

3D Printing: Rewriting Global Manufacturing

Implications of New Disruptive Technology on Global Cap Goods

■ Industry Overview



- **What is new** – We believe 3D printing has the potential to rewrite the rules of global manufacturing, with an impact that could be as significant to the industrial sector as the now pervasive adoption of the principles of the Toyota Production Systems and Lean Manufacturing.
- **Insights from Citi's global industrials analysts** – In this collaborative report, Citi analysts across the global industrials sectors have identified the implications of this new disruptive technology, early adopters and the potential losers.
- **3D printing basics** – The term 3D printing is defined as the fabrication of a product (such as an intricate jet engine part) through the deposition of a material or binder using a print head, nozzle or other printer technology. We view 3D printing as one of several emerging additive manufacturing techniques—the terms 3D printing and additive manufacturing are essentially interchangeable. We believe the global market is approaching \$2bn, of which materials are nearly 30%. Wohlers Associates forecasts compound annual growth of over 20% while the Consumer Electronics Association (US) expects the industry to grow to \$5bn by 2017.
- **Who are the main players?** – The two largest listed names in the US are 3D Systems (DDD) and Stratasys (SSYS), and are averaging organic growth of 21% with an additional lift from acquisitions. ExOne completed its IPO on Feb 7. We also expect more consolidation in this sector, as evidenced by GE Aviation's acquisition of Morris Technologies and Rapid Quality Manufacturing in November 2012.
- **Potential winners in 3D** – In addition to early-movers like 3D Systems and Stratasys, suppliers of print material, services and CAD, software makers all benefit.
- **Who loses as 3D gains traction?** – Makers of metal dies, molds and machine-cutting tools could lose out as 3D printing advances in mass-volume manufacturing. This would include names like Mori Seiki and Okuma. Similarly, makers of plastic injection molding equipment, like Sumitomo Heavy, could be threatened if 3D printing becomes faster and cheaper, not just customized. In both cases though, this threat is likely to take several years to play out.
- **Long term investment strategy?** – A basket of long 3D companies, print suppliers and CAD firms could be paired against a basket of metal dies, molds, machine-cutting and plastic-injection molding companies.
- **What happens next?** – Proof of concept has already happened. It is now common for a business lunch 3D printing demonstration to include the while-you-watch fabrication of a customized trinket. Shares of 3D Systems are up 105% over the last year. There could be more IPOs in this space. There is also a 3D Printing Conference in New York City on April 22-23.

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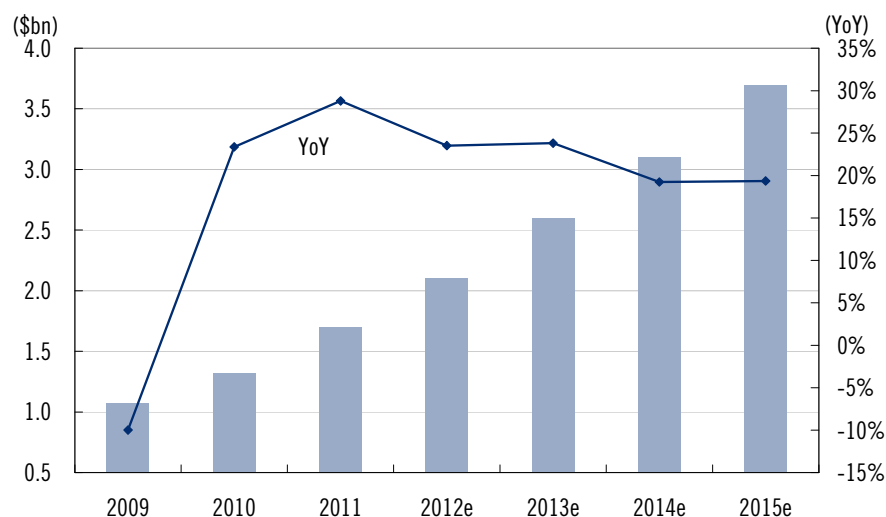
3D Printing as a Disruptive Technology

Projecting Market Size and Growth

3D printing – at least a \$1.7bn market in 2011

According to the consulting firm Wohlers Associates, the market for 3D systems was worth \$1.1bn in 2009 and by 2011 had grown to \$1.7bn. The original projection for 2012 was for 25% growth, to \$2.1bn, with the potential to expand to \$6.5bn by 2019. Reflecting the exciting growth opportunities, last October, US-based Consumer Electronics Association separately forecast the industry could grow to \$5bn by 2017. We believe these industry estimates understate the real size of the industry as they only include the primary market, that is, revenues from products, materials and services directly associated with 3D printing. Wohlers Associates estimates that in 2011 the value of the secondary market, including tooling, molded parts and castings was an additional \$1.1bn (+25% YoY).

