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3D PRINTING: A DISRUPTIVE INNOVATION IN ITS INFANCY

RESEARCH WHITE PAPER BY

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3D printing, or more broadly additive manufacturing, is a technologically enabled innovation that has the potential to disrupt the manufacturing sector. By building objects layer-by-layer instead of using a mold or removing material from a larger block, 3D printing dramatically shortens the time between design and production, shifts power to designers, and creates products with radically new architectures and less waste at a fraction of the cost of traditional manufacturing. Similar to other disruptive innovations, however, 3D printing experienced a period of hype “before its time” and has gone through a period of restructuring. While 2015 was a turbulent year for 3D printing companies and their stocks, the long-term prospects are intact and profound... but not well understood.

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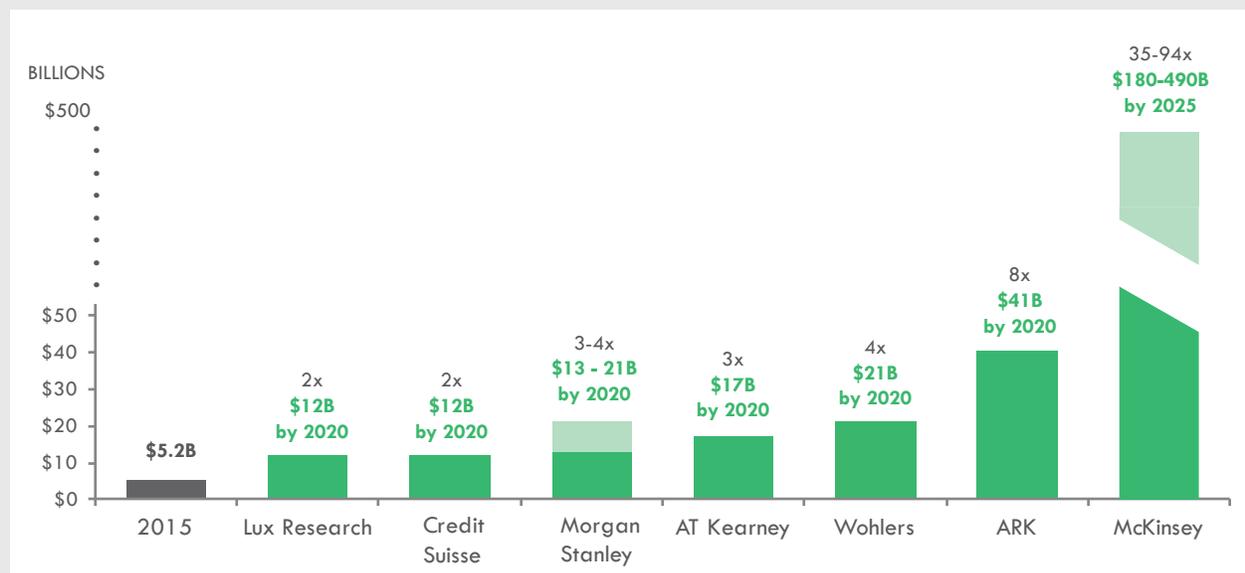
3D PRINTING: SHAPING THE FUTURE OF DESIGN

ARK believes that 3D printing, or more broadly additive manufacturing, is a revolutionary platform technology that will usher in the Third Industrial Revolution. Building objects layer-by-layer—a stark contrast to traditional manufacturing techniques, which either shave material away from a larger block or require a mold to shape parts—additive manufacturing offers a range of benefits:

- | **Production becomes more adaptable and less labor intensive.**
- | **Product design is freed from manufacturing constraints and can accommodate greater complexity with little to no additional cost.**
- | **Products become more customizable with performance metrics a closer match to end-use-requirements.**

While 3D printing is only a \$5.2 billion market today, ARK estimates that it could grow to more than \$40 billion by 2020.¹ Other analysts' estimates range from \$12 billion to \$490 billion for the next five to ten years, as shown in Figure 1. 3D printing dramatically shortens the time between design and production, shifts power to designers, and creates products with radically new architectures and less waste at a fraction of the cost of traditional manufacturing. At the high end of estimates, 3D printing technology currently has penetrated less than 1% of the total addressable market.² ARK believes 3D printing, now in its earliest days, is poised to grow more than 40% per year over the next five years.³

FIGURE 1
Global Estimates for 3D Printing Market 2020 to 2025



Source: ARK Investment Management LLC

1 Source: ARK Investment Management LLC

2 Assuming the market is \$5.2 today (Source: Wohler's <http://wohlersassociates.com/press71.html>) and could reach \$490B (ARK Investment Management LLC, McKinsey).

