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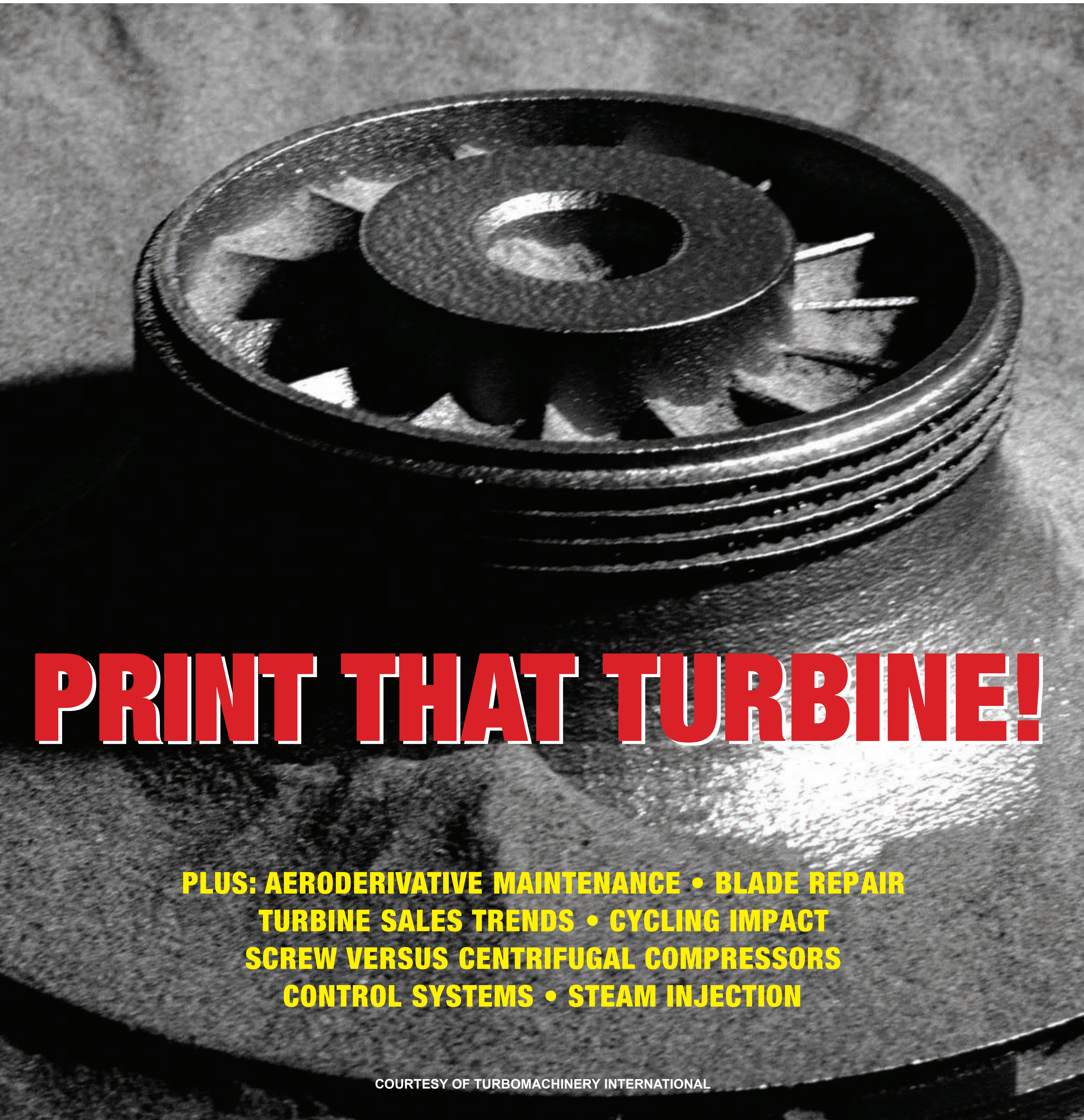

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PRINT THAT TURBINE!

3D PRINTING OPENS THE DOOR TO RAPID TURBINE DEVELOPMENT, MORE COMPLEX BLADE DESIGN AND FASTER PART REPLACEMENT

Drew Robb

Imagine hooking up Computer Aided Design (CAD) software to a printer, hitting a few keys and out pops an entire gas turbine. While the possibility of achieving that for a heavy frame turbine remains very much the stuff of science fiction, the technology is not too far away from making it potentially feasible for microturbines and perhaps even small turbines.

