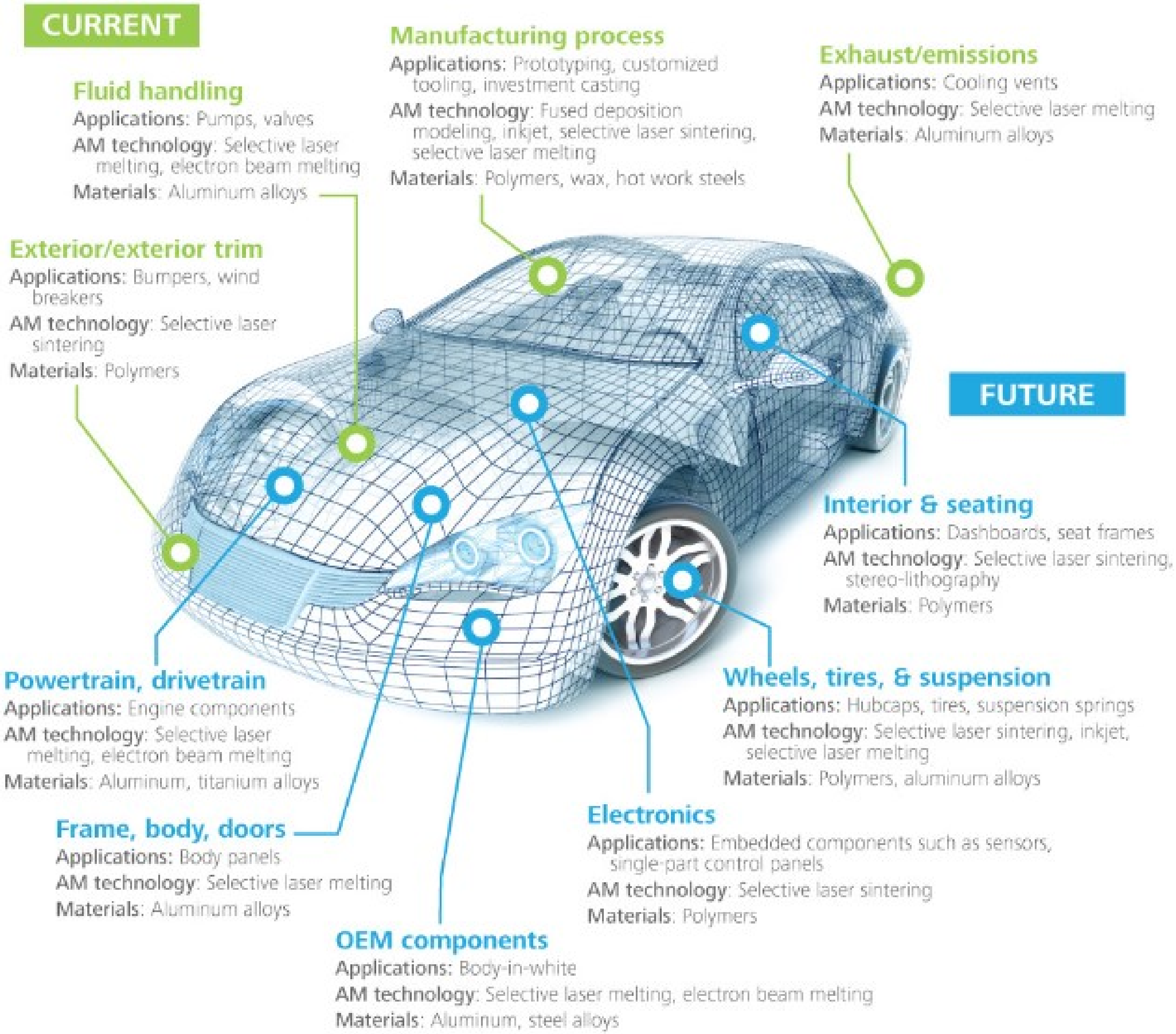
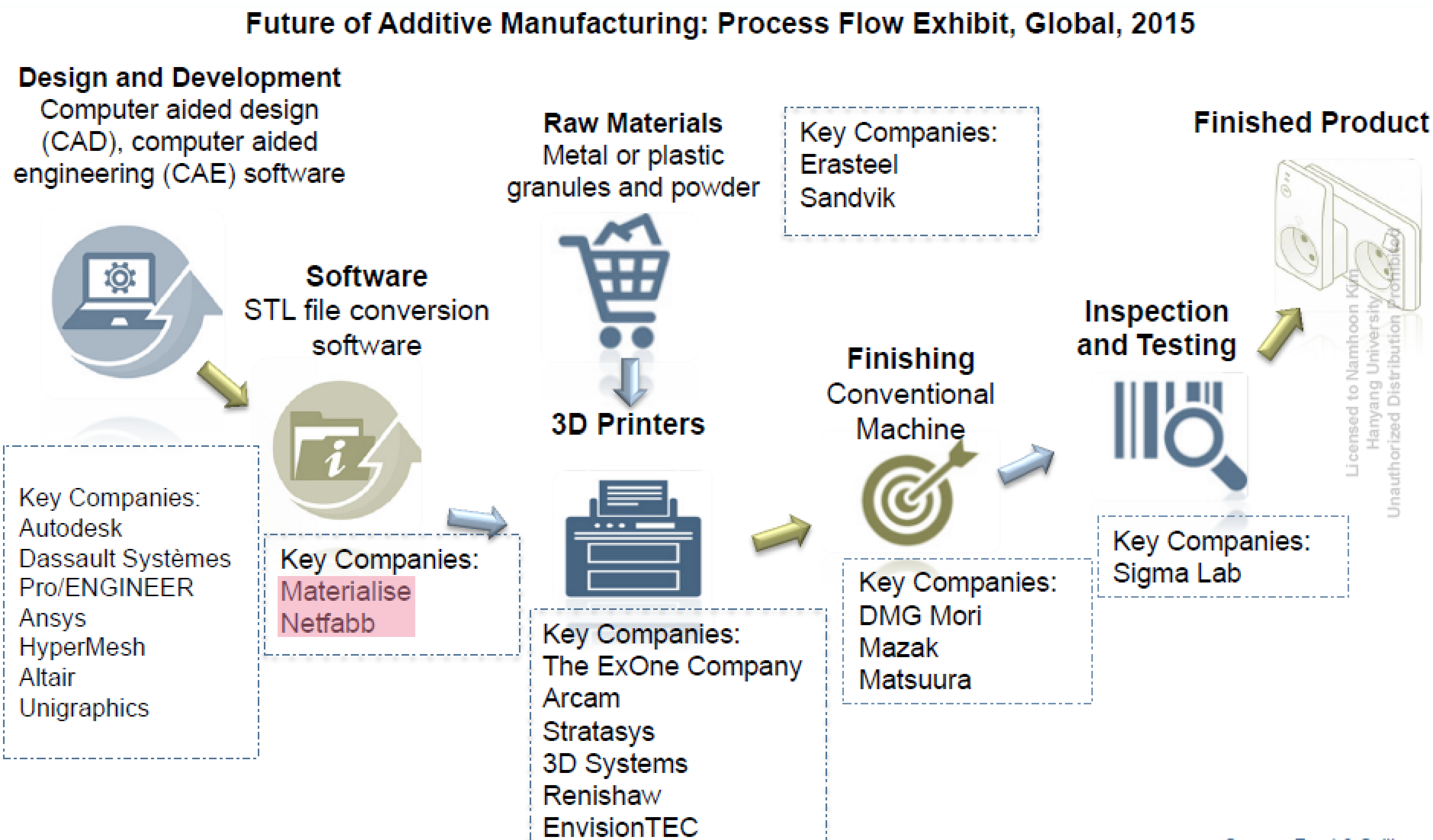
AM in an Automobile (Deloitte, 2015)



Global AM Market, Forecast to 2025 (2016.05)

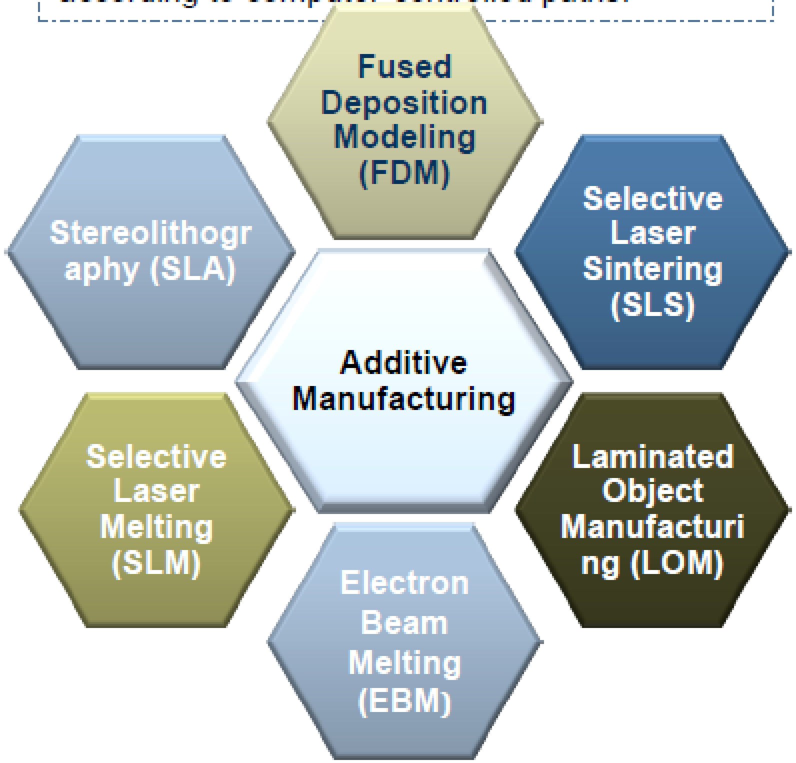


Source: Frost & Sullivan

Technology Classification

Future of Additive Manufacturing: Technologies Used, Global, 2015

The system uses thermoplastic material, which is melted to a semi-liquid state and extruded according to computer-controlled paths.



