# Ceramic & Glass MANUFACTURING

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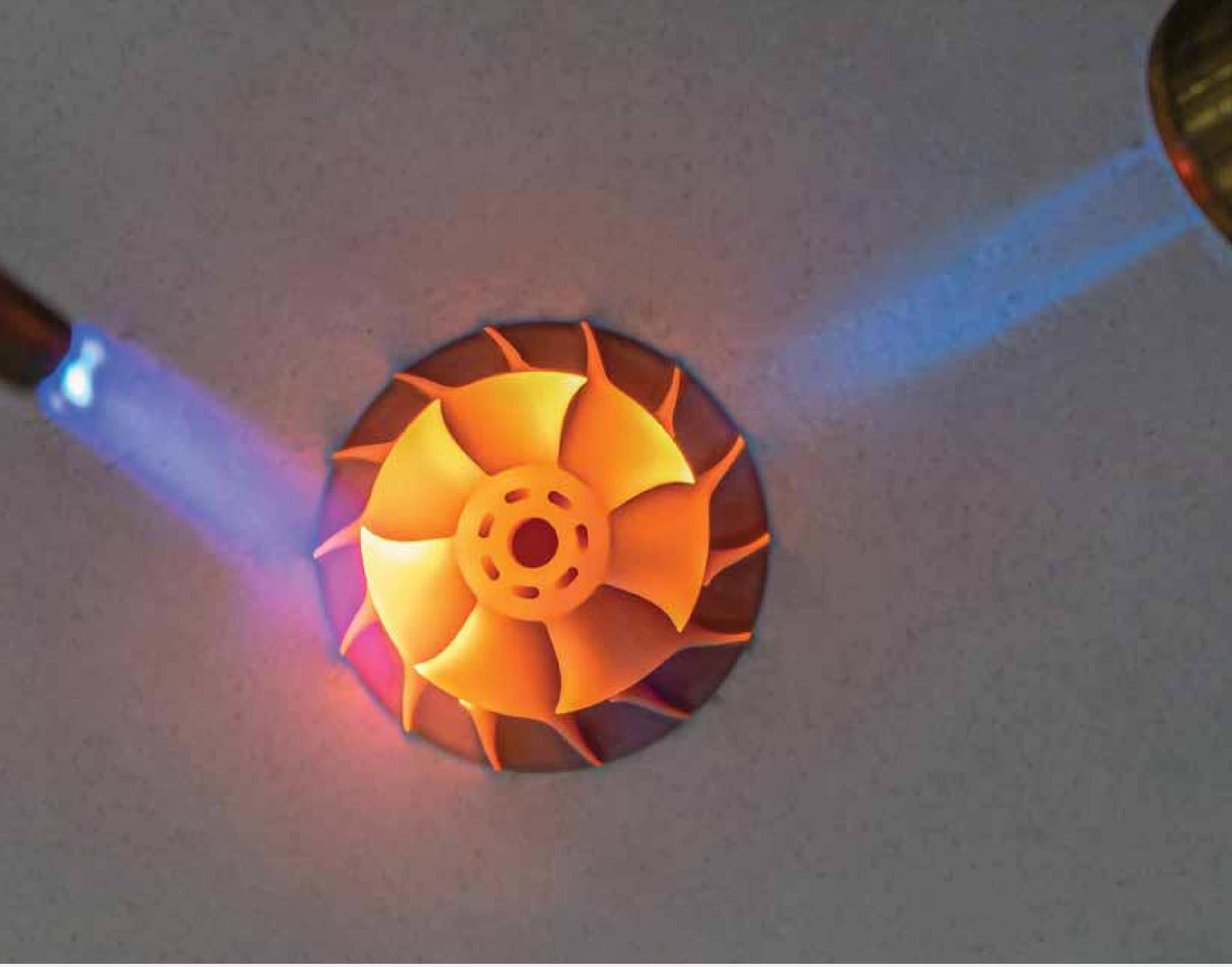

