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Rachel Gordon  
Technology Analyst

Rachel Gordon has a BA in Natural Sciences and first-class MSci in Materials Science and Metallurgy from Cambridge University. Her master's project focussed on manufacturing and testing novel, sustainable, photovoltaic materials. She has also worked on projects including sustainably synthesising graphene from glucose in Cambridge University Engineering Department, developing deposition techniques for organometallic thin films at the University of Goettingen, and researching lead-free piezoelectric ceramics at the University of Technology in Hamburg.

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Overview of IDTechEx services

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Energy Storage
Hybrid & Pure Electric Vehicles
3D Printing
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Journals
e.g. www.PrintedElectronicsWorld.com

With bases in the US, UK, Germany and Japan we have served clients in 80 countries since 1999.
The printer market may eventually saturate so long-term profit will be made from materials supply.
## Markets for 3D Printing

<table>
<thead>
<tr>
<th>Market Growth</th>
<th>STAR</th>
<th>PROBLEM CHILD</th>
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<tbody>
<tr>
<td>High</td>
<td>Hobbyist Orthopaedics</td>
<td>Education</td>
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<td>Military</td>
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<td>Architecture</td>
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<td>Low</td>
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<td>Jewelry</td>
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<td>Critical Aerospace</td>
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<td>Medical Research</td>
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<td>Construction</td>
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<td>Automotive</td>
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<td>CASH COW</td>
<td>Non-Critical Aerospace Prototyping</td>
<td>Film Industry</td>
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<td>Medical</td>
<td>Off-Planet Manufacturing</td>
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<td>Fashion</td>
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<td>Food</td>
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<td>Electronics</td>
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<td>DOG</td>
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<table>
<thead>
<tr>
<th>Market Share</th>
<th>High</th>
<th>Low</th>
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Future of 3D printing by application

Expectations

- Critical aerospace
- Architecture
- Sports
- Education
- Bioprinting
- Medical research
- Clothing
- Construction
- Military
- Electronics

Dental
Hobbyist
Prototyping
Non-critical aerospace
Orthopaedics
Jewelry

Technology Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity

Time
As industry moves to producing final parts using 3D Printing, as opposed to rapid prototyping, thermoplastic powders and metal powders will gain market share.
A Review of Materials

- Welding
- Blown-Metal
- Selective Laser Melting and Selective Laser Sintering
- Extrusion
- Valve / Laser / Maglev
- Ink-Jetting
- Stereolithography/DLP

- Metal
- Thermoplastic
- Food
- Concrete
- Biomaterials
- Binder (onto Powder)
- Photopolymer
3D Printing in Plastics

- Photopolymers
  - Precision
  - Speed
  - Cost and Build Volume
- Thermoplastic powder
- Thermoplastic filament
Stereolithography (SLA) and Direct Light Polymerisation (DLP)

**How does it work?**
UV-light source is used to cure a vat of photopolymer, either point-wise using a laser (SLA), or layer-by-layer using a projector (DLP) to create a hard plastic object with high precision.

**What can it do?**
High precision articles made from one photopolymer.

**Who makes them?**
Asiga, Autodesk, B9Creations, CMET, DWS Lab, Formlabs, Kevvox, QSQM Corporation, Qubea, Rapidshape, Rays Optics, Robot Factory, Sprintray…

**Who uses them?**
Medical, Dental, Production of Jewelry.
**Ink-Jetting Photopolymers**

How does it work? The 3D printer jets tiny droplets of liquid photopolymer onto a build tray then instantly cures them with UV-light. A removable gel-like support material is used to support overhangs and is removed with water.

What can it do? Jet multiple materials simultaneously to incorporate a variety of colors and properties.

Who makes them? Stratasys Polyjet, 3D Systems Cubify

Who uses them? Prototyping Consumer Products, Dental, Medical
Applications of 3D Printed Photopolymers

Stereolithography or Digital Light Processing are used to produce jewelry, dental models, hearing aids, architectural models, and sculptures.