A stereolithography apparatus uses liquid plastic, a perforated platform, and a UV laser to print 3D objects.

Small particles of plastic, glass, or ceramics are fused together from a high-powered laser to form a solid 3D object.

Similar to electron beam melting, this method creates complex objects by completely melting the metal powder using a high-powered laser beam.

An economic process in which layers of adhesive-laminated paper or plastic sheets are glued together and cut to create complex shapes.

A focused beam of high-energy electrons is used to melt the metal powder layer by layer in the vacuum as per the pre-defined dimensions.

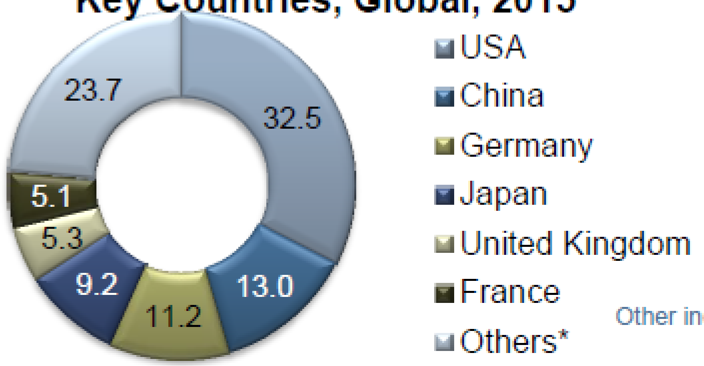
Source: Frost & Sullivan

Comparative Analysis of 3D Printing Technologies

Future of Additive Manufacturing: Comparative Analysis of Major 3D Printing Technologies, Global, 2015

Technology	Stereolithography	Fused Deposition Modeling	Selective Laser Sintering	Electron Beam Melting	Laminated Object Manufacturing	Selective Laser Melting
North America	High	High	Medium	High	Medium	High
APAC	Medium	High	Medium	Medium	Low/Nil	Medium
EME	High	Medium	High	High	Low/Nil	High
ROW	Medium	Medium	Low/Nil	Medium	Low/Nil	Medium

Future of Additive Manufacturing: Market Share Percent of Key Countries, Global, 2015



- North America and Europe being early adaptors of CAD and CAE, have the highest market shares in the additive manufacturing market.
- The APAC countries, particularly China, is poised to see large-scale adoption of additive manufacturing in consumer electronics and retail markets.

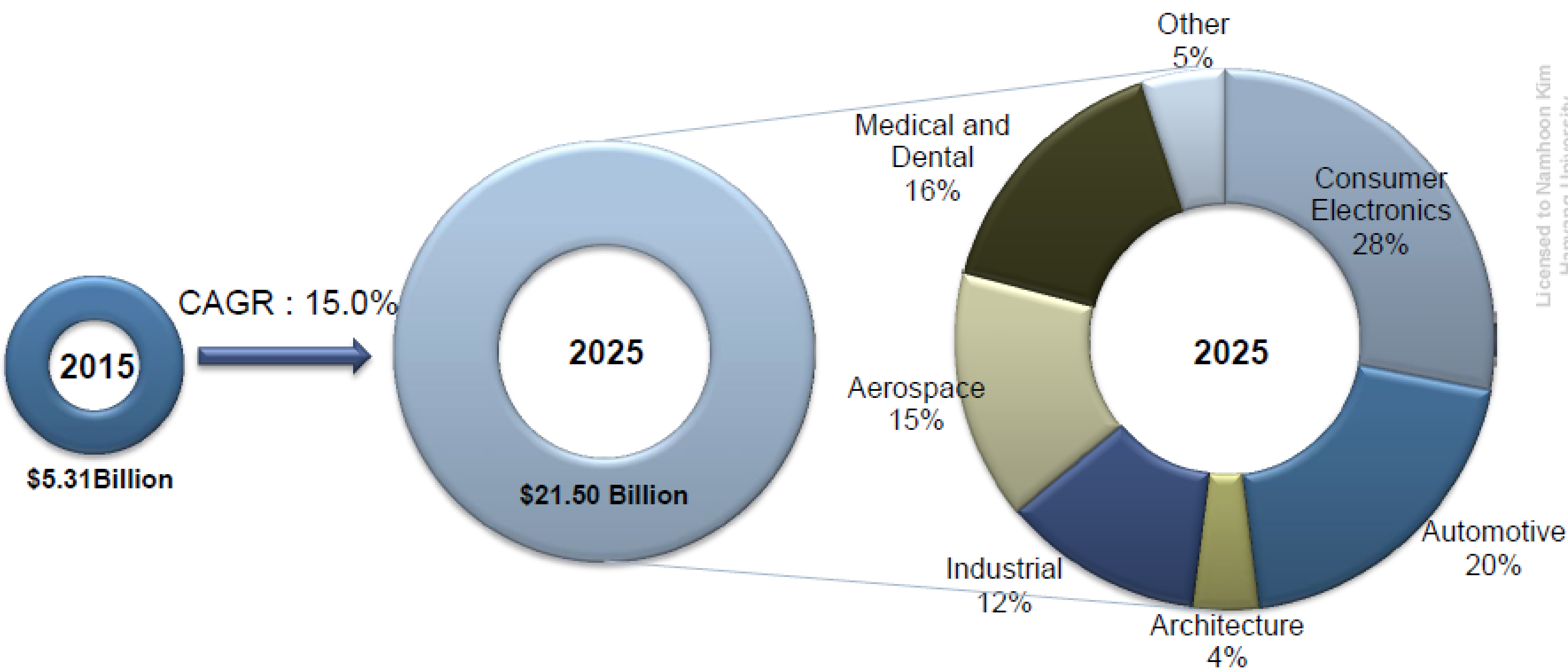
Other include India, Latin America, Russia, Australia, Italy Sweden, Belgium, Spain, Netherlands

Source: Frost & Sullivan

3D Printing Market Potential

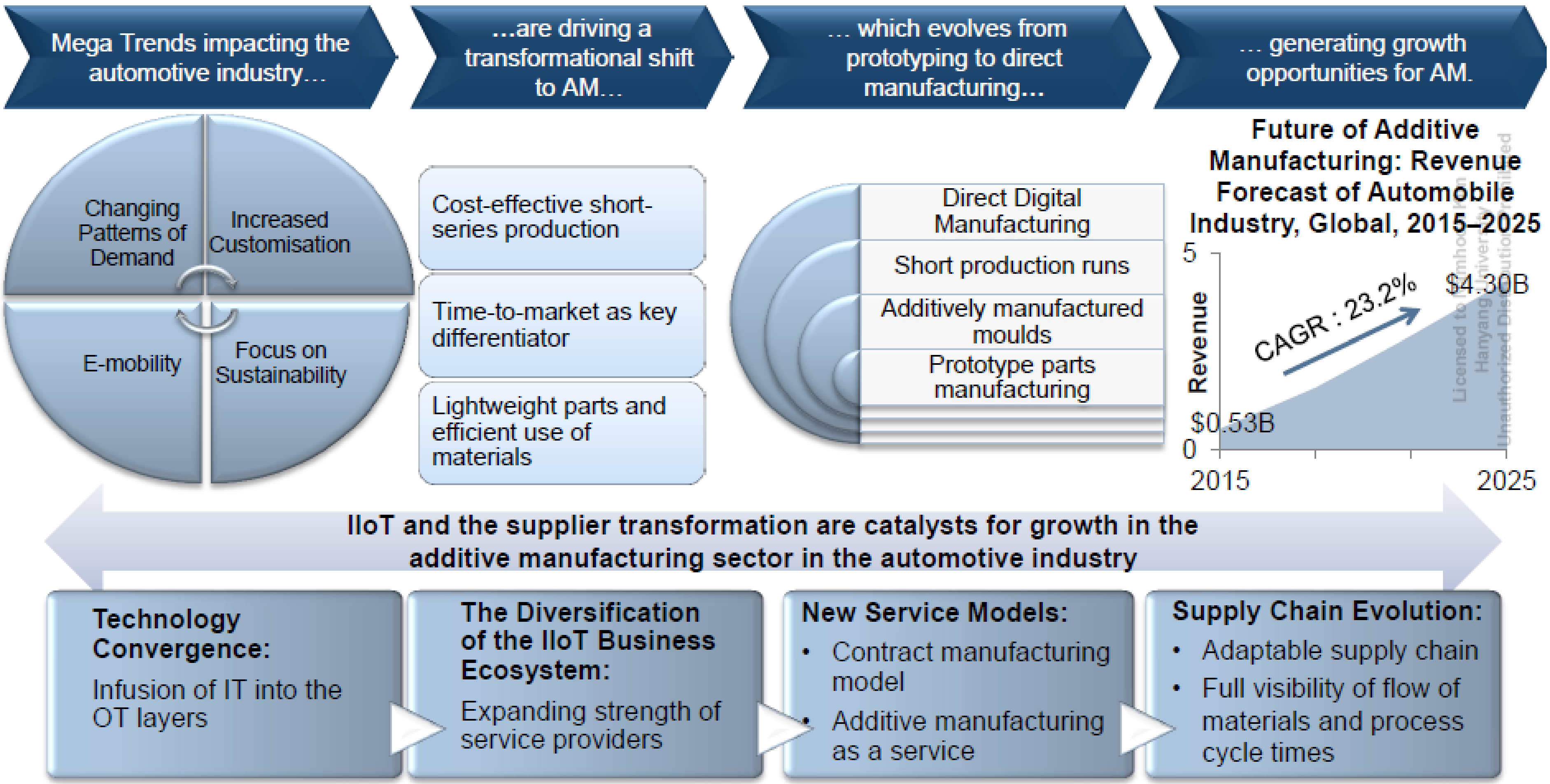
Future of Additive Manufacturing: Schematic of Revenue Generation in Manufacturing Sectors, Global, 2015–2025

The aerospace, automotive, and medical industries are expected to account for 51% of the 3D printing market by 2025.

