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STIFEL | Global Technology Group

DIGITAL MANUFACTURING MARKET MONITOR

March 2020

Opening Remarks from Stifel

Dear Friends,

As I write this, like many of you, I am hunkered down at home trying to juggle my professional responsibilities as an investment banker and personal life of being a Dad to three young kids and an extremely patient wife. While this pandemic is full of so many negative consequences, as an eternal optimist, I am trying to focus on the positive. While my clients are keeping me plenty busy I was afforded the time to FINALLY complete this digital manufacturing market monitor. I have been an investment banker for 16+ years and covering this sector for 7+ years and many of you have seen my previous digital manufacturing and 3D printing monitors. I get a weekly email from someone asking if I have the latest and greatest. Since the inaugural market monitor, the sector has evolved and so has our materials to the point where a complete restart was needed. Well, I'd thank everyone for their continued interest and patience because here it is!

On the digital manufacturing front, there have been some ebbs and flows in terms of M&A and capital raising activity over the past five years culminating in a record level in 2019. This has been driven by a variety of factors, including continuing maturity in the sector, advent of new technologies, robust economic environment and increasing sophistication and appetite from the strategic and financial community.

Historically, M&A activity in the space has been spread across the value chain from materials, machines and digital manufacturers while investment activity was primarily in machine companies where all of the "unicorns" live (Carbon, Desktop Metal and Formlabs).

In 2019, there was a robust venture capital market for digital manufacturers raising nearly $150M across four companies (3DHubs, Fast Radius, Fictiv and Xometry), by far the most venture interest in this business model. That said, machine companies continue to dominate the venture capital inflow. M&A activity in 2019 remained strong across the board with digital manufacturers leading the charge. At Stifel we were sole advisor on three of these deals (FATHOM, FORECAST 3D and ICOMold) as private equity (Riverside, CORE) continues to show interest in the business models and EBITDA profiles along with a push from "out-of-segment" strategic companies buying into the sector (Proto Labs, GKN).

Before the COVID-19 pandemic, we continued to experience strong momentum in the sector to begin 2020 but we expect to see a pause for a few quarters as the market evaluates the impact. We expect this to hit machine companies hardest as voluntary capex is effectively put on hold. That said, some sector deals will get done opportunistically where supply chain disruption in Asia shifts more business to domestic manufacturers.

Hope you enjoy our monitor, and it provides a nice escape from your bunker.

Sincerely,

Bryan Dow
Managing Director, Investment Banking
bdow@stifel.com

#1 Firm in Technology Mid-Market Investment Banking

One of the most active technology-focused advisory groups in the world – differentiated by deep sector knowledge, global footprint and a collaborative business model

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#1 in M&A(1) Mid-Market (<$1.0B) Technology Advisory	**Full Service Offering** M&A | Public and Private Equity Capital Markets | SPAC Leveraged Finance | Restructuring | Fund Advisory	**#1 in Equity**(2) Mid-Market (<$1.0B) Technology Advisory
Team of 100+ 15+ Nationalities 10+ Languages Spoken	**Four Industry Practice Groups** Electronics & Industrial Technology I Software I Tech Enabled Services I Internet & Digital Media	**Unrivaled** Experience from 2,000+ Deals Closed in Combined Careers
44 Senior Bankers Operating from the US and Europe	**Global Reach** Serving North American, European and Asian markets from offices across the US and Europe	**Collaborative** One Integrated Group, One Global P&L

(1) <$1B deal values from 2010 – 2019 1H - Source: 451
(2) All Managed Equity ($1B market cap from 2010 – Feb 2020 - Source: Dealogic

#1 Firm in Advanced Manufacturing

Digital Mnfg
FORECAST 3D
Has Been Acquired by
GKN POWDER METALLURGY
Advisor to Seller
January 2020

Digital Mnfg
ICOMold
CUSTOM DIGITAL MANUFACTURING
Has Been Acquired by
MCT
a portfolio company of
CORE INDUSTRIAL
Advisor to Seller
December 2019

3DP
FISHERUNITECH
a portfolio company of
Riverside
Has Been Acquired by
COMPUTER AIDED TECHNOLOGY
a portfolio company of
GTCVC
Advisor to Seller
October 2019

Digital Mnfg
FATHOM
Has Been Acquired by
MCT
a portfolio company of
CORE INDUSTRIAL
Advisor to Seller
September 2019

Automation
OPTIWARE
a portfolio company of
Capidea
Has Been Acquired by
aptean
a portfolio company of
TA ASSOCIATES VISTA
Advisor to Seller
April 2019

3DP
FATHOM
3D Printer VAR Business
Has Been Acquired by
GoEngineer
Advisor to Seller
August 2018

Robotics
TERADYNE
Has Acquired
MiR
MOBILE INDUSTRIAL ROBOTS
Advisor to Buyer
April 2018

Automation
$402,600,812
Exa CORPORATION
Has Been Acquired by
DASSAULT SYSTEMES
Advisor to Seller
November 2017

Digital Mnfg
XCENTRIC MOLD & ENGINEERING
Has Received an Investment from
Riverside
Advisor to Xcentric
January 2017

Robotics
CMR SURGICAL
Has Secured Series A Financing from
LGT ABB Cambridge Innovation Capital
Advisor to CMR
July 2016

Automation
iTAC SOFTWARE
Has Been Acquired by
DÜRR
Advisor to Seller
December 2015

Robotics
adept
Has Been Acquired by
OMRON
Advisor to Seller
October 2015

Robotics
UNIVERSAL ROBOTS
Has Been Acquired by
TERADYNE
Advisor to Seller
June 2015

Digital Print
£1,030,000,000
DOMINO
Has Acquired
brother
Advisor to Buyer
*March 2015**

Automation
CONFIDEX
Has Been Acquired by
WIOT Technologies Oy
a holding company backed by a group of international Investors
Advisor to Seller
February 2015

3DP
FSL3D
Has Secured Growth Equity Investment from
SUMMER STREET CAPITAL PARTNERS
Advisor to FSL3D
November 2014

3DP
Simbionix
Has Been Acquired by
3D SYSTEMS
Advisor to Seller
*July 2014**

Automation
Despatch INDUSTRIES
Has Been Acquired by
ITW
Advisor to Seller
*July 2014**

Automation
LOREX
Has Been Acquired by
Veeco
Advisor to Seller
July 2014

Automation
mixed signals
Has Been Acquired by
Tektronix
a subsidiary of
DANAHER
Advisor to Seller
April 2014

Digital Mnfg
FINELINE PROTOTYPING
Has Been Acquired by
proto labs
Advisor to Seller
April 2014

Automation
spire
Semiconductor Business
Has Been Acquired by
MASIMO
Advisor to Seller
*April 2014**

Automation
oerlikon
Etch business
Has Been Acquired by
Plasma-Therm
A LEADING SUPPLIER OF PLASMA PROCESS EQUIPMENT
Advisor to Seller
April 2014

Automation
EPCOS
Has Been Acquired by
TDK
Advisor to Seller
April 2014

3DP
Delcam
Has Acquired
AUTODESK
Advisor to Buyer
*November 2013**

Automation
w2bi
Has Been Acquired by
ADVANTEST
Advisor to Seller
June 2013

Automation
GSI Group
Has Divested its Semiconductor Systems Business to
esi
Advisor to Seller
May 2013

Automation
DDi
Has Been Acquired by
VIASYSTEMS
Advisor to Seller
May 2012

Automation
MKS
Has Been Acquired by
PTC
Advisor to Seller
May 2011

Robotics
adept
Has Acquired
MOBILE ROBOTS
Advisor to Buyer
January 2011

Automation
DDi
Has Acquired
CORETEC
Advisor to Buyer
January 2011

Robotics
adept
Has Acquired
InMoTx
Advisor to Buyer
January 2011

**Worked on transaction while at a previous, unaffiliated firm.*

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#1 Firm in Digital Manufacturing

FORECAST 3D	ICOMold®	FATHOM	XCENTRIC	FINELINE
Has Been Acquired by GKN POWDER METALLURGY Advisor to Seller *January 2020*	Has Been Acquired by MCT / CORE INDUSTRIAL Advisor to Seller *December 2019*	Has Been Acquired by MCT / CORE INDUSTRIAL Advisor to Seller *September 2019*	Has Received an Investment from Riverside Advisor to Xcentric *January 2017*	Has Been Acquired by proto labs Advisor to Seller *April 2014*
3D Printing, CNC, Casting	**Injection Molding**	**3D Printing, CNC, Injection Molding, Casting**	**Injection Molding**	**3D Printing, CNC**
▪ Provider of 3D printing services and short-run manufacturing across a variety of industries ▪ Largest capacity of HP MJF technology ▪ Proprietary software ▪ Acquired by leading advanced materials, metallurgy and parts manufacturer	▪ Provider of innovative plastic injection molding ▪ Proprietary software for automated front-end quoting and project management ▪ Acquired by leading digital manufacturing platform company owned by a key financing sponsor in the sector	▪ Manufacturer of advanced technology-driven prototypes and production parts ▪ Proprietary software for automated front-end quoting ▪ Acquired by leading digital manufacturing platform company owned by a key financing sponsor in the sector	▪ Provider of quick-turn, digital manufacturing ▪ Proprietary software to automate short-run production injection molded parts ▪ Acquired by leading financial sponsor creating a strong platform in the sector	▪ Provider of high-quality 3D printing services to corporate customers in a variety of industries ▪ Proprietary quotation software ▪ First acquisition for the leading public company in digital manufacturing to enter 3D printing market

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Digital Manufacturing –
Digital Disruption in Manufacturing

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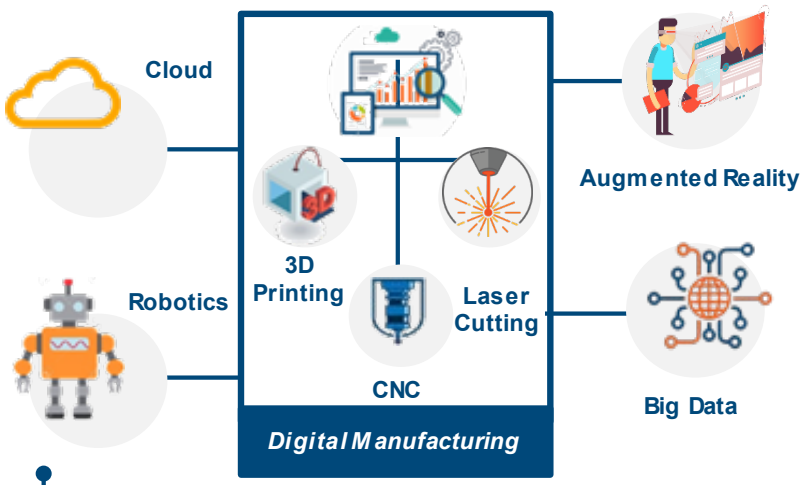
Digital Disruption in Manufacturing

Digital manufacturing helps increase productivity and process intelligence faster

Digitization in Manufacturing

The Ecosystem of fourth Revolution



Digital manufacturing belongs to a much larger trend known as the Industrial Revolution 4.0, which combines CAD[1], robotics, sensors, and data & analytics to redefine industrial production

- This digitalization of manufacturing is changing how products are designed, fabricated, operated, and serviced, just as it's transforming the operations, processes, and energy footprint of factories, as well as the management of manufacturing supply chains
- The amalgamation of production techniques with the latest technological developments is making manufacturing autonomous, cheaper, and more efficient
- Technological advancements in industrial robotics, IoT, cloud computing, machine learning, and data analytics are greatly assisting operators to heighten consistency and streamline operations
- Overall, this digital environment has led operators in the manufacturing sector to rely less on human input at each stage of production and more on advanced digital tools & processes

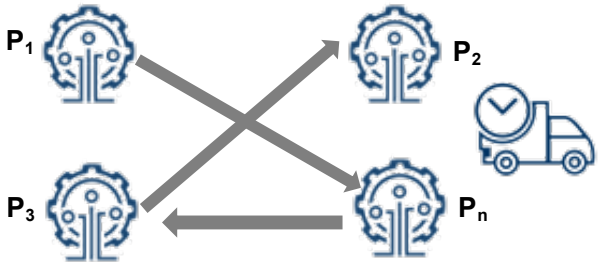
Conventional Manufacturing

- Mass production
- Large quantities
- Small margins
- Sequential value chain
- Long turnaround time
- Low flexibility

P_1, P_2, P_n indicate different processes

Digital Manufacturing

- Custom production
- Small quantities, short run
- High margins
- Changing collaborative partnerships
- Short turnaround time
- Highly flexible and adaptive



Source: Hexaware, Industry Reports, GPS Consulting, and Press Articles; 1) Computer Aided Design

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Digital Disruption in Manufacturing – Evolution

Digital manufacturing is revolutionizing with advancements in areas such as AI

Evolution of Digital Manufacturing Business

Increased digitalization of information over the past decades has allowed more departments across the extended enterprise to access and utilize information

Firms are likely to see significant improvements in operational efficiencies as intelligent devices connect machines on many different factory floors across the supply chain. For instance, BMW has set a goal of knowing the real-time status of all major production equipment at each of its companies that produce key components for its vehicles.

