Overview

Revolutionary inventions such as the television, the light bulb, the telephone, and the internet, to name a few, often take decades to come to fruition, and initially their impact may go unnoticed or underestimated. One technology that could potentially add to the list of inventions that have changed the world is *3D printing*, or *Additive Manufacturing*, which could overturn the last two centuries of approach to design and manufacturing, with obvious economic, social and geopolitical implications.

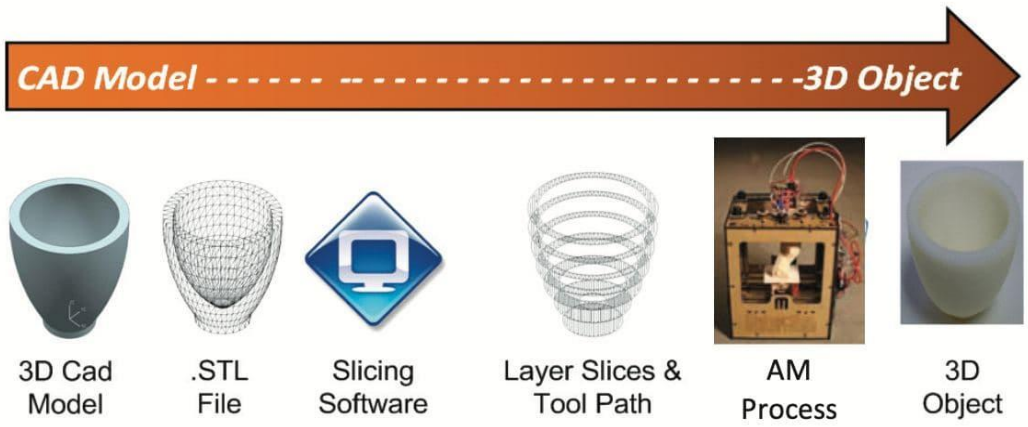
AM (*Additive Manufacturing*), at the time of writing, can be compared to where the first computers were, or to the dawn of the Internet. This technology could prove to have as profound an impact on the world of manufacturing as PCs and the Internet had on the world of information. In this report we will examine the current advantages and disadvantages in using this technology, real case studies, the degree of maturity of the technology, make a comparison between geographic areas, and to conclude a brief analysis of two companies that could potentially profit from this exciting industry.

Note: Within this publication, the terms Additive Manufacturing (or AM) and 3D Printing will be used interchangeably, although technically they are not the same thing, as 3D Printing is an additive manufacturing process.

The Third Industrial Revolution

Before we continue, since not all readers are likely engineers who specialize in 3D design and manufacturing, it's important to understand how this technology works and what differentiates it from traditional manufacturing, without digging into much detail.

Casting, forming and molding are just a few of the processes that involve machinery. computers and robots in the larger process of traditional manufacturing. This type of manufacturing is called '*subtractive*', as objects are created through the subtraction of material from a single initial piece. In contrast, additive manufacturing builds products layer by layer, in an additive fashion, creating objects from the bottom up, and not from the top down, as in traditional manufacturing. This small distinction, the fact that material is added rather than subtracted, is of fundamental importance in understanding this technology.



In figure [1], the manufacturing process is illustrated, which begins with a 3D model of the object, usually created by design software (CAD) or a scan of an existing object. Specialized software 'slices' the model into cross-sectional states, creating a file that is sent to the 3D Printer, which then initiates the printing process by placing the material needed to create the object, much like a regular printer adds ink to the sheet until it is completed. For the purposes of understanding the potential of the technology, it is not important to give much further details about the technical processes of printing.

Benefits

Now that we have a general understanding of how the printing process works, let's now look at why we believe the technology has the potential to lead to the third industrial revolution. To summarize, the key benefits of the technology are:

- **On-demand manufacturing**

  Balancing supply and demand is often difficult. That's why suppliers use sophisticated algorithms to predict how much of their products will be needed, at a given time and place, to meet uncertain demand. But what if you could flip the supply-demand equation on its head? Instead of producing in anticipation of demand, what if you could produce

only on demand, after the customer has committed to buying your product? Obviously, this would not be possible with traditional manufacturing techniques.

