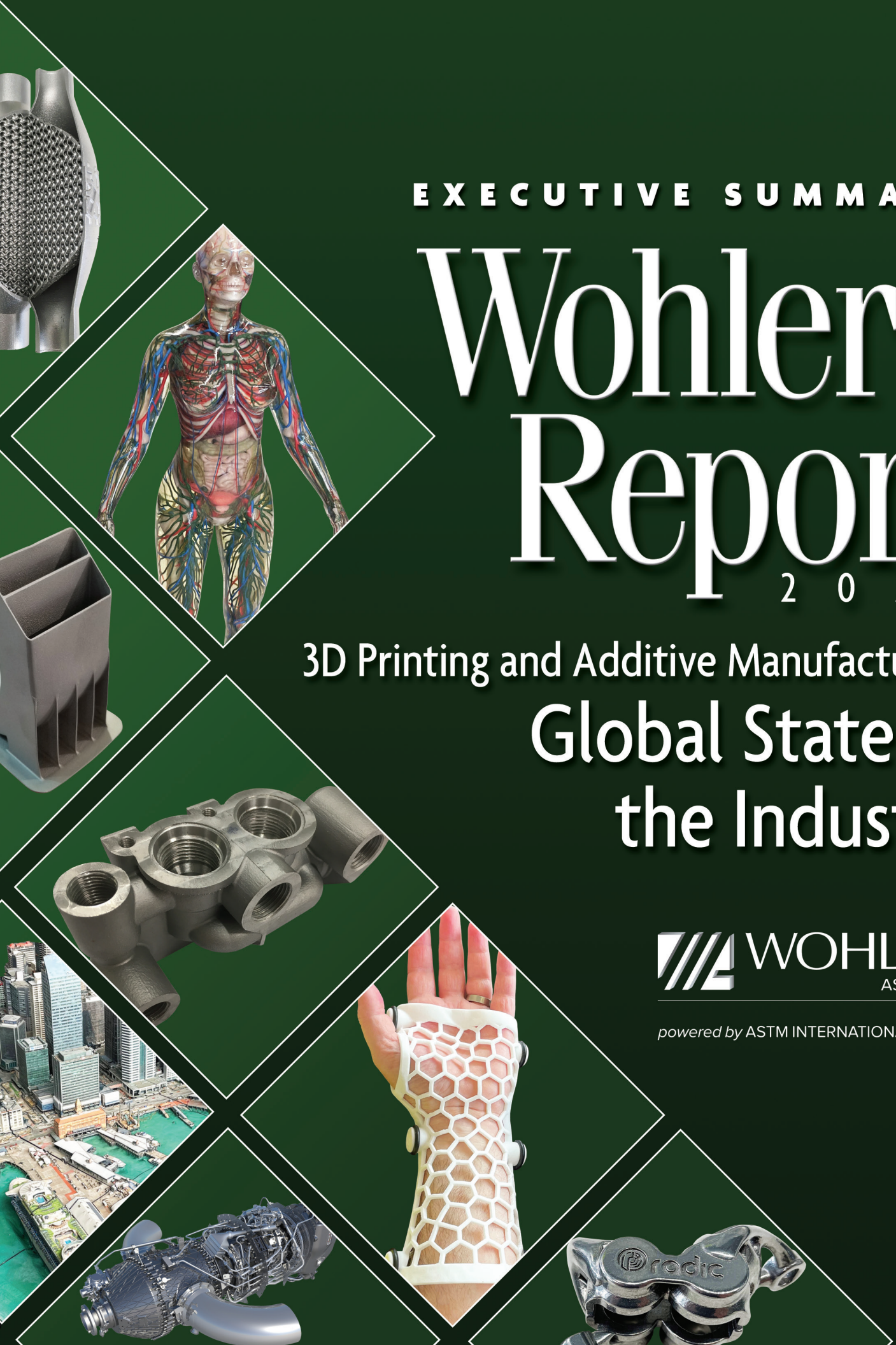
EXECUTIVE SUMMARY

Wohlers Report 2022

3D Printing and Additive Manufacturing Global State of the Industry



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Terry Wohlers, Noah Mostow, Ian Campbell, Olaf Diegel, Joseph Kowen, and Ismail Fidan authored sections of this report. Unless otherwise noted, images and illustrations are from Wohlers Associates.

