C H A P T E R 2

The Impact of Additive Manufacturing on the Supply Chain

Energy Production

Research Support Service

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Executive Summary

This report is the second in our four-part series exploring how additive manufacturing and 3D printing are reshaping industries.

Additive manufacturing has come more slowly to the natural resources industries, which are sometimes known for their conservative adoption of new technologies. Among natural resources industries, **oil and gas companies are relative leaders** in their use of additive manufacturing techniques, particularly for the on-site creation of parts in remote locations. While the market remains small today, the isolation of many energy generation facilities and resource extraction operations provide a strong incentive to **shorten the supply chain for components**. Additionally, as the use of composite parts continues to grow, the ability of additive manufacturing to build these complex parts adds to its attractiveness. However, the adoption of additive manufacturing in the natural resources industries will likely continue to lag behind that of areas like aerospace and high tech over the next decade.

Natural resources industries have not been at the forefront of additive manufacturing, but they have been widely testing and experimenting with components. Market research for natural resources industries is limited, due to **low commercial utilization** to date.

The **wind industry** has started using 3D printing to produce small components for repairs and replacement. 3D printing is also used to produce molds for blades in commercial production, which may be the most essential part of a wind turbine. Large turbine blades cannot be printed with the current 3D-printing technology, yet entire small turbines may be printed. The development of the 3D-printed turbine will expand wind power usage in remote areas while reducing logistics challenges.

Executive Summary

The **solar industry's** use of additive manufacturing centers on the printing of solar cells. The use of additive manufacturing in solar differs somewhat from other industries, due to the complex layering of materials in a thin cell.

The **oil and gas industry** has shown great interest in 3D printing, due to the need to reduce supply-chain complexity and the availability of significant capital. In the upstream sector with exploration and production, 3D printing has been used in the R&D process. Examples include Shell and GE. In field operation, 3D printing shows the potential to easily manufacture parts in remote areas, saving time and costs. In the midstream sector with transportation, 3D printing enables parts with complex designs to be manufactured in a cost-effective manner, which increases efficiency and profits. In the downstream sector with refineries, current applications are still few, even though some demonstrations have shown the potential of 3D printing to reduce assembly costs.

The **nuclear industry** is the least advanced of the natural resources sector, largely due to regulatory requirements. Still, some investments are being made. For example, in the United States, the Department of Energy has partnered with industrial companies, including startups, to show the potential of using additive manufacturing to produce more efficient fuel cores, enable better component designs, and manufacture replacement parts that meet industrial standards. Additive manufacturing can also help nuclear operators manage obsolescence of parts.

3D printing has noticeable applications in **water treatment**, as the technology brings better component designs in an affordable way. Currently, applications have appeared in polymer filter membranes, metal filters, and supporting structures for filter assemblies. 3D printing can produce complex filter structures, which can improve efficiency, reduce energy use, and reduce fouling and contamination.

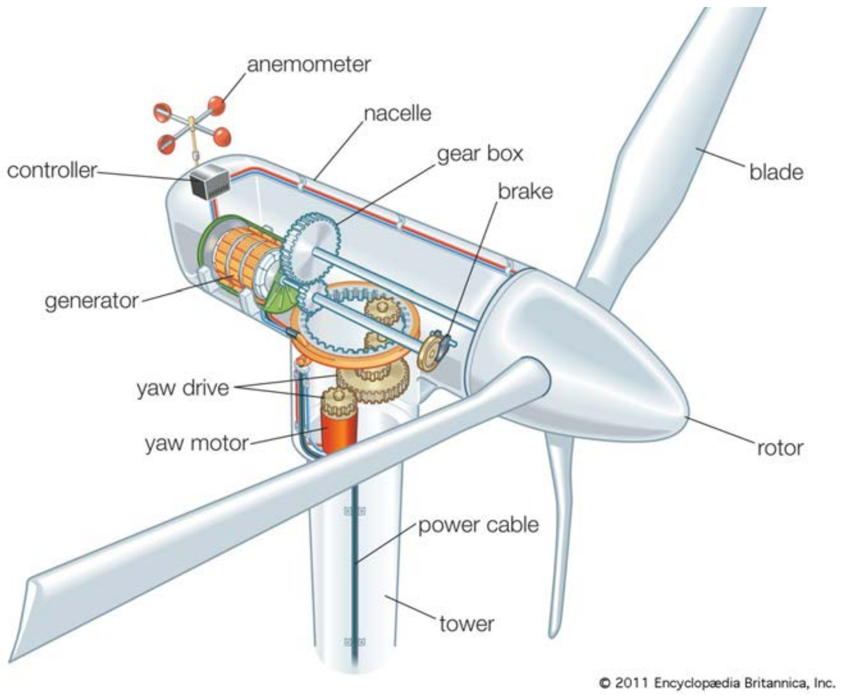
Executive Summary

Power plants, including hydroelectric and gas, have used 3D-printing technology in the research and development process to improve turbine efficiency. Most of the 3D-printing applications are related to turbines, as they are the keys to power generation, while some minor applications focus on part repair and replacement. 3D printing helps not only the prototyping of the turbines, but also the manufacturing of turbines with complex designs.

To conclude, while additive manufacturing has so far seen relatively limited commercial use in natural resources industries, its contributions have steadily grown. If these prominent first parts prove themselves over years of use and abuse, the historically cautious industries in this sector will likely adopt 3D printing as a more common method of generating parts and building devices.

WIND INDUSTRY

Wind turbines convert the wind's kinetic energy into electricity. When wind flows over the blades, the blades turn and drive the generator, through a gearbox, to generate electricity. Wind energy usage is rapidly growing in the United States as well as all around the world. Currently, 3D printing is mainly used for rapid prototyping, although more applications for component production are appearing. Due to the strength requirements of large turbine blades, most 3D-printing applications are on small blades, gear box components, and molds.

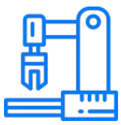


The main components of a wind turbine. Source: Britannica.

