3D opportunity: Additive manufacturing paths to performance, innovation, and growth

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Closing thoughts to keep in mind as you evaluate the business case for AM

- AM is not a panacea.
  – No reason to view it as a universal replacement for traditional manufacturing methods.
  – We do see it as important within the constellation of manufacturing methods that business can deploy in pursuit of performance, innovation, and growth.

- Consider the blessing and potential curse of flexibility-enabled product innovation
  – Redesign to reduce material and assembly while improving product performance
  – What is your position and value add in the supply chain?

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What is Additive Manufacturing?

U.S. DEPARTMENT OF ENERGY

OAK RIDGE National Laboratory

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Additive Manufacturing Defined

Additive manufacturing can transform the way products are manufactured and brought to market

Additive manufacturing is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies

Electronic design file (e.g., .STL) of object created using CAD or scanner

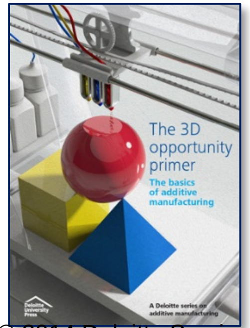
Software slices model into cross-sectional layers and sends file to AM

Following the design, the AM layers raw material(s) until the final object emerges

Final object is produced with little/no waste

Additive Manufacturing can be used to….

Improve Quality | **Reduce Costs** | **Increase Flexibility**



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Additive Manufacturing Adoption Timeline

Additive Manufacturing has been slowly gaining traction, specifically within design, however, new technologies have the potential to amplify growth and extend usage within production

Additive Manufacturing Timeline: *The Shift in Additive Manufacturing Applications*

Product Design
Prototyping and Customization

Production
Scaling in Volume, Size, and Availability

AM Milestones

- **1986** *AM Invented (SLA)*
- **1989** *AM Rapid Prototype System (FDM)*
- **2007** *RepRap Movement*
- **2008** *User Generated Art*
- **2009** *FDM Patent Expires – Growth in Consumer 3DPs*
- **2014** *Selective Laser Sintering Patent Expires*

Impacts on Aerospace Industry

- **1986** *Rapid Prototyping*
- **2004** *Component Manufacture*
- **2007** *Real-time Spare Parts Manufacture*
- **2011** *SULSA Prototype*
- **2012** 3D System Acquires Z Corp; GE Acquires Morris Technology
- **2016** *Mass Production LEAP engine part*
- **2030-2050 (Estimated)** *Completed Product*

Main Applications 1986 - 2011:

- *Product Design*
- *Product Part Production*
- *Rapid Prototyping*
- *Concept Modeling*

Catalyst for Mass Production Adoption[1]:

- *GE plans to mass-produce 25,000 LEAP engine nozzles with AM – already have $22B in commitments*
- *Parts will drive production and operational cost savings*
- *First test to see if AM can revolutionize production*

Main Applications 2014 - Future:

- *End Product Production*
- *Mass Production*
- *Democratized Consumer 3D Printing*

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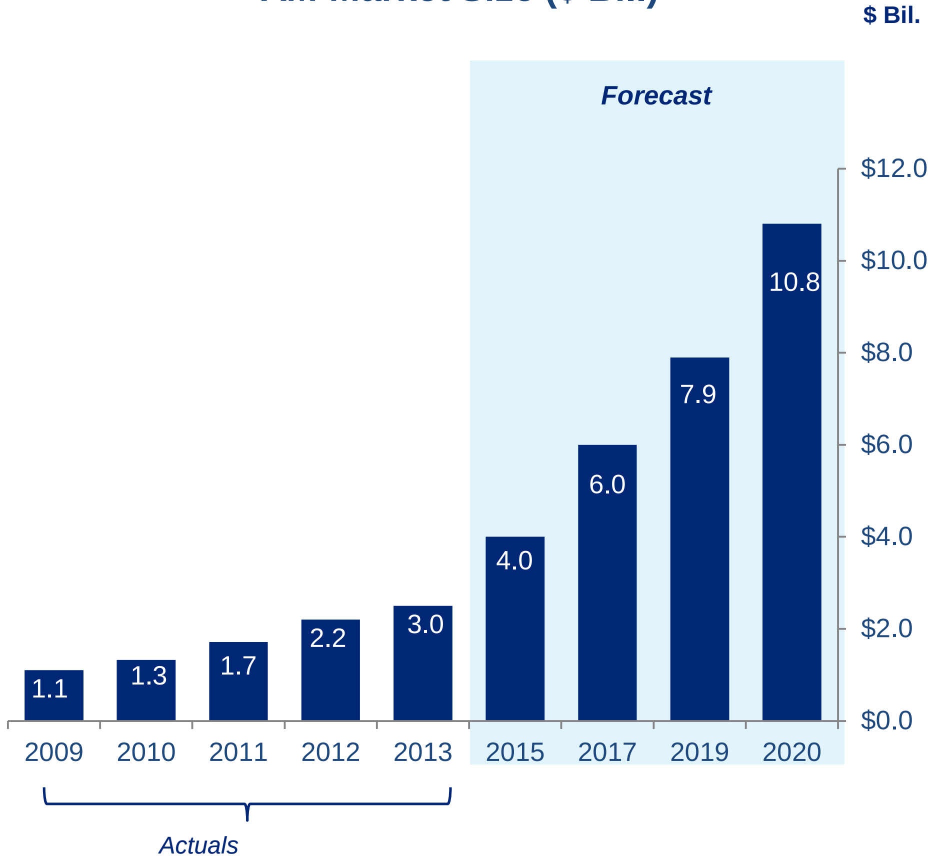
Global Additive Manufacturing (3D Printing) Market Size and Forecast

The global additive manufacturing market, reached sales of $3.0 billion in 2013, on annualized growth of 35 percent over sales of $2.3 billion in 2012. AM industry growth over the last 25 years has been 25.4 percent, and 29 percent in the last three years.