Figure 1. 3D printing market



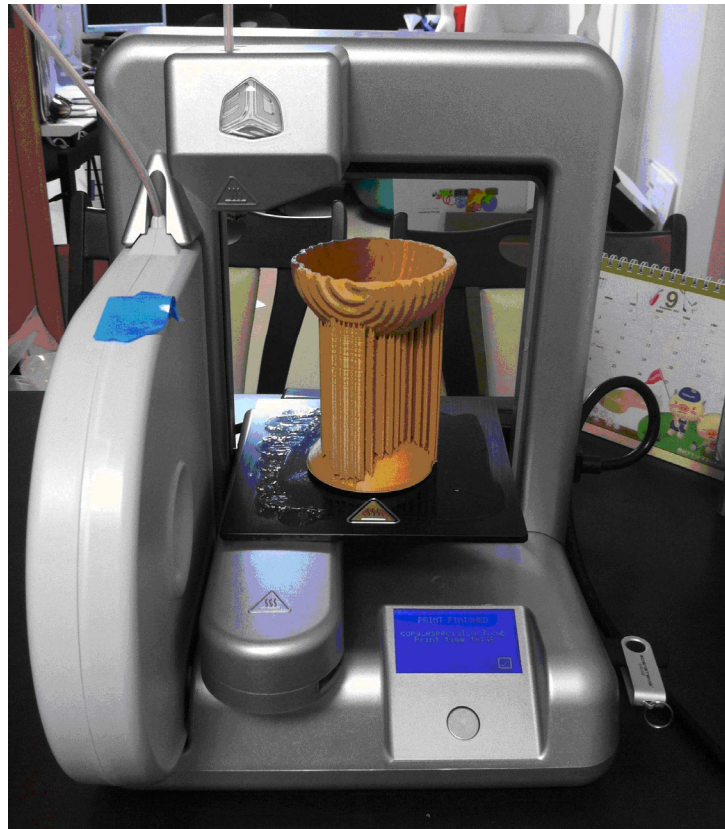
Source: Wohlers Associates, Citi Research

Figure 2. Cube 3D printer – unpacked and ready to go



Source: Citi Research

Figure 3. Cube 3D printer – wine “glass” printed using ABS resin



Source: Citi Research

Projecting the Winners

In addition to the printer makers, the service providers and material suppliers will be winners

The \$1.7bn estimate of the primary market for 3D printing in 2011 includes \$643mn from service providers (or service bureaus); \$502mn from systems (of which personal 3D printers accounted for only \$26mn); and \$327mn for materials. Service providers play an important role in providing finished parts, products and prototypes mainly to professional customers. Examples of these providers, often SMEs, include Harvest Technologies (Texas), which includes Boeing amongst its customers; Solid Concepts (California), a custom manufacturer supplying the aerospace and auto industries; Synergeering (Michigan) which produces engine components for the auto industry; and Materialise (Belgium) whose customers include Japanese auto parts makers.

Made in New Japan... not yet!

To show that the road is not paved with gold, we note that two of the most famous service providers in Japan have both had major financial problems. ARRK is still listed, but after a dramatic drop in the share price since 2006 the market cap now sits at around \$120mn. However, in mid-2011, the company received ¥9bn of new capital from the ETIC (Enterprise Turnaround Initiative Corporation of Japan) and a new management team was installed in August 2011, with the CEO a former director of Komatsu. Another popular company, at least within the media, was INCS, which filed for bankruptcy in 2009, and re-emerged as Solize as of 1 April 2013.

In true “razor and razor blade” form, 3D Systems print materials had a gross margin of 68% in CY12

The range of materials used in 3D printing is broad but the main types are photo polymers and laser-sintered polymers, and specific examples include ABS plastic, nickel based super alloys, titanium, ceramics and even chocolate. While there are a number of specialist suppliers of materials for the 3D printing industry, including DSM (Holland), Evonik Degussa (Germany) and JSR (Japan), we note that both 3D Systems and Stratasys also sell materials. In 2012, 3D Systems generated \$103mn (+46% YoY) from the sale of print materials, making up 29% of total revenues. With a gross margin of 68%, print materials accounted for 39% of total gross profits. As part of its commitment to R&D, Stratasys notes that just in Q4 2012 it launched a high performance thermoplastic, used in its FDM (fused deposition modeling) 3D printing process, a new rigid black Polyjet material and 16 new rigid/rubber-like composites. The fact that these makers have a captive audience is one of the strong points of their business model and helps to explain their high margins. Not surprisingly, this is an area that the printer makers are keen to protect, and we note the recent decision by the US District Court for the Northern District of Illinois which rejected claims by DSM Desotech that 3D Systems had engaged in anti-competitive conduct.

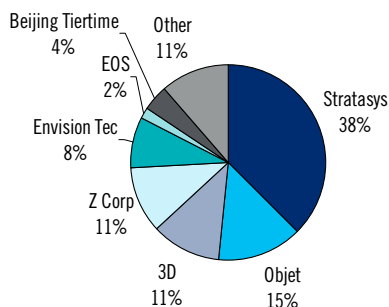
Don't forget the role of the CAD makers

As we noted in our July 30 report [Japanese machinery sector - Are there any 3D printing plays in Japan?](#), in very basic terms the first step in making an object with a 3D printer is to produce a digital model using a CAD (computer aided design) program. The main CAD suppliers are Autodesk, Dassault Systemes, PTC and Siemens PLM Software. Since then, we have also become aware of a relatively simple and fast 3D program called Sketch-Up Pro. This business was previously owned by Google but was sold to Trimble in April 2012. One downside of this program, according to one industry consultant, is that it does not create a solid, fully closed model such that applications are limited to individual-use rather than in industrial.