Companies such as GE, Siemens, Turbocam, Rapid Prototyping Services and others are able to print metal blades and impellers using a technique known as 3D printing (Figure 1). Most of these parts are prototypes, though some applications are finding their way into production parts. At its Greenville, South Carolina plant, for example, GE showed off a printed combustion fuel injector that is more advanced than any cast alternative (Figure 2).

"3D printing opened the door to far more complex part geometry and the creation of a one-piece component that couldn't have been done using a casting process," said Kurt Goodwin, General Manager, Advanced Manufacturing Works, GE Power and Water.

3D printing, also known as additive manufacturing (AM), has been in commercial use since the nineteen eighties. This technology takes engineering designs and transforms them into fully functional and durable objects. Printing is done in layers with each layer's particles bound by heat or chemicals; then more layers are added. The technique enables the manufacture of geometries that would not previously have been possible.

While not yet appropriate for high-volume manufacturing, 3D printing has blazed inroads in rapid design development and could do well in the manufacture of high-value, low-volume products.

From plastic to metal

Thermoplastic powders and filaments, photopolymers, plaster, sand and binder have long predominated in 3D printing. Now the use of metal powders, such as aluminum, steel, titanium, cobalt chrome, Hastelloy X and Inconel 718, is growing. Emerging materials include silicone, carbon fiber, electrically conducting materials and ceramics. The total market for any and all consumable 3D printing materials was $800 million in 2013 and is expected to reach $8 billion by 2025, according to IDTechEx Research.

"The metals we're now printing are starting to meet the structural requirements of the turbomachinery market, and are rapidly improving as the processes are refined," said Ken Brace, Owner of Rapid Prototyping Services (RPS). "We're able to print internal cavities for cooling that can't be made using conventional manufacturing processes."

Far from being a distant dream, a niche market or a matter for laboratory experiment, 3D printing is already big business. Wohlers Associates, a consulting firm specializing in this segment, reported that AM products and services worldwide grew at a rate of 35.2% in 2014 to reach $4.1 billion. President Terry Wohlers said the industry expanded by more than $1 billion in 2014, with 49 manufacturers producing and selling industrial-grade AM machines.

Worldwide shipments of these machines will reach 217,350 units in 2015, up from 108,151 in 2014, according to market research firm Gartner. They are expected to more than double every year between 2015 and 2018, by which time worldwide shipments are forecast to reach more than 2.3 million.

"Shipment growth rates for 3D printers, which languished in the low single and double digits per year throughout the 30 years since the first 3D printers were invented, are poised to increase dramatically," said Pete Basiliere, Research Vice President at Gartner.

Many of these printers are finding their way into turbomachinery applications, particularly oil and gas. Rachel Gordon, Technology Analyst at IDTechEx, stated that sales of 3D printers into the oil and gas industry totalled $98 million in 2014 and are forecast to reach $1.8 billion by 2025 (Figure 3).

More importantly, 3D printing has moved up the food chain. While it once was purely a prototyping and design tool, it is increasingly finding its way into the production line. Wohlers said that revenue from the production of parts for final products now represents 42.6% of the entire market for 3D printing, up from less than 4% in 2003 (Figure 4).

