, and India
April 2020	Breaking in: A small company guide to working with big companies
June/July 2020	Smart manufacturing: Good business practices for manufacturers
September 2020	Workforce development
December 2020	Standards: Guideposts to quality

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Calendar of events

November–December 2020

29–Dec 3 2020 MRS Fall Meeting & Exhibit – VIRTUAL EVENT ONLY; www.mrs.org/fall2020

January 2021

19–22 Electronic Materials and Applications (EMA2021) – VIRTUAL EVENT ONLY; www.ceramics.org/ema2021

February 2021

8–12 45th International Conference and Expo on Advanced Ceramics and Composites (ICACC2021) – VIRTUAL EVENT ONLY; www.ceramics.org/icacc2021

March 2021

15–17 China Refractory Minerals Forum 2021 – InterContinental Dalian, Liaoning, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2020

24–25 56th Annual St. Louis Section/Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo. www.ceramics.org

24–29 ➡ 2nd Global Forum on Smart Additive Manufacturing, Design and Evaluation (SmartMADE) – Osaka University, Nakanoshima Center, Japan; http://www.jwri.osaka-u.ac.jp/~conf/Smart-MADE2021

27–31 ➡ The Int'l Conference on Sintering 2022 – Nagaragwa Convention Center, Gifu, Japan; https://www.sintering2021.org

April 2021

25–30 ➡ International Congress on Ceramics (ICC8) – Bexco, Busan, Korea; www.iccs.org

May 2021

1–4 6th Ceramics Expo – Cleveland, Ohio; https://ceramics.org/event/6th-ceramics-expo

3–7 6th International Conference on Competitive Materials and Technology Processes (ic-cmtp6) – Hunguest Hotel Palota, Miskolc-Lillafüred, Hungary; www.ic-cmtp6.eu

16–19 ➡ Ultra-high Temperature Ceramics: Materials for Extreme Environment Applications V – The Lodge at Snowbird, Snowbird, Utah; http://bit.ly/5thUHTC

17–20 China Ceramitec 2021 – Messe München, Germany; https://www.ceramitec.com/en

23–28 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) – Hyatt Regency Vancouver, Vancouver, British Columbia, Canada; www.ceramics.org/PACRIM14

June 2021

7–9 ACerS 2021 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Austin Hotel Downtown, Austin, Texas; www.ceramics.org

28–30 MagForum 2021: Magnesium Minerals and Markets Conference – Grand Hotel Huis ter Duin, Noordwijk, Amsterdam; http://imformed.com/get-imformed/forums/magforum-2020

July 2021

18–23 Materials Challenges in Alternative & Renewable Energy 2020 (MCARE 2020) combined with the 4th Annual Energy Harvesting Society Meeting (EHS 2020) – RESCHEDULED-Hyatt Regency Bellevue Bellevue, Wash.; www.ceramics.org

September 2021

14–17 20th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; www.ceramics.org

October 2021

NEW DATE

12-15 ➡ International Research Conference on Structure and thermodynamics of Oxides/carbides/nitrides/borides at High Temperature (STOHT) – Arizona State University, Ariz.; https://mccormacklab.engineering.ucdavis.edu/events/structure-and-thermodynamics-oxidescarbidesnitridesborides-high-temperatures-stoht2020

17–21 ACerS 123rd Annual Meeting with Materials Science & Technology 2021 – Greater Columbus Convention Center, Columbus, Ohio; www.ceramics.org

January 2022

18–21 Electronic Materials and Applications 2022 (EMA 2022) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla; www.ceramics.org

23–28 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; www.ceramics.org

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

Entries in **BLUE** denote ACerS events.

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

[video camera icon] denotes virtual meeting

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Ownership, Management and Circulation Statement per 39 U.S. Code 3685 for *American Ceramic Society Bulletin* as filed Sept. 29, 2020, with the U.S. Postal Service.

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	Avg. each issue during previous 12 months	Actual no. of single issue nearest filing date
A. Total number of copies (net press run)	7,523	8,078
B. Paid and/or requested circulation		
1. Paid/requested outside-county mail subscriptions	2,972	2,850
2. Paid in-county subscriptions	none	none
3. Sales through dealers and carriers, street vendors, counter sales and other non-USPS paid distribution	1,674	1,478
4. Other classes mailed through the USPS	none	none
C. Total paid and/or requested circulation	4,646	4,328
D. Free distribution by mail (samples, complimentary and other free)		
1. Outside-county	2,337	3,390
2. In-county	none	none
3. Other classes mailed through the USPS	none	none
4. Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	227	152
E. Total Free or Nominal Rate Distribution	2,564	3,542
F. Total distribution	7,210	7,870
G. Copies not distributed	255	194
H. **Total**	7,465	8,064
I. Percent paid and/or requested circulation	64.44%	54.99%

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FELDCO Intl CA
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Cutting Tools

Advanced Ceramics Manufacturing AZ
Advanced Materials Associates China
Astro Met Advanced Ceramics Inc OH
Cerakote Ceramic Coatings OR
CeramTec North America Corp SC
China Unipretec Ceramic Technology Co Ltd China
CoorsTek CO
Ferro-Ceramic Grinding Inc MA
New Tech Ceramics Inc IA
NGK Spark Plug Co Ltd Japan
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA **See ad on pg 69**
RocCera LLC NY
Thermocarbon FL
Zibo Guangtong Chemical Co Ltd China

Cylinders

Advanced Ceramics Manufacturing AZ
Cerakote Ceramic Coatings OR
CoorsTek CO
Ferrotec Ceramic Products China
Morgan Technical Ceramics Auburn CA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Dies

Astro Met Advanced Ceramics Inc OH
North Star Equipment Inc WA
Petro Mold Company PA
Ram Products Inc OH
Refractron Technologies Corp NY
China Unipretec Ceramic Technology Co Ltd China
Zircoa Inc OH

Engine Components

Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Cerakote Ceramic Coatings OR
CeramTec North America Corp SC
China Unipretec Ceramic Technology Co Ltd China
Elcon Precision LLC CA **See ad on pg 107**
Federal-Mogul MI
Ferrotec Ceramic Products China
GE Global Research NY
H.C. Starck GmbH Germany
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Toyota Central R&D Labs Inc Japan

Filters

Akron Porcelain & Plastics Co OH
Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Induceramic Canada
Maryland Ceramic & Steatite Co Inc MD
Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY
Robocasting Enterprises LLC NM
Starfire Systems Inc NY
Valley Design Corp MA
Zhengzhou Mission Ceramic Products Co Ltd China

Glass-Ceramics

Accuratus Corp NJ
Aremco Products Inc NY
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
Cerlase France
China Unipretec Ceramic Technology Co Ltd China
CoorsTek CO
Elan Technology GA
Ferro-Ceramic Grinding Inc MA
Israel Ceramic & Silicate Inst Israel
Morgan Advanced Materials CA
Ortech Inc CA
Petro Mold Company PA
P-Ker Engineering NY
Polymer Innovations Inc CA
Precision Ceramics FL
PremaTech Advanced Ceramics MA
RISE Research Institutes of Sweden, RISE Glass Sweden
Schott North America Inc NY **See ad on pg 41**
Starfire Systems Inc NY
Technical Products Inc WI
TevTech LLC MA **See ad on pg 83**
Valley Design Corp MA
Zibo Guangtong Chemical Co Ltd China

Heat Exchangers

Arkema Inc PA
Blasch Precision Ceramics Inc NY
Dowa High Temp Furnaces India
Elcon Precision LLC CA **See ad on pg 107**
FCT Ingenieurkeramik GmbH Germany
Ferrotec Ceramic Products China
Induceramic Canada
Precision Ceramics FL
Refrac Systems AZ
Saint-Gobain High Performance Ceramics & Refractories MA

Honeycombs

Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Induceramic Canada
Rauschert Industries Inc GA **See ad on pg 69**
Robocasting Enterprises LLC NM
Zhengzhou Mission Ceramic Products Co Ltd China

Industrial Parts

Accuratus Corp NJ
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Astral Material Industrial Co Ltd China
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CerCo LLC OH
China Unipretec Ceramic Technology Co Ltd China
Dowa High Temp Furnaces India
Du-Co Ceramics Company PA
Elcon Precision LLC CA **See ad on pg 107**
EZG Manufacturing Inc OH **Inside front cover**
FCT Ingenieurkeramik GmbH Germany
Ferrotec Ceramic Products China
GE Global Research NY
H.C. Starck GmbH Germany
Induceramic Canada
Industrial Ceramic Products Inc OH
Jyoti Ceramic Industries Pvt Ltd India
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Morgan Advanced Materials CA
Morgan Technical Ceramics Auburn CA
NGK Spark Plug Co Ltd Japan
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA **See ad on pg 69**
Silicon Carbide Products Inc NY
Sonya Ceramics (Export Division) India
Zhengzhou Mission Ceramic Products Co Ltd China

Injection-Molded Ceramics

AdTech Ceramics TN
Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CerCo LLC OH
CerPoTech AS Norway
China Unipretec Ceramic Technology Co Ltd China
Diamorph AB UK
Ferro-Ceramic Grinding Inc MA
Indo US MIM Tec India
Ortech Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Starfire Systems Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Superior Technical Ceramics Corp VT **See ad on pg 63**

Lasers, Ceramic

Accuratus Corp NJ
Ceranova Corp MA
Cerinnov France
Cerlase France
CerPoTech AS Norway

II-VI Aerospace & Defense **See ad on pg 67**
Israel Ceramic & Silicate Inst Israel
Morgan Technical Ceramics Auburn CA
nGimat LLC KY
Precision Ceramics FL
Technology Assessment and Transfer Inc (TA&T) MD

Magnesium & Compounds

Elcon Precision LLC CA **See ad on pg 107**

Membranes, Ceramic

Bharat Heavy Electricals Ltd NY
Cerlase France
CerPoTech AS Norway
Induceramic Canada
norECs AS Norway

Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY

Nitride Products

Accuratus Corp NJ
AdTech Ceramics TN
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Beijing Cerametek Materials Co Ltd China
Blasch Precision Ceramics Inc NY
FCT Ingenieurkeramik GmbH Germany
H.C. Starck GmbH Germany
Induceramic Canada
Momentive Performance Materials Inc NY
NEVZ-Ceramics, Close JSC Russia
NGK Spark Plug Co Ltd Japan
O'Keefe Ceramics Inc CO
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY

Superior Technical Ceramics Corp VT **See ad on pg 63**
Treibacher Industrie AG Austria
Zhengzhou Mission Ceramic Products Co Ltd China

Nuclear Waste Containers

Precision Ferrites and Ceramics Inc CA

Optical Ceramics

Ceranova Corp MA
Elcon Precision LLC CA **See ad on pg 107**
FELDCO Intl CA
Innovnano - Advanced Materials SA Portugal
Morgan Technical Ceramics Auburn CA
MSE Supplies AZ
nGimat LLC KY
PremaTech Advanced Ceramics MA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Surmet Corp MA
Technology Assessment and Transfer Inc (TA&T) MD
Toto Ltd Japan

Oxide Products

Accuratus Corp NJ
Arlimin Industries CO

Associated Ceramics & Technology Inc PA **See ad on pg 65**
Astro Met Advanced Ceramics Inc OH
Beijing Cerametek Materials Co Ltd China
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CerPoTech AS Norway
Du-Co Ceramics Company PA
FELDCO Intl CA
H.C. Starck GmbH Germany
Hunter Chemical LLC PA
Imerys Fused Minerals Murg GmbH Germany
Innovnano - Advanced Materials SA Portugal
Jyoti Ceramic Industries Pvt Ltd India
MSE Supplies AZ
Nanocerox UT
nGimat LLC KY
Nyacol Nano Technologies Inc MA
Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY
Robocasting Enterprises LLC NM
Superior Technical Ceramics Corp VT **See ad on pg 63**
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
ZIRCAR Ceramics Inc NY

Porous Ceramics

Associated Ceramics & Technology Inc PA **See ad on pg 65**
Bharat Heavy Electricals Ltd NY
Ceramco Inc NH
P-Ker Engineering NY
Robocasting Enterprises LLC NM
Technology Assessment and Transfer Inc (TA&T) MD
Tethon 3D NE
Zhengzhou Mission Ceramic Products Co Ltd China
ZIRCAR Ceramics Inc NY
Zircar Zirconia, Inc NY

Reinforcements, Fiber

MemPro Materials Corp CO

Reinforcements, Whiskers

ZIRCAR Ceramics Inc NY

Rings

Astro Met Advanced Ceramics Inc OH
CeramTec-ETEC Germany
CoorsTek CO
China Unipretec Ceramic Technology Co Ltd China
Dunhua Zhengxing Abrasive Co Ltd China
Elcon Precision LLC CA **See ad on pg 107**
FCT Ingenieurkeramik GmbH Germany
Ferrotec Ceramic Products China
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY

Saint-Gobain High Performance Ceramics & Refractories MA
Saint-Gobain norPro OH
Silicon Carbide Products Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT **See ad on pg 63**
Zhengzhou Mission Ceramic Products Co Ltd China

Rods

Accuratus Corp NJ
Advanced Ceramics Manufacturing AZ
Astro Met Advanced Ceramics Inc OH
CeramTec-ETEC Germany
China Unipretec Ceramic Technology Co Ltd China
CoorsTek CO
Du-Co Ceramics Company PA
Dunhua Zhengxing Abrasive Co Ltd China
Elcon Precision LLC CA **See ad on pg 107**
FCT Ingenieurkeramik GmbH Germany
Ferrotec Ceramic Products China
Industrial Ceramic Products Inc OH
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT **See ad on pg 63**
Zhengzhou Mission Ceramic Products Co Ltd China

Silicide Products

Astral Material Industrial Co Ltd China

Silicon Carbide Products

Accuratus Corp NJ
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Astral Material Industrial Co Ltd China
Blasch Precision Ceramics Inc NY
Cancarb Limited Canada
CoorsTek CO
Custom Processing Services PA
Diamorph AB UK
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferrotec Ceramic Products China
H.C. Starck GmbH Germany

II-VI Aerospace & Defense **See ad on pg 67**
Morgan Advanced Materials CA
O'Keefe Ceramics Inc CO
Ortech Inc CA
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA **See ad on pg 69**
Refratechnik Ceramics GmbH Germany
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
TevTech LLC MA **See ad on pg 83**
Zhengzhou Mission Ceramic Products Co Ltd China

Silicon Nitride Products

Accuratus Corp NJ
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Beijing Cerametek Materials Co Ltd China
CoorsTek CO
FELDCO Intl CA
Ferrotec Ceramic Products China
H.C. Starck GmbH Germany
Induceramic Canada
International Ceramic Engineering MA
Morgan Advanced Materials CA
O'Keefe Ceramics Inc CO
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Saint-Gobain High Performance Ceramics & Refractories MA
Technology Assessment and Transfer Inc (TA&T) MD
Zhengzhou Mission Ceramic Products Co Ltd China

Thread Guides

Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Astro Met Advanced Ceramics Inc OH
Ceramco Inc NH
CeramTec North America Corp SC
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Ortech Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Superior Technical Ceramics Corp VT **See ad on pg 63**
Zhengzhou Mission Ceramic Products Co Ltd China

Transparent Ceramics

Ceranova Corp MA
CoorsTek CO
Ferrotec Ceramic Products China
Israel Ceramic & Silicate Inst Israel
nGimat LLC KY
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Surmet Corp MA

Tubes

Accuratus Corp NJ
AdValue Technology LLC AZ **See ad on pg 43**
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Aremco Products Inc NY
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Astro Met Advanced Ceramics Inc OH
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
China Unipretec Ceramic Technology Co Ltd China
CoorsTek CO
Du-Co Ceramics Company PA
Dunhua Zhengxing Abrasive Co Ltd China
EBL Products Inc CT
Elcon Precision LLC CA **See ad on pg 107**
Ferrotec Ceramic Products China
Induceramic Canada
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Jyoti Ceramic Industries Pvt Ltd India
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL
Progressive Technology Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT **See ad on pg 63**
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Wear-Resistant Parts

Accuratus Corp NJ
AdValue Technology LLC AZ **See ad on pg 43**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Astral Material Industrial Co Ltd China
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CerCo LLC OH
China Unipretec Ceramic Technology Co Ltd China
CoorsTek CO
Diamorph AB UK
EBL Products Inc CT
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferrotec Ceramic Products China
H.C. Starck GmbH Germany
Ipsen Ceramics IL
Jyoti Ceramic Industries Pvt Ltd India
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Morgan Advanced Materials CA
Morgan Technical Ceramics Auburn CA
NEVZ-Ceramics, Close JSC Russia
New Tech Ceramics Inc IA
NGK Spark Plug Co Ltd Japan
O'Keefe Ceramics Inc CO
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Rauschert Industries Inc GA **See ad on pg 69**
Refrac Systems AZ
Refractron Technologies Corp NY
RocCera LLC NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Superior Technical Ceramics Corp VT **See ad on pg 63**
Technology Assessment and Transfer Inc (TA&T) MD
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Zirconia Products

Accuratus Corp NJ
AdTech Ceramics TN

AdValue Technology LLC AZ **See ad on pg 43**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Akron Porcelain & Plastics Co OH
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Astral Material Industrial Co Ltd China
Astro Met Advanced Ceramics Inc OH
Beijing Cerametek Materials Co Ltd China
Bharat Heavy Electricals Ltd NY
Ceramco Inc NH
CeramTec North America Corp SC
CeramTec-ETEC Germany
CoorsTek CO
EBL Products Inc CT
FCT Ingenieurkeramik GmbH Germany
Ferrotec Ceramic Products China
H.C. Starck GmbH Germany
Imerys Fused Minerals Murg GmbH Germany
Induceramic Canada
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Israel Ceramic & Silicate Inst Israel
Jyoti Ceramic Industries Pvt Ltd India
Lithoz GmbH NY
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Morgan Advanced Materials CA
MSE Supplies AZ
Nanoe France
NEVZ-Ceramics, Close JSC Russia
Nyacol Nano Technologies Inc MA
O'Keefe Ceramics Inc CO
Ortech Inc CA
PicoParts Ltd Israel
P-Ker Engineering NY
Precision Ferrites and Ceramics Inc CA
PremaTech Advanced Ceramics MA
Progressive Technology Inc CA

Rauschert Industries Inc GA **See ad on pg 69**
Refractron Technologies Corp NY
Robocasting Enterprises LLC NM
RocCera LLC NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain norPro OH
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Superior Technical Ceramics Corp VT **See ad on pg 63**
Wistra GmbH Germany
China Unipretec Ceramic Technology Co Ltd China
Zhengzhou Mission Ceramic Products Co Ltd China
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

ARTWARE

Ceramic Artware
Arlimin Industries CO
Art On Ceramic NY
Ceramic Arts Network OH
Milestone Decal Art LLC NY
StudioLX - Home Decor IL
Tethon 3D NE
Viridis3D LLC MA

Glass Artware
Arlimin Industries CO
RISE Research Institutes of Sweden, RISE Glass Sweden
StudioLX - Home Decor IL
Viridis3D LLC MA

Lighting
Akron Porcelain & Plastics Co OH
Viridis3D LLC MA

Ornamental Artware
Ceramic Arts Network OH
StudioLX - Home Decor IL
Viridis3D LLC MA

Pottery
ACCCO Inc/Burley Clay Products Co OH
Arlimin Industries CO
Ceramic Arts Network OH

North Star Equipment Inc WA
Peter Pugger Mfg Inc CA
Petro Mold Company PA
Ram Products Inc OH
Sheffield Pottery MA
StudioLX - Home Decor IL
Viridis3D LLC MA

■ CERAMIC & METALLIC POWDERS & MATERIALS

Abrasive Grains
Alteo NA LLC OH **See ad on pg 11**
Baikowski Malakoff Inc NC
Electro Abrasives Corp NY
FELDCO Intl CA
GMA Industries Inc MI
Imerys Refractory Minerals GA
Kyanite Mining Corp VA
Prince Minerals Inc TX
Saint-Gobain Abrasives MA
Saint-Gobain Ceramics & Plastics MA
Specialty Glass Inc FL
Washington Mills Electro Minerals Co NY

Adsorbants & Catalysts
GFS Chemicals Inc OH
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain norPro OH

Alumina, Activated
AluChem Inc OH
Applied Ceramics Inc CA
Denka Corp NY
Momentive Performance Materials Inc NY
Nanoe France
Prince Minerals Inc TX
Sauereisen Inc PA

Alumina, Calcined
Almatis Inc PA
Alteo NA LLC OH **See ad on pg 11**
AluChem Inc OH
APF Recycling Inc OH
Baikowski Malakoff Inc NC
Denka Corp NY
Electro Abrasives Corp NY
Fusion Ceramics Inc OH
Hindalco Industries Limited India
Maryland Refractories Co OH
Nabaltec AG Germany
Nanoe France

PIDC MI **See ad on pg 69**
Prince Minerals Inc TX
Refractory Minerals Co Inc PA
Sauereisen Inc PA

Alumina, Fused
Alteo NA LLC OH **See ad on pg 11**
APF Recycling Inc OH
Denka Corp NY
Electro Abrasives Corp NY
GMA Industries Inc MI
Imerys Refractory Minerals GA
Lithoz GmbH NY
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Nanoe France
Prince Minerals Inc TX
Washington Mills Electro Minerals Co NY

Alumina, Fused Brown
Alteo NA LLC OH **See ad on pg 11**
APF Recycling Inc OH
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
Electro Abrasives Corp NY
GMA Industries Inc MI
Imerys Refractory Minerals GA
Washington Mills Electro Minerals Co NY
Alteo NA LLC OH **See ad on pg 11**
APF Recycling Inc OH
Electro Abrasives Corp NY
Imerys Refractory Minerals GA
Sauereisen Inc PA
Washington Mills Electro Minerals Co NY

Alumina, High-Purity
Alteo NA LLC OH **See ad on pg 11**
AluChem Inc OH
APF Recycling Inc OH
Applied Ceramics Inc CA
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Baikowski Malakoff Inc NC
CARBO TX
CoorsTek CO
Denka Corp NY
International Ceramic Engineering MA
Ipsen Ceramics IL
Lithoz GmbH NY
Materion Advanced Materials NY
Nanoe France
PIDC MI **See ad on pg 69**
Pred Materials International Inc NY
Prince Minerals Inc TX
Rauschert Industries Inc GA **See ad on pg 69**
Sauereisen Inc PA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Valley Design Corp MA
China Unipretec Ceramic Technology Co Ltd China

Alumina, Hydrated
Almatis Inc PA
Alteo NA LLC OH **See ad on pg 11**
Denka Corp NY
Fusion Ceramics Inc OH
Hindalco Industries Limited India
Nanoe France
PIDC MI **See ad on pg 69**
Prince Minerals Inc TX
RE Carroll Inc PA

Alumina, Other Grades
Almatis Inc PA
Alteo NA LLC OH **See ad on pg 11**
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Baikowski Malakoff Inc NC
CoorsTek CO
Denka Corp NY
Hindalco Industries Limited India
Imerys Refractory Minerals GA
Nanoe France
PIDC MI **See ad on pg 69**
Prince Minerals Inc TX
Trinity Ceramic Supply Inc TX
Wesbond Corp DE

Alumina, Reactive
Almatis Inc PA
Alteo NA LLC OH **See ad on pg 11**
AluChem Inc OH
Baikowski Malakoff Inc NC
Denka Corp NY
Hindalco Industries Limited India
Nabaltec AG Germany
Nanoe France
Prince Minerals Inc TX

Alumina, Single Crystal
Denka Corp NY
Nanoe France
Prince Minerals Inc TX

Alumina, Tabular
Almatis Inc PA
Alteo NA LLC OH **See ad on pg 11**
AluChem Inc OH
APF Recycling Inc OH
Denka Corp NY
GrainBound LLC PA
Imerys Refractory Minerals GA
Nanoe France
Prince Minerals Inc TX
Sauereisen Inc PA

Alumina, Zirconia Toughened
Applied Ceramics Inc CA
Associated Ceramics & Technology Inc PA **See ad on pg 65**
CerCo LLC OH
Denka Corp NY
Innovnano - Advanced Materials SA Portugal
Nanocerox UT
Nanoe France
PicoParts Ltd Israel
PIDC MI **See ad on pg 69**
Prince Minerals Inc TX
Rauschert Industries Inc GA **See ad on pg 69**
Sauereisen Inc PA
Washington Mills Electro Minerals Co NY
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zircoa Inc OH