## A BRIGHT AND BOLD FUTURE AHEAD: HOW CERAMIC ADDITIVE MANUFACTURING IS DRIVING GROWTH

THE PROMISING PATH FORWARD FOR ADDITIVELY MANUFACTURED CERAMICS

ALFRED UNIVERSITY-CACT PARTNERSHIP SUPPORTS LAUNCH OF START-UP COMPANY AT INCUBATORWORKS

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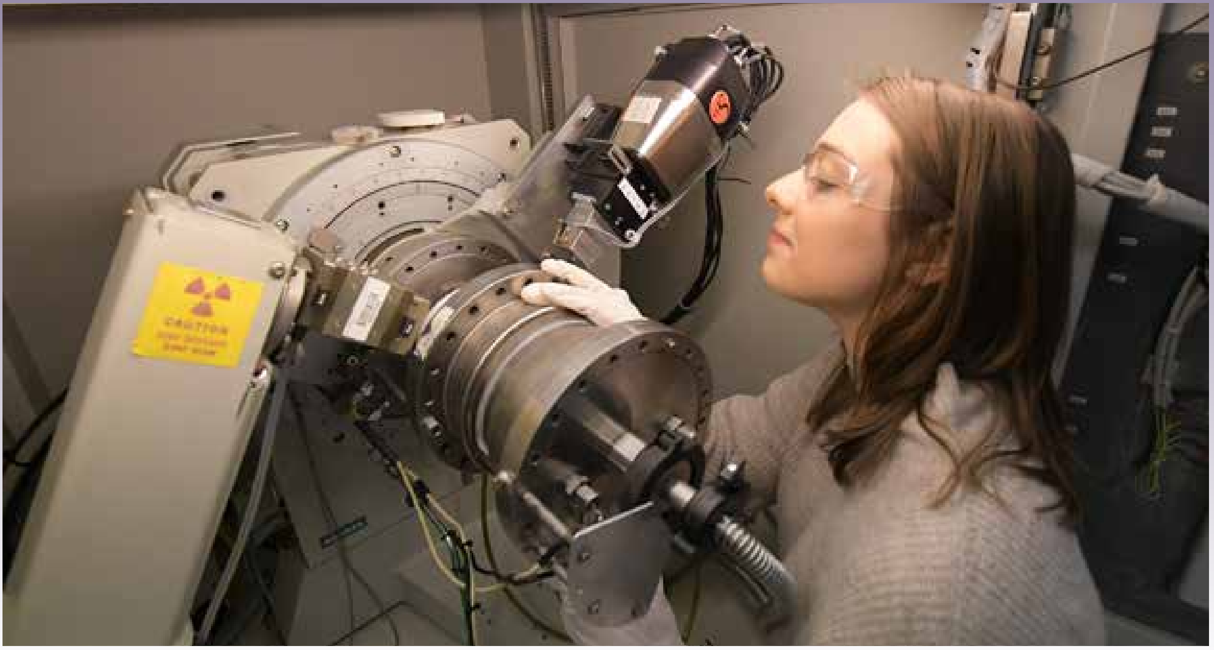

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# INDUSTRY NEWS

## SCHOTT EXPANDS PHARMACEUTICAL GLASS OPERATION

Specialty glass manufacturer SCHOTT plans to build a second melting tank for pharmaceutical glass tubing at its main plant in Mainz, Germany. The investment amounts to 40 million euros. The facility is scheduled to go into operation in mid-2022. SCHOTT said it is responding to increasing global demand for glass tubing for pharmaceutical packaging. The manufacturer significantly expanded its production capacities for pharmaceutical tubing in Asia in the fall of 2020 with the commissioning of another tank in India and a new plant in China.

SCHOTT AG is based in Mainz, Germany

The Center for Glass Innovation will be a research resource for glass producers.

## ALFRED CENTER FOR GLASS INNOVATION AIMS TO IMPROVE RECYCLING MARKET

The state of New York announced a collaboration with the State College of Ceramics at Alfred University to strengthen markets for recycled glass and improve the quality of glass available for recovery. The Center for Glass Innovation will be a resource for glass producers and will create space for basic and applied research, user facilities, and experimental glass tanks for applied, industrial-scale research, with an emphasis on creating higher-value end markets for curbside collected glass. This center will be the first of its kind in the United States, where glass companies will be able to test small batches of new glass compositions in a pilot production environment.

## KYOCERA R&D CENTER SLATED TO OPEN IN FALL 2022

Kyocera announced the construction of a research and development center at its Kokubu campus in Kirishima City, Kagoshima, Japan. The center will focus on innovations in information and communications, environmental preservation, and smart energy. The Kokubu campus is the site of three R&D groups: Kyocera's Monozukuri R&D Laboratory, which focuses on advanced material technologies; its Production Technology Division, focusing on manufacturing process innovation; and its Analysis Center, which develops simulation and evaluation technologies. Kyocera said the investment is approximately 10 billion yen (approximately $96 million), and the facility should open in September 2022.

A rendering of the new R&D center.

## CERAMICS EXPO SCHEDULED FOR AUGUST

ceramics expo

The 2021 Ceramics Expo is scheduled to be held in person Aug. 30 to Sept. 1 at the Huntington Convention Center in Cleveland, Ohio. The theme will be "Advanced Ceramics: Enabling a Clean, Efficient and Electrified Future." Event organizers revised the format to follow physical distancing guidelines, increase aisle widths, and reduce wait time for registrations. Updates and free registration are available at www.ceramicsexpousa.com.

Total wants to reach 35 GW of production capacity from renewable sources by 2025.

## TOTAL CREATES JOINT VENTURE TO DEVELOP CLEAN ENERGY IN THE US

Global energy company Total and 174 Power Global, a wholly owned affiliate of Hanwha Group, signed an agreement to form a 50-50 joint venture to develop 12 utility-scale, solar, and energy storage projects of 1.6 gigawatts cumulative capacity in the United States, transferred from 174 Power Global's development pipeline. The first project started production in 2020, and the remainder will be put on stream between 2022 and 2024. The projects will be in Texas, Nevada, Oregon, Wyoming, and Virginia. Total said it is building a portfolio in renewables and electricity that could account for up to 40% of its sales by 2050.