Source: OpenText and Hexaware Report

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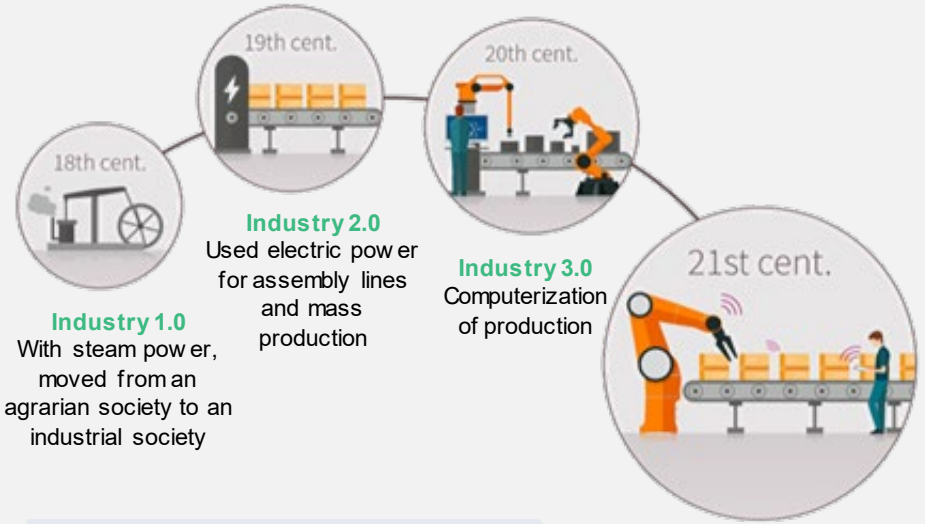
Smart Manufacturing – The Industry 4.0 Revolution

Smart and connected systems are changing the way production works

Road to the Connected Intelligent Value Creation Chain



Industry 1.0
With steam power, moved from an agrarian society to an industrial society

Industry 2.0
Used electric power for assembly lines and mass production

Industry 3.0
Computerization of production

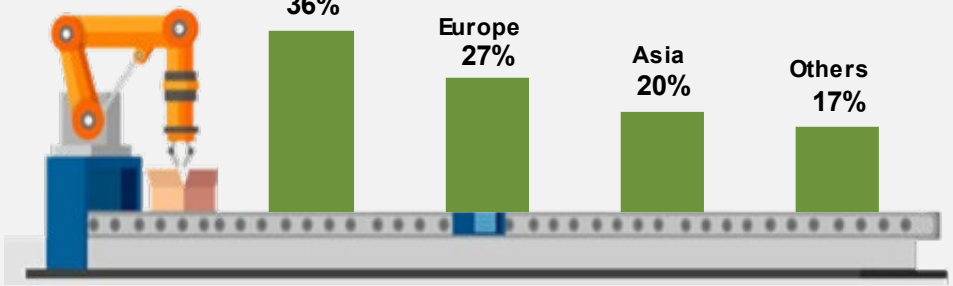
Industry 4.0
Intelligent networking of humans, machines, and products

This fourth industrial revolution is moving manufacturers from mass production to customized production through a digital supply network

Examples:

Automotive Sector	Daimler evaluates machine data to improve the quality of cylinder head production
Logistics Sector	In logistics, Industry 4.0 technologies help optimize transport routes, utilize storage capacities perfectly, and plan ahead

The US is the major contributor to the industry 4.0 market in North America as it offers a large industrial base and high production capacity among companies, thereby attracting a large amount of investments



An estimated **70%** new value created in the economy globally over the next decade will be based on digitally enabled platforms

As per a 2019 BCG survey, over **80%** of the manufacturing companies that are investing in digital operations witnessed **10–20%** reduction in supply chain cost and a **6%** uptick in incremental revenue

By **2023**, digital transformation spending will grow to **more than 50%** of all ICT investments from **36%** in 2019 – the highest growth in data intelligence and analytics

Source: World Economic Forum, IDC Report, BCG Report, Cision PRNewswire, and Press Articles

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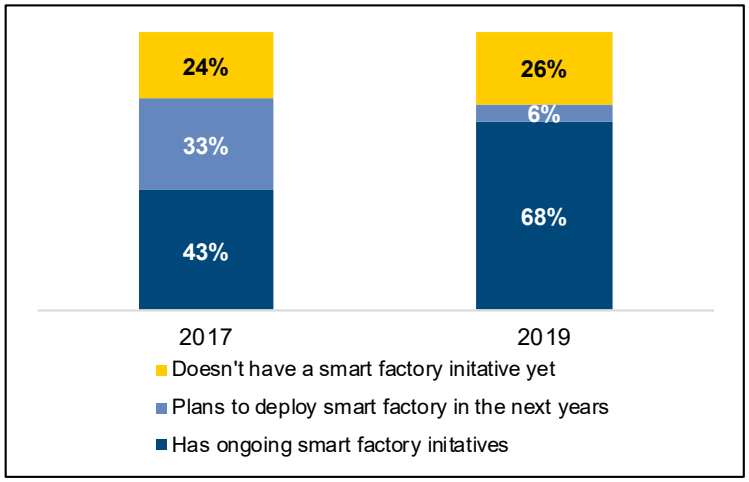
Smart Factories – Digital Industrial Revolution

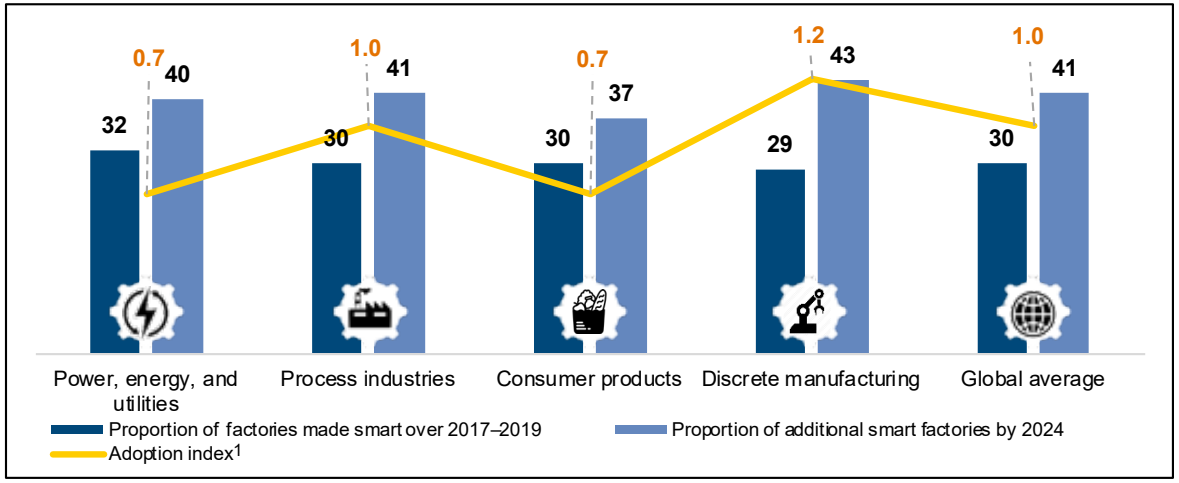
On average, 30% organizations across major countries are now smart

Percentage Share of Smart Factories Across Various Sectors and Countries

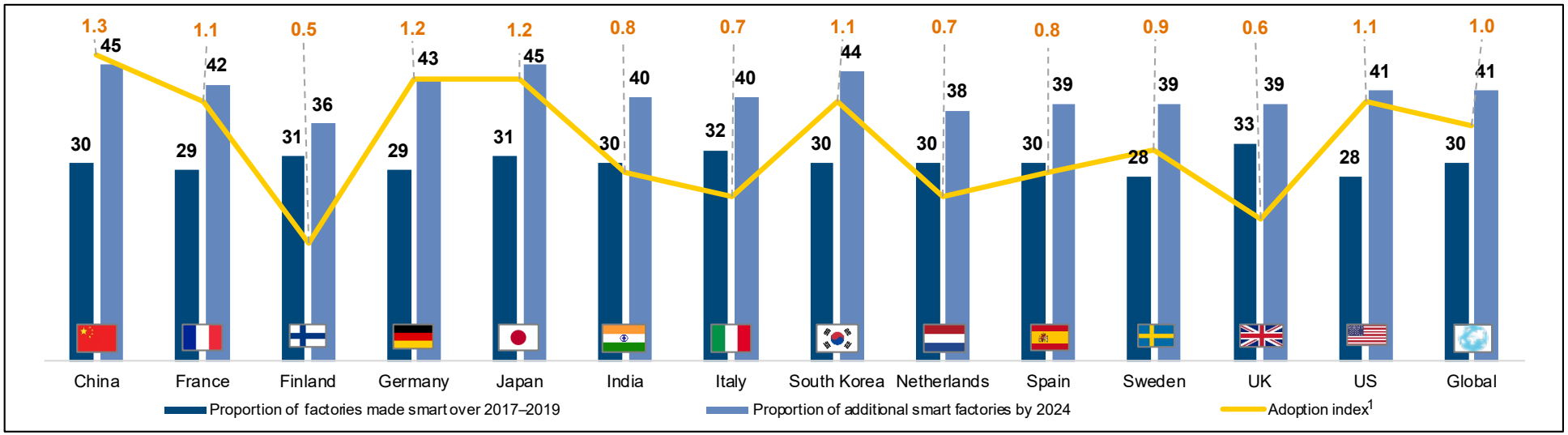
Smart Factory Adoption Comparison (2017 vs. 2019)



Percentage of Smart Factory Operations in the Last Two Years and Future Expansion Plans – By Sector



Percentage of Smart Factory Operations in the Last Two Years and Future Expansion Plans – By Country



Source: Capgemini Report 2019; 1) Shows the future expansion plans – An index greater than one means that the country has a more aggressive expansion plan than the average

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Smart Factories – Massive Market Opportunity

By 2023, smart factories will have the potential to add $1.5–2.2tn annually

Percentage Share of Smart Factories Across Geography and Various Industries

	Conservative Scenario	Average Scenario	Aggressive Scenario
A. Share of factories that became smart over 2017–2018	**29.6%**	**29.8%**	**31.6%**
B. Expected increase in productivity gains by 2023, as compared with productivity gains achieved	**15.9%**	**20.0%**	**21.7%**
C. Share of additional smart factories by 2023	**37.3%**	**41.2%**	**42.7%**
D. Productivity gain target by 2023 at the factory level due to smart factory initiatives	**27.8%**	**33.7%**	**36.5%**
E. Overall productivity gain due to smart factory initiatives by 2023 **(A*B) + (C*D)**	**15.0%**	**19.8%**	**22.5%**
F. Average annual productivity gain due to smart factory initiatives until 2023 **(CAGR computation from E)**	**2.8%**	**3.7%**	**4.1%**
G. Approx. manufacturing industry value added in the surveyed geographies in 2019	**$9.8tn**		
H. Expected additional value added by the manufacturing industry due to productivity gain in smart factories by 2023 **(G*E)**	**Total Value Added: $1.5tn**	**Total Value Added: $1.9tn**	**Total Value Added: $2.2tn**

Source: Capgemini Report 2019

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Market Dynamics – Digital Manufacturing Driving Efficiency

Technological advancements in manufacturing are making workers more efficient

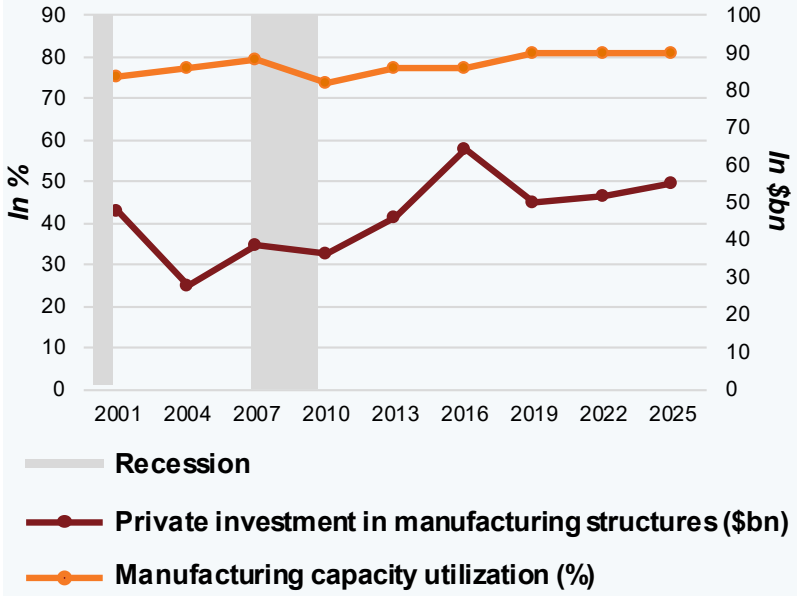
Drivers

Smart factories and automated production

With an increase in the adoption of Internet of Things (IoT), manufacturers can seamlessly integrate previously discrete segments of production, leading to the proliferation of smart factories, in which interconnected automated production processes enable unprecedented levels of optimization and efficiency

- By incorporating network connectivity to gather data from their environment, smart factories can generate context that ultimately produces a more autonomous, adaptive, and flexible response to any changes that occur

Manufacturing Indicators[1]

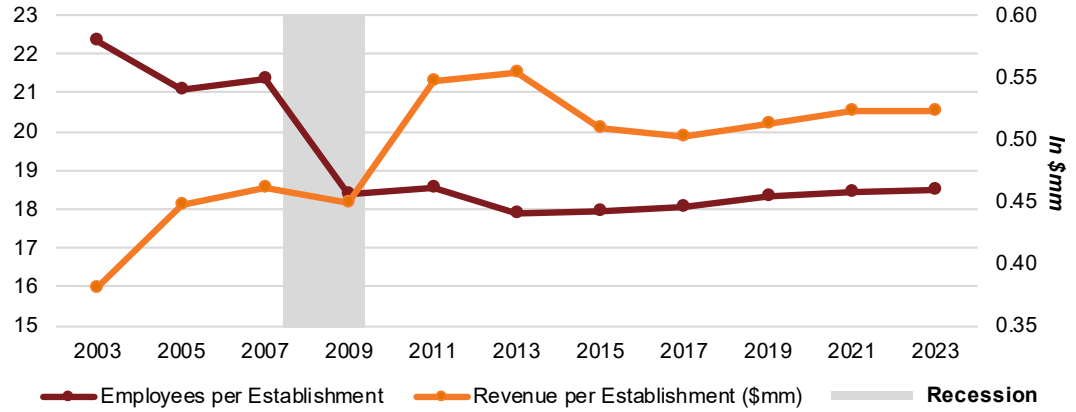


Increased demand for high productivity

The simultaneous increase in manufacturing output and decline in manufacturing jobs over long term show that American manufacturers have become far more productive than they were two decades ago

Manufacturers are now able to produce more goods or higher-value goods, with less labor, represented by a long-term uptick in revenue per employee, which has been accomplished through focused investment in R&D, supporting both product and process innovation

More Production from Fewer Employees[1]



Computer-aided design and computer-aided manufacturing

Manufacturers are increasingly implementing computer-aided design (CAD) and computer-aided manufacturing (CAM) software to assist with the design and manufacture of prototypes and finished products

- The conceptual overlap between design and production enables manufacturers to use CAD/CAM systems in tandem, enabling operators to develop an initial concept in days rather than months and drastically reduce the manufacturing life cycle
- By integrating technical drawings with 3D visuals, CAD/CAM interfaces have provided manufacturers with powerful tools for product design and delivery

Source: Press Articles; 1) The graph has been scaled to approximations

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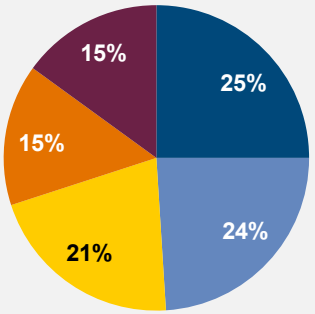
Market Dynamics – Benefits of Digital Manufacturing

Technology is helping broaden manufacturers' horizons by capturing more value

Benefits of Digital Manufacturing

Manufacturing is undergoing a revolution as advanced connectivity and big data unleash a new wave of innovation. The upheaval is not confined to the factory floor; business models are also in flux as manufacturers get new insights into how their products are used and can then repackage products into services

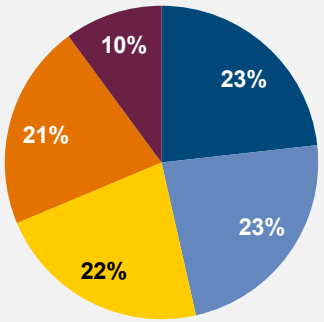
Opportunity for Value Creation



- Traditionally, manufacturers were exclusively operating in the product business, focused on growing their customer bases and enhancing customer service, while keeping production costs low
- However, as they look to the future digital economy, they see more value creation potential in service innovation and new payment models than in improving their products and customer services

Cost Savings Through New Efficiences
Service Innovation
New Payment Models
Product Innovation
Customer Experience