Aluminum & Compounds
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Denka Corp NY
Hindalco Industries Limited India
Leico Industries Inc NJ
Refractory Minerals Co Inc PA
Valley Design Corp MA
China Unipretec Ceramic Technology Co Ltd China

Aluminum Nitride
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
Bullen OH
Centerline Technologies OH
Denka Corp NY
Ferro-Ceramic Grinding Inc MA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
International Ceramic Engineering MA
Pred Materials International Inc NY
Reade Advanced Materials RI
Surmet Corp MA
Toyal America Inc IL
Valley Design Corp MA

Aluminum Silicate
Goodfellow Corp PA
Sauereisen Inc PA

Antimony & Compounds
Alfa Aesar Johnson Matthey MA
Atlantic Equipment Engineers NJ
Goodfellow Corp PA
Pred Materials International Inc NY

Arsenic Oxide
Alfa Aesar Johnson Matthey MA

Barium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
Trinity Ceramic Supply Inc TX

Barium Carbonate
BassTech Intl NJ
Fusion Ceramics Inc OH
Hexion Inc OH

Barium Titanate
AVX Corp SC
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Haiku Tech Inc FL
Hexion Inc OH
nGimat LLC KY

Bauxite, Sintered
Alteo NA LLC OH **See ad on pg 11**

Beryllium & Compounds
APF Recycling Inc OH
Centerline Technologies OH
Leico Industries Inc NJ
Materion Advanced Materials NY

Bismuth & Compounds
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
nGimat LLC KY

Boric Acid
Sauereisen Inc PA

Boron & Compounds
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Denka Corp NY
Electro Abrasives Corp NY
FELDCO Intl CA
Fusion Ceramics Inc OH
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
New Tech Ceramics Inc IA
Rio Tinto Minerals Australia

Boron Carbide
Atlantic Equipment Engineers NJ
CoorsTek CO

Custom Processing Services PA
Denka Corp NY
Dunhua Zhengxing Abrasive Co Ltd China
Electro Abrasives Corp NY
FELDCO Intl CA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Reade Advanced Materials RI
Washington Mills Electro Minerals Co NY

Boron Nitride
Atlantic Equipment Engineers NJ
Denka Corp NY
Diamorph AB UK
FELDCO Intl CA
Ferro-Ceramic Grinding Inc MA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
International Ceramic Engineering MA
Momentive Performance Materials Inc NY
Precision Ceramics FL
Reade Advanced Materials RI
Saint-Gobain Ceramics & Plastics MA
China Unipretec Ceramic Technology Co Ltd China

Cadmium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements CA **Outside back cover, 54**
FELDCO Intl CA
GFS Chemicals Inc OH
Hunter Chemical LLC PA

Calcium & Compounds
C&L Development Corp CA
CerPoTech AS Norway
Denka Corp NY
GFS Chemicals Inc OH
Prince Minerals Inc TX

Calcium Aluminates
Almatis Inc PA
CerPoTech AS Norway
Gorka Cement Poland
Mineral Research Processing France
nGimat LLC KY
Sauereisen Inc PA

Calcium Carbonate
Arkema Inc PA
Fusion Ceramics Inc OH
Prince Minerals Inc TX
RE Carroll Inc PA
Unimin Corp CT

Calcium Silicate
Fusion Ceramics Inc OH
Mineral Research Processing France
Sauereisen Inc PA

Carbon Fibers
Goodfellow Corp PA

Carbons, Carbon Black
Cancarb Limited Canada

Carbons, Diamond
Goodfellow Corp PA

Carbons, Graphite
APF Recycling Inc OH
FELDCO Intl CA
Goodfellow Corp PA
Pred Materials International Inc NY
Semco Carbon OH
Superior Graphite Co IL **See ad on pg 73**

Cements
Aremco Products Inc NY
ESL ElectroScience PA
Gwent Electronic Materials Ltd UK

Cements, Refractory
Almatis Inc PA
Aremco Products Inc NY
Diamorph AB UK
Gorka Cement Poland
Kerneos Inc VA
Mineral Research Processing France
Sauereisen Inc PA
Unifrax I LLC NY

Cerium & Compounds
American Elements Inc CA **Outside back cover, 54**
Arlimin Industries CO
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
nGimat LLC KY
PIDC MI **See ad on pg 69**
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Treibacher Industrie AG Austria
Zircar Zirconia Inc NY

Chamotte
Imerys Refractory Minerals GA

Chrome & Compounds
Arlimin Industries CO

Chrome & Compounds
Atlantic Equipment Engineers NJ
CerPoTech AS Norway
Hunter Chemical LLC PA
Monofrax LLC NY

Clay Bodies, Formulated
American Art Clay Co Inc IN
Imerys GA
Laguna Clay Co CA
Sheffield Pottery MA
Tethon 3D NE
Unimin Corp CT

Cobalt & Compounds
Arlimin Industries CO
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
Goodfellow Corp PA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Hunter Chemical LLC PA
nGimat LLC KY

Copper & Compounds
American Chemet Corp IL
APF Recycling Inc OH
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
Goodfellow Corp PA
Shoei Chemical Inc Japan

Dielectric Powders
AVX Corp SC
CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
Haiku Tech Inc FL
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Dysprosium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
PIDC MI **See ad on pg 69**
Treibacher Industrie AG Austria

Electrically Conducting Powders
BassTech Intl NJ
CerPoTech AS Norway
Innovnano - Advanced Materials SA Portugal

Erbium Oxide
C&L Development Corp CA
CerPoTech AS Norway
FELDCO Intl CA
Leico Industries Inc NJ
MSE Supplies AZ
PIDC MI **See ad on pg 69**
Treibacher Industrie AG Austria

Europium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
MSE Supplies AZ
PIDC MI **See ad on pg 69**
Treibacher Industrie AG Austria

Ferrites & Ferromagnetics
Centerline Technologies OH
Powder Processing & Technology LLC IN
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Fibers, Ceramic
MemPro Materials Corp CO
Thermal Products Co Inc GA
Unifrax I LLC NY
Wesbond Corp DE
Zircar Zirconia Inc NY

Fibers, Glass
BassTech Intl NJ
Mo-Sci Corp MO **See ad on pg 97**
RISE Research Institutes of Sweden, RISE Glass Sweden
Schott North America Inc NY **See ad on pg 41**
Unifrax I LLC NY

Fluorides
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Sauereisen Inc PA

Frit
Ceradyne Inc, a 3M Co KY
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Laguna Clay Co CA
Polymer Innovations Inc CA
RISE Research Institutes of Sweden, RISE Glass Sweden
Trinity Ceramic Supply Inc TX
Zibo Guangtong Chemical Co Ltd China

Gadolinium Oxide
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
PIDC MI **See ad on pg 69**

Gallium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
Goodfellow Corp PA
MSE Supplies AZ

Germanium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
C&L Development Corp CA
MSE Supplies AZ
Treibacher Industrie AG Austria

Grain, Refractory
Christy Minerals LLC MO
Imerys Refractory Minerals GA

Graphite
APF Recycling Inc OH
Applied Ceramics Inc CA
Aremco Products Inc NY
Beijing Cerametek Materials Co Ltd China
CoorsTek CO
Momentive Performance Materials Inc NY
Semco Carbon OH
Superior Graphite Co IL **See ad on pg 73**
TevTech LLC MA **See ad on pg 83**

Indium & Compounds
American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
MSE Supplies AZ
Pred Materials International Inc NY

Iron & Compounds
Beijing Cerametek Materials Co Ltd China
CerPoTech AS Norway
GFS Chemicals Inc OH
Goodfellow Corp PA
Kyanite Mining Corp VA
Leico Industries Inc NJ
Prince Minerals Inc TX

Iron Oxide
Fusion Ceramics Inc OH
Nutec Bickley Mexico
Prince Minerals Inc TX
Reade Advanced Materials RI

Lanthanides (also see Rare-Earths)
Alfa Aesar Johnson Matthey MA
American Elements CA **Outside back cover, 54**
C&L Development Corp CA
FELDCO Intl CA
GFS Chemicals Inc OH
MSE Supplies AZ
Nanocerox UT
PIDC MI **See ad on pg 69**
Treibacher Industrie AG Austria

Lanthanum & Compounds
Alfa Aesar Johnson Matthey MA
BassTech Intl NJ
C&L Development Corp CA
CerPoTech AS Norway
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and
Ceramic Powders GmbH Germany
PIDC MI **See ad on pg 69**

Lead & Compounds
Goodfellow Corp PA

Lithium & Compounds
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
GFS Chemicals Inc OH
MSE Supplies AZ
nGimat LLC KY
Pred Materials International Inc NY
Trinity Ceramic Supply Inc TX

Magnesia, Fused
APF Recycling Inc OH
Du-Co Ceramics Company PA
Fluid Energy Processing & Equipment Co PA
Washington Mills Electro Minerals Co NY

Magnesia-Alumina, Sintered
Baikowski Malakoff Inc NC
Fluid Energy Processing & Equipment Co PA

Magnesium & Compounds
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
CerPoTech AS Norway
FELDCO Intl CA
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and
Ceramic Powders GmbH Germany
Pred Materials International Inc NY
Prince Minerals Inc TX
Atlantic Equipment Engineers NJ
BassTech Intl NJ
CerPoTech AS Norway
Fusion Ceramics Inc OH
Goodfellow Corp PA
nGimat LLC KY
Prince Minerals Inc TX
RE Carroll Inc PA

Metallic Salts
Alfa Aesar Johnson Matthey MA

American Elements CA **Outside back cover, 54**
Arlimin Industries CO
Hunter Chemical LLC PA

Metallizing Compounds

Alfa Aesar Johnson Matthey MA
Elcon Precision LLC CA **See ad on pg 107**
Gwent Electronic Materials Ltd UK
Sigma Advanced Materials NY

Microspheres, Hollow

Washington Mills Electro Minerals Co NY

Molybdenum & Compounds

APF Recycling Inc OH
Atlantic Equipment Engineers NJ
C&L Development Corp CA
CerPoTech AS Norway
Elcon Precision LLC CA **See ad on pg 107**
GFS Chemicals Inc OH
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany

Nanomaterials

American Elements CA **Outside back cover, 54**

Cerion Nanomaterials NY **See ad on pg 71**
CerPoTech AS Norway
Innovnano - Advanced Materials SA Portugal
MSE Supplies AZ
Nanocerox UT
nGimat LLC KY
Nyacol Nano Technologies Inc MA
Polymer Innovations Inc CA
Pred Materials International Inc NY
TevTech LLC MA **See ad on pg 83**

Neodymium Oxide

Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
MSE Supplies AZ
PIDC MI **See ad on pg 69**

Nickel & Compounds

American Chemet Corp IL
American Elements Inc CA **Outside back cover, 54**
APF Recycling Inc OH
Arlimin Industries CO
Atlantic Equipment Engineers NJ
Ceramic Color & Chemical Mfg Co PA
CerPoTech AS Norway
FELDCO Intl CA
GFS Chemicals Inc OH
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Hunter Chemical LLC PA
Shoei Chemical Inc Japan

Niobium & Compounds

American Elements Inc CA **Outside back cover, 54**
CerPoTech AS Norway
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Leico Industries Inc NJ

Organic Precursors

Starfire Systems Inc NY

Pastes, Conductor

Aremco Products Inc NY
Haiku Tech Inc FL
Sauereisen Inc PA
Shoei Chemical Inc Japan

Phosphates

Arkema Inc PA
BassTech Intl NJ
nGimat LLC KY
Refractory Minerals Co Inc PA
Sauereisen Inc PA

Piezoelectric Compositions

APC International Ltd PA
AVX Corp SC
CerPoTech AS Norway
Sparkler Ceramics Pvt Ltd India

Pigments

Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH
Sauereisen Inc PA
Wistra GmbH Germany

Plaster, Gypsum

Sheffield Pottery MA

Plaster, Industrial

Sheffield Pottery MA

Potassium & Compounds

CerPoTech AS Norway
GFS Chemicals Inc OH

Powdered Metals

Alfa Aesar Johnson Matthey MA
Arlimin Industries CO
Beijing Cerametek Materials Co Ltd China
Cancarb Limited Canada
Polymer Innovations Inc CA
Pred Materials International Inc NY

Praseodymium Oxide

Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
Nanocerox UT
PIDC MI **See ad on pg 69**

Precious Metals

Alfa Aesar Johnson Matthey MA
APF Recycling Inc OH
Gwent Electronic Materials Ltd UK
Leico Industries Inc NJ
Shoei Chemical Inc Japan

Rare-Earth Titanates

CerPoTech AS Norway
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Rare-Earths

Alfa Aesar Johnson Matthey MA
American Elements CA **Outside back cover, 54**
Beijing Cerametek Materials Co Ltd China
C&L Development Corp CA
FELDCO Intl CA
GFS Chemicals Inc OH
Innovnano - Advanced Materials SA Portugal
MSE Supplies AZ
Nanocerox UT

PIDC MI **See ad on pg 69**
Pred Materials International Inc NY
Spontaneous Materials CO
Treibacher Industrie AG Austria
Wistra GmbH Germany
Zircar Zirconia Inc NY

Refractory Oxides

Arlimin Industries CO
Christy Minerals LLC MO
Innovnano - Advanced Materials SA Portugal
Leico Industries Inc NJ
nGimat LLC KY

Resins, Molding

Hexion Inc OH
Starfire Systems Inc NY

Samarium Oxide

Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Nanocerox UT
PIDC MI **See ad on pg 69**

Sand, Foundry

Kyanite Mining Corp VA
U.S. Silica Co MD

Sand, Glass

Fusion Ceramics Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden
U.S. Silica Co MD

Sand, High-Purity Silica

BassTech Intl NJ
Maryland Refractories Co OH
U.S. Silica Co MD
Unimin Corp CT

Scandium & Compounds

Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
C&L Development Corp CA
FELDCO Intl CA
Leico Industries Inc NJ
Nanocerox UT
Trinity Ceramic Supply Inc TX
Alfa Aesar Johnson Matthey MA
American Elements Inc CA **Outside back cover, 54**
FELDCO Intl CA
Pred Materials International Inc NY

Semiconducting Powders

American Elements Inc CA **Outside back cover, 54**

SiAlON Powder

Pred Materials International Inc NY

Silica

Arkema Inc PA
Denka Corp NY
Ipsen Ceramics IL
Maryland Refractories Co OH
Momentive Performance Materials Inc NY
Nanocerox UT
Saint-Gobain Ceramics & Plastics MA
Sauereisen Inc PA
Sibelco Benelux Belgium
U.S. Silica Co MD

Silica, Fused

APF Recycling Inc OH
BassTech Intl NJ
Bosai Minerals Group Co Ltd China
Centerline Technologies OH
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
Momentive Performance Materials Inc NY
Valley Design Corp MA

Silicates

BassTech Intl NJ
Denka Corp NY
Nanocerox UT
Sauereisen Inc PA

Silicon & Compounds

Atlantic Equipment Engineers NJ
Elkem Metals Inc PA
FELDCO Intl CA
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Reade Advanced Materials RI
Valley Design Corp MA

Silicon Carbide

American Elements Inc CA **Outside back cover, 54**
APF Recycling Inc OH
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
Bullen OH
Cancarb Limited Canada
CerCo LLC OH
CoorsTek CO
Custom Processing Services PA
Electro Abrasives Corp NY
FELDCO Intl CA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Imerys Refractory Minerals GA
Momentive Performance Materials Inc NY
Ortech Inc CA
Pred Materials International Inc NY
Rauschert Industries Inc GA **See ad on pg 69**
Saint-Gobain Ceramics & Plastics MA
Starfire Systems Inc NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Superior Graphite Co IL **See ad on pg 73**
Texers Technical Ceramics Inc Canada
Treibacher Industrie AG Austria
Valley Design Corp MA
Washington Mills Electro Minerals Co NY

Silicon Nitride

Alteo NA LLC OH **See ad on pg 11**
Applied Ceramics Inc CA
Atlantic Equipment Engineers NJ
Bullen OH
CerCo LLC OH
CoorsTek CO
Denka Corp NY
FELDCO Intl CA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
International Ceramic Engineering MA
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Ortech Inc CA
Pred Materials International Inc NY
Rauschert Industries Inc GA **See ad on pg 69**
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Texers Technical Ceramics Inc Canada
China Unipretec Ceramic Technology Co Ltd China

Sodium & Compounds

Atlantic Equipment Engineers NJ
GFS Chemicals Inc OH

Spheres, Ceramic

Saint-Gobain norPro OH
Zircar Zirconia Inc NY

Spheres, Glass

Imerys Refractory Minerals GA
Mo-Sci Corp MO **See ad on pg 97**
RISE Research Institutes of Sweden, RISE Glass Sweden

Strontium & Compounds

Alfa Aesar Johnson Matthey MA
BassTech Intl NJ
CerPoTech AS Norway
Fusion Ceramics Inc OH
GFS Chemicals Inc OH
nGimat LLC KY

Superabrasives

Alteo NA LLC OH **See ad on pg 11**
Diamond Industrial Tools Inc IL
Saint-Gobain Ceramics & Plastics MA

Superconducting Powders

Alfa Aesar Johnson Matthey MA
nGimat LLC KY

Tantalum Metal Powder
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Leico Industries Inc NJ

Tantalum Oxide
CerPoTech AS Norway
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
PIDC MI — **See ad on pg 69**

Terbium Oxide
Alfa Aesar Johnson Matthey MA
C&L Development Corp CA
CerPoTech AS Norway
Leico Industries Inc NJ
Nanocerox UT

Thin-Film Materials

American Elements Inc CA — **Outside back cover, 54**

Thick-Film Materials
CerPoTech AS Norway
ESL ElectroScience PA
New Tech Ceramics Inc IA
Shoei Chemical Inc Japan
Cerakote Ceramic Coatings OR
CerPoTech AS Norway
FELDCO Intl CA
Innovnano - Advanced Materials SA Portugal
Materion Advanced Materials NY
New Tech Ceramics Inc IA
Valley Design Corp MA

Tin & Compounds
Arlimin Industries CO
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
Trinity Ceramic Supply Inc TX

Titanium & Compounds
APF Recycling Inc OH
Atlantic Equipment Engineers NJ
C&L Development Corp CA
FELDCO Intl CA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Leico Industries Inc NJ
Nanocerox UT
TAM Ceramics NY

Titanium Carbide
Atlantic Equipment Engineers NJ
Beijing Cerametek Materials Co Ltd China
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Reade Advanced Materials RI

Titanium Diboride
Dunhua Zhengxing Abrasive Co Ltd China
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Momentive Performance Materials Inc NY
New Tech Ceramics Inc IA
Pred Materials International Inc NY
Surmet Corp MA

Titanium Dioxide
BassTech Intl NJ
Beijing Cerametek Materials Co Ltd China
FELDCO Intl CA
Fusion Ceramics Inc OH
Nanocerox UT
nGimat LLC KY
Pred Materials International Inc NY

Titanium Nitride
Atlantic Equipment Engineers NJ
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Pred Materials International Inc NY

Tungsten Carbide
Associated Ceramics & Technology Inc PA — **See ad on pg 65**
Atlantic Equipment Engineers NJ
C&L Development Corp CA
Centerline Technologies OH
Custom Processing Services PA
FELDCO Intl CA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
MSE Supplies AZ
PicoParts Ltd Israel
Pred Materials International Inc NY

Tungsten Oxide
CerPoTech AS Norway
FELDCO Intl CA
H.C. Starck North American Trading LLC MA

Uranium & Compounds
Wistra GmbH Germany

Vanadium & Compounds
Atlantic Equipment Engineers NJ
CerPoTech AS Norway
FELDCO Intl CA

Yttria
APF Recycling Inc OH
Associated Ceramics & Technology Inc PA — **See ad on pg 65**
Bullen OH
CoorsTek CO
ESL ElectroScience PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Innovnano - Advanced Materials SA Portugal
Nanocerox UT
nGimat LLC KY
PIDC MI — **See ad on pg 69**
Pred Materials International Inc NY
Washington Mills Electro Minerals Co NY
Zircar Zirconia Inc NY

Yttrium & Compounds
Alfa Aesar Johnson Matthey MA
American Elements CA — **Outside back cover, 54**
C&L Development Corp CA
CerPoTech AS Norway
GFS Chemicals Inc OH
Nanocerox UT
nGimat LLC KY
PIDC MI — **See ad on pg 69**

Zinc & Compounds
CerPoTech AS Norway
FELDCO Intl CA
Leico Industries Inc NJ
Prince Minerals Inc TX
RE Carroll Inc PA
Sauereisen Inc PA
TevTech LLC MA — **See ad on pg 83**

Zinc Oxide
American Chemet Corp IL
FELDCO Intl CA
Fusion Ceramics Inc OH
nGimat LLC KY
Prince Minerals Inc TX
Sauereisen Inc PA
uttam industries India

Zirconia
Applied Ceramics Inc CA
China Unipretec Ceramic Technology Co Ltd China
C&L Development Corp CA
Custom Processing Services PA
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Leico Industries Inc NJ
Nanocerox UT
Nanoe France
nGimat LLC KY
Ortech Inc CA
PIDC MI — **See ad on pg 69**
PremaTech Advanced Ceramics MA
Rauschert Industries Inc GA — **See ad on pg 69**
Saint-Gobain Ceramics & Plastics MA
Sauereisen Inc PA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
TAM Ceramics NY
Washington Mills Electro Minerals Co NY
Zibo Guangtong Chemical Co Ltd China
Zircar Zirconia Inc NY
Zircoa Inc OH

Zirconia, Engineering-Grade
Innovnano - Advanced Materials SA Portugal
Leico Industries Inc NJ
McDanel Advanced Ceramic Technologies LLC PA — **See ad on pg 61**
Nanoe France
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

Zirconia, High-Purity
APF Recycling Inc OH
Applied Ceramics Inc CA
CARBO TX
CoorsTek CO
Innovnano - Advanced Materials SA Portugal
International Ceramic Engineering MA
Nanocerox UT
Nanoe France
Sauereisen Inc PA
Zibo Guangtong Chemical Co Ltd China

Zirconia, Refractory-Grade
McDanel Advanced Ceramic Technologies LLC PA
See ad on pg 61
Nanoe France
Washington Mills Electro Minerals Co NY
Zircoa Inc OH

Zirconium & Compounds
Atlantic Equipment Engineers NJ
C&L Development Corp CA
CerPoTech AS Norway
FELDCO Intl CA
Goodfellow Corp PA
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Innovnano - Advanced Materials SA Portugal
Luxfer MEL Technologies NJ
Monofrax LLC NY
PIDC MI **See ad on pg 69**
Saint-Gobain Ceramics & Plastics MA
Zibo Guangtong Chemical Co Ltd China

Zirconium Carbide
Cancarb Limited Canada
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany

Zirconium Carbonate
C&L Development Corp CA
Zibo Guangtong Chemical Co Ltd China

Zirconium Diboride
H.C. Starck North American Trading LLC MA
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany

■ CLAY & NATURAL MINERALS

Bauxite
APF Recycling Inc OH
Bosai Minerals Group Co Ltd China
Fluid Energy Processing & Equipment Co PA
Hindalco Industries Limited India
Imerys Refractory Minerals GA
Prince Minerals Inc TX

Bentonite
Custom Processing Services PA
Reade Advanced Materials RI
Trinity Ceramic Supply Inc TX
Vanderbilt Minerals, LLC CT

Borax
Rio Tinto Minerals Australia

Chromite
Prince Minerals Inc TX

Clays, Ball
Fusion Ceramics Inc OH
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX
Unimin Corp CT

Clays, No
Fusion Ceramics Inc OH
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals, LLC CT

Clays, Enamel
Old Hickory Clay Co KY
RISE Research Institutes of Sweden, RISE Glass Sweden
Sibelco Benelux Belgium
Vanderbilt Minerals, LLC CT

Clays, Engobe
Imerys GA
Old Hickory Clay Co KY
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals, LLC CT