AM Market Size ($ Bil.)



Market Outlook

- Forecasts for growth of the AM market by equity research analysts range from: $7 billion by 2020, on 18 percent CAGR (Paul Coster of JP Morgan), to bull market scenarios as high as $21.3 billion by 2020, on 34 percent CAGR (Ben Uglow of Morgan Stanley)
- Wohlers Associates predicts the market for AM products and services will reach $10.8 billion worldwide by 2020

Note: Actuals based on Wohlers data.
Source: Wohlers Associates, May 2013; Morgan Stanley Research, September 2013; J.P. Morgan, January 2013

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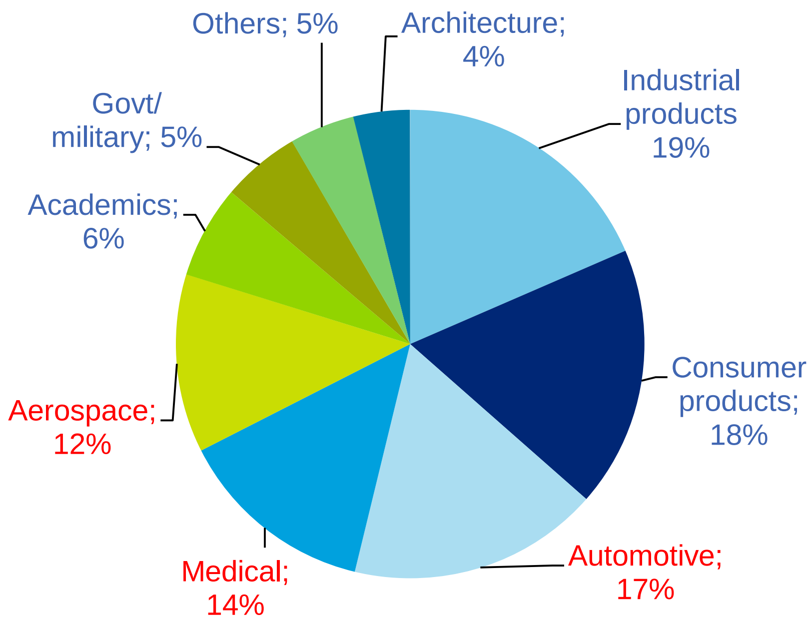
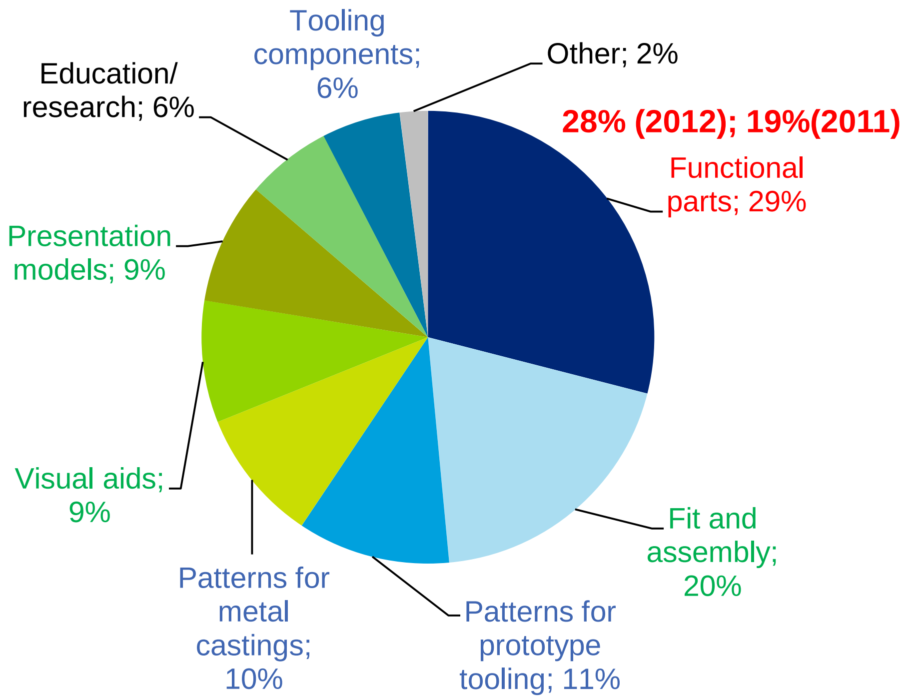
AM is used in varied sectors for multiple applications

AM system sales revenue to various sectors: 2013



AM systems deployments by applications: 2013



AM systems are sold into a wide range of sectors.

- Multiple industry verticals contributed to double-digit sales of AM systems in 2013.
- Automotive, Medical, and Aerospace lead (43%) among targeted sectors.

Prototyping (38%), tooling (27%) and functional parts (29%) lead among applications.

- Functional part production is growing faster than rest of market.
- Companies typically spend 10 times more on production than prototyping — an imperative for AM users and providers is to look beyond prototyping and focus on end-parts production.