Target for Supply Chain Improvement

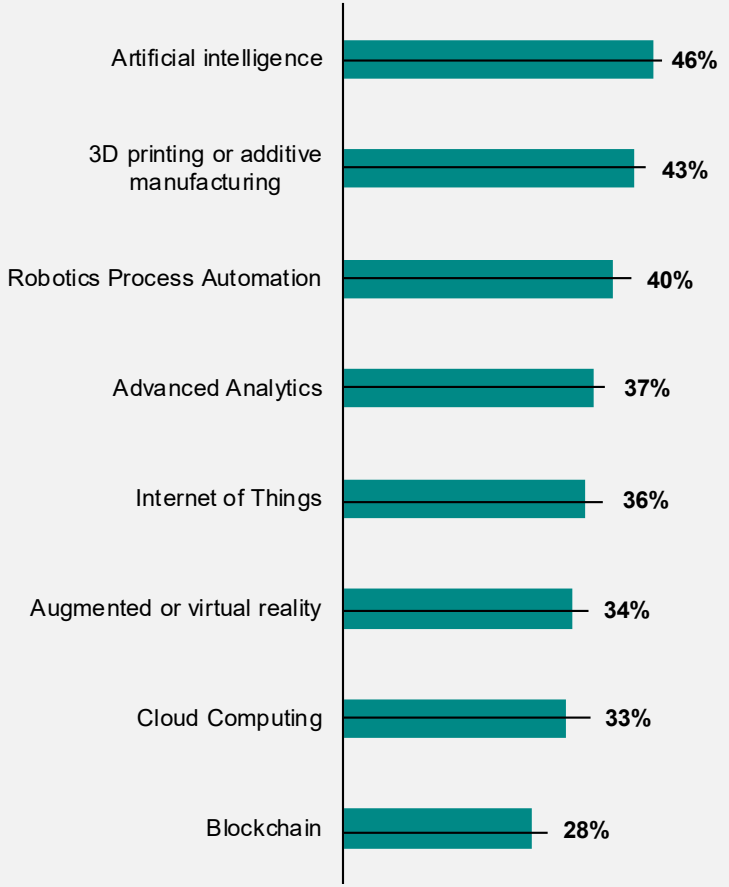


- When considering supply chains, manufacturers are divided in the metrics identified for improvement
- Upper-middle-market organizations (revenue: $1–3bn) are aiming to speed up customer order cycle times and are less focused on getting their total delivered costs down
- On the other hand, lower-middle-market manufacturers (revenue: $200–500mm) prefer reducing inventory turnover, which is their biggest priority

Overall, strengthening customer service increases in importance with the size of an organization

Total delivered Cost
Customer Order Cycle Time
Performance to Plan
Inventory Turnover
Customer service

Advanced Technologies that Manufacturers Plan to use



Source: BDO Report 2019

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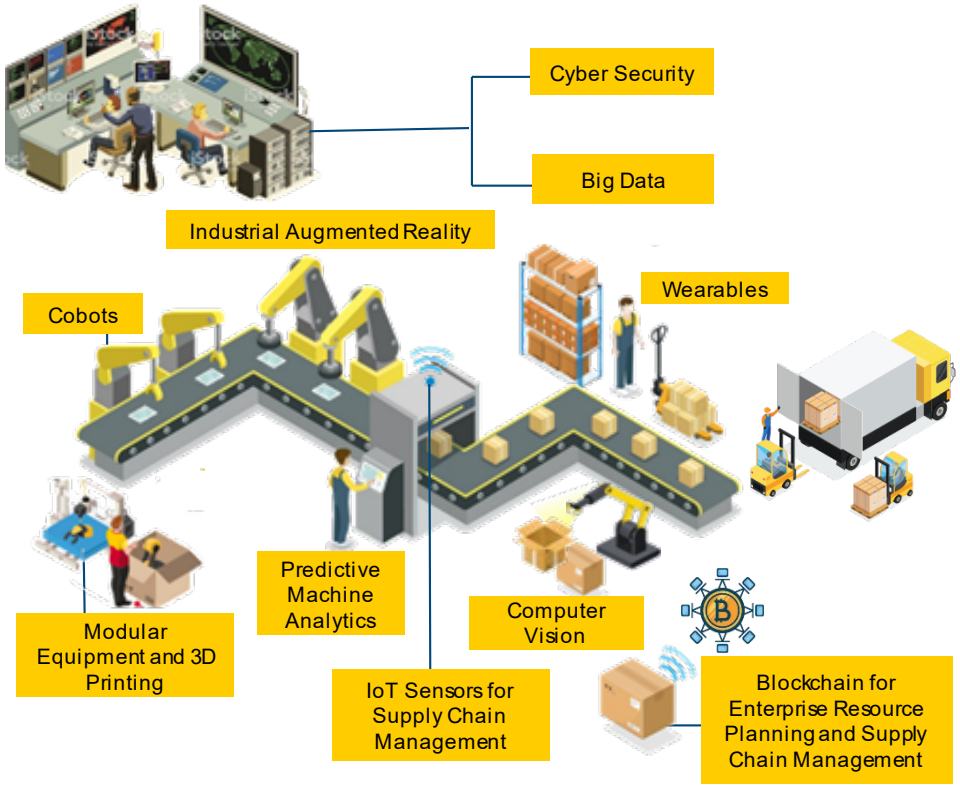
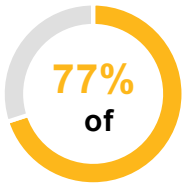
Digital Disruption – Future of Manufacturing

Technology is making an impact on every step of the manufacturing process

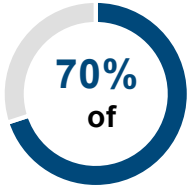
The Future of Manufacturing



Major Contributions



Global R&D



Global Trade

Global GDP

Source: Hexaware Report and CB Insights

Different steps of the manufacturing process: How these steps are changing

- **Product R&D:** This helps the product development team to enable sensors, actuators, and digital identification tags within production lines, and communicate in real-time with on-floor employees to achieve a high level of quality control
- **Resource Planning & Sourcing:** On-demand decentralized manufacturing and blockchain projects are working on the complexities of integrating suppliers
- **Operations Technology Monitoring & Machine Data:** Operations teams can access real-time information on the process, inventory, and order status by automating and integrating business processes
- **Labor Augmentation & Management:** AR and wearables are augmenting human capabilities on the factory floor
- **Machining Production &Assembly:** Modular equipment and custom machines, such as 3D printers, are enabling manufacturers to handle greater demand for variety
- **Quality Assurance (QA):** Gives a brief about how computer vision will find imperfections, and how software and blockchain tech will more quickly be able to identify problems
- **Warehousing:** With the help of robotics and vision tracking, new warehouse demand could bring "lights-out" warehouses even faster than an unmanned factory
- **Transport & Supply Chain Management:** Telematics, IoT, and autonomous vehicles will bring greater efficiency and granularity for manufacturers delivering their products

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Digital Disruption – Adoption of Connectivity Technologies

Use of connectivity technologies and data analytics is set to significantly increase

Manufacturer's adoption of connectivity technologies and analytics

Technology/Analytics	As of 2017	Change over the next five years	By 2022
Predictive maintenance	28%	+38%	66%
Big data-driven process and quality optimization	30%	+35%	65%
Process visualization/ automation	28%	+34%	62%
Connected factory	29%	+31%	60%
Integrated planning	32%	+29%	61%
Data-enabled resource optimization	52%	+25%	77%
Digital twin of the factory	19%	+25%	44%
Digital twin of the production asset	18%	+21%	39%
Digital twin of the product	23%	+20%	43%
Autonomous intra-plant logistics	17%	+18%	35%
Flexible production methods	18%	+16%	34%
Transfer of production parameters	16%	+16%	32%
Modular production assets	29%	+7%	36%
Fully autonomous digital factory	5%	+6%	11%

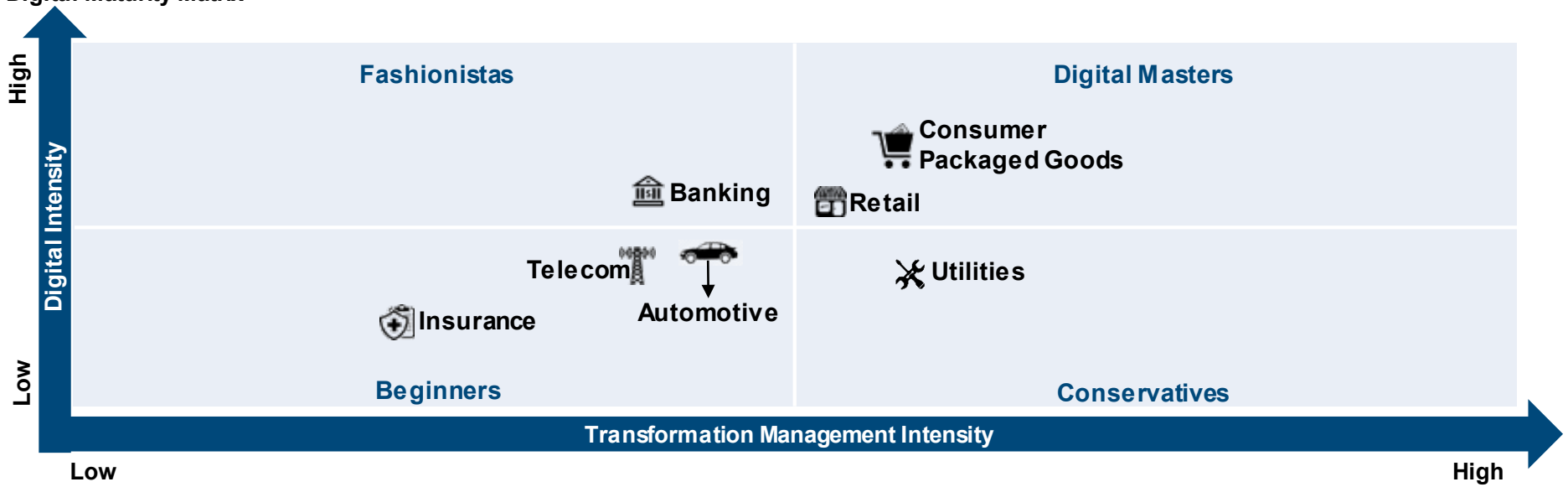
Source: PwC Report 2017

Digital Maturity

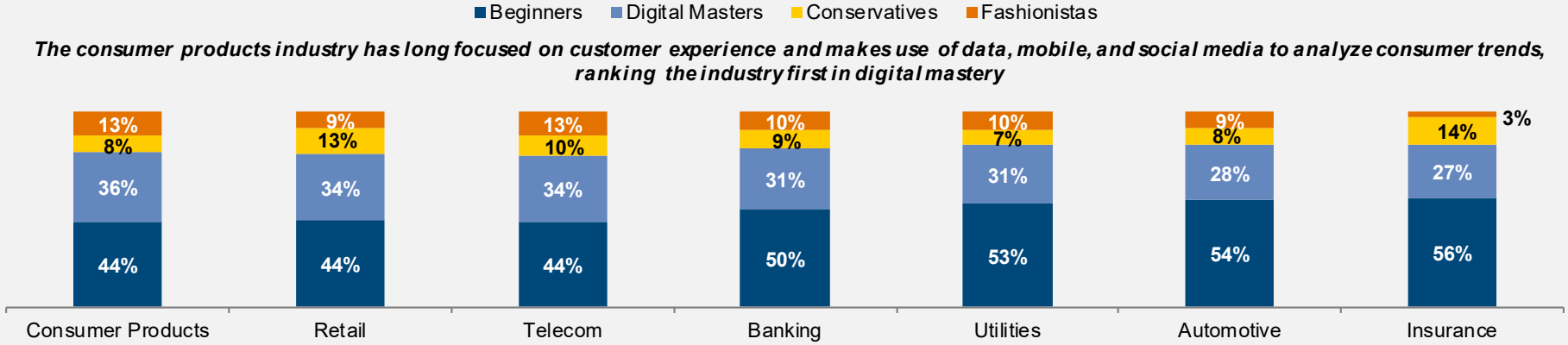
Industries are in the midst of the first phase of their digital transformation journey

Introduction to Digital Maturity

Digital Maturity Matrix



Digital Maturity of Firms Across Sectors[1]



Source: Capgemini Report 2018 and Press Articles; 1) Percentages represent proportion of categories based on digital maturity across industries

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Digital Manufacturing –
3D Printing

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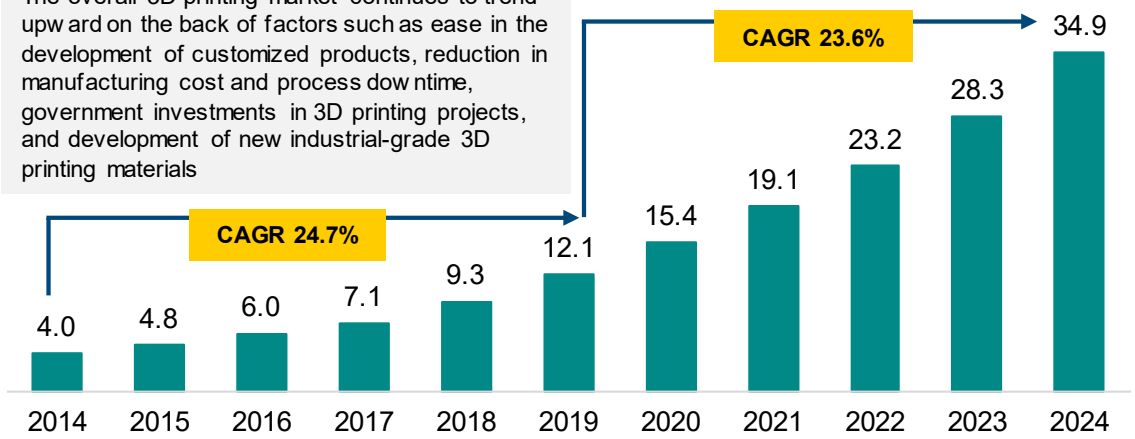
3D Printing Market Overview

As of 2019, 3D printing market has been witnessing 25% YoY growth since 2014

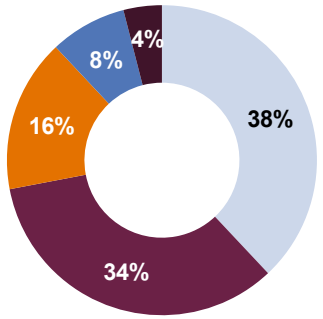
Global Market Highlights

The overall 3D printing market continues to trend upward on the back of factors such as ease in the development of customized products, reduction in manufacturing cost and process downtime, government investments in 3D printing projects, and development of new industrial-grade 3D printing materials

3D Printing Market Size ($*bn*)



3D Printing Market (2019)