Main printer makers

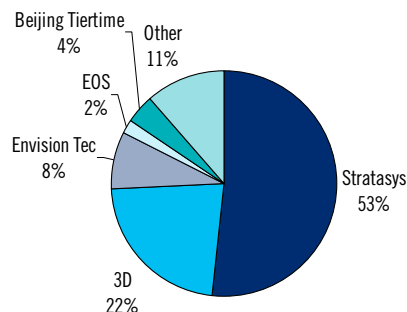
Once the product or prototype has been designed, using 3D printer software the model is divided (or sliced) into thousands of layers which are then sent to the printer. The main suppliers of these printers are 3D Systems (US), Stratasys (US), EOS (Germany) and those more focused on personal systems, including RepRap (US) and MakerBot (US).

Figure 4. Market share for 3D printers (CY11)



Source: Wohlers Associates, Citi Research

Figure 5. Market share for 3D printers (CY11) – after M&A



Source: Wohlers Associates, Citi Research

M&A is hot – and this will impact market share data but acquisitions are in hardware, software and materials

Over the past few years, there has been a wave of consolidation among makers, with 3D Systems leading the charge. Notable acquisitions for Stratasys in 2012 included Objet (Israel), while last year 3D Systems bought Z Corp, Bespoke Innovations (US), Tim The Innovative Modelmakers (Holland) and Rapidform (South Korea). In January, 3D Systems also announced the acquisition of Geomagic. The importance of M&A to this industry was underlined last November when GE Aviation announced the purchase of Morris Technologies and Rapid Quality Manufacturing. All this M&A activity will impact market share. In 2011, Wohlers Associates estimated that the top share in unit terms was held by Stratasys (see Figures 4 and 5), but if we include the share held by Objet, and add back the share held by Z Corp which was bought by 3D Systems, the dominance of these two names is clear.

Figure 6. Acquisitions by 3D Systems

Date	Acquired company	Acquisition Details
2009/8/31	Key Desktop Factory	a company engaged in the development of a sub-\$5,000 desktop printer.
2009/10/1	Acu-Cast Technologies	a leading provider of rapid prototyping and manufacturing services that offers precision parts made on a wide range of traditional and additive manufacturing systems and a variety of finishing, molding and casting capabilities
2009/11/24	AdvaTech Manufacturing	a leading provider of rapid prototyping and manufacturing services to the aerospace and defense industries.
2010/2/16	Moeller Design	a leading provider of premium precision investment casting services and prototyping for the most demanding aerospace, medical device and MCAD prototyping applications
2010/4/6	Design Prototyping Technologies Inc	a leading online provider of fast turnaround high quality functional parts and prototypes.
2010/7/7	CEP and PROTOMETAL	two leading French rapid prototyping and manufacturing service providers,
2010/9/16	Express Pattern	a leader in rapid prototyping, direct patterns for investment casting and manufacturing services
2010/10/5	Bits from Bytes	acquired UK Bits From Bytes Limited, a leading maker of affordable 3D printers and 3D printer kits that print real plastic parts from a variety of materials
2010/10/12	Provel, S.r.l	an Italian provider of rapid prototyping, tooling and manufacturing services
2011/1/5	National RP Support	a leading provider of customer support services and a factory-authorized source of parts, maintenance, and other services for 3D Systems' equipment.
2011/2/11	Quickparts	a leading custom parts services company based in Atlanta, GA with 2010 annual revenue of \$25 million.
2011/3/14	Accelerated Technologies	a Texas based provider of custom parts services, as part of the company's continued expansion of its 3Dproparts™ services.
2011/4/14	SYCODE™	a software development company based in Goa, India that specializes in providing plug-ins for all commercially available CAD packages.
2011/4/26	Print3D Corporation	a startup company that develops custom parts services for CAD users through advanced desktop tools that integrate directly into their design environment.
2011/5/9	The3dStudio.com	a leading provider of 3D and 2D digital media libraries, offering over 1.7 million resources and expert support
2011/5/12	Freedom Of Creation	a recognized leader for printable collections of innovative and practical 3D content.
2011/7/19	Alibre, Inc	a leading provider of affordable 3D design productivity solutions.
2011/9/20	Formero Pty, Ltd	a leading provider of on-demand custom parts services and 3D printing solutions headquartered in Melbourne, Australia.
2011/10/4	Kemo Modelmakerij B.V. (Kemo)	a leading provider of on-demand custom parts services headquartered in Budel, The Netherlands.
2011/11/1	Huntsman Corporation (NYSE: HUN)	Advanced Materials Division of Huntsman Corporation its RenShape® stereolithography print materials and Digitalis® rapid manufacturing 3D printer product line
2011/11/21	Contex Group (Z Corp and Vidar)	acquired Z Corporation ("Z Corp") and Vidar Systems ("Vidar") from Contex Group, a subsidiary of Ratos AB, a listed private equity company located in Stockholm, Sweden.
2012/4/10	My Robot Nation	a leading consumer technology platform that provides intuitive, game-like content creation for 3D printing.
2012/4/17	Paramount Industries	a leader in product development and manufacturing solutions for aerospace and medical devices
2012/5/7	FreshFiber BV	a leading 3D printed consumer goods brand, based in Amsterdam, The Netherlands.
2012/5/24	Bespoke Innovations	a startup based in San Francisco, California, that is bringing a more personal approach to the way a broad spectrum of medical devices are developed and used.
2012/7/23	Viztu Technologies	the developer of Hypr3D, an online platform that allows anyone to turn their pictures and videos into printable 3D creations.
2012/10/1	Tim The Innovative Modelmakers B.V. ("TIM")	a leading full service provider of on-demand custom parts services, located in Eindhoven, The Netherlands.
2012/10/9	Rapidform	a leading global provider of 3D scan-to-CAD and inspection software tools, located in Seoul, South Korea
2013/1/3	Geomagic, Inc	a leading global provider of 3D authoring solutions including design, sculpt and scan software tools
2013/1/10	COWEB	based in Paris, France, a start-up that creates consumer customized 3D printed products and collectibles