HOW 3D PRINTING CAN IMPROVE THE PERFORMANCE OF WIND TURBINE COMPONENTS

Allows more complex architectures

Requires fewer assembly steps



Permits a quicker production time

Has fewer costs

References:

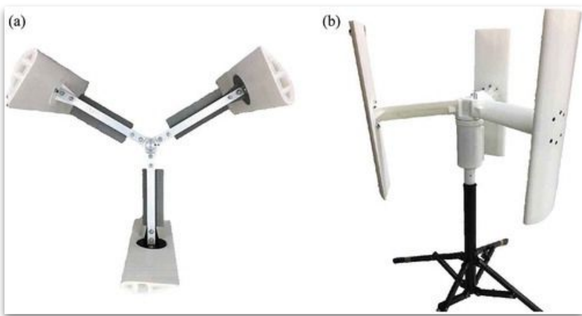
1. https://www.eia.gov/energyexplained/index.php?page=wind_electricity_generation
2. https://www.azocleantech.com/article.aspx?ArticleID=832

Examples of AM in the wind energy sector

The Advanced Manufacturing Office (AMO) of the US Department of Energy has started to print molds for blades with a large-size printing system (25x20x100 ft). The use of 3D printing greatly reduced the manufacturing steps, production time, and cost. The traditional route may take several weeks to months, while 3D printing only takes a single day.

Image of a 3D-printed turbine mold at Oak Ridge National Laboratory. Source: Make Parts Fast

Small energy turbines are undergoing rapid development. They are suitable for residential usage and remote power supplies. Researchers from the University of Louisiana at Lafayette designed and produced a small wind turbine for power generation. Their work demonstrated the cost efficiency of the technology ($100 USD) and the short production time (28 h), while a commercial turbine of similar specifications cost $500. Similarly, Taiwan researchers created a mini wind turbine for small power generation in public utilities such as street lights using 3D technology (seen in image below).



Turbine blade structure of the experiment model. Source: Lin et al., 2019.

Solar cells are batteries that turn solar energy into electrical energy. The solar cells have joined P-type and N-type semiconductors. When light hits the P-type semiconductor, an electrical field can be generated between the N-type and the P-type, which moves the electrons and produces electricity. In the solar industry, the key component is the solar cell.

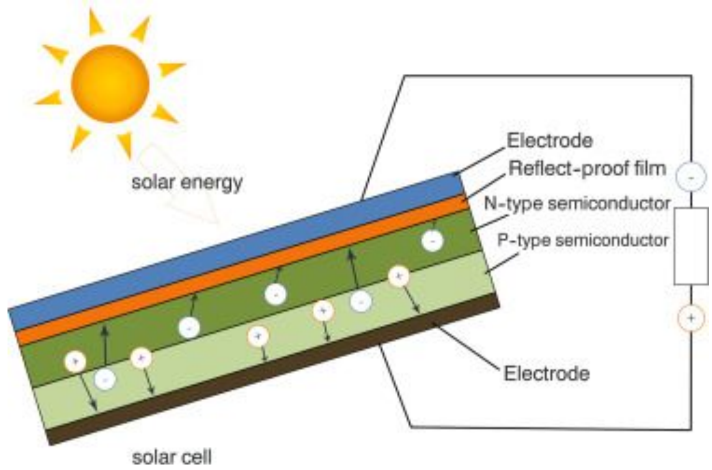


Illustration of a solar cell structure. Source: [Husain et al.](#)

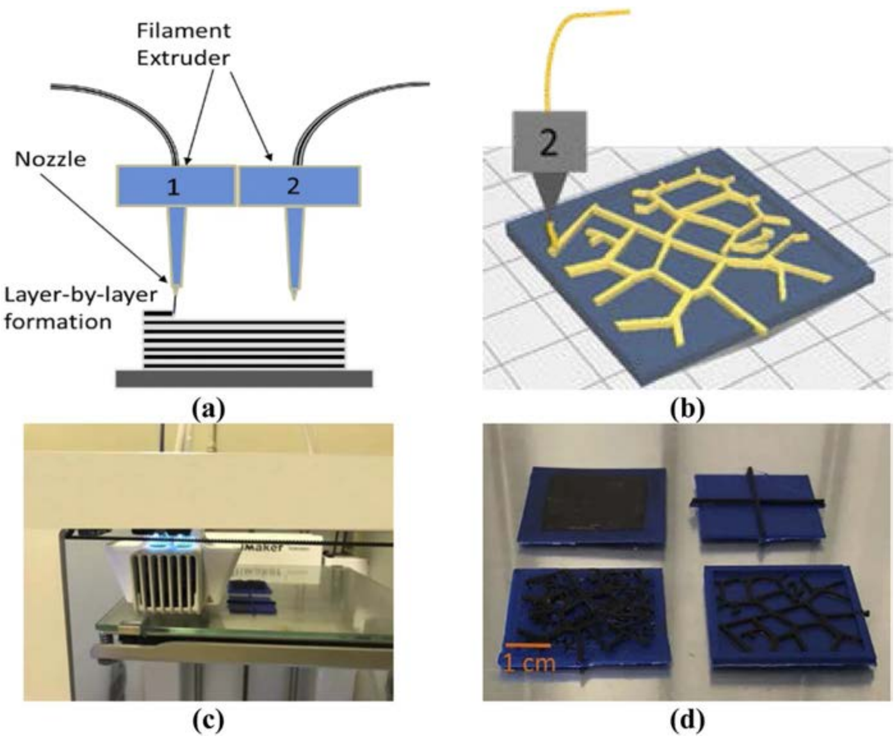
Examples of AM in the solar energy sector

The industry trend for solar cell development is to make solar cells more portable, efficient, and flexible. In 2018, **CSIRO researchers** in Australia printed, installed, and tested perovskite photovoltaic solar cells in rolls for surface solar panels. By developing new materials and processes, they have reached 19% efficiency on small-scale devices. The printing process has been tested at a pilot scale to print 30-cm-wide rolls that can be cut to length.

Photo of printed flexible, light, and thin solar cells. Source: CSIRO.