## US DEPARTMENT OF DEFENSE FUNDS RARE EARTHS PLANT

Lynas Rare Earths Limited entered into an agreement with the U.S. Department of Defense to build a commercial light rare earths separation plant in the U.S., through its Lynas USA LLC subsidiary. Lynas said DOD funding is expected to be capped at approximately $30 million, and Lynas also will be expected to contribute approximately $30 million. The plant is expected to be located in Texas. Once operational, it is expected to produce approximately 5,000 tons per year of rare earths products. "COVID-19 has exposed the risks within global supply chains of the single sourcing of critical materials," says Lynas CEO Amanda Lacaze.

Lynas CEO Amanda Lacaze


CoorsTek participated in a traditional Thai blessing to break ground on the new facility.

## COORSTEK EXPANDS IN THAILAND

CoorsTek is expanding its manufacturing footprint in southeast Asia, beginning construction on the first phase of a 400,000-square-foot engineered ceramics manufacturing facility in Rayong, Thailand. CoorsTek said it expects the facility to be fully operational by early 2022. The company will hire approximately 300 employees over the next two years, and up to 600 within five years. "We are expanding our operations into regions with better access to growing markets," says Michael Coors, co-CEO of the Colorado-based company.

# MORE INDUSTRY NEWS

## MURATA COMPLETES ELECTRODE MANUFACTURING PLANT

Murata Manufacturing Co., Ltd. completed a new production building at its Yasu Division in Shiga, Japan. The facility was constructed to increase the production capacity of electrode materials in order to meet medium- to long-term increases in demand, the company says. The cost of the facility was 14 billion yen (approximately $133 million). Murata designs, manufactures, and sells ceramic-based passive electronic components, communication modules, and power supply modules.

Workers will produce electrode materials at the new facility.


Peter Morten, CEO of STC, left, and Dr. Rick Yoon, former CEO & owner of IJ Research.

## SUPERIOR TECHNICAL CERAMICS GROWS WITH ACQUISITION

Superior Technical Ceramics acquired Santa Ana, Calif.-based manufacturer IJ Research. IJ Research specializes in applications that include electrical feedthroughs and opto-electronic windows, along with various sapphire-to-metal brazed hermetic assemblies. The firm provides conceptual design, research and development, materials selection consulting, and prototyping through to manufacturing. STC, based in St. Albans, Vermont, is a privately owned company with more than 100 employees.

## VELCO CELEBRATES 50 YEARS

50 Years 1971 - 2021 velco www.velco.de

For 50 years VELCO GmbH/Germany has served the foundry, steel, and refractory industries.

The company was established in 1971 by Kurt Wolf, father of today's owner Christian Wolf, in the city of Velbert located at the border of the Ruhr industrial area. Velco's first Rotamat rotor gunning machine was launched that same year, and there are almost 1,300 in use around the world today.

Over the decades, VELCO improved and broadened its machines, respecting industry's demand for cost savings, improved efficiencies, and rising safety. Besides the Rotamat, VELCO's delivery program now comprises pressure vessel gunning machines and gunning robots for the refractory repair of the different aggregates.

VELCO built up a second business line for the pneumatic transport of dry bulk materials. In steel plants, this transport mainly involves the injection of carbon or lime for slag foaming in the EAF. Other areas are secondary metallurgy or the injection into the blast furnace.

Developments continue for improving dry gunning regarding quality and dust creation as well as implementing industry 4.0 technologies. A remote access module that allows for worldwide connection using only a smartphone is available for all machines and can access data such as operation hours, flow rates, water pressure, operational conditions, fault messages, and even the location of the machine.

For further information, visit www.velco.de.

# A BRIGHT AND BOLD FUTURE AHEAD: HOW CERAMIC ADDITIVE MANUFACTURING IS DRIVING GROWTH

By Alice Elt and Isabel Potestio

As the global leader in the field of industrial additive manufacturing for ceramics, Lithoz has constantly pushed the boundaries of innovation since its founding in 2011. Based in Vienna, Austria, Lithoz's mission is to grow ceramic 3D printing as a reliable manufacturing technology for industrial production, and many of our customers are now using additive manufacturing (AM) as an established production method to meet industrial standards. We have become market and technology leaders with a wide range of 3D printers, ceramic materials, and training programs in use worldwide, including in Asia, Australia, and Brazil, while the founding of a subsidiary in the United States has allowed us to better connect with customers and strengthen our global presence.

**THE TIME IS NOW—THE GROWTH OF 3D PRINTING**

In a world that is becoming ever more digital, ceramic 3D printing is quickly growing into an established production technique. The fact that 25% of Lithoz customers have invested in multiple additive manufacturing systems highlights the success they have had with this technology. They believe AM to be a growing manufacturing market—and they are not the only ones. A recent SmarTech Analysis study showed that the additive manufacturing industry is expected to grow over the next decade to become a $4.8 billion market by 2030,[1] with the area of technical applications representing the most significant sector for driving market growth to more than $3 billion. The adoption of ceramic AM is expected to rapidly increase, with the main inflection point being in 2025 as major ceramic AM technologies come to maturity and benefit from having enough of a presence in the market to support the serial production of final components. Figure 1 shows growth trends expected for materials and applications.[2]

Many early adopters of ceramics AM are now up to eight years ahead in terms of AM experience, giving them a significant business advantage, while the fact that customers are now using 3D-printed parts means that suppliers offering 3D printing are quickly surpassing those who do not. Finally, as the technology becomes more well-known, the range of applications is broadening—new players in various fields are entering the ceramic AM market, finding new applications in the process and innovating past traditional ceramic companies. This innovation puts them at a great advantage, allowing them to explore new design ideas and functionalities unachievable using conventional forming techniques.