Source: Wohlers Associates Additive Manufacturing and 3D Printing State of the Industry, 2012, 2013

Note: Based on a survey of leading AM systems providers conducted by Wohlers Associates

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AM is not one thing; it is many technologies

Additive Manufacturing

Vat photopolymerization	• Stereolithography (SLA) • Digital light processing (DLP)
Material jetting	• Multi-jet modeling (MJM)
Material extrusion	• Fused deposition modeling (FDM)
Powder bed fusion	• Electron beam melting (EBM) • Selective laser sintering (SLS) • Selective heat sintering (SHS) • Direct metal laser sintering (DMLS)
Binder jetting	• Powder bed and inkjet head 3D printing (PBIH) • Plaster-based 3D printing (PP)
Sheet lamination	• Laminated object manufacturing (LOM) • Ultrasonic consolidation (UC)
Directed energy deposition	• Laser metal deposition (LMD)

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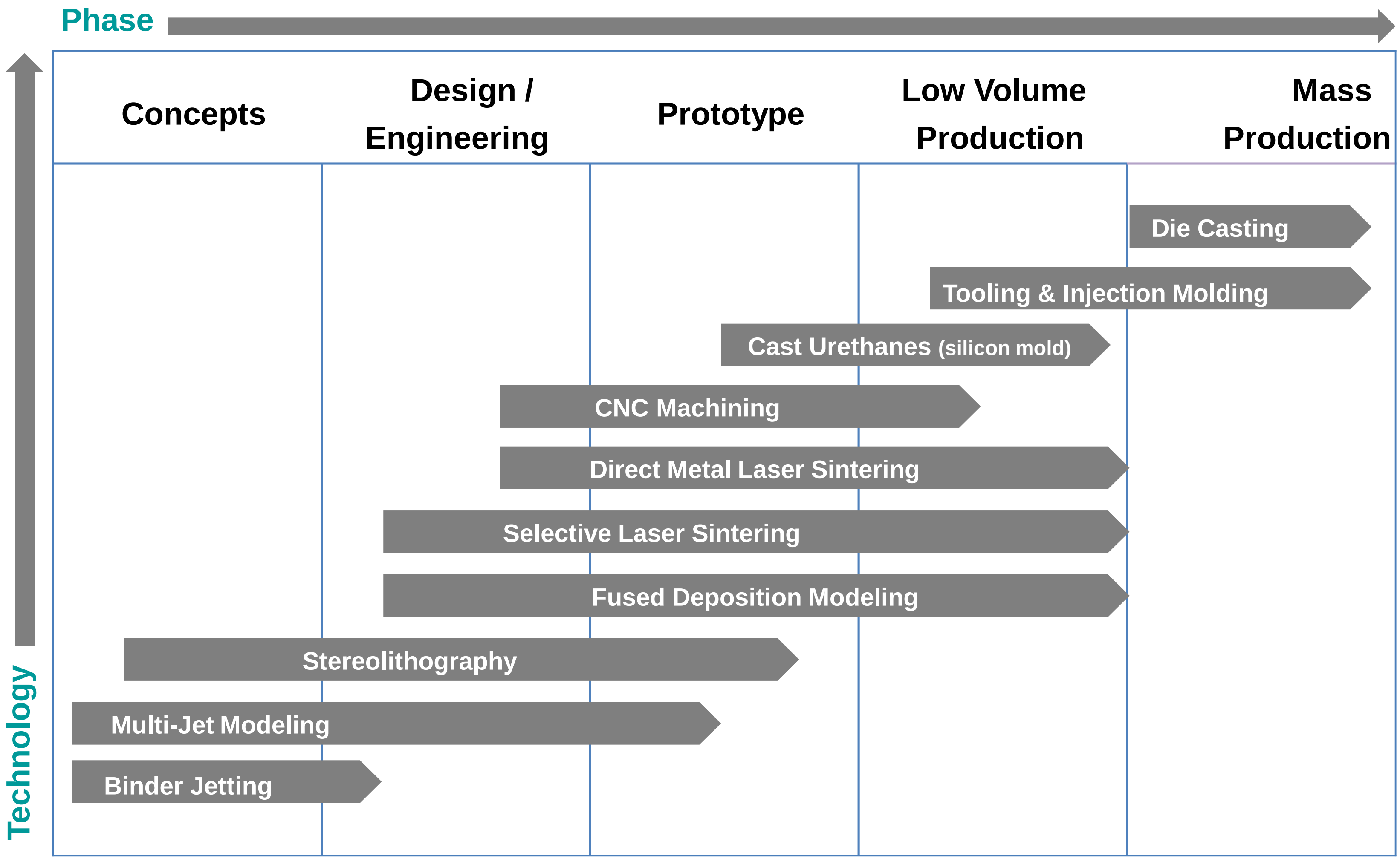
Manufacturing technologies and the application spectrum



