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Seminar 9 – Emerging Technologies in the Built Environment: Geographic Information Science (GIS), 3D Printing, and Additive Manufacturing

New Frontiers in Additive Manufacturing

2014 Winter Conference, NY, NY

Learning Objectives

1. Explain the current state of the geographical information systems
2. Describe recent advances in geographical science and technology
3. Showcase modern applications of geographical applications for energy information at local and global scales
4. Explain the current state of 3D printing
5. Describe recent advances in additive manufacturing techniques and capabilities
6. Showcase modern applications of next generation manufacturing for efficient energy and materials use to allow cost-effective production

Outline/Agenda

- What is additive manufacturing?
  - Materials, processes, markets, state of the industry
- Trends and growth of the industry
- Challenges facing the industry
- R&D to enable broader application of the technology
- Future

Additive Manufacturing: What

Additive manufacturing, commonly known as “3D Printing,” is a suite of emerging technologies to fabricate parts using a layer-by-layer technique, where material is placed precisely as directed from a 3D digital file.

Advantages

- Energy savings throughout product lifecycles
- Design freedom & complex geometries
- Cost savings
- Shorter leads times from design to product

Disadvantages

- Limited material selection and supply
- Relatively slow
- Rough surfaces
- Barriers to adoption – evaluation, workforce, etc.

Additive Manufacturing: What - processes

Process Type	Materials	Market
Powder Bed Fusion	Metals, Polymers	Direct Part, Prototyping
Directed Energy Deposition	Metals	Direct Part, Repair
Material Extrusion	Polymers	Direct Part, Prototyping
Vat Photopolymerization	Photopolymers	Prototyping
Binder Jetting	Polymers, Foundry Sand, Metals	Prototyping, Casting Molds, Direct Parts
Material Jetting	Polymers, Waxes	Prototyping, Casting Patterns
Sheet Lamination	Paper, Metals	Prototyping, Direct Part

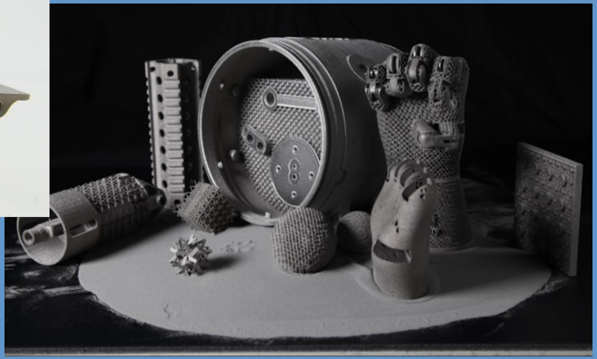
7 Process Categories by ASTM F42 these vary by: materials, speed to build, accuracy, finished part quality, cost, accessibility and safety, multi-color or multi-functional part capabilities

Additive Manufacturing: What - processes

Powder Bed Fusion

Thermal energy (laser or electron beam) selectively fuses regions of a powder bed

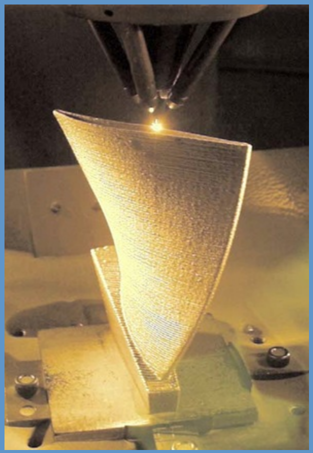
- Laser offers finer finish, EBDM is faster
- Smaller parts, metals or plastics



Directed Energy Deposition

Focused thermal energy (laser or electron beam) is used to fuse materials by melting as they are deposited

- Larger build volume, useful for repair; may need further machining

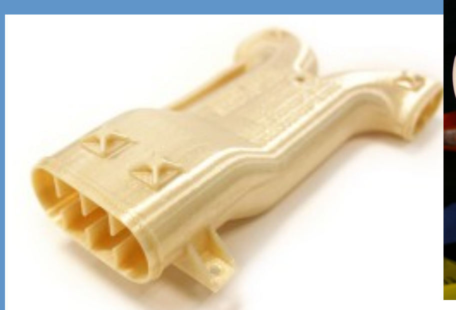


Additive Manufacturing: What - processes

Material Extrusion

Material is selectively dispensed through a nozzle (typically polymers) and material laid down in layers

- For polymers - these types are growing in use



Vat Photopolymerization

Liquid photopolymer in a vat is selectively cured by light-activated polymerization

- One of the first types of A.M., common in industry though use is on the decline

Additive Manufacturing: What - processes

Binder Jetting

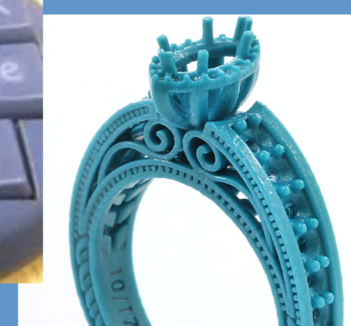
Liquid bonding agent is selectively deposited to join powder materials