- **Mass Customization**

  Indeed, in today's consumer landscape, consumers are demanding more and more personalized and tailor-made experiences. In essence, the mass customization model involves creating one-off products that are precisely tailored to the needs or whims of individual buyers. 3D printing enables companies to explore this business model by providing a more viable solution for producing customized products. Unlike conventional techniques, which would require substantial investment in tools to produce custom parts, 3D printing requires only loading custom digital designs of a product, or part thereof, into a 3D printer. Often, the technology is also used to create custom disposable molds, which would typically be cost and time prohibitive with conventional manufacturing.

- **Increased Part Complexity**

  Another obvious benefit is the ability to create complex shapes that cannot be produced by other means. As AM processes allow designers to selectively place material, only where it is needed. In addition, creating the part directly from the computer model ensures that the part created accurately represents the designer's intent, thus reducing the inaccuracies typical of traditional processes. With this technology, manufacturing becomes more adaptable and less labor intensive. Product design is free from manufacturing constraints and can adapt to greater complexity, with little or no additional cost. Products become more customizable, with performance better matched to the end user's usage requirements.

- **Eco-friendly?**

  According to our vision, another advantage of the technology lies in the fact that AM processes are inherently Eco-friendly, since, as material is added layer by layer, only the material needed for the part is used, drastically reducing the waste produced – especially when compared to traditional manufacturing. On the other hand, however, there is a heavy reliance on plastic materials, and plastic as a whole is not considered an environmentally friendly material. In addition, a study reveals that second-hand printing fumes emitted when the plastic material is heated to high temperatures retain toxic by-products. However, an analysis of the ecological profile of 3D printing compared to all other manufacturing processes, particularly mass production, shows that the technology has much less impact on our environment than traditional manufacturing.

  3D printers demonstrate a significant advantage over traditional machines in terms of carbon footprint. In manufacturing, 3D printers generate less waste by using slightly more of the amount of material needed for the product, eliminating the drilling, cutting and milling process. Another benefit of 3D printers is that they reduce the refining and assembly stage and eliminate the need for product storage before and during the sale, which generally has always contributed to the overuse of resources. On-site, on-demand 3D printed manufacturing reduces overall energy waste and has a lower carbon footprint. The environmental costs of assembly, transportation, logistics, maintenance, and storage are completely or nearly eliminated. The idea behind 3D printing is to efficiently and

effectively produce cost-effective products in a way that is durable, lighter (especially beneficial during shipping), and with near-zero waste.

Limitations

Of course, given the advantages described above, you might be wondering why this technology is not already being used by most manufacturers around the world. In fact, despite the countless advantages, we should also talk about the current limitations in the processes that prevent Additive Manufacturing from being a solution for all our manufacturing nightmares. As it happens with many revolutionary technologies, the road to full adoption will be long and full of obstacles. We can summarize the main limitations of the technology as follows:

- **Limited materials**

  Although 3D printing can creates items in a selection of plastics and metals, the available selection of raw materials is limited. Reason being that not all metals or plastics can be sufficiently temperature controlled to allow for 3D printing.

- **Limited Size**

  3D printers currently have small print chambers that limit the size of parts that can be printed. Anything larger will have to be printed in separate parts and joined together after production. This can increase cost and time for larger parts due to the printer's need to print multiple parts before relying on manual labor to join the parts together.

- **Speed**

  Many 3D printers currently in operation are still relatively slow compared to other manufacturing processes. This limits the ability of 3D printing to compete in the mass production space.

- **Copyright Issues**

  As 3D printing is becoming more popular and accessible, there is a greater opportunity for people to create fake and counterfeit products, and it will be nearly impossible to tell the difference. This has obvious repercussions related to copyright and quality control. Other limitations can be material and operational prices that are sometimes too high, and the complexity of 3D modeling.

We firmly believe that the majority of these limitations will be overcome as the technology advances.