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Remarks from ASTM International

ASTM International has supported the development of additive manufacturing (AM) for more than a decade. In 2009, it established the first committee (F42) on developing consensus-based globally recognized standards. In 2018, the organization accelerated the pace of standards, education, and workforce development by establishing a global AM center of excellence (AM CoE).

ASTM International has expanded its vision for AM by joining forces with Wohlers Associates. Over the past 35 years, Wohlers Associates has developed exceptional capabilities around AM market intelligence and consulting. The company's brand and reputation are unmatched.

The synergy from acquiring Wohlers Associates and the *Wohlers Report* has expanded the offerings of the AM CoE. Together, the two are providing advisory services, training, and expert reports. Through the AM CoE, a fast-growing team of experts are contributing to events, publications, special initiatives, and the development of standards.

The *Wohlers Report* has been a trustworthy and highly respected source on 3D printing for more than 25 years. The report is a resource for new and experienced professionals from industry, governments, and research institutes interested in understanding the current state of the AM industry and where it is headed. It will continue to serve as a valuable resource for many years to come.

Input and feedback on the report are encouraged. We hope it provides the information and insight you are seeking.

Mohsen Seifi, PhD
Director of Global Additive Manufacturing Programs
Executive Director, Additive Manufacturing Center of Excellence
ASTM International
Washington, DC, U.S.

A note from Terry Wohlers

I could not be happier with ASTM International's acquisition of Wohlers Associates. We have experienced incredible synergy since Day One and could not be more aligned. The ASTM AM CoE leadership is in full support of continuing and expanding the portfolio of products and services from Wohlers Associates, including the *Wohlers Report*.

We are committed to helping the AM industry develop the talent and resources it needs for standards, education, and the workforce. I am more excited than ever about the future of AM and hope to be a part of the industry for many years to come.

Our goal is for *Wohlers Report 2022* to serve as a resource and guide to companies, the research community, and government agencies as they navigate toward success with AM. We look forward to receiving your candid feedback on this new edition.

Terry Wohlers, MSc, Dr. h.c., FSME
Head of Advisory Services and Market Intelligence
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Wohlers Associates, Powered by ASTM International
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Introduction

This executive summary provides a sampling of information published in *Wohlers Report 2022*, a 425-page global study. The publication provides a thorough review and analysis of additive manufacturing (AM) and 3D printing—terms used interchangeably. This is the 27th consecutive year of the report's publication.

Wohlers Report 2022 was written for organizations worldwide seeking clear insight into the AM market. Groups that find it useful include manufacturers, service providers, researchers, educators, analysts, investors, startups, government agencies, and developers of industry standards and regulations.

An important part of the report is its comprehensive coverage of the AM industry's growth. It includes revenues and machine unit sales, complete with tables and charts that illustrate relevant trends, history, and industrial segments. At the foundation of this reporting is 27 years of data and information from the producers of systems, software, and materials, and many service providers and users of AM.

The report concludes with a discussion of the many emerging applications and trends in AM's developing ecosystem. It provides insights into the future—what is driving the industry today and what to expect in the years ahead—to assist in strategic planning and investing.

Wohlers Report 2022 can be used as a tool for education and knowledge acceleration. Information can provide a competitive edge, and that is what this report aims to do. Readers new to AM will gain a comprehensive understanding of the technology and industry. Seasoned veterans will benefit from the up-to-date information on growth, trends, and the latest and most important developments worldwide.

History of AM

Some may be surprised to learn that the fundamental concepts of AM were developed and demonstrated more than 150 years ago. The first computer-based AM systems were shown about 55 years ago. Vat photopolymerization (VPP) machines were introduced to the market in 1987 as beta test systems, with full commercialization a year later.

Prototype of an automotive distributor cap produced in 1987 using VPP, courtesy of 3D Systems

The history of the industry is filled with new process developments, bold entrepreneurs, and daring business ventures. Several startups and new processes succeeded, but others did not.

Industry survey

Wohlers Associates receives data and insight from industry insiders, producers of machines and materials, service providers, and others. The information provided from these sources helps to create unparalleled breadth and depth of information for this report. It supports the tracking of the AM industry, estimating its size, and forecasting the future. No other resource in the AM industry provides this level of information and detail. The results and takeaways from this report are based on 27 years of collecting and analyzing data and market intelligence.