Clays, Fire or Refractory
Alsey Refractories Co MO
Christy Minerals LLC MO
Endiccott Clay Products Company NE
Furnace Products & Services Inc PA
Imerys Refractory Minerals GA
Maryland Refractories Co OH
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Riverside Refractories Inc AL
Sheffield Pottery MA
Sibelco Benelux Belgium

Clays, Glaze
Imerys GA
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Sibelco Benelux Belgium
Vanderbilt Minerals, LLC CT

Clays, Stoneware
Christy Minerals LLC MO
Old Hickory Clay Co KY
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Sibelco Benelux Belgium

Cordierite
Maryland Ceramic & Steatite Co Inc MD
Mason Color Works Inc OH
Reade Advanced Materials RI
Refratechnik Ceramics GmbH Germany
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Diatomateous Earth
Reade Advanced Materials RI

Dolomite
Fusion Ceramics Inc OH
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Feldspar
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH
Imerys GA
Prince Minerals Inc TX
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Flint
Christy Minerals LLC MO
Fusion Ceramics Inc OH
Sheffield Pottery MA

Forsterite
Du-Co Ceramics Company PA
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Kaolin
Arkema Inc PA
Bosai Minerals Group Co Ltd China
CARBO TX
Christy Minerals LLC MO
Fusion Ceramics Inc OH
Imerys GA
Imerys Refractory Minerals GA
M&M Clays Inc GA
Old Hickory Clay Co KY
RE Carroll Inc PA
Reade Advanced Materials RI
Sheffield Pottery MA
Trinity Ceramic Supply Inc TX
U.S. Silica Co MD
Vanderbilt Minerals, LLC CT

Kyanite
Kyanite Mining Corp VA

Lime & Limestone
Prince Minerals Inc TX
RE Carroll Inc PA

Lithium Minerals
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH

Magnesite
APF Recycling Inc OH
Bosai Minerals Group Co Ltd China
Fluid Energy Processing & Equipment Co PA
Imerys Refractory Minerals GA

Mica
Imerys GA

Montmorillonite
Reade Advanced Materials RI
Vanderbilt Minerals, LLC CT

Mullite
Christy Minerals LLC MO
Imerys Refractory Minerals GA
International Ceramic Engineering MA
Kyanite Mining Corp VA
Pred Materials International Inc NY
Reade Advanced Materials RI
Texers Technical Ceramics Inc Canada
Washington Mills Electro Minerals Co NY

Nepheline Syenite
Fusion Ceramics Inc OH
Sheffield Pottery MA
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX

Olivine
Prince Minerals Inc TX
Sibelco Benelux Belgium

Pyrite
Kyanite Mining Corp VA
Washington Mills Electro Minerals Co NY

Pyrophyllite
Maryland Ceramic & Steatite Co Inc MD
Vanderbilt Minerals, LLC CT

Quartz
Applied Ceramics Inc CA
Fusion Ceramics Inc OH
Goodfellow Corp PA
Imerys GA
International Ceramic Engineering MA
Momentive Performance Materials Inc NY
Multi Lab UK
Prince Minerals Inc TX
Sibelco Benelux Belgium

Rutile
Fusion Ceramics Inc OH
Prince Minerals Inc TX

Sapphire
Applied Ceramics Inc CA
Centerline Technologies OH
Goodfellow Corp PA
International Ceramic Engineering MA
MSE Supplies AZ

Silica
APF Recycling Inc OH
Centerline Technologies OH
Imerys GA
Imerys Refractory Minerals GA
Maryland Refractories Co OH
Prince Minerals Inc TX
Sibelco Benelux Belgium
Trinity Ceramic Supply Inc TX
U.S. Silica Co MD

Soda Ash
Fusion Ceramics Inc OH
RE Carroll Inc PA

Spinels
Almatis Inc PA
Baikowski Malakoff Inc NC
Fluid Energy Processing & Equipment Co PA
GrainBound LLC PA
Pred Materials International Inc NY
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Washington Mills Electro Minerals Co NY

Spodumene
Avalon Advanced Materials Inc Canada
Fusion Ceramics Inc OH
Prince Minerals Inc TX
Trinity Ceramic Supply Inc TX

Steatite
Du-Co Ceramics Company PA
International Ceramic Engineering MA
Maryland Ceramic & Steatite Co Inc MD

Talc
Custom Processing Services PA
Fusion Ceramics Inc OH
Rio Tinto Minerals Australia
Trinity Ceramic Supply Inc TX

Wollastonite
Bosai Minerals Group Co Ltd China
Fusion Ceramics Inc OH
Reade Advanced Materials RI
Trinity Ceramic Supply Inc TX
Vanderbilt Minerals, LLC CT

Zircon
AluChem Inc OH
APF Recycling Inc OH
Fusion Ceramics Inc OH
Lithoz GmbH NY
Prince Minerals Inc TX
Reade Advanced Materials RI
TAM Ceramics NY

■ CONSTRUCTION CERAMICS

Brick
Belden Brick Co OH
Brick Industry Assn VA
Cancarb Limited Canada
Endicott Clay Products Company NE
Niokem Inc NC
Zibo Guangtong Chemical Co Ltd China

Brick & Paving
Belden Brick Co OH
Brick Industry Assn VA
Cancarb Limited Canada
Endicott Clay Products Company NE
Niokem Inc NC

Pipe, Ceramic-Lined
CerCo LLC OH

Sanitaryware
Roca Sanitario SA Spain
Zibo Guangtong Chemical Co Ltd China

Tile, Floor & Pavers
Endicott Clay Products Company NE
Foundation Floors FL
Heartland Wood Flooring FL
Somany Ceramics Ltd India

Tile, Wall
Comtrust Architectural Mesh Co Ltd China
Endicott Clay Products Company NE
Peter Pugger Mfg Inc CA
Somany Ceramics Ltd India

■ CONSULTANTS & SERVICES
Jenike & Johanson MA

Advanced Coatings
Activation Laboratories Ltd Canada
Advanced Materials Associates China
Bharat Heavy Electricals Ltd NY
Cerakote Ceramic Coatings OR
CoorsTek CO
Delkic & Associates FL
Gwent Electronic Materials Ltd UK
New Tech Ceramics Inc IA
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Viridis3D LLC MA
Activation Laboratories Ltd Canada
Alfred University NY
AVEKA MN
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
CMC Laboratories Inc AZ
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Hitech Materials Pty Ltd NY
Israel Ceramic & Silicate Inst Israel
JTF Microscopy Services, LLC NY
Micromeritics Instrument Corp GA
Micron Inc DE

NSL Analytical Services Inc OH **See ad on pg 75**
OPF Enterprises TX
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL
Refractory Consulting Services OH
RISE Research Institutes of Sweden, RISE Glass Sweden
SEMTech Solutions Inc UK
Spectrochemical Laboratories PA
TA Instruments DE

Analytical Services

NSL Analytical Services Inc OH **See ad on pg 75**

Spectrochemical Laboratories PA

Brick & Structural Clay Processing

Ceramitec Germany
Lucideon UK
Niokem Inc NC
OPF Enterprises TX
Peter Pugger Mfg Inc CA
Verity Technical Consultants LLC OH

Ceramic Materials

Activation Laboratories Ltd Canada
Advanced Materials Associates China
Alfred University NY
AVEKA MN
Bharat Heavy Electricals Ltd NY

Bomas Machine Specialties Inc MA **See ad on pg 81**
Cancarb Limited Canada
CelSian Glass & Solar BV The Netherlands
Cerakote Ceramic Coatings OR
Ceralink Inc NY
Cerion Nanomaterials NY **See ad on pg 71**
Elan Technology GA
Elcon Precision LLC CA **See ad on pg 107**
Ferro-Ceramic Grinding Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NY
Imerys GA
Inst for Applied Materials-Ceramics in Mechanical Engineering, Karlsruhe Inst of Technology Germany
International Ceramic Engineering MA
Lithoz GmbH NY
Lucideon UK
MemPro Materials Corp CO
NSL Analytical Services Inc OH **See ad on pg 75**
O'Keefe Ceramics Inc CO
OPF Enterprises TX
P-Ker Engineering NY
Rauschert Industries Inc GA **See ad on pg 69**
Refrac Systems AZ
Rensselaer Polytechnic Inst NY
Schott North America Inc NY **See ad on pg 41**
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Verity Technical Consultants LLC OH
Viridis3D LLC MA

Chemistry

Activation Laboratories Ltd Canada
CelSian Glass & Solar BV The Netherlands

Cerion Nanomaterials NY **See ad on pg 71**
Chemical Abstracts Service OH
CHEMIR - A Division of Evans Analytical Group MO
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NY
NSL Analytical Services Inc OH **See ad on pg 75**

Combustion Systems
Air Products PA
CelSian Glass & Solar BV The Netherlands
Ceramic Services Inc PA

Harrop Industries Inc OH **See ad on pg 58**

Compositions
Activation Laboratories Ltd Canada
Advanced Materials Associates China
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Gwent Electronic Materials Ltd UK
Hitech Materials Pty Ltd NY
NSL Analytical Services Inc OH **See ad on pg 75**

Decorating Processes & Materials
Cerlase France
Lucideon UK
OPF Enterprises TX

Design
Air Force Civil Engineer Center China
CoorsTek CO
Deltech Kiln and Furnace Design, LLC CO
General Glass Equipment Co NJ
I Squared R Element Co NY **See ad on pg 89**
Ingredient Masters Inc OH **See ad on pg 103**
Jenike & Johanson Inc MA
OPF Enterprises TX
RocCera LLC NY
Tethon 3D NE
Viridis3D LLC MA

Electronics & Electrical Materials
Advanced Energy CO
APC International Ltd PA
AVEKA MN
Centerline Technologies OH
Elan Technology GA
Electrosciences Ltd UK
Gwent Electronic Materials Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Harrop Industries Inc OH **See ad on pg 58**

I Squared R Element Co NY **See ad on pg 89**
Powder Processing & Technology LLC IN
Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**

Energy
A123 Systems Inc MI
Advanced Energy CO
Air Force Civil Engineer Center China
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
FCT Systeme GmbH Germany
Lucideon UK
Polymer Innovations Inc CA
Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**
Texers Technical Ceramics Inc Canada

Engineering
Advanced Materials Associates China
Air Force Civil Engineer Center China
CelSian Glass & Solar BV The Netherlands
Cerinnov France
Ceritherm France
Cyclonaire Corp NE
Deltech Kiln and Furnace Design, LLC CO
FCT Systeme GmbH Germany
General Glass Equipment Co NJ
Hitech Materials Pty Ltd NY
Ingredient Masters Inc OH **See ad on pg 103**
International Ceramic Engineering MA
Jenike & Johanson Inc MA
Lithoz GmbH NY
Nol-Tec Systems Inc MN
Teeter Marketing Services LLC FL
Verity Technical Consultants LLC OH
Wistra GmbH Germany

Environmental
Activation Laboratories Ltd Canada
Air Force Civil Engineer Center China
CelSian Glass & Solar BV The Netherlands
Lucideon UK
SEMTech Solutions Inc UK
Texers Technical Ceramics Inc Canada
Tri-Mer Corp MI

Expert Witness
Advanced Materials Associates China
CHEMIR - A Division of Evans Analytical Group MO
H&M Analytical Services Inc NJ
Hitech Materials Pty Ltd NY
JTF Microscopy Services, LLC NY
Lucideon UK
Particle Technology Labs IL **See ad on pg 99**
Refrac Systems AZ
Refractory Consulting Services OH
Spontaneous Materials CO
Verity Technical Consultants LLC OH

Fabrication
Accuratus Corp NJ
Advanced Materials Associates China
Bullen OH
Ingredient Masters Inc OH **See ad on pg 103**
Lithoz GmbH NY
O'Keefe Ceramics Inc CO
PremaTech Advanced Ceramics MA
Refrac Systems AZ
RocCera LLC NY
Technology Assessment and Transfer Inc (TA&T) MD
Thermal Products Co Inc GA
Verity Technical Consultants LLC OH

Furnaces
Advanced Materials Associates China
American Isostatic Presses OH
CelSian Glass & Solar BV The Netherlands
Centorr Vacuum Industries NH **See ad on pg 87**

Deltech Kiln and Furnace Design, LLC CO
Fosbel Inc OH
General Glass Equipment Co NJ

Harper International Corp NY **See ad on pg 77**
I Squared R Element Co NY **See ad on pg 89**
JTF Microscopy Services, LLC NY
Nutec Bickley Mexico
Refrac Systems AZ
Technology Assessment and Transfer Inc (TA&T) MD
The Furnace Source LLC CT
Trent Inc PA
Winner Technology The Republic of Korea

Glass Processes & Materials
Alfred University NY
CelSian Glass & Solar BV The Netherlands
Ceradyne Inc, a 3M Co KY
Elan Technology GA
JTF Microscopy Services, LLC NY
NSL Analytical Services Inc OH **See ad on pg 75**
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden, RISE Glass Sweden
Saxon Glass Technologies Inc NY
Schott North America Inc NY **See ad on pg 41**
Specialty Glass Inc FL
Tri-Mer Corp MI
Verity Technical Consultants LLC OH
Vesuvius SC

Glazes/Colorants
Cancarb Limited Canada
Ceradyne Inc, a 3M Co KY
Laguna Clay Co CA
Lucideon UK
NSL Analytical Services Inc OH **See ad on pg 75**
OPF Enterprises TX
RISE Research Institutes of Sweden, RISE Glass Sweden

High-Technology Ceramics
Advanced Materials Associates China
APC International Ltd PA
ARBURG GmbH + Co KG Germany
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
Ceramitec Germany
CHEMIR - A Division of Evans Analytical Group MO
Elcon Precision LLC CA **See ad on pg 107**
Gwent Electronic Materials Ltd UK
Hitech Materials Pty Ltd NY
Lucideon UK
NSL Analytical Services Inc OH **See ad on pg 75**
OPF Enterprises TX
P-Ker Engineering NY
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Viridis3D LLC MA
Wistra GmbH Germany
Zircoa Inc OH

Kilns

Ceritherm France

Deltech Kiln and Furnace Design, LLC CO
FCT Systeme GmbH Germany
Lucideon UK
Nabertherm Inc DE
OPF Enterprises TX

Litigation

H&M Analytical Services Inc NJ
Lucideon UK
Particle Technology Labs IL **See ad on pg 99**
Refractory Consulting Services OH
Spontaneous Materials CO
Verity Technical Consultants LLC OH

Maintenance & Repairs, After Sales

Cerinnov France

Management

OPF Enterprises TX
Teeter Marketing Services LLC FL

Manufacturing

Advanced Materials Associates China
AVEKA MN
Ceramco Inc NH
CeramTec North America Corp SC
Cerinnov France
CoorsTek CO
Custom Processing Services PA
Cyclonaire Corp NE
Endiccott Clay Products Company NE
Ferro-Ceramic Grinding Inc MA
Ingredient Masters Inc OH **See ad on pg 103**
Jenike & Johanson Inc MA
Laserage Technology Corp IL
Lucideon UK
Maryland Ceramic & Steatite Co Inc MD
Matmatch Germany
O'Keefe Ceramics Inc CO
OPF Enterprises TX
P-Ker Engineering NY
Refrac Systems AZ
Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**
Technology Assessment and Transfer Inc (TA&T) MD
Verity Technical Consultants LLC OH
Wistra GmbH Germany

Markets

Advanced Materials Associates China
Matmatch Germany
OPF Enterprises TX
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada

Materials Testing & Characterization

Advanced Materials Associates China
Alfred University NY
ARBURG GmbH + Co KG Germany
AVEKA MN
Bharat Heavy Electricals Ltd NY
BuzzMac Intl LLC ME
Ceramitec Germany
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA
Cyclonaire Corp NE
Edward Orton Jr Ceramic Foundation OH
Elan Technology GA
Fluid Energy Processing & Equipment Co PA
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Hitech Materials Pty Ltd NY
Hysitron Inc MN
Inst for Applied Materials-Ceramics in Mechanical Engineering, Karlsruhe Inst of Technology Germany
Jenike & Johanson Inc MA
JTF Microscopy Services, LLC NY
Lucideon UK
Micromeritics Instrument Corp GA
Nol-Tec Systems Inc MN
norECs AS Norway

NSL Analytical Services Inc OH **See ad on pg 75**
OPF Enterprises TX

Particle Technology Labs IL **See ad on pg 99**
P-Ker Engineering NY
Refractory Consulting Services OH
Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**

Spectrochemical Laboratories PA
Taber Industries NY
Washington Mills Electro Minerals Co NY

Modeling
CelSian Glass & Solar BV The Netherlands
CoorsTek CO
Lucideon UK
Ram Products Inc OH
Spontaneous Materials CO
Tethon 3D NE

Nuclear Materials
Advanced Materials Associates China
Dunhua Zhengxing Abrasive Co Ltd China
NSL Analytical Services Inc OH **See ad on pg 75**

Patents
Modern Times Legal MA
Refrac Systems AZ
Spontaneous Materials CO
Teeter Marketing Services LLC FL

Professional Engineer
NSL Analytical Services Inc OH **See ad on pg 75**
Spontaneous Materials CO
Texers Technical Ceramics Inc Canada
Verity Technical Consultants LLC OH

Quality Management/ISO 9000
Elcon Precision LLC CA **See ad on pg 107**
Lucideon UK

Refractories
CelSian Glass & Solar BV The Netherlands
Ceramitec Germany
Dunhua Zhengxing Abrasive Co Ltd China
Edward Orton Jr Ceramic Foundation OH
Fluid Energy Processing & Equipment Co PA
Fosbel Inc OH
Hitech Materials Pty Ltd NY
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
JTF Microscopy Services, LLC NY
Laguna Clay Co CA
Lucideon UK
Maryland Refractories Co OH
NSL Analytical Services Inc OH **See ad on pg 75**
Refractory Consulting Services OH
Silicon Carbide Products Inc NY
Teeter Marketing Services LLC FL
Texers Technical Ceramics Inc Canada
Viridis3D LLC MA
Wistra GmbH Germany

Research
Advanced Materials Associates China
Alfred University NY
ARBURG GmbH + Co KG Germany
AVEKA MN
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
Cerion Nanomaterials NY **See ad on pg 71**
Cerlase France
CHEMIR - A Division of Evans Analytical Group MO
Inst for Applied Materials-Ceramics in Mechanical Engineering, Karlsruhe Inst of Technology Germany
Laeis GmbH Luxembourg
Lithoz GmbH NY
Lucideon UK
OPF Enterprises TX
Refrac Systems AZ
RISE Research Institutes of Sweden, RISE Glass Sweden
Technology Assessment and Transfer Inc (TA&T) MD
Viridis3D LLC MA
Wistra GmbH Germany

Semiconductors (Consultants)
Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Software
Chemical Abstracts Service OH
General Glass Equipment Co NJ

Object Research Systems Inc Canada **See ad on pg 81**
Outotec Research Oy Pori
Rockwell Automation, Inc WI
Throughput Bluestreak WI

Structural Ceramics
Advanced Materials Associates China
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
Ceramitec Germany
CeramTec North America Corp SC
FCT Ingenieurkeramik GmbH Germany
Hitech Materials Pty Ltd NY
OPF Enterprises TX
Rauschert Industries Inc GA **See ad on pg 69**
Silicon Carbide Products Inc NY
Technology Assessment and Transfer Inc (TA&T) MD

Superconductors
NSL Analytical Services Inc OH **See ad on pg 75**

Technical Writing
Advanced Materials Associates China
Bharat Heavy Electricals Ltd NY
CelSian Glass & Solar BV The Netherlands
Hitech Materials Pty Ltd NY
JTF Microscopy Services, LLC NY
Spontaneous Materials CO
Teeter Marketing Services LLC FL

Technology Transfer
CelSian Glass & Solar BV The Netherlands
Ceralink Inc NY
Cerlase France
Gwent Electronic Materials Ltd UK
Lucideon UK
Particle Technology Labs IL **See ad on pg 99**
Spontaneous Materials CO
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Viridis3D LLC MA

■ CUSTOM CERAMICS FABRICATION & ENGINEERING SERVICES

Advanced Ceramics, Structural
Accuratus Corp NJ
AdTech Ceramics TN
AdValue Technology LLC AZ **See ad on pg 43**
Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Astro Met Advanced Ceramics Inc OH

Bomas Machine Specialties Inc MA **See ad on pg 81**
Bullen OH
CeramTec North America Corp SC
Ceranova Corp MA
CerCo LLC OH
CiDRA Precision Services LLC CT
CoorsTek CO
Custom Processing Services PA
Dunhua Zhengxing Abrasive Co Ltd China

Elcon Precision LLC CA **See ad on pg 107**
Exothermics Inc NH
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
GE Global Research NY
Induceramic Canada
Innovnano - Advanced Materials SA Portugal
Israel Ceramic & Silicate Inst Israel
Lithoz GmbH NY
Machined Ceramics Inc KY
Maryland Ceramic & Steatite Co Inc MD

McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
MemPro Materials Corp CO
Morgan Technical Ceramics Auburn CA
Petro Mold Company PA
P-Ker Engineering NY
Precision Ceramics FL
Precision Ferrites and Ceramics Inc CA

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA

Rauschert Industries Inc GA **See ad on pg 69**
Refrac Systems AZ
Refractron Technologies Corp NY
RocCera LLC NY
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Starfire Systems Inc NY
Superior Technical Ceramics Corp VT **See ad on pg 63**
Technical Products Inc WI
Tethon 3D NE
Toto Ltd Japan
Zircoa Inc OH

Calcining, Custom

CerPoTech AS Norway
Christy Minerals LLC MO
OPF Enterprises TX

Powder Processing & Technology LLC IN

Classification, Custom

AVEKA MN

Bomas Machine Specialties Inc MA **See ad on pg 81**
Christy Minerals LLC MO
Du-Co Ceramics Company PA
Fluid Energy Processing & Equipment Co PA

Coatings, Corrosion-Resistant

Aremco Products Inc NY
Cerakote Ceramic Coatings OR
CoorsTek CO
ESL ElectroScience PA
Hexion Inc OH
Induceramic Canada
Master Bond Inc NJ
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
TevTech LLC MA **See ad on pg 83**
Verity Technical Consultants LLC OH

Coatings, Thermal-Resistant
Aremco Products Inc NY
Cancarb Limited Canada
Cerakote Ceramic Coatings OR
Delkic & Associates FL
ESL ElectroScience PA
Induceramic Canada
New Tech Ceramics Inc IA
Sigma Advanced Materials NY
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Unifrax I LLC NY
Verity Technical Consultants LLC OH
ZYP Coatings Inc TN

Coatings, Wear-Resistant
Cerakote Ceramic Coatings OR
CeramTec-ETEC Germany
CoorsTek CO
ESL ElectroScience PA
Master Bond Inc NJ
New Tech Ceramics Inc IA
Starfire Systems Inc NY
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
TevTech LLC MA See ad on pg 83

Crushing, Custom
AVEKA MN
Christy Minerals LLC MO
Fluid Energy Processing & Equipment Co PA
Reade Advanced Materials RI
Stedman Machine Co IN

Dielectrics
Accuratus Corp NJ
AdTech Ceramics TN
Associated ceramics CA
CerPoTech AS Norway
Ferro-Ceramic Grinding Inc MA
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Sigma Advanced Materials NY
Starfire Systems Inc NY
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Drying, Custom
AVEKA MN
Fluid Energy Processing & Equipment Co PA
General Spray LLC NJ
Ipsen Ceramics IL
Reade Advanced Materials RI

Engineering
Ferro-Ceramic Grinding Inc MA

Films, Thick
CoorsTek CO
ESL ElectroScience PA
Gwent Electronic Materials Ltd UK
New Tech Ceramics Inc IA
P-Ker Engineering NY
Polymer Innovations Inc CA
Sigma Advanced Materials NY
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Films, Thin
Advanced Energy CO
Cerakote Ceramic Coatings OR
CoorsTek CO
Industrial Hard Carbon LLC NC
Morgan Technical Ceramics Auburn CA
New Tech Ceramics Inc IA
Technology Assessment and Transfer Inc (TA&T) MD
Teeter Marketing Services LLC FL
Verity Technical Consultants LLC OH

Furnace Rebuilds
Cancarb Limited Canada
Fosbel Inc OH
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH See ad on pg 89
TevTech LLC MA See ad on pg 83
ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Grinding, Custom

Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH

Bomas Machine Specialties Inc MA See ad on pg 81
Bullen OH
Christy Minerals LLC MO
CiDRA Precision Services LLC CT
CoorsTek CO
Du-Co Ceramics Company PA
FCT Ingenieurkeramik GmbH Germany
Ferro-Ceramic Grinding Inc MA
Fluid Energy Processing & Equipment Co PA
International Ceramic Engineering MA
Machined Ceramics Inc KY
McDanel Advanced Ceramic Technologies LLC PA See ad on pg 61
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
PremaTech Advanced Ceramics MA
Reade Advanced Materials RI
Refractory Machining Services PA
Refractory Minerals Co Inc PA
Refractron Technologies Corp NY
RocCera LLC NY
Stedman Machine Co IN
Union Process OH
Valley Design Corp MA
Washington Mills Electro Minerals Co NY
Zibo Guangtong Chemical Co Ltd China

Hot Repair
Fosbel Inc OH

Joining
Advanced Ceramic Technology CA
CeramTec North America Corp SC
Fosbel Inc OH
Fuse Tech/Hot Tech Group OH
Induceramic Canada
Morgan Technical Ceramics Auburn CA
P-Ker Engineering NY
Precision Ferrites and Ceramics Inc CA
Refrac Systems AZ
RocCera LLC NY
Sigma Advanced Materials NY
Starfire Systems Inc NY

Lapping & Polishing
Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH
Bullen OH
CoorsTek CO
Du-Co Ceramics Company PA
Dunhua Zhengxing Abrasive Co Ltd China
International Ceramic Engineering MA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
PremaTech Advanced Ceramics MA
Superior Technical Ceramics Corp VT See ad on pg 63
Technical Products Inc WI
Texers Technical Ceramics Inc Canada
Valley Design Corp MA

Laser Cutting & Scribing Services
Cerlase France
CoorsTek CO
Laserage Technology Corp IL
Ortech Inc CA

Machining

Advanced Ceramic Technology CA
Advanced Ceramics Manufacturing AZ
Aremco Products Inc NY
Astro Met Advanced Ceramics Inc OH

Bomas Machine Specialties Inc MA See ad on pg 81
Bullen OH
CerCo LLC OH
CiDRA Precision Services LLC CT
Du-Co Ceramics Company PA
Elan Technology GA
FCT Ingenieurkeramik GmbH Germany
FELDCO Intl CA
Ferro-Ceramic Grinding Inc MA
Fosbel Inc OH
International Ceramic Engineering MA
Laserage Technology Corp IL
Machined Ceramics Inc KY
Maryland Ceramic & Steatite Co Inc MD
McDanel Advanced Ceramic Technologies LLC PA See ad on pg 61
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
Precision Ceramics FL

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA

Ram Products Inc OH
Refractory Machining Services PA
RocCera LLC NY
Stahli USA Inc WI
Superior Technical Ceramics Corp VT **See ad on pg 63**
Technical Products Inc WI
Valley Design Corp MA
Zircar Zirconia Inc NY

Milling, Custom

Advanced Ceramic Technology CA
AVEKA MN
Bullen OH
CiDRA Precision Services LLC CT
Custom Processing Services PA
Fluid Energy Processing & Equipment Co PA
International Ceramic Engineering MA
MSE Supplies AZ
Powder Processing & Technology LLC IN
Precision Ceramics FL
PremaTech Advanced Ceramics MA
Reade Advanced Materials RI
Refractory Machining Services PA
RocCera LLC NY
Stedman Machine Co IN
Union Process OH
Valley Design Corp MA
Washington Mills Electro Minerals Co NY

Nuclear Materials

Dunhua Zhengxing Abrasive Co Ltd China
Morgan Technical Ceramics Auburn CA
Peter Pugger Mfg Inc CA
Refrac Systems AZ
Verity Technical Consultants LLC OH

Piezoelectrics

APC International Ltd PA
CerPoTech AS Norway
Electrosciences Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Meggitt Piezo Technologies IN
Sparkler Ceramics Pvt Ltd India

Powder Synthesis

CerPoTech AS Norway

Prototypes

Accuratus Corp NJ
Advanced Ceramic Technology CA
Astro Met Advanced Ceramics Inc OH
Bullen OH
CeramTec North America Corp SC
CerCo LLC OH
CoorsTek CO
Du-Co Ceramics Company PA
ESL ElectroScience PA
FCT Ingenieurkeramik GmbH Germany
Goceram AB Sweden
Industrial Ceramic Products Inc OH
International Ceramic Engineering MA
Lithoz GmbH NY
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL

PremaTech Advanced Ceramics MA
Progressive Technology Inc CA
Ram Products Inc OH
Refrac Systems AZ
Robocasting Enterprises LLC NM
RocCera LLC NY
Silicon Carbide Products Inc NY
Technical Products Inc WI
Technology Assessment and Transfer Inc (TA&T) MD
Tethon 3D NE

Refractory Installation

Diamorph AB UK
Fosbel Inc OH
Refractory Consulting Services OH
Riverside Refractories Inc AL
Wistra GmbH Germany

Screen Printing

Aremco Products Inc NY
Gwent Electronic Materials Ltd UK
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Screening, Custom
AVEKA MN
CerPoTech AS Norway
Fluid Energy Processing & Equipment Co PA
General Spray LLC NJ
Reade Advanced Materials RI

Seals
Astro Met Advanced Ceramics Inc OH
Bharat Heavy Electricals Ltd NY
CerCo LLC OH
Dunhua Zhengxing Abrasive Co Ltd China
Elan Technology GA
Morgan Technical Ceramics Auburn CA
Ortech Inc CA
P-Ker Engineering NY
Precision Ceramics FL
Refrac Systems AZ
Saint-Gobain High Performance Ceramics & Refractories MA
Texers Technical Ceramics Inc Canada

Spray Drying
Arch Maintenance Services GA
AVEKA MN
CeramTec North America Corp SC
CerPoTech AS Norway
Dorst America Inc PA
Elan Technology GA
General Spray LLC NJ

Powder Processing & Technology LLC IN
Verity Technical Consultants LLC OH

Superconductors
Precision Ceramics FL

Toll Blending, Processing
AVEKA MN
CerPoTech AS Norway
Custom Processing Services PA
Euro Support Advanced Materials The Netherlands
Fluid Energy Processing & Equipment Co PA
Fusion Ceramics Inc OH
General Spray LLC NJ
Gwent Electronic Materials Ltd UK
Peter Pugger Mfg Inc CA
Powder Processing & Technology LLC IN
Reade Advanced Materials RI
Refrac Systems AZ
TAM Ceramics NY

Toll Firing, Contract
ACCCO Inc/Burley Clay Products Co OH
Advanced Ceramics Manufacturing AZ
Astro Met Advanced Ceramics Inc OH
CeramTec North America Corp SC
Christy Minerals LLC MO
FCT Ingenieurkeramik GmbH Germany
FCT Systeme GmbH Germany

Harrop Industries Inc OH **See ad on pg 58**
Ipsen Ceramics IL
Oxy-Gon Industries Inc NH **See ad on pg 89**
Refrac Systems AZ
Sunrock Ceramics Co IL
TAM Ceramics NY
TevTech LLC MA **See ad on pg 83**

Ultrasonic Machining
Ferro-Ceramic Grinding Inc MA
PremaTech Advanced Ceramics MA

DECORATING

Coating Equipment
Cerakote Ceramic Coatings OR
Cerinnov France
Haiku Tech Europe BV The Netherlands
Industrial Hard Carbon LLC NC
Laguna Clay Co CA

Colors
Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Cerlase France
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Decal Equipment
Art On Ceramic NY
Cerinnov France

Decals
Cerlase France
IPS Ceramics LTD UK
Milestone Decal Art LLC NY

Decorating Equipment
Cerinnov France

Decorating Supplies
Ceramic Color & Chemical Mfg Co PA

Enamels
Ceramic Color & Chemical Mfg Co PA
Cerinnov France
Cerlase France
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden

Engobes
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Frits
Ceradyne Inc, a 3M Co KY
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden
Trinity Ceramic Supply Inc TX

Glazes
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Cerlase France
Fusion Ceramics Inc OH
Laguna Clay Co CA
Mason Color Works Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden
Sheffield Pottery MA

Glazing Equipment
Arlimin Industries CO
Cerinnov France
Du-Co Ceramics Company PA
HED Intl Inc NJ

Inks
American Art Clay Co Inc IN
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK
Zibo Guangtong Chemical Co Ltd China

Lehrs
Nabertherm Inc DE
Recco Furnaces CA

Pigments
Arlimin Industries CO
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH

Porcelain Enamels
Cerlase France
Fusion Ceramics Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden

Precious Metals
FELDCO Intl CA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK

Screen Printing Equipment
Aremco Products Inc NY
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL

Silver Pastes, Conducting
Master Bond Inc NJ

Spray Booths
American Art Clay Co Inc IN
Laguna Clay Co CA

Stains
Ceramic Color & Chemical Mfg Co PA
Fusion Ceramics Inc OH
Mason Color Works Inc OH
Sheffield Pottery MA
Trinity Ceramic Supply Inc TX

Used Equipment

Mohr Corp MI **See ad on pg 79**

■ DINNERWARE

China, Fine
Cerinnov France
StudioLX - Home Decor IL

Earthenware
Petro Mold Company PA
Sheffield Pottery MA
Tethon 3D NE

Porcelain
Akron Porcelain & Plastics Co OH
Art On Ceramic NY
Cerinnov France
Sheffield Pottery MA
StudioLX - Home Decor IL
Tethon 3D NE
Wistra GmbH Germany

Stoneware
ACCCO Inc/Burley Clay Products Co OH
Petro Mold Company PA
Sheffield Pottery MA
Tethon 3D NE

Tableware, Glass
RISE Research Institutes of Sweden, RISE Glass Sweden
StudioLX - Home Decor IL

■ DRYING, FIRING & MELTING

Blowers
Zenith China

Burners
Air Products PA
Ceritherm France
Furnace Products & Services Inc PA
HED Intl Inc NJ
Swindell Dressler Intl Co PA
Zenith China

Calciners
Applied Test Systems Inc PA
Euro Support Advanced Materials The Netherlands
Fluid Energy Processing & Equipment Co PA
Harper International Corp NY — **See ad on pg 77**
HED Intl Inc NJ
Keith Co CA
Nabertherm Inc DE
Raymond Bartlett Snow
Recco Furnaces CA
Thermcraft Inc NC — **See ad on pg 88**
Wistra GmbH Germany
Wyssmont Co NJ
Zenith China

Cars, Dryer
Zenith China

Cars, Kiln
Basic Machinery Co Inc NC
Ceritherm France
Deltech Inc CO — **See ad on pg 85**
Harrop Industries Inc OH — **See ad on pg 58**
Keith Co CA
Magneco Metrel Inc IL
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany
Zenith China

Cars, Transfer
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan

Controllers
Applied Test Systems Inc PA
Carbolite Gero UK — **See ad on pg 101**
General Glass Equipment Co NJ
HED Intl Inc NJ
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Zenith China

Controllers, Combustion
Air Products PA
Fives north American Combustion Inc OH

Controllers, Furnace
Carbolite Gero UK — **See ad on pg 101**
Nabertherm Inc DE

Thermcraft Inc NC — **See ad on pg 88**
Verder Scientific Inc PA — **See ad on pg 101**

Controllers, Temperature
Applied Test Systems Inc PA
Datapaq Inc NH
Edward Orton Jr Ceramic Foundation OH
Nabertherm Inc DE
Optocon AG Germany
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Verder Scientific Inc PA — **See ad on pg 101**

Data Acquisition Systems
Applied Test Systems Inc PA
Datapaq Inc NH
HED Intl Inc NJ
Nabertherm Inc DE

Dryers
Aadvanced Machinery Inc MI
Applied Test Systems Inc PA
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Cerlase France
Cober Muegge LLC CT
Fives north American Combustion Inc OH
Fluid Energy Processing & Equipment Co PA
Furnace Products & Services Inc PA
Goceram AB Sweden
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Harrop Industries Inc OH — **See ad on pg 58**
HED Intl Inc NJ
Keith Co CA
Laeis GmbH Luxembourg
Littleford Day Inc MI
Nabertherm Inc DE
Raymond Bartlett Snow
Spray Drying Systems Inc MD
Swindell Dressler Intl Co PA
Wyssmont Co NJ
Zibo Guangtong Chemical Co Ltd China

Electrodes
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
I Squared R Element Co NY — **See ad on pg 89**

Environmental Control Systems
Air Products PA
Applied Test Systems Inc PA
Control Instruments Corp NJ

Furnaces
American Isostatic Presses OH
Applied Test Systems Inc PA
Carbolite Gero UK — **See ad on pg 101**

Centorr Vacuum Industries NH — **See ad on pg 87**
CM Furnaces Inc NJ
Cober Muegge LLC CT
Deltech Inc CO — **See ad on pg 85**
FCT Systeme GmbH Germany
Furnace Products & Services Inc PA
Gasbarre Products Inc PA — **See ad on pg 95**
Goceram AB Sweden
Harper International Corp NY — **See ad on pg 77**

Harrop Industries Inc OH — **See ad on pg 58**
HED Intl Inc NJ
L&L Kiln Mfg Inc NJ

L&L Special Furnace Co Inc PA — **See ad on pg 87**
Materials Research Furnaces Inc NH
Mohr Corp MI — **See ad on pg 79**
Nabertherm Inc DE
Oxy-Gon Industries Inc NH — **See ad on pg 89**
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Quintus Technologies LLC OH
RD Webb Company Inc MA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA

TevTech LLC MA — **See ad on pg 83**
The Furnace Source LLC CT
Thermcraft Inc NC — **See ad on pg 88**
Trent Inc PA

Verder Scientific Inc PA — See ad on pg 101
Wyssmont Co NJ

Furnaces, Alternative Fuels

Ceritherm France
Harper International Corp NY — See ad on pg 77
Harrop Industries Inc OH — See ad on pg 58
Keith Co CA
Recco Furnaces CA
Swindell Dressler Intl Co PA
Thermcraft Inc NC — See ad on pg 88
Verder Scientific Inc PA — See ad on pg 101

Furnaces, Electric

Aadvanced Machinery Inc MI
American Isostatic Presses OH
Applied Test Systems Inc PA
Aremco Products Inc NY
Carbolite Gero UK — See ad on pg 101

Centorr Vacuum Industries NH — See ad on pg 87
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ

Deltech Inc CO — See ad on pg 85
Deltech Kiln and Furnace Design, LLC CO
FCT Systeme GmbH Germany
Gasbarre Products Inc PA — See ad on pg 95
Harper International Corp NY — See ad on pg 77
Harrop Industries Inc OH — See ad on pg 58
HED Intl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA — See ad on pg 87
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Oxy-Gon Industries Inc NH — See ad on pg 89
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
Seco/Warwick Corp PA
The Furnace Source LLC CT
Thermcraft Inc NC — See ad on pg 88
Trent Inc PA
Verder Scientific Inc PA — See ad on pg 101
Winner Technology The Republic of Korea
Wyssmont Co NJ
Zircar Zirconia Inc NY

Furnaces, Gas

Aadvanced Machinery Inc MI
Ceramic Services Inc PA
Ceritherm France
Harper International Corp NY — See ad on pg 77
Harrop Industries Inc OH — See ad on pg 58
HED Intl Inc NJ

Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA — **See ad on pg 87**
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Recco Furnaces CA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA
The Furnace Source LLC CT
Thermcraft Inc NC — **See ad on pg 88**
Wyssmont Co NJ

Furnaces, Glass-Melting

Applied Test Systems Inc PA
Carbolite Gero UK — **See ad on pg 101**
Ceradyne Inc, a 3M Co KY
CM Furnaces Inc NJ

Deltech Inc CO — **See ad on pg 85**
Deltech Kiln and Furnace Design, LLC CO
Furnace Products & Services Inc PA
General Glass Equipment Co NJ
Magneco Metrel Inc IL
Nabertherm Inc DE
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RISE Research Institutes of Sweden, RISE Glass Sweden
Verder Scientific Inc PA — **See ad on pg 101**
Zircar Zirconia Inc NY

Furnaces, High-Temperature

Applied Test Systems Inc PA
Cancarb Limited Canada
Carbolite Gero UK — **See ad on pg 101**
Centorr Vacuum Industries NH — **See ad on pg 87**
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
Dalmia Inst of Scientific & Industrial Research India
Deltech Inc CO — **See ad on pg 85**
Detroit Process Machinery MI
FCT Systeme GmbH Germany
Furnace Products & Services Inc PA
Gasbarre Products Inc PA — **See ad on pg 95**
Harper International Corp NY — **See ad on pg 77**
Harrop Industries Inc OH — **See ad on pg 58**
HED Intl Inc NJ
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Nutec Bickley Mexico

Oxy-Gon Industries Inc NH — **See ad on pg 89**
Plansee SE MA
PSH Kilns & Furnaces Canada
Quintus Technologies LLC OH
RD Webb Company Inc MA
Seco/Warwick Corp PA
Swindell Dressler Intl Co PA
The Furnace Source LLC CT

Thermcraft Inc NC — **See ad on pg 88**
Verder Scientific Inc PA — **See ad on pg 101**
Winner Technology The Republic of Korea
Zircar Zirconia Inc NY

Furnaces, Laboratory

Carbolite Gero UK — **See ad on pg 101**
Centorr Vacuum Industries NH — **See ad on pg 87**
CM Furnaces Inc NJ
Cober Muegge LLC CT
Deltech Inc CO — **See ad on pg 85**
Deltech Kiln and Furnace Design, LLC CO
FCT Systeme GmbH Germany
Harper International Corp NY — **See ad on pg 77**
L&L Special Furnace Co Inc PA — **See ad on pg 87**
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Nutec Bickley Mexico
Oxy-Gon Industries Inc NH — **See ad on pg 89**
RD Webb Company Inc MA
RocCera LLC NY
The Furnace Source LLC CT
Verder Scientific Inc PA — **See ad on pg 101**
Winner Technology The Republic of Korea
Zircar Zirconia Inc NY

Furnaces, Vacuum

Applied Test Systems Inc PA
AVS Inc MA
Centorr Vacuum Industries NH — **See ad on pg 87**
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Gasbarre Products Inc PA — **See ad on pg 95**
Goceram AB Sweden
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Nutec Bickley Mexico

OXY-GON INDUSTRIES, INC.
P.O. Box 40, Epsom, NH 03234-0040
(603) 736-8422 • Fax (603) 736-8734
e-mail: sales@oxy-gon.com
website: www.oxy-gon.com

Oxy-Gon Industries Inc NH — **See ad on pg 89**
RocCera LLC NY
Seco/Warwick Corp PA

The Furnace Source LLC CT
Verder Scientific Inc PA — See ad on pg 101

Heating Elements

Applied Test Systems Inc PA
CM Furnaces Inc NJ
Hotek Alliance Ltd Zibo

I Squared R Element Co NY — See ad on pg 89
Keith Co CA
L&L Kiln Mfg Inc NJ
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH — See ad on pg 89
Plansee SE MA
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Seco/Warwick Corp PA
Thermal Products Co Inc GA
Thermcraft Inc NC — See ad on pg 88
Trent Inc PA
Verder Scientific Inc PA — See ad on pg 101
Winner Technology The Republic of Korea

Humidification Systems

CM Furnaces Inc NJ

Kilns

Applied Test Systems Inc PA
Carbolite Gero UK — See ad on pg 101
Ceramic Services Inc PA
Ceritherm France
Detroit Process Machinery MI
FCT Systeme GmbH Germany
Fives north American Combustion Inc OH
Furnace Products & Services Inc PA
Harper International Corp NY — See ad on pg 77
Harrop Industries Inc OH — See ad on pg 58
HED Intl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ

L&L Special Furnace Co Inc PA — See ad on pg xx
Laeis GmbH Luxembourg
Laguna Clay Co CA
Lucifer Furnaces Inc PA
Mohr Corp MI — See ad on pg 79
Nutec Bickley Mexico
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
RocCera LLC NY
Takasago Industry Co Ltd Japan
Thermcraft Inc NC — See ad on pg 88
Wistra GmbH Germany

Kilns, Bell

Carbolite Gero UK — See ad on pg 101
Ceramic Services Inc PA

Ceritherm France
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED Intl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**
Aadvanced Machinery Inc MI
American Art Clay Co Inc IN
Applied Test Systems Inc PA
Carbolite Gero UK **See ad on pg 101**
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED Intl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**
Verder Scientific Inc PA **See ad on pg 101**

Kilns, Box
Nutec Bickley Mexico

Kilns, Chamber
Carbolite Gero UK **See ad on pg 101**
Ceritherm France
Harrop Industries Inc OH **See ad on pg 58**
L&L Kiln Mfg Inc NJ
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**
Verder Scientific Inc PA **See ad on pg 101**

Kilns, Conveyor
Ceramic Services Inc PA
Ceritherm France
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED Intl Inc NJ
Keith Co CA
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA

Kilns, Elevator
Aadvanced Machinery Inc MI
Applied Test Systems Inc PA
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Euro Support Advanced Materials The Netherlands
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED Intl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan

Kilns, Envelope
Ceritherm France
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Nabertherm Inc DE
Nutec Bickley Mexico
PSH Kilns & Furnaces Canada
Recco Furnaces CA
Swindell Dressler Intl Co PA

Kilns, Periodic (Batch)
Aadvanced Machinery Inc MI
Carbolite Gero UK **See ad on pg 101**
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
RD Webb Company Inc MA
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**

Kilns, Pusher Plate
Ceritherm France
CM Furnaces Inc NJ
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Ipsen Ceramics IL
Keith Co CA
Lucifer Furnaces Inc PA
Nutec Bickley Mexico
Recco Furnaces CA

Kilns, Roller Hearth
Ceramic Services Inc PA
Ceritherm France
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Keith Co CA
Lucifer Furnaces Inc PA
Nutec Bickley Mexico
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany

Kilns, Rotary
Ceritherm France
CM Furnaces Inc NJ
Deltech Inc CO **See ad on pg 85**
Fives north American Combustion Inc OH
Furnace Products & Services Inc PA
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Lucifer Furnaces Inc PA
Nutec Bickley Mexico
Raymond Bartlett Snow
Thermcraft Inc NC **See ad on pg 88**
Verder Scientific Inc PA **See ad on pg 101**

Kilns, Shuttle
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
HED INtl Inc NJ
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**
Wistra GmbH Germany

Kilns, Test/Lab
American Art Clay Co Inc IN
Applied Test Systems Inc PA
Carbolite Gero UK **See ad on pg 101**
Ceramic Services Inc PA
CM Furnaces Inc NJ
Cober Muegge LLC CT
FCT Systeme GmbH Germany
Harper International Corp NY **See ad on pg 77**
Harrop Industries Inc OH **See ad on pg 58**
Keith Co CA
L&L Kiln Mfg Inc NJ
L&L Special Furnace Co Inc PA **See ad on pg 87**
Lucifer Furnaces Inc PA
Nabertherm Inc DE
Nutec Bickley Mexico
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
RD Webb Company Inc MA
Recco Furnaces CA
Takasago Industry Co Ltd Japan
Thermcraft Inc NC **See ad on pg 88**
Verder Scientific Inc PA **See ad on pg 101**

Kilns, Tunnel (Continuous)
Applied Test Systems Inc PA
Basic Machinery Co Inc NC
Ceramic Services Inc PA
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
Deltech Inc CO **See ad on pg 85**
Euro Support Advanced Materials The Netherlands

Harper International Corp NY — **See ad on pg 77**

Harrop Industries Inc OH — **See ad on pg 58**
Keith Co CA
Nutec Bickley Mexico
Recco Furnaces CA
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
Wistra GmbH Germany

Lehrs

Ceramic Services Inc PA
Harrop Industries Inc OH — **See ad on pg 58**
Keith Co CA
Recco Furnaces CA

Microwave Systems

Bharat Heavy Electricals Ltd NY
Ceralink Inc NY
Ceritherm France
CM Furnaces Inc NJ
Cober Muegge LLC CT
Gerling Applied Engineering Inc CA
Harper International Corp NY — **See ad on pg 77**