Additionally, additive manufacturing gives businesses a secure supply chain in a way other production methods simply cannot. This independence has made AM invaluable for many companies during the pandemic, as they could be self-reliant in times of economic and manufacturing uncertainty. The entire AM method is modeled after digital independence—once a customer has a digital file of the part, components can be produced and edits made to reach certain parameters, and files can be saved and accessed anywhere in the world. Where there is a 3D printer, this part can now be produced. The use of digital files opens up an entire digital warehouse for the customer, making it easy to gain new connections and innovate with others in their field.

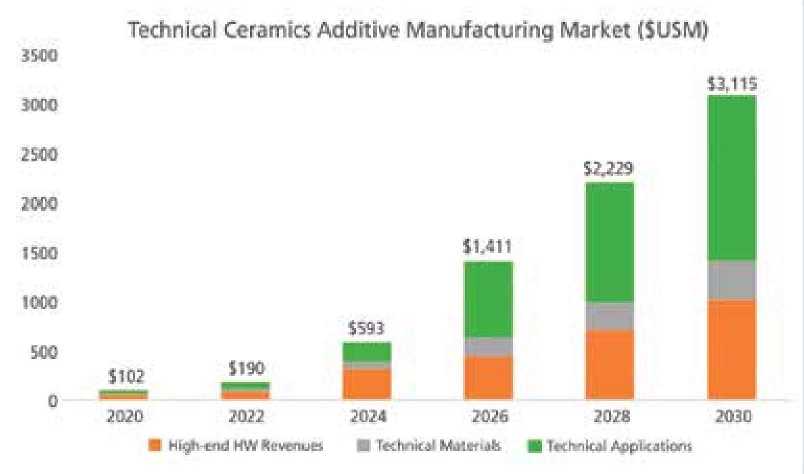


**Figure 1. The rapid growth of the technical ceramics market in 3D printing. (Reference 2)**
*Credit: Anusci, 3D Printing Media Network*

Figure 2. Lithoz 3D-printed silicon nitride. Ceramic 3D printing can print parts that might be too costly or impossible to produce using traditional manufacturing. *Credit: Lithoz*

Ceramic 3D printing is very well suited to modern manufacturing and development, no matter what field a company is based in, and the market will grow rapidly as more businesses implement AM as a serial production method to find new, innovative applications and enjoy the advantages of digitalization and a stable supply chain.

**THE ADVANTAGES OF CERAMIC 3D PRINTING**

As we have seen, ceramic additive manufacturing will undergo a huge period of growth in the next decade as customers take advantage of 3D printing technologies, making huge waves in the manufacturing market and disrupting traditional manufacturing processes. However, when considering the fact that there are already many well-established and conventional manufacturing methods available for ceramics, the question is: Why is another technology needed?

The reason lies in the development of today's increasingly complex and customized applications. Customers demand ever more from their technology and, as manufacturing environments develop further, demand grows for more complex components to be rapidly produced, while new ideas for applications require more freedom in design to be made a reality (Fig. 2).

When it comes to conventional forming methods, such as milling, pressing, and injection molding, companies are often limited to designing parts that can be produced, instead of parts they want to produce. The design freedom offered by 3D printing is, in this area, simply unparalleled, allowing designers to focus more on functionality when coming up with new concepts. As Ing. Tassilo of Fraunhofer IKTS states, the manufacture of "extremely complex-shaped or individualized components … has primarily been occupied by AM" so far.[3] Using AM, it is possible to construct unique geometries, unachievable using traditional methods, and this ability greatly expands the range of possible applications for businesses in all fields. As such, Lithoz's ceramic 3D printing is an enabling technology for customers that can keep pace with even their most innovative ideas. While conventional technologies have reached their limits in terms of fulfilling modern aims, AM has grown and become a strong industry that can be used for such projects.

Another reason for implementing AM is the fact that this technology greatly speeds up the entire product development process, resulting in a shorter time to market. Design changes can be made more quickly and easily, which encourages the improvement of existing products, while the rapid production of prototypes facilitates entry into new markets. The speed of the entire process enables a quick start to exchanges between businesses and potential customers. Trend forecasters predict that customers in the future will want technology that facilitates hyper-customization, meaning that products can be rapidly altered without complication. Using AM, new designs can be created without losing the original form simply by altering digital files. This opportunity is a great one for companies to use AM to extend or change their business models and enable profitable mass customization.

Figure 3. Lithoz is known for its high-resolution and accurate technology, which is trusted for even the most precise of applications, such as these surgical tool components. *Credit: Lithoz*

One significant advantage of AM is that it does not require any set-up costs. The tooling required for traditional manufacturing processes not only has a negative impact on a part's time-to-market, but also makes such processes costly for small- or medium-sized production runs. AM technology makes small- and medium-sized runs more economical, while the fact that customers can use AM to specifically customize their designs enables easy improvements and further innovation in product design, as customers have no cost or time worries.