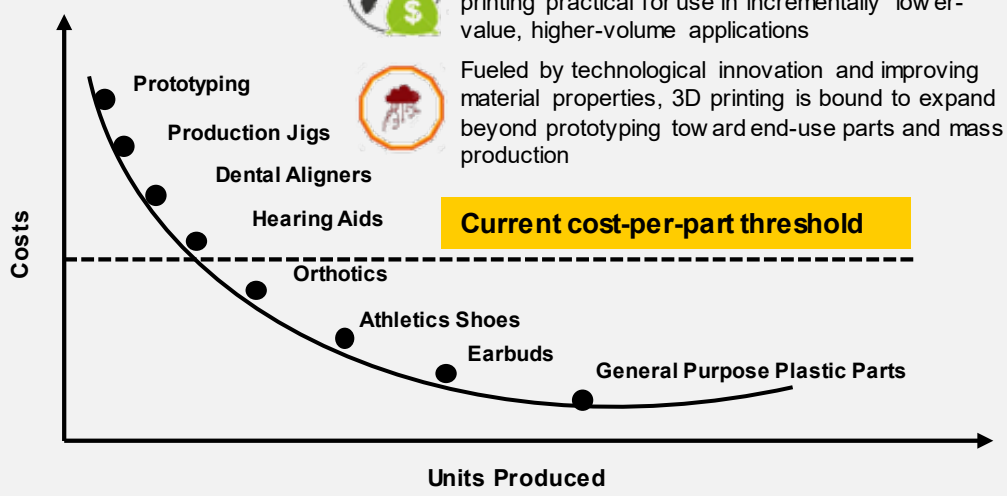


Large enterprises are making their first steps toward small-scale production and mass manufacturing with 3D printing, opening new growth opportunities

Categories	Prototypes	Molds and Tools	End-Use Parts
	3D printing manufactures test parts quickly and cost-effectively	3D printing produces parts that streamline the manufacturing process	3D printing manufactures parts for finished products
Market Potential[1]	**$12.5bn**	**$30.0bn**	**$490.0bn**
Current Penetration (2019)	**40–50%**	**6%**	**1%**

The economics of 3D printing is improving, and the cost-per-part threshold is moving; this makes 3D printing practical for use in incrementally lower-value, higher-volume applications

Fueled by technological innovation and improving material properties, 3D printing is bound to expand beyond prototyping toward end-use parts and mass production



Source: 3DHubs and EY Report; 1) ARK Investment Management Estimate

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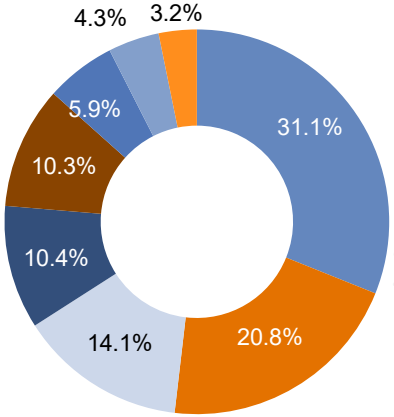
SMEs Driving 3D Printing

SMEs are the major drivers of the online 3D printing market

Global Market Highlights

Online 3D Printing by Industry (2018)

(Based on 100,000 3D printed parts)



Over **65%** demand emanated from engineers working in the development of industrial, electrical, or consumer goods

Only **10%** demand came from engineers in the aerospace and automotive sectors, who use online services; this shows immense potential for the market to grow

Online 3D printing refers to highly automated manufacturing platforms, while the term offline 3D printing includes traditional services and in-house 3D printing, where most processes are done manually

Online 3D printing services streamline the ordering process through software, reducing the time to production from days to minutes

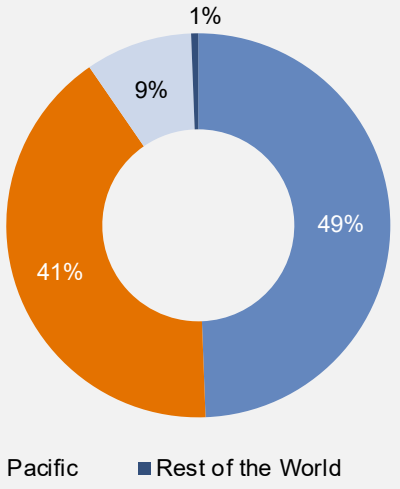
- Currently, online 3D printing accounts for 35–45% of all service providers, i.e., ~$1.3–1.6bn, which is expected to grow as more engineers turn to online 3D printing to move faster

Online 3D Printing Sale breakdown by Geography (2018)

Over **750,000+** 3D printers were ordered in 2018

The US alone accounted for **45%** demand

25% demand came in from the US, the UK, and Germany



Currently, Asia Pacific has a relatively small market share, but it is on the rise

- A review of Google trends shows that queries related to 3D Printing in a business and industrial setting were as popular in Asia Pacific as in Europe and the US in 2018, thus showing the emerging role of Asian markets in the growth of the 3D printing industry in the future

Source: Industry Report

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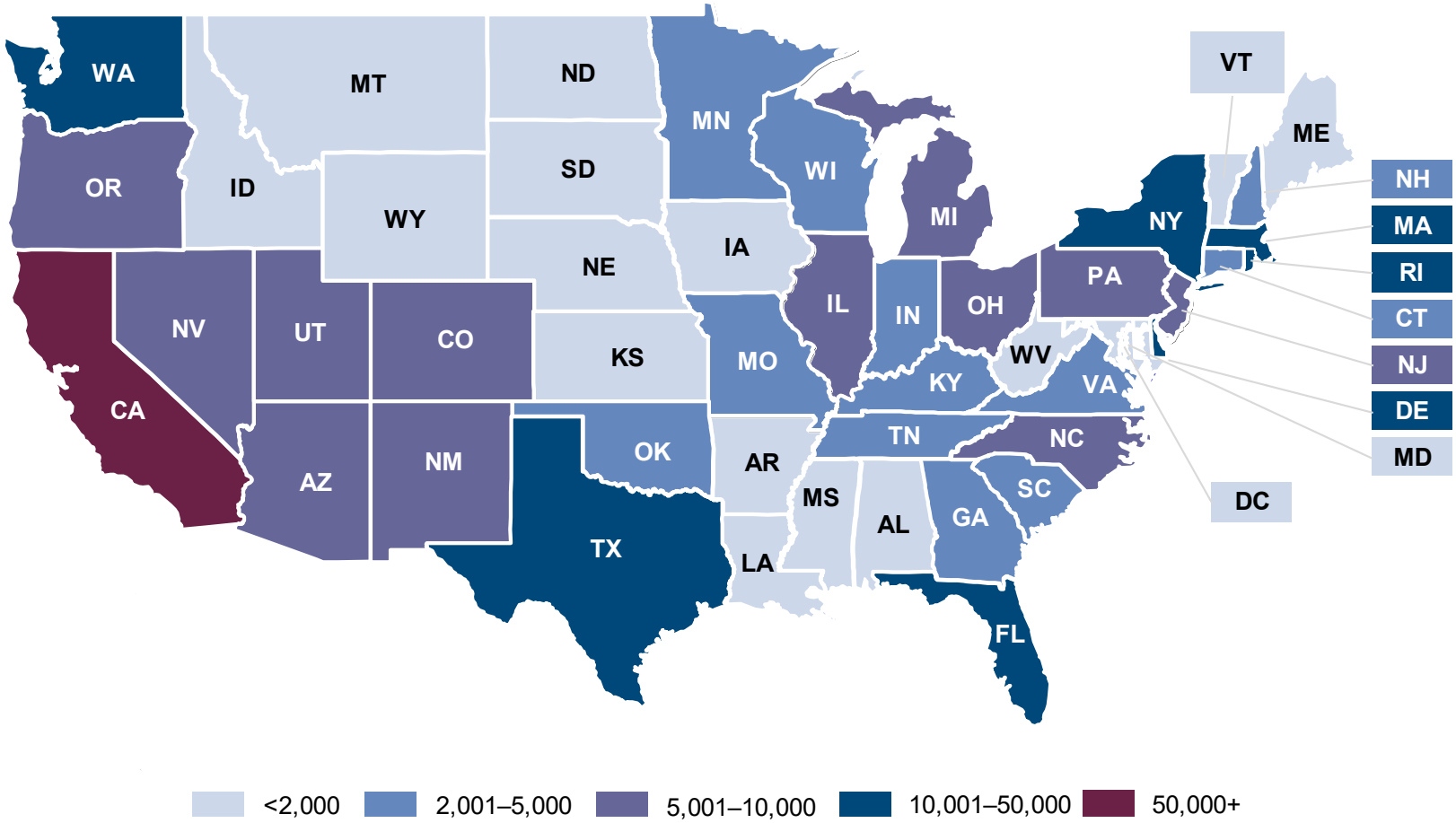
3D Printing Online Platforms Growing Rapidly

In 2019, ~260,000 parts were 3D printed by an online platform[1] in the US

US Online 3D Printing Demand By State

California witnessed the highest online 3D printing demand in 2019 with more than 22% of the total US demand from customers based there, owing to strong presence of tech start-ups



Source: 3DHubs; 1) 3DHubs online manufacturing platform

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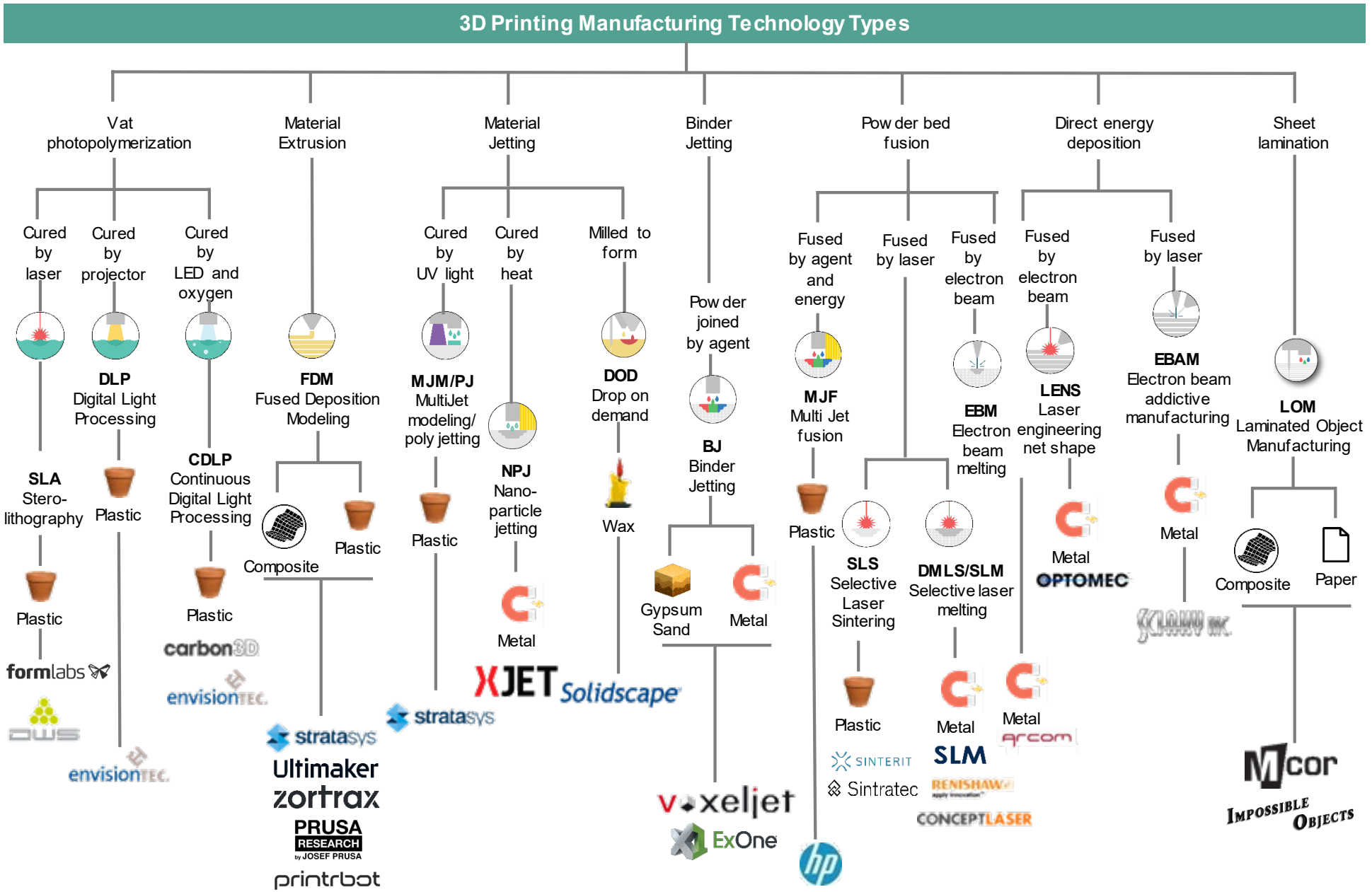
3D Printing Technologies Continue to Expand



Source: 3DHubs

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Market Trends in 3D Printing

Advancements in software & hardware have led to the hybridization of technologies

Market Trends

Rise of Additive Process Control Software

Most application-specific AM[1] technologies require a comprehensive build setup such as ***virtual machines and in situ monitoring*** to ensure the part completes the printing process and can undergo post processing

- ***Velo3D*** *has reinvented the metal laser sintering platform by incorporating a software that* ***predicts and mitigates overhangs****, its AM solution can make metal parts with much* ***less support****, flipping traditional DMLS paradigms upside down*

Increased Isotropic Print Possibilities

Innovations in 3D printing technologies such as ***continuous 3D printing***, ***novel fusion on filament-based systems***, and ***3D contouring*** have opened the possibility of isotropic parts (uniformity in all orientations) to bring greater structural strength to parts

- ***RIZE*** *has 3D printers that deposit specially formulated agents between layers, which can either* ***enhance the layer bond*** *or* ***promote release for features such as a support structure,*** *exhibiting isotropic properties*

Novel Materials and Processes

Innovation in 3D printing is being moved forward by new material families such as ***reaction polymers***, ***ceramics***, ***and 3D printing circuit boards*** that further bridge gaps between prototype and end-use production without traditional manufacturing methods

- ***DLyte's dry electropolishing*** *uses alternating charges between anodes and cathodes in an electrolytic media base to homogeneously even out the material surface while retaining feature details. By reducing acute stress junction on the part surface, 3D prints can achieve smooth surfaces to meet both* ***cosmetic and strength requirements***

Viable Hybrid 3D Printing Technologies

CNC machining, ***urethane casting***, ***injection molding***, and other established production technologies can be combined with AM to enhance surface smoothness, low tolerances, and material types in industrial applications

- ***Mazak's INTEGREX*** *series has an AM head that can deposit metal in a fashion such as* ***directed energy deposition (DED)****, the material deposited hits a near-net shape of the final feature and is completed with* ***CNC tooling***