Harrop Industries Inc OH — **See ad on pg 58**
RocCera LLC NY
Takasago Industry Co Ltd Japan

Oxygen Supply

Air Products PA

Process/Quality Control Systems

Applied Test Systems Inc PA
Datapaq Inc NH
General Glass Equipment Co NJ
Materials Research Furnaces Inc NH

Pyrometric Cones/Plaques

American Art Clay Co Inc IN
Edward Orton Jr Ceramic Foundation OH
Industrial Ceramic Products Inc OH
PSH Kilns & Furnaces Canada
Trinity Ceramic Supply Inc TX

Sensors, Temperature

Datapaq Inc NH
Penn Tool Co NJ
Zibo Guangtong Chemical Co Ltd China

Thermocouples & Accessories

AdValue Technology LLC AZ — **See ad on pg 43**
American Art Clay Co Inc IN
American Isostatic Presses OH
CM Furnaces Inc NJ
Datapaq Inc NH
Gasbarre Products Inc PA — **See ad on pg 95**
Harrop Industries Inc OH — **See ad on pg 58**
Keith Co CA
Leico Industries Inc NJ
Materials Research Furnaces Inc NH
McDanel Advanced Ceramic Technologies LLC PA — **See ad on pg 61**
PSH Kilns & Furnaces Canada
Quintus Technologies LLC OH
Recco Furnaces CA
Verder Scientific Inc PA — **See ad on pg 101**

■ EDUCATION & RESOURCES

Associations & Societies

Assoc of American Ceramic Component Manufacturers (AACCM) OH
Brick Industry Assn VA
Glass Mfg Industry Council OH
Indian Ceramic Society India
International Centre for Diffraction Data PA
Journal of the American Ceramic Society OH
SAMPE CA
The American Ceramic Society OH

Books

APC International Ltd PA
Bharat Heavy Electricals Ltd NY
Journal of the American Ceramic Society OH
SAMPE CA
Sheffield Pottery MA

Computer Software

Matmatch Germany

Continuing Education

Alfred University NY
Arizona State University AZ
CelSian Glass & Solar BV The Netherlands
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
International Centre for Diffraction Data PA
Jenike & Johanson Inc MA
JTF Microscopy Services, LLC NY
Spontaneous Materials CO
Tethon 3D NE

Degree Programs, ABET Accredited

Alfred University NY
Case Western Reserve University OH
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO
Rensselaer Polytechnic Inst NY

Degree Programs, Ceramic

The American Ceramic Society OH
Alfred University NY
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO

Degree Programs, Glass Engrg Science

Alfred University NY
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany

Degree Programs, Materials Science
Alfred University NY
Arizona State University AZ
Case Western Reserve University OH
Fraunhofer Institute for Ceramic Technologies and Systems IKTS Germany
Massachusetts Inst of Technology MA
Missouri University of Science and Technology MO
Rensselaer Polytechnic Inst NY

Employment Services
SAMPE CA

Publications
American Ceramic Society Bulletin OH
American Scientific Publishers CA
Chemical Abstracts Service OH
GrainBound LLC PA
Indian Ceramic Society India
Journal of the American Ceramic Society OH

■ ELECTRICAL/ELECTRONIC CERAMICS

Antennas, Dielectric
Euro Support Advanced Materials The Netherlands
O'Keefe Ceramics Inc CO
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Capacitors
Associated Ceramics & Technology Inc PA **See ad on pg 65**
AVX Corp SC
Euro Support Advanced Materials The Netherlands
Ferro-Ceramic Grinding Inc MA
Induceramic Canada
Murata Manufacturing Co Ltd Japan
Polymer Innovations Inc CA

Ceramic-Brazed Assemblies
AdTech Ceramics TN
CeramTec North America Corp SC

Elcon Precision LLC CA **See ad on pg 107**
Induceramic Canada
Morgan Technical Ceramics Auburn CA
Precision Ferrites and Ceramics Inc CA

Conductors
AdTech Ceramics TN
CerPoTech AS Norway
ESL ElectroScience PA
Master Bond Inc NJ
norECs AS Norway

Crystals
Induceramic Canada
Kyocera International Inc CA
Momentive Performance Materials Inc NY
MSE Supplies AZ
TevTech LLC MA **See ad on pg 83**

Dielectrics
AVX Corp SC
Centerline Technologies OH
CerPoTech AS Norway
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
Morgan Advanced Materials CA
NGK Spark Plug Co Ltd Japan
Pacific Ceramics Inc CA

Ferrites & Ferromagnetics
Advanced Ceramic Technology CA
Pacific Ceramics Inc CA
Polymer Innovations Inc CA
Precision Ferrites and Ceramics Inc CA
Spontaneous Materials CO

Filters, Dielectric
CerPoTech AS Norway
Euro Support Advanced Materials The Netherlands
Murata Manufacturing Co Ltd Japan
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Fuel Cells, Solid Oxide
AdTech Ceramics TN
Associated Ceramics & Technology Inc PA **See ad on pg 65**
Bharat Heavy Electricals Ltd NY
Cancarb Limited Canada
CerPoTech AS Norway
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Gwent Electronic Materials Ltd UK
H.C. Starck GmbH Germany
H.C. Starck Surface Technology and Ceramic Powders GmbH Germany
Morgan Technical Ceramics Auburn CA
Nexceris LLC OH
norECs AS Norway
Polymer Innovations Inc CA
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

High-Voltage Insulators
Akron Porcelain & Plastics Co OH
Bharat Heavy Electricals Ltd NY
Ceramco Inc NH
CeramTec North America Corp SC
Du-Co Ceramics Company PA
Elcon Precision LLC CA **See ad on pg 107**
Morgan Technical Ceramics Auburn CA
Precision Ferrites and Ceramics Inc CA
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**

Hybrid Circuits & Packages
AdTech Ceramics TN
AVX Corp SC
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Precision Ferrites and Ceramics Inc CA

IC Packages
AdTech Ceramics TN
Kyocera International Inc CA
NGK Spark Plug Co Ltd Japan

Insulators, Electrical/Electronic
Accuratus Corp NJ
AdTech Ceramics TN
AdValue Technology LLC AZ **See ad on pg 43**
Akron Porcelain & Plastics Co OH
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
CeramTec North America Corp SC
CerCo LLC OH
Du-Co Ceramics Company PA
ER Advanced Ceramics Inc OH
ESL ElectroScience PA
Federal-Mogul MI
Maryland Ceramic & Steatite Co Inc MD
Materion Ceramics AZ
Morgan Technical Ceramics Auburn CA
NEVZ-Ceramics, Close JSC Russia
P-Ker Engineering NY
Precision Ferrites and Ceramics Inc CA
Sonya Ceramics (Export Division) India
Superior Technical Ceramics Corp VT **See ad on pg 63**
Toto Ltd Japan
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zircoa Inc OH

Magnets
Spontaneous Materials CO

Microwave Packages
AdTech Ceramics TN
Kyocera International Inc CA
Precision Ferrites and Ceramics Inc CA

Multilayer Ceramic Capacitors
Euro Support Advanced Materials The Netherlands
Murata Manufacturing Co Ltd Japan
Polymer Innovations Inc CA

Multilayer Ceramics, AlN
AdTech Ceramics TN
NEVZ-Ceramics, Close JSC Russia
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**

Multilayer Ceramics, Custom
AdTech Ceramics TN
EBL Products Inc CT
Euro Support Advanced Materials The Netherlands
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**

Piezoelectrics
APC International Ltd PA
AVX Corp SC
EBL Products Inc CT
Meggitt Piezo Technologies IN
Morgan Advanced Materials CA
Polymer Innovations Inc CA
Sparkler Ceramics Pvt Ltd India

Resistors, Thick-Film
ESL ElectroScience PA
Murata Manufacturing Co Ltd Japan
Polymer Innovations Inc CA

Resonators
AVX Corp SC
Murata Manufacturing Co Ltd Japan
NGK Spark Plug Co Ltd Japan
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

RF Components
AdTech Ceramics TN
Advanced Ceramic Technology CA
Advanced Energy CO
Murata Manufacturing Co Ltd Japan
Precision Ferrites and Ceramics Inc CA
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Semiconductors
Cancarb Limited Canada
Elcon Precision LLC CA **See ad on pg 107**
Momentive Performance Materials Inc NY
NEVZ-Ceramics, Close JSC Russia

Semiconductor Energy Laboratory Co Ltd Japan
See ad on pg 91

Toto Ltd Japan

Sensors
AdTech Ceramics TN
AVX Corp SC
Bullen OH
CeramTec North America Corp SC
EBL Products Inc CT
Gwent Electronic Materials Ltd UK
Murata Manufacturing Co Ltd Japan
Neoptix Canada
Optocon AG Germany
Polymer Innovations Inc CA
Quality Thermistor Inc ID
Sparkler Ceramics Pvt Ltd India
Technisonic Research Inc CT

Spark Plugs
Associated Ceramics & Technology Inc PA
See ad on pg 65

CerCo LLC OH
Federal-Mogul MI
Gwent Electronic Materials Ltd UK
NGK Spark Plug Co Ltd Japan

Substrates, Alumina
Accuratus Corp NJ
AdTech Ceramics TN
Bullen OH
Centerline Technologies OH
CeramTec North America Corp SC
CoorsTek CO
Du-Co Ceramics Company PA
Laserage Technology Corp IL
NEVZ-Ceramics, Close JSC Russia
NGK Spark Plug Co Ltd Japan
Ortech Inc CA
Saint-Gobain norPro OH
Toto Ltd Japan
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China
See ad on pg 93

Substrates, Aluminum Nitride
Accuratus Corp NJ
AdTech Ceramics TN
Bullen OH
Centerline Technologies OH
CoorsTek CO
Laserage Technology Corp IL
MSE Supplies AZ
NEVZ-Ceramics, Close JSC Russia
Ortech Inc CA
Starfire Systems Inc NY
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China
See ad on pg 93

Substrates, Glass
Accuratus Corp NJ
Bullen OH
Centerline Technologies OH
Laserage Technology Corp IL
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Valley Design Corp MA
Accuratus Corp NJ
Akron Porcelain & Plastics Co OH
Bullen OH
Centerline Technologies OH
CoorsTek CO
Du-Co Ceramics Company PA
MSE Supplies AZ
NGK Spark Plug Co Ltd Japan
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Valley Design Corp MA
Zircar Zirconia Inc NY

Substrates, Silicon Carbide
Bullen OH
Centerline Technologies OH
Ortech Inc CA
Toto Ltd Japan
Valley Design Corp MA

Superconductors, High-Temperature
Xiamen Innovacera Advanced Materials Co Ltd China
See ad on pg 93

Tapes
Du-Co Ceramics Company PA
ESL ElectroScience PA
Euro Support Advanced Materials The Netherlands
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Maryland Ceramic & Steatite Co Inc MD
Polymer Innovations Inc CA

Thermistors
AVX Corp SC
Gwent Electronic Materials Ltd UK
Murata Manufacturing Co Ltd Japan
Polymer Innovations Inc CA
Quality Thermistor Inc ID

Transducers
APC International Ltd PA
CSC Force Measurement Inc MA
EBL Products Inc CT
Meggitt Piezo Technologies IN
Neoptix Canada
Sparkler Ceramics Pvt Ltd India
Technisonic Research Inc CT

Transformers
RoMan Manufacturing MI
Warner Power LLC MI

Ultrasonic Ceramics
APC International Ltd PA
EBL Products Inc CT
Meggitt Piezo Technologies IN

Varistors
AVX Corp SC
Kyocera International Inc CA
Polymer Innovations Inc CA

FABRICATING & FINISHING

Abrasives

Allied High Tech Products Inc CA
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dunhua Zhengxing Abrasive Co Ltd China
Dynacut Inc PA
Electro Abrasives Corp NY
Engis Corp IL
FELDCO Intl CA
Jet Edge Waterjet Systems MN
Reade Advanced Materials RI
Saint-Gobain Abrasives MA
Sigmadiamant Spain
Stahli USA Inc WI

Superior Graphite Co IL **See ad on pg 73**
Suntech Advanced Ceramics (Shenzhen) Co Ltd China
Washington Mills Electro Minerals Co NY

Brickmaking Equipment

Basic Machinery Co Inc NC
EZG Manufacturing Inc OH **Inside front cover**
Laeis GmbH Luxembourg
Stedman Machine Co IN

Casting Equipment, Pressure

American Isostatic Presses OH
Cerinnov France
Cerlase France
Dorst America Inc PA
HED INtl Inc NJ
Laguna Clay Co CA
Maryland Ceramic & Steatite Co Inc MD

Casting Equipment, Tape

Ferro-Ceramic Grinding Inc MA
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
HED INtl Inc NJ
Polymer Innovations Inc CA

CNC Mills

Elcon Precision LLC CA **See ad on pg 107**
Liberty Machinery Co IL
OptiPro Systems LLC NY
Penn Tool Co NJ
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Coating Equipment

Allied High Tech Products Inc CA
Cerakote Ceramic Coatings OR
Dynacut Inc PA
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Liberty Machinery Co IL

Cold-End Coatings, Glass

RISE Research Institutes of Sweden, RISE Glass Sweden

Controllers

Dorst America Inc PA
General Glass Equipment Co NJ
Laguna Clay Co CA
Rockwell Automation, Inc WI

Cutting Equipment

Basic Machinery Co Inc NC
Diamond Industrial Tools Inc IL
General Glass Equipment Co NJ
Haiku Tech Inc FL
Jet Edge Waterjet Systems MN
Liberty Machinery Co IL
OptiPro Systems LLC NY
Penn Tool Co NJ
Sigmadiamant Spain
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Cutting Tools

Diacut Inc CO
Dynacut Inc PA
Engis Corp IL
Jet Edge Waterjet Systems MN
New Tech Ceramics Inc IA
Penn Tool Co NJ
Sigmadiamant Spain

CVD Equipment

Advanced Energy CO
Centorr Vacuum Industries NH **See ad on pg 87**
Liberty Machinery Co IL

Deburring Equipment

Engis Corp IL
Liberty Machinery Co IL
Mohr Corp MI **See ad on pg 79**
Penn Tool Co NJ

Diamond Drills

Diamond Industrial Tools Inc IL
Greenlee Diamond Tool Co IL

Diamond Hones

Diamond Industrial Tools Inc IL
Engis Corp IL
Greenlee Diamond Tool Co IL
Saint-Gobain Abrasives MA
Stahli USA Inc WI

Diamond Saw Blades

Allied High Tech Products Inc CA
Aremco Products Inc NY
Comtrust Architectural Mesh Co Ltd China
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Liberty Machinery Co IL
Saint-Gobain Abrasives MA
Texers Technical Ceramics Inc Canada

Diamond Saws

Allied High Tech Products Inc CA
Aremco Products Inc NY
Diacut Inc CO
Dynacut Inc PA
Greenlee Diamond Tool Co IL
Liberty Machinery Co IL

Diamond Tools

Diamond Industrial Tools Inc IL
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Penn Tool Co NJ
Saint-Gobain Abrasives MA
Sigmadiamant Spain

Dicing Equipment

Aremco Products Inc NY
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Liberty Machinery Co IL
Nutec Bickley Mexico

Dies

Gasbarre Products Inc PA **See ad on pg 95**
Ram Products Inc OH

Dressing Wheels, Diamond

Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL

Electroplating Equipment

Haiku Tech Inc FL
Liberty Machinery Co IL
Penn Tool Co NJ

Extruders

Aadvanced Machinery Inc MI
American Art Clay Co Inc IN
Basic Machinery Co Inc NC
Detroit Process Machinery MI
Dorst America Inc PA
Ipsen Ceramics IL
Laguna Clay Co CA
Mohr Corp MI **See ad on pg 79**
North Star Equipment Inc WA
Peter Pugger Mfg Inc CA

Feeders

Ingredient Masters Inc OH **See ad on pg 103**
Isoform Ltd UK
Mohr Corp MI **See ad on pg 79**
Wyssmont Co NJ

Forming Equipment

American Isostatic Presses OH
ARBURG GmbH + Co KG Germany
Dorst America Inc PA
HED INtl Inc NJ
Ipsen Ceramics IL
Isoform Ltd UK
Lithoz GmbH NY
Mohr Corp MI **See ad on pg 79**
Quintus Technologies LLC OH
Ram Products Inc OH

Glass Finishing Equipment

General Glass Equipment Co NJ
Liberty Machinery Co IL
Lithoz GmbH NY
OptiPro Systems LLC NY

Glass Forming Equipment

General Glass Equipment Co NJ

Glass Shear Spray

RISE Research Institutes of Sweden, RISE Glass Sweden

Glass Supplies

Ipsen Ceramics IL

Grinders, Centerless

Diamond Industrial Tools Inc IL
Liberty Machinery Co IL
Precision Ferrites and Ceramics Inc CA
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Grinders, Cylindrical
Diamond Industrial Tools Inc IL
Liberty Machinery Co IL
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Grinders, Finished Product
DCM Tech MN
Ipsen Ceramics IL
Liberty Machinery Co IL
OptiPro Systems LLC NY
Stahli USA Inc WI

Grinding Wheels
Allied High Tech Products Inc CA
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
Penn Tool Co NJ
Sigmadiamant Spain
Stahli USA Inc WI

Hydraulic Systems
Isoform Ltd UK
Ram Products Inc OH

Injection-Molding Equipment
ARBURG GmbH + Co KG Germany
Goceram AB Sweden
Mohr Corp MI **See ad on pg 79**
Rockwell Automation, Inc WI
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Jiggering Equipment
Cerinnov France
Ram Products Inc OH

Lapping Equipment
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Liberty Machinery Co IL
OptiPro Systems LLC NY
Sigmadiamant Spain
Stahli USA Inc WI

Lapping Supplies
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dunhua Zhengxing Abrasive Co Ltd China
Engis Corp IL
FELDCO Intl CA
Stahli USA Inc WI

Laser Scribers
Centerline Technologies OH
Cerlase France
Laserage Technology Corp IL

Machining Equipment
Advanced Ceramic Technology CA
Dynacut Inc PA
International Ceramic Engineering MA
Liberty Machinery Co IL
OptiPro Systems LLC NY
Penn Tool Co NJ
Stahli USA Inc WI

Mandrels, Diamond
Diacut Inc CO
Diamond Industrial Tools Inc IL

Engis Corp IL
Greenlee Diamond Tool Co IL

Molds, Case
Petro Mold Company PA
Ram Products Inc OH

Molds, Ceramic-Forming
Akron Porcelain & Plastics Co OH
Cerinnov France
Cerlase France
Goceram AB Sweden
Ipsen Ceramics IL
Isoform Ltd UK
Laeis GmbH Luxembourg
Laguna Clay Co CA
Petro Mold Company PA
Ram Products Inc OH
Viridis3D LLC MA

Molds, Models
Petro Mold Company PA
Ram Products Inc OH
Viridis3D LLC MA

Plasma Etching Systems
Advanced Energy CO
Liberty Machinery Co IL

Pneumatic Systems
Cyclonaire Corp NE
Ingredient Masters Inc OH See ad on pg 103
Ram Products Inc OH
Young Industries Inc PA

Polishing Equipment
Allied High Tech Products Inc CA
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
LECO Corp MI
Liberty Machinery Co IL
OptiPro Systems LLC NY
Penn Tool Co NJ
Sigmadiamant Spain
Stahli USA Inc WI

Polishing Powder & Supplies
Baikowski Malakoff Inc NC
C&L Development Corp CA
Engis Corp IL
Sigmadiamant Spain
Stahli USA Inc WI

Presses, Compacting

Detroit Process Machinery MI
Digital Press Inc PA
Dorst America Inc PA

Gasbarre Products (PTX Pentronix) PA See ad on pg 95
Gasbarre Products Inc PA See ad on pg 95
Mohr Corp MI See ad on pg 79
Quintus Technologies LLC OH

Presses, Dry
Aadvanced Machinery Inc MI
Dorst America Inc PA
Gasbarre Products Inc PA See ad on pg 95
Maryland Ceramic & Steatite Co Inc MD
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Presses, Extrusion
Dorst America Inc PA
Maryland Ceramic & Steatite Co Inc MD
Mohr Corp MI See ad on pg 79
Peter Pugger Mfg Inc CA

Presses, Hot
American Isostatic Presses OH
Centorr Vacuum Industries NH See ad on pg 87
FCT Ingenieurkeramik GmbH Germany
FCT Systeme GmbH Germany
Materials Research Furnaces Inc NH
Oxy-Gon Industries Inc NH See ad on pg 89
Refrac Systems AZ

Presses, Hot Isostatic
American Isostatic Presses OH
AVS Inc MA
FCT Ingenieurkeramik GmbH Germany
Quintus Technologies LLC OH

Presses, Hydraulic
Aadvanced Machinery Inc MI
ARBURG GmbH + Co KG Germany
AVS Inc MA
Digital Press Inc PA
Dorst America Inc PA
Gasbarre Products Inc PA See ad on pg 95
Laeis GmbH Luxembourg
Materials Research Furnaces Inc NH
Mohr Corp MI See ad on pg 79
Ram Products Inc OH

Presses, Isostatic
Aadvanced Machinery Inc MI
American Isostatic Presses OH
Cerinnov France
Cerlase France
Detroit Process Machinery MI
Dorst America Inc PA

Gasbarre Products (PTX Pentronix) PA See ad on pg 95
Gasbarre Products Inc PA See ad on pg 95
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Isoform Ltd UK
Mohr Corp MI See ad on pg 79
Quintus Technologies LLC OH
RocCera LLC NY
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

Presses, Other
ARBURG GmbH + Co KG Germany
Isoform Ltd UK

Presses, Pressure Casting
Cerlase France
Dorst America Inc PA
Peter Pugger Mfg Inc CA
Ram Products Inc OH

Presses, Refractory Shapes
Laeis GmbH Luxembourg

Presses, Rotary
Aadvanced Machinery Inc MI
Materials Research Furnaces Inc NH

Presses, Tile (Ceramic)
Laeis GmbH Luxembourg
Peter Pugger Mfg Inc CA

Pug Mills
Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
Dorst America Inc PA
Mohr Corp MI See ad on pg 79
Peter Pugger Mfg Inc CA
Sheffield Pottery MA
Young Industries Inc PA

PVD Equipment
Liberty Machinery Co IL
Teeter Marketing Services LLC FL

Roofing Tile Machinery
Laeis GmbH Luxembourg

Setting Equipment
Basic Machinery Co Inc NC

Slab Rollers
North Star Equipment Inc WA

Spray Booths
Treibacher Industrie AG Austria

Sputtering Equipment
Advanced Energy CO
FCT Ingenieurkeramik GmbH Germany

Superabrasives
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
Liberty Machinery Co IL
Teeter Marketing Services LLC FL

Surface Modification Systems
Teeter Marketing Services LLC FL

Tilemaking Equipment
Basic Machinery Co Inc NC
Peter Pugger Mfg Inc CA
Ram Products Inc OH

Tools, Modeling
Sheffield Pottery MA
Viridis3D LLC MA

Turning Machines, Insulator
Liberty Machinery Co IL

Ultrasonic Machining Equipment
Bullen OH
International Ceramic Engineering MA
Liberty Machinery Co IL
OptiPro Systems LLC NY

Used Equipment
Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
Cerinnov France
Diamond Industrial Tools Inc IL
Dorst America Inc PA
Dynacut Inc PA
Liberty Machinery Co IL
Mohr Corp MI **See ad on pg 79**
Ram Products Inc OH
Viridis3D LLC MA

Vibratory Finishing Equipment
Liberty Machinery Co IL
Penn Tool Co NJ
Rockwell Automation, Inc WI

Wheels, Cutoff & Grinding
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Liberty Machinery Co IL
Penn Tool Co NJ

Wheels, Diamond
Aremco Products Inc NY
Diacut Inc CO
Diamond Industrial Tools Inc IL
Dynacut Inc PA
Engis Corp IL
Greenlee Diamond Tool Co IL
LECO Corp MI
Sigmadiamant Spain
Stahli USA Inc WI

■ GLASS PRODUCTS

Automotive Glass
Arkema Inc PA
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Schott North America Inc NY **See ad on pg 41**