Examples of AM in the solar energy sector

Dye-sensitized solar cells are a new type of solar cell that has better durability, a wider range of operating light conditions, and easier handling compared to traditional silicon cells. However, their low efficiency has limited the use of real-life applications. Researchers from California State University Fullerton have tried to address the issue by introducing a fractal-based design and 3D-printing manufacturing process. The new design expanded the active reaction sides into 3D space. The results showed that the 3D fractal design increased cell efficiency from 1.26% (traditional planar cell) to 4.67%. The fractal designs and additive manufacturing technology helped in addressing the problems of low efficiency and high fabrication cost.



(a) Fused deposition modeling (FDM) 3D-printing process

(b) Printed 2D fractal structure

(c) FDM 3D-printing process

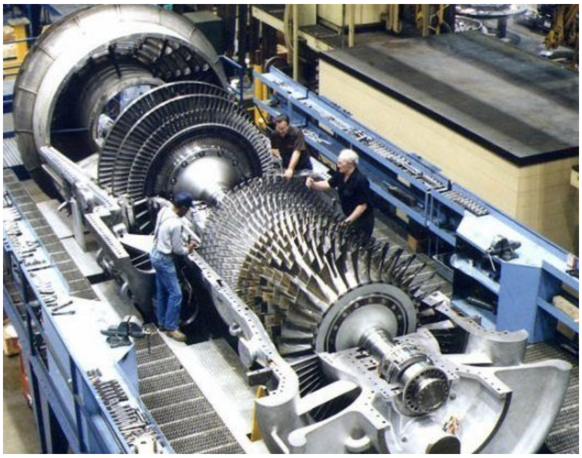
(d) Electrodes fabricated using FDM

Source: [James and Contractor, Scientific Reports, Nature](#).

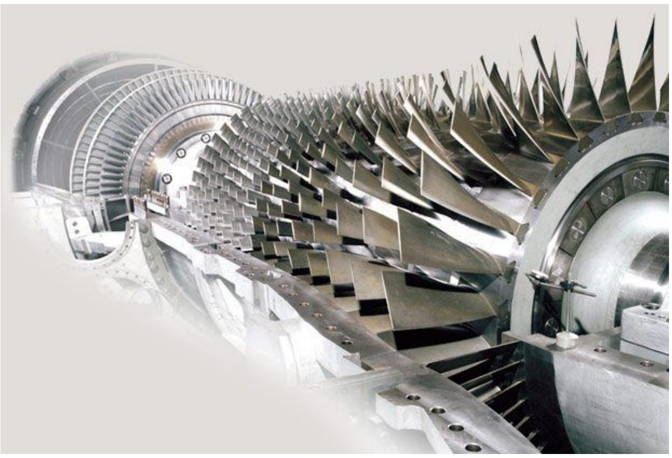
Examples of AM in the oil and gas energy sector

In 2016, Baker Hughes (BH) built its first production line using additive manufacturing for nozzle production in Italy. The line was fully operational in 2017.

After extensive validation during prototyping of the NovaLT16 gas turbine, BH moved the technology into full additive manufacturing production, which would benefit the design and product quality while reducing production time. BH expected that the approach would bring the product to market in a more efficient and cost-effective way.



(a) A nozzle production line using 3D-printing technologies by Baker Hughes.



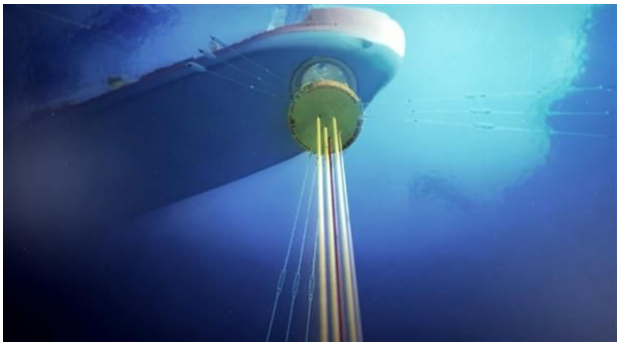
(b) A closeup of the nozzle. Source: 3D Printing Industry.

Examples of AM in the oil and gas energy sector

One current use of AM is in the design phase, where the prototyping process can be greatly accelerated. Shell used AM in the design phase of their deepest oil and gas project, the Stones.

The engineers printed the prototypes of the detachable system to connect an offloading vessel to pipelines. The printed prototypes were then shown to the authorities for demonstrations for its first use. 3D printing accelerated the development of the system, increased efficiency, and reduced the time and cost of the fabrication of the system.

(a) The buoy contains hundreds of solid foam blocks that keep it afloat in water. The Stones team used a 3D printer connected to their computer design system to produce scaled-down plastic versions of all components in only four weeks.



b) The connecting system features a huge buoy 19 metres tall, moored at the surface, which receives oil and gas from the seabed. The buoy slots into a turret inside the FPSO, like a plug and socket, enabling production while holding the vessel safely in place. By 3D printing the system in miniature, the team could show how it allows the FPSO to turn and remain stable in rough seas and disconnect when the wind and waves become too strong, helping the vessel and crew stay safe. Source: Shell.

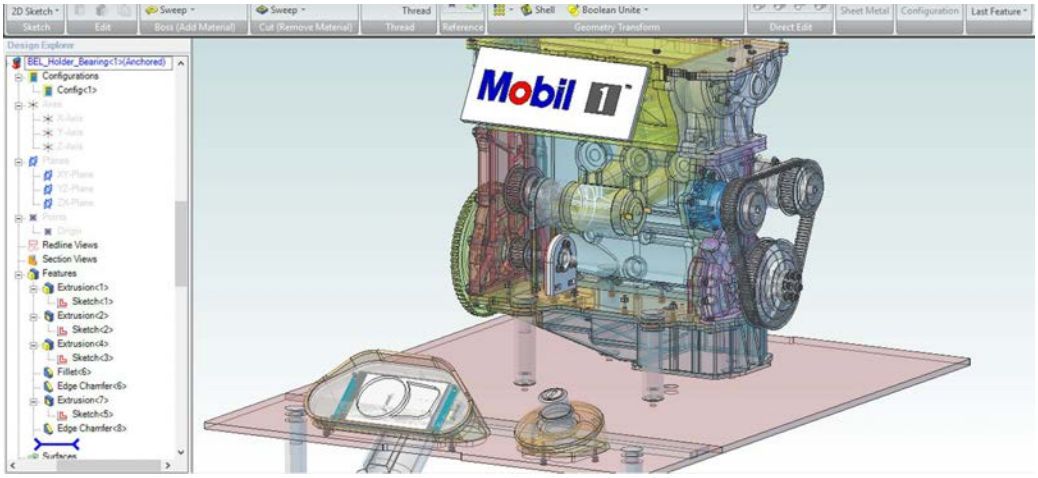
Examples of AM in the oil and gas energy sector

Exxon Mobil partnered with Milk Lab to 3D print a specially designed engine to explain the differences between engine oils.