Case Studies

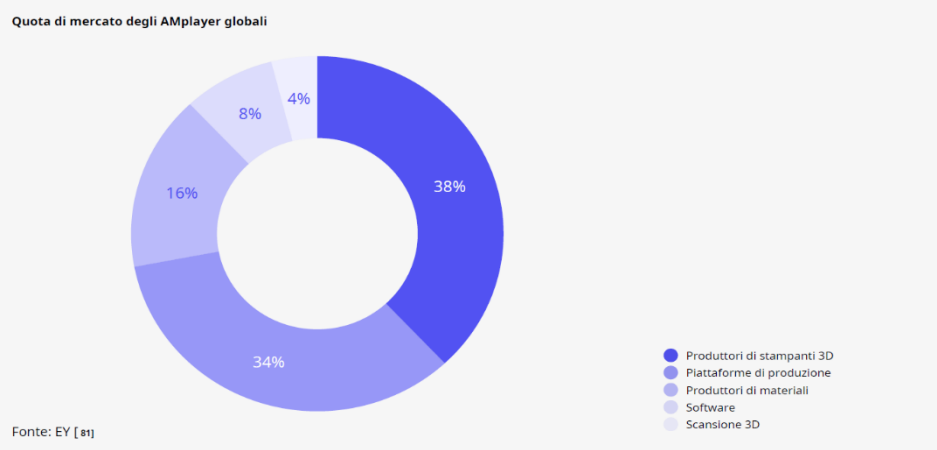
It is critical to understand that this technology is not “new”, as it has been around for decades. But in recent years, due to specific technical breakthroughs it has been re-discoverd. Initially, additive manufacturing was referred to as "rapid prototyping" and was primarily used to rapidly fabricate conceptual models of new products for form and fit evaluation. As material properties and process repeatability improved, the use of the technology evolved from the creation of prototypes to the creation of parts for functional testing, to the creation of tools, and finally to the direct production of parts for end use. In fact, as time goes by, more and more companies are slowly converting part of their manufacturing processes. The following are just a few of the businesses that are investing millions, if not billions, of dollars in this manufacturing transition:

- AIRBUS expects 3D printing to bring 50% weight savings and 60-70% cost savings to its aircraft parts. Stratasys, one of the two companies we're going to look at, has provided 1,000 3D printed parts for Airbus, which has 8 millions of parts in total, the majority of which are likely to be 3D printed.
- Even ROLLS ROYCE, with 3D printing, has reduced the production time of an engine by a third.
- Nike and Adidas have already introduced additive manufacturing techniques to transform footwear design and production. This methodology reduces labor costs by up to 50% and cuts material usage by up to 20%. As a result, it has reduced material waste by more than two million pounds since 2012. Previous Nike’s CEO Eric Sprunk commented that 3D printing entire shoes is not far off. Furthermore, instead of shipping samples back and forth from Asia, Nike simply needs to send design and code files to the factory to print the final product.
- GE (General Electric) acquired two metal 3D printing companies for $1.4 billion and predicts that 3D printing will reduce costs by $3-5 billion for the company, and that the technology will touch more than 50% of its manufacturing processes within 20 years. Today, GE uses 3D printing to make the fuel nozzles for its LEAP engines. During the next five years, GE plans to invest an additional $1 billion in additive manufacturing.
- FORD is using 3D printing to produce molds and prototypes, reducing lead times from months or weeks. to days or hours, and reducing parts costs to a fraction of what has been normal until now. Ford has been experimenting with 3D printing for 25 years. Ten years ago, it 3D printed about 4,000 prototype parts in total. Today, Ford has five 3D printing centers, each of which can print 20,000 parts per year, and uses printers from 3D Systems, ExOne and Carbon3D.

These are just a few of the cases of companies that are investing in 3D printing, others include: BMW, AUDI, Volkswagen, VOLVO, Renault, US Air Force, US Navy and many more cases.