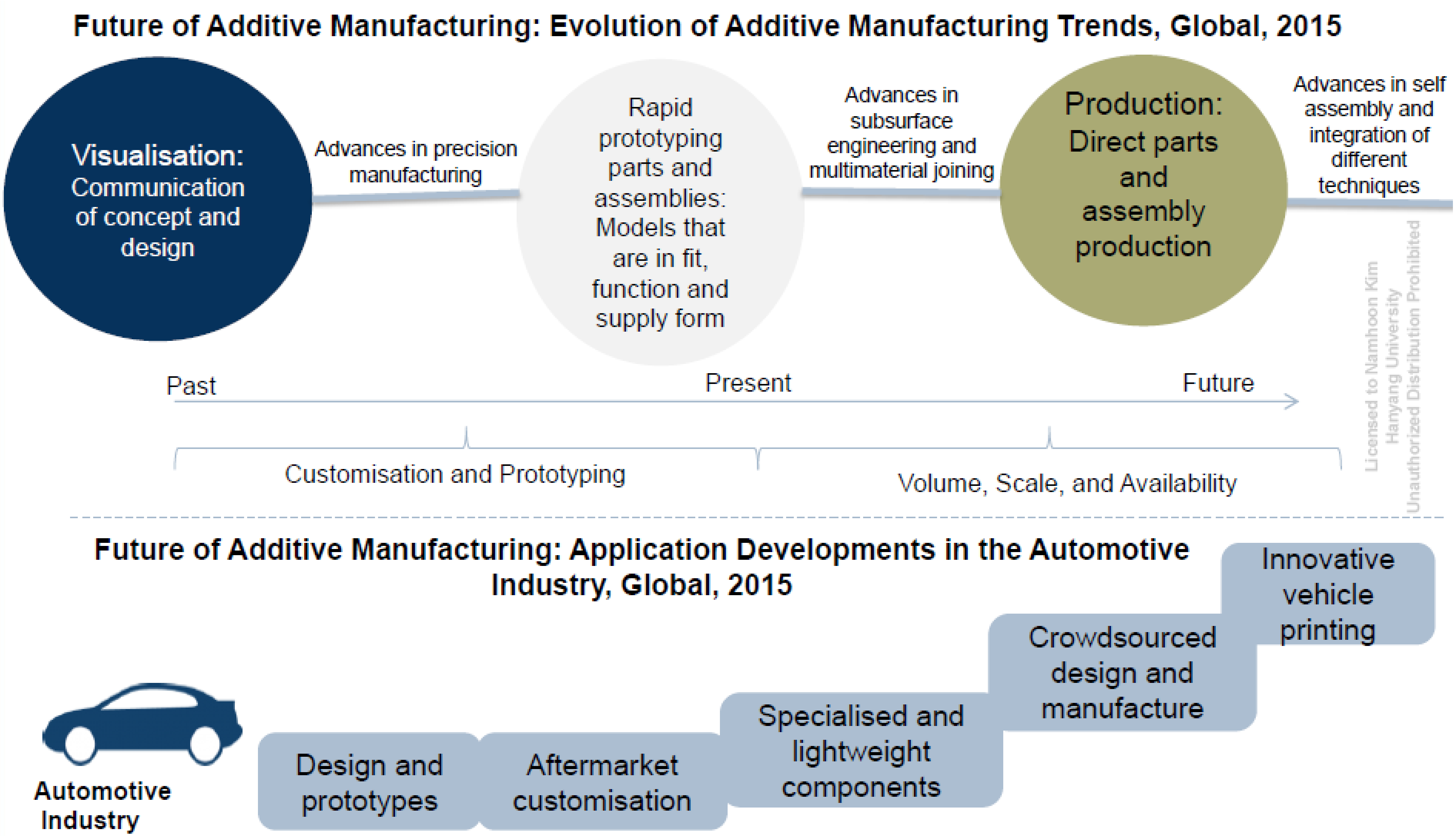


3D Printing in the Automotive Industry

Additive Manufacturing in the automotive industry is poised to become a $4.30 Billion global business by 2025



The Shift in Applications



A Print, Assemble, Drive Scenario?

Future of Additive Manufacturing: Automotive Applications, Global, 2015

1. Strati

- Local Motors and Cincinnati Incorporated have developed a car that is entirely manufactured through 3D printed.
- The car body comprises of carbon fibres and the body is printed over 44 hours with 212 layers.
- This enables the development of micro factories that support quick delivery times, reduces waste, and lowers distribution costs by 97%.

2. Ford 3D Store

- Ford uses the following techniques for its 3D printing solutions - FDM, SLS, and 3D sand printing to print over 500,000 parts.

2. BMW

- Apart from prototyping, BMW uses 3D printing to build hand tools for automobile testing and assembly.
- Using SLS, BMW has managed to create “thumbs” for its workers to help prevent injuries and pain.

Additive manufacturing: A long-term game changer for manufacturers (McKinsey, 2017.09)

- Additive Manufacturing (AM)
  - the process of making a product layer by layer instead of using traditional molding or subtractive methods
- Best-known forms of AM today depend on the material:
  - SLS (selective laser sintering), SLA (stereolithography), and FDM (fused deposition modeling) in plastics
  - DMLS (direct metal laser sintering) and LMD (laser metal deposition) in metals
  - A wide range of new plastics has been developed, along with processes and machines for printing with ceramics, glass, paper, wood, cement, graphene, and even living cells
- Used for spare parts, small series production, and tooling

AM is already a reality in many industries

Aerospace	Industrial	Healthcare
• **Fuel nozzle** for flight engines • **5x more durable, 25% lighter**	• **Repair of burner heads** for gas turbines • Reduction of **repair time from 44 to 4 weeks**	• **Hearing aids** • Mass production of **highly customized** parts
• **Thrust chamber** for aerospace rocket engine. **More reliable, robust, and efficient**	• Printing of industrial **filters with geometrical optimization** • **15% pumping energy reduction**	• **Model to aid tumor surgery** • **Reduction of surgery time and complications**
• **Metal brackets designed** for additive manufacturing • Resulting in **up to 50% less weight** and less raw material input	• **Increase** of machine parts **performance through special design** • Reduction of **production time from days to hours**	• **Artificial limbs constructed in 2 weeks,** replacing lower half of left leg • Perfect **physical fit with aesthetic components**

Additive manufacturing: A long-term game changer for manufacturers (September 12, 2017)

AM offers significant benefits

Design and engineering

Faster time to market
- Fast prototyping
- Fast design adjustments

Greater customization
- New customized applications
- More differentiated products

Product enhancements
- Better functionalities/ product performance
- New designs
- Less weight

Manufacturing

Faster/more flexible manufacturing process
- No setup time in production
- Fewer production steps/ interfaces
- Fewer required parts
- Less assembly time
- More flexibility and better load balance
- Inherent quality assurance process
- Fewer dedicated machines

Higher material productivity
- Less material waste
- New material features

Service

Simplified supply chain
- Localized production
- Elimination of obsolete parts
- Refurbishment for specific components
- Less dependence on suppliers

More efficient sales process
- Customized product exemplification

Relevant for

- Engineering-intensive business
- High-value/ low-volume business
- Spare parts-intensive business

AM's limitations

Design and engineering	Manufacturing	Service
A. **Lack of design knowledge** (eg, long-term performance of materials and design for 3D printing) B. High **risk of design pirating** through users	C. **High production costs** (eg, material costs and limits on production speed) D. **Limitations on size** (for specific AM technologies) E. **Limitations on product quality** (eg, in range and combination of materials, resilience, surface finish) F. Dependence on **small number of machine suppliers**	G. Lack **of industry-specific testing procedures** (eg, for production processes) H. Lack of **structural regulations** in supplier networks I. Risk of **supply chain disruption**

Cross-value chain topics include: • Process certification • Cyber security • IP rights

McKinsey&Company | Source: Expert interviews; team analysis

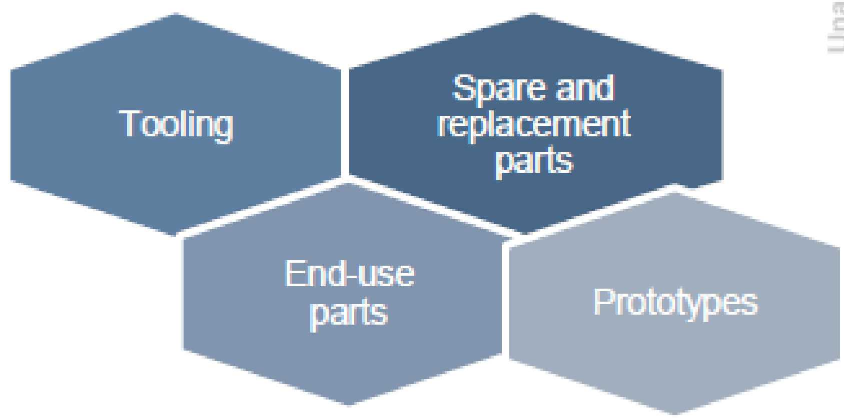
Various Stakeholders

- Major governments are setting up R&D funds
  - European Union's Horizon 2020 program
- Universities are partnering with manufacturers' research centers
  - Advanced Remanufacturing and Technology Centre in Singapore
  - RWTH Aachen University/Fraunhofer Institute for Production Technology
- New design and service companies are being set up and new technologies developed
  - BigRep and Carbon3D
- Entire business models on AM
  - Align Technology, with Invisalign, an alternative to metal dental braces
  - Sonova for in-ear hearing aids
  - Mykita with eyeglasses
  - Shapeways with crowd design of consumer products

Impact of 3D Printing in the Automotive Industry

- significantly reduce the need for multiple participants in the manufacturing value chain
- reduce associated costs
- improve deliveries
- enable implementing an organized logistics chain.