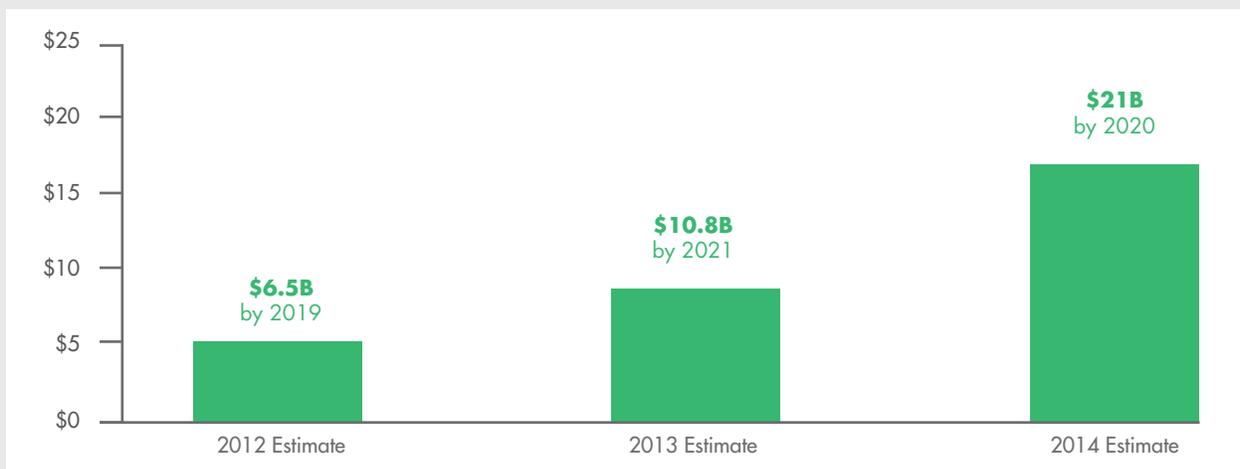
3 Source: ARK Investment Management LLC



While ARK and McKinsey approached the addressable market for 3D printing from the top down, other firms appear to have taken a more conservative approach based on recent history when estimating future growth rates. This disparity highlights the high degree of uncertainty among analysts about the technology's potential. Further supporting this uncertainty is the magnitude of forecast revisions to the upside during the last few years. As shown in Figure 2, Wohler's nearly doubled its estimates for the potential size of the 3D printing market twice from 2012-2014. Clearly the market had been outpacing expectations, though Wohler's next forecast will not be released for a few months.

FIGURE 2

Wohler's Estimates in 2012-2014 for 3D Printing Market in 2019-2021



Source: Wohler's Associates

The beneficiaries of disruptive technological innovations, like 3D printing, are wide ranging, as illustrated in the diagram below. They include the producers of component technologies that enable the technology platforms and the end-users and service-providers who deliver the output of those platforms to the end-user. Besides the 3D printing equipment manufacturers, who provide the technology platforms, the following players should benefit.

- | **Software and modeling tool providers should collapse the time and distance between design and production.**
- | **Innovative materials manufacturers will enable performance and form factors that would be impossible otherwise.**
- | **Scanning and measurement companies will help incorporate real-world measurement as an important design input for production.**
- | **Service centers will help manufacturers transition from traditional to additive techniques, accelerating adoption of additive techniques into design-cycles.**
- | **Innovative manufacturers should enjoy competitive advantages as they provide customers with better performance and more customized products at a faster pace and cheaper cost than their competitors.**