The Trend

As with all revolutionary technologies, the beneficiaries of such disruptive technological innovations could be far-reaching. Suffice it to say that the invention of the telephone did indeed benefit phone manufacturers, but indirectly entire economies were created based on that revolution. As described in infographic 2, the other players that could benefit from the advancement of additive manufacturing are:



- **Suppliers of modeling software and tools**, which should reduce the time and distance between design and production; In fact, exciting new developments show that this segment is rapidly catching up, enabling companies to create complex designs faster, increasing print success rates (including through simulation software, to increase the likelihood of successful printing), ensuring part quality, and managing workflows more efficiently. Software is the key to profitable manufacturing with 3D printing. Designing for AM offers unique challenges and opportunities not found in traditional design methods. It involves the creation of new design practices aimed at reducing material usage and exploring complex design features.

- **Manufacturers of innovative materials** that will enable performance and form factors that would otherwise be impossible. Polymers remain the largest segment of 3D printing materials in terms of market share. From 2014 to 2018, 80.6% of global revenues for 3D printing materials came from polymers and reached more than $3 billion in 2018. In fact, the high demand for polymers is not surprising, as polymer 3D printers have a larger market, as they are easier to use and cheaper. While relatively simple plastics, such as PLA and ABS, dominate the polymer market, there is a growing demand for robust and functional materials that can withstand harsh environments and high temperatures. Across the industry, chemical companies are increasingly developing these advanced materials. The new material boasts great resistance to high temperatures, thanks to its ability to deflect heat up to 230°C. The development of high-performance thermoplastics is critical to the industrialization of AM, as they support the transition of technology from prototyping to advanced applications in critical industries such as medical and aerospace.

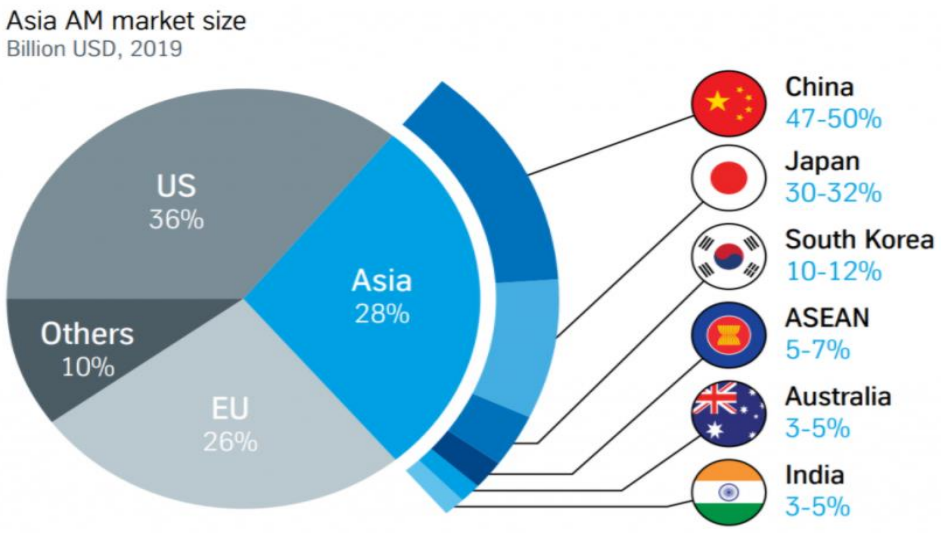
- **Scanning and measurement companies** will also help incorporate real-world measurement as an important design input for manufacturing.

US, Europe or Asia ?

Well, hoping to have given a good picture of the potential of the technology, it is now important to try to understand the sheer size of the market, but more importantly in which part of the world the technology is gaining momentum. The **Global 3D Printing Market** is expected to grow at a CAGR of between 20 and 30% during the forecast period (2021-2027).

Until 2019, North America and Europe were the undisputed leaders in online 3D printing, together accounting for over 95% of global demand. The United States alone accounted for nearly 50% of global demand for 3D printed parts. California extended its lead as the state with the highest demand for 3D printing in 2019. More than 22% of total parts produced in the U.S. were shipped to customers based in the region. The growing hardware and technology needs of Silicon Valley, Los Angeles and San Diego are a substantial driver of this trend. New York, Texas and Massachusetts followed at 7%, 6% and 5%, respectively. These are also states that are home to companies with a strong focus on innovation and technology.