Source: Company data, Citi Research

Figure 7. Acquisitions by Stratasys

Date	Acquired company	Acquisition Details
2011/5/3	Solidscape	New Hampshire-based Solidscape is a manufacturer of 3D printers serving investment casting applications in the jewelry, medical, dental and industrial markets. The company's technology produces patterns that are used to cast highly precise metal parts.
2012/4/16	Objet	Merger completed 2012/12/3, former Stratasys stockholders hold approximately 55%, former Objet shareholders 45% of the combined company's common stock. Stratasys is maintaining dual headquarters in Eden Prairie, Minnesota and Rehovot, Israel, and is incorporated in Israel.

Source: Company data, Citi Research

Figure 8. Acquisitions by General Electric

Date	Acquired company	Acquisition Details
2012/11/20	Morris Technologies and Rapid Quality Manufacturing	In November 2012, GE Aviation acquired sister companies Morris Technologies and Rapid Quality Manufacturing, two privately-held precision manufacturing companies based in Ohio. With 130 employees, the companies specialize in additive manufacturing for building rapid prototypes and end-use production components for the aerospace, energy, oil & gas, and medical industries. They had been suppliers of parts to GE Aviation and GE Power Systems for several years prior to the acquisition.

Source: Company data, Citi Research

We note that according to 3D Systems, in 2012, organic growth was still an impressive +22% YoY compared to total revenue growth of 54%. The company also generated \$53mn of cash from operations. Stratasys posted 30% YoY growth in total revenues, with unit sales growth of 29%. According to Stratasys, these unit figures include the contribution of Solidscape and Objet.

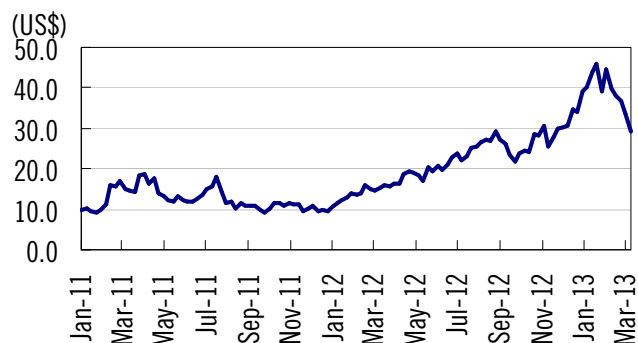
Initial sweet-spot for 3D printing

In 2011, 24% of the market was made up of parts for final products, and the aerospace industry is at the forefront of the drive to develop new parts using both plastics and metals. The technology is still nascent, but several aerospace companies commented on the ability of 3D printing to reduce cost and weight. Indicative of the potential for this technology in the aerospace industry, it has been said that, in the future, 50% of parts used in jet engines could be manufactured by 3D printers. Another important application is orthopedic implants such as hip cups. In general, this technology is more geared to high value, low volume parts which means that the take-up in the auto industry has been relatively slow.

3D Systems and Stratasys have early-mover advantage

With a combined market share of around 75%, the 3D printer market is dominated by the two major US companies: Stratasys (SSYS) and 3D Systems (DDD). Both companies have continued to deliver impressive organic growth with an additional lift from acquisitions. In spite of the relatively small size of this industry, M&A is a key feature. This was underlined last November when GE Aviation announced the purchase of Morris Technologies and Rapid Quality Manufacturing. Other listed 3D printer makers include The ExOne Company (XONE), which became publicly-traded on Feb-7.

Figure 9. 3D System share price



Source: Bloomberg, Citi Research

Figure 10. Stratasys share price



Source: Bloomberg, Citi Research

Who could lose out?

A disruptive technology

We fully embrace the concept that 3D printing represents a novel way of fabricating prototypes and on-demand parts, especially for high value added products in individual or small lots. 3D printing has been described as the next industrial revolution and it is a classic example of a disruptive innovation, that is, an innovation that helps create a new market and eventually goes on to disrupt an existing market, displacing an earlier technology. As Stratasys noted in their most recent Q4 release “our financial results reflect the strong demand for our products driven by the rapidly growing interest in additive manufacturing worldwide, as more companies recognize how our technology can reshape the way their products are designed and manufactured”.

Possible losers?

It seems that the winners of this technology are fairly obvious, including the listed manufacturers of 3D printers, materials and CAD software. But who are the possible losers? Although the time frame is possibly quite long, we would suggest that sectors that could lose out from the growth of 3D printing would include machine tools (used to manufacture dies and molds); plastic injection molding companies (both are examples of the more traditional form of subtractive manufacturing); suppliers of foundry equipment; and possibly also operators of industrial warehouses as there is less need to hold parts as inventory. We also note a comment by Chris Anderson in his 2012 book “Makers: the new industrial revolution” about the disruptive threat from 3D printing posed to makers of plastic toys.