PLAYERS IN THE 3D PRINTING INDUSTRY

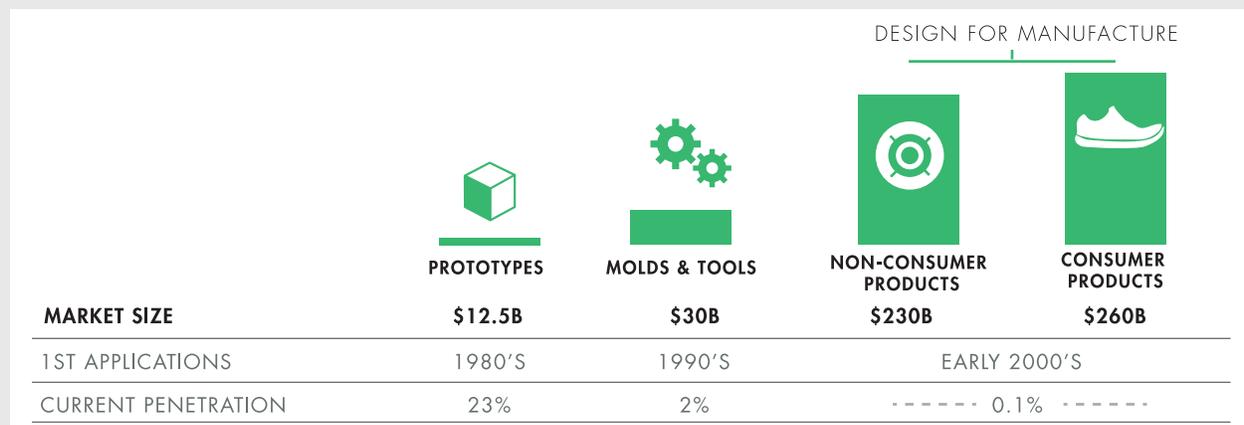
MATERIALS	SCANNING & MEASUREMENT	CAD & SIMULATION SOFTWARE	PRINTER MANUFACTURERS	SERVICE CENTERS	END PRODUCTS
Alcoa Sandvik Eastman Chemical PolyOne Fenner Atlas Copco Allegheny Tech	FARO Perceptron Hexagon Align Technology	Autodesk Dassault Adobe Materialise Trimble Ansys PTC Exa Corp. Mentor Graphics Microsoft	Stratasys ExOne Voxeljet 3D Systems Organovo Hewlett Packard Camtek Groupe Gorge Arcam SLM Solutions	Proto Labs Renishaw MGI Group France Bertrandt	GE Nike Adidas New Balance Airbus Lockheed Martin Orbital ATK

Note: This is a list of U.S. publicly traded companies in the 3D printing ecosystem compiled by ARK Investment Management LLC.

While increasingly used to manufacture prototypes, 3D printing has penetrated just a slice of the end-use parts market. Before the advent of 3D printing, a prototype might be cast, injection molded, or milled using traditional subtractive manufacturing techniques, or even hand-carved. Each of those processes would take weeks, largely leaving designers on the sidelines after their initial contribution. In contrast, a 3D printed prototype is much less expensive, takes days or hours, and saves on materials waste. Importantly, design changes can be incorporated and sent to the printer for each iteration seamlessly. Aside from the \$12.5 billion prototyping market, 3D printing is also penetrating injection and cast molding applications, opening up a potential addressable market of an additional \$30 billion globally.⁵ The final frontier for 3D printing will be the finished product market, an additional \$500 billion opportunity, as shown in Figure 3. Already, Airbus, Nike, Adidas, and GE use 3D printing for direct product manufacturing, while Ford uses it for molds and prototypes with plans eventually to 3D print finished products.

ARK believes that, while the 3D printing manufacturing space will remain fiercely competitive, 3D printed parts that are being designed into supply-chains should prove to be more durable and more defensible than those in the consumer and prototyping spaces. This strong barrier to entry should benefit Stratasys and 3D Systems.

FIGURE 3
3D Printing Global Market Penetration



Source: McKinsey, ARK Investment Management LLC, Fredonia Group, US Congressional Research Service

* CAD - Computer-aided design

4 This is because there are more design limitations with these processes.

5 Source: ARK Investment Management LLC. Assumes that 3D printing could capture 60% of the \$100B mold market with a cost savings average of 50%.



PRODUCT CASE STUDIES



AIRBUS

Airbus expects 3D printing to bring 50% in weight savings and 60-70% in cost savings to its A350 aircraft parts.⁶ Both Stratasys and Materialise have made 3D printed parts for Airbus' A350 XWB. Stratasys supplied 1,000 3D printed parts⁷ for the aircraft, which has millions⁸ of parts in total, many more of which likely will be 3D printed.

Airbus' A350 XWB also has conducted test flights with Rolls Royce engines containing the largest 3D printed aerospace components ever used. The engines have 48 3D printed aerofoils manufactured with help from the University of Sheffield using Arcam technology. With additive manufacturing, Rolls Royce has cut the time to manufacture an engine by a third.⁹

Airbus also used Autodesk's generative software to design a new 3D printed aircraft dividing wall. The resulting part was 45% lighter than the current partition and, if used on the full backlog of A320 planes, could save 465,000 metric tons of CO₂ emissions per year. For perspective, such savings would result from taking 96,000 cars off the road.¹⁰



VIDEO: <http://arkin.v.st/1SCyG7p>



VIDEO: <http://arkin.v.st/1LTR5Ls>



NIKE & ADIDAS

Nike's Chief Operating Officer, Eric Sprunk, has commented that the 3D printing of entire shoes at home or in Nike stores is not far away.¹¹ Nike and Adidas already have introduced additive manufacturing techniques—Flyknit and Primeknit, respectively—to transform footwear design and production. Both companies use automated knitting machines to weave the upper of each shoe in one piece. Flyknit reduces labor costs by up to 50% and cuts material usage by up to 20%. Consequently, it has lowered materials waste by more than two million pounds since 2012.¹² In addition, Nike can command a premium price for the shoes, which are lighter and deliver better performance. Furthermore, instead of shipping samples back and forth from Asia, Nike simply has to send design files and code to the factory to print the final product.