Source: Press Articles; 1) Additive Manufacturing

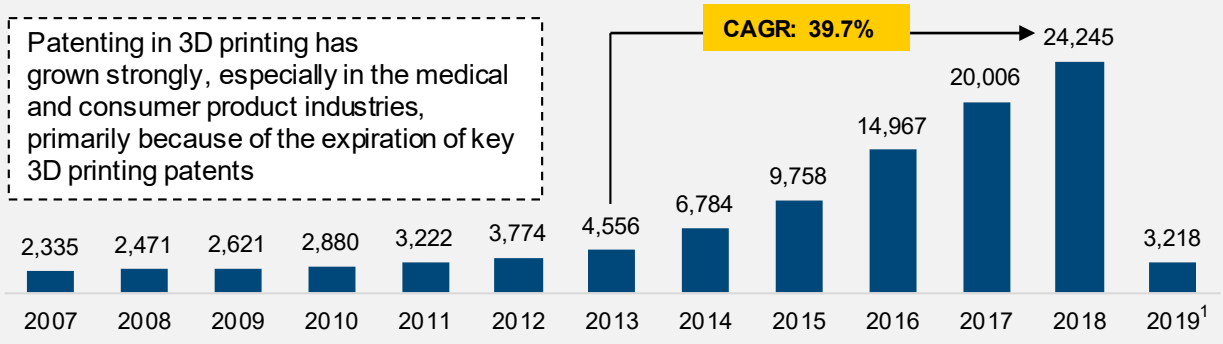
3D Printing Patents Expanding

Patents for 3D printing products posted a 39.7% CAGR over 2013–2018

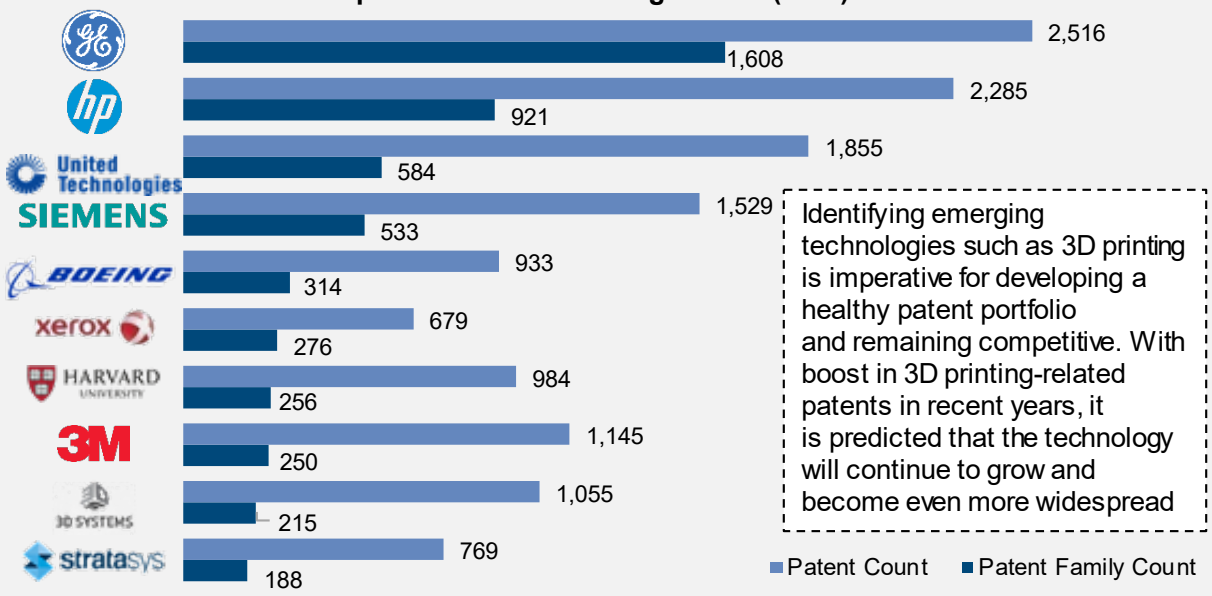
3D Printing Patents Highlights

3D Printing Patent Applications Per Year

Patenting in 3D printing has grown strongly, especially in the medical and consumer product industries, primarily because of the expiration of key 3D printing patents

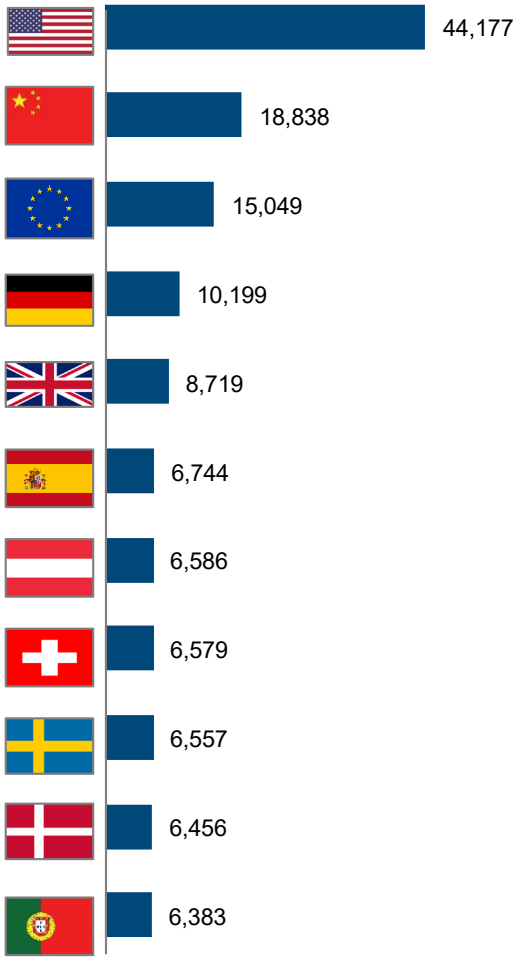


Top Owners of 3D Printing Patents (2019)



Identifying emerging technologies such as 3D printing is imperative for developing a healthy patent portfolio and remaining competitive. With boost in 3D printing-related patents in recent years, it is predicted that the technology will continue to grow and become even more widespread

3D Printing Patents Per Country (2019)[2]



Source: IplyticsReport; 1) As of Feb 2019, 2) By number of 3D patent applications filed

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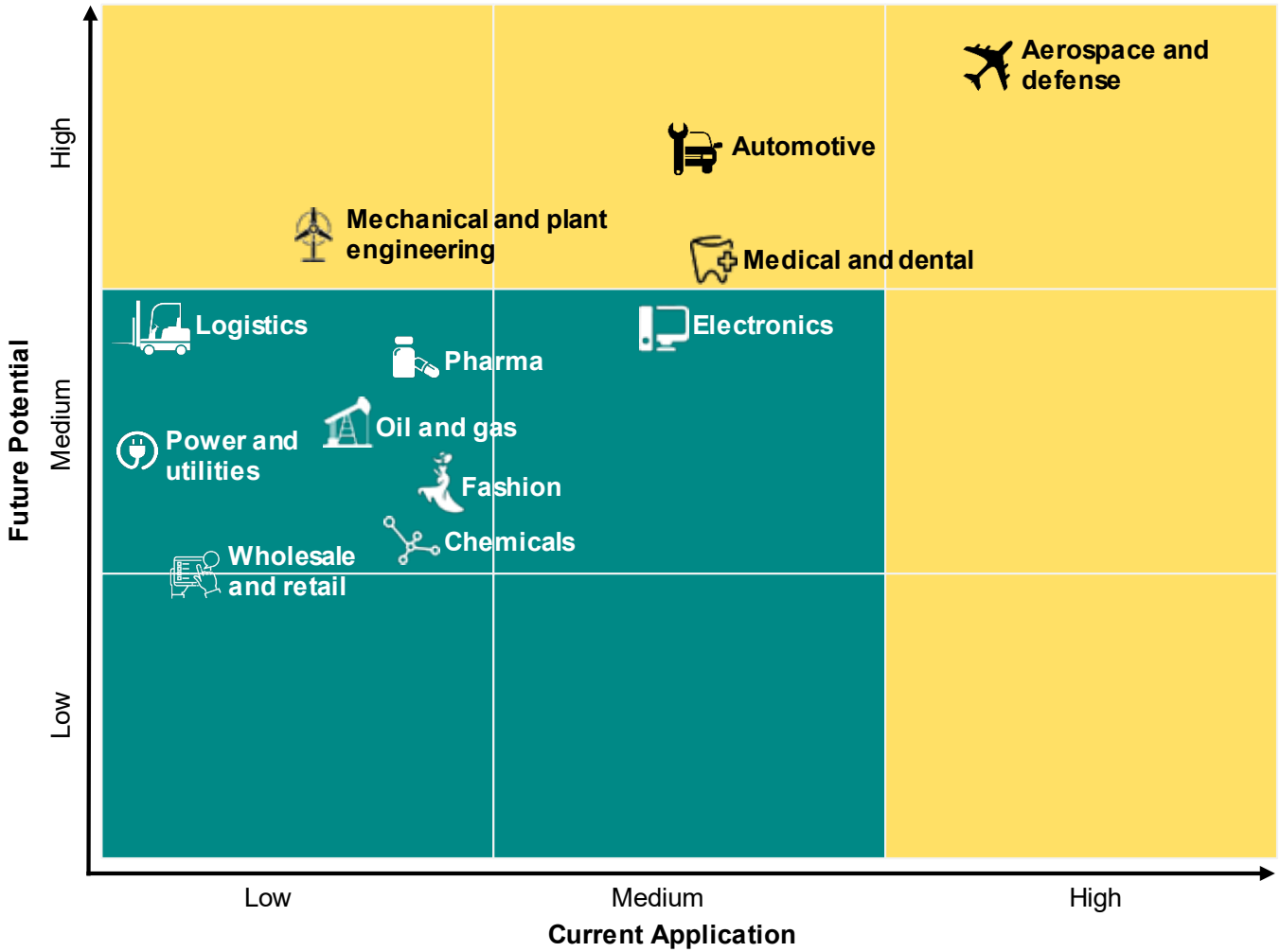
Large Market Opportunity for 3D Printing

With 1% share in the addressable market[1], 3D printing has growth potential

3D Revolution by Industry



Aerospace

Traditionally, creating an aerospace tool or mold took 6–12 months (or more); however, with additive machines, manufacturers can design a part, print a tool, and produce the part in just one week

With 3D printing technology aircraft can fly further, faster, cheaper, and with more payload

For Example:

GE tested its advanced turboprop engine with 3D-printed parts and experienced the following benefits:

- Number of parts dropped from **855 to just 12**
- Fuel burn lowered **20%**
- Weight reduced **5%**
- Test schedules cut in half to **6 months**

Source: EY Report; 1) for aircraft

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Industry Applications

3D printing is used across multiple industries and offers several cost benefits

Selected Applications of 3D Printing Demand

Industry	Current Applications	Potential Future Applications	Cost Advantages
 **Automotive**	• Rapid prototyping and manufacturing of end-use auto parts • Parts and assemblies for antique cars and race cars • Quick production of parts	• Sophisticated auto components • Auto components designed for crowd sourcing	• Opel, a car manufacturer, admitted a tooling cost reduction of 90% in the assembly process
 **Commercial Aerospace and Defense**	• Concept modeling and prototyping • Structural and nonstructural production parts • Low-volume replacement parts	• Aircraft wing and structural components • Complex engine parts • Embedding additively manufactured electronics directly on parts	• Boeing estimates that 3D printing can save $2–3mm per plane
 **Consumer Goods**	• Rapid prototyping • Customized jewelry and watches	• Co-designing and creating with customers • Customized living spaces	• Stratasys estimates that 3D printers can lead to an average cost savings of 70–95%
 **Healthcare and Medicine**	• Prostheses and implants • Medical instruments and models • Hearing aids and dental implants	• Developing organs and transplants • Large-scale pharmaceutical production • Developing human tissues for regenerative therapies	• According to Forbes research, 3D printing results in cost savings of up to 70% for its medical clients
 **Space**	• Specialized parts for space exploration • Structures that require lightweight, high-strength materials	• On-demand parts/spares for use in space • Large structures directly created in space	• As per Lockheed Martin, 3D printing aids decline in manufacturing cost of rockets, satellites, and antennas

Source: Industry Report, Forbes, and Press Articles

Recent Developments – Transitioning to Production

A rising no. of firms are adopting 3D printing technologies for serial production

Recent Developments (2019) – By Industry Types

Key Industries: Automotive, Aerospace, Medical, Industrial Operation, Railway, Motor Sport, Defense, Sustainability, Mobility, Product Development

Lima Corporate opens an implant 3D printing facility at a hospital in New York

In Jan 2019, Lime Corporate opened an on-site metal 3D printing facility to work closely with a hospital's leading physicians to produce patient-specific implants for a range of orthopedic conditions; this is expected to begin operating by early-2020

Local Motors deploys 3D printed, self-driving shuttle

In Feb 2019, Local Motors deployed the first two 3D printed, autonomous shuttles that will be independently roaming in the Sacramento State University campus. Later that year, the company partnered with Airbus to create Neorizon, a micro-factory that focuses on producing 3D printing solutions for ground and air mobility, such as urban cargo and drones

Smile DirectClub partners with HP to make 50,000 3D printed molds per day

In May 2019, SmileDirectClub announced its plan to 3D print molds for its dental aligners on a massive scale with 49 HP's Multi Jet Fusion 3D Printing technology, following the success of Invisalign[1]. The printers will make more than 50,000 molds a day. The company is on track to make 20 million 3D printed molds over the next 12 months

Norsk Titanium expands partnership with Boeing

In Jun 2019, Norsk Titanium expanded the collaboration with Boeing for the serial production of structural titanium parts for passenger airplanes

Formula One and Fia use additive manufacturing to test 2021 car

In Aug 2019, FIA, the governing body of Formula One, used additive manufacturing (AM) to determine the design, rules, and regulations of its 2021 cars. The 2021 vehicle underwent extensive wind tunnel testing using a 50% scale model produced with the help of AM

Stratasys and Angel Trains deploy the first 3D printed parts on British passenger trains

In Sep 2019, Stratasys collaborated with Angel Trains, DB ESG (engineering consultancy), and Chiltern Railways (train operator) to upgrade trains with 3D printed parts. Components that were being fabricated via the AM technology included four passenger armrests and seven grab handles, which were certified and put into operation in UK trains on a trial basis

Made In Space sends plastic recycling system to support an AM facility at the International Space Station (ISS)

In Oct 2019, Made In Space sent a recycling system on Northrop Grumman's commercial cargo resupply flight, in partnership with Braskem, to improve the sustainability of the ISS' manufacturing capacity

America Makes inks a 7-year $322m agreement with the U.S. Air Force to advance AM

In Dec 2019, America Makes signed a $322 million cooperative agreement with the U.S. Air Force's Air Force Research Laboratory (AFRL). The deal will help America Makes advance AM for the defense industry and its supply chain, specifically focusing on the areas of materials, design, education, and community in AM

Source: Press Articles; 1) 3D printing clear teeth aligners production facilities

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Recent Developments – "Out-of-Segment" Players Moving-in

3D printing is being increasingly adopted by leading companies across industries

Recent Developments (2018) – By Industry Types

Key Industries: Automotive, Aerospace, Consumer, 3D Printing
Key Themes: Mass Production, Spare Parts & Supply, Mass Customization, Standardization

Bugatti develops 3D-printed brake caliper

In Jan 2018, Bugatti revealed a new titanium caliper which reduced the weight by ~40% in comparison to aluminum while increasing strength, setting a new paradigm in the 3D printing of metal component automobiles. In the same sector, **Porsche, Audi**, and **Mercedez-Benz** also disclosed their activities on metal 3D printing – primarily the production of spare parts

Adidas releases shoe with 3D-printed insole

In Feb 2018, a limited no. of **Adidas** Futurecraft sneakers were released. Their insole was 3D-printed using **Carbon's** CLIP 3D printing technology. Adidas announced plans to push the production volume from 5,000 pairs to hundreds of thousands by year end

HP integrates MJF[1] in their Supply Chain

In April 2018, HP announced plans to integrate its MJF technology into its internal supply chain. The company's Jet Fusion 300/500 series 3D printers feature over 140 3D-printed parts

ASTM[2] releases two new standards for metal 3D printing

Standardization is a necessity for the adoption of metal 3D printing in the aerospace and medical industries.