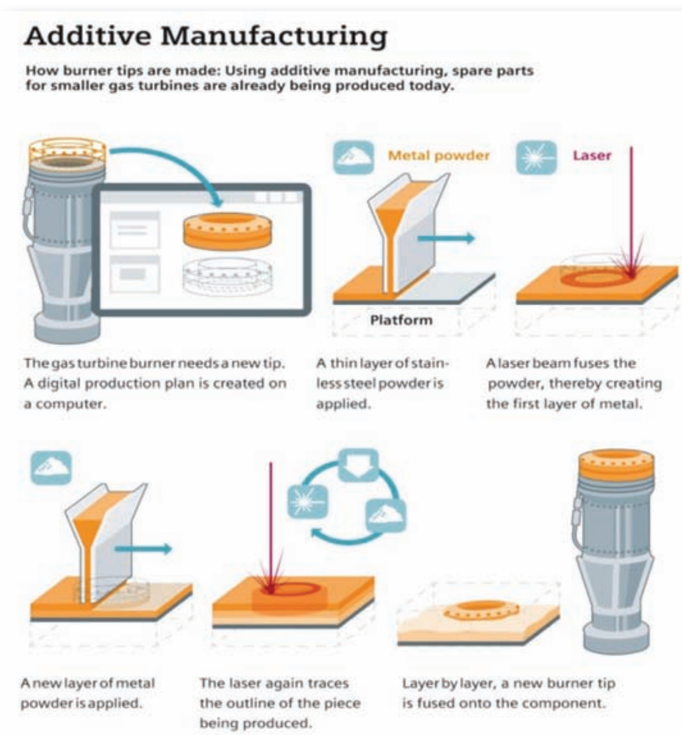


Figure 1: Courtesy of Siemens

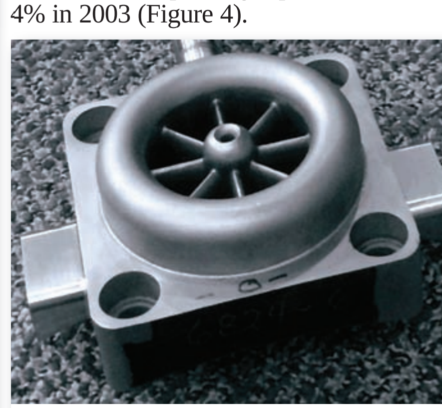


Figure 2: This GE fuel injector was produced by 3D printing

Existing hurdles

While 3D printing is good at making small parts, once the part exceeds a meter, effectiveness dwindles. And for simple parts, it may not make sense to use 3D printing for either prototyping or production. The more complex the part, the more value gained.

The lack of quality assurance is also a challenge. As this approach is so new, it is difficult to guarantee that printed parts are fit for purpose. Much work remains to be done on how to certify printed parts, and the best way to standardize materials, equipment and processes so that CAD files can be reliably used to create parts within engineering tolerances.

But the advantages of 3D printing outweigh its limitations. OEMs such as GE and Siemens are early adopters. GE, which has more than 300 3D printers in operation, is building a 120,000 square foot facility in Greenville, SC that will serve as an incubator for process development and rapid prototyping for heavy-duty gas turbines and other equipment.

"We have been using 3D printing mainly for engine prototypes and new parts going to testing," said Goodwin.

Turbine development is more than twice as fast using 3D printing due to the ability to implement rapid prototyping, added Bob Gilligan, President and CEO of GE's Industrial Solutions Division.

"3D printing lets you see if you have the right fit and function of the parts so you can go much further with design before you transition to soft and hard tooling," he said. "By being able to do many more iterations, you achieve cost reductions, faster development and fewer components."

3D printing eliminates much of the missteps of earlier machinery workflows, such as separate siloes of knowledge, and the need for concept and market studies, followed by engineering design, then figuring out how best to automate manufacturing for mass production. At this point, the design might have to be revised for the sake of workability.

A pump manufacturer, for example, reduced impeller prototype costs by up to 90%, cutting lead times by over a month. 3D printing vendor ExOne used 420 stainless steel and bronze for the 8-inch diameter impeller, taking only 15 days from receipt of purchase order to shipment of the part at a cost of $1,200. A traditional pattern-based method would have taken anywhere from six-to-twelve weeks at a cost range of $5,000 to $15,000, according to ExOne.

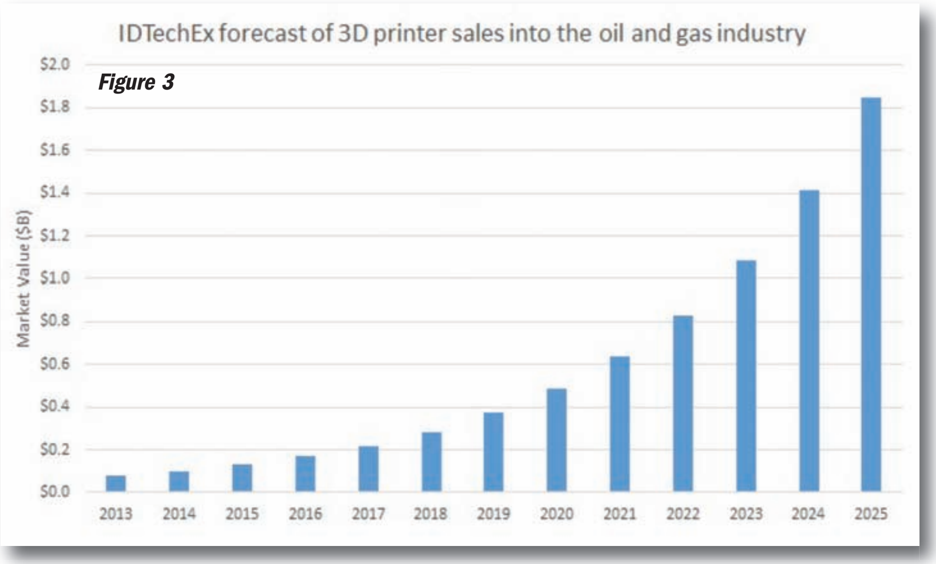
Nowadays, an engineer's CAD design can be printed within a few hours and reviewed by design and manufacturing process engineers simultaneously. Their input and coordination can lead to minor or major modifications; and the next day the resulting part can be created and reviewed.

