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3D Printing in Oil and Gas Industry

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ABSTRACT

Oil and gas industry is one of the biggest industries in the world in terms of dollar values. Companies in the oil and gas industry influence the global economy by engaging in the exploration, extraction, refining, and transportation of one of the primary fuel sources. As oil and gas production needs increase, so too do operators' demand for efficiency and sustainability. Additive manufacturing (or 3D printing) is a valuable tool that enables the faster and more efficient manufacturing of spare parts, equipment, and components, while reducing downtime and maintenance costs. 3D printed parts are being utilized by the energy sector to harness the natural resources of our planet. This paper aims to highlight significant opportunities and challenges relating to the adoption of 3D printing in the oil and gas industry.

KEYWORDS: *3D printing, additive manufacturing, oil and gas industry, petroleum industry*

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INTRODUCTION

The oil & gas (O&G) industry is one of the largest industries in the world and it is a critical part of the energy sector. It is the number one energy source, especially as it comes to heating. To reduce wasteful consumption and accidents due to leaking, oil & gas companies are turning to 3D printing (aka additive manufacturing) to create geometrically complex, cost-effective parts [1]. These include companies such Shell, AML3D, ExxonMobil, Chevron, BP, Siemens Energy, Halliburton, Total, and General Electric. These major companies have published stories around their use of 3D printing for prototyping and production applications in their industry. Also, the US Department of Energy (DOE) has been supporting the development of 3D printing for applications in energy sector. In July 2018, the department selected some projects for R&D to develop innovative technologies for fossil fuel power systems.

The advent of 3D printing technology has emerged as a game-changer in numerous industries, completely transforming conventional methods of production. The oil and gas industry, known for its complex and demanding operations, is one of the major untapped markets for additive manufacturing although it is important for the industry as it can help in boosting productivity and reduce operational costs. According to the World Economic Forum, Additive manufacturing can make oil and gas companies save cost and time worth up to $30 billion.

WHAT IS 3D PRINTING?

3D printing (also known as additive manufacturing (AM) or rapid prototyping (RP)) was invented in the early 1980s by Charles Hull, who is regarded as the father of 3D printing. Since then it has been used in manufacturing, automotive, electronics, aviation, aerospace, aeronautics, engineering, architecture, pharmaceutics, consumer products, education, entertainment, medicine, space missions, military, chemical industry, maritime industry, food industry and jewelry industry. All the parts created using a 3D printer need to be designed using some kind of CAD software [2,3].

The process of 3D printing has three basic components: computer assisted (i.e. digital) design, machine equipment, and an added material. Different materials can be used to build 3D-printed objects,

from plastic, metal and rubber to human cells. A 3D printer works in similar ways as a regular printer. 3D Printing essentially describes a assortment of technologies that digitally formulate three dimensional objects on a layer-by-layer basis. It has been adopted by students, entrepreneurs, hobbyists, and various industries. As shown in Figure 1, 3D printing involves three steps [4]. A typical 3D printer is shown in Figure 2 [5]. The business uses of 3D printing are growing year by year.

In essence, 3D printing is a manufacturing process in which material is laid down, layer by layer, to form a three-dimensional object. 3D printing can create physical objects from a geometrical representation by successive addition of material. 3D printing is an umbrella concept for a set of processes and technologies that offer a wide range of the production of parts and products in different materials. Varieties of 3D printing technologies have been developed with different functions. One thing common in all these processes is the manner in which production is carried out – layer by layer in an additive process. Not all 3D printers use the same technology.

Depending on the technology, 3D printers can use a variety of materials, including but not limited to metals (stainless steel, solder, aluminum, and titanium among them); plastics and polymers (including composites that combine plastics with metals, wood, and other materials); ceramics; plaster; glass; and even foodstuffs like cheese, icing, and chocolate. Even composites can be used. The choice of material greatly depends on the product's function and desired properties [6,7].

TYPES OF 3D PRINTING

There are generally three types of additive manufacturing: selective binding, selective solidification, and selective deposition. Typically, people refer to these technologies as Selective Laser Sintering (SLS), Stereolithographic (SLA), and Fused Deposition Modeling (FDM), which are discussed as follows [8,9].