Take this electrosurgical tool (Fig. 3) as an example. Used in precise medical applications, this component is characterized by its extremely small size, complex internal geometry, and challenging features—aspects which are very difficult to achieve using traditional molding technologies, and which would require expensive and time-consuming tooling. However, as tooling is not required using AM, this part can be produced quickly and economically, while still ensuring that the exact form requirements are met.

### HOW CERAMICISTS CAN LEVERAGE THEIR KNOW-HOW WHEN SETTING UP 3D PRINTING PROCESSES

In terms of materials, ceramicists are at a great advantage when implementing AM. This advantage is due to ceramic AM being very similar to other ceramic manufacturing processes—in terms of actually implementing 3D printing, thermal post-processing is essentially unchanged. Only the product designs need reworking, and prior ceramic experience and knowledge can still be used for the second step of the process. Furthermore, 3D printing gives ceramic businesses another option when it comes to forming technologies. Ceramics are known as being rather difficult to process in comparison to other materials, and having a new forming process alongside machining or pressing enables new ceramic applications. By adopting 3D printing, ceramicists put themselves at a great advantage to beat competitors still solely using conventional forming methods, and they can now work with difficult-to-process materials such as silicon nitride.

Overall, ceramic industries can greatly benefit from implementing AM. This technology can be used as a single manufacturing platform for everything from prototyping and small-batch production up to mass manufacturing, opening the door to a myriad of manufacturing possibilities that businesses may not have had access to before.

At Lithoz, we have already seen the success with which many different companies have implemented ceramic additive manufacturing into their production environments and how they have been able to innovate even further as a result. One company that has already taken advantage of AM is technical ceramic producer Ceramco (Fig. 4), who has been working with Lithoz's technology since 2015 and has doubled its 3D printing production capability. Thomas Henriksen, president and CEO of Ceramco, describes how the company originally implemented AM for cheaper prototyping before realizing its full potential: "Since we make parts by ceramic injection molding (CIM), we initially thought 3D printing would be a good way to give customers prototypes if they didn't want to pay for any CIM tooling. However, it turned out that many additive customers remained as additive customers, and seldom went to serial production that required CIM."

After seeing the success of AM with businesses, Ceramco decided to invest in this technology. "More often than you might think, customers persistently want additively made parts, even over conventionally made parts," Henriksen says. As leading ceramic part producers, Ceramco's experience has been that "with the right parts of ideal sizes, Lithoz 3D printing technology can be used to make very good quantities."

Figure 4. President and CEO of Ceramco Thomas Henriksen stands with the Lithoz 3D printer CeraFab 7500. *Credit: Ceramco*

As Ceramco was so far ahead of the curve in terms of investing in this technology, it is well-trained in working with this process. "We were considered an early adopter by purchasing our first machine in 2015, long before any other technical ceramic manufacturers in the U.S. invested in a machine," Henriksen says. Early investment in additive manufacturing allowed Ceramco to innovate beyond other ceramic companies, becoming leaders in the field and benefiting from the economical and effective aspects of 3D printing.

**HOW AM IS DRIVING INNOVATION IN MULTIPLE MARKETS**

It is now clear that AM excels in applications where injection molding, milling, and pressing cannot. But where are businesses benefiting the most? It is areas such as medical devices, the semiconductor industry, machinery, electronics, and dental components that are most driving the growth of ceramic 3D printing. Ceramco found that since AM allows for the printing of such complex structures, this technology encourages and enables the production of interlocking ceramic components that contain more features than an injection molded part. Such parts can have multiple functionalities in varying industries, thus benefiting the entire ceramic industry and meaning that components "are not necessarily market specific." Henriksen believes that ceramic AM "will give people access to ceramics much more readily, which I think will spur innovation in finding new applications."

AM has great uses in the aerospace and industrial gas turbine industries, where the freedom offered is being used to develop new designs for casting cores with more complex structures than ever before, including multiple walls and fine branches (Fig. 5). These new forms cannot be produced using conventional injection molding methods, showing how AM has greatly expanded applications in this area in ways that other technologies could not.

Developments in AM opened the door to applications far beyond technical parts. It is now possible to manufacture components for medical and dental applications, with the material properties of ceramics coming into their own in terms of biocompatibility. Additive manufacturing is being used to serially produce surgical tools in lot sizes of up to 10,000 parts, while dental parts and bone implants can be efficiently produced and expertly customized simply by editing the digital file. This ability means that medical components and implants can be matched to individual patients and certain properties modified to best suit the situation. In these fields, CE-certified Medical Devices (Class III) and FDA-approved Medical Devices (Class IIa) have already been successfully produced, used, and implanted in vivo.

Redesigning allows for improvements and new products to become fully customizable, while the entire process is made more economical and cost-effective due to the material-saving and tool-free characteristics of AM. As a result, it is clear that while companies may not currently consider themselves to be suited to AM, it only takes a few small changes to start taking advantage of this innovative technology.