3D printing exhibits wide applications within the automotive sector for prototyping and tooling, research and development, and product innovation. On the other hand, the market faces certain challenges such as very high volume requirements, the high cost of 3D printing software and the dearth of skilled labor.



Automotive Industry

- profoundly influenced major companies such as AUDI, BMW, Rolls Royce, and Porsche
- Debut in 2014, the Strati electric car
  - 3D printed from thermoplastic using large-scale fused deposition (big area additive manufacturing) technology
  - collaborative effort by Cincinnati Incorporated, Oak Ridge National Laboratory, Local Motors, and other companies
- In early 2014, Local Motors, OLLI
  - Very first 3D printed electric bus (commercial vehicles) out of recyclable materials

Strati (2015.02)

- Local Motors + Oak Ridge National Laboratory (Manufacturing Demonstration Facility)
  - world's first 3D-Printed electric car
  - 3D Printer (BAAM, Cincinnati사), 5축 절삭가공기, 조립공간 (컨베이어, 대차 등 불필요)
  - 차체질량 550kg (일반 차체+도어+후드+내장부품: 400kg)
  - 부품수가 1/400로 줄어듬 (EV: 2만개→50개, 일체화)
  - (기존)철판을 프레스로 성형하여 용접 등으로 조립
  - (3D 프린터) 충격흡수구조도 1개 부품 내부로 제조
  - 강도확보 (미국 법규): ABS 80%, carbon fiber 20%
  - 5축 가공기: 조립부 형상 정밀도 향상, 외관 매끄럽게, 도장? Wrapping film
  - 조형 44시간, 조립 24시간


b
LOCAL MOTORS
THERMWOOD

BAAM

- Big Area Additive Manufacturing
- 개발: ORNL(Oak Ridge National Laboratory)
- 제조사: 미국 Cincinnati사 (공작기계)
- 세계 최대 3D 프린터 (2015.03 기준)
- 노즐: 직경 8mm, 초당 이동거리 76mm
- 적층 두께: 4mm
- 제조영역: 6.0 x 2.3 x 1.8m
- 속도: 45kg/hr

4.0 x 2.0 x 0.9m, 16kg/hr(탄소섬유강화ABS)

Microfactory

- 수송비용절감
- 지역생산, 지역소비로 제품을 개발/생산
- 고객이 제품설계나 디자인에 참여하여 공동 작업

디자인을 단기간에 변경/조정 가능

Rally Fighter (Phoenix, Arizona)

Olli (2016.09)

– (미) Local Motors, (미) IBM사와 공동 개발
– 전기자동차(EV)기반 소형(12인승) 자동운전 버스
– 운행속도: 24~32 km/h

Honda 소형 EV: MC-b (2016.10)

– 사이드 도어 이외 외장부품: ABS 수지

금속 3D프린터가 3조엔(2030년) 시장창출 독일, 미국이 양산적용으로 선행

- GE Additive
  - 항공우주분야에서 선행: 부품단가 높음, 경량화 장점이 큼
  - 항공기용엔진사업 (센서하우징, 터빈블레이드, 연료노즐 등) → 발전기사업
  - 2012, GE Aviation acquires Morris Technologies
  - 2016, 금속AM 장치 메이커 2개사 인수: Arcam (스웨덴), Concept Laser (독일)
- Safran Aircraft Engines (프랑스, (구)Snecma)
  - Jet Engine “LEAP”연료노즐
  - [경량화(25%), 내구성향상(5배), 부품수 감소, 용접회수 (25→5회)] → (강도향상, 조립공수 저감)

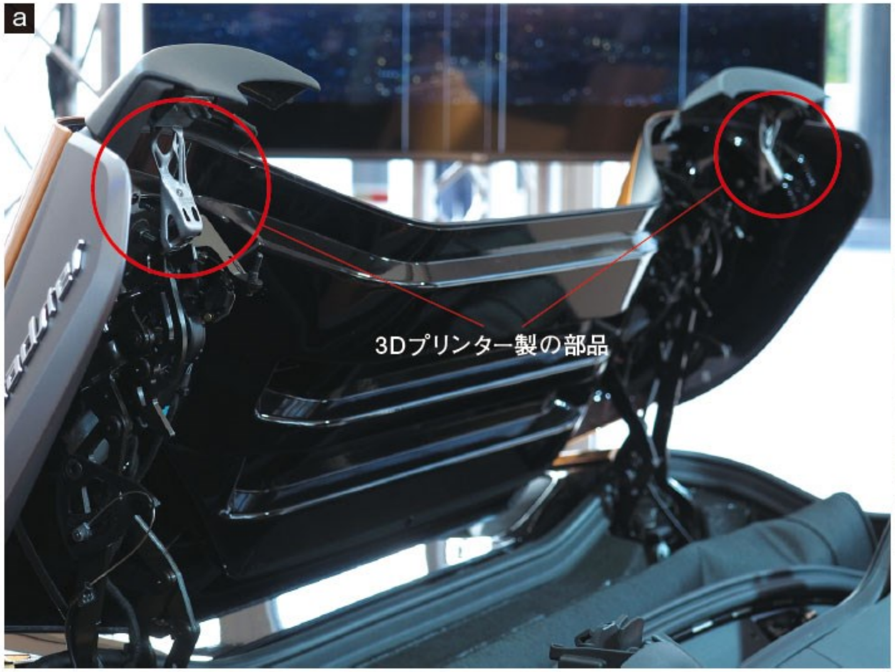
Source: Nikkei Monozukuri 2019년 5월호

Jet Engine 부품에 활용

항공기용 엔진 "GE-94B"에 탑재한 온도센서"T25"의 하우징
고압 컴프레서 흡기부에 부착하여 온도와 압력을 계측하여 엔진제어시스템에 전달
FAA(Federal Aviation Administration)인증(2015.04, 금속AM 부품 최초)

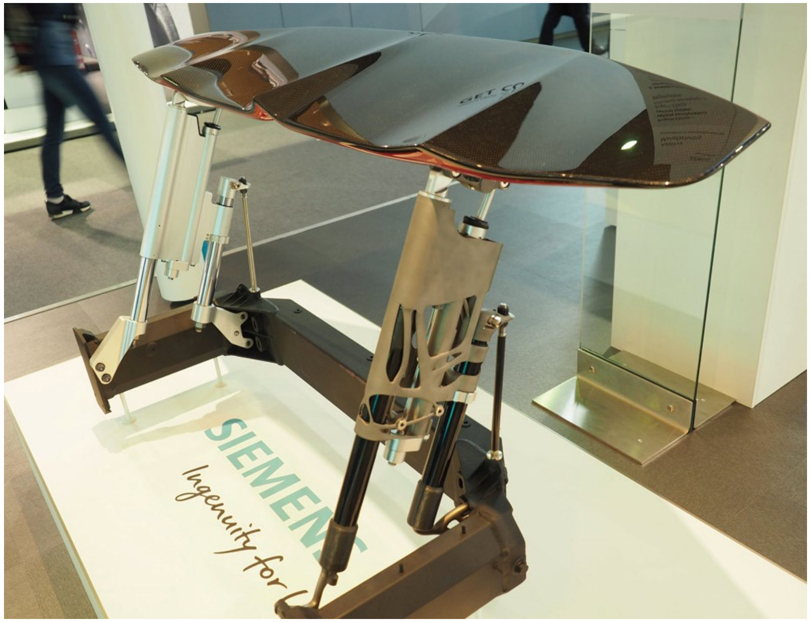
BMW i8 roadster: bracket

– 2018.04, 2억원 이상 고급 양산차에 최초로 금속AM 부품 적용
– 수지 사출성형품(PA6 GF30, 동적시험에서 강도 부족) → Al합금의 AM 부품(AlSi10Mg, Powder Bed Fusion 방식)
– 강도 10배, 질량 40% (22g)
– Mg합금 다이캐스트(금형, 초기투자)와 비교하여 6만개까지는 금속AM이 유리



Bugatti Chiron

- Brake caliper
  - 길이41x폭21x높이13.6cm
  - Al합금(4.9kg) → Ti합금(Ti6Al4V, 2.9kg)
  - AM조형 후 일부분을 기계가공
- 공력제어시스템(rear wing) 부품



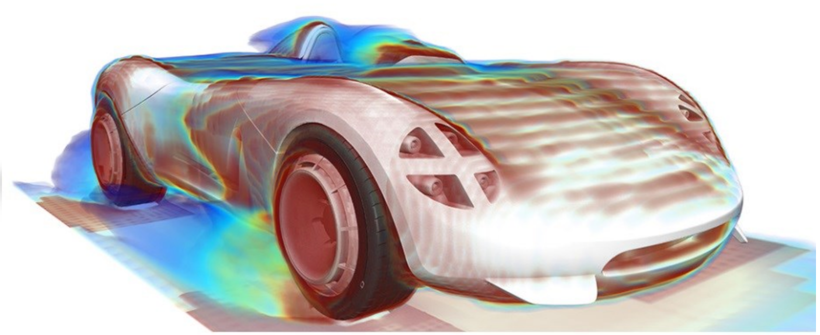
Volkwagen: Shift Knob

- 2018, HP(미국) 신 장비
  - 조형시간 단축
  - 금속분말을 바인더로 굳혀서 소결하는 방식 [분말야금, MIM(metal injection molding, 금속사출성형)] vs. 레이저나 전자빔으로 용융결합하는 방식 [주조]