- *Stereolithography* (SLA): This was the world's first 3D printing technology, invented in the 1980s. It is an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts' layers one at a time. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. SLA parts have the highest resolution and accuracy and the smoothest surface finish of all plastic 3D printing technologies. Although stereolithography can produce a wide variety of shapes, it has often been expensive.
- *Selective laser sintering* (SLS): This is an additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (ceramic, or glass powders into a mass that has a three-dimensional shape. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point. SLS is trusted by engineers and manufacturers across different industries for its ability to produce strong, functional parts. Low cost per part, high productivity, and established materials make the technology ideal for a custom manufacturing. The material selection for SLS is limited compared to FDM and SLA.
- *Fused Deposition Modeling* (FDM): This is the most widely used form of 3D printing at the consumer level, fueled by the interest of hobbyists of 3D printers. This technique is suited for basic proof-of-concept models, as well as quick and low-cost prototyping of simple parts. FDM is regarded as a very clean technology, usually simple and office-friendly. It uses a continuous filament of a thermoplastic material. The technology can produce complex geometries and cavities that would otherwise be quite problematic. Since 2004, FDM technology has been used in a particular sector to produce load-bearing scaffold. Home printer based on FDM typically work with plastic filament.

Which technology makes the most sense for you to use depends on your budget, the model's complexity, and the finest detail that is necessary.

3D PRINTING IN OIL AND GAS

The oil and gas (O&G) industry is among the most demanding and complex domains. Its complexity is demonstrated in Figure 3 [10]. 3D printing is already disrupting supply chains in automotive, aerospace, and consumer products. It is in its infancy in the oil & gas sector. The oil and gas sector lags behind industries like automotive and aerospace in finding applicable use cases for AM. This is possibly due to the widespread adherence to a conservative culture that supports tried and tested methods of production and operation often referred to as "the race to be second." There is considerable resistance to change. Initially 3D printing was largely limited to polymer-based products, which had limited appeal to the oil and gas industry. However, advances in metal-based printing are making the technology much more relevant. Figure 4 shows the oil and gas industry supply chain with its segments and corresponding activities [11]. The segments are explained as follows:

- *Upstream Sector*: This includes the exploration and production segment. It is comprised of the following: exploration, drilling, production, and plug and abandonment.
- *Midstream Sector:* This consists of pipes and transportation methods. It is comprised of the following: compressor and pumping stations, geopolitical issue, and maintenance. Additionally, trucking companies, barge companies, and rail service belong to this segment.
- *Downstream Sector*: This is composed of those relating to the consumers, such as manufacturing, petrochemical refining, retail production distribution, and retail. The upstream and downstream segments are characterized by their heavy investments in infrastructure, equipment, and maintenance.

APPLICATIONS OF 3D PRINTING IN OIL AND GAS

Engineers can use 3D printers to visualize, design, and validate designs without putting in extra time and resources. They create 3D printing facilities across locations to produce tools or parts whenever the need arises. Some of the most common uses for 3D printing in the oil and gas industry include creating jigs and fixtures, functional prototypes, and display and presentation models. Applications of additive manufacturing in O&G industry include the following [12,13]:

- *Rapid Prototyping:* A key application of 3D printing in the O&G sector is rapid prototyping. Time to market is one of the most critical issues any industry faces. With pressure to create solutions quickly, engineers and designers must make quick, accurate decisions during the concept stage. Rapid prototyping is a key step in design verification. It goes hand-in-hand with 3D printing. 3D printing prototypes allow engineers to produce multiple iterations and change a component design overnight to meet deadlines. Figure 5 shows a typical rapid prototyping [14].
- *End-use Parts:* The oil and gas industry requires parts to meet robust performance and environmental standards. Utilizing 3D printing to fabricate production, end-use parts has become an increasingly mainstream operation in the energy sector. Because 3D printing can create custom, complex parts faster than traditional manufacturing processes, engineers have found the technology to be a perfect solution for low-volume projects.
- *Spare Parts:* One increasingly crucial application of 3D printing in the energy sector is in the spare parts market. The high cost of downtime and logistical challenges of distribution to wide-spread, remote locations has amounted to overstocking of spare parts. 3D printing provides a solution through fast, on-demand printing of legacy parts from an on-site system. 3D printing enables on-site manufacturing, for fast replacement of broken parts. Printing replacement parts quickly and on-site eliminates costly wait times associated with shipping parts from industrial centers located far away. Solving outdated parts is made easy with 3D printing technology. Additive manufacturing requires only enough storage space to keep the part's digital file on hand. It works best when there are no specs available for legacy parts needed for oil drilling rigs that may have been around for decades. In the oil and gas sector, 3D printing is primarily used for rapid prototyping, creating custom parts like gas turbine nozzles, downhole tools, valves, and other components. Figure 6 shows 3D-printed fuel nozzle made by GE engineers [15].
- *Metal Parts:* Metal 3D printing is a process of constructing three-dimensional parts from metal powder. It works like the regular 3D printing process. The main benefit of metal 3D printing is its ability to create complex parts without needing multiple steps or processes. Metal 3D printing also allows for more efficient use of materials since only what is needed is used, so waste can be minimized based on design specifications. Any metal that can be ground into powder and melts at a high temperature can, in theory, be utilized.
- *Reverse Engineering:* 3D printing can make reverse engineering custom or legacy parts for oil drilling rigs more efficient than ever before. By using digital designs and 3D scanning, a detailed model and exact measurements of a part can be created from scratch. Reverse engineering new parts through 3D printing reduces downtime caused by equipment breakdowns. It also leads to optimization, customization, and improvements for your machinery.

BENEFITS

As 3D printing technology has become more efficient, with lightweight components, cost-efficient services and environmentally-friendly materials. The entire supply chain for the maintenance and operation of drilling rigs has been completely transformed by additive manufacturing. 3D printing offers significant benefits to the oil and gas industry by enabling the creation of complex, customized parts on-demand, leading to improved design flexibility, faster production times, cost reductions, and enhanced

operational efficiency. Even the most demanding components for a rig or plant can be produced locally, cutting down significantly on transportation costs and customs delays. The attractive benefits of 3D printing are numerous. These include the following [13,15]:

- *Prototyping:* Rapid prototyping and bespoke engineering support are recognized as key benefits of 3D printing. 3D printing provides rapid and accurate generation of prototypes and components, specifically where original molding casts no longer exist. 3D printing allows for quick and inexpensive prototyping. It can create custom parts faster than traditional manufacturing methods. AM supports innovation by enabling rapid iteration of physical objects during R&D.
- *Operating in Remote Areas:* Although the oil and gas industry is a crucial economic sector, it faces many challenges from operating in remote areas. Sourcing spare parts can be a challenge. Manufacturing often occurs thousands of miles away from drilling sites. But with the introduction of 3D printing technology, these problems are becoming easier to address.
- *On-site Manufacturing:* 3D printing allows companies to produce parts on-site, which can reduce downtime and costs. This is especially useful in remote locations where shipping parts can be expensive and time-consuming. 3D printing can support the local economy by retaining production within the country.
- *Customization:* The 3D printing technology allows for customization on smaller production runs since each component can be tweaked during manufacture through software manipulation, ensuring accuracy during production without loss of quality or performance.
- *Parts On-demand:* 3D printing can be used to quickly print spare parts on-demand. By allowing companies to produce parts on-demand, 3D printing can reduce lead times significantly and virtually eliminate the need for storage space. This means that when an operator needs a part quickly, they no longer have to wait weeks or months for the part to be delivered. Instead, they can simply print it themselves onsite with an on-site 3D printer. Additive manufacturing allows engineers to create parts on demand with minimal setup time.
- *Cost Reduction:* AM eliminates the cost of capital associated with stocking inventory that may never get used—because only digital files are needed to print parts. In other words, 3D printing offers immense cost savings and efficiency gains throughout the entire supply chain in the oil and gas industry by reducing lead times and storage costs. The industrial-scale additive manufacturing capabilities have enabled O&G companies to not only drastically reduce costs but also save labor and capital.
- *Reducing Carbon Footprints:* AM could help the oil & gas, offshore and maritime industries decarbonize operations in the energy transition. Distributed just-in-time production close to or exactly where products are required reduces transportation needs. This in turn means less exhaust emissions, including greenhouse gases.
- *Less Waste*: 3D printing generally produces less waste than conventional methods that usually involve machining away material from a large piece of material. In contrast, 3D printing adds only material that is needed, and co-locating it with recycling of materials could boost local circular economies.
- *Speed*: Speed is important for most oil and gas projects. One of the key benefits of 3D printing is its ability to speed up the product development process. Speed of delivery from order receipt to manufacture to avoid lengthy procurement processes is regarded as a key advantage. This should be compared against traditional methods of order placement, and delivery.
- *Design Freedom:* 3D printing allows for more design freedom, which can lead to higher quality parts with unusual geometries. In addition to speed and efficiency, metal 3D printing provides design freedom that is not available in traditional manufacturing methods due to its unique layered approach.
- *Design Optimization:* AM allows for intricate geometries and internal structures that can be tailored to specific applications, resulting in lighter, stronger, and more efficient components compared to traditional manufacturing methods.
- *Material Flexibility:* AM can utilize a wide variety of materials, including high-performance metals and polymers, allowing for customized part properties to suit demanding operating conditions.
- *Complex Geometries:* Printing can produce complex components that may be impossible to manufacture using conventional processes. AM can create parts with intricate features, like internal cooling channels or complex interlocking components, which may be impossible with traditional manufacturing techniques.