**THE SWITCH TO 3D PRINTING—HOW TO GET THE MOST OUT OF THIS GAME-CHANGING TECHNOLOGY**

While the implementation of AM requires relatively few changes, adopting a wholly new manufacturing process does, of course, require patience and can pose challenges in terms of mindset changes. Having an experienced partner is a key element in the optimal integration of AM into existing processes and structures. Having worked with many customers across research and industry, Lithoz understands the importance of supporting new and existing AM adopters and has therefore tailored its business model to support clients all the way from initial adoption to eventual scale-up. We offer our customers an experienced support service that enables them to seamlessly integrate our ceramic 3D printing technology and, when the time comes, implement scale-up capabilities for serial production.


Figure 5. From small, complex parts such as aerospike nozzles (above) up to much larger industrial components such as casting cores (right), AM can produce near limitless geometries. *Credit: Lithoz*

In May 2020, Lithoz opened the Lithoz Innovation Lab (LIL, Fig. 6) for this precise purpose—to advance ceramic 3D printing and enable businesses to accelerate their developments and further innovate in ceramic manufacturing. Alexander Michaelis of the Fraunhofer Institute for Ceramic Technologies and Systems IKTS gave his opinion of the new space: "This new state-of-the-art facility is a huge leap forward, as it gives industry and R&D the opportunity to push the limits of ceramic 3D printing, while making discoveries along the way."

By ensuring that businesses are fully using AM for their industries, we are helping the growth of the AM market as an established manufacturing technology. Johannes Homa, CEO of Lithoz, says, "We see ourselves not only as a machine supplier, but as a partner for our customers. We have learned that a partnership approach is the key to successfully implement ceramic AM. AM has already made huge waves in many industries, and we at Lithoz are looking forward to seeing the new applications this technology will offer and where it will take us in the years to come."

Figure 6. The newly opened Lithoz Innovation Lab. *Credit: Lithoz*

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# THE PROMISING **PATH FORWARD** FOR ADDITIVELY **MANUFACTURED** CERAMICS

By David Holthaus

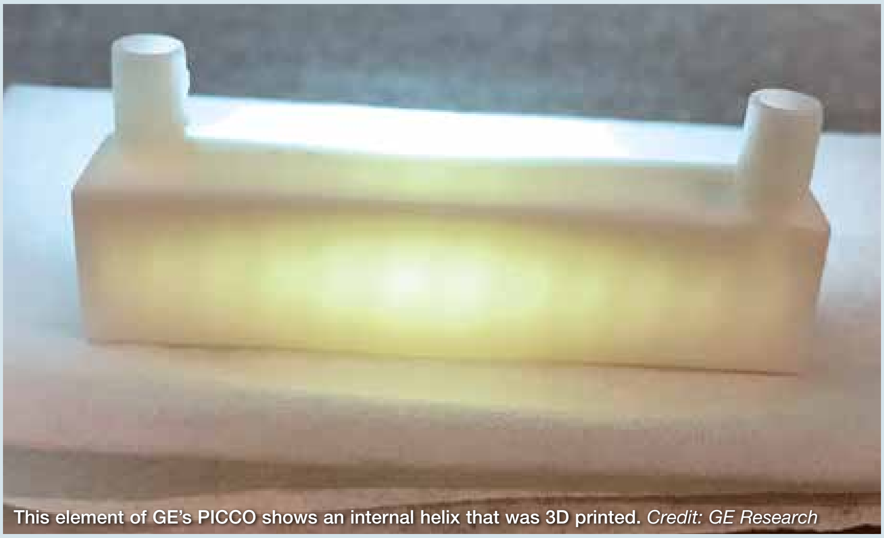
The Army's Bradley Fighting Vehicle is being us

The U.S. Army is building a growing fleet of electric vehicles that demand resiliency, as well as speed and durability.

Military vehicles, of course, must perform in high-stress situations, and the inner workings and power drive systems of an electrified fleet must withstand high voltage and temperatures. The silicon carbide semiconductor chips used in these vehicles can improve the efficiency and performance, but they can face thermal challenges when pushed to extremes.

As a potential solution, the U.S. Army Research Laboratory and GE Research are working together to develop a next-generation cooling system called the Package Integrated Cyclone Cooler (PICCO) that uses additive manufacturing to create a critical component.

In PICCO, a cold plate for electronics cooling is fabricated with an internal helix that swirls boiling fluid to increase the heat transfer coefficient and the critical heat flux, says Cathleen Hoel, a senior materials scientist at GE. The cyclone cooler is made using cutting-edge additive manufacturing, or 3D-printing technology, to produce ceramic parts that will permit the power electronics packages to stay cool and maintain their performance, even when transmitting heavy loads of power.



This element of GE's PICCO shows an internal helix that was 3D printed. *Credit: GE Research*

It is a prime example of how additive manufacturing, or AM, can be put to use in advanced systems that use ceramic materials.

"At GE, we are working closely with system and component designers and learning about areas where ceramics formed by AM can play a critical role in enabling next-generation systems," Hoel says.

Additive manufacturing of ceramics, although in its early stages, is growing rapidly and the market has significant potential, experts say.

The ceramics 3D printing market is expected to generate overall revenues of more than $3.6 billion by 2028, rapid growth from

ed to prototype hybrid electric drives to reduce costs and fuel consumption. *Credit: U.S. Army photo*

$185 million in 2019, according to SmarTech Analysis, a Crozet, Va.-based market research firm.