The printed engine, called the SmARt engine, can run stand-alone to mimic a real engine but is also controllable from an iPad application. The app also uses augmented-reality technology to visualize the engine oil in the SmARt engine. The 3D-printed engine is a convenient, cost-efficient, yet powerful presentation and has won several awards.

(a) 3D-printed engine by Exxon Mobil and Milk Lab.

(b) The application dashboard. Source: [Milk Lab](#).

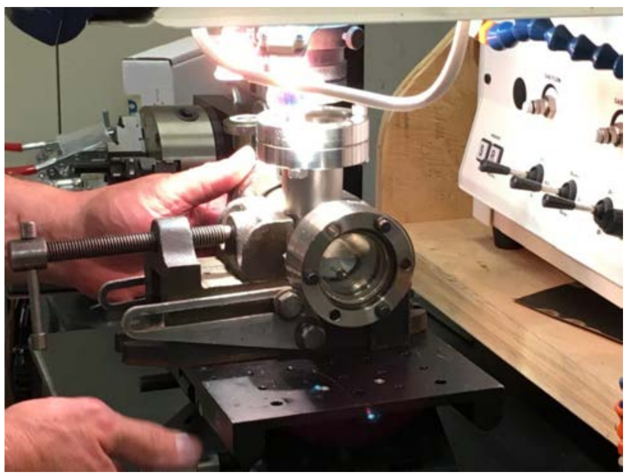


Examples of AM in the nuclear energy sector

As part of a US Department of Energy project, in 2017, an Idaho National Lab researcher developed a nuclear fuel manufacturing process with 3D printing, which is much simpler than conventional methods. The process was designed for U_3Si_2 fuel and potentially for other fuels. The process applied a laser in multiple steps at one place to convert powdered material into dense U_3Si_2 pellets. Compared to the traditional UO_2-based fuels, U_3Si_2 fuel can provide benefits in safety as well as in economics. The new process accepted a wider range of raw materials, which simplified the process, increased flexibility, and reduced costs.

Image of a printed impeller for a nuclear power plant. Source: Siemens.

Nuclear power plants usually have a very long operating lifetime, which may be longer than part suppliers. Thus, replacement or repair of an obsolete part can be problematic. In 2016, a nuclear power plant in Slovenia faced a challenge to replace an impeller for a fire protection water pump when the original manufacturer was no longer in business. Siemens eventually provided the solution by printing and installing the first 3D-printed impeller, which extended the plant's life expectancy. The plant is still currently running.



Device to initiate the 3D printing of U_3Si_2 fuel. Source: INL.

Examples of AM in the nuclear energy sector

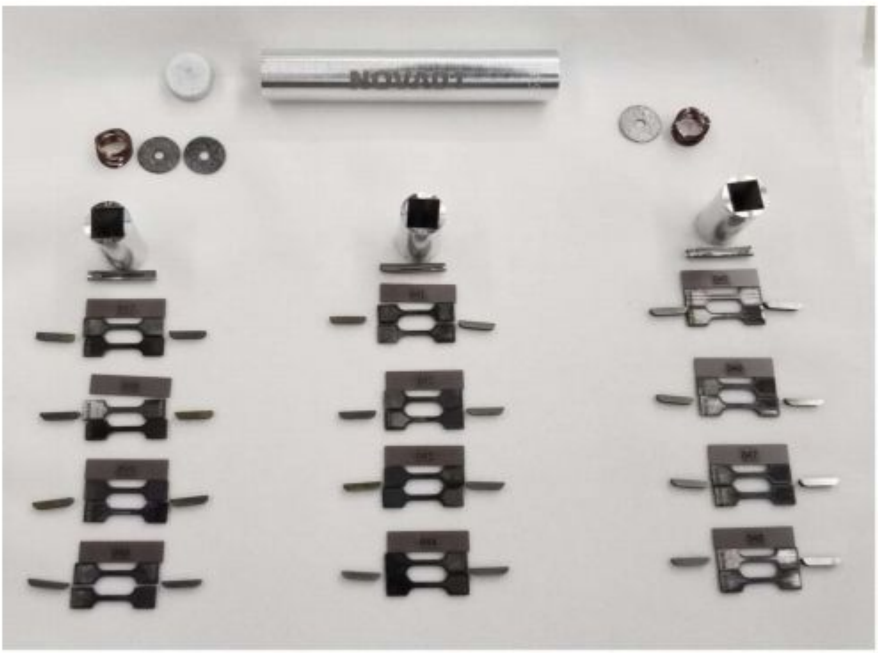
Most 3D-printing applications are of small-length scales, barely beyond 1 meter. However, the industry is actively exploring the possibilities of printing large objects, which, once working, will greatly expand the potential of 3D printing. **Nanfang Additive Manufacturing Technology Co.**, China, signed a contract with the CNPC Tubular Goods Research Institute to create new materials and apply electronic beam melting (EBM) 3D-printing technology to produce a thick-walled three-way pipe fitting for nuclear plants. To demonstrate the possibility, they initially printed a prototype pressure vessel cylinder weighing 400 kg. They are currently capable of printing objects up to 5.6 m in diameter and 9 m in height.

3D-printed pressure vessel cylinder by Nanfang. Source: 3Ders.