CHALLENGES

With any new technology, the additive manufacturing in O&G sector faces some challenges. Potential challenges include batch inconsistency of materials for AM, variation in hardware, differing environmental and operational conditions, and regulatory change. Other challenges include the following [13,16]:

- *Toxicity:* Metal additive manufacturing processes release toxic VOCs (volatile organic compounds), which can have serious health consequences. 3D printing metal parts present a number of potential workplace risks that must be taken seriously by all involved workers and employers alike.
- *Safety:* Safety is the most critical issue in the oil and gas industry, where even minor equipment failures can have catastrophic consequences. When it comes to 3D printing, the safety and reliability of the processes and products is paramount. When printing metal parts using a 3D printer, there are several potential dangers that can arise due to the use of metal powder and laser-based processes. Small particles of metal powder can become airborne during the 3D printing process, meaning they can be accidentally inhaled. All safety protocols must be followed rigorously in order to ensure that everyone remains safe while working with this technology. It is absolutely necessary that workers wear proper personal protective equipment to protect themselves from potential exposure. Strict guidelines should be put in place to prevent any eating or drinking in the printing environment, as this could lead to contamination.
- *Standardization*: The absence of standardization and certification is often cited as one of the key challenges that affect the wider adoption of 3D printing technologies in the oil and gas sector. AM needs a systematic qualification process, standards, and specialized knowledge towards qualification and certification of 3D-printed components and materials. Without standardization, printed parts and components in oil & gas industries could raise the risk of unexpected or premature failures due to inherent variation of mechanical and metallurgical properties associated with the AM parts. Non-standard practices for testing parts raise the probability of overall material costs rising compared to the traditional manufacturing route.
- *Trust*: Greater trust and understanding in the industry of the benefits of 3D printing is required if adoption is to reach its potential growth.
- *Lack of Awareness:* The lack of knowledge of 3D printing, particularly at senior levels in the oil and gas industry, is a challenge. There is a lot of ignorance in the oil and gas industry around new technology – people just do not understand the possibilities. The lack of awareness of 3D printing is concerning and must be addressed if the oil and gas industry is to make the most of the range of technology benefits available to it.
- *Reducing Carbon Emissions:* Oils and gas companies account for 33% of direct and indirect carbon emissions in the world. Many oil and gas companies reduce carbon emissions by switching from subtractive manufacturing to additive manufacturing. An oil and gas company can significantly reduce carbon emissions using 3D printing instead of subtractive manufacturing.
- *Quality Control*: Implementing robust quality control measures to guarantee the integrity of AM parts is essential. For this reason, it is vital that companies consider ways to ensure production repeatability to improve confidence in 3D-printed parts and simplify the path to certification.
- *Intellectual Property Rights (IPR):* 3D printing is facing a strong challenge of IPR. This challenge is also faced by sectors like automotive and aerospace. This challenge will also be faced by the oil & gas industry.