In Jun 2018, **ASTM** released a set of standards that detail best practices for metal powder bed fusion processes to ensure quality for critical applications

BMW 3D prints parts for commercial vehicles

In Aug 2018, **BMW** revealed the first metal 3D-printed bracket to be used in a commercial vehicle that is 44% lighter than the roof bracket conventionally manufactured for the previous Roadster model

GM kicks off 3D printing for electric vehicles (EVs)

In Aug 2018, GM revealed its plan to 3D print thousands of parts for its EVs with a goal to increase the adoption of electric cars by improving their fuel efficiency through weight reduction. In the same space, **XEV** (an Italian car manufacturer) announced plans to test the production of its EV with over 50 3D-printed plastic components

Lufthansa opens additive manufacturing center for aircraft MRO[3]

In Oct 2018, **Lufthansa Technik** (MRO division of aerospace company Lufthansa) established a new AM center in Germany to develop lightweight aircraft parts. Other aerospace companies – such as **Airbus, Emirates** have also ramped up their 3D printing capabilities

Gillette Pilots razors with customizable 3D-printed handles

In Nov 2018, **Gillette** partnered with **Formlabs** to offer razors with customizable 3D-printed handles. This is one of the first commercially viable examples of mass customization of consumer products with 3D printing to hit the market

Source: Press Articles; 1) Multi Jet Fusion, 2) American Society for Testing and Materials, 3) Maintenance, Repair, and Overhaul

3D Printing's Impact on Manufacturing Processes

3D printing offers major benefits at various stages of the manufacturing process

Associated Manufacturing Impacts

Potential reduction in the number of discrete parts per product

*Several distinct manufacturing processes such as **machining and welding** can be integrated into a single 3D printing operation*

Potential reduction in part weight or improvement in part strength

*The capacity to create complex internal structures using 3D printing has improved manufacturers' ability to create **lighter or stronger**, particularly in the **aerospace and automotive** industries*

Potential reduction in inventory

***Low set-up costs** associated with 3D printing allow for **smaller production runs**, reducing the amount of capital tied up in inventory, as well as overhead costs, such as storage and insurance*

- *According to an MIT report, with 3D printing, spare parts inventory can be reduced by **90%***

Mass customization

*3D-printing production of **unique parts** and modification from a basic design to suit the needs of individual consumers, allowing individual customization on a large scale*

- *As per a recent survey[1], **35%** manufacturers consider mass customization as a major benefit of 3D printing*

Improved prototyping abilities

***Easy modification** of design files, combined with the **cost effectiveness** of short runs of parts, supports the ability to rapidly prototype parts through 3D printing, allowing designs to be optimized and adjusted quickly*

Potential environmental efficiency

*Reduced waste and lack of a need for retooling 3D printers supports **environmental efficiency** in manufacturing*

- *GEnx reported **90% reduction** in waste after implementing 3D printing manufacturing*

Potential reduction in manufacturing costs

*The **smaller size** of a 3D printer than traditional manufacturing equipment reduces the required physical plant size and related costs*

Decentralized manufacturing

*3D printers can be used to develop parts in a **decentralized capacity** to reduce the time required to provide parts to consumers, as well as lower the cost, energy, and environmental impacts of shipping*

Source: US Congressional Research Service Report and Press Articles; 1) 2019 State of 3D Printing survey by Sculpteo

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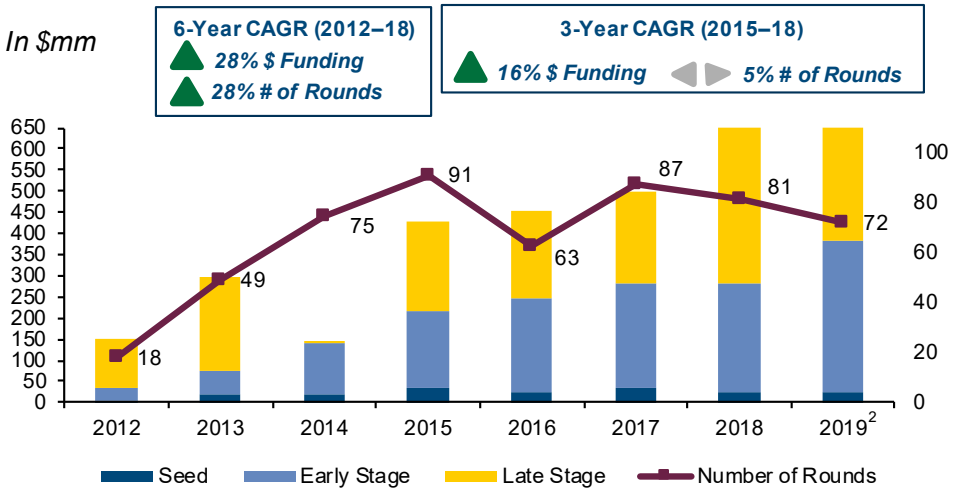
3D Printing Investment Landscape

VC/PE funding in 3D printing was expected to cross the $1.1bn mark in 2019

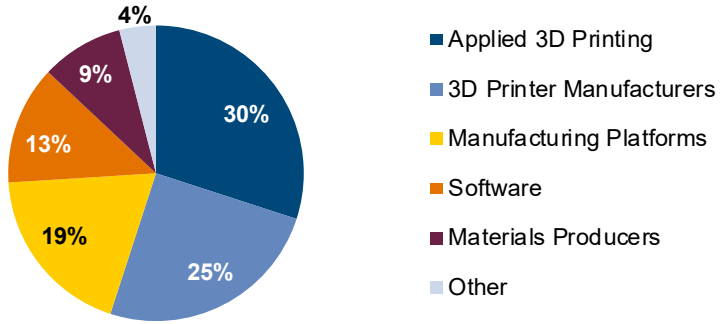
Overview on the Global Financial Sponsor Landscape

- **Inclusions**: All companies that develop and manufacture machinery for addictive manufacturing, such as 3D printers with various base technologies, 3D printing materials, 3D fabricators, and 3D printing pens; also includes software providers that offer slicing, model fixing, print management, and other functions. In addition, companies that provide 3D printed objects to consumers (jewelry, toys, collectables, etc.), healthcare products, etc. are also covered
- **Exclusions:** Resellers of 3D printers and materials, and 3D printing service providers

Global Funding Rounds[1]

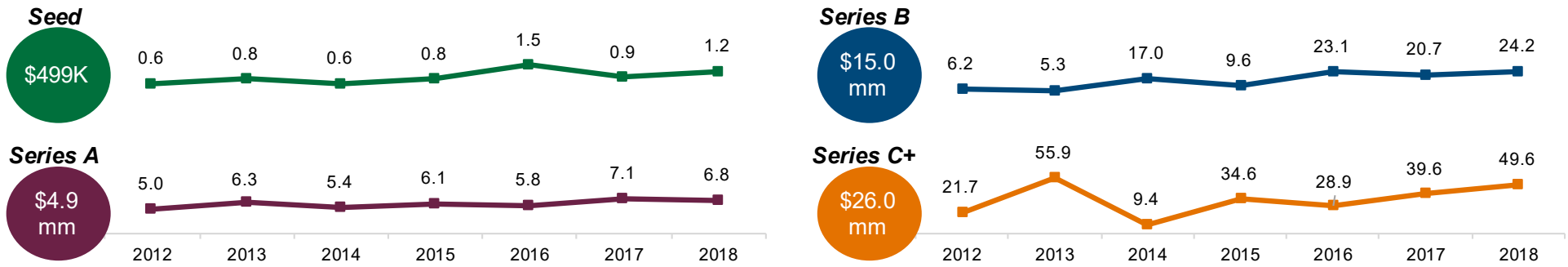


Number of 3D Printing Investments By Category (2019)



VC investments in 3D printing are primarily centralized in the US, with companies such as Carbon ($2.4bn), Desktop Metal ($1.5bn), and Formlabs ($1.0bn) – all 3D printing system US-based manufacturers – acquiring the **"unicorn"** status

Median and Average Deal Size and Trend (In $mm)



Source: Tracxn; 1) Excludes Grant, Debt, and Post IPO Rounds; and information of Chinese companies, 2) As of Nov'19

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3D Printing Private Funding Landscape

VC investments eclipsed in 2019 signaling an increase in viable applications

Selected Private Financing Transactions (2019)

3D Printer Manufacturers

Jan'19	Jan'19	Mar'19	Jun'19	Jul'19	Jul'19	Oct'19	Nov'19
Desktop Metal	ESSENTIUM	Markforged	Carbon	FORTIFY	MADE IN SPACE	VOXEL8	inkbit
Raised	Raised	Raised	Raised	Raised	Raised	Raised	Raised
$160mm–Series E	$22mm–Series A	$82mm–Series D	$260mm–Series E	$10mm–Series A	$74mm	Undisclosed–Series B	$12mm
KOCH	BASF We create chemistry	SUMMIT PARTNERS	BAILLIE GIFFORD	Accel	NASA	DSM	DSM

Post Processing

Oct'19	Nov'19
ADDITIVE MANUFACTURING TECHNOLOGIES	POSTPROCESS
Raised	Raised
$5mm–Series A	$20mm–Series B
DSM	Tom Golisano

Applied 3D Printing

Oct'19
Relativity
Raised
$140mm–Series B
TRIBE

Software

Apr'19	Oct'19
Dyndrite	LINK3D
Raised	Raised
$10mm–Series A	$7mm–Series A
COTA CAPITAL	APPLIED ARTIFICIAL INTELLIGENCE

Digital Manufacturers

Mar'19	Mar'19	Apr'19	May'19
fictiv	3D HUBS	FAST RADIUS	Xometry
Raised	Raised	Raised	Raised
$33mm–Series C	$18mm–Series C	$48mm–Series B	$50mm–Series D
intel	endeit	ups	BOSCH

Source: Press Articles

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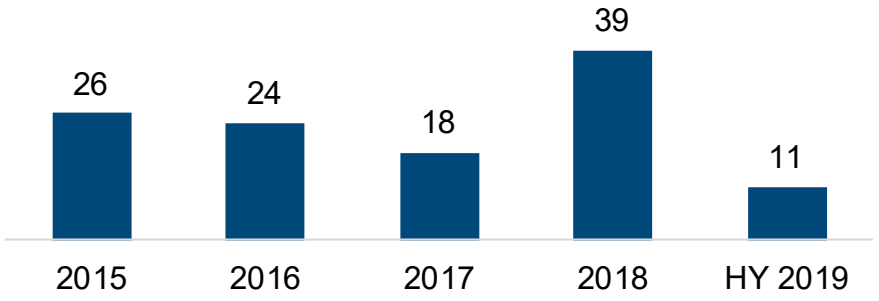
3D Printing M&A Transaction Landscape

Strategic and financial buyers continue to pursue M&A activities in the 3DP space

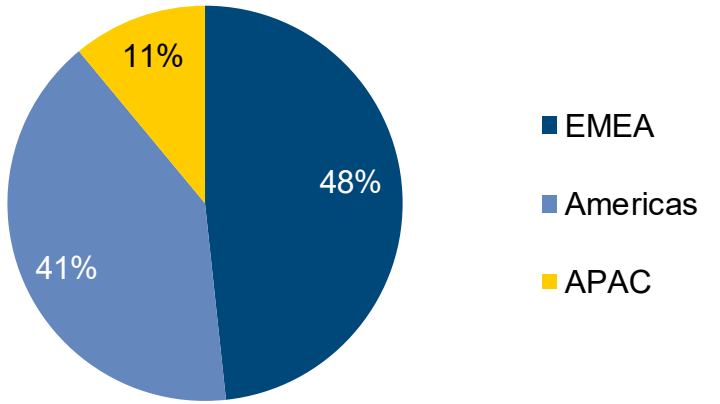
Global M&A Activity Overview (2015–2019)[1]

Number of M&A Deals

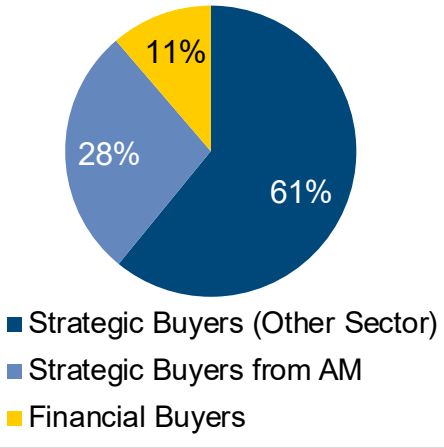
3D printing service providers were the most prized targets across all market sub-sectors and accounted for more than half of all acquisitions



Deal Breakdown by Geography

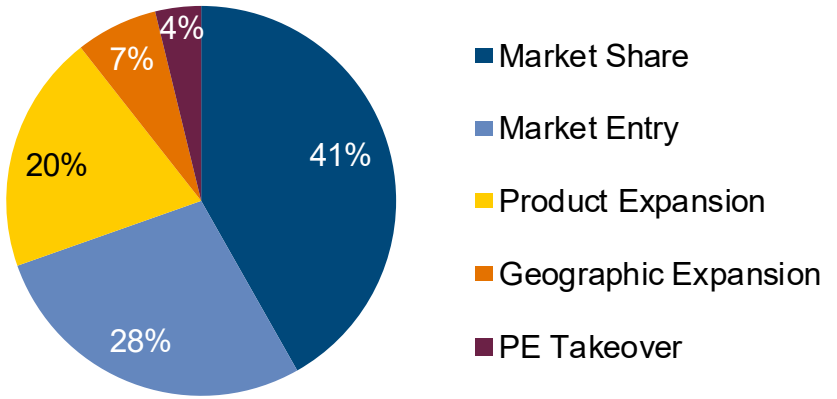


Deal Breakdown by Buyer Type[2]



Strategic players from other sectors form a significant pool of buyers as they are looking to change their production processes and extend offerings either through AM technology or by entering a new high-growth market

Deal Breakdown by Transaction Rationale



Source: EY Report; 1) As of June 2019, 2) Some deals include multiple buyers

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3D Printing M&A Landscape

Product innovation and intensifying competition boosting M&A activities

Selected M&A Transactions (2019)