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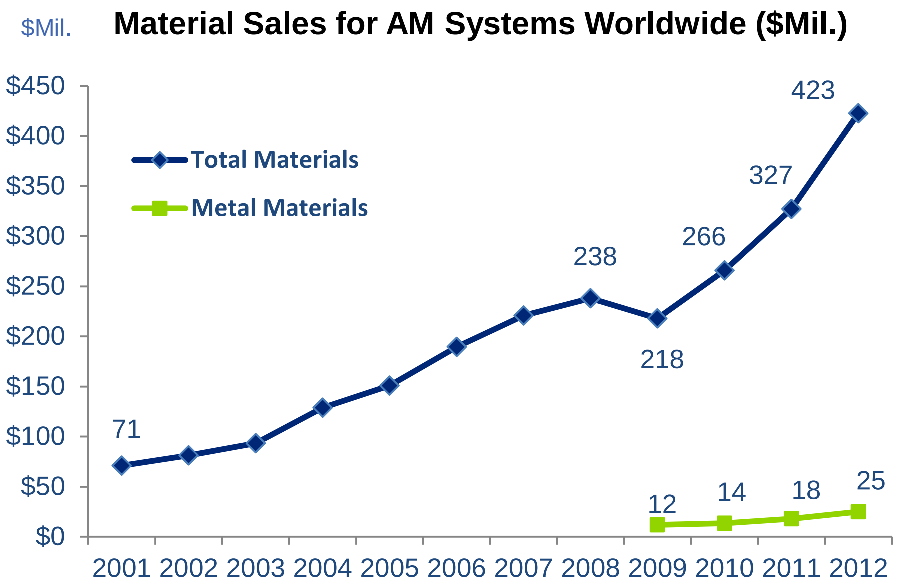
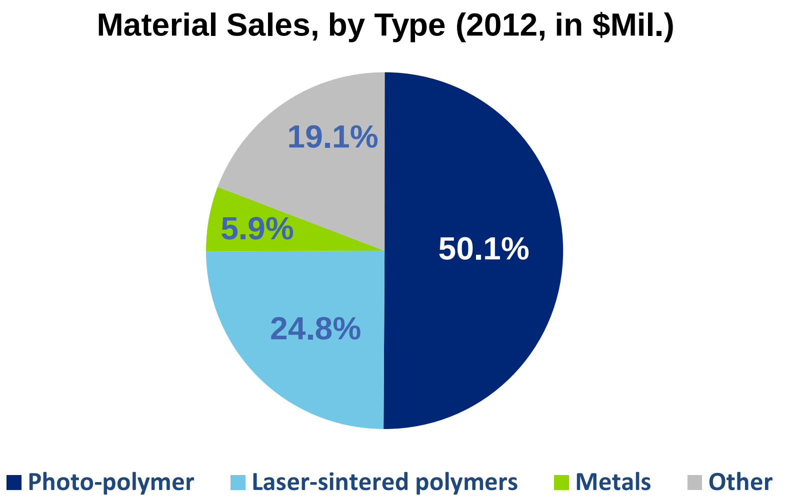
AM Material Sales Growth and Metals / Advanced Materials Opportunity



- AM Materials posted sales of $422.6 million in 2012, an increase of 29.2 percent from sales of $327.1 million in 2011;
- Materials comprised 19.2 percent of total AM sales of $2.2 billion in 2012, and have enjoyed a 5 year CAGR of 15.4 percent;
- Credit Suisse estimates 2013 Materials sales of $528 million, and forecasts Materials sales of $1 billion by 2016;
- Better materials at a lower cost are both a hope and hurdle for the industry. Thermoplastics and photopolymers are $175-$250 per kg, while those used in injection-based molding cost just $2-3 per kg. Likewise, 3D steel is currently 100x costlier than commercial grade.

- Plastics (polymer, resin, composite, other) account for an estimated 80+ percent of industry sales, and metals (which largely became available in 2009), ~6 percent;
- Aerospace and automotive demand for strong and flexible advanced and high-value manufactured metal parts, should drive metals sales growth, and advances in hybrid metals (like aluminum-titanium alloys) appear promising;
- New and improved ceramic and biocompatible materials have and will continue to drive MedTech AM adoption, while demand for multi-material and novel material attributes (color, edible, etc.) should increase across most AM end-market sectors.



Source: Credit Suisse, September 2013; Wohlers Associates, May 2013

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Maturity of Advanced Materials for Additive Manufacturing

Materials capabilities are expanding from plastics and metals used commercially today, to complex materials being developed for use in future applications

Most Mature → **Least Mature**

Prototyping, tooling & piloting

Floor console prototype from GM

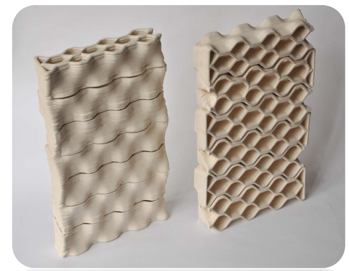
- Polystyrene
- ABS
- Steel
- Aluminum
- Copper
- Nickel alloys
- Bonded plaster
- Alumina
- Zirconia
- Paper

Manufacturing

Production ready jet engine components from GE

- Titanium
- Cobalt chrome alloys
- Polyurethanes
- Nylon
- PEEK & PEKK
- Polylactic acid
- Polycarbonate
- Sand (Casting)
- Epoxies

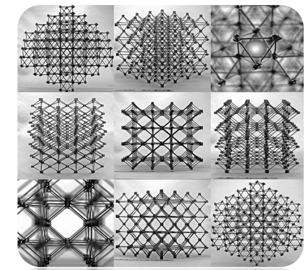
Early development



3D printed honeycomb bricks from Building Bytes

- Concrete
- Living tissue
- Carbon fiber-reinforced plastics
- Glass
- Food
- Clay

Theoretical



3D printed modular "Lego" Structures from MIT

- Hierarchical composites
- Graded materials
- Localized, multimodal shaping and processing
- Multi-scale design and optimization

Materials Currently Under Development

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How will Additive Manufacturing Will Impact Industry?