The US Department of Energy supported many projects to develop AM technologies for the nuclear industry, including **Novatech**. Novatech won many awards to use AM to fabricate small nuclear fuel reactors, bottom nozzles, hold-down springs, top nozzles, and boiling water reactor lower tie plates for nuclear plants. They systematically tested the mechanical and chemical properties of the 3D-printing materials and printed components to determine which ones would satisfy the requirements.

Examples of AM in the nuclear energy sector

They also adopted new designs for the printed components to achieve better performance. For example, they printed debris filters with small holes and tortuous paths that have twice the debris resistance compared to current filters. They also printed hold-down springs that passed quality tests and could be easily tuned for different reactors and fuel assemblies, as each spring can be printed differently. The printed springs also reduced the number of parts, which reduced costs and time.



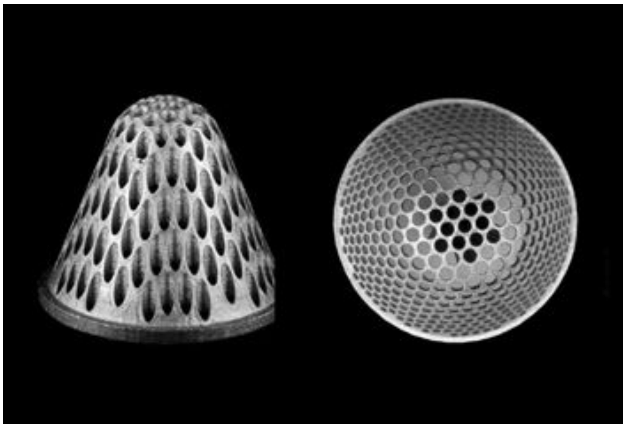
Parts of 3D-printed bottom nozzles by Novatech. Source: Novatech.

Examples of AM in the water treatment sector

Additive manufacturing can easily create objects with complex structures, which is one of the advantages over traditional milling. In the field of water treatment, this enables better design and process performance. Researchers from Nano Sun in Singapore produced the first 3D-printed nanofiber membranes for water filtration, and they delivered more than 15 water treatment systems in 2018. The printed membrane overcomes the mechanical problems of conventional membranes, including biofouling and breakage. The membranes are ultra thin, yet still porous. They allow more water to be treated in the same time period and can last longer.

Establishers of Nano Sun and their 3D-printed membrane. Source: 3D Print.

Filters are common components in water treatment that can see advantages from 3D printing. A good filter design for a 3D-printed filter usually has a complex structure that is not cost efficient to produce with conventional machining methods. Croft Filters in the United Kingdom has used additive manufacturing to build better filtration components, allowing a higher flow rate with a lower pressure drop. These filters feature holes aligned in the same direction as the flow, which allows for better performance over a longer period, compared to its traditionally manufactured competitors.

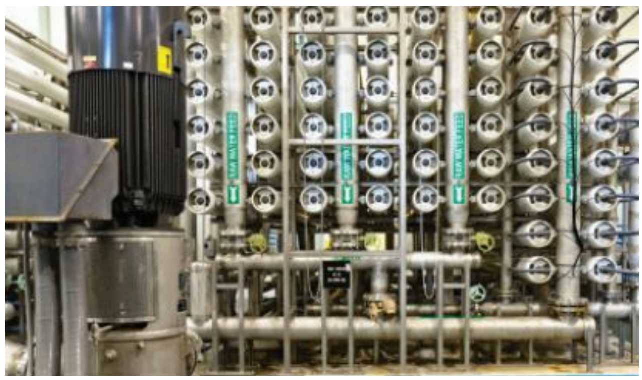


High-flow filters by Croft Filters. Source: Metal AM.

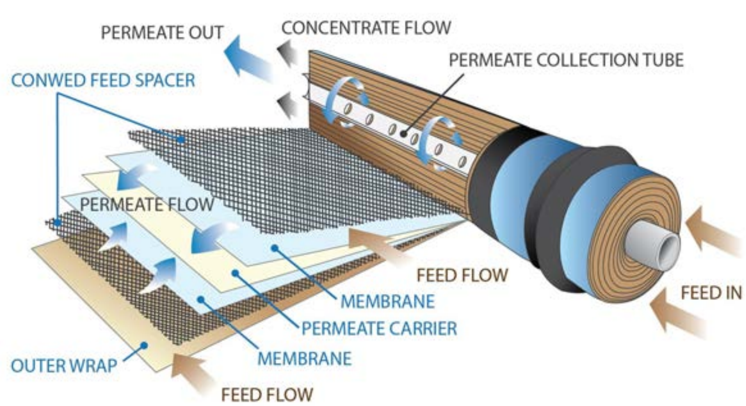
Examples of AM in the water treatment sector

Many technologies exist for water treatment, including reverse osmosis. Reverse osmosis uses pressure to push water molecules through a membrane to obtain purified water, and these systems usually contain complex structures. One important component of this complex structure is the feed spacer, which ensures a uniform water flow in and out of the membrane. To address biofouling issues, where microorganisms accumulate and gradually block the spacers, Conwed used 3D printing to manufacture feed spacers with a new geometry. The new geometry has greater thickness, a higher strand count, modified interweaving angles, and improved composition to substantially reduce pressure drop and biofouling.

(a) 3D-printed feed spacer for reverse osmosis water treatment by Conwed.



(b) The reverse osmosis filter illustration.



(c) The installed filters. Source: 3D Print.

A gas turbine is a type of continuous internal combustion engine. The turbine can be connected to a turboshaft to generate electricity, a turbofan to increase efficiency, or a propeller to generate movement. Gas turbines are widely used in aircrafts, trains, ships, and power plants. The development of gas turbines focuses on size, power, and efficiency. Advanced materials, good designs, and good manufacturing processes can potentially increase gas turbine performance. 3D-printing technologies can potentially address these issues by introducing new materials and complex structures.