Figure 11. Companies potentially threatened by the long-term growth of (industrial) 3D printing

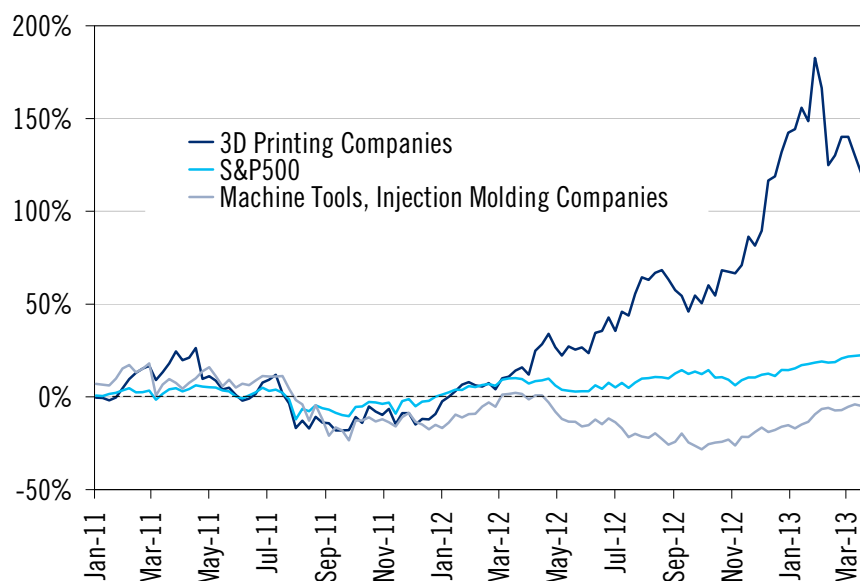
Company	Products	Key markets (% of sales)	Market cap (\$mn)
Mori Seiki	Machine tools	Japan (34%), Americas (33%)	1,360
Okuma	Machine tools	Japan (37%), Americas (27%)	1,300
Makino Milling	Machine tools	Americas (27%), Japan (23%)	770
Sumitomo Heavy	Injection molding	Japan (47%), Asia (25%)	2,480
Toshiba Machine	Injection molding, machine tools	N/A	795
Sintokogio	Foundry equipment	Japan (56%), China (13%)	505
Vesuvius	Foundry	N/A	1,620
Proto Labs	Low volume parts	US (80%)	1,140

Source: Company data, Citi Research

Performance of 3D printing stocks have greatly exceeded machine tool / injection molding companies

Though the industry remains small and pure-plays are scant, 3D printing has experienced considerable momentum and outperformance over the past year. The average stock price of additive manufacturing companies, including 3D Systems, Stratasys and CAD makers like Autodesk, is up 125% since Jan 2011. This is compared to an average decline of 10% for a basket of traditional manufacturing players in the machine tools and injection molding sectors. However, as shown in Figure 12, the two baskets traded relatively inline up until Jan 2012, when the stocks began to meaningfully diverge. Traditional manufacturing stocks continued to trade flat to down slightly, while 3D printing companies began to markedly accelerate in growth. We believe early 2012 was when the potential of 3D printing achieved mainstream appeal to investors, and the divergence in stock price growth rates has continued to roughly widen over time. Over the near term, 3D printing stocks should continue to show superior growth over traditional manufacturing competitors. That said, the industry is still in its high growth phase, but as new competitors enter the market, such as ExOne's recent IPO, we could see fiercer competition begin to dilute the margins and growth potential of existing players.

Figure 12. Avg Stock Price Growth of 3D Printing Companies vs Competitors Since Jan 2011



Note: 3D Printing companies basket includes DDD, SSYS, ADSK, DSY-FR, ARCM-SE, and XONE (post IPO)
Source: Bloomberg, Citi Research

Since Jan 2011, 3D printing stocks on average are up ~125%, while traditional manufacturing stocks have remained flat. The two baskets moved relatively inline until Jan 2012, when the long-term potential of additive manufacturing likely achieved mainstream appeal

The larger population of productive workers in the US manufacturing sector makes it ideal for high skill, low labor-content processes like additive manufacturing

Could 3D printing be more complementary to traditional manufacturing?

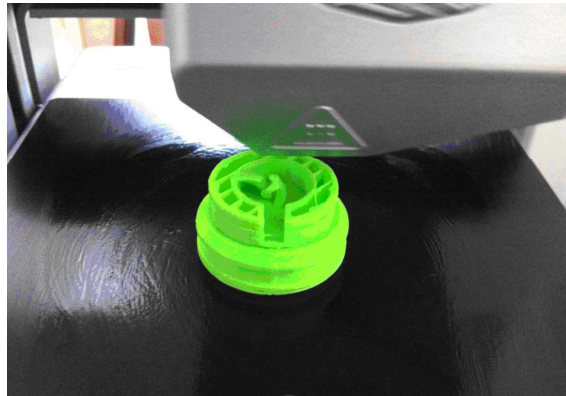
Having steadily weakened over the last several decades and during the 2008 recession, the US machine tool manufacturing sector has seen much of its global market share poached by lower-cost foreign competitors, such as the Chinese manufacturing sector as a result of its cheaper labor. We expect China to be at a greater long-term risk from the emergence of 3D-printing as an even lower-cost production methodology; the country currently ranks as the #1 producer of machine tools worldwide. Conversely, the US manufacturing sector as a whole could be a net beneficiary of 3D-printing, due to the country's relatively large population of more educated workers that are better suited for advanced manufacturing techniques. Further analysis on recent trends in the US manufacturing sector can be found in our 14 January report: [Is There a US Manufacturing Renaissance?](#)