Digital Manufacturers

Mar'19	Apr'19	Jul'19	Sep'19	Oct'19	Oct'19	Nov'19	Dec'19
Aerojet Rocketdyne	Lincoln Electric	Sintavia	MCT	Thogus	GKN	BASF	MCT
Acquired	Acquired	Acquired	Acquired	Acquired	Acquired	Acquired	Acquired
3DMT	Baker Industries	QC labs	Fathom	Proto Plastics	Forecast 3D	sculpteo	ICOMold

3D Printer Manufacturers

Feb'19	Feb'19	Mar'19	Apr'19
xerox	Voxeljet	KVP	Technoprobe
Acquired	Acquired	Acquired	Acquired
VADER	FORM3D	MakeShaper	Microfabrica

Value Added Resellers

Jan'19	Apr'19	Apr'19	Oct'19
GoEngineer	CIVC Partners	Hawk Ridge Systems	Computer Aided Technology
Acquired	Acquired	Acquired	Acquired
Advanced RP	Computer Aided Technology	Parsons Technologies	FisherUnitech

Software

Oct'19	Nov'19	Nov'19	Dec'19
ptc	Lulzbot	Siemens	Saratech
Acquired	Acquired	Acquired	Acquired
Onshape	Aleph Objects	Atlas 3D	TekPro

Materials

Jan'19	May'19	Jul'19	Nov'19
Evonik	Henkel	3D Systems	formlabs
Acquired	Acquired	Acquired	Acquired
Structured Polymers	molecule	BCI	spectra group limited, inc

Source: Press Articles

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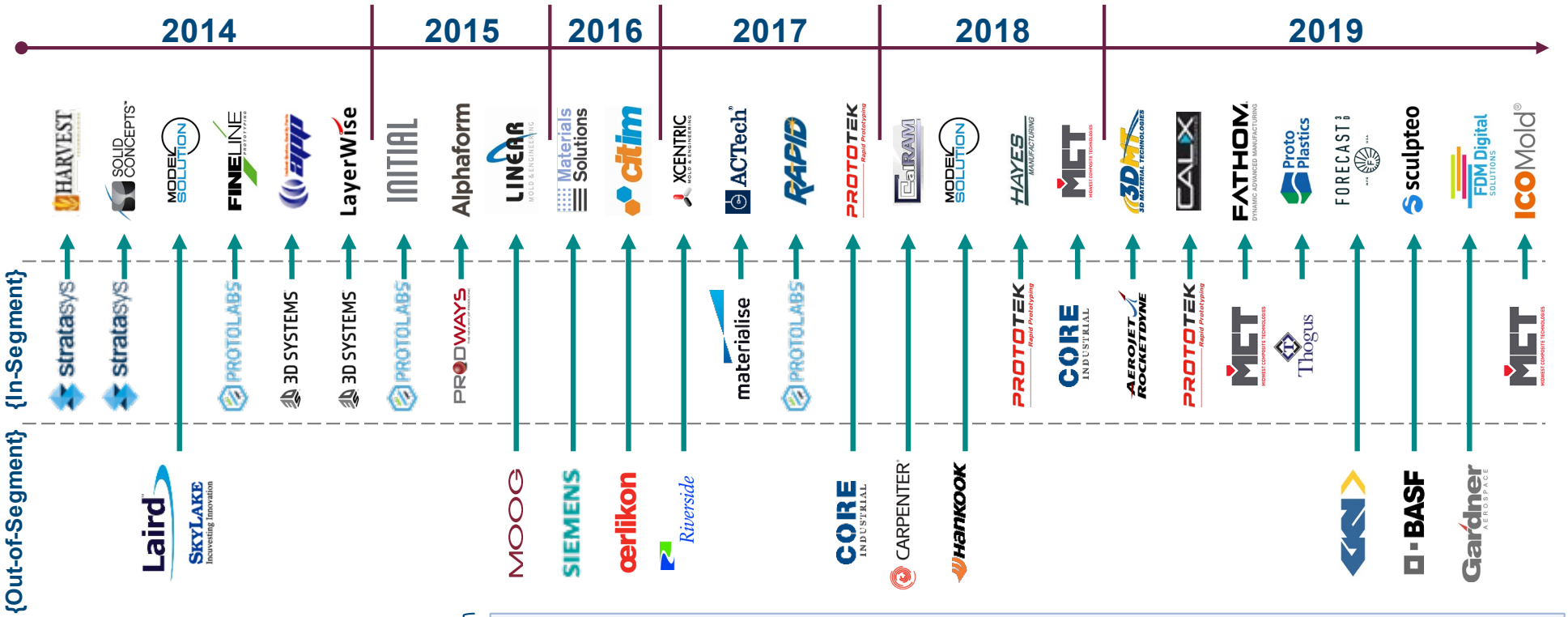
Emerging Buyer Universe of Digital Manufacturing Companies

Selected M&A Transactions



In-Segment Buyers

- Focus on increasing market share and establishing a presence in diversified end markets
- *Typical buyer profile: Large operating companies looking to improve technology or expand market coverage by acquiring targets with complementary profiles to their existing product and service portfolios*

Out-of-Segment Buyers

- Build out and expand presence in digital manufacturing solutions as part of a broader industrial capabilities platform
- *Typical buyer profile: Large tech conglomerates diversifying into a new market niche, and PE firms looking for differentiated companies that are EBITDA positive*

Sources: Capital IQ, 451 Research, publicly available information. Reflects announced date.

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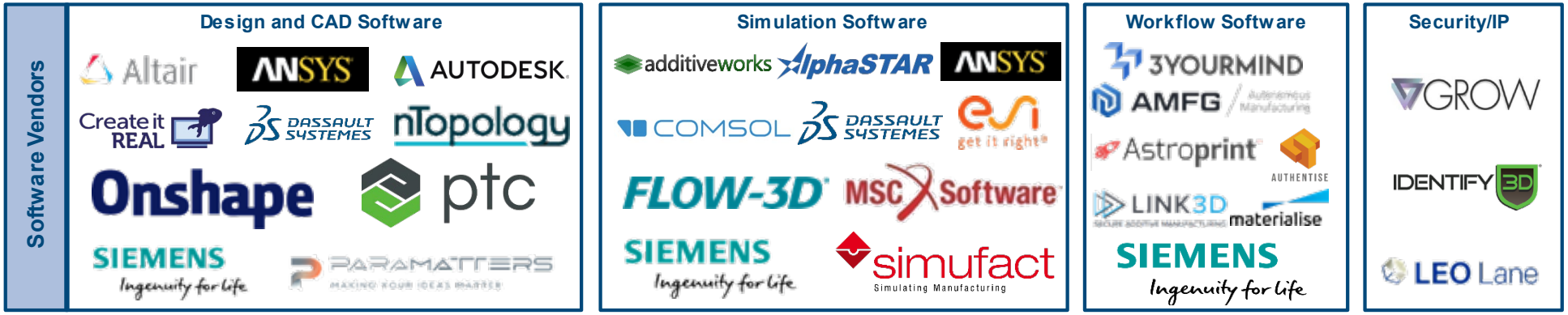
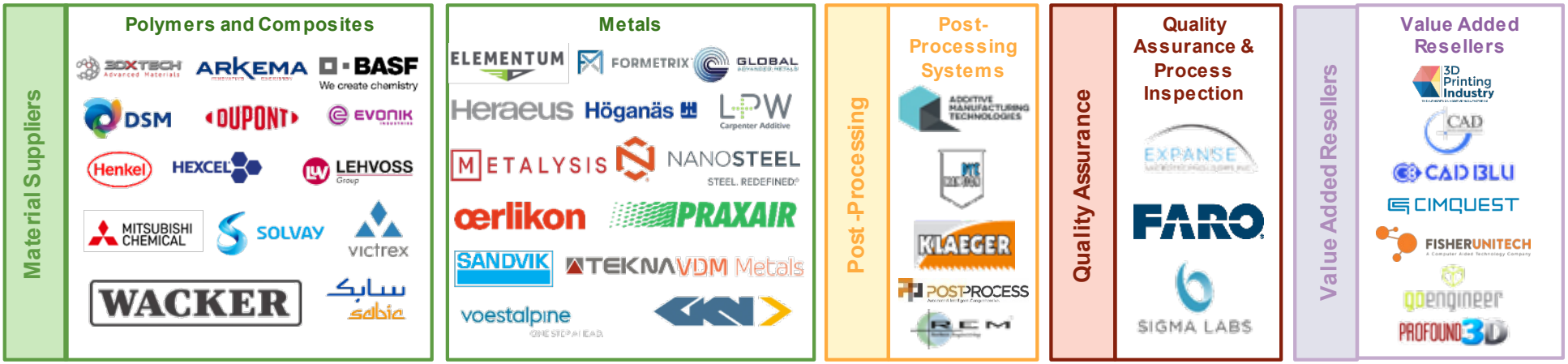
Market Map – 3D Printing





Source: AMFG Research and Press Article

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Market Map – 3D Printing Digital Manufacturers

Source: Wohlers Associates and Press Articles

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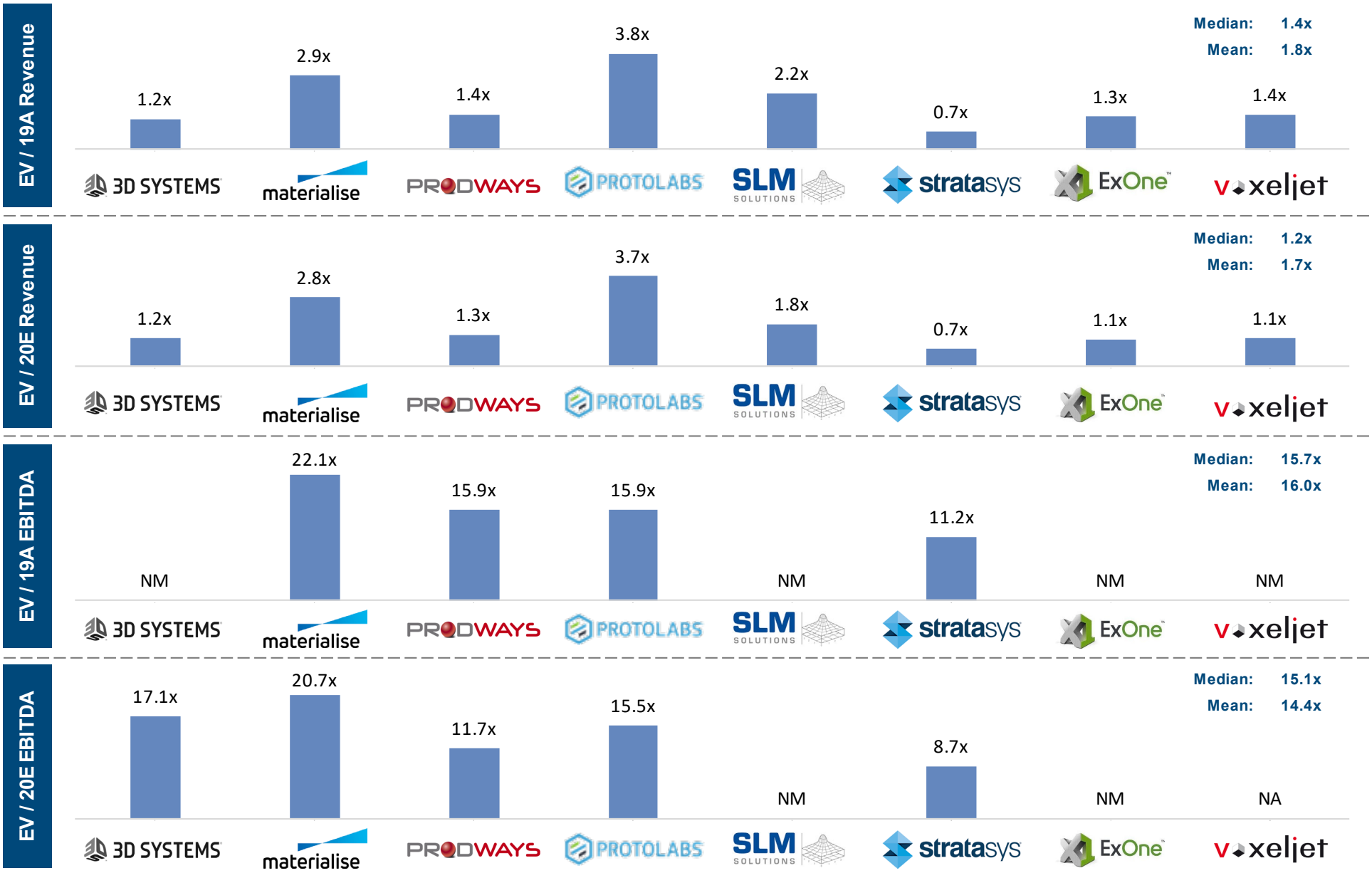
3D Printing Public Companies – Market Data



Source: Capital IQ as of 3/12/20; NM indicates "No Metric"; NA indicates "Not Available"

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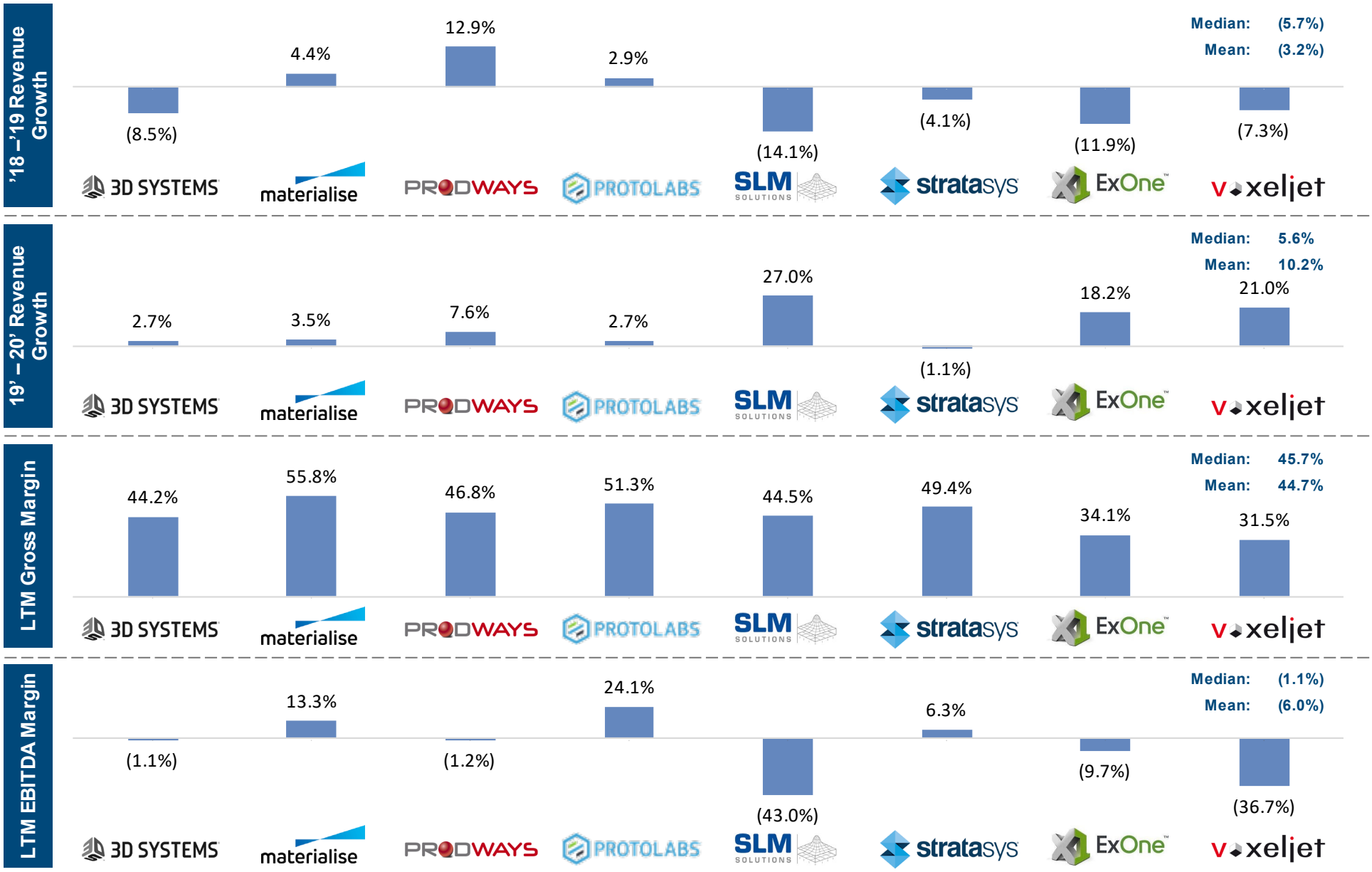
3D Printing Public Companies – Operating Data