For this edition of the report, 117 service providers worldwide responded to a detailed questionnaire. Also, 114 manufacturers of AM systems (both industrial and desktop systems) and 29 producers of third-party materials responded. This extensive body of data was used for this and other sections of the report. These companies provided information based on knowledge of their customers and the AM industry. In total, 260 companies responded to our request for data and information for this edition of the report.

Industrial sectors

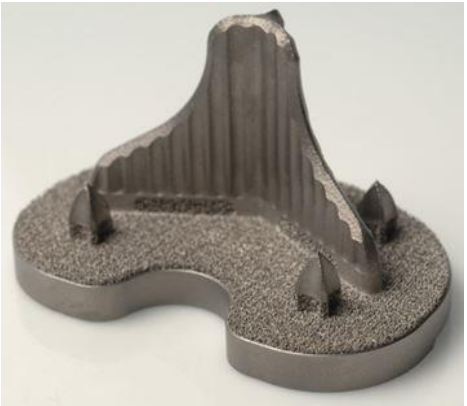
The aerospace industry was an early adopter of AM. Boeing and Bell Helicopter began to use polymer AM parts for non-structural production applications in the mid-1990s. Airbus, GE Aviation, Honeywell Aerospace, Lockheed Martin, and Northrop Grumman are also major AM users. The European Space Agency, NASA, Relativity Space, and SpaceX are using AM to produce igniters, injectors, combustion chambers, and fuel tanks for rockets.

Most commercial aircraft have 3D-printed parts, but they are not visible in the cabin. They include airducts, brackets, clips, and devices to secure wires and cables. According to Melissa Orme, vice president of additive manufacturing at Boeing, the company is flying more than 70,000 AM parts on commercial and military aircraft and satellites.

3D-printed gearbox for the Chinook military helicopter, courtesy of Boeing

Every human body is different, yet most medical devices are currently made in standard sizes. AM offers new methods and possibilities in device design and production. AM applications in healthcare continue to develop for both patient-specific designs and standard products. As a result, medical applications of AM are gaining traction at hospitals and other healthcare-related organizations.

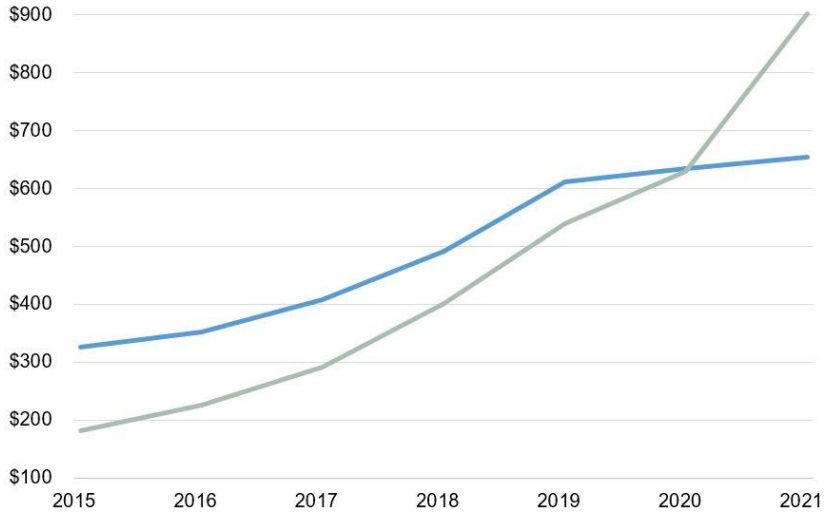
Most orthopedic implants used today are made in standard sizes. They are typically produced using traditional methods such as casting, machining, and molding. However, a growing number of polymer and metal devices in serial production are being made using AM. As of February 2022, the Food and Drug Administration (FDA) had cleared more than 250 medical devices made by AM, according to a representative of the FDA's Additive Manufacturing Working Group.