Nike and Adidas also are exploring ways to 3D print shoe soles. Last year, Nike created a pair of concept cleats¹³ with 3D printing, allowing for designs that otherwise would be impossible to manufacture. The resulting cleats helped improve speed and traction on turf. Recently, Adidas forged a relationship with Materialise,¹⁴ New Balance teamed up with 3D Systems, and Under Armour with Autodesk and 3D Systems, to create lines of running shoes with 3D printed midsoles, giving us a glimpse of a future in which shoes will be custom printed for an individual's foot.



VIDEO: <http://arkin.v.st/1R9C2cO>

6 Source: <http://ow.ly/Ak9vj>

7 Source: <http://blog.stratasys.com/2015/05/06/airbus-3d-printing/>

8 Source: <http://blog.seattlepi.com/aerospace/2007/03/29/a380-ride-and-factoids/>

9 Source: <http://3dprint.com/104518/rollsroyce-powerful-jet-engine/>

10 Source: <http://3dprint.com/109310/airbus-autodesk-dividing-wall/>

11 Source: <http://www.fool.com/investing/general/2015/10/13/nike-inc-says-3d-printed-shoes-are-on-the-horizon.aspx>

12 Source: Nike Investor Day http://s1.q4cdn.com/806093406/files/doc_events/NIKE-Inc-2015-Investor-Day-Transcript-Complete-withQA-FINAL.pdf

13 Source: <http://news.nike.com/news/nike-football-accelerates-innovation-with-3d-printed-concept-cleat-for-shuttle>

14 Source: <http://www.materialise.com/cases/adidas-futurecraft-the-ultimate-3d-printed-personalized-shoe>



GE

GE acquired two metal 3D printing companies, Arcam and SLM Solutions, for \$1.4 billion.¹⁵ GE expects 3D printing to cut \$3-5 billion in costs for the firm and reduce part costs by 30-50% depending on the material.¹⁶ GE foresees the technology touching more than 50% of its manufacturing processes within 20 years. Today GE uses 3D printing to make fuel nozzles for its LEAP engines. The 3D printed fuel nozzles replace 18 parts with one, resulting in a part that is five times more durable than the previous model.¹⁷ The new design would have been impossible to manufacture with traditional techniques. Also, it is important to note, 3D printing took a year off the normal product development cycle.

During the next five years, GE plans to invest an additional \$1 billion in additive manufacturing.¹⁸ GE Aviation produces roughly 40 million¹⁹ parts in total per year for new engines, and GE as a whole makes billions of parts per year²⁰, offering massive potential for additional 3D printed parts.

▶ VIDEO: <http://arkiniv.st/1WbS3mT>



FORD

Ford uses 3D printing to produce molds and prototypes, cutting lead times down from months or weeks to days or hours,²¹ and reducing part costs to a fraction of what has heretofore been normal.²²

Ford has been experimenting with 3D printing for 25 years.²³ Ten years ago, it 3D printed roughly 4,000 prototype parts in total. Today, Ford has five 3D printing centers, each of which can print 20,000 parts per year.²⁴ Ford uses printers from 3D Systems, ExOne, and Carbon3D.²⁵ It has 3D printed more than 500,000 parts over the last decade, saving billions of dollars and millions of labor hours.²⁶ Ford sees a future in which 3D printing will be used at dealerships for replacement parts and will allow customers to design 3D printable customized car accessories.²⁷

▶ VIDEO: <http://arkiniv.st/1QGHqqx>

15 Source: http://www.geaviation.com/press/other/other_20160906.html

16 Source: GE Additive Manufacturing Investor Meeting, September 6, 2016.

17 Source: GE Global Research, <http://www.geglobalresearch.com/innovation/3d-printing-creates-new-parts-aircraft-engines>

18 Source: GE Additive Manufacturing Investor Meeting, September 6, 2016.

19 There are roughly 25,000 parts in a jet engine and GE produces about 1,600 per year. Sources: <http://www.cfmaeroengines.com/files/brochures/LEAP-Brochure-2015.pdf>, <http://www.madehow.com/Volume-1/Jet-Engine.html>