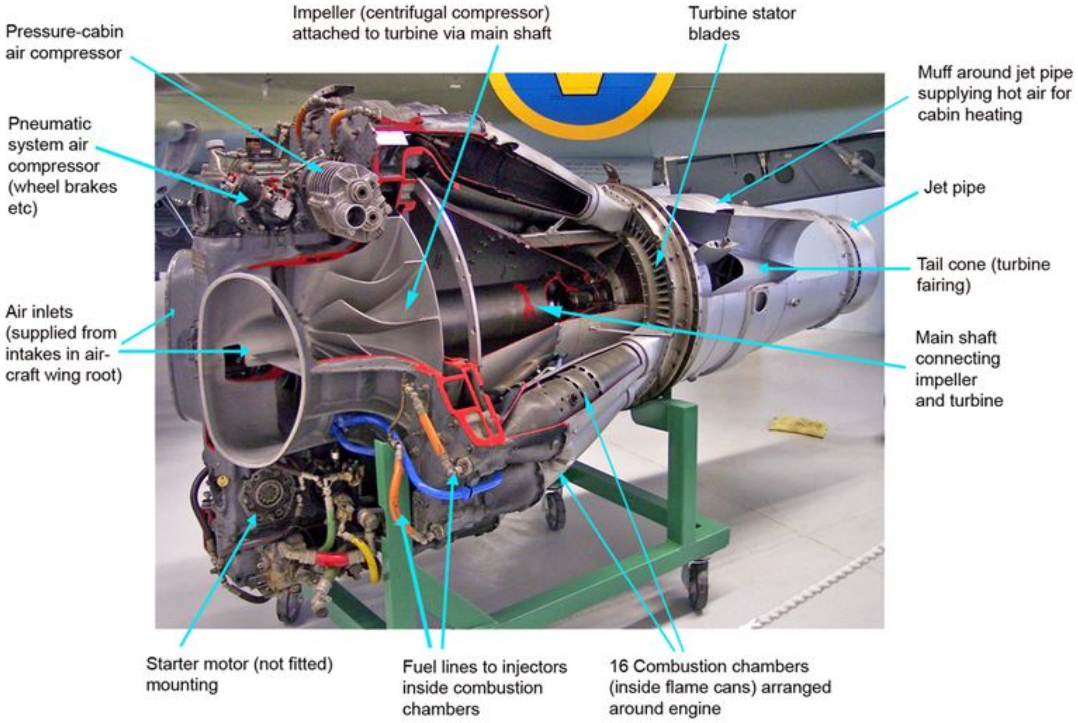


Illustration of a gas turbine structure. Source: [Wikipedia]

Examples of AM in the gas turbine sector

Durability is an important factor in evaluating additively manufactured components. In 2018, Siemens presented an example to demonstrate the maturity of the technology. At the time, a 3D-printed gas turbine burner reached 8,000 operating hours in a power plant. The burner was manufactured in Sweden in a pilot project. After 8,000 hours of operation, there was still no noticeable wear, proving the product had similar or even better durability than conventional parts. The new burner also took advantage of additive manufacturing to reduce the assembly pieces and the welding areas.

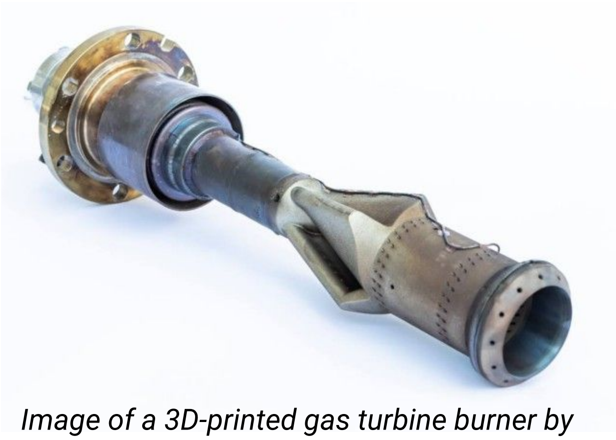


Image of a 3D-printed gas turbine burner by Siemens. Source: Siemens.

More turbine parts can now be printed. In 2018, Siemens installed the first printed sealing ring on steam turbines operating in India. The 3D-printed part contained two sealing rings to keep oil from the steam under pressurization inside an SST-300 steam turbine. In this case, 3D printing reduced the lead time by 40% from the traditional manufacturing process. This project set a milestone for 3D-printed metal part replacements for steam turbines.

Image of a 3D-printed steam turbine sealing ring. Source: Siemens.

Examples of AM in the gas turbine sector

A long-lasting challenge for 3D printing was its relatively weak mechanical properties. Such weak properties made it difficult to print a turbine blade for actual use, because engine operating conditions are very harsh (i.e., high temperatures, high pressures, and high loading).

In 2018, Siemens reported a breakthrough. They printed the first gas turbine blades and tested them in an engine with success. Critically, the testing conditions were above 1250ºC and at extremely high pressure.The blades were printed using nickel superalloy powder, and they were tested on a 13-MW SGT-400 industrial gas turbine. The mechanical strength of the blades was remarkable. Their 180-g weight held 11 tons of equivalent force during operation. The manufacturing of these blades showed a significant reduction of design-to-test time, from 18 months down to just three. 3D printing also showed the ease of adopting a completely new internal cooling design.

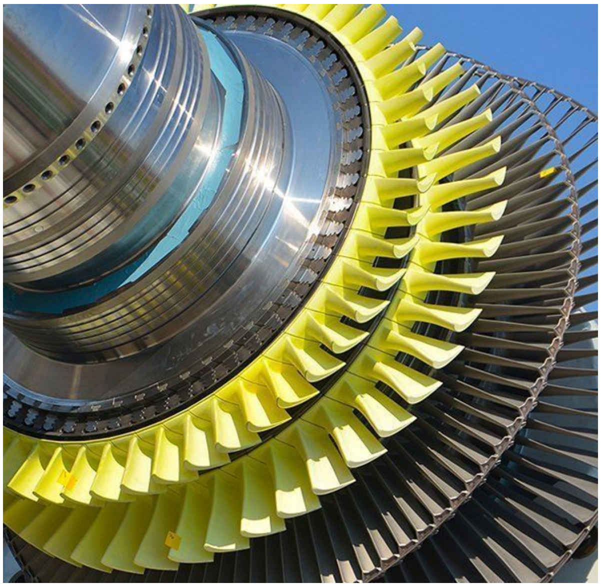
Image of a 3D-printed gas turbine burner by Siemens. Source: Siemens.