Our Point of View: Additive Manufacturing is an innovative technology that can significantly impact products and the ways that they are distributed

Additive Manufacturing Impact on Products and Supply Chains

High Impact on Product

Product Impact

3 Product evolution
- Customization to customer requirements
- Increased product functionality/performance
- Zero cost of increased complexity

4 Business model evolution
- Mass customization
- Manufacturing at point of use
- Supply chain disintermediation
- Customer empowerment and co-creation

1 Stasis
- Design and rapid prototyping
- Production and custom tooling
- Supplementary or "insurance" capability

2 Supply chain evolution
- Manufacturing closer to point of use
- Responsiveness and flexibility
- Management of demand uncertainty
- Reduction in required inventory

Low Impact on Product and Supply Chain

Supply Chain Impact

High Impact on Supply Chain

Benefits of AM Exist Across the Value Chain

Design:
- Reduced constraints
- Faster product development

Production:
- Reduced barriers to entry
- Reduced/eliminated tooling
- Less material waste
- Reduced manufacturing steps
- Print on demand

Transportation & Distribution:
- Localized production

Maintenance Support:
- Store/distribute designs electronically

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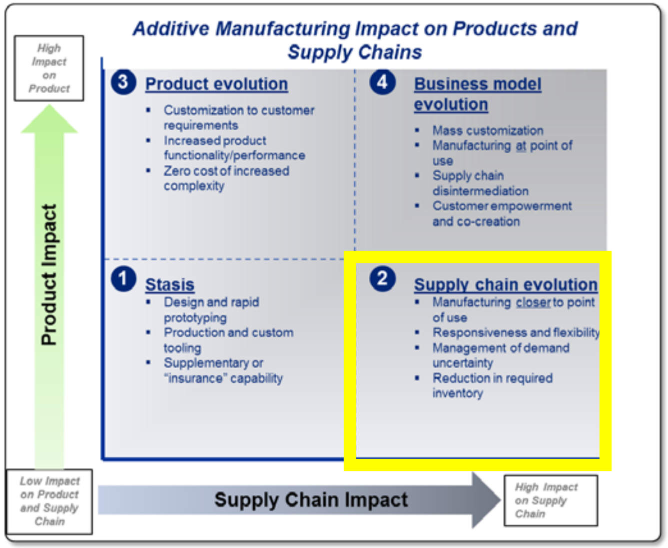
Supply chain impact for responsiveness

Manufacturing closer to the end customer

Ability to shift end-part production closer to end-use customers so as to streamline the logistics of distribution and accelerate delivery



Military Mobile Parts Hospitals

Technology used: various

The U.S. military is investing in mobile production facilities that can manufacture parts in the combat zone to get rarely requested, but vital, replacement parts quickly to the field.

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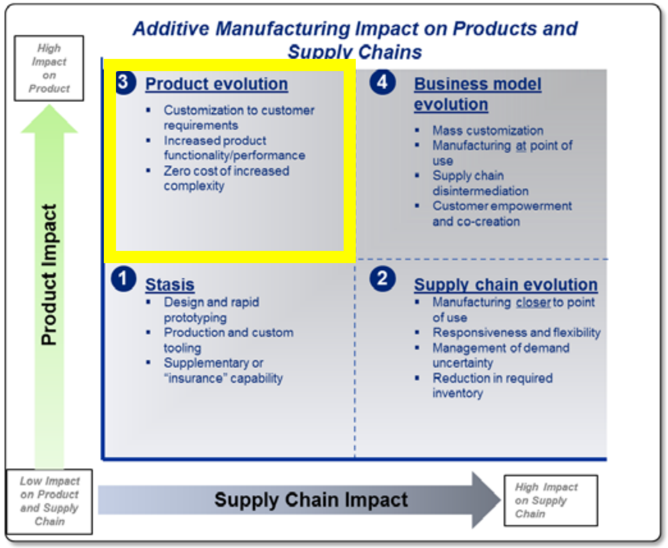
… and what specifically might that look like?

Product impact and market expansion

Component simplification

Provides opportunities to use AM in support of simplified product structures requiring fewer components, less assembly, and improved quality



GE Aviation

GE Aviation
Technology used:
direct metal laser sintering

GE fuel nozzles formerly involved assembly of 20 parts. GE now uses AM to produce as a single unit reportedly 5x more durable than before.

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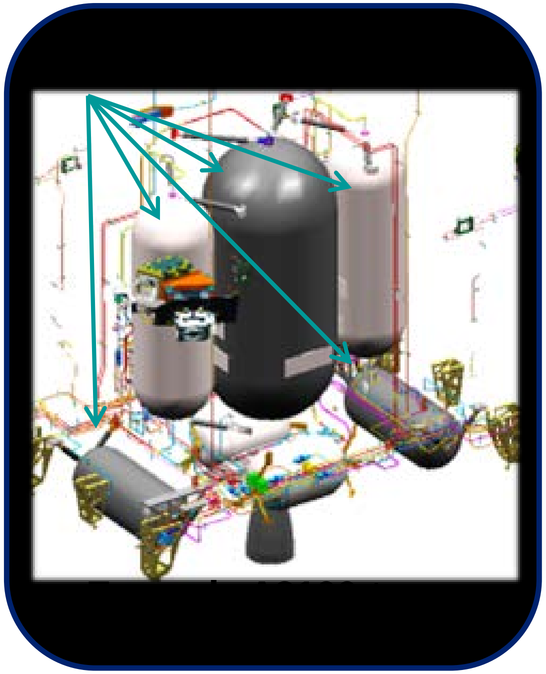
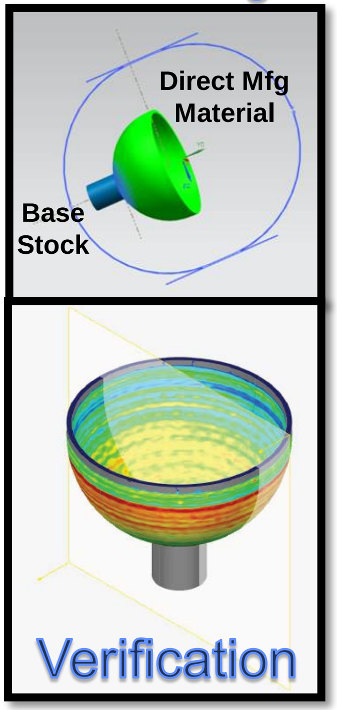
Lockheed Example:
Titanium Propellant Tank