Titanium tibial baseplate, courtesy of Stryker

AM material sales

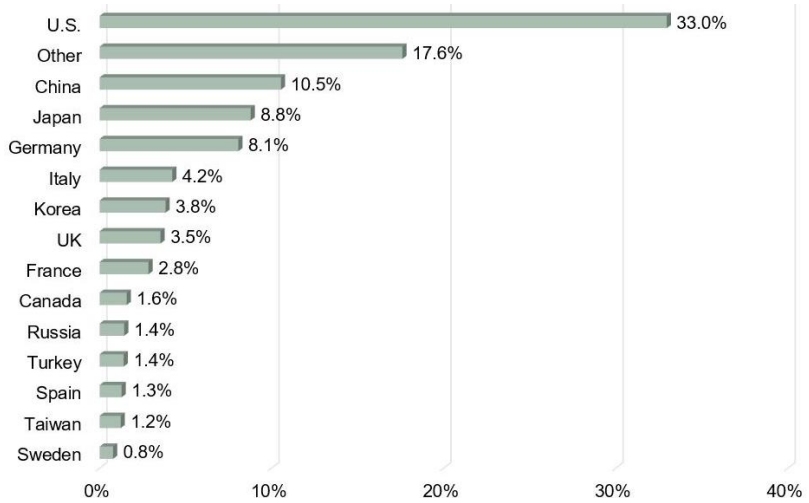
For three decades, photopolymer has been the dominant AM material. Just in the past two years, as seen in the following chart, polymer for powder bed fusion (green) has overtaken photopolymer (blue). The values in the vertical axis represent millions of dollars in revenue from these materials. Wohlers Associates expects polymer powders to continue to outpace photopolymers as the dominant material over the coming years as series production applications increase.



Source: Wohlers Associates

Installations by country

The following graph estimates, by percentage, the number of industrial AM systems installed by country or region. The estimates are cumulative totals from the technology's inception through 2021. Used system sales have been excluded from the estimates so machines are not counted more than once.



Source: Wohlers Associates

The U.S. continues to serve as home to more than three times the number of industrial AM systems than any other country. China, Japan, and Germany have the next largest installation base of machines, respectively.

Many AM system manufacturers and service providers worldwide supplied the data used to produce the previous charts. This information, coupled with data from third-party material producers, manufacturers of desktop 3D printers, and others, was used to complete other sections of *Wohlers Report 2022*. No other organization in the world has access to this breadth and depth of data and market intelligence on AM. It is used to track industry growth, provide historical perspective, uncover trends, and offer insight into the future of this exciting industry.

Summary

The AM industry has grown from a small community to a global movement of innovators, entrepreneurs, and professionals. From small businesses to large corporations in most industrial sectors, many are asking what AM can do for them. The use of AM has developed from a few applications related to modeling and prototyping to a far-reaching technology of critical importance. Governments around the world see the adoption of AM as a strategic benefit on multiple levels.

The industry recently has seen an increase in the number of mergers and acquisitions, while several other companies began to trade shares on the stock market. Privately held companies are receiving impressive rounds of investment, giving them the resources to advance their product and service offerings and expand their market reach. The investment community is optimistic and betting part of its future on the success of AM.

With all the progress, AM faces obstacles. They range from material characterization and qualification to improving efficiency, quality and methods of inspection. Over the past several years, the industry has shifted much of its fundamental research to applied R&D. Other areas of interest are improving speed, repeatability, automation, and supporting a greater number of materials and applications.

Acknowledgments

Wohlers Associates thanks the hundreds of individuals and organizations that contributed to this report. Creating this edition would have been impossible without them.

Wohlers Associates is grateful for the generous input from 117 service providers, 114 manufacturers of additive manufacturing systems, and 29 producers of third-party materials.

The following 85 contributors authored sections of this report. Wohlers Associates acknowledges their hard work and kind support.

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About the Authors and Editors

At the core of *Wohlers Report 2022* is a global team of five principal authors spanning four continents. These individuals collect, analyze, and organize contributions and data from around the world. They also write many sections of the report. A vital part of the core group is an editorial team and associate author. These professionals played a key role in the development of the report.

Principal authors

Terry Wohlers, MSc, Dr. h.c., FSME**:** Wohlers founded Wohlers Associates, a global consulting firm, 35 years ago. The company was sold to ASTM International in Q4 2021. Through this company, Wohlers and his team have provided consulting assistance to more than 280 organizations in 27 countries. Wohlers has also provided insight to nearly 200 additional clients in the investment community.