These blades won the 2017 American Society of Mechanical Engineers award.

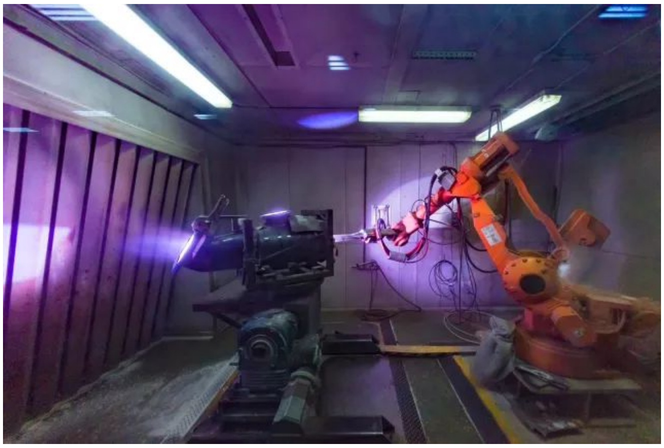
Examples of AM in the gas turbine sector

While 3D printing is mostly used in prototyping, **Mitsubishi Hitachi** reported a valuable example of applying 3D printing to produce commercial turbine parts. Key turbine specifications include operating temperature and pressure. High-strength turbine parts are generally made from multiple crystals. The final strength is related to the initial crystal grain alignment.

Mitsubishi Hitachi uses a 3D-printing technology called "plasma spray thermal barrier coating" to control the crystal growth, which adds one atomic layer coating growth at a time. The delicate control of the growth ensures the alignment of each crystal, drastically increasing the temperature limit of the turbine by 150°C as well as the fuel efficiency.



(a) Energy-efficient gas turbine parts from 3D-printing technology by Mitsubishi Hitachi. Source: MHPS-AMER.



(b) Inside the plasma spray booth. Source: MHPS-AMER.

Examples of AM in the power plant sector

Oak Ridge National Lab successfully applied 3D printing to their research and development process. In the development of hydropower systems with **Emrgy Inc.**, they used 3D printing to rapidly manufacture gearbox prototypes that have complex structures. They also manufactured sand molds for the final products. The new 3D-printing process saves time for testing and modifications, and it saves costs due to the reduction of lead time and waste.

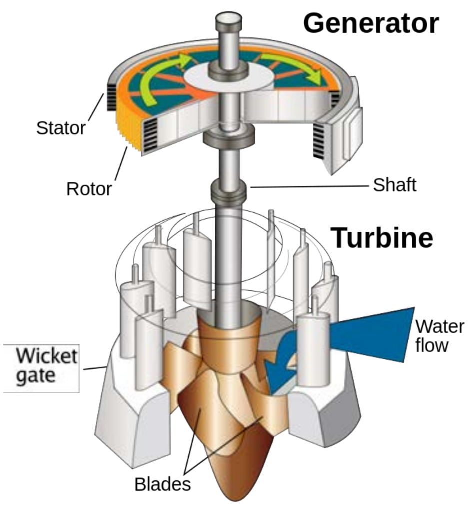


Illustration of a hydropower turbine. Source: Wikipedia.

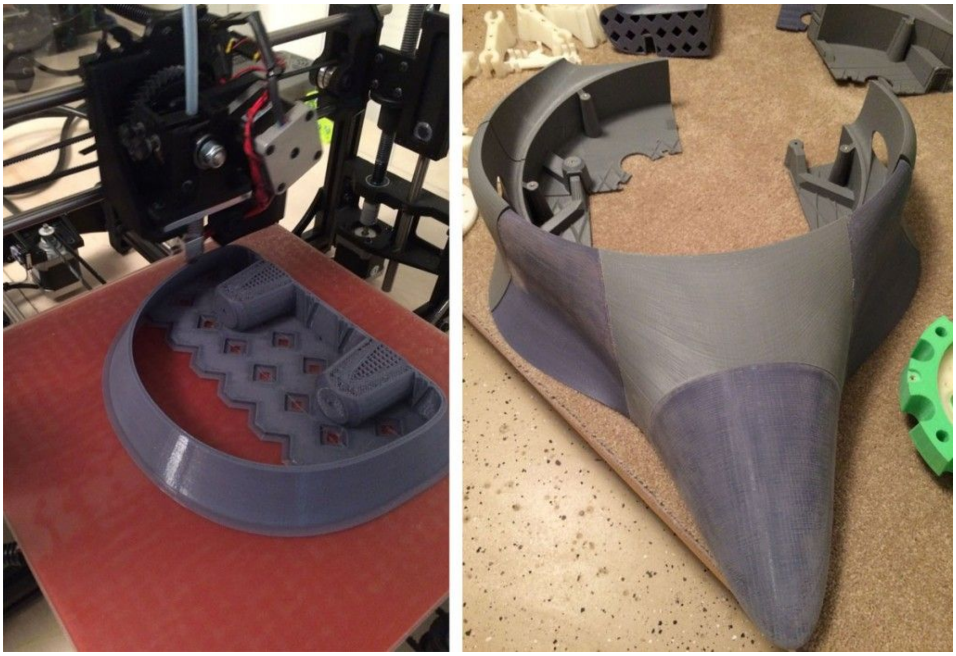
Another company focusing on the 3D printing of hydropower turbines is **Eaton**. In 2017, Eaton contracted with the Department of Energy to 3D print the first hydropower concept models and then some individual turbine components for small-scale dams. The 3D-printed parts served as prototypes and were used in preliminary tests of design concepts such as structure optimization and operating efficiency. Eaton combined advanced materials and manufacturing technologies to improve the design and performance of the new turbines for power generation.

3D-printed gearbox prototype and sand molds by Oak Ridge National Lab. Source: NREL.