- Foundry sand, metals

Material Jetting

Droplets of build material are selectively deposited, “ink-jet printer” like

- Make multi-material parts, prototypes

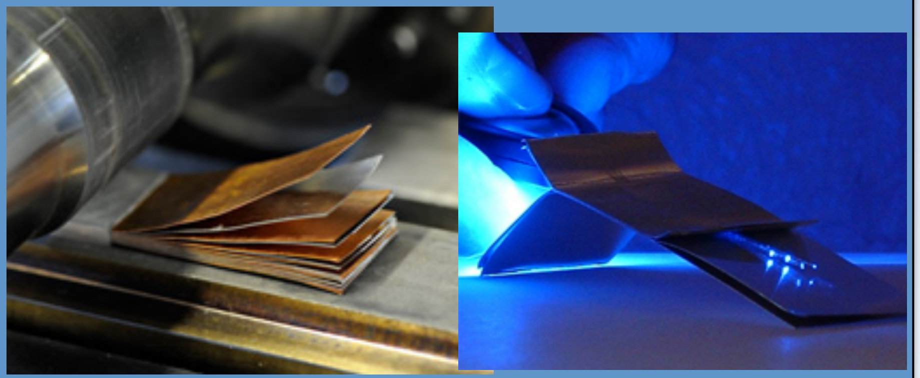


Additive Manufacturing: What - processes

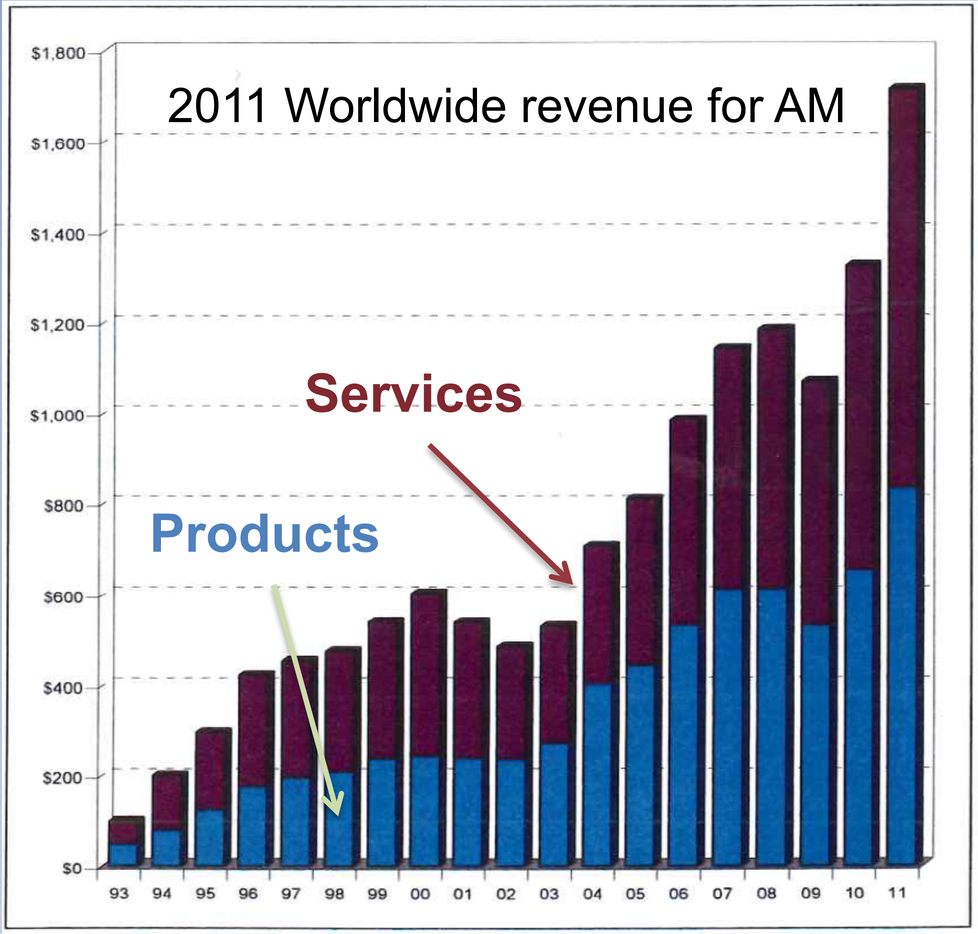
Sheet Lamination

Sheets of material are bonded to form an object

- Limited applications

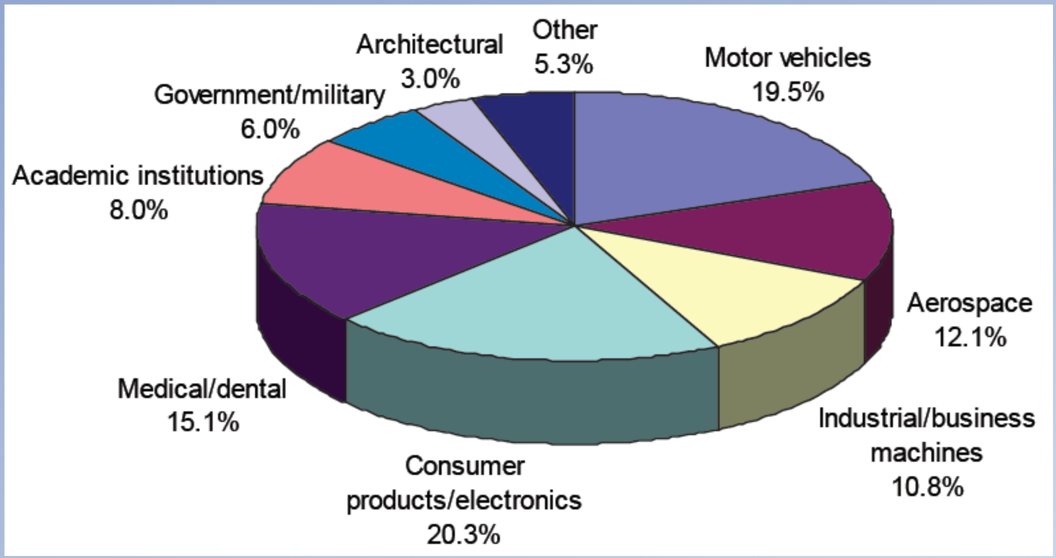


State of the Industry