Avoiding tooling costs

3D printing can also replace soft tooling functions, which typically use a plastic mold that will work for the first 10,000 units or so before it loses shape. If you want to avoid the cost of expensive tooling, said GE's Gilligan, it might make sense to move forward initially with 3D-printed products until you see where a new market is heading. Once the demand is there, hard tooling can be purchased and manufacturing moved off the 3D printing line.

Siemens, too, is riding this new manufacturing wave. It has produced a commercially available burner swirler with 3D printing (Figure 1). The company is also preparing to produce 3D printed fuel strainers with a total of 2,400 0.3mm holes, said IDTechEx's Gordon.

"At one of our gas turbine plants in Finspång in Sweden, we are repairing burners while replacing the damaged tip with a printed one," said Sebastian Piegert, Siemens Head of Additive Manufacturing Enabling



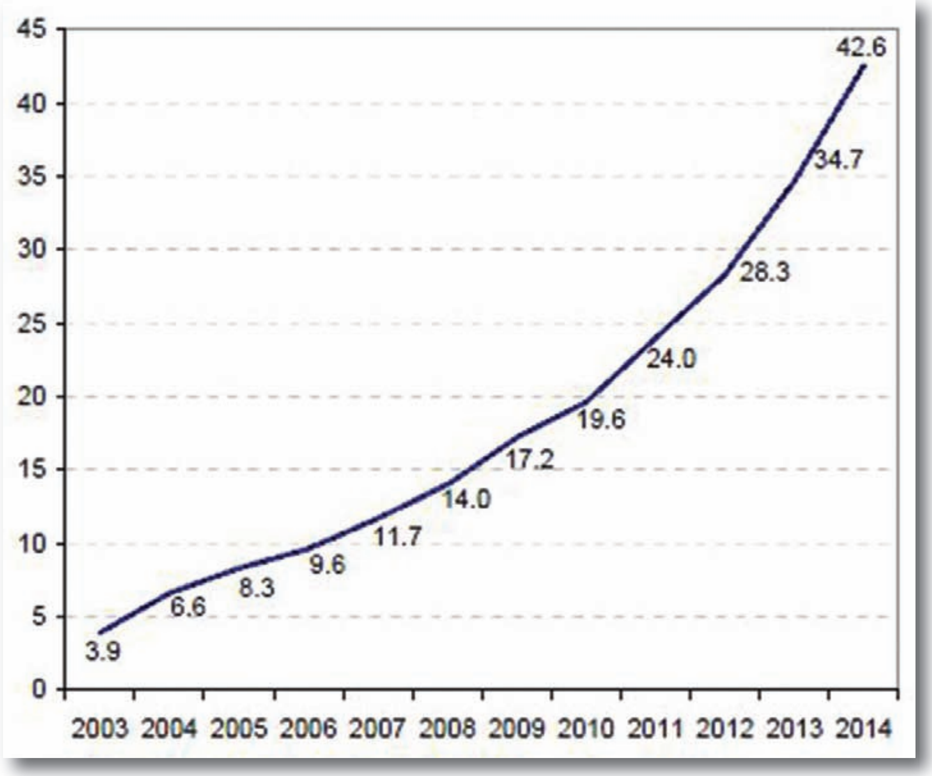


Figure 4: Revenue from the production of parts for final products represents 42.6% of the entire market for 3D printing. Source: Wohlers Associates

Technologies, Large Gas Turbines and Generators. The benefits include quick manufacture of spare parts, and in the long-term, such manufacture will take place directly on site where the parts are needed."