IRaD funded manufacturing demonstration

- 16” scale demo manufacturing study
- Baseline tank domes are forged titanium
- Each A2100 has 5 or more tanks (10 domes)
- Laser scan of DM part ‘bulls-eye’ on deposition



CAD Design



Advantages

- DM Accelerates schedule
- Baseline forged dome: 12 Mo lead time
- DM Dome Preform was made in 3 hours
- DM Dome is ~50% cost of forged dome
- Baseline forging limitation 46” diameter
- DM Dome does not have same size limitation

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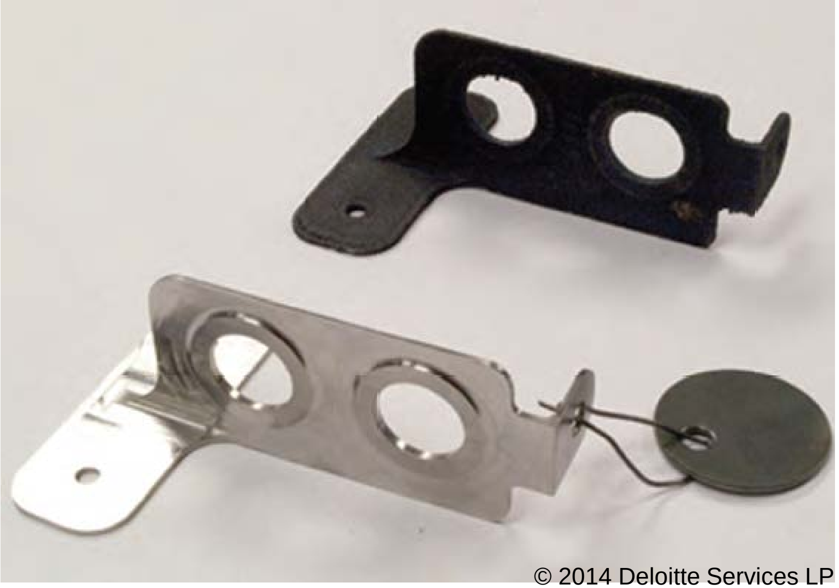
Lockheed Example:
Bleed Air Leak Detect Bracket (BALD) for Joint-Strike Fighter

- Bracket used in the hot side of the engine on Lockheed Martin's Joint Strike Fighter
- Traditionally, machined from wrought Ti-6Al-4V plate.
- Very thin cross section resulting in "buy-to-fly ratio" of 33:1
  - 33 pounds of raw stock plate is purchased to produce a 1-lb machined bracket.
- Produced using Electron Beam Melting – A powder bed fusion AM process.

"EBM technology is a suitable additive manufacturing technology to produce complex aerospace components, such as the BALD bracket."

"[AM parts] have consistent mechanical properties…, meeting the ASTM specification for wrought Ti-6Al-4V material for yield strength, ultimate tensile strength, and elongation."

"A simple cost analysis shows that EBM technology provides a 50% cost reduction over the current production method."



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AM's increasing adoption: Challenges and potential solutions

AM's ability to manage small volumes, complex designs, and light-weight but strong structures, make it a natural fit for the A&D industry. In its current state, the technology faces some challenges associated with size and scalability, high material costs, narrow range of materials, limited multi-material printing capabilities, and quality consistency issues. Continuing advancements in the AM technology and material sciences are likely to address these limitations and are expected to drive AM's wider adoption in the A&D industry.

Size limitations

- AM underperforms traditional manufacturing when it comes to production of large A&D components.
- AM providers are focusing their R&D efforts to address the size limitations of existing AM systems.

Scalability limitations

- AM providers are working to improve the build speed of existing AM systems to support the industry's bulk-production needs.
- AM systems where different parts can be produced concurrently or production and unloading can happen simultaneously will help improve AM's scalability.

Narrow material choice and high material cost

- AM predominantly uses polymers, metal powder to manufacture various A&D parts. Also, the costs of materials used in AM are much higher compared to those used in traditional methods.
- Over the next few years, advances in materials sciences are likely to expand the choice of AM materials and bring their costs down.

Limited multi-material printing capability

- AM systems that can print with multiple materials at a time offer huge design flexibilities; currently, there are only a few such printers available.
- Advances in multi-material printing capability will help designers to make a part using different materials with varied properties.