"It has a tremendous amount of upside and development potential and hasn't even scratched the surface yet," says David A. Gottfried, deputy director of business development at the Center for Advanced Ceramic Technology at Alfred University.

The Center is developing a new $7.75 million Center for Advanced Ceramic Manufacturing (CACME) at the University, which is focused on helping industry develop and commercialize additive manufacturing of ceramics and glass.

Cathleen Hoel

"It's not for blue-sky research," Gottfried says. "It was done as an economic development project for companies that want to develop new materials and processes."

The biggest strength of AM for ceramic manufacturing lies in its ability to make designs that cannot be made any other way, Hoel says. "Expanding the design space of ceramics, as well as metals and polymers, allows more efficient systems and the ability to overcome limitations imposed by traditional manufacturing methods," she explains.

Sectors that are strong candidates for ceramic AM include aerospace, power generation, energy storage, and health care, according to Hoel.

AM helps engineers with rapid prototyping and demonstrations of new designs without a big investment in new tooling, says Igor Levin, a leader in the materials structure and data group at the National Institute of Standards and Technology (NIST). By offering "tool-free" fabrication, AM allows for design flaws to be discovered early, without the investment that other methods would require, he says.

The technology also holds promise for replacing parts that may have become obsolete, says Brandon Ribic, technology director at America Makes, the Youngstown, Ohio-based additive manufacturing accelerator of the National Center for Defense Manufacturing and Machining. America Makes is one of eight Manufacturing Innovation Institutes established and managed by the U.S. Department of Defense as public-private partnerships.

Researchers there conducted a project called "Maturation of Advanced Manufacturing for Low-Cost Sustainment (MAMLS)," which was partly funded by the Air Force Research Laboratory. Air Force aircraft have an average lifespan of about 27 years, according to the America Makes website, meaning critical parts are often out of production because they are obsolete, cost too much to create, or are made in small quantities.

The first phase of the project showed promise for additive manufacturing. "In terms of the ability to readily get out a product that gets to the customer in a shorter period of time and with low-volume production, it does offer a cost benefit and time savings," Ribic says.

The project was able to demonstrate that AM technologies could improve the ability to rapidly replace parts and improve maintenance for legacy aircraft, as well as enable on-demand replacement of damaged or obsolete components that could not be replaced through conventional supply chains.

Scaling up the volume of additively manufactured ceramic parts is something that needs more research. "That was low volume," Ribic says. "How does that scale to thousands and tens of thousands? We have a lot to learn still."

Additive manufacturing is an emerging technology, so there are growing pains. One that is unique to the ceramics industry is the need to debind and sinter parts after printing, Hoel says. The process can lead to stress and defects in the printed part, she says.

"The ceramics community has been debinding and sintering green parts for many years, so the difficulty is appreciated," she says. "AM uses binder chemistries that are not often used in traditional forming methods, so these differences need to be understood to overcome the defects."

AM can enable part designs of greater complexity, but that complexity can aggravate the challenges that are already present for printing, debinding, and sintering.

"Designs can be printed that could not be made by other methods, but the cost associated with those parts can be high because complex parts are generally more prone to defects," Hoel says.

The cyclone cooler also is an example of the challenges that can be associated with fabricating with additive. The PICCO is a complex design that can experience stress during debinding and sintering due to the nonuniform wall thicknesses in the design, Hoel says. The right ceramic slurry composition must be used to reduce those stresses.

Because AM is a nascent technology, parts made by it will be more expensive than those made by traditional methods. For that reason, GE researchers are focusing on parts that can only be made by AM and play a critical role in an advanced system, according to Hoel.

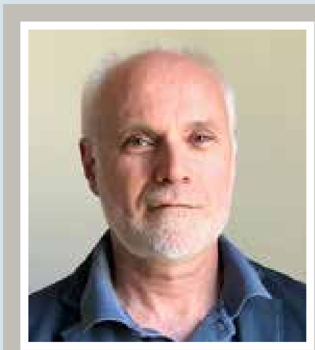
"AM is best leveraged in next-generation systems where the design benefits can be maximized and challenging aspects, such as anisotropic strength, can be managed," she says.

For example, GE is researching artificial bone scaffolds that can be used to repair damaged bone in patients. 3D printing allows for fine pore sizes to be fabricated in the artificial bone. However, removing uncured material from the pores can be challenging. "We are developing methods to effectively and consistently clean printed parts with fine pores," Hoel says.

Post-processing of additively manufactured parts is one of the main challenges for ceramic parts, Levin said. Debinding can be a source of defects, and sintering of green parts can also introduce defects and failures.

Biomedical applications are among the most promising areas for the use of additive manufacturing. The technology can enable patient-specific solutions, including for bone implants, dental implants, crowns, and bridges, as well as for medical device components and surgical tools, Levin wrote in a paper he co-authored for NIST.

Brandon Ribic



Igor Levin

"AM is envisioned to reduce the complexity of surgeries, improve biological response to implants, and lower cost" compared to conventionally manufactured materials because there is less machining, according to the paper, "Materials Research and Measurement Needs for Ceramics Additive Manufacturing," published in November 2020.[1] The paper reports on a November 2019 NIST-sponsored workshop to identify the most pressing research and metrology issues for additive manufacturing of ceramics.