Over the past 2-3 years we have seen the emergence of a new market especially for personal use, exemplified by the so-called "maker movement". As Wohlers Associates illustrates, with compound annual growth in excess of 20%, the growth of the 3D market has been impressive. But without wanting to get caught up in semantics, we wonder if it is accurate to describe additive manufacturing as new. Yes, it has helped create a new market, but through techniques such as rapid stereo-lithography and rapid prototyping, some additive manufacturing processes have been around for thirty years. With this in mind, we do not see 3D printing as undermining, yet alone replacing, key established manufacturing processes such as machine tooling or plastic injection molding any time soon, though there is undeniable potential to take away some business. Limitations on the growth of the 3D printing market at present include the relatively slow speed of printing (at least relative to injection molding), the physical size of the object that can be printed, low levels of throughput and productivity especially for large volume production runs and the high cost of printing each object, especially if the materials are captive to the maker of the 3D printer.

**Proto Labs – “Real Parts, Really Fast”
does not have 3D printers – at least for
now**

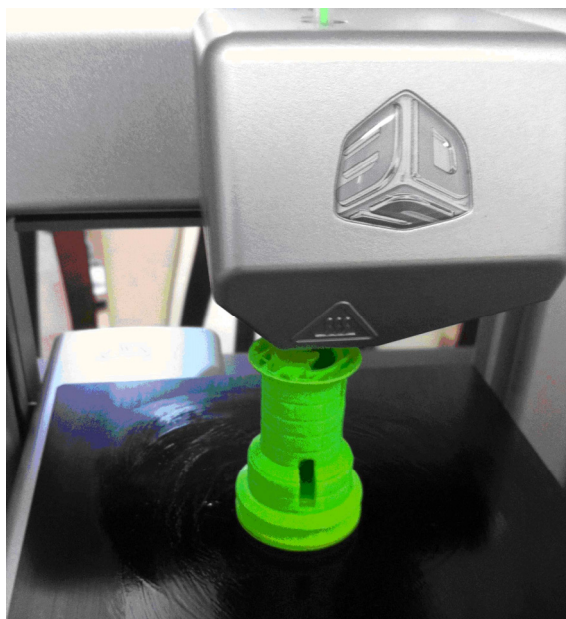
In a recent conversation with an overseas subsidiary of Proto Labs (“the world’s fastest source for custom CNC machined and injection molded parts”), we were told that they own a number of injection molding machines (including Sumitomo Heavy and Toshiba Machine) and CNC machining centers (Haas), but did not use 3D printers to produce custom parts for prototyping or short production runs due to the high cost and limited choice of materials. There is a clear preference at the company to use standard materials from established suppliers. They did not want to be tied into using captive materials. But having said that, a strong case can be made that the manufacturing processes of Proto Labs and the likes of 3D Systems and Stratasys are actually more complementary rather than competitive. Proto Labs also noted that there are also differences in the quality of the finished part and also the surface finish. Given the extent of innovation in this industry over the past few years, it would be wrong to believe that makers cannot address these issues while at the same time also continue to increase the range of materials for customers.

Figure 13. Printing a chess piece, stage 1 (using ABS resin)



Source: Citi Research

Figure 14. Printing a chess piece, stage 2



Source: Citi Research

Figure 15. A finished piece, part 3



Source: Citi Research

Citi 3D printing event – time constrained

As noted above, one issue for 3D printing is speed, a key concept for any manufacturer. A simple example shows this clearly. In January 2013, Citigroup Japan hosted a small event for investors on 3D printing. On the basis that “seeing is believing”, we set up a 3D printer (a Cube from 3D Systems) and tried to print out a ring from a CAD file (using SketchUP) that had already been set up. The printing process took just under twenty minutes and attendees were impressed by the quality of the end product. What was perhaps less impressive, however, was the actual time taken and also the surface finish. To us, it was a reminder that while the technology works and could have a place in some industries, the drawbacks of time and finish mean for now at least the chances that it will be fully adopted by the auto industry for mass-produced components and parts are misplaced. This is important as the auto industry is a key customer for both the machine tool and plastic injection molding industries, representing c30% of total Japanese machine tool orders and more than 20% of total demand for Japanese injection molding companies.