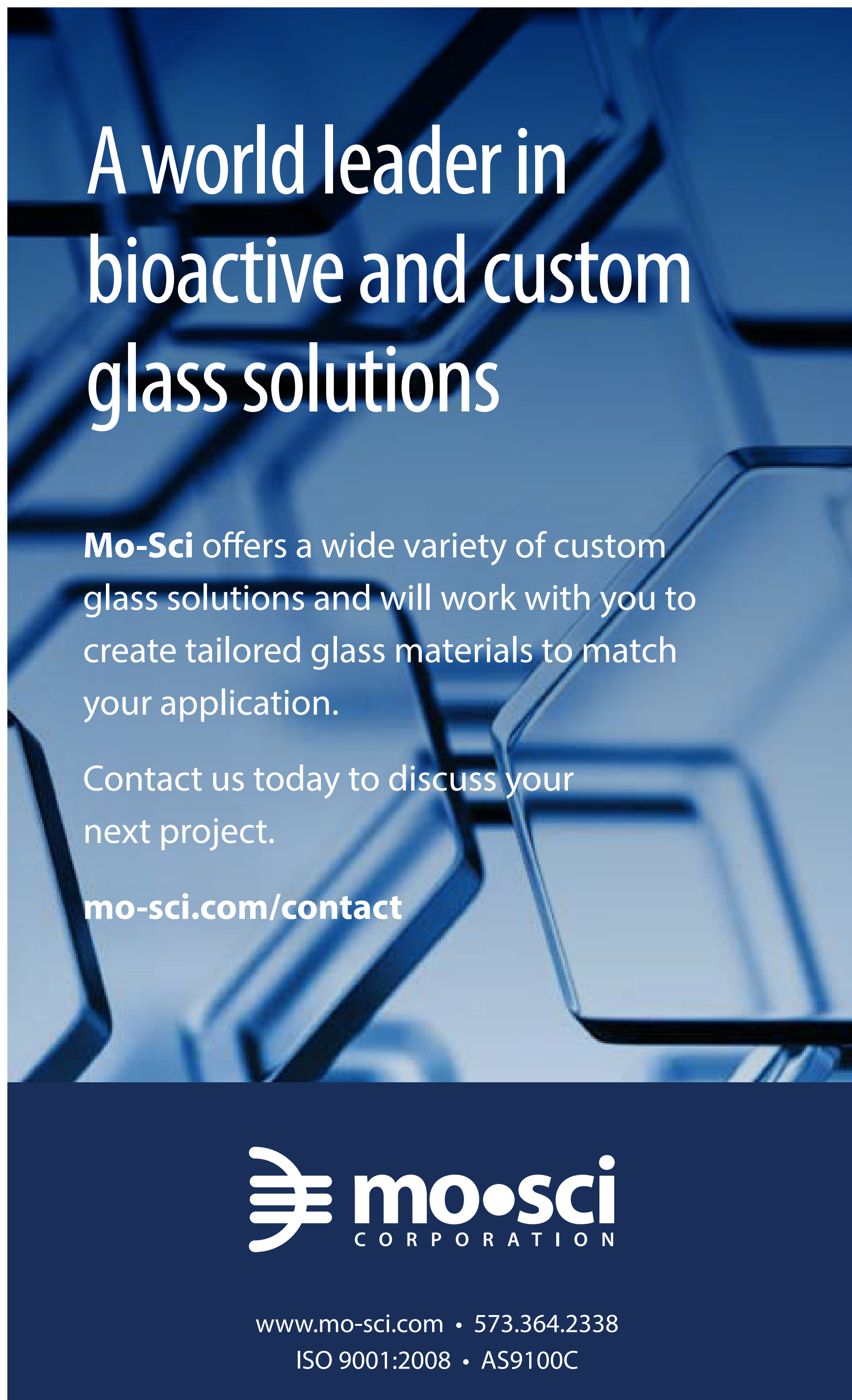
Beads/Spheres
Ceradyne Inc, a 3M Co KY
Maryland Ceramic & Steatite Co Inc MD

Mo-Sci Corp MO **See ad on pg 97**
Reade Advanced Materials RI
Zircoa Inc OH

Bioglass
Ceradyne Inc, a 3M Co KY

Mo-Sci Corp MO **See ad on pg 97**
RISE Research Institutes of Sweden, RISE Glass Sweden
Specialty Glass Inc FL

Borosilicate Glass
Bullen OH
Elan Technology GA



Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden, RISE Glass Sweden
Schott North America Inc NY **See ad on pg 41**

Specialty Glass Inc FL
Valley Design Corp MA

Chemically Strengthened Glass
Arkema Inc PA
Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Saxon Glass Technologies Inc NY
Schott North America Inc NY See ad on pg 41
Vesuvius SC

Container Glass
Arkema Inc PA
Cerinnov France
Owens-Illinois Inc OH
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Vesuvius SC

Fibers, Continuous
Saint-Gobain Recherche France
Verity Technical Consultants LLC OH

Fibers, Optical
Adamant Co Ltd Japan
Corning Incorporated NY
Optocon AG Germany
Schott North America Inc NY See ad on pg 41

Flat & Safety Glass
Arkema Inc PA
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Vesuvius SC

Fused Silica Glass
Accuratus Corp NJ
Arkema Inc PA
Bullen OH
Imerys Refractory Minerals GA
RISE Research Institutes of Sweden, RISE Glass Sweden
Valley Design Corp MA

Glass-Ceramics
Accuratus Corp NJ
Advanced Ceramic Technology CA
Arkema Inc PA
Bullen OH
Cerlase France
Elan Technology GA

Ivoclar Vivadent, Inc See ad on pg 95
Petro Mold Company PA
PremaTech Advanced Ceramics MA

Schott North America Inc NY See ad on pg 41
Specialty Glass Inc FL
StudioLX - Home Decor IL
TevTech LLC MA See ad on pg 83
Texers Technical Ceramics Inc Canada
Valley Design Corp MA
Xiamen Innovacera Advanced Materials Co Ltd China See ad on pg 93

Glass-to-Metal Seals
Elan Technology GA
ESL ElectroScience PA
RISE Research Institutes of Sweden, RISE Glass Sweden
Schott North America Inc NY See ad on pg 41
Specialty Glass Inc FL

Laboratory & Technical Glass
Arkema Inc PA
Garg Process Glass India Pvt Ltd India
LECO Corp MI
RISE Research Institutes of Sweden, RISE Glass Sweden
Saxon Glass Technologies Inc NY
Schott North America Inc NY See ad on pg 41
Specialty Glass Inc FL
TevTech LLC MA See ad on pg 83

Laminated Glass
Arkema Inc PA
RISE Research Institutes of Sweden, RISE Glass Sweden
Vesuvius SC

Laser Glasses
Cerinnov France
Israel Ceramic & Silicate Inst Israel
RISE Research Institutes of Sweden, RISE Glass Sweden

Lenses
TevTech LLC MA See ad on pg 83

Lighting
Osram Sylvania Inc MA

Mirrors
Valley Design Corp MA

Optical & Optoelectronic Ceramics
NEVZ-Ceramics, Close JSC Russia
Specialty Glass Inc FL
TevTech LLC MA See ad on pg 83
Vesuvius SC

Optical Substrates
Bullen OH
FELDCO Intl CA
Schott North America Inc NY See ad on pg 41
Specialty Glass Inc FL
Valley Design Corp MA
Vesuvius SC

Optical Thin Films
FELDCO Intl CA
Schott North America Inc NY See ad on pg 41
TevTech LLC MA See ad on pg 83

Solar
Ceradyne Inc, a 3M Co KY
FELDCO Intl CA
Materion Ceramics AZ
TevTech LLC MA See ad on pg 83
Texers Technical Ceramics Inc Canada
Vesuvius SC

Specialty Glass
Ceradyne Inc, a 3M Co KY
Corning Incorporated NY
Fusion Ceramics Inc OH
Garg Process Glass India Pvt Ltd India
Israel Ceramic & Silicate Inst Israel
Refrac Systems AZ
RISE Research Institutes of Sweden, RISE Glass Sweden
Saint-Gobain Recherche France
Saxon Glass Technologies Inc NY
Schott North America Inc NY See ad on pg 41

Specialty Glass Inc FL
Vesuvius SC

Technical Glass
Ceradyne Inc, a 3M Co KY
Elan Technology GA
RISE Research Institutes of Sweden, RISE Glass Sweden
Saxon Glass Technologies Inc NY

Schott North America Inc NY See ad on pg 41

Specialty GLASS
solving the science of glass™
since 1977
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Phone (813) 855-5779 • e-mail: info@sgiglass.com
www.sgiglass.com

Specialty Glass Inc FL
Vesuvius SC

Tubing & Rod
AdValue Technology LLC AZ See ad on pg 43
Garg Process Glass India Pvt Ltd India
Morgan Advanced Materials CA
Specialty Glass Inc FL

■ LABORATORY EQUIPMENT & SUPPLIES

Chemicals
Arkema Inc PA
Bayville Chemical Supply Co Inc NY
Nanofilm OH
RocCera LLC NY

Colorimeters
HunterLab VA

Density Measurement Instruments
Micromeritics Instrument Corp GA
Particle Technology Labs IL See ad on pg 99
Penn Tool Co NJ
Quantachrome Instruments FL
RocCera LLC NY

Detectors
Control Instruments Corp NJ
Penn Tool Co NJ
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Dimension Measurement Instruments
CSC Force Measurement Inc MA
Penn Tool Co NJ

Dryers
Applied Test Systems Inc PA
Ceramic Services Inc PA
Cober Muegge LLC CT
Detroit Process Machinery MI
EIRICH Machines, Inc IL
Goceram AB Sweden
Littleford Day Inc MI
Recco Furnaces CA
Wyssmont Co NJ

Fiberoptic Illuminators
Carl Zeiss MircoImaging Inc NY

Glass Testing Instruments
Mo-Sci Corp MO **See ad on pg 97**
RISE Research Institutes of Sweden, RISE Glass Sweden
Taber Industries NY

Glassware
AdValue Technology LLC AZ **See ad on pg 43**
Garg Process Glass India Pvt Ltd India
RISE Research Institutes of Sweden, RISE Glass Sweden

Glossimeters
Horiba Instruments Inc CA

Hardness Measurement Instruments
Allied High Tech Products Inc CA

Buehler Ltd IL **See ad on pg 99**
Carl Zeiss MircoImaging Inc NY
LECO Corp MI
Nanoscience Instruments AZ
Penn Tool Co NJ
Taber Industries NY

Hot Plates
RocCera LLC NY
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Crucibles
AdValue Technology LLC AZ **See ad on pg 43**
Ceramco Inc NH
CoorsTek CO
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Robocasting Enterprises LLC NM
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Furnace Tubes
AdValue Technology LLC AZ **See ad on pg 43**
Carbolite Gero UK **See ad on pg 101**
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Nabertherm Inc DE
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zhengzhou Mission Ceramic Products Co Ltd China

Lab Furnaces

Aadvanced Machinery Inc MI
American Isostatic Presses OH
Applied Test Systems Inc PA
AVS Inc MA
Carbolite Gero UK See ad on pg 101

Centorr Vacuum Industries NH See ad on pg 87
Ceramic Services Inc PA
CM Furnaces Inc NJ
CSC Force Measurement Inc MA
Deltech Inc CO See ad on pg 85
Detroit Process Machinery MI
L&L Special Furnace Co Inc PA See ad on pg 87
Lucifer Furnaces Inc PA
Materials Research Furnaces Inc NH
Nabertherm Inc DE
Oxy-Gon Industries Inc NH See ad on pg 89
Paragon Industries LP TX
RD Webb Company Inc MA

TevTech LLC MA See ad on pg 83
The Furnace Source LLC CT
Thermcraft Inc NC See ad on pg 88
Trent Inc PA
Verder Scientific Inc PA See ad on pg 101
Zhengzhou Mission Ceramic Products Co Ltd China
ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Light Sources

Allied High Tech Products Inc CA
Carl Zeiss MircoImaging Inc NY
Spectronics Corp NY

Mechanical Property Measurement Instruments

Applied Test Systems Inc PA
Buehler Ltd IL See ad on pg 99
BuzzMac Intl LLC ME
CSC Force Measurement Inc MA
Nanoscience Instruments AZ
TA Instruments DE
Taber Industries NY

Microscopes, Hot Stages

Carl Zeiss MircoImaging Inc NY
Dalmia Inst of Scientific & Industrial Research India
TA Instruments DE

Microscopes, Interference

Buehler Ltd IL See ad on pg 99
Carl Zeiss MircoImaging Inc NY

Microscopes, Other

AdValue Technology LLC AZ See ad on pg 43
Allied High Tech Products Inc CA
Carl Zeiss MircoImaging Inc NY
Nanoscience Instruments AZ
TA Instruments DE

Microscopes, Polarizing

Buehler Ltd IL See ad on pg 99
Carl Zeiss MircoImaging Inc NY
JTF Microscopy Services, LLC NY

Microscopes, Reflected Light

Allied High Tech Products Inc CA
Buehler Ltd IL See ad on pg 99
Carl Zeiss MircoImaging Inc NY
LECO Corp MI

Microscopes, Scanning Electron

Nanoscience Instruments AZ
SEMTech Solutions Inc UK

Microscopes, Transmission Electron

Horiba Instruments Inc CA

Mills, Laboratory

Advanced Ceramics Manufacturing AZ
Custom Processing Services PA
Detroit Process Machinery MI
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Ivoclar Vivadent, Inc See ad on pg 95
MSE Supplies AZ
Stedman Machine Co IN
Union Process OH

Mixers, Laboratory

Custom Processing Services PA
Detroit Process Machinery MI
EIRICH Machines, Inc IL
Fritsch GmbH - Milling and Sizing Germany
Lancaster Products PA
Littleford Day Inc MI
Peter Pugger Mfg Inc CA
Ram Products Inc OH
Verder Scientific Inc PA See ad on pg 101

Moisture Testing

LECO Corp MI
Micromeritics Instrument Corp GA

Optical Comparitors

Penn Tool Co NJ

Optical Property Measurement Instruments

Fritsch GmbH - Milling and Sizing Germany

pH Meters

Horiba Instruments Inc CA
Mettler-Toledo Inc OH
Ocean Optics Inc FL

Porosimeters

Micromeritics Instrument Corp GA
Particle Technology Labs IL See ad on pg 99
Quantachrome Instruments FL

Powders Samplers

Fritsch Milling & Sizing Inc NC
Quantachrome Instruments FL

Recorders

CSC Force Measurement Inc MA
Datapaq Inc NH
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Rheometers

Particle Technology Labs IL See ad on pg 99
TA Instruments DE

Sample Preparation Equipment

Allied High Tech Products Inc CA

Buehler Ltd IL See ad on pg 99
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Micromeritics Instrument Corp GA
Ram Products Inc OH

Verder Scientific Inc PA See ad on pg 101

Thermometers

Optocon AG Germany
Penn Tool Co NJ
Xiamen Innovacera Advanced Materials Co Ltd China See ad on pg 93

Viscosity Measurement Instruments

Carl Zeiss MircoImaging Inc NY
norcross Viscosity Controls MI
RISE Research Institutes of Sweden, RISE Glass Sweden
Rockwell Automation, Inc WI
TA Instruments DE

Visual Inspection Instruments

Buehler Ltd IL See ad on pg 99
Haiku Tech Inc FL
Penn Tool Co NJ
Taber Industries NY

Weighing/Scales

CSC Force Measurement Inc MA
Mettler-Toledo Inc OH
Penn Tool Co NJ
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

■ LABORATORY SERVICES

Atomic Adsorption
Spectrochemical Laboratories PA

Auger Analysis
Evans Analytical Group LLC CA
High Temperature Materials Lab TN
Micron Inc DE

Chemical Analysis
Activation Laboratories Ltd Canada
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Lucideon UK
NSL Analytical Services Inc OH **See ad on pg 75**
RISE Research Institutes of Sweden, RISE Glass Sweden
Setaram Instrumentation France
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Clay Testing
Activation Laboratories Ltd Canada
Edward Orton Jr Ceramic Foundation OH
Imerys GA
Laguna Clay Co CA
Technology of Materials CA

Composition
Activation Laboratories Ltd Canada
Alfred University NY
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
Japan Fine Ceramics Center Japan
P-Ker Engineering NY
Rauschert Industries Inc GA **See ad on pg 69**
Viridis3D LLC MA

Corrosion Testing
Activation Laboratories Ltd Canada
All Waste Matters UK
CelSian Glass & Solar BV The Netherlands
CHEMIR - A Division of Evans Analytical Group MO
Dalmia Inst of Scientific & Industrial Research India
Edward Orton Jr Ceramic Foundation OH
P-Ker Engineering NY
SEMTech Solutions Inc UK

Density Determination
Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Cyclonaire Corp NE
Edward Orton Jr Ceramic Foundation OH
GrainBound LLC PA
Hindalco Industries Limited India
Hysitron Inc MN
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
NSL Analytical Services Inc OH **See ad on pg 75**
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL

Differential Thermal Analysis
Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
High Temperature Materials Lab TN
Hindalco Industries Limited India
Japan Fine Ceramics Center Japan
Micron Inc DE
Netzsch Instruments NA LLC MA
RISE Research Institutes of Sweden, RISE Glass Sweden
Setaram Instrumentation France
TA Instruments DE
Technology of Materials CA

Electron Microprobe Analysis
Activation Laboratories Ltd Canada
GrainBound LLC PA
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
Rensselaer Polytechnic Inst NY
Technology of Materials CA

Failure Analysis
CHEMIR - A Division of Evans Analytical Group MO
CMC Laboratories Inc AZ
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
JTF Microscopy Services, LLC NY
Micron Inc DE
NSL Analytical Services Inc OH **See ad on pg 75**
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden, RISE Glass Sweden
SEMTech Solutions Inc UK
Technology of Materials CA

Fracture Analysis
CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
JTF Microscopy Services, LLC NY
Micron Inc DE
NSL Analytical Services Inc OH **See ad on pg 75**
Rensselaer Polytechnic Inst NY
RISE Research Institutes of Sweden, RISE Glass Sweden
SEMTech Solutions Inc UK
Spectrochemical Laboratories PA

Materials Analysis
Activation Laboratories Ltd Canada
Alfred University NY
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA

Edward Orton Jr Ceramic Foundation OH
Elan Technology GA
Evans Analytical Group LLC CA
Geller Microanalytical Laboratory Inc MA
GrainBound LLC PA
H&M Analytical Services Inc NJ
Harper International Corp NY **See ad on pg 77**

Harrop Industries Inc OH **See ad on pg 58**
High Temperature Materials Lab TN
Hysitron Inc MN
Japan Fine Ceramics Center Japan
Jenike & Johanson Inc MA
JTF Microscopy Services, LLC NY
Micromeritics Instrument Corp GA
Micron Inc DE
Monofrax LLC NY
NSL Analytical Services Inc OH **See ad on pg 75**
Particle Technology Labs IL **See ad on pg 99**
RISE Research Institutes of Sweden, RISE Glass Sweden
SEMTech Solutions Inc UK
Setaram Instrumentation France
Spectrochemical Laboratories PA
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Mechanical Properties
Activation Laboratories Ltd Canada
Advanced Ceramics Manufacturing AZ
Alfred University NY
BuzzMac Intl LLC ME
CHEMIR - A Division of Evans Analytical Group MO
CSC Force Measurement Inc MA
Edward Orton Jr Ceramic Foundation OH
High Temperature Materials Lab TN
Hysitron Inc MN
Japan Fine Ceramics Center Japan
TA Instruments DE
Taber Industries NY

Nondestructive Testing
SEMTech Solutions Inc UK

Optical Properties
Activation Laboratories Ltd Canada
CHEMIR - A Division of Evans Analytical Group MO
Rensselaer Polytechnic Inst NY

Particle-Size Analysis
Activation Laboratories Ltd Canada
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Custom Processing Services PA
Cyclonaire Corp NE
Geller Microanalytical Laboratory Inc MA
H&M Analytical Services Inc NJ
Harper International Corp NY **See ad on pg 77**
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
Micron Inc DE
NSL Analytical Services Inc OH **See ad on pg 75**

Particle Technology Labs IL **See ad on pg 99**
P-Ker Engineering NY
SEMTech Solutions Inc UK
Technology Assessment and Transfer Inc (TA&T) MD
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Pore Structure Analysis
GrainBound LLC PA
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
Particle Technology Labs IL **See ad on pg 99**
P-Ker Engineering NY
Quantachrome Instruments FL
SEMTech Solutions Inc UK

Residual Stress Analysis
American Stress Technologies Inc PA
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
RISE Research Institutes of Sweden, RISE Glass Sweden
TA Instruments DE

Scanning Electron Microscopy
Activation Laboratories Ltd Canada
Alfred University NY
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
GrainBound LLC PA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN

Hitachi High Technologies America, Inc **See ad on pg 101**
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
JTF Microscopy Services, LLC NY
Micron Inc DE
NSL Analytical Services Inc OH **See ad on pg 75**
Particle Technology Labs IL **See ad on pg 99**
SEMTech Solutions Inc UK
Technology of Materials CA
Washington Mills Electro Minerals Co NY

Spectroscopy
Activation Laboratories Ltd Canada
CHEMIR - A Division of Evans Analytical Group MO
CoorsTek CO
Evans Analytical Group LLC CA
GrainBound LLC PA
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH **See ad on pg 75**
Spectrochemical Laboratories PA

Surface-Area Analysis
AVEKA MN
Harper International Corp NY **See ad on pg 77**
Hindalco Industries Limited India
Japan Fine Ceramics Center Japan
Micromeritics Instrument Corp GA
NSL Analytical Services Inc OH **See ad on pg 75**
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL

RISE Research Institutes of Sweden, RISE Glass Sweden
SEMTech Solutions Inc UK
Technology Assessment and Transfer Inc (TA&T) MD

Thermal Analysis

Activation Laboratories Ltd Canada
Alfred University NY
AVEKA MN
CHEMIR - A Division of Evans Analytical Group MO
Datapaq Inc NH

Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
Harper International Corp NY — **See ad on pg 77**

Harrop Industries Inc OH — **See ad on pg 58**
High Temperature Materials Lab TN
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Mettler-Toledo Inc OH
Micron Inc DE
Netzsch Instruments NA LLC MA
Particle Technology Labs IL — **See ad on pg 99**
P-Ker Engineering NY
Setaram Instrumentation France
TA Instruments DE
Technology Assessment and Transfer Inc (TA&T) MD

Transmission Electron Microscopy

Evans Analytical Group LLC CA
GrainBound LLC PA

Hitachi High Technologies America, Inc — **See ad on pg 101**
High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH — **See ad on pg 75**

Tribological Studies

High Temperature Materials Lab TN
Japan Fine Ceramics Center Japan
Micron Inc DE
Taber Industries NY

X-Ray Diffraction

Activation Laboratories Ltd Canada
Alfred University NY
American Stress Technologies Inc PA
CHEMIR - A Division of Evans Analytical Group MO
Edward Orton Jr Ceramic Foundation OH
Evans Analytical Group LLC CA
GrainBound LLC PA
H&M Analytical Services Inc NJ
High Temperature Materials Lab TN
Hindalco Industries Limited India
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Micron Inc DE
NSL Analytical Services Inc OH — **See ad on pg 75**
Technology of Materials CA
Washington Mills Electro Minerals Co NY

X-Ray Fluorescence

CHEMIR - A Division of Evans Analytical Group MO
Euro Support Advanced Materials The Netherlands
H&M Analytical Services Inc NJ
Spectrochemical Laboratories PA

MATERIALS PREPARATION, HANDLING & PACKAGING

Agglomerators

Applicon Co IN
Lancaster Products PA
Littleford Day Inc MI

Bagging Equipment

Applicon Co IN
Cyclonaire Corp NE
Ingredient Masters Inc OH — **See ad on pg 103**
Lancaster Products PA
Nol-Tec Systems Inc MN

Barcode Labels

Rockwell Automation, Inc WI
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
General Glass Equipment Co NJ
Ingredient Masters Inc OH — **See ad on pg 103**
Laguna Clay Co CA
Lancaster Products PA
Mohr Corp MI — **See ad on pg 79**
Nol-Tec Systems Inc MN
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA
Young Industries Inc PA