Ink-jetting of photopolymers is used to make prototypes, props for the film industry, shoes, and surgical training models.
Photopolymers – Key Players

- Asiga
- B9Creator
- Bucktown Polymers
- Carima
- DSM
- DWS
- EnvisionTEC
- KEVVOX
- MakerJuice Labs
- RAHN
- Sartomer
- Stratasys
- 3D Systems
Thermoplastic Extrusion

<table>
<thead>
<tr>
<th>How does it work?</th>
<th>Selective deposition of molten thermoplastic heated through a nozzle.</th>
</tr>
</thead>
<tbody>
<tr>
<td>What can it do?</td>
<td>Print engineering thermoplastics such as ABS</td>
</tr>
<tr>
<td>Who makes them?</td>
<td>Stratasys, 3D Systems, Makerbot, Ultimaker, Printrbot, Flashforge, Airwolf 3D, Mark Forg3D, EOS</td>
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<td>Many start-ups have started selling consumer level thermoplastic extrusion printers since Stratasys’ patent expired in 2009.</td>
</tr>
<tr>
<td>Who uses them?</td>
<td>Prototyping, Education, Architecture, Art, Home</td>
</tr>
</tbody>
</table>
Applications of 3D Printed Thermoplastic Filament

Extrusion of thermoplastic filaments can be used to produce a huge variety of household objects, toys, educational models and bespoke cars.
Thermoplastic Filament – Key Players
Thermoplastic Filament – Chemical Suppliers

- EVONIK Industries
- NatureWorks LLC
- SOLVAY
- LG Chem
Thermoplastic Filament – 3 Behaviours

Hobbyist

Prosumer

Industrial
Thermoplastic Recycling – Disruptive Technology

- Desktop thermoplastic extruders make filament from cheap pellets or ground-up unwanted items
- Unique co-polymers can be created
- Omnidynamics plan to sell their Strooder for only $400
- Threatens to undermine thermoplastic filament market
Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Electron Beam Melting (EBM)

How does it work?
A laser or electron beam is rastered across the surface of a powder bed to melt or sinter the particles together. Then another layer of powder is rolled across the top and the process is repeated to build up a 3D object.

What can it do?
Suitable for production of fully-dense metal or plastic parts

Who makes them?
3D Systems, Arburg, Arcam, Blue Printer, Bright Laser Technology, CitimAM, Concept Laser, EOS, Matsuura Machinery, Realizer, Renishaw, SLM Solutions

Who uses them?
Aerospace, Automotive, Jewelry, Oil and Gas, Construction, Medical, Military
Applications of 3D Printed Thermoplastic Powders

Selective Laser Sintering of Thermoplastic Powders is used to produce non-critical parts for aerospace, orthopaedic implants, several components for the KySat-2 satellite, decorative covers for structural supports and shoes.
Thermoplastic Powders – Key Players
Thermoplastic Powder - Case Study

- Using 3D printing for approx. 12 years
- Using laser sintered thermoplastic parts in production for 10 years
- Over 20,000 3D printed parts used in non-critical applications
- Expect full clearance for flight-critical parts to take 10-20 years for manned aircraft
- Unitized monolithic structures would be a strong case for 3D printing but build volumes of current technology is too small
- 3D printing must offer 10% cost saving to be economically viable due to cost of regulation.
Dyson UK have 3 SLS printers, 2 stereolithography printers, and 2 Polyjet (ink-jetted photopolymer) printers.

Their weekly spend on 3D printing materials for the company is $46,000.

Nylon powder makes up 95% by volume.

The company notes difficulties in achieving adequate mechanical properties with 3D printing specifically citing weakness due to build line direction and dimensional instability.

Dyson manufacture 206 million components per month and as such, does not consider that 3D printing is a realistic option for production.
Blown-Powder

How does it work?
Metal powder is blown coaxially to the laser beam which melts the particles on a base metal to form a metallurgical bond when cooled.

What can it do?
Large dense parts of titanium, aluminium, nickel, cobalt, stainless steels, tool steels, copper, precious metals and alloys.

Who makes them?
DM3D Technology, EFESTO, Optomec.

Who uses them?
Aerospace, Military, Oil and Gas.
Applications of 3D Printed Metal Powders

Selective Laser Melting, Electron Beam Melting and Blown Powder can be used to make 3D printed metal objects for non-critical aerospace applications, orthopaedic implants, jewelry, and critical aerospace parts such as fuel nozzles.
Metal Powders – Key Players
GE Aviation are printing over 114,000 fuel nozzles for use in 6000 jet engines that will start flying in 2016.

They are using Direct Metal Laser Melting (DMLM) to melt 20-100 micron layers of a powdered alloy.

Previously nozzles were manufactured by welding together 18 smaller pieces which was labour-intensive and wasteful.

Design flexibility has allowed the nozzle to be 25% lighter.

It seems likely that other aerospace manufacturers are using 3D printing to at least the same extent as GE Aviation.
Emerging Materials

Electrically Conductive Materials

- Graphene
- Silicone
- Ceramics
- Biomaterials
- Regolith
- Carbon Fibre
For more on 3D Printing…
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