In Europe. on the other hand, the United Kingdom is leading the field the field. In fact, in recent years, technology has been the focus of research and development in the rest of the world as well. The growing interest of Asia-Pacific manufacturing companies and the introduction of many government-led strategies and policies have helped several Asian countries to create a sustainable additive manufacturing ecosystem. As you will notice from figure [3] below, China is the biggest force behind the growth of 3D printing in Asia in light of the huge government support to promote the industry. It is currently the third largest market for 3D printing, after the US and Western Europe. In 2017, the Chinese government issued the "*Action Plan for the Development of Additive Manufacturing Industry*" seeking to achieve a domestic AM industry worth $3 billion by 2020.



The action plan, which is part of the country's "*Made in China 2025*" strategic roadmap for manufacturing sector, outlines long-term ambitions and development goals to make China a leading 3D printing nation. One of the highlights of the plan is the goal of introducing more than 100 AM pilot projects in 10 key sectors, including medical, cultural, educational and Internet. To achieve these goals, China is nurturing promising companies, supporting

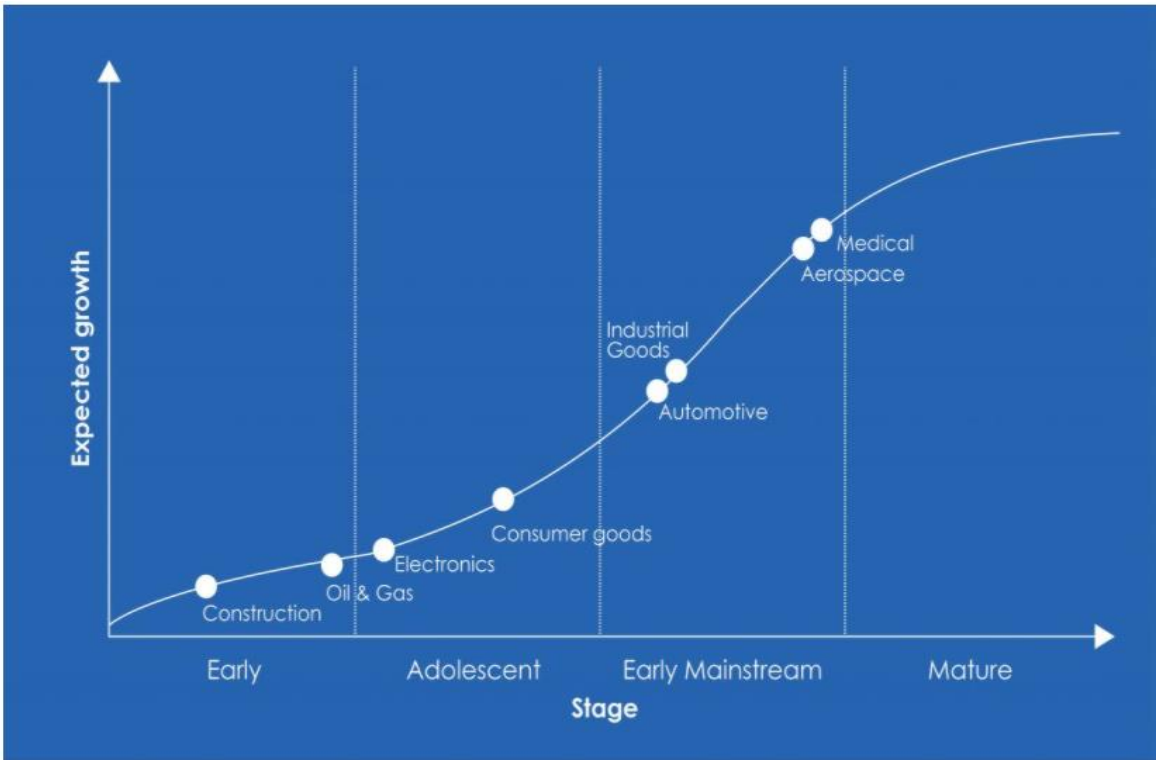
standardization for China's 3D printing industry, and investing in 3D printing workforce development. For example, China recently established the world's first 3D printing college, the *Baiyun-Winbo 3D Printing Technology College* in Guangzhou. The country also plans to install 3D printers in 400,000 elementary schools. Initiatives like these will benefit Chinese society in the long run, as people will be educated and skilled in 3D technology from a young age.