CONCLUSION

It is evident that 3D printing has opened up new possibilities for the O&G industry. It not only helps reduce downtime through quick repairs, but also reduces costs associated with sourcing replacement parts from remote locations. Major companies across the oil and gas industry have adopted industrial-scale additive manufacturing capabilities for production. The market growth potential for 3D printing in the oil and gas industry is significant and growing. Additive manufacturing has the potential to significantly transform the oil and gas industry by enabling the design and production of highly customized, efficient components, leading to improved operational performance and cost savings across the entire supply chain. More information about additive manufacturing in oil & gas industry can be found in the books in [17,18] and the following related journals/magazines:

- International Journal of Petroleum and Petrochemical Engineering
- Journal of Petroleum Science and Engineering
- Petroleum
- Petroleum Research

- Energy Reports
- Oil & Gas Journal

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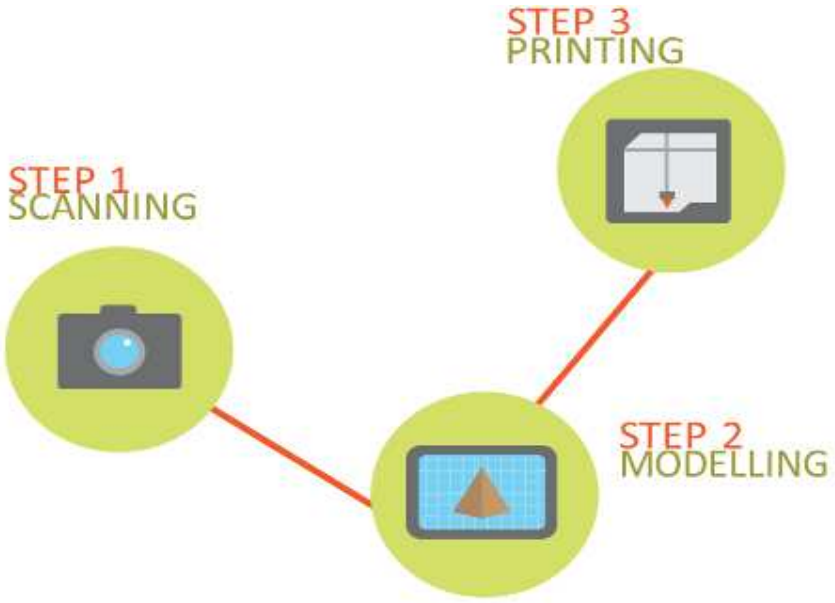

Figure 1 3D printing involves three steps [4].

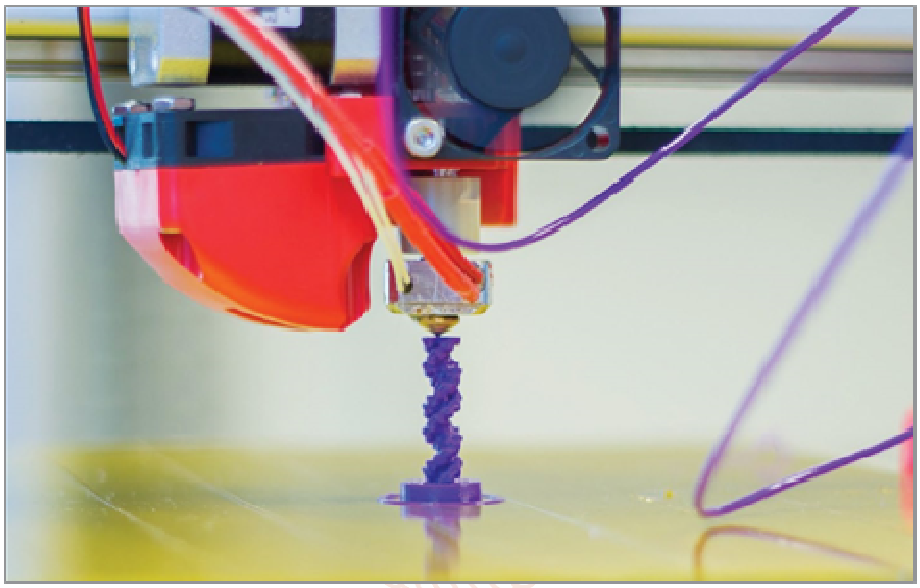

Figure 2 A typical 3D printer [5].

Figure 3 The complexity of oil and gas industry [10].

Figure 4 Oil and gas industry segments and corresponding activities [11].

Figure 5 A typical rapid prototyping [14].

Figure 6 3D-printed fuel nozzle made by GE engineers [15].