20 ARK Estimate

21 Sources: <http://www.computerworld.com/article/2490192/emerging-technology-inside-ford-s-3d-printing-lab-where-thousands-of-parts-are-made.html>
<http://www.forbes.com/sites/ricksmith/2015/06/29/7-ways-3d-printing-is-already-disrupting-global-manufacturing/>

22 Source: <http://www.forbes.com/sites/ricksmith/2015/06/29/7-ways-3d-printing-is-already-disrupting-global-manufacturing/>

23 Source: https://media.ford.com/content/fordmedia/fna/us/en/news/2013/12/12/ford_s-3d-printed-auto-parts-save-millions-boost-quality.html

24 Source: <http://www.computerworld.com/article/2490192/emerging-technology-inside-ford-s-3d-printing-lab-where-thousands-of-parts-are-made.html>

25 Source: <https://corporate.ford.com/innovation/building-in-the-automotive-sandbox.html>

26 Source: <https://corporate.ford.com/innovation/building-in-the-automotive-sandbox.html>

27 Source: <https://corporate.ford.com/innovation/building-in-the-automotive-sandbox.html>



CONCLUSION: 3D PRINTING — A MISUNDERSTOOD OPPORTUNITY

Given their substantial promise, capital markets have treated 3D printing stocks harshly during the past year and a half, as shown in Figure 4. The stocks most negatively impacted have been those of the 3D printer manufacturers. Software-focused companies like Materialise and Autodesk and other more diversified players like Protolabs have been less volatile. The two largest players, as measured by market capitalization, Stratasys and 3D Systems, each carry little to no debt and have enjoyed a five year trailing sales growth rate of more than 20%.²⁸ Coupled with these characteristics, they were the only two non-financial publicly traded stocks in the U.S. with market capitalizations over \$300 million trading below book value until very recently.²⁹

Why have 3D printing stock valuations collapsed? ARK believes a number of factors have conspired against them.

- | **Companies poured resources into a consumer 3D printing opportunity that was over-hyped and didn't materialize. Now they are writing down inventory and goodwill from those efforts.**
- | **Thanks to a sharp 25% appreciation of the dollar and China's industrial recession, U.S. manufacturing has been hit hard. On the heels of a huge investment cycle in 3D printing, manufacturers had purchased too many printers and have had plenty of room to increase capacity utilization.**
- | **Manufacturers still are facing a steep learning curve with 3D printing technology³⁰ and many have turned to service centers to test the technology before making investments in hardware themselves.**
- | **The threat of competition and new disruptive technologies has cast doubt on the long-term profitability, if not viability, of printer manufacturers.**

While those factors have been relevant short-term considerations, ARK believes they will prove to be transitory. As with many disruptive technologies, 3D printing stocks suffered because too much capital chased too few

FIGURE 4
Total 3D-Printing Index (3DPRNT)



Source: ARK Investment Management, LLC

Note: The data in the chart above represents the Total 3D-Printing Index, disseminated by Solactive AG. From initiation on October 17, 2014 leading up to, and including, October 1, 2015, the data represents historical back-testing. Following October 1, 2015, the data was live index published data, captured through Bloomberg L.P. (3DPRNT). Index Description: The Total 3D-Printing Index is composed of equity securities and depositary receipts of exchange listed companies from the U.S., non-U.S. developed markets and Taiwan that are engaged in 3D printing related businesses within the following business lines: (i) 3D printing hardware, (ii) computer aided design and 3D printing simulation software, (iii) 3D printing centers, (iv) scanning and measurement, and (v) 3D printing materials. You cannot invest directly in an index.

28,29 As of 3/10/16

30 According to a McKinsey survey, 40% of manufacturers are unfamiliar with 3D printing beyond press coverage.

Source: http://www.mckinsey.com/insights/manufacturing/are_you_ready_for_3-d_printing



additive manufacturing opportunities too soon. Yet, despite the price performance of many of the stocks, its long-term potential has not changed.

In fact, the dollar's sudden 25% appreciation could accelerate the shift to 3D printing now that manufacturers are trying to salvage profitability. The 3D printing industry is likely to see top-line growth exceeding 40% through 2020, and the depressed valuations of the 3D printer portion of the value chain could be a setup for substantial returns. Moreover, some of the core value propositions associated with additive manufacturing—higher productivity, lower costs, and more agility—should enhance the attractiveness of 3D printing during turbulent and uncertain times, as the shift toward disruptive innovation typically accelerates during these times.

ARK believes that continued innovations and improvements in material and printer capabilities will accelerate adoption and create new applications for additive manufacturing. ARK's research shows that given today's low penetration rates, the world has seen only a glimpse of the technology's ultimate potential. ARK sees a future of more adaptable, better designed-for-use products made possible only by 3D printing.

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