Quality consistency

- Quality consistency issues, especially in producing fully-dense metal parts, result from excess heat that is generated from heating the material leading to stress and voids particularly on layer boundaries.
- Repeatability can be improved by embedding controls within the machines so that in-situ dimensional accuracy is ensured and subsequently conducting automated inspections.

Source: Deloitte analysis

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A word on the business case for AM

High level factors we are looking at

In a typical comparison with injection molding of plastic parts:

Labor

- We find ***no clear evidence*** that labor rates systematically differ based on IM vs. AM.
- ***Part simplification*** may reduce total.

Machine costs

- ***Machine costs*** can ***dominate*** business case for AM.
- Acquisition, depreciation, build volume, utilization, and maintenance are also factors.

Materials

- There are ***extreme cost differentials*** between AM and traditional material feedstock.
- Material recycle rates should be carefully evaluated.

Tooling

- The ***cost of IM tooling*** can far outweigh unit costs for each additional part.
- A key attribute of AM is its ability to ***reduce or eliminate*** tooling costs.

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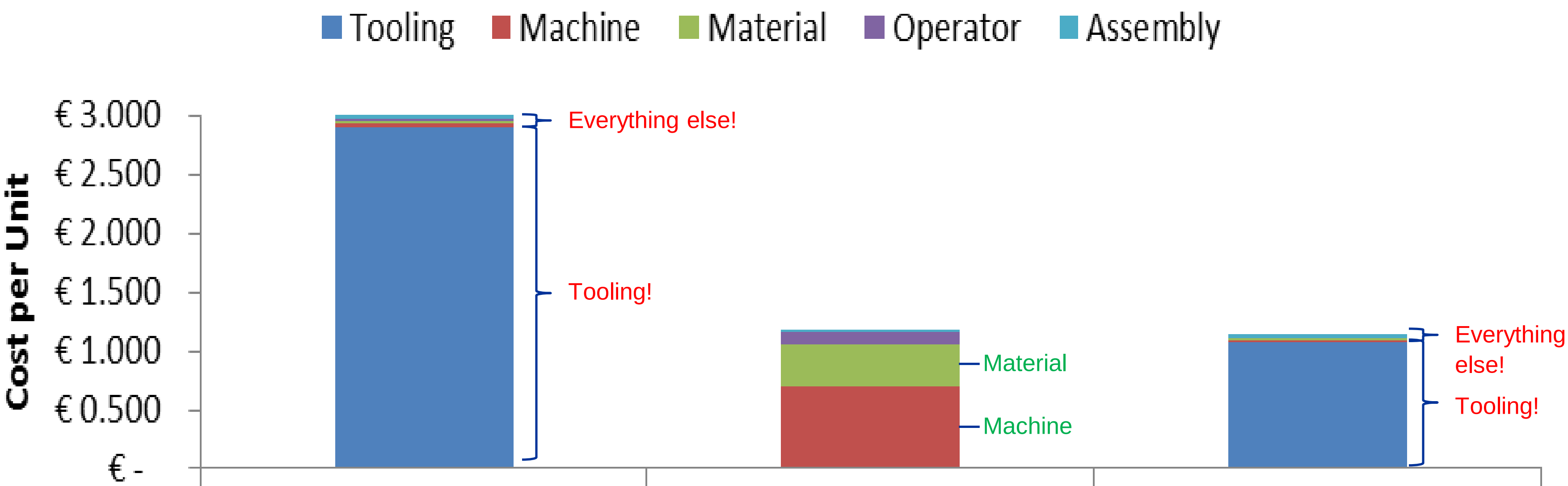
Direct cost breakdown for a small, non-flammable, plastic electrical component using IM and AM.



	IM@20K	AM	IM@100K
Assembly	€ 0.035	€ 0.012	€ 0.035
Operator	€ 0.009	€ 0.117	€ 0.004
Material	€ 0.011	€ 0.360	€ 0.011
Machine	€ 0.042	€ 0.694	€ 0.024
Tooling	€ 2.900	€ -	€ 1.075

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Closing thoughts to keep in mind as you evaluate the business case for AM

- AM is not a panacea.
  - No reason to view it as a universal replacement for traditional manufacturing methods.
  - We do see it as important within the constellation of manufacturing methods that business can deploy in pursuit of performance, innovation, and growth.
- Consider the blessing and potential curse of flexibility-enabled product innovation
  - Redesign to reduce material and assembly while improving product performance
  - What is your position and value add in the supply chain?
- Start with focus on relatively small, complex, plastic components but remain open to applications for larger and metallic components
  - Especially where using high-cost materials, involving high buy-to-fly ratios, and/or lots of machining.
- Develop a clear picture of the financial implications of new technology investment.
  - Machine costs dominate for AM. Seek advice on depreciation and tax incentives.
  - Tooling may shift the calculus toward AM due to expense, flexibility, and impact on time-to-market
  - Watch materials costs.
- Adopt a broad perspective on time.
  - Before deciding AM is “slow,” consider the full production cycle involved in traditional methods.
    - Latency between production steps, time-to-market, delivery lead times are crucial to value proposition.