Hackrod (미국): La Bandita

– 2014년 미국 CA주에서 창업, Siemens PLM Software와 함께 개발한 CAD와 VR기술을 결합한 설계방법
– 사막에서 주행테스트로 데이터 수집
– 대형 다축식 3D프린터를 이용해 바디와 샤시를 제작: Al합금과 카본소재를 조합
– Floor와 Powertrain은 Tesla제품 사용

Hackrod (미국): La Bandita



Divergent Blade

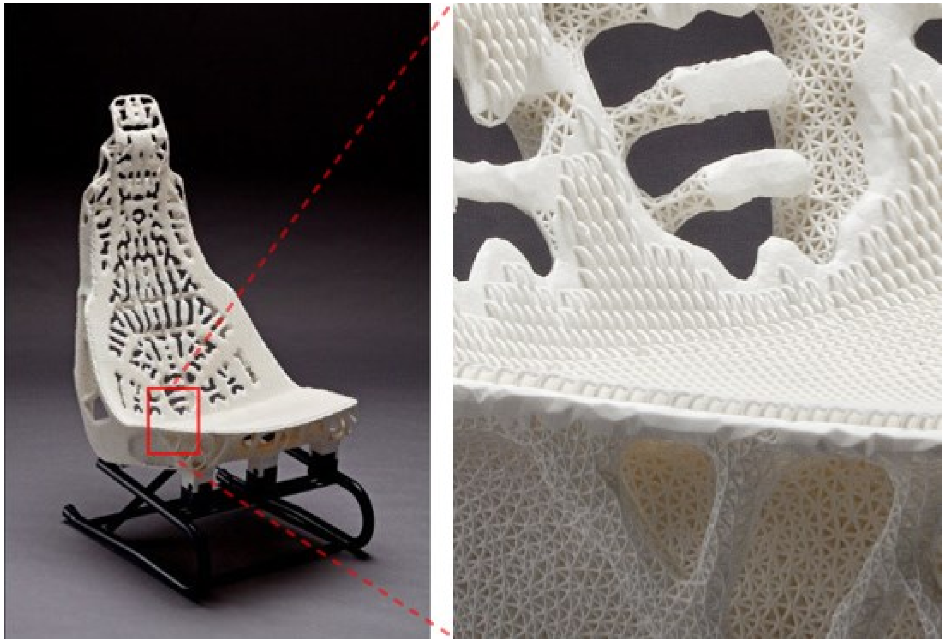
- Divergent 3D: 2012년 설립,
- Al합금을 소재로 샤시, 바디를 3D프린터로 제작
- 2016년 LA Motor Show에서 발표

Porsche

- 2020.04.10
- 버킷 시트의 '바디 폼'

Toyota’s Lightweight Car Seat

– Challenge: create such a revolutionizing model, but manipulate and build such a large file
  - apply the 3D geometry at the slice level instead of at the STL level, and save all information about structures and textures as metadata
  - (STL) 250GB (metadata) 36MB
– Reduction: (volume) 72%, (weight) 25→7kg, (heat capacity) 35.4→14.5J/K



https://www.materialise.com/en/cases/materialise-slicing-technology-enables-toyota%E2%80%99s-lightweight-car-seat

Automotive Industry

- Wire as Material Source for 3D Printing
  - US-based Digital Alloys Inc.
  - Joule Printing technology
  - fabricating functional metal alloys with a very high isotropic structure
  - producing tooling and low-volume cast parts in a quick manner
  - 25% to 50% less expensive than conventional (hard metal)
- Large Scale Printing of Automotive Parts
  - Israel-based Massivit3D Printing Technologies Ltd. (Massivit3D)
  - Gel Dispensing Technology
    - 1.5 x 1.2 x 1.8 meters (4 x 5 x 6 feet) or 160 cubic feet (3 m^3) in volume
    - 1,000 mm/39 in. per sec in x and y axes

AM Technologies and Component Mapping

AM Technology	Process	Target Components
Fused Deposition Modelling (FDM)	The FDM process uses thermoplastics such as Acrylonitrile Butadiene Styrene (ABS) for the designing and rapid prototyping of automotive components. This particular process deposits the material in ultra-fine beads along the extrusion path, after heating the material to a semi-liquid state for printing 3D objects and working prototypes.	▪ Component/Vehicle design prototyping ▪ Emission filter and filter housing caps and housing units ▪ Physical model of fuel doors, dashboard, and cluster ▪ Gauge pod, fork tube covers, headlight bezel, floorboard mounts, floorboard undercover, and wheel spacer cover ▪ Working prototype and low-volume components
Stereolithography (SLA)	SLA process uses materials such as composite photopolymers, resins, photopolymers, and thermoplastics for manufacturing automotive components. The technology uses an ultraviolet laser to produce the design of the component layer-by-layer using a liquid material. The material quickly hardens when it comes in contact with the laser light.	▪ Gear shift knobs ▪ Prototypes of pneumatic and hydraulic systems ▪ Transparent prototypes for engine components and tooling devices ▪ Headlamp, tail lamp, and lenses prototype ▪ Body kits and bumpers for a vehicle manifold and engine covers
Selective Laser Sintering (SLS)	The SLS process uses metal alloys, polymers, ceramic, and carbon fiber materials. It uses a power source to selectively melt and fuse powdered materials layer-by-layer to create a 3D printed object. The process involves a counter-rotating roller that spreads the material powder in precise amounts, as the laser fuses the powder to build the desired component or object.	▪ Gearbox prototypes ▪ Grills and fenders ▪ Fuel tanks ▪ Small engine components ▪ Hydraulic actuator systems ▪ Heat exchangers ▪ Rapid prototyping of low volume parts ▪ Tubes and nodes
Electron Beam Melting (EBM)	The EMB technique uses an electron beam in high vacuum as its power source, which selectively melts the metal powder bed to print the design of the object layer-by-layer. This novel technology is compatible with metal materials, such as aluminum and its alloys, superalloys, titanium and its alloys, cobalt chrome, and so on. Material is layered according to the data obtained from a 3D Computer-aided Design (CAD) model.	▪ Pump impeller ▪ Wheel rims ▪ Small compressor components ▪ Frame construction ▪ Variable density system ▪ Turbine blades

Source: FutureBridge (2019.10.16)

Major Digital Manufacturing Trends in Automotive Industry (1)

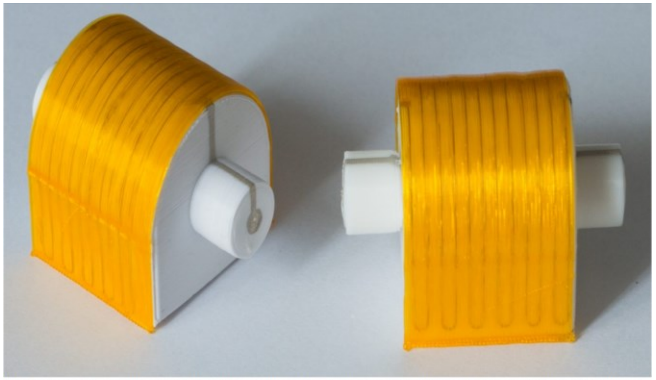
- 3D printing will power the electrification of vehicles
  - Olli's (Local Motors): ORNL's Big Area Additive Manufacturing (BAAM), Thermwood's Large Scale Additive Manufacturing (LSAM) machines
  - Fun Utility Vehicles (FUVs, Arcimoto): XponentialWorks
- Integrating AM in automotive series production: HW+SW+Material
  - larger parts, higher volumes and faster production

Electric shuttle Olli (left) and Arcimoto's FUV (right) feature 3D-printed components. The use of 3D printing helped to reduce the weight of the vehicles. [Image credits: Local Motors, Arcimoto]

[Image credit: Desktop Metal]

Major Digital Manufacturing Trends in Automotive Industry (2)

- Collaboration drives AM industrialisation in automotive
  - Industrialization and Digitalization of Additive Manufacturing (IDAM) project from Germany
    - at least 50,000 components per year in common parts production and more than 10,000 individual and spare parts
  - POLYLINE project
    - to overcome existing challenges in integrating AM into automotive production lines
- 3D-printed electronics for connected cars
  - smaller, more complex electronics
  - embed these sensors directly into mechanical components and the structure of vehicles



Electronics 3D printing works by jetting conductive and insulating inks on the printing surface in lines as thin as few microns. UV light is then applied to solidify the inks. [Image credit: Neotech AMT]

Source: amfg.ai (2020.09.03)

Innovations in AM (2019.04)

- Powder-Based 3D Printing to Provide High Quality Prints using Predictive Simulation Software and Support-Free AM
  - *Velo3D Inc., US*
- Additive Manufacturing of Micrometer Level Components
  - *Nanofabrica, Israel*
- X-rays for Identifying Defects in Laser Powder Bed 3D Metal Printing
  - *Carnegie Mellon University and Argonne National Laboratory*
- 3D Printed Tool for Titanium Cutting
  - *RMIT University, Melbourne, and RMIT Advanced Manufacturing Precinct*

Expanding Applications for AM (2020.03)