Examples of AM in the power plant sector

Hydropower plants convert the gravity potential of water into mechanical energy and then electricity. The key to this conversion is the hydropower turbine. In 2016, **Verterra Energy** used additive manufacturing to fabricate large-scale (1.2 m) prototypes of their turbines using a LulzBot TAZ desktop printer.

The printer supports multiple materials, but mostly polymers. 3D printing has greatly accelerated their development process such that they expect to have commercial products this year.



Photos of the 3D-printed hydropower turbine by Verterra Energy Inc. Source: 3D Printing Industry.

Insights

1. Most current applications of AM are in R&D and have shown great benefits in accelerating prototyping, design, and demonstration. The applications save costs and increase efficiency but are often not yet economic on a large scale.

2. Many commercial applications are advanced by larger organizations due to their previous technology accumulation. More startups have appeared in the last five years.

3. One of the main challenges is that the specifications of the printed products cannot economically meet the application requirements.

4. Standardizations and guidelines for 3D printing are being made by industries to help advance commercial usage.

5. Supply chain advantages include reduction of parts, reduction of spare parts storage, reduced shipping costs, a more secure supply chain with fewer suppliers, and rapid replacement.

IMPACT ON SUPPLY CHAIN

6

Obsolete parts or rare parts can be produced:

- Reduces the complexity of management by decreasing the amount of necessary parts
- Reduces production time with fewer production steps
- Reduces management costs of aging assets and obsolete parts
- Reduces storage and shipping costs for spare parts and increases supply stability and security
- Examples include parts from remote manufacturers and parts on aging assets

7

Complex parts can be printed as one piece:

- Simplifies the manufacturing process with fewer components
- Increases component performance by allowing more complex design

8

Parts with critical mechanical strength may not be printable in the near future:

- Both the printing material and the method needs to be improved
- Examples include turbine blades and high-pressure components

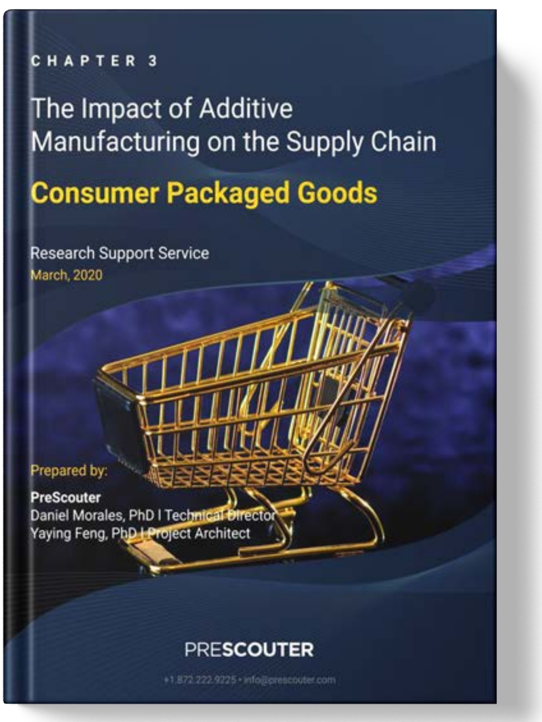
9

AM printing can be complementary to current production methods to increase supply chain efficiency and effectiveness

AM IN THE SUPPLY CHAIN
RELEASED & UPCOMING REPORTS

CLICK ON IMAGE TO VIEW

03 Consumer Packaged Goods



04 High Tech

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Kyle is a Technical Director for Natural Resources Industry. Kyle has overseen and managed over 75 PreScouter projects with clients in water, utilities, renewable energy, mining, metals, and fossil fuels. A recognized expert in sustainability technologies and policies, Kyle previously worked for private and nonprofit natural resources consulting firms, sustainability think tanks, the United States Departments of Transportation and the Treasury, the White House, Carnegie Mellon University, and the United Nations. Kyle's research, publications and education are in the fields of environmental engineering, geophysical sciences, public policy, economics, and biochemistry/biophysics.

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Xianwei is currently a research fellow at the Colorado School of Mines. He earned his PhD in chemical engineering in 2017. His research focuses on the upstream sector of the energy industry. He collaborates globally with industrial and academic partners to study the fundamental challenges of energy production and seek novel solutions. As a researcher, Xianwei is passionate about the frontier of new technologies. With his scientific training, he follows and analyzes trends in new technologies, their application potential, and their impacts on different businesses.

NEXT STEPS

SOME POSSIBILITIES THAT PRESCOUTER CAN OFFER FOR CONTINUATION OF OUR RELATIONSHIP

- COMPETITIVE INTELLIGENCE
- TECHNOLOGY & PATENT LANDSCAPING
- TECHNOLOGY ROADMAPPING
- MARKET RESEARCH & ANALYSIS

- TRENDS MAPPING
- ACQUIRE NON-PUBLIC INFORMATION
- PATENT COMMERCIALIZATION STRATEGY
- DATA ANALYSIS & RECOMMENDATIONS

- REVIEW BEST PRACTICES
- SUPPLIER OUTREACH & ANALYSIS
- CONSULT WITH INDUSTRY SUBJECT MATTER EXPERTS
- INTERVIEWING COMPANIES & EXPERTS

WE CAN ALSO DO THE FOLLOWING

- **CONFERENCE SUPPORT:** Attend conferences of interest on your behalf.
- **WRITING ARTICLES:** Write technical or more public-facing articles on your behalf.
- **WORKING WITH A CONTRACT RESEARCH ORGANIZATION:** Engage with a CRO to build a prototype, test equipment, or any other related research service.

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Innovation Discovery: PreScouter provides clients with a constant flow of high-value opportunities and ideas by keeping you up to date on new and emerging technologies and businesses.

Privileged Information: PreScouter interviews innovators to uncover emerging trends and non-public information.

Customized Insights: PreScouter finds and makes sense of technology and market information in order to help you make informed decisions.

500+
CLIENTS WORLDWIDE

4000+
RESEARCH REPORTS CREATED

150,000+
HOURS OF RESEARCH COMPLETED FOR CLIENTS