3D printing is still niche

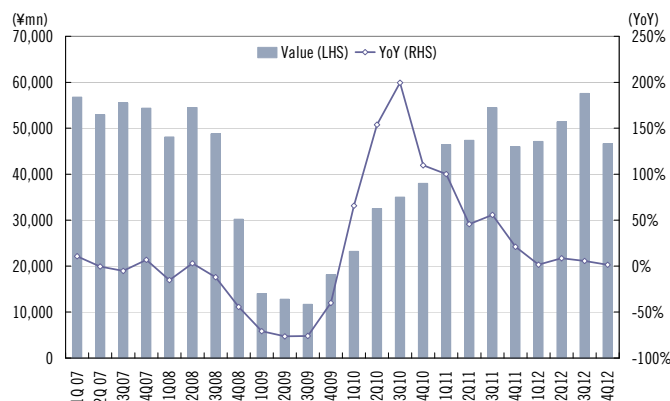
We think it is also necessary to bear in mind the size of the respective industries for two reasons: 1) to consider how small the 3D printing market is at present; and 2) to try to imagine what kind of total addressable market it is facing. According to Gardner Publications, in 2012 the total value of global machine tool production was \$93.2bn (-1% YoY), down from \$94.3bn (+35%) in 2011, with approximately 3/4 of total production from metal cutting tools and the remainder from presses and other forming equipment. In 2012, the largest country in terms of production was China (\$27.5bn), followed by Japan (\$18.3bn), Germany (\$13.6bn) and then South Korea (\$5.7bn). The US ranked #7 at \$4.9bn, equivalent to 5.3% of total production.

Different regional trends – only 5% of global machine tool production in the US but more than 1/2 of total 3D printing sales at 3D Systems and Stratasys

The relevance of regional production for machine tools is clear when we consider where the two largest makers of 3D printers generate the bulk of their sales: in 2012 Stratasys generated 51% of pro-forma sales in North America, 29% in EMEA and only 18% in APAC. At 3D Systems, the geographical split of its revenues was similar: North America (55%); Europe (29%); and Asia-Pacific (16%). If 3D printing

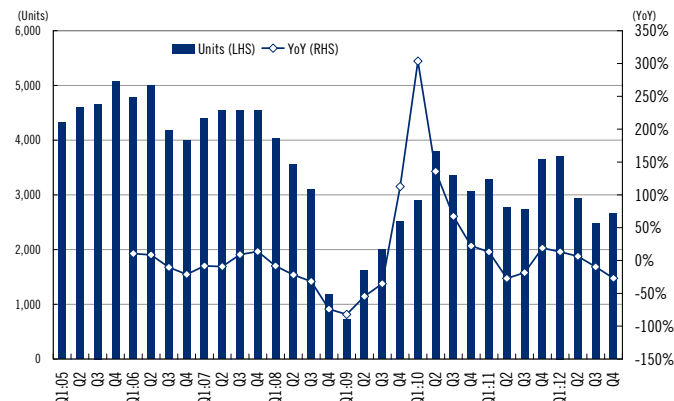
does represent a disruptive threat to the machine tool industry, then we should probably look first at the situation in North America. However, a chart of the recent trend of Japanese machine tool exports to North America highlights the strength of demand from US manufacturers in general, in spite of the strong yen, and it is not apparent over the last few years what disruptive impact 3D printing has actually had.

Figure 16. Japanese machine tool exports to North America



Source: JMTBA, Citi Research

Figure 17. Recent trend of Japanese injection molding orders (volume)



Source: Nikkan Kogyo Shimbun, Citi Research

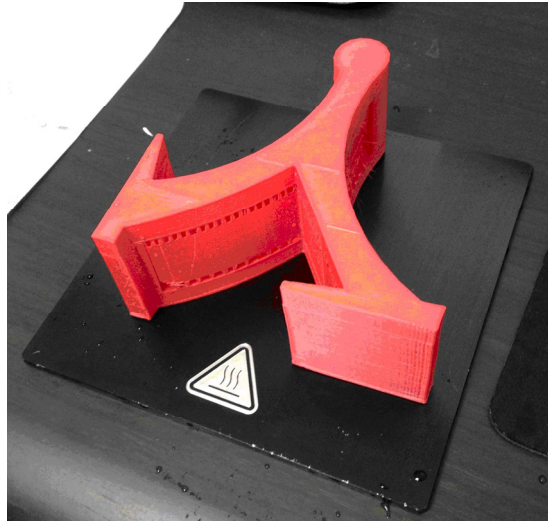
Injection molding companies also dismissive of threat from 3D printing – as they are more concerned with other competitive threats

From a different perspective, but with a similar conclusion, the Japanese makers of plastic injection molding equipment also dismiss the current threat posed to their business from makers of 3D printers. Unlike the machine tool industry, we do not have an accurate value of the global market, but estimate it to be around \$25bn. We do have better data on volumes, which helps us put the 3D printer market into perspective. According to Sumitomo Heavy Industries, volume demand for injection molding equipment (domestic and exports) peaked in 2010 at 13,100 units (+92% YoY) and slipped by 5% in both 2011 and 2012. Rather than any impact from the 3D printing industry, the decline has been a function of the slowing Chinese economy, the drag from the strong yen especially against the euro and the depressed level of demand from the electronics industry. In addition, we would also note the rise of the main Chinese maker of injection molding equipment Haitian International, which has a reported annual production capacity of more than 20,000 units. The emergence of this one company represents a bigger threat to the plethora of Japanese makers of injection molding equipment than 3D printing. For reference, according to Wohlers Associates, unit sales of professional-grade, industrial machines sold by Japanese 3D printer makers in 2011 only totaled 15 (from CMET, a subsidiary of Nabtesco, and Aspect Inc), out of total global sales of close to 6,500 units.