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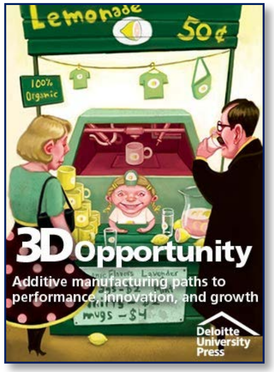
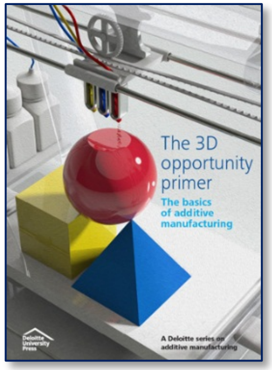
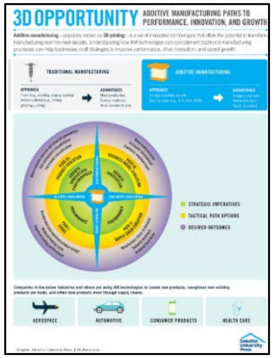
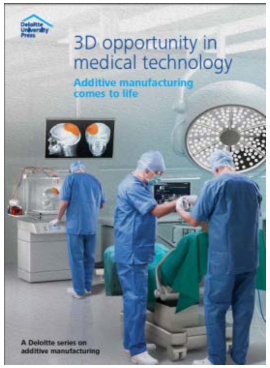
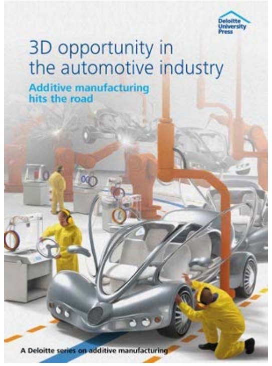
Additive manufacturing resources from Deloitte

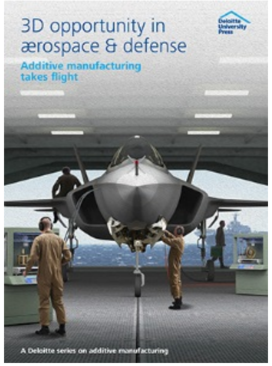












Massive Online Open Course on Additive Manufacturing!

3D-Opportunity: The course on additive manufacturing for business leaders

Free course launches online October 20!!

Deloitte University Press *3D Opportunity series*

- 3D Opportunity: Additive manufacturing paths to performance, innovation, and growth
- The 3D opportunity primer: The basics of additive manufacturing
- 3D Opportunity in Tooling: Additive manufacturing shapes the future.
- 3D Opportunity in medical technology: Additive manufacturing comes to life
- 3D Opportunity in the automotive industry: Additive manufacturing hits the road
- 3D Opportunity in aerospace & defense: Additive manufacturing takes flight
- *Fast Company* infographic
- 3D printing: "Complexity is free" may be costly for some

- Video: Additive manufacturing – A 3D Opportunity.

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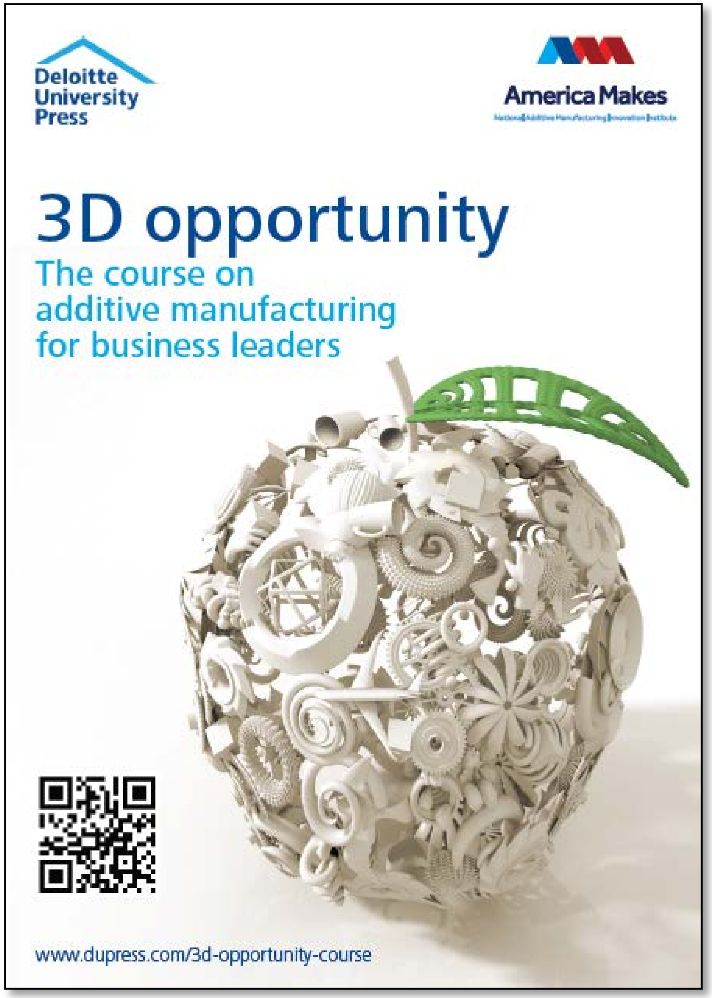
3D Opportunity MOOC
(Massive open online course)

- Complimentary course on Additive Manufacturing, aka 3D printing
  - ~3 hours of video broken into 5-7 minute segments with motion graphics, assessments, optional assignments
  - Collaboration with America Makes, 3D Systems, Oak Ridge National Laboratory

- Course participants will walk away with:
  - A foundation in AM principals and trends
  - An understanding of how AM will transform industry
  - Approaches companies can take to evaluate and integrate AM into their business
  - Sector-specific information for target industries



Course launch: October 19
View a preview and register: www.dupress.com/3d-opportunity-course

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