Wohlers has been cited in countless domestic and foreign publications, including *Bloomberg Businessweek, CNNMoney, The Economist, Financial Times,* and *Forbes*. He has also been included in coverage in *Fortune, Nature, Reuters, The New York Times, Parade, Scientific American, USA Today, The Wall Street Journal,* and *WIRED*. Wohlers has been featured in broadcasts by Bloomberg, CBS Radio News, CNBC, CNN, Fox Business, MSNBC, National Public Radio (NPR), Australia's Sky News, Canada's Business News Network, and China's CCTV News.

Wohlers has authored or co-authored more than 440 books, articles, and technical papers on rapid product development and manufacturing. He has given 170 keynote presentations on six continents in cities ranging from Seoul and São Paulo to Bangalore and Cape Town. Wohlers was a featured speaker in events held at the U.S. White House in 2012 and 2014.

His appetite for adventure has motivated him to climb the Great Wall of China, hike the rain forests of New Zealand, dive among sharks in Belize, and bathe in the Dead Sea. He has ridden elephants in Thailand, encountered lions in Africa, explored the ancient pyramids of Egypt, and traveled the crocodile-infested rivers of Malaysian Borneo. He jumped from a bridge near Queenstown, New Zealand, where commercial bungy jumping originated. Most recently, he has skied the peaks of southwest British Columbia, Canada, by helicopter.

Wohlers received an Honorary Doctoral Degree in Mechanical Engineering from Central University of Technology in Bloemfontein, South Africa, in 2004. The following year, he became a Fellow of the Society of Manufacturing Engineers, a distinction granted to less than 1% of the membership. He currently serves as an adjunct professor at RMIT University in Melbourne, Australia.

Ian Campbell, PhD: Campbell is an associate consultant at Wohlers Associates. He is also an emeritus professor in computer-aided product design at Loughborough University in the UK. He has led the Design Practice Research Group, served as director of the Research School of Design, and led the Digital Technologies Research Theme.

Prior to 2000, Campbell was a lecturer at the University of Nottingham, working in the ground-breaking Rapid Prototyping Research Group led by Phill Dickens.

Campbell began his career as an engineering designer at Ford Motor Company and the Rover Group.

Campbell has been working in the field of additive manufacturing since 1993. He has established international partnerships with colleagues in South Africa, Portugal, Slovenia, Egypt, China, and Romania. He is particularly interested in new design opportunities afforded by additive manufacturing and has advised industrial partners.

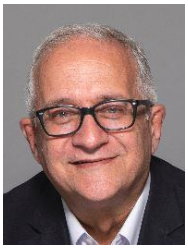
He is an international honorary member of the Rapid Product Development Association of South Africa and was editor of the *Rapid Prototyping Journal* from 1995 to 2020.

Olaf Diegel, PhD: Diegel is an associate consultant at Wohlers Associates, as well as an educator and practitioner of rapid product development and engineering. Diegel also serves as a professor of additive manufacturing at the University of Auckland in New Zealand.

He has an impressive track record of developing innovative solutions to engineering problems. Over the past 20 years, Diegel has created more than 100 commercial products for theater lighting, security, marine, and home health-monitoring. He has also designed and manufactured a world-class line of guitars that has captured media attention globally. Additive manufacturing is used as the core technology to produce the main body of these extraordinary products.

Diegel is fluent in English and French and can speak Japanese. He is skilled in using SolidWorks for complex organic shapes and features. Diegel has a strong interest in additive manufacturing and advanced manufacturing systems. He has published widely and frequently speaks at international events around the world.

Joseph Kowen, LLB, MBA: Kowen is an associate consultant at Wohlers Associates. He has been a consultant, marketing executive, and business development professional for many years in the additive manufacturing industry. He has also served in several positions focusing on new business development, international markets, and distribution channels. Kowen holds a bachelor-of-law degree from Hebrew University of Jerusalem in Israel and an MBA from the Weatherhead School of Management at Case Western Reserve University in Cleveland, Ohio.



Kowen served as vice president of sales and marketing at Voxeljet AG, a manufacturer of large-format industrial 3D printing systems based in Augsburg, Germany. As an entrepreneur, Kowen was a founder of iDent Imaging, a dental imaging software and 3D-printed surgical guide company.