Is price no object? It is for some!

We note that in Japan the cost of buying a new cartridge for the 3D Systems Cube is approx \$45/kg. This compares with around \$5/kg for the price of injection-molding use ABS plastic used by manufacturers of mass-produced, plastic parts and components. With respect to price, we think it is also important to illustrate the difference in ASP between professional-use, industrial systems (+\$70,000) and the personal-use 3D printers (of less than \$1,500). The almost vertical growth in volume demand for low-cost, personal use 3D printers is impressive but it has limited relevance to makers of machine tools and injection molding equipment.

Figure 18. Printed iPhone stand



Source: Citi Research

Figure 19. Printed iPhone stand



Source: Citi Research

3D printing is “a revolutionary technology that has the power to give shape to our imaginations” but court battles loom

What could go wrong for 3D printing?

Reports in the media suggest that we are at the starting point of a new era of manufacturing, that 3D printing represents a new paradigm for mass-customization of products and that the only barrier to growth are an individual's own imagination. That may all be true but what is also clear is that market players and new entrants need to be careful around areas like infringement of copyrights and patents, with possible negative headline risk from court battles. As noted above, 3D Systems recently won its case in the US District Court for the Northern District of Illinois, which rejected claims by DSM Desotech that the former had engaged in anti-competitive conduct. We also note that in November 2012, 3D Systems announced it was bringing a suit against Formlabs (spun off from the MIT media lab) and Kickstarter. The former is seeking injunctive relief and damages for infringements for one of its patents relating to the stereo lithography process. Formlabs began marketing its low priced, individual-use Form 1 3D printer stating that certain patents had expired. However, 3D Systems argues that many of its patents are still active. From a different perspective, we note the comments from Wohlers Associates that the expiration of the original FDM patent (by Scott Crump, co-founder of Stratasys) allowed systems like RepRap to become commercially available, which was a key factor in the shipment of more than 23,000 personal-use 3D printers in 2011.

Risk free?

Separately, other potential liability issues have been raised in a situation where individuals using 3D scanners, such as Konica Minolta's Range7 or those produced by Artec (Germany), Microsoft's Kinect, or even apps on an iPhone can download and print out popular Disney characters for sale. Other risks to the industry could involve the headline risk of someone being shot by a 3D printed gun or someone being injured while living in a 3D printed house.

Is M&A risk free?

As noted above, the two main makers of 3D printers (Stratasys and 3D Systems) have actively used M&A as a tool to grow. This is not a bad thing, but there are risks involved with successful execution, integration, the evaluation of assets purchased and also possible financings.

Comments from Global Industrials Companies

As the advent of widespread 3D printing adoption approaches, we expect global industrials companies to accelerate investments into this sector to remain competitive in the long-run. Observations from our companies on the additive manufacturing thematic include:

North America

- **General Electric:** GE has made significant strides in bringing 3D-printed components into large-scale commercial production, and its CEO Jeff Immelt has been vocal about the sector's potential to revolutionize traditional manufacturing. By switching to additive manufacturing for components like fan blades, fuel injectors, and ceramics for gas turbines, GE saves an estimated \$25,000 in labor and material per jet engine. The company forecasts that by 2020, it will have applied over 100,000 3D-printed parts into GE and CFM aircraft engines. So far, its investments in 3D-printing have been mostly centered on its Aviation platform, including the Nov-2012 vertical acquisitions of Morris Technologies and Rapid Quality Manufacturing, which supplied parts to GE Aviation and Power Systems.
- **Boeing:** 3D printing is still used in largely a "one-off manner" as opposed to being a methodological approach to substituting current production methods. The

technology is used more on the defense vs. the commercial side, especially for advanced UAV prototyping in its Phantom Works business and some Chinook helicopter applications. Boeing Commercial also uses 3D systems to produce some interiors including on the 787.

- **Precision Castparts:** PCP manufactures complex high-performance structural parts for aerospace and energy applications. The company is closely watching the technology for opportunities to take out cost using 3D printing and we would expect it to acquire capabilities as appropriate. However, PCP has already been using stereolithography for almost 20 years to make models for castings.

Europe

- **EADS:** EADS opened its Centre for Additive Layer Manufacturing (ALM) in 2011 in conjunction with Exeter University and has been showcasing its 3D printing technologies at various industry and investor events for some time, including the “Airbike” (a nylon bicycle built using ALM) and an Unmanned Aerial Vehicle (UAV) at last year’s Farnborough Air Show. This technology is currently at a prototype stage but is one that Andy Hawkins, lead engineer for ALM at EADS, describes as a potential “game change” for manufacturing. At the moment, Airbus has the ability to print relatively small parts (up to 60cm³) and this is a slow process. This makes 3D printing a process suited to the production of low volume, high value aerospace components. However, at Farnborough Air Show last year, EADS showcased a concept aircraft for release by 2050 built entirely using 3D printing. EADS cites a number of advantages to ALM, including reduced wastage (particularly for titanium parts), up to 65% weight savings and that manufacturing a component with a complex design costs no more than a simple one.
- **BAE Systems:** BAE Systems uses 3D printers to produce working models, prototypes and components.
- **Rolls Royce:** Rolls Royce is leading a project to print an aircraft engine using 3D printers.

Appendix A-1

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