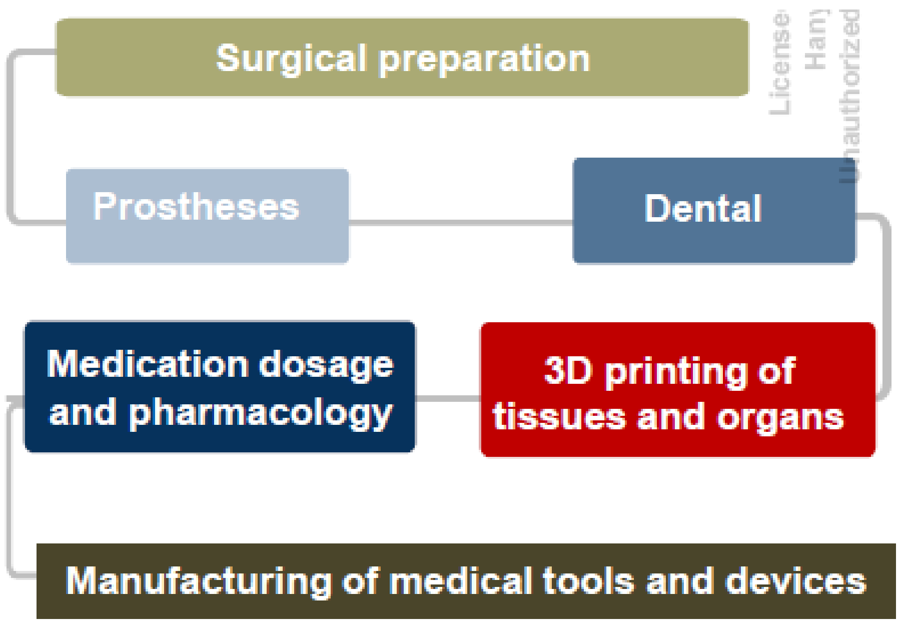
- Building and Construction Industry
  - Contour Crafting Corp., Dr. Behrokh Khoshnevis at USC
  - Eco-friendly Contraction Technique Reducing Material Waste
    - WinSun Decoration Design Engineering: five-story apartment that is 11,840 square feet
  - Resilient Materials for a Strong Structure
    - Austria-based ICON
  - Multi-axis 3D Printer for Commercial Applications
    - Amsterdam-based MX3D
- Fabric and Fashion Industry
  - shoes, consumer goods, clothing as well as jewelry
  - Key Participants and Innovations Relevant to the Fabric and Fashion Manufacturing: Adidas, Casca Laboratory, Faunhofer UMSICHT collaborated with AddiTex

Food Industry

Company	3D printer company Partnership/Collaboration	Application and Principle
Pepsico	PEPSICO has adopted one of the most unique food creation machines the Foodini Natural Process 3D printer for printing of edible products using fresh ingredients.	Plastic prototypes of potato chips
Hershey	Hershey is in collaboration with Cocojet, ideal for chocolate printing	Chocolate candy
Barilla	Barilla, the leading ilalian pasta manufacturer, collaborated with TNO to allow consumers to print a variety of differently shaped pasta using CAD	Pasta
Oreo (Nabisco)	MAYA, a design and 3D printer services company, teamed with Oreo and Twitter to offer consumers a unique journey of purchasing cookies by allowing them to create, mash, and remix flavors using options on a vending machine to create new cookie flavors. In the US, Oreo is made by the Nabisco Div. of Mondelez International.	Cookies and customized crème
CSM Bakery Solutions and 3D Systems Corporation	Are working together on the development, sale, and distribution of 3D printers, products and materials for the food industry.	Customized chocolate and cakes
3D Systems	3D systems has partnered with Chefjet that uses a FFF (fused filament fabrication) 3D printer to produce sugar candies made out of edible ink.	Crystalizes layers of sugar to form geometric configurations
byFlow	byFlow and De Verspillingsfabriek collaborated to create awareness of food waste upcycling in schools and universities. Coordinators and lecturers at HAS University of Applied Sciences guide students and researchers in upcycling food waste to be reused as materials for 3D food printing.	Aimed at servicing the airline and schools industry with nutritional uniform mass products
Dinara Kasko	Dinara Kasko, a pastry artist in Ukraine, has partnered with Ultimaker 3D printer to enhance the visual appearance of pastries, such as printing fancy desserts of geometric and abstract designs.	Unique plastic molds for pastry making
Systems & Materials Research Corporation (SMRC)- NASA	In 2013, NASA awarded SMRC a Phase I Small Business Innovation Research (SBIR) contract to 3D print foods using inkjet technology. In 2016, BeeHex, Inc. was created based on this work to provide astronauts with 3D printed nutrition in microgravity.	Bee Hex is under contract with the US Army to develop smart field kitchen systems for soldiers based on their physiological needs.

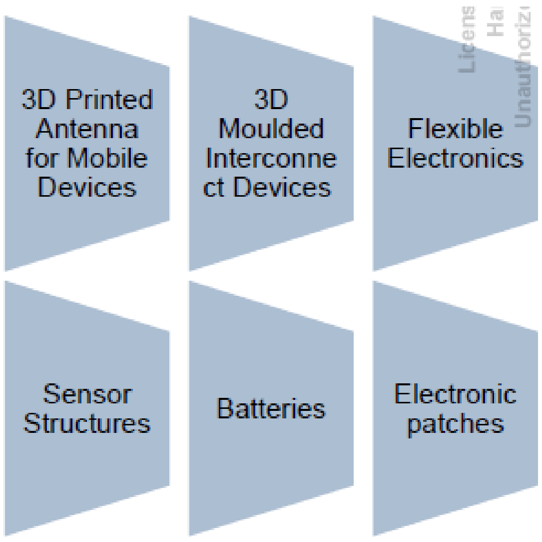
Medicine & Healthcare Industry

- printing of skin, for pharmaceutical research
- developing bone and cartilage using biomaterials
- replacement of organs, tissue research
- preparing artificial organs using biomaterials
  - MHOX, an Italian design studio, Enhance Your Eye project



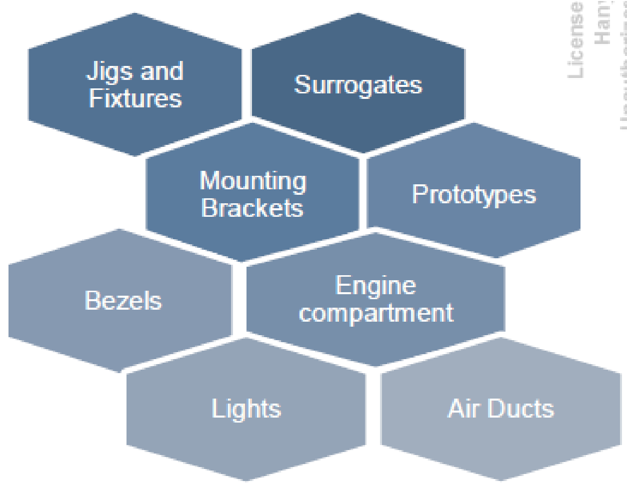
Electric and Electronic Industry

- Aerosol Compatible with Conductive, Ceramic, and Plastic Materials
  - Optomec, Aerosol Jet printing
- 3D-printed Semiconductor Packaging Technology
  - EoPlex Inc., Configurable Sintered Interconnect (CSI™) Manufacturing Platform
- 3D Printed Circuits and Single-layer PCBs
  - BotFactory, Squink desktop 3D printer

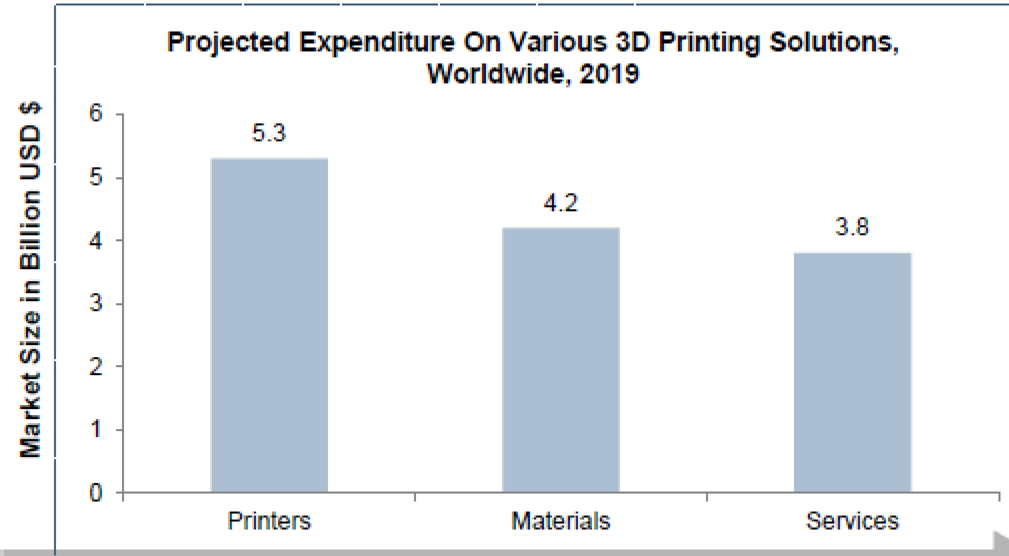


Aerospace Industry

- In-house Laboratory Enabling Accurate 3D Printed Parts
  - China Eastern Airlines Technic, Fortus® 450mc and ULTEM™ 9085 resin from Stratasys
- Composites Leading Material Used in Aerospace 3D Printing
  - Continuous Composites' CF3D (continuous fiber 3D printing process)
- Multi-material Powder Bed fusion Printing Metal and Polymer Parts
  - Selective powder deposition developed by Aerosint



Commodity and Factors Impacting 3D Printing Market



Source: Statista

Market Growth

The 3D printing market is predominantly segmented into printers, materials, and services. The printer market accounts for about $5.3 billion having the highest sales and will continue to rise in the future. Software solutions and related services are another area that will find significant growth, due to the need for computer-aided design (CAD) services and data analytics software that must be integrated with the printer to assist the process. The expansion in the 3D printing market is due to companies across industries increasingly adopting this technology for primary as well as secondary operational activities and not just for rapid prototyping of parts.