Source: Capital IQ as of 3/12/20; NM indicates "No Metric"; NA indicates "Not Available"

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Digital Manufacturing –
Disruption in Traditional Manufacturing

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Hybrid Manufacturing

Hybrid manufacturing is the combination of additive and subtractive manufacturing

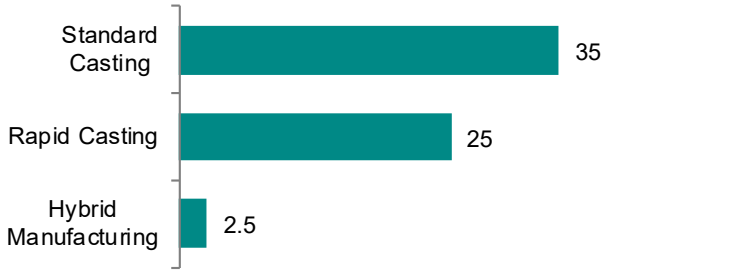
Introduction to Hybrid Manufacturing

Hybrid manufacturing is essentially a combination of laser cladding (additive/3D printing) and CNC machining/milling (subtractive) in a single machine environment

CNC + 3D = Hybrid Manufacturing

CNC Machining	HYBRID	3D Printing
+ High productivity		+ Less material wastage
+ Good surface finish	+	+ Geometrical freedom
+ Precise		+ Material options
+ Repeatability		- Long cycle time
- Waste material		- Poor surface finish

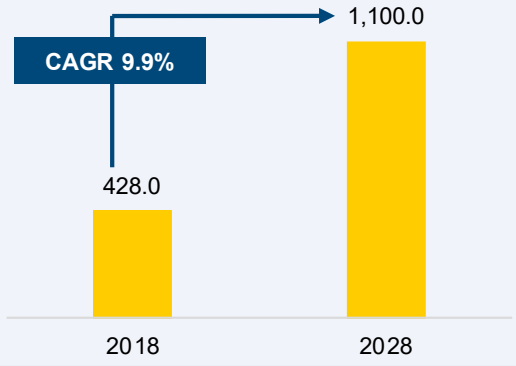
Production time for different manufacturing processes (days)



- Hybrid machines use DED[1] AM technology, in which a nozzle feeds powder is spread over a printing surface and then melted by beam/laser, which solidifies the metal afterwards
- Initially, the 3D printed portion's surface is rough, so after it's deposited, the subtractive CNC tools are used to smooth it

Using CNC machining on 3D-printed parts delivers the best of both technologies, making them complementary rather than competing

North America's Market size ($mm)



Key Players

3D-HYBRID, DMG MORI, FABRISONIC, HERMLE Machine Company, HYBRID, Matsuura, Mazak, OPTOMEC, SIEMENS, Sodick

By 2025

40% revenue generation from other markets

$260mm value of shipped machines

$475mm hybrid material revenue

75% revenue is generated in the aerospace industry

Advantages:

- Used across multiple industries
- Reduced production time for complex parts
- High accuracy and precision
- Lower costs and decreased material wastage

Source: Press Articles; 1) Direct Energy Deposition

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Injection Molding

3D printing and injection molding are complementary ways of manufacturing

3D Printing vs. Injection Molding

Although 3D printing manufacturing is emerging as a preferred manufacturing technology, it cannot completely replace traditional manufacturing through injection molding and other mass manufacturing processes

Benefits –

Injection Molding	3D Printing
• Faster time to part • Accurate and repeatable • Low raw material cost • Wide variety of materials • Uninterrupted production process • Readily available, low-cost hardware	• Nearly unlimited geometric freedom • Part cost not dictated by complexity • Access to CAD design files • Zero tooling investment • Zero iteration cost • Downtime in production cycle

Drawbacks –

Injection Molding	3D Printing
• Time-consuming tooling build process • Up-front tooling costs • Production limited to tooling location • Requires warehousing and capital outlay • Tooling requires storage • Costly design iteration • Part complexity directly linked to tool cost	• Slower process for each part made • Capital expenditure for 3D printer • Limited accuracy and surface finish • Limited pallet of available material • High material costs

When the two processes are brought together as part of a well-managed workflow, their respective disadvantages are mitigated and strengths are enhanced; 3D printing and injection molding are complementary ways of manufacturing

3D printing can quickly deliver one-off prototypes with minimal cost, while injection molding delivers consistency, quality, and cost-effectiveness when large-scale production begins

- The precision and repeatability of 3D printing makes it an effective and accurate process for functional prototyping while **injection molding is a cost- and time-efficient process** to produce parts for larger production runs of tens of thousands
- These two processes work well together over a product's life cycle, starting with the design-risk mitigation of 3D printing prototyping and then shifting to the manufacturing method of injection molding to ramp up for high volumes
  - For example, a business may use SLS for rapid prototyping and low-volume production, and then switch to injection molding once the volume of parts is above a certain threshold

3D Printing to Injection Molding: Examples

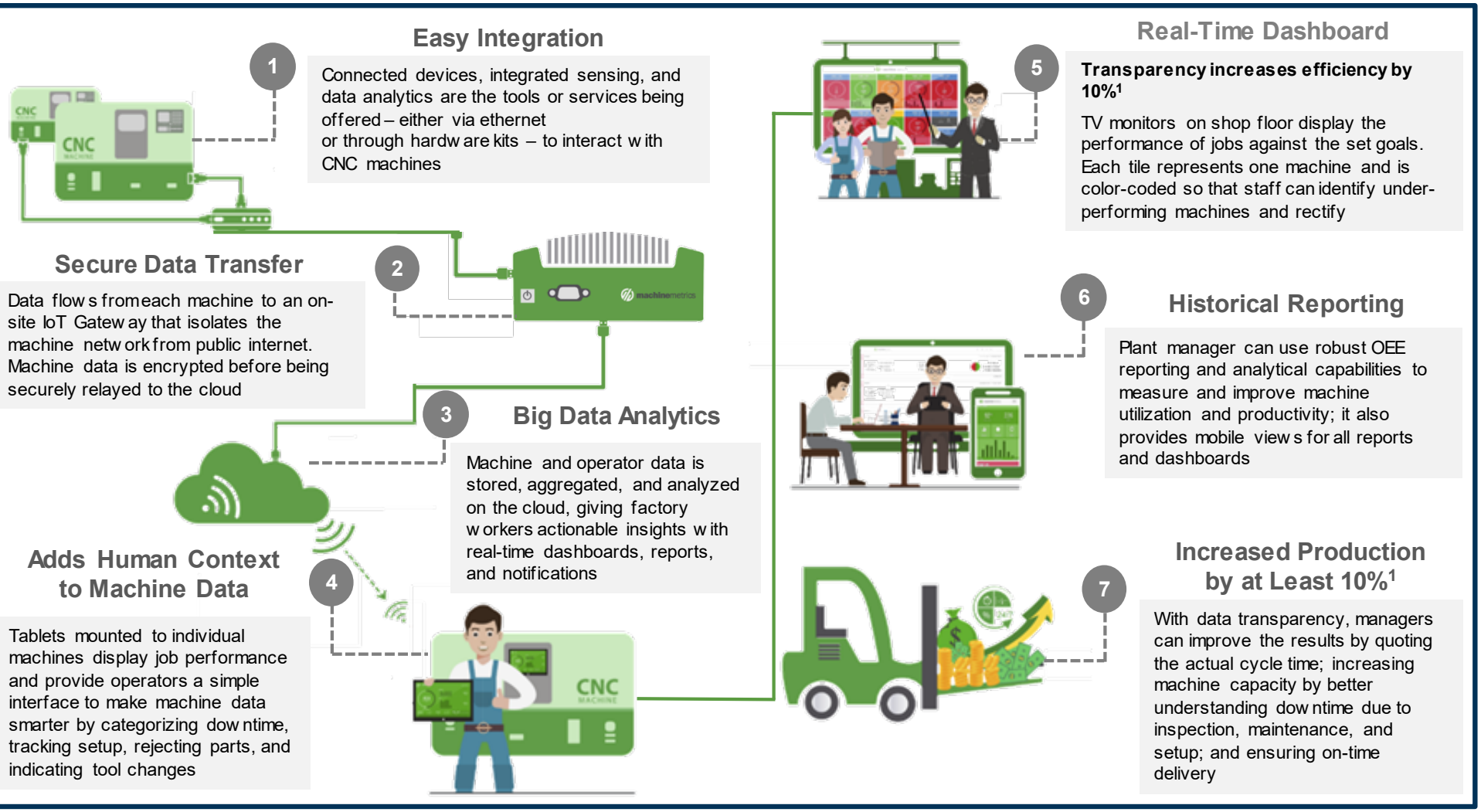
- LOCKHEED MARTIN: Launched its **Indago Quadcopter**, a small, portable drone by moving from 3D printing to injection molding
- BrainPost Technologies: Moved from 3D printing prototypes and **cast-urethane parts to injection molding**
- HEMOSONICS: Used **3D processes** together with **injection molding finishing** options and sheet metal fabrication

Source: Press Articles

CNC Machining and Industrial Internet-of-Things

Integrating IIoT with CNC helps manufacturers increase efficiency and transparency

How IIoT Improves CNC Operations



Source: Machine Metrics and Machine Design; 1) As per Machine Metrics

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CNC Machining and Artificial Intelligence

AI automatically adapts and optimizes machining parameters based on sensors

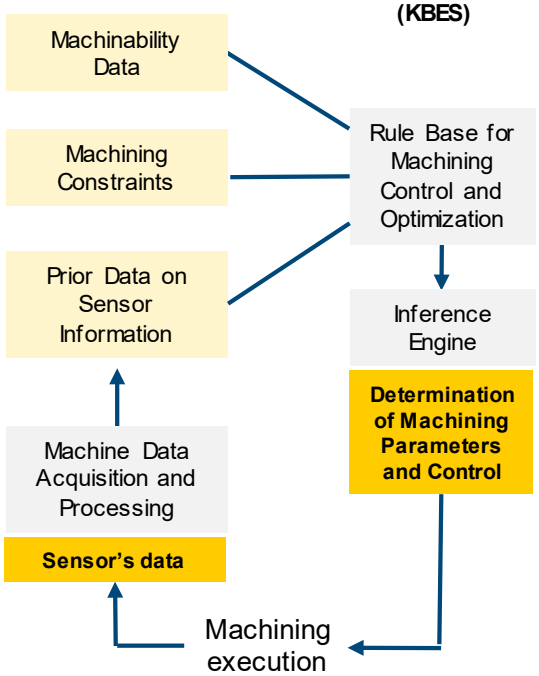
Integration of AI and CNC Machining

The optimal cutting parameters can lower machining errors such as tool breakage, tool deflection, and tool wear, resulting in higher productivity at lower cost.

The researchers identified three main categories of **AI**-based methods for controlling CNC machining parameters:

Approaches

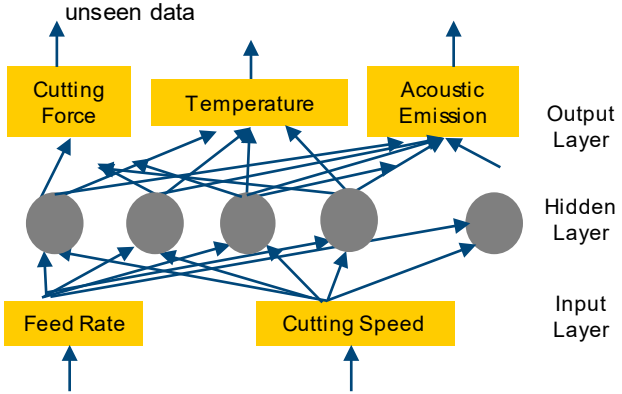
Knowledge-Based Expert Systems (KBES)



KBES can capture causal and inferential knowledge about machining processes to provide valuable recommendations for increasingly complex tasks

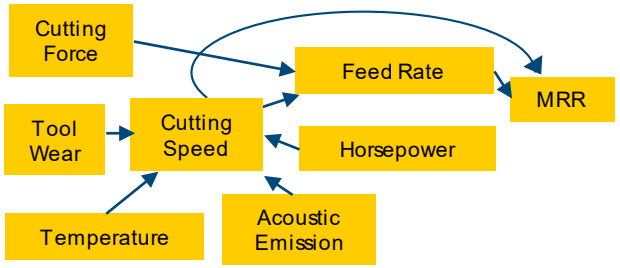
Neural Networks Approach

- Neural Networks generate their own knowledge by implementing a learning rule and learning from examples
- Learning is supervised, in which connection weights of the network are adapted in response to the inputs and desired output pairs
- Neural computing is also both distributed and associative, which means that multi-layer neural networks can register important features in their hidden layers
- A trained neural network for machining could use this "hidden knowledge" to produce important generalizations, allowing for a reasonable response even when presented with incomplete or previously unseen data



Probabilistic Inference Approach

- This AI-based approach uses influence diagrams specially developed for making complex decisions based on information from a variety of sources
- Key variables are then identified with influences or relationships between each other, and represented as nodes:
  - ► Chance nodes represent highly variable values such as cutting force, tool wear, and acoustic emissions
  - ► Decision nodes are values such as feed rate or cutting speed that are chosen by the operator
  - ► Value nodes represent the objective to be maximized. This would most likely be the metal removal rate



Source: Equipment News

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Selected Market Map – Machining

Source: PitchBook Data

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Selected Market Map – Injection Molding

Source: PitchBookData

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