South Korea is also very involved in the development of AM technology, accounting for about 4% of all 3D Printing systems worldwide, as well as being the third largest machine country in Asia-Pacific. Korea could become the global leader, thanks to a national government-led research and development roadmap focused on 3D printing. Other countries such as Singapore and Australia are certainly worth monitoring as well. In 2019, Australia's AM market accounted for only about 3-5% of the total AM market in APAC. By adopting the technology, Australia has lagged behind the rest of the world. However, the country has seen an influx of new companies in recent years.

Interestingly, most of the developments are focused on metal-based technologies. One reason may lie in the country's abundant natural resource deposits, including some of the largest mineral reserves for metals such as aluminum, titanium, nickel, steel and tantalum. This means that instead of sending a huge amount of these resources overseas, the country is looking for ways to tap these resources at home. Metal 3D printing is emerging as one of the most promising technologies for processing metals such as titanium, nickel and aluminum.

Applications

Where has the technology reached the highest level of maturity?



Now that we have a good understanding of the why, how and where of this technology, it is important to understand the current level of maturation of AM. In a world that is advancing so fast, it is of paramount importance to try not only to understand which technologies can usher a bright future, but also to understand which ones are still too young to implemented into society. As you may have guessed from the infographic [4], among the sectors that are already benefiting the most from this technology, it is worth mentioning:

- **Aerospace:**

  The aerospace industry is an early adopter of 3D printing, with the first application of the technology dating back to 1989. In 2020, aerospace will represent a 16.8% share of the $10.4 billion additive manufacturing market, contributing heavily to industry advancements.

- **Healthcare Sector:**

  Early traditional 3D printing has gained significant traction in the healthcare sector, expanding the opportunity to provide personalized care, produce custom medical devices and pre-surgical models. According to a report by market research firm SmarTech, the medical 3D printing market, including materials, services, software and hardware, is currently estimated at $1.50 billion, and is expected to grow to $6 billion by 2027, in segments such as orthopedics, custom surgery, medical devices and dental.

- **Automotive:**

  As of 2020, 3D printing has emerged in the automotive industry primarily as a technology for prototyping and tooling applications. However, it is gaining more traction in mass production and custom end parts, particularly for motorsports and luxury vehicles. Although still lagging other industries, the automotive industry is racing toward industrializing 3D printing within its manufacturing workflow. Moving forward, we will see more 3D printed parts installed in vehicles beyond luxury and sports cars.

- **Industrial Goods:**

  The industrial goods sector includes the production of machinery components, tools and equipment used in the manufacturing of other goods. For this sector, 3D printing offers a number of benefits, including shorter lead times, new design opportunities and on-demand manufacturing. For example, one of the world's largest industrial goods companies, CNH Industrial, recently announced that it will introduce 3D printing into its manufacturing processes. The key area of focus will be the production of parts for buses and agricultural equipment. The industrial goods industry has already begun to reap the benefits of 3D printing. To build on these advances, the industry must collaborate on standardization and research efforts. This will help identify more suitable use cases and increase confidence in the technology.

- **Consumer Goods:**

  In the consumer goods industry, the application of 3D printing is primarily focused on creating prototypes used in the design and product development phases. Footwear,

eyewear, jewelry, and bicycle manufacturing are the largest segments leveraging 3D printing in manufacturing. Adoption rates of 3D printing is still relatively low here, especially when compared to pioneering industries such as aerospace and medicine. For most consumer goods companies, implementing a 3D printing production line is not economically viable, at least for now. In fact, 3D printing production volumes cannot currently compete with the volumes achieved with conventional manufacturing. However, even as the cost-effectiveness of 3D printing improves, it is unlikely that the technology will ever completely replace mass production methods, but it can certainly be an important part of the manufacturing process.