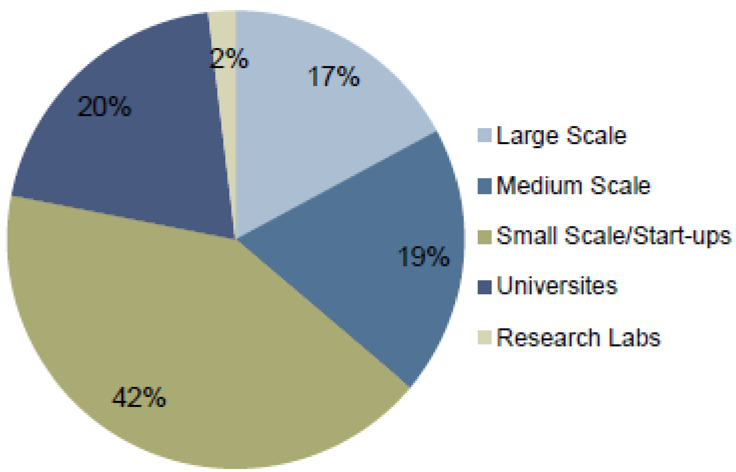
Opportunities in the 3D printing market have expanded with the greater availability of different 3D printing materials to print complex structures and the ability of 3D printing market participants to improve their scalability by accommodating more materials in a single machine. Moreover, hardware features such as speed of machines has also been enhanced as research continues to unveil new innovations that offer 3 times quicker results when compared to relatively slow SLS printing systems. As more and more companies begin to involve themselves into the market, each firm offers different services with the aim to close gaps in the market – from companies involved in printing lightweight parts, fully functional end products, completely functional electronic components, and even wearable products such as shoe insoles or jewelry.

Assessment of Emerging Innovations in 3D Printing Market

Key Application sectors

- **Automotive**
- **Aerospace**
- **Electronics**
- **Healthcare**
- **Petroleum & Mining**
- **Chemicals and Materials**
- **Building & Construction**

3D Printing Market, Type of Companies, Global, 2017-2019

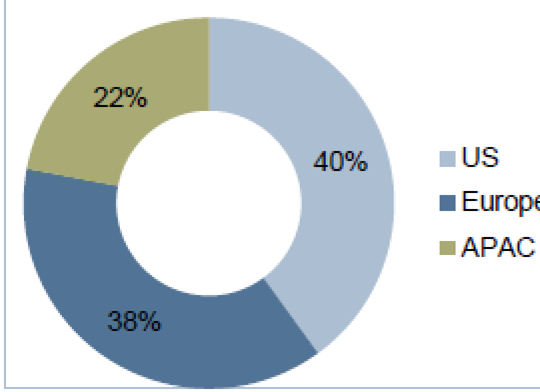


Access to companies of all sizes:

A majority of the companies fall under the small scale and start-up areas that seem to indulge in major research and innovations closing gaps in the 3D Printing market.

According to Frost & Sullivan's analysis around **42%** of the companies that provide 3D printing technology, processes, materials, software solutions are either small scale companies or start-ups with minimum global presence and a limited workforce. A majority of the companies are based in the US and Germany followed by other start-ups and small scale firms in China, Canada, Israel, India, and Australia.

3D Printing Market, Regional Analysis, Global, 2017-2019



Representative Advanced 3D Printing Technologies

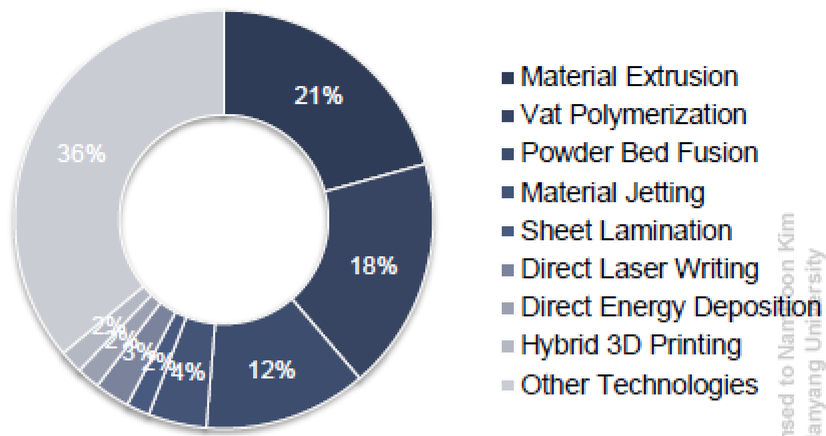
- Aerosol Jet Technology
- LaserComb™ Technology
- Bioprinting
- MagnetoJet Technology
- Rapid Plasma Deposition Technology
- Augmented Polymer Deposition Technology
- Continuous Fiber 3D Printing Technology

Other Technologies

There are over 30+ proprietary technologies developed by small and large scale companies with the aim to become pioneers in the 3D printing field. The diversity scope of the technology does not limit its use to one industry or material alone, but allows widespread scope.

Note: Material extrusion includes fused deposition modeling/fused filament fabrication); powder bed fusion includes direct metal laser sintering, electron beam melting, selective heat sintering, selective laser melting, and selective laser sintering. Vat polymerization includes stereolithography and digital light processing, continuous liquid interface production. Material jetting includes binder jet 3D printing.

Analysis of Evolving 3D Printing Market, Technologies, Global, 2016-2019



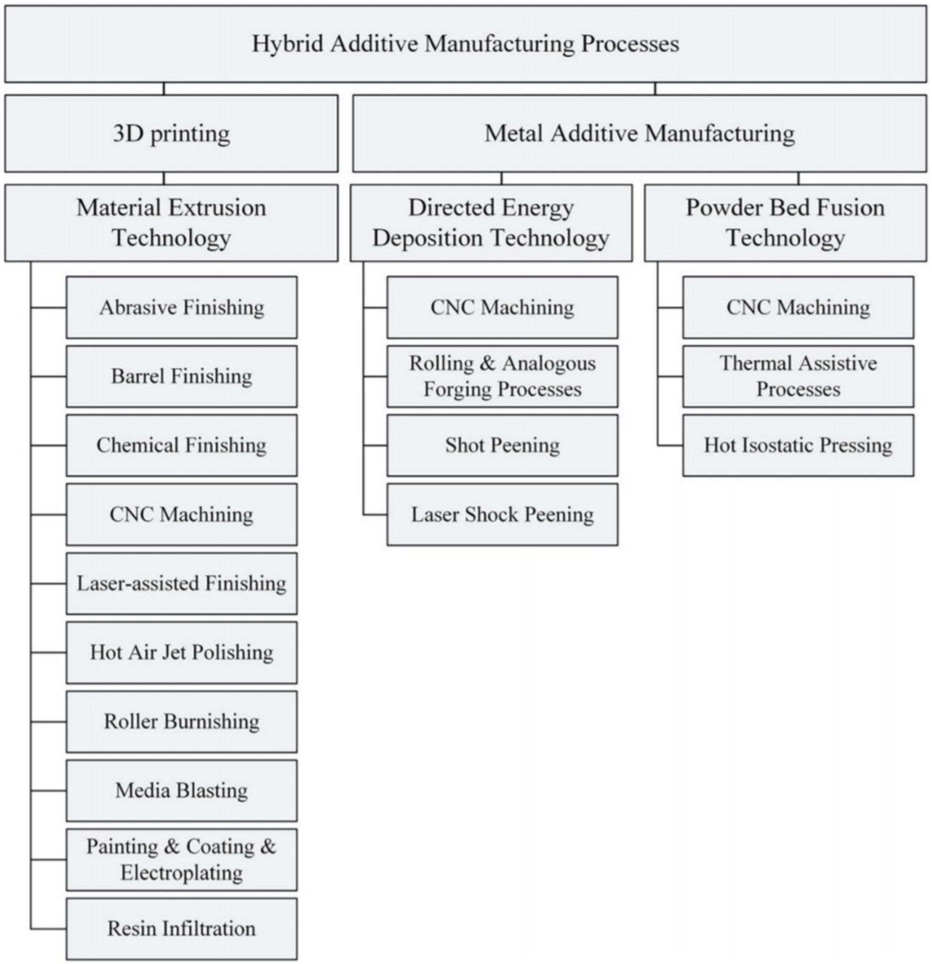
MELD Technology	Electrodynamics Technology	Microforging and Casting Sync Composite Device	Large Area Additive Manufacturing	Computed Axil Lithography 3D Printing Technology
Digital Construction Platform	Laser Metal Deposition	Magnetic Platform Technology	Arc Welding Technology (3DMP®)	Liquid Additive Manufacturing
Multi Jet Fusion Technology	FluidANT™ Technology	Fiber Light Technology	Joule Printing™	PolyJet
Lubricant Sublayer Photo-curing Technology	Resistor Jet™ Technology	Rapid Manufacturing Technology	Water-based metal paste Technology	Daylight Polymer Printing
Electrodynamics Technology	Lithography-based Ceramic Manufacturing Technology	Fluxprint™ Technology	Augmented Polymer Deposition Technology	Rapid Additive Forging Technology

Emerging concepts in Post Processing

As post processing is a very crucial stage in any 3D printing technology there is a upsurge in initiatives. Automated processes focused on improving post processing of 3D printed materials such as removal of support material, resin, or powder are some of the common secondary operations to be performed to a 3D printed part. Manually removing these excess material is time consuming, hence there is a need to integrate a traditional manufacturing process or a special equipment that is capable of removing excess material cautiously. With companies trying to close gaps in the 3D printing market with proprietary technologies, processing technique varies and types of post processing suitable for different techniques will vary. European Companies such as IRösler, PostProcess Technologies, AMT, and DyeMansio have been identified to focus on simplifying the post processing stages after 3D printing of a part.