Previously, Kowen served as vice president of marketing at Objet, which merged with Stratasys in 2012. He was responsible for the launch of first-generation machines to the market and for the establishment and management of distribution channels in the Asia/Pacific region. Previously, Kowen was stationed in Brazil, where he managed the sale of tungsten carbide cutting tools for Iscar.

Noah Mostow, MSc: Mostow is the market intelligence and analytics manager at Wohlers Associates. He earned a master's degree in Advanced Manufacturing from the Colorado School of Mines in 2020. He focused his studies on 3D printing, lean six-sigma manufacturing, and engineering management. Mostow is a dedicated professional who works to exceed expectations. He is passionate about exploring the impact of additive manufacturing on consumer and commercial products. Away from his computer, Mostow is an avid outdoorsman who enjoys traveling and getting into the colorful Colorado mountains.

Mostow became interested in 3D printing as an undergraduate at the University of Vermont while studying mechanical engineering. During his final year, he gained hands-on experience with industrial 3D printing systems at Burton Snowboard's Rapid Prototype Laboratory. After Mostow moved from Vermont to Colorado, he worked at 3D Systems Healthcare as a biomedical engineer focusing on craniomaxillofacial reconstruction surgeries. He worked with surgeons to plan procedures and collaborated with internal teams at the company to design, manufacture, inspect, and deliver FDA-cleared, 3D-printed medical devices.

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Ismail Fidan, PhD: Ismail Fidan is a professor in the Department of Manufacturing and Engineering Technology at Tennessee Technological University. He served as a research scientist at Oak Ridge National Laboratory and is active in SME, ASEE, ABET, ASME, and IEEE. Fidan is the recipient of more than two dozen university, board of regents, state, national, and international awards. He serves as associate editor of *IEEE Transactions on Components, Packaging, and Manufacturing Technology, The Journal of Advanced Technological Education,* and the *International Journal of Rapid Manufacturing*. He is the production editor of the *Journal of Engineering Technology*.

Fidan's research and teaching interests are in additive manufacturing, electronics manufacturing, distance learning, and STEM education. His additive manufacturing research is being funded by multiple National Science Foundation awards. Fidan is developing an Additive Manufacturing Workforce Advancement Training Coalition and Hub with several U.S. institutions.

He received a PhD in mechanical engineering at Rensselaer Polytechnic Institute and did post-doctorate work at Stevens Institute of Technology. Fidan was a U.S. Fulbright Senior Scholar at Turkey's Nigde University.

Editorial team

David L. Bourell, PhD: Bourell is an associate consultant at Wohlers Associates and one of three honorary consultants granted by the company. He is the Temple Foundation Professor of Mechanical Engineering at the University of Texas at Austin. He is a leading expert in advanced materials for laser sintering (LS), having worked in this area since 1988. Since 1995, he has chaired the organizing committee for the Annual International Solid Freeform Fabrication Symposium, a leading research conference on additive manufacturing.

Bourell holds nine primary patents dealing with materials innovations in LS dating back to 1990. Bourell was the lead author on the original materials patent for LS technology. This patent, issued in 1990, has been cited by more than 300 other patents. He has published more than 300 papers in journals, conference proceedings, and books.

Bourell is a Fellow of ASM International and the Minerals, Metals & Materials Society (TMS). He was elected to the TMS Board of Directors in 2020. In 2009, Bourell received the TMS Materials Processing and Manufacturing Division Distinguished Scientist/Engineer Award. In 2017, he was honored with the Society of Manufacturing Engineers Albert Sargent Award. He is a founding member of ASTM Committee F42 on Additive Manufacturing Technologies and currently serves on the ASTM/ISO Joint Group 51 on Terminology for Additive Manufacturing.

Jenny van Rensburg: Van Rensburg retired in 2019 after 20 years as administration officer at Central University of Technology (CUT) in Bloemfontein, South Africa. She served as administrator of the ISO 13485 certification at CUT's Centre for Rapid Prototyping and Manufacturing.

Van Rensburg has a keen interest in 3D printing. She has stayed in touch with developments in the industry as a proofreader for CUT's Department of Mechanical and Mechatronics Engineering. She has served as proofreader of the *Wohlers Report* over the past five years.

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