Batching Equipment

Ingredient Masters Inc OH — **See ad on pg 103**

Batching Plants & Systems

Applicon Co IN
Cyclonaire Corp NE
EIRICH Machines, Inc IL
Ingredient Masters Inc OH — **See ad on pg 103**

Lancaster Products PA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Belts, Elevator
Carolina Material Technologies NC

Bin Activators
Carolina Material Technologies NC

Bin Dischargers
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN

Bins, Storage
Ingredient Masters Inc OH — **See ad on pg 103**
Jenike & Johanson Inc MA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Penn Tool Co NJ
Tempo Plastic CA

Blenders
Aadvanced Machinery Inc MI
Applicon Co IN
Cyclonaire Corp NE
Detroit Process Machinery MI
EIRICH Machines, Inc IL
Gasbarre Products Inc PA — **See ad on pg 95**
Glen Mills Inc NJ — **See ad on pg 43**
Laguna Clay Co CA
Lancaster Products PA
Littleford Day Inc MI
Mohr Corp MI — **See ad on pg 79**
Netzsch Premier Technologies LLC PA
Nol-Tec Systems Inc MN
Young Industries Inc PA

Briquetting & Tableting Equipment
Aadvanced Machinery Inc MI
Applicon Co IN
Mohr Corp MI — **See ad on pg 79**

Classifiers
Applicon Co IN
AVEKA MN
Fluid Energy Processing & Equipment Co PA
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow
Young Industries Inc PA

Conveyors
Basic Machinery Co Inc NC
Carolina Material Technologies NC
General Glass Equipment Co NJ
Nol-Tec Systems Inc MN
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA
Velco GmbH The Netherlands
Young Industries Inc PA

Conveyors, Belt
Applicon Co IN
Carolina Material Technologies NC
Ingredient Masters Inc OH — **See ad on pg 103**
Mixer Systems Inc WI

Conveyors, Bucket
Applicon Co IN
Ingredient Masters Inc OH — **See ad on pg 103**

Conveyors, Pneumatic
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Ingredient Masters Inc OH — **See ad on pg 103**
Nol-Tec Systems Inc MN
Velco GmbH The Netherlands

Conveyors, Screw
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Ingredient Masters Inc OH — **See ad on pg 103**
Mixer Systems Inc WI

Conveyors, Vibrating
Applicon Co IN
Carolina Material Technologies NC
OH Vibrator Co OH

Crushers
Aadvanced Machinery Inc MI
AVEKA MN
Basic Machinery Co Inc NC
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ — **See ad on pg 43**
Lancaster Products PA
Mohr Corp MI — **See ad on pg 79**
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Hammermill
AVEKA MN
Glen Mills Inc NJ — **See ad on pg 43**
Mixer Systems Inc WI
Stedman Machine Co IN
Verder Scientific Inc PA — **See ad on pg 101**
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Impact
Applicon Co IN
Glen Mills Inc NJ — **See ad on pg 43**
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Crushers, Jaw
Applicon Co IN
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ — **See ad on pg 43**
Verder Scientific Inc PA — **See ad on pg 101**

Crushers, Primary
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO

Crushers, Roll
Applicon Co IN
Lancaster Products PA
Williams Patent Crusher & Pulverizer Co Inc MO

Cullet-Handling Equipment
Applicon Co IN
General Glass Equipment Co NJ

Drum Tumblers
Glen Mills Inc NJ — **See ad on pg 43**

Dryers, Fluid Bed
Applicon Co IN
AVEKA MN
Williams Patent Crusher & Pulverizer Co Inc MO

Dryers, Rotating Tray
Raymond Bartlett Snow
Wyssmont Co NJ

Dust Collectors
Cyclonaire Corp NE
Nol-Tec Systems Inc MN
RoboVent MI

Dust Control Equipment
Carolina Material Technologies NC
Mixer Systems Inc WI
Penn Tool Co NJ
RoboVent MI
Young Industries Inc PA

Edge Protectors
Tempo Plastic CA

Electric Screen Heating
Midwestern Industries Inc OH

Environmental/Waste Treatment Equipment
Carolina Material Technologies NC
Cober Muegge LLC CT
Control Instruments Corp NJ
Fritsch GmbH - Milling and Sizing Germany
Mixer Systems Inc WI
OPF Enterprises TX
Oxy-Gon Industries Inc NH — **See ad on pg 89**
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA
Young Industries Inc PA

Feeders
Basic Machinery Co Inc NC
Carolina Material Technologies NC

EZG Manufacturing Inc OH — **Inside front cover**
OH Vibrator Co OH
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
General Glass Equipment Co NJ
Jenike & Johanson Inc MA
Nol-Tec Systems Inc MN
Young Industries Inc PA

Feeders, Batch
Applicon Co IN
Carolina Material Technologies NC
Ingredient Masters Inc OH — **See ad on pg 103**
Merkle International Inc IL
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
Siemens Process Industries and Drives GA

Feeders, Gravimetric
Applicon Co IN
Carolina Material Technologies NC

Feeders, Pneumatic
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN

Filters
Texers Technical Ceramics Inc Canada

Granulators
Aadvanced Machinery Inc MI
Applicon Co IN
Fritsch GmbH - Milling and Sizing Germany
Littleford Day Inc MI
Mohr Corp MI **See ad on pg 79**
Netzsch Premier Technologies LLC PA
Wyssmont Co NJ

Grinders
Buehler Ltd IL **See ad on pg 99**
Diamond Industrial Tools Inc IL
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on pg 43**
Mohr Corp MI **See ad on pg 79**
Netzsch Premier Technologies LLC PA
Stedman Machine Co IN
Verder Scientific Inc PA **See ad on pg 101**
Wyssmont Co NJ

Grinding Media
CerCo LLC OH
CoorsTek CO
Dunhua Zhengxing Abrasive Co Ltd China
ER Advanced Ceramics Inc OH
Federal-Mogul MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on pg 43**
Jyoti Ceramic Industries Pvt Ltd India
MSE Supplies AZ
Netzsch Premier Technologies LLC PA
Texers Technical Ceramics Inc Canada
Union Process OH
Verder Scientific Inc PA **See ad on pg 101**
Zibo Guangtong Chemical Co Ltd China
Zircoa Inc OH

Grinding Mills, Vibratory
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Gunning Equipment, Refractory
Reed Gunite & Shotcrete Equipment CA
Velco GmbH The Netherlands

Hoppers
Basic Machinery Co Inc NC
Carolina Material Technologies NC
Ingredient Masters Inc OH **See ad on pg 103**
Jenike & Johanson Inc MA
Mixer Systems Inc WI
Reed Gunite & Shotcrete Equipment CA

Hydraulic Systems
Basic Machinery Co Inc NC
Ram Products Inc OH

Impeller, Mixing
Lancaster Products PA
Mixer Systems Inc WI

Materials Handling Equipment
Basic Machinery Co Inc NC
Carolina Material Technologies NC
Cyclonaire Corp NE

EZG Manufacturing Inc OH **Inside front cover**
Gasbarre Products Inc PA **See ad on pg 95**
Lancaster Products PA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
North Star Equipment Inc WA
Penn Tool Co NJ
Reed Gunite & Shotcrete Equipment CA
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA
Tempo Plastic CA
Young Industries Inc PA

Mill Linings
CerCo LLC OH
ER Advanced Ceramics Inc OH
Jyoti Ceramic Industries Pvt Ltd India

Mills
Custom Processing Services PA
ER Advanced Ceramics Inc OH
Euro Support Advanced Materials The Netherlands
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on pg 43**
Hockmeyer Equipment Corp NC
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow
Stedman Machine Co IN
Union Process OH

Mills, Attritor
Aadvanced Machinery Inc MI
Custom Processing Services PA
Detroit Process Machinery MI
Glen Mills Inc NJ **See ad on pg 43**
Netzsch Premier Technologies LLC PA
Union Process OH
Wyssmont Co NJ

Mills, Ball & Pebble
Aadvanced Machinery Inc MI
Advanced Ceramics Manufacturing AZ
Detroit Process Machinery MI
ER Advanced Ceramics Inc OH
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on pg 43**
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Mohr Corp MI **See ad on pg 79**
MSE Supplies AZ
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow
Union Process OH

Mills, Centrifugal
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on pg 43**
Verder Scientific Inc PA **See ad on pg 101**

Mills, Hammer
AVEKA MN
Glen Mills Inc NJ — **See ad on pg 43**
Stedman Machine Co IN
Verder Scientific Inc PA — **See ad on pg 101**
Williams Patent Crusher & Pulverizer Co Inc MO

Mills, Jar
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Mills, Jet
AVEKA MN
Fluid Energy Processing & Equipment Co PA
Netzsch Premier Technologies LLC PA

Mills, Planetary
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Hockmeyer Equipment Corp NC
MSE Supplies AZ
Verder Scientific Inc PA — **See ad on pg 101**

Mills, Rod
Wyssmont Co NJ

Mills, Roll
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
MSE Supplies AZ
Raymond Bartlett Snow
Williams Patent Crusher & Pulverizer Co Inc MO

Mills, Vibratory
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC

Mining & Beneficiation Equipment
Netzsch Premier Technologies LLC PA
Reed Gunite & Shotcrete Equipment CA
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Mixers, Batch
Carolina Material Technologies NC
Custom Processing Services PA
EIRICH Machines, Inc IL

EZG Manufacturing Inc OH — **Inside front cover**

Glen Mills Inc NJ — **See ad on pg 43**
Goceram AB Sweden
Lancaster Products PA
Mixer Systems Inc WI
Mohr Corp MI — **See ad on pg 79**
Netzsch Premier Technologies LLC PA
Nol-Tec Systems Inc MN
OPF Enterprises TX
Peter Pugger Mfg Inc CA

Mixers, Drum
Glen Mills Inc NJ — **See ad on pg 43**
Hockmeyer Equipment Corp NC

Mixers, Pneumatic
Carolina Material Technologies NC
EIRICH Machines, Inc IL
Nol-Tec Systems Inc MN

Mixers, Portable
Jiffy Mixer Co Inc CA
Mixer Systems Inc WI
Peter Pugger Mfg Inc CA

Mixers, Refractory
Applicon Co IN
EIRICH Machines, Inc IL

EZG Manufacturing Inc OH — **Inside front cover**
Laeis GmbH Luxembourg
Lancaster Products PA
Littleford Day Inc MI
Mixer Systems Inc WI
Netzsch Premier Technologies LLC PA
Peter Pugger Mfg Inc CA
Reed Gunite & Shotcrete Equipment CA

Mixers, Vacuum
Applicon Co IN
EIRICH Machines, Inc IL
Netzsch Premier Technologies LLC PA
Peter Pugger Mfg Inc CA

Mixing Equipment
Aadvanced Machinery Inc MI
Carolina Material Technologies NC
Custom Processing Services PA

Detroit Process Machinery MI
EIRICH Machines, Inc IL
ER Advanced Ceramics Inc OH
General Glass Equipment Co NJ

Glen Mills Inc NJ — **See ad on pg 43**
Goceram AB Sweden
Hockmeyer Equipment Corp NC
Laguna Clay Co CA
Lancaster Products PA
Littleford Day Inc MI
Mixer Systems Inc WI
Mohr Corp MI — **See ad on pg 79**
Netzsch Premier Technologies LLC PA
OPF Enterprises TX
Peter Pugger Mfg Inc CA
Resodyn Acoustic Mixers Inc MT
Young Industries Inc PA

Nozzles
CerCo LLC OH
Dunhua Zhengxing Abrasive Co Ltd China
H.C. Starck GmbH Germany
Maryland Ceramic & Steatite Co Inc MD

Packaging
Tempo Plastic CA

Packaging Equipment
Basic Machinery Co Inc NC

Pneumatic Systems
Applicon Co IN
Carolina Material Technologies NC
Cyclonaire Corp NE
Nol-Tec Systems Inc MN
Reed Gunite & Shotcrete Equipment CA
Velco GmbH The Netherlands
Young Industries Inc PA

Process Control Equipment
Control Instruments Corp NJ
Datapaq Inc NH
General Glass Equipment Co NJ
Ingredient Masters Inc OH — **See ad on pg 103**
Nol-Tec Systems Inc MN
norcross Viscosity Controls MI
Ram Products Inc OH
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Pulverizers
Aadvanced Machinery Inc MI
Applicon Co IN
Basic Machinery Co Inc NC
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ — **See ad on pg 43**
Mixer Systems Inc WI
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Pumps
ER Advanced Ceramics Inc OH
Ram Products Inc OH
Reed Gunite & Shotcrete Equipment CA

Pumps, Concrete
Reed Gunite & Shotcrete Equipment CA

Scale Systems
CSC Force Measurement Inc MA
Mettler-Toledo Inc OH
Nol-Tec Systems Inc MN

Screens & Screening Equipment
Aadvanced Machinery Inc MI
Basic Machinery Co Inc NC
OH Vibrator Co OH
Control Instruments Corp NJ
Detroit Process Machinery MI
Fritsch GmbH - Milling and Sizing Germany

Fritsch Milling & Sizing Inc NC
Glen Mills Inc NJ **See ad on pg 43**
Midwestern Industries Inc OH
Mohr Corp MI **See ad on pg 79**
Sicco Engineering Works India

Separators
Fritsch GmbH - Milling and Sizing Germany
Midwestern Industries Inc OH
Williams Patent Crusher & Pulverizer Co Inc MO
Basic Machinery Co Inc NC
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on pg 43**
Stedman Machine Co IN
Williams Patent Crusher & Pulverizer Co Inc MO

Single-Wafer Packs
Tempo Plastic CA

Size Reduction Equipment
AVEKA MN
Basic Machinery Co Inc NC
Custom Processing Services PA
EIRICH Machines, Inc IL
ER Advanced Ceramics Inc OH
Fluid Energy Processing & Equipment Co PA
Fritsch GmbH - Milling and Sizing Germany
Glen Mills Inc NJ **See ad on pg 43**
Lancaster Products PA
Netzsch Premier Technologies LLC PA
Raymond Bartlett Snow
Stedman Machine Co IN
Union Process OH
Williams Patent Crusher & Pulverizer Co Inc MO
Wyssmont Co NJ

Spray Dryers
Aadvanced Machinery Inc MI
Arch Maintenance Services GA
AVEKA MN
Detroit Process Machinery MI
Dorst America Inc PA
Elan Technology GA
Euro Support Advanced Materials The Netherlands
Mohr Corp MI **See ad on pg 79**
Spray Drying Systems Inc MD

Storage Equipment
Basic Machinery Co Inc NC
Cyclonaire Corp NE

Substrate Wafer Trays
Tempo Plastic CA

Used Equipment
Aadvanced Machinery Inc MI
American Isostatic Presses OH

Detroit Process Machinery MI
Dorst America Inc PA

Mohr Corp MI **See ad on pg 79**
Reed Gunite & Shotcrete Equipment CA

Vacuum Cleaning Systems
Carolina Material Technologies NC

Ventilating Equipment
American Art Clay Co Inc IN

Vibrators
Carolina Material Technologies NC
OH Vibrator Co OH
Rockwell Automation, Inc WI

Vibrators, Bin
Carolina Material Technologies NC
OH Vibrator Co OH
Cyclonaire Corp NE

Weighing Equipment
Carolina Material Technologies NC
CSC Force Measurement Inc MA
Cyclonaire Corp NE
Mettler-Toledo Inc OH
Nol-Tec Systems Inc MN
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Wire Cloth
Midwestern Industries Inc OH

■ PLANT CONSTRUCTION, DESIGN & ENGINEERING

Brick Production
Basic Machinery Co Inc NC
Laeis GmbH Luxembourg
Swindell Dressler Intl Co PA

Casting Plants
Dorst America Inc PA
ER Advanced Ceramics Inc OH

Ceramic Production
Cerinnov France
Cerlase France
GrainBound LLC PA
Lucideon UK
Maryland Ceramic & Steatite Co Inc MD
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Viridis3D LLC MA

Combustion Systems
Air Products PA
Swindell Dressler Intl Co PA

Decals & Decorating
Cerinnov France
Cerlase France
Gwent Electronic Materials Ltd UK

Drying & Firing
Basic Machinery Co Inc NC
Ceramic Services Inc PA

Harrop Industries Inc OH **See ad on pg 58**
Swindell Dressler Intl Co PA
Wistra GmbH Germany

Electronic Materials Production
Haiku Tech Europe BV The Netherlands
Haiku Tech Inc FL
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD

Environmental Control
Cyclonaire Corp NE
Ferro-Ceramic Grinding Inc MA
Mixer Systems Inc WI
Nol-Tec Systems Inc MN
RoboVent MI
Rockwell Automation, Inc WI
Saint-Gobain norPro OH
Tri-Mer Corp MI

Fabrication Shops
Ferro-Ceramic Grinding Inc MA
Maryland Ceramic & Steatite Co Inc MD

Glass Production
CelSian Glass & Solar BV The Netherlands
General Glass Equipment Co NJ
RISE Research Institutes of Sweden, RISE Glass Sweden
Schott North America Inc NY **See ad on pg 41**
Tri-Mer Corp MI

Inspection Systems
CSC Force Measurement Inc MA
Fosbel Inc OH
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Laboratories
Activation Laboratories Ltd Canada

Optical-Fiber Production
Ocean Optics Inc FL

Refractory Production
ER Advanced Ceramics Inc OH
Fosbel Inc OH
Laeis GmbH Luxembourg
Laguna Clay Co CA
Swindell Dressler Intl Co PA

Structural Ceramics Production
CerCo LLC OH
Maryland Ceramic & Steatite Co Inc MD
Swindell Dressler Intl Co PA
Takasago Industry Co Ltd Japan
TevTech LLC MA **See ad on pg 83**

Tile Production
Laeis GmbH Luxembourg
LIXIL Corporation Japan
Peter Pugger Mfg Inc CA

Whiteware Production
LIXIL Corporation Japan
Ram Products Inc OH
Swindell Dressler Intl Co PA

■ PORCELAIN ENAMEL

Appliances
Roca Sanitario SA Spain
Zenith China

Architectural Units
Roca Sanitario SA Spain
Zenith China

Ceramic Coatings, Thermal Protection
Cerinnov France
Cerlase France
Trans-Tech Inc, a subsidiary of Skyworks Solutions Inc MD
Zenith China

■ REFRACTORIES

Acid
Allied Mineral Products Inc OH
Magneco Metrel Inc IL
Pacific Refractories Ltd India
Vitcas Ltd UK

Aggregate
Christy Minerals LLC MO
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
Maryland Refractories Co OH

Alumina
Advanced Ceramic Technology CA
Allied Mineral Products Inc OH
Associated Ceramics & Technology Inc PA
See ad on pg 65
Astral Material Industrial Co Ltd China
Baikowski Malakoff Inc NC
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Dalmia Inst of Scientific & Industrial Research India
Du-Co Ceramics Company PA
Elcon Precision LLC CA **See ad on pg 107**
ER Advanced Ceramics Inc OH
Fosbel Inc OH
General Material Industrial Co China
GrainBound LLC PA
IPS Ceramics LTD UK
Ipsen Ceramics IL
Magneco Metrel Inc IL
Maryland Refractories Co OH
Pacific Refractories Ltd India
Plibrico Company IL **See ad on pg 105**
Precision Ferrites and Ceramics Inc CA
Rath Inc DE
Refractory Minerals Co Inc PA
RHI US Ltd NY
Refratechnik Ceramics GmbH Germany
Riverside Refractories Inc AL
Selee Corp NC
Sunrock Ceramics Co IL
Texers Technical Ceramics Inc Canada
Wistra GmbH Germany
Xiamen Innovacera Advanced Materials Co Ltd China
See ad on pg 93
ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY

Zircar Zirconia Inc NY

Anchors
Associated Ceramics & Technology Inc PA
See ad on pg 65
Magneco Metrel Inc IL

Arches, Suspended
Fosbel Inc OH
Ipsen Ceramics IL
Merkle International Inc IL

AZS
Bucher Emhart Glass SA Switzerland
Fosbel Inc OH
Magneco Metrel Inc IL
Monofrax LLC NY
RHI US Ltd NY

Backwalls
Fosbel Inc OH
Merkle International Inc IL

Basic
Allied Mineral Products Inc OH
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
RHI US Ltd NY

Bauxite
Refratechnik Ceramics GmbH Germany

Blankets
Associated Ceramics & Technology Inc PA
See ad on pg 65
Morgan Thermal Ceramics GA
RHI US Ltd NY
Thermal Products Co Inc GA
Unifrax I LLC NY
ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY
Zircar Zirconia Inc NY

Boards
Agni Fiber Boards Pvt Ltd India
Morgan Thermal Ceramics GA
RHI US Ltd NY
Saint-Gobain Ceramics & Plastics MA
Thermal Products Co Inc GA
Unifrax I LLC NY

ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY
Zircar Zirconia Inc NY

Brick
APF Recycling Inc OH
Cancarb Limited Canada

General Material Industrial Co China
HarbisonWalker Intl PA
Insulating Firebrick Inc PA
Morgan Thermal Ceramics GA
Pacific Refractories Ltd India
Refratechnik Ceramics GmbH Germany
RHI US Ltd NY
Sunrock Ceramics Co IL
Wistra GmbH Germany

Brick, Acid-Resisting
Pacific Refractories Ltd India
Vitcas Ltd UK

Brick, Fireclay
Allied Mineral Products Inc OH
Alsey Refractories Co MO
Pacific Refractories Ltd India
RHI US Ltd NY
Vitcas Ltd UK

Carbon
Astral Material Industrial Co Ltd China
Cancarb Limited Canada
Pacific Refractories Ltd India

Castable
Allied Mineral Products Inc OH
Alsey Refractories Co MO
Aremco Products Inc NY
Cancarb Limited Canada
Capital Refractories Ltd UK
Furnace Products & Services Inc PA
HarbisonWalker Intl PA
Industrial Ceramic Products Inc OH
Magneco Metrel Inc IL
Pacific Refractories Ltd India

Plibrico Company IL **See ad on pg 105**
Plibrico Japan Co Ltd Japan
Reno Refractories Inc AL
RHI US Ltd NY
Riverside Refractories Inc AL
Selee Corp NC
Vitcas Ltd UK
Zircar Refractory Composites Inc NY

Cements
Allied Mineral Products Inc OH
Aremco Products Inc NY
Capital Refractories Ltd UK
Dalmia Inst of Scientific & Industrial Research India
Furnace Products & Services Inc PA
Gorka Cement Poland
Kerneos Inc VA
Plibrico Company IL **See ad on pg 105**
Reno Refractories Inc AL
Unifrax I LLC NY
Vitcas Ltd UK
ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Clay Flux
Furnace Products & Services Inc PA
Peter Pugger Mfg Inc CA
RHI US Ltd NY

Coatings
Allied Mineral Products Inc OH
Aremco Products Inc NY
Elcon Precision LLC CA **See ad on pg 107**
Fosbel Inc OH
Furnace Products & Services Inc PA
Fusion Ceramics Inc OH
Gwent Electronic Materials Ltd UK
Induceramic Canada
Magneco Metrel Inc IL
Plibrico Japan Co Ltd Japan
Rath Inc DE
Riverside Refractories Inc AL
Starfire Systems Inc NY
Thermal Products Co Inc GA
Unifrax I LLC NY
Vitcas Ltd UK
Zibo Guangtong Chemical Co Ltd China
Zircar Refractory Composites Inc NY
ZYP Coatings Inc TN

Cordierite
Advanced Ceramic Technology CA
Akron Porcelain & Plastics Co OH
Astral Material Industrial Co Ltd China
CoorsTek CO
Du-Co Ceramics Company PA
ER Advanced Ceramics Inc OH
Industrial Ceramic Products Inc OH
IPS Ceramics LTD UK
Maryland Refractories Co OH
Rauschert Industries Inc GA **See ad on pg 69**
Saint-Gobain Ceramics & Plastics MA

Crucibles
AdValue Technology LLC AZ **See ad on pg 43**
Allied Mineral Products Inc OH
APC International Ltd PA
Aremco Products Inc NY
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Furnace Products & Services Inc PA
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Progressive Technology Inc CA
Selee Corp NC
Silicon Carbide Products Inc NY
Zhengzhou Mission Ceramic Products Co Ltd China
Zircoa Inc OH