Company Name	Region	Process	Material Compatibility	End Result	End Users
Additive Manufacturing Technologies (AMT)	UK	**PostPro3**- De-powdering, smoothing, coloring, and inspecting.	**Polymers**- Polyetherimide, nylons, Thermoplastic polyurethane, and Thermoplastic elastome, and 95 polymers are validated to be compatible.	Chemical vapor smoothening to obtain smooth surface finish.	Research institutes and service bureaus.
DyeMansion	Germany	**Powerfuse S-** Uses **VaporFuse Surfacing technology** for surface smoothing and coloring.	**Polymers**- Hard polymers such as PA11 or PA12, but also with flexible materials such as TPU.	Smooth, high-gloss surface finishes.	Research & development institutes
Rösler's AM Solutions	Germany	**RapidFinish-** Surface-finish (removal of support structures, residual), unpacking, powder, surface cleaning, polishing, and coloring.	**Plastics and Metal**	Homogeneous surface appearance	Research & development institutes
PostProcess Technologies	US	**AUTOMAT3D™**- software driven platform	**Plastics and Metal-** PolyJet, FDM, SLA, SLS, DLP, MJF, DMLS, EBM, DED	Smooth surface finish.	Small- and large-scale OEMs
Hirtenberger Engineered Surfaces	Austria	**Hirtisation technology-** Removal of support structures, surface smoothening.	**Metals and alloys**	Ultra-smooth surface finish	Large scale metal 3D printing companies

Hybrid-AM Processes



		Secondary Process	Surface Quality Ra [µm]	Processing Time [min]	Processed Layer [µm]
Subtractive Combinations	Initial / Final	CNC Machining	2-4	10-42	200-690
		Chemical Finishing	0.1-1	3-40	40-800
		Barrel Finishing	3-5	100-1000	50-400
		Abrasive Finishing	1-6	20-60	50-350
Transformative Combinations	Initial / Final	Laser-assisted Finishing	0.3-10	4-10	-
		Hot Air-jet Polishing	0.2-4	3-5	-
		Roller Burnishing	0.11-0.15	2-5	300-350
		Media Blasting	4-12	1-5	-
Additive Combinations	Initial / Final	Painting/ Coating	0.7-4	60-3000	60-180
		Resin Infiltration	-	3-240	40-800

Growth Opportunities in Hardware

Metal Printer Market:

- The metal 3D printing market has been identified to be a fast growing one as the technologies' capabilities rapidly focus on delivering functionally adoptable parts and production ready hardware systems. By expanding hardware features the speed of 3D printers can be increased to obtain fully finished parts. 3D Systems, EOS, Concept Laser (GE), SLM Solutions, Desktop Metal, GE Additive, Renishaw, and Additive Industries are a few of the major 3D metal printer companies.
- The closed Loop System is an emerging concept especially in the metals market, with the integration of sensors and machine vision systems to capture operations within 3D printer such as build rate, feed rate, material deposition speed. Data obtained from these operational sequences can be used to analyze and provide feedback on operation optimization to improve printing speed and reduce cycle time. This will ensure end users to identify bottlenecks and improve on areas that require special attention to obtain consistent print quality and geometries thus allowing a prototype machine to be used for high volume production in the future.

Polymer Printer Market:

- FFF (fused filament fabrication) is witnessing the highest installation base due to ease of access of both the printer and material and to due to its lower cost than conventional FDM printers.
- SLA (stereolithography) and DLP (digital light processing) are two key established technologies within the photopolymer 3D printing market segment. SLA, an early 3D printing technology is used in areas such as automotive, aerospace, and dental. SLA machines have been very expensive, but cost has been reduced in desktop SLA printers. DLP has been widely used in applications such as hearing aid shells. Companies are introducing features to minimize the cost spent on support materials and improve print speeds to reduce 3D printing costs.

Electronics Printer Market:

The electronics 3D printing market, though relatively underdeveloped, has high prospects, considering the large volumes of electronics equipment required for the connected digital market. Companies such as Nano Dimension and Optomec are helping to drive this market with the production of antennae, printed circuit boards (PCBs), capacitors, and sensors. Advancements in electronics 3D printing involves shift towards the ability of 3D printer to produce conductive materials that can be readily integrated onto PCB's for use.

Growth Opportunities for Software Solutions

1	Easily Accessible Simulation Platform system

Simulation and modeling solutions are perceived to provide accurate results about product and design feasibility, but can often be time-consuming and require highly skilled professionals. Solution providers such as Ansys are offering advanced software solutions that provide a more **accessible simulation** platform expanding adoption in the chemicals and processing industry where routine tasks and operations can be performed swiftly.

2	Shift in Focus Area of Single to Multi physics Solutions

Another trend is toward adoption of **multi-physics solutions**. Software simulation industry incorporates advanced modeling solutions that provide better predictive analysis and can perform numerous iterations.

3	Virtual Factory for Efficient Production

An additional trend that industries are witnessing is the incorporation of simulation (automation and digitization) and the model being more visual by integrating futuristic technology such as AR (augmented reality)/MR (mixed reality).

What's Next?

Cloud Deployment: Accessibility of software solutions via a Web-browser rather than installation can offer multiple benefits, such as reduced operation time, maintenance cost, and permit storage of large files in the cloud, enabling scalability. Easy accessibility and user-friendly interface are two major competencies offered by cloud-based solutions. This would enable shift from module oriented purchase to **flexible accounting** that is payable based on software usage.

App Development: The trend of "appification" can potentially close the barrier that is experienced due to the lack of real-time subject matter expertise. Use of apps can help in routing expert's knowledge to others of similar interest through a simplified simulation interface that requires minimal training for use.

Novel Materials Leading the Way for Growth

Polymer Market

- **High-performance thermoplastics:** The rise of materials that can withstand harsh surroundings and high temperatures is a growing demand. Materials companies such as Victrex, SABiC, and Evonik are developing high performance thermoplastics that can be used to print functional prototypes and parts that can be adopted for end-use applications. Hardware companies and industry users also collaborate with materials manufacturers to develop new materials.
- **Rise of composite and graphene materials:** Companies are migrating to the adoption of composite materials that are reinforced thermoplastics as well as graphene materials, one of the most strongest materials found on earth to be compatible with 3D printing methods. Organizations such as Continuous Composites, XG Sciences, and Lawrence Livermore National Laboratory are some of the participants venturing into integrating composite and graphene materials with 3D printing to widen applications.
- **Growth of flexible materials:** There is scope for 3D printing technology in the medical and consumer markets, where material texture, strength, and flexibility are features that fuel growth. This allows for highly customizable printing of products such as implants, footwear insoles, robotic grippers, and other rubber products that require high level of flexibility. Use of expandable, soft, flexible materials will expand applications in new industries. One key emerging area is the use of silicone to enable items that are stronger, more flexible, and comfortable than those using conventional materials.
- **Flame retardant:** There is a strong need for materials that are flame-retardant with policy requirements in industries for materials that adhere to fire safety requirements as the adoption of 3D printing technologies increases in aerospace as well as automotive and electronics applications. Several companies have developed proprietary materials that adhere to these policies such as composite materials by CRP Technology, Markforged. The development of these specialized materials will continue to grow as the requirement and application scope increase.

Metal Market

- **Rise in Powder-based Metal Materials:** The metal 3D printing market is witnessing more investments in powder-based metal additive manufacturing. This has garnered attention of material manufacturing companies toward metal production capabilities that are suitable with metal 3D printing technologies such as EBM, SLS, and DED. Leading material manufacturers are beginning to construct material atomization plants to offer easily accessible materials for 3D printing market.
- **Application Based Materials:** 3D printing technology providers, OEMs are collaborating and partnering to develop materials that are manufactured for specific needs. The application should define material properties as well as the suitable manufacturing process to be carried out to obtain an end product with appropriate mechanical and chemical properties.

Conclusion

Functional and Production-Grade 3D Printing

The hardware and printer modules focus on enhanced speed, quality, and resolution as 3D printing technology maneuvers to become the industry standard by enabling more efficient production of functional or production-read parts.

Automation of Post Processing

3D printing is not as easy as feeding in the desired drawing and printing it in a few seconds; therefore, companies are moving toward automating post processing techniques to simplify the 3D printing supply chain.

Growth Driver- New Materials

As the industry is rapidly growing, material manufacturers must constantly seek to develop polymer and metal materials for mass adoption of 3D printing. Improvements in 3D printed materials can include greater impact strength, elasticity, tensile strength, and higher temperature capability. With high material cost being one of the key bottlenecks, large scale companies and start-ups flourish to shape the industry with development of liquid materials, smart materials, and high strength polymer materials.

Creation of New Business Solutions

Cloud-based subscription offerings will evolve to address the cost issues and upfront software purchases.

Speed up the Design Process

Manufacturers with the most complex products can quickly assess and launch their designs by capitalizing on new distributed memory parallel algorithms and reduce their runtime.

Utilizing Advanced Technologies

Technologies such as AI/ML (artificial intelligence/machine learning), digital twin and AR/VR can develop solutions to manufacture reliable and high quality products. Such technologies can also help optimize and extend applications of 3D printing. Simulation through digital twins (that replicate the functions of a machine or process) can perform what-if analysis for optimal performance. AI/ML can bring advanced predictive capabilities, speed, and accuracy in developing new materials and products.

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