Selected Companies

To conclude this study, we have selected two very interesting companies that could play a key role in ushering Additive Manufacturing into the mainstream in the near future.

STRATASYS (SSYS)

Company Profile:

- *HQ:* Minnesota
- *Market Cap.:* $1.5 Bn
- *Stock price:* $25
- *Current Asset:* $560 M
- *Current Liabilities:* $123 M

Stratasys Ltd. provides 3D printing and additive manufacturing solutions for individuals, businesses and enterprises. In addition, the company offers *GrabCAD Print* software that provides scheduling, planning, tracking and analysis of jobs on various 3D printing technologies. The software also rents 3D printers and 3D manufacturing systems, produces prototypes and end-use parts for customers from a customer-supplied computer-aided design (CAD) file, and offers plastic and metal parts for manufacturing and rapid prototyping processes. Stratasys products and services are used primarily in the automotive, aerospace, medical, dental, education and consumer goods markets.

Stratasys holds a leadership position in the 3D printing revolution. In fact, its founder, Scott Crump, invented *FDM (Fused Deposition Modeling)*, a clean, easy-to-use technology for making robust, durable and stable parts with a high degree of accuracy. Gross margin stands at a healthy 45%, while Net Income is negative, as the company does not yet generate satisfactory cash flow. It is interesting to note that the R&D and Net Property items are constant and growing over time, an excellent sign for future growth.

DESKTOP METAL (DM)

Company Profile:

- *HQ:* Massachusetts
- *Market Cap.:* $3.5 Bln
- *Stock Price:* $14
- *Current Assets:* $613M
- *Current Liabilities:* $30M

Dekstop Metal is an American company that designs and markets 3D printing systems. The company has raised $438 million in financing since its founding day, from investors such as Google Ventures, BMW and Ford Motor Company. At the time of its creation, the company's goal was to develop a metal 3D printing process that was fast, compact and simple enough to be used in an office. Stratasys, the aforementioned company, since 2017 has entered into a strategic partership with Desktop metal, in order to combine Stratasys' Deep knowledge and experience, with Desktop Metal's pioneering technologies. In 2018, DM won an emerging technology award from digital trends, as well as being mentioned by the World Economic Forum as well. That same year, Ford Motor led a $65 million investment round, with Ford's CTO joining Desktop Metal's board of directors.

The company launched its two main products in 2017:

- *Production System*, a product aimed at manufacturers and large-scale printing, with a method called *Single Pass Jetting*, used for rapid, scale production of metal parts, nearly 100 times faster than traditional laser methods.
- *Studio System*, designed for engineers and small volume production. Because the process uses no hazardous lasers, it can be housed within office spaces. Plus, thanks to their proprietary *'Fabricate'* software, all aspects of parts creation are automated, which is why you don't need to be an engineer or expert metallurgist to create complex metal structures, unlike most competing products.

Conclusions

Many of the world's largest manufacturers have already invested heavily in additive manufacturing technology, which is arguably the future of manufacturing and its impact is already being felt around the world. This sector, in our opinion, has the potential to revolutionize and innovate entire supply chains in the long run. Even though the technology is not exactly novel, it has found a lifeline especially in the last decade, following developments in the materials used and improvements in software design, which make printing increasingly efficient and convenient. It is also interesting to note that until recently the technology has only managed to enter a small part of the market, such as prototypes or small industrial uses, as in terms of cost-effectiveness it is not yet ready for intensive use. But according to our vision, despite all these limitations in the short term, technological adoption will make its course, removing these limitations.

In fact, in the coming years, 3D printing will continue to evolve and change the landscape of manufacturing, it will be at the heart of custom manufacturing and will be used in large-scale production in many other industries, generating a market far larger than it is today. Bio-printing' technology is also very interesting, thanks to which it will be possible to potentially repair or replace parts of the body such as the heart, kidneys or skin, using the patient's own tissues, thus solving many problems such as organ unavailability or rejection. In short, AM technology has all the cards stacked in it favor in order to play an important role in the world economy in the next 10 to 15 years. We look forward to observing and commenting on future developments of this promising technology.

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