Dead-Burned
Fluid Energy Processing & Equipment Co PA

Fiber Products
Allied Mineral Products Inc OH

Chiz Bros. Inc **See ad pg 109**
Furnace Products & Services Inc PA
LECO Corp MI
Thermal Products Co Inc GA
Unifrax I LLC NY
Vitcas Ltd UK

ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Fillers
Refratechnik Ceramics GmbH Germany

Filters, Molten Metal
Akron Porcelain & Plastics Co OH
Induceramic Canada
Industrial Ceramic Products Inc OH
Selee Corp NC

Foundry
Allied Mineral Products Inc OH
Blasch Precision Ceramics Inc NY
Capital Refractories Ltd UK
Fosbel Inc OH
H.C. Starck GmbH Germany
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Plibrico Company IL **See ad on pg 105**
Riverside Refractories Inc AL
Selee Corp NC
Silicon Carbide Products Inc NY
Zircar Refractory Composites Inc NY

Fused Cast
Fosbel Inc OH
Furnace Products & Services Inc PA
Monofrax LLC NY
Saint-Gobain Ceramics & Plastics MA

Fused Spinel Refractories
Dalmia Inst of Scientific & Industrial Research India

Glass Furnace
Deltech Inc CO **See ad on pg 85**
Fosbel Inc OH
Furnace Products & Services Inc PA
HarbisonWalker Intl PA
Ipsen Ceramics IL
Magneco Metrel Inc IL
RHI US Ltd NY
RISE Research Institutes of Sweden, RISE Glass Sweden
Vesuvius SC

Graphite
Applied Ceramics Inc CA
Furnace Products & Services Inc PA

Grog
Alsey Refractories Co MO
Maryland Refractories Co OH

Gunning
Allied Mineral Products Inc OH
Blastcrete Equipment Co AL
Capital Refractories Ltd UK
Fosbel Inc OH
Plibrico Company IL **See ad on pg 105**
Plibrico Japan Co Ltd Japan
Reno Refractories Inc AL
Riverside Refractories Inc AL
Unifrax I LLC NY
Velco GmbH The Netherlands

High-Alumina
Advanced Ceramic Technology CA
Allied Mineral Products Inc OH
Applied Ceramics Inc CA
Astral Material Industrial Co Ltd China
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Custom Processing Services PA
Dalmia Inst of Scientific & Industrial Research India
ER Advanced Ceramics Inc OH
Fosbel Inc OH
IPS Ceramics LTD UK
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Maryland Refractories Co OH
Monofrax LLC NY
Plibrico Company IL **See ad on pg 105**
Plibrico Japan Co Ltd Japan
Precision Ferrites and Ceramics Inc CA
Rath Inc DE
RHI US Ltd NY
Riverside Refractories Inc AL
Selee Corp NC
Sunrock Ceramics Co IL
Tethon 3D NE
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zhengzhou Mission Ceramic Products Co Ltd China
ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY

Insulating Brick
Dalmia Inst of Scientific & Industrial Research India
Furnace Products & Services Inc PA
General Material Industrial Co China
Insulating Firebrick Inc PA
Laguna Clay Co CA
PSH Kilns & Furnaces Canada
RHI US Ltd NY
Zircoa Inc OH

Insulation
Agni Fiber Boards Pvt Ltd India
Capital Refractories Ltd UK
Du-Co Ceramics Company PA
Furnace Products & Services Inc PA
General Material Industrial Co China
HarbisonWalker Intl PA
Induceramic Canada
Plibrico Company IL **See ad on pg 105**
Plibrico Japan Co Ltd Japan
PSH Kilns & Furnaces Canada
Rath Inc DE
Refratechnik Ceramics GmbH Germany
Reno Refractories Inc AL
RHI US Ltd NY
Thermal Products Co Inc GA
Unifrax I LLC NY
Vesuvius SC
Wistra GmbH Germany

ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY

Zircar Zirconia Inc NY

Insulation Board
Agni Fiber Boards Pvt Ltd India
Thermal Products Co Inc GA
Unifrax I LLC NY
ZIRCAR Ceramics Inc NY
Zircar Refractory Composites Inc NY
Zircar Zirconia Inc NY

Insulation Slabs, Calcium Silicate
Furnace Products & Services Inc PA
Zircar Refractory Composites Inc NY

Insulation Slabs, Vermiculite
Insulating Firebrick Inc PA

Insulation, Microporous
Furnace Products & Services Inc PA
Thermal Products Co Inc GA
Unifrax I LLC NY
ZIRCAR Ceramics Inc NY

Kiln Car Insulation
Refratechnik Ceramics GmbH Germany
Sunrock Ceramics Co IL
Thermal Products Co Inc GA
ZIRCAR Ceramics Inc NY

Kiln Furniture
Advanced Ceramic Technology CA
American Art Clay Co Inc IN
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
Induceramic Canada
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
L&L Kiln Mfg Inc NJ
Laguna Clay Co CA
Magneco Metrel Inc IL
Nutec Bickley Mexico
Paragon Industries LP TX
PSH Kilns & Furnaces Canada
Refratechnik Ceramics GmbH Germany
RHI US Ltd NY
Saint-Gobain Ceramics & Plastics MA
Saint-Gobain High Performance Ceramics & Refractories MA
Selee Corp NC
Silicon Carbide Products Inc NY

Sunrock Ceramics Co IL
Texers Technical Ceramics Inc Canada
Zircar Refractory Composites Inc NY
Zircoa Inc OH

Magnesite

Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Dalmia Inst of Scientific & Industrial Research India
Fluid Energy Processing & Equipment Co PA
Furnace Products & Services Inc PA
RHI US Ltd NY

Monolithic

Allied Mineral Products Inc OH
Blasch Precision Ceramics Inc NY
Cancarb Limited Canada
Ceramco Inc NH
Furnace Products & Services Inc PA
Magneco Metrel Inc IL
Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc AL
Saint-Gobain Ceramics & Plastics MA
Selee Corp NC
Zili USA LLC PA

Mortars

Allied Mineral Products Inc OH
Alsey Refractories Co MO
CoorsTek CO
Monofrax LLC NY
Pacific Refractories Ltd India
Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
Refratechnik Ceramics GmbH Germany
Reno Refractories Inc AL
RHI US Ltd NY
Riverside Refractories Inc AL
Vitcas Ltd UK

Mullite

Advanced Ceramic Technology CA
Akron Porcelain & Plastics Co OH
Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Atlantic Equipment Engineers NJ
Bharat Heavy Electricals Ltd NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Dalmia Inst of Scientific & Industrial Research India
ER Advanced Ceramics Inc OH
Fosbel Inc OH
General Material Industrial Co China
Industrial Ceramic Products Inc OH
IPS Ceramics LTD UK
Magneco Metrel Inc IL
McDanel Advanced Ceramic Technologies LLC PA See ad on pg 61
Reade Advanced Materials RI
RHI US Ltd NY
Robocasting Enterprises LLC NM
Unifrax I LLC NY

Nozzles

Advanced Ceramic Technology CA
Blasch Precision Ceramics Inc NY
Blastcrete Equipment Co AL
CeramTec-ETEC Germany
FELDCO Intl CA
Industrial Ceramic Products Inc OH
Jyoti Ceramic Industries Pvt Ltd India
LECO Corp MI
Magneco Metrel Inc IL
Reed Gunite & Shotcrete Equipment CA
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Xiamen Innovacera Advanced Materials Co Ltd China See ad on pg 93
Zircoa Inc OH

Paper

Thermal Products Co Inc GA
Unifrax I LLC NY
ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Plastic

Allied Mineral Products Inc OH
Capital Refractories Ltd UK
Maryland Ceramic & Steatite Co Inc MD
Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc AL

Precast Shapes

Allied Mineral Products Inc OH
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Capital Refractories Ltd UK
Ceramco Inc NH
CeramTec-ETEC Germany
Fosbel Inc OH
Industrial Ceramic Products Inc OH
Magneco Metrel Inc IL

Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc AL
Selee Corp NC
Silicon Carbide Products Inc NY
Zircar Refractory Composites Inc NY

Ramming Mixes

Allied Mineral Products Inc OH
Alsey Refractories Co MO
Monofrax LLC NY
Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
RHI US Ltd NY
Riverside Refractories Inc AL
Selee Corp NC

Rods

AdValue Technology LLC AZ See ad on pg 43
Blasch Precision Ceramics Inc NY
CerCo LLC OH
Du-Co Ceramics Company PA
Industrial Ceramic Products Inc OH
LECO Corp MI
McDanel Advanced Ceramic Technologies LLC PA See ad on pg 61
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY

Rollers

Keith Co CA
Recco Furnaces CA
Saint-Gobain High Performance Ceramics & Refractories MA

Saggers

AdValue Technology LLC AZ See ad on pg 43
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
IPS Ceramics LTD UK
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Selee Corp NC
Sunrock Ceramics Co IL

Setters

AdValue Technology LLC AZ See ad on pg 43
Blasch Precision Ceramics Inc NY
Ceramco Inc NH
Industrial Ceramic Products Inc OH
Ipsen Ceramics IL
LECO Corp MI
Magneco Metrel Inc IL
Maryland Ceramic & Steatite Co Inc MD
Saint-Gobain High Performance Ceramics & Refractories MA
Selee Corp NC
Sunrock Ceramics Co IL
Zircar Zirconia Inc NY

Silica

Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Dalmia Inst of Scientific & Industrial Research India
Fosbel Inc OH
Ipsen Ceramics IL
Maryland Refractories Co OH
RHI US Ltd NY
Selee Corp NC
Sibelco Benelux Belgium

Silicon Carbide

Allied Mineral Products Inc OH
Astral Material Industrial Co Ltd China
Bharat Heavy Electricals Ltd NY
Blasch Precision Ceramics Inc NY
Cancarb Limited Canada
CoorsTek CO
Custom Processing Services PA
Electro Abrasives Corp NY
Fosbel Inc OH
IPS Ceramics LTD UK
Magneco Metrel Inc IL
Momentive Performance Materials Inc NY
Plibrico Company IL See ad on pg 105
Plibrico Japan Co Ltd Japan
Precision Ferrites and Ceramics Inc CA
Reade Advanced Materials RI
Saint-Gobain High Performance Ceramics & Refractories MA
Selee Corp NC
Silicon Carbide Products Inc NY
Xiamen Innovacera Advanced Materials Co Ltd China See ad on pg 93

Specialty
Allied Mineral Products Inc OH
Alsey Refractories Co MO
Blasch Precision Ceramics Inc NY
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
CoorsTek CO
Goceram AB Sweden
Industrial Ceramic Products Inc OH
Magneco Metrel Inc IL
McDanel Advanced Ceramic Technologies LLC PA **See ad on pg 61**
Refrac Systems AZ
Riverside Refractories Inc AL
Zircar Zirconia Inc NY

Tap Hole Clays
Cancarb Limited Canada
Riverside Refractories Inc AL
Vitcas Ltd UK

Textile

Chiz Bros. Inc **See ad pg 109**
Thermal Products Co Inc GA
ZIRCAR Ceramics Inc NY
Zircar Zirconia Inc NY

Tubes

AdValue Technology LLC AZ **See ad on pg 43**
Bucher Emhart Glass SA Switzerland
Ceramco Inc NH
CeramTec-ETEC Germany
Industrial Ceramic Products Inc OH
Jyoti Ceramic Industries Pvt Ltd India
LECO Corp MI
Saint-Gobain High Performance Ceramics & Refractories MA
Silicon Carbide Products Inc NY
Texers Technical Ceramics Inc Canada
Zhengzhou Mission Ceramic Products Co Ltd China
Zircar Refractory Composites Inc NY

Zircon
Custom Processing Services PA
Dalmia Inst of Scientific & Industrial Research India
Fosbel Inc OH
RHI US Ltd NY
Vitcas Ltd UK
Zircoa Inc OH

Zirconia
Astral Material Industrial Co Ltd China
Ceramco Inc NH
CeramTec-ETEC Germany
CerCo LLC OH
CoorsTek CO
Custom Processing Services PA
Dalmia Inst of Scientific & Industrial Research India
Fosbel Inc OH
Lithoz GmbH NY
Precision Ferrites and Ceramics Inc CA
Refractron Technologies Corp NY
RHI US Ltd NY
Selee Corp NC
Texers Technical Ceramics Inc Canada
Xiamen Innovacera Advanced Materials Co Ltd China **See ad on pg 93**
Zhengzhou Mission Ceramic Products Co Ltd China
Zibo Guangtong Chemical Co Ltd China

Zircar Zirconia Inc NY
Zircoa Inc OH

RESEARCH ORGANIZATIONS
Academic
Alfred University NY
Applied Research Center SC
Cerinnov France
Cerlase France
Inst for Applied Materials-Ceramics in Mechanical Engineering, Karlsruhe Inst of Technology Germany
Israel Ceramic & Silicate Inst Israel
Universidad Autonoma de Nuevo Leon Mexico

Certification, ISO
GE Global Research NY
Lucideon UK

Government Contract/Independent
Advanced Ceramics Manufacturing AZ
Applied Research Center SC
CelSian Glass & Solar BV The Netherlands
Central Glass & Ceramic Research Institute UK
Ceramitec Germany
CHEMIR - A Division of Evans Analytical Group MO
GE Global Research NY
Inst for Applied Materials-Ceramics in Mechanical Engineering, Karlsruhe Inst of Technology Germany
Israel Ceramic & Silicate Inst Israel
Japan Fine Ceramics Center Japan
Korea Inst of Industrial Technology The Republic of Korea
Lucideon UK
Maryland Ceramic & Steatite Co Inc MD
Sandia National Laboratories NM

Semiconductor Energy Laboratory Co Ltd Japan **See ad on pg 91**
SRI International CA
Technology Assessment and Transfer Inc (TA&T) MD
Viridis3D LLC MA

TESTING/EVALUATION INSTRUMENTS & EQUIPMENT
Acoustic Instruments
BuzzMac Intl LLC ME
James Instruments IL
Matmatch Germany

Chemical Analysis Instruments
Ocean Optics Inc FL

Color Measurement Equipment
HunterLab VA
Lucideon UK

Compression Testing Equipment
Advanced Ceramics Manufacturing AZ
Applied Test Systems Inc PA
CSC Force Measurement Inc MA
Dalmia Inst of Scientific & Industrial Research India

Computer Software
Applied Test Systems Inc PA
CelSian Glass & Solar BV The Netherlands
CSC Force Measurement Inc MA
Datapaq Inc NH
General Glass Equipment Co NJ

Object Research Systems Inc Canada **See ad on pg 81**
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Couplants, Ultrasonic Instruments
James Instruments IL

Density Analyzers
Micromeritics Instrument Corp GA
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL
RocCera LLC NY

Differential Scanning Calorimetry Instruments
Dalmia Inst of Scientific & Industrial Research India
Datapaq Inc NH
Linseis Inc NJ
Netzsch Instruments NA LLC MA
Particle Technology Labs IL **See ad on pg 99**
Setaram Instrumentation France
TA Instruments DE

Differential Thermal Analysis Instruments
Linseis Inc NJ
Neoptix Canada
Netzsch Instruments NA LLC MA
Setaram Instrumentation France
TA Instruments DE

Dilatometers
Edward Orton Jr Ceramic Foundation OH
Haiku Tech Inc FL
Linseis Inc NJ
Netzsch Instruments NA LLC MA
TA Instruments DE

Dye Penetrant Equipment & Supplies
RocCera LLC NY
Spectronics Corp NY

Eddy-Current Testing Instruments
ETher NDE UK

Electrochemical Analysis Instruments
Gamry Instruments PA
Haiku Tech Inc FL
Nanoscience Instruments AZ
Ocean Optics Inc FL

Electromechanical Analysis Instruments
APC International Ltd PA
CSC Force Measurement Inc MA
James Instruments IL
norECs AS Norway

Electronic Analysis Instruments
ETher NDE UK
James Instruments IL

Flexural Analysis Instruments
Advanced Ceramics Manufacturing AZ
RocCera LLC NY
TA Instruments DE
Taber Industries NY

Gas Analysis Instruments
CelSian Glass & Solar BV The Netherlands
Control Instruments Corp NJ
Dalmia Inst of Scientific & Industrial Research India
Horiba Instruments Inc CA
Ocean Optics Inc FL
Setaram Instrumentation France

Image Analysis Instruments
Buehler Ltd IL **See ad on pg 99**
Carl Zeiss MircoImaging Inc NY
Cilas Particle Size WI
Fritsch Milling & Sizing Inc NC
Horiba Instruments Inc CA
LECO Corp MI
Micromeritics Instrument Corp GA
Nanoscience Instruments AZ
Particle Technology Labs IL **See ad on pg 99**
TA Instruments DE

Infrared Spectroscopy Instruments
Ocean Optics Inc FL

Interferometers
OptiPro Systems LLC NY

Leak Detectors
Spectronics Corp NY

Microfocus X-Ray Imaging Instruments
Horiba Instruments Inc CA

Moisture Analyzers
James Instruments IL
Mettler-Toledo Inc OH
Micromeritics Instrument Corp GA
MoistTech Corp FL
Ocean Optics Inc FL
Penn Tool Co NJ
Quantachrome Instruments FL

Nondestructive Evaluation Instruments
American Stress Technologies Inc PA
BuzzMac Intl LLC ME
Dalmia Inst of Scientific & Industrial Research India
Datapaq Inc NH
ETher NDE UK
James Instruments IL
Nanoscience Instruments AZ
Spectronics Corp NY
Thermal Wave Imaging Inc MI

Oxygen Analyzers
Ocean Optics Inc FL
Verder Scientific Inc PA **See ad on pg 101**

Particle Size Analysis Instruments
Brookhaven Instruments Corp NY
Cilas Particle Size WI
Dalmia Inst of Scientific & Industrial Research India
Fritsch GmbH - Milling and Sizing Germany
Fritsch Milling & Sizing Inc NC
Horiba Instruments Inc CA
Micromeritics Instrument Corp GA
Microtrac Inc PA
Particle Technology Labs IL **See ad on pg 99**
Quantachrome UK- Anton Paar VA
Verder Scientific Inc PA **See ad on pg 101**

Pore Size Analyzers
Dalmia Inst of Scientific & Industrial Research India
Micromeritics Instrument Corp GA
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL

Pressure Sensors
Rockwell Automation, Inc WI
Siemens Process Industries and Drives GA

Raman Spectroscopy Instruments
Horiba Instruments Inc CA
Ocean Optics Inc FL

Sonic Testing
James Instruments IL
Penn Tool Co NJ

Spectroscopy Instruments
Cilas Particle Size WI
Horiba Instruments Inc CA
LECO Corp MI
Ocean Optics Inc FL
Optocon AG Germany

Surface Analysis Instruments
Carl Zeiss MircoImaging Inc NY
Dalmia Inst of Scientific & Industrial Research India
Euro Support Advanced Materials The Netherlands
Horiba Instruments Inc CA
Hysitron Inc MN
Nanoscience Instruments AZ
OptiPro Systems LLC NY
Particle Technology Labs IL **See ad on pg 99**
Quantachrome Instruments FL
Taber Industries NY

Tensile Testers
Applied Test Systems Inc PA
CSC Force Measurement Inc MA
TA Instruments DE

Thermal Diffusivity/Conductivity Analysis Instruments
Dalmia Inst of Scientific & Industrial Research India
Linseis Inc NJ
Netzsch Instruments NA LLC MA
Setaram Instrumentation France
TA Instruments DE
Thermal Wave Imaging Inc MI

Thermal Imaging
CelSian Glass & Solar BV The Netherlands
Neoptix Canada
Thermal Wave Imaging Inc MI

Thermogravimetric Analysis Instruments
BuzzMac Intl LLC ME
LECO Corp MI
Linseis Inc NJ
Mettler-Toledo Inc OH
Netzsch Instruments NA LLC MA
Setaram Instrumentation France
TA Instruments DE

Thermomechanical Analysis Instruments
Edward Orton Jr Ceramic Foundation OH
Linseis Inc NJ
Optocon AG Germany
Setaram Instrumentation France
TA Instruments DE

Ultrasonic Instruments
APC International Ltd PA
James Instruments IL
APC International Ltd PA
James Instruments IL
Technisonic Research Inc CT

Visual & Optical Testers
Haiku Tech Inc FL
Optocon AG Germany
Penn Tool Co NJ
RISE Research Institutes of Sweden, RISE Glass Sweden
TA Instruments DE
Taber Industries NY

X-Ray Diffraction Instruments
American Stress Technologies Inc PA
Dalmia Inst of Scientific & Industrial Research India
Horiba Instruments Inc CA
MSE Supplies AZ
RocCera LLC NY

X-Ray Instruments
American Stress Technologies Inc PA

X-Ray Spectroscopy Instruments
Cilas Particle Size WI

Zeta Potential Analyzers
Brookhaven Instruments Corp NY
Cilas Particle Size WI
Fritsch GmbH - Milling and Sizing Germany
Horiba Instruments Inc CA
Micromeritics Instrument Corp GA
Particle Technology Labs IL **See ad on pg 99**

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Chattanooga TN 37405

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EIRICH offers innovative technologies for the preparation of raw materials and bodies in the ceramic industry. EIRICH develops and manufactures equipment (stand-alone machines and complete systems) for material processing, including grinding, mixing, granulating, kneading, and suspending. The equipment is used for preparing refractory mixes for shaped and unshaped products, tap hole clay, silicate ceramics slurries for table and sanitary ware, technical ceramics for dental and ballistic protection application, proppants, and much more. The unique design of the EIRICH Mixer allows for mixing, granulating, kneading, and dispersing in one single machine, which saves on costs, energy, time, and space. The tool speed can easily be adjusted and guarantees short batch times and homogenization. The mixer sizes for ceramics applications range from 1 liter to 7,000 liters and can be combined with vacuum drying technology. EIRICH also offers mills for grinding and size reduction.

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http://www.elantechnology.com/
info@elantechnology.com

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http://valleydesign.com
info@valleydesign.com

Manufactures substrates, windows, wafers, shims, and spacers from ceramics, glass, and metals. Precision lapping, polishing, 4-axis CNC machining, dicing, edge-polishing, thinning, grinding services. Specializes in ultrathin, ultraflat, superpolishing.

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Norwalk CT 06856-5150

http://www.vanderbiltminerals.com
mineralsales@vanderbiltminerals.com

Vanderbilt Minerals LLC specializes in industrial minerals and chemicals, including kaolin clays, pyrophyllite, wollastonite, smectite and hectorite clays, dispersing agents, and xanthan gum.

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https://www.velco.de
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info-us@verder-scientific.com

Verder Scientific Inc, comprised of the Retsch, Retsch Technology, Carbolite Gero, and ELTRA brands, sets the standard in high-tech scientific equipment, serving research institutions and analytical laboratories, as well as manufacturing companies, for decades. The company manufactures and supplies instruments for sample preparation and elemental analysis as well as heat treatment of solid materials.

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New Albany OH 43054-9409

http://www.verityconsultants.com
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Verity provides manufacturing consulting, technical investigations, analysis, reports, and testimony for the resolution of litigation and claims involving failures of glass and ceramic materials, product liability, and industrial workplace accidents.

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http://www.vesuvius.com
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http://www.viridis3d.com
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http://www.vitcas.com
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Niagara Falls NY 14302 Fax: 716-278-6650

http://www.washingtonmills.com
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ZILI USA LLC
149 Nichol Ave No 2
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http://www.zilialutech.com
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Zili USA is a subsidiary of Zhejiang Zili Alumina Materials Co Ltd, specializing in high-purity alumina materials development and manufacturing. Its products include tabular alumina, low sodium alumina, reactive alumina, and calcined alumina. With warehouses situated in the states, Zili has fully stocked inventories ready for shipment.

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PO Box 519
Florida NY 10921-0458

http://zircarceramics.com
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ZIRCAR Ceramics Inc manufactures ceramic fiber based high temperature thermal and electrical insulation products for use at temperatures up to 1,825°C. Offering boards, cylinders, blankets, papers, textiles, coatings, and adhesives. Furnace insulation assemblies, resistance heated modules, and a special emphasis on precision custom CNC machined components. Legendary heritage in high performance!

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http://zrci.com
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