The paper notes that a challenge for the health industry is to validate parts manufactured by AM. That is true for other industries using AM, Ribic says. "Inspection can be a challenge. If we're going to introduce complexity, being able to confirm that the interior features that I've put in there, that I can't see, are in the correct form and they're going to function as I anticipate them to—there needs to be a means to certify that," he says.

X-ray computed tomography has become a standard tool for certifying additively manufactured parts, but it presents challenges in ceramics because of variation in the densities of the material, Ribic says. Using acoustic sensing techniques could play a role in certifying ceramic parts, too, he adds.

Much more research is needed in this area and others, Levin says, before the technology can be more widely adopted. That is especially true for the creation of standards for feedstock materials and for identifying best practices for post-processing methods.

As the technology becomes more accessible, collaborations among industry, government agencies, and academia will help move this promising manufacturing method forward, the NIST authors say, as well as periodic meetings to review and share data.

**REFERENCES**

[1] Allen, A. J., Levin, I., and Witt, S. E. "Materials research & measurement needs for ceramics additive manufacturing." *Journal of the American Ceramic Society*, Vol. 103, Iss. 11 (November 2020): 6055–6069.

# ALFRED UNIVERSITY-CACT PARTNERSHIP SUPPORTS LAUNCH OF START-UP COMPANY AT INCUBATORWORKS

By Mark Whitehouse and David Gottfried

ALFRED, NY—Alfred University and its Center for Advanced Ceramic Technology (CACT) are supporting the launch of a new business that will commercialize a new additive manufacturing-based system for the terra cotta industry.

William Carty, professor of ceramic engineering and the J.F. McMahon Chair in Ceramics at the Inamori School of Engineering at Alfred University, launched the new firm Replacement Tiles Solutions, which is located at the IncubatorWorks facility in Alfred. IncubatorWorks—established in 1992 and previously operated as the Ceramics Corridor Innovation Center—is a state-of-the-art incubator offering services and facilities to foster growth of entrepreneurial businesses in ceramics, glass, advanced materials, and related technology-based industries.

Replacement Tiles Solutions is developing innovative solutions to 3D scan terra cotta roof tiles and other terra cotta elements in order to produce high-resolution molds used to make precise duplicates of the material needing replacement. Because this unique process allows for near-perfect color matching, replacement terra cotta can be installed without negatively impacting a roof's aesthetics.

Replacement Tiles Solutions is working closely with Orchard Park, N.Y.-based Boston Valley Terra Cotta, a global manufacturer of architectural ceramics that will serve as a subcontractor to the new company. Alfred University alumnus John Krouse '85 (B.S., ceramic engineering) is president of Boston Valley Terra Cotta, a company with over 40 years' experience as a grade 1 terra cotta roof tile replacement company, which will assist Replacement Tiles Solutions in bringing their new process to market.

Steven Hyde, left, and Mark Ciccarella, junior ceramic engineering majors at Alfred University, observe two sample molds created in a 3D printer at Replacement Tiles Solutions, where the students work as research assistants. *Credit: IncubatorWorks/Replacement Tiles Solutions*

"Thanks to significant advances in additive manufacturing, and leveraging our decades-long experience in working with terra cotta materials, we are transforming the way terra cotta roofs are repaired," Carty says. When terra cotta roofs are damaged, it is not uncommon for the entire roof to be removed and replaced, which can be an extremely expensive proposition. "Using our process, a homeowner can not only save thousands of dollars in materials and contactor costs by replacing only the damaged tiles, but also significantly reduce the amount of time needed to conduct the repairs," Carty adds.

Replacement Tiles Solutions also partnered with CACT, one of 15 NYSTAR Centers for Advanced Technology. The CACT is providing support for internships, access to analytical services, and partnership opportunities. One such partnership includes restoration of the historic Celadon Terra Cotta building located on Alfred Village's Main Street. Built in 1892 by the Celadon Terra Cotta Company, the building was designed as a sales office and display center for the company, and was considered a "catalog" of their work. Due in large part to the Celadon Terra Cotta Company's location in Alfred, this prompted then Governor Theodore Roosevelt in 1900 to establish the New York State School of Clay-Working and Ceramics (now the New York State College of Ceramics) in Alfred.

"Thanks to funding being made available through Governor Cuomo's Smart Growth Community Grant program that was awarded to the Village of Alfred, we're able to utilize state-of-the-art technology to scan and duplicate certain terra cotta elements on that building that could otherwise never be reproduced," says John Simmins, CACT executive director.

A committee of faculty, staff, and students from Alfred University have begun the process of identifying the repairs needed to both preserve its historic elements and ensure the building is structurally secure for another hundred years.

Adds Simmins, "The CACT was launched to support the growth of New York State's ceramic industry, including the creation of start-up companies like Replacement Tiles Solutions. This is an exciting opportunity to support the growth of a new business in Alfred, leading to significant capital investment and sustainable job creation in our region."

To date, Replacement Tiles Solutions has invested approximately $500,000 in specialized equipment used in its process, and the firm employs a handful of part-time and student workers. The firm hopes to graduate from the IncubatorWorks facility within the next two years and relocate to a larger facility to allow for expanded manufacturing while remaining in the Alfred community.

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