Piegert added that manufacturing times for prototypes are reduced by 75%. Longer term, Siemens intends to make turbine blades for gas turbines using 3D printing once it overcomes the manufacturing challenges of the materials to achieve proper heat resistance and can do so economically.

Meanwhile, aerospace giants are looking at 3D printing to reduce the number of parts in engine assemblies from the 15-to-20 range down to only two or three. By redesigning engines to have fewer parts, they aim to lower inventories, reduce labor and cut down on paperwork.

GE Aviation predicts it will have manufactured 100,000 AM aviation parts by 2020. Jet engine test rigs have already tested 3D printed turbine blades, said Wohlers.

The turbomachinery supply chain is also taking greater interest in AM. "Additive manufacturing opens up some exciting opportunities for innovation in design and manufacturing," said Jonathan Bicknell, General Manager, Turbocam Energy Solutions.

He points out that 3D printing does not always produce a finished product. "You cannot succeed without final machining via subtractive manufacturing methods such as 5-axis or electrochemical machining."

3D printing typically is done via a technique known as Direct Metal Laser Sintering (DMLS), said Bicknell. Software slices the CAD model into thin layers, which the DMLS machine builds layer by layer, fusing metal powder into a solid part by melting it locally using a focused laser beam. AM allows for the design of internal features or passages that could not be cast or otherwise machined, and for complex assemblies to be simplified to fewer parts.

Speedier part production also allows for more rigorous testing and the ability to make additional design modifications. Functional prototypes made out of the same material as production components can be rigorously tested. Parts printed via DMLS are said to possess excellent detail resolution, accuracy and strengths closer to that of forgings.

Figure 5: Turbocam 3D printed these aero-engine turbine blades with intricate cooling channels and complex instrumentation, reducing development time by 80%

Figure 6. The largest 3D printer in the world at Oak Ridge National Lab can print metal parts up to 20 feet long

Rather than waiting weeks to order a large and expensive nickel-based forging and then having to machine it down, companies can save cost and lead time by using off-the-shelf powder metal. For example, an aero-engine manufacturer had designed vanes with intricate internal cooling details and complex instrumentation. Pursuing a conventional fabrication route would have prevented any further design modifications. Turbocam 3d printed several versions so modifications could be made along the way (Figure 5).

Research continues

Hewlett-Packard has been working on what it calls multi-jet fusion technology to transition its 3D printers from polymers to metals and ceramics. If commercialized, it promises to make the entire process faster and cheaper.

Research is also focused on reducing the time to repair parts. Parts could be quickly 3D printed on site as needed, allowing regionalization of support. Siemens is already repairing and upgrading burner tips, and producing spare parts for smaller gas turbines in this way, said IDTechEx's Gordon. 3D printing in this case is ten times faster than traditional technologies.

Evolving approaches, such as those offered by 3D printer Optomec, allow parts to be repaired inside printers. Certain damaged components can be inserted into the equipment with powder added to the surface to complete the repair.

"3D printing can be used to make replacement parts for machines that are out of production or where the manufacturer is not in business anymore," said RPS's Brace. "With the 3D scanning process, we've taken broken parts, scanned them to create a CAD file, and recreated them to spec."

Oak Ridge National Laboratory (ORNL), too, has been conducting extensive research on AM. It made a splash at the Detroit Car Show earlier this year by producing a 3D-printed Shelby Cobra car. In conjunction with tool manufacturer Cincinnati Inc., it has developed a printer capable of working with steel and aluminum.

The idea here is to move 3D printing from more exotic and costly materials to mainline industrial materials, while upping the scale of manufacturing so larger components can be produced. Accordingly, the ORNL printer is said to be capable of producing metal parts up to 20 feet long, 8 feet wide and 6 feet tall (Figure 6).

Casting and forging were developed during the industrial revolution and today's techniques are not much different from those used by Henry Ford a century ago. Whether AM brings about another industrial revolution remains to be seen. But what is certain is that the technology is going to find itself employed extensively up and down the turbomachinery supply chain. Perhaps it could even reach the point where every power plant and oil & gas facility has their own 3D printer onsite.

"A revolution is taking place in industry as additive manufacturing means you can create designs that would be impossible to implement by means of traditional processes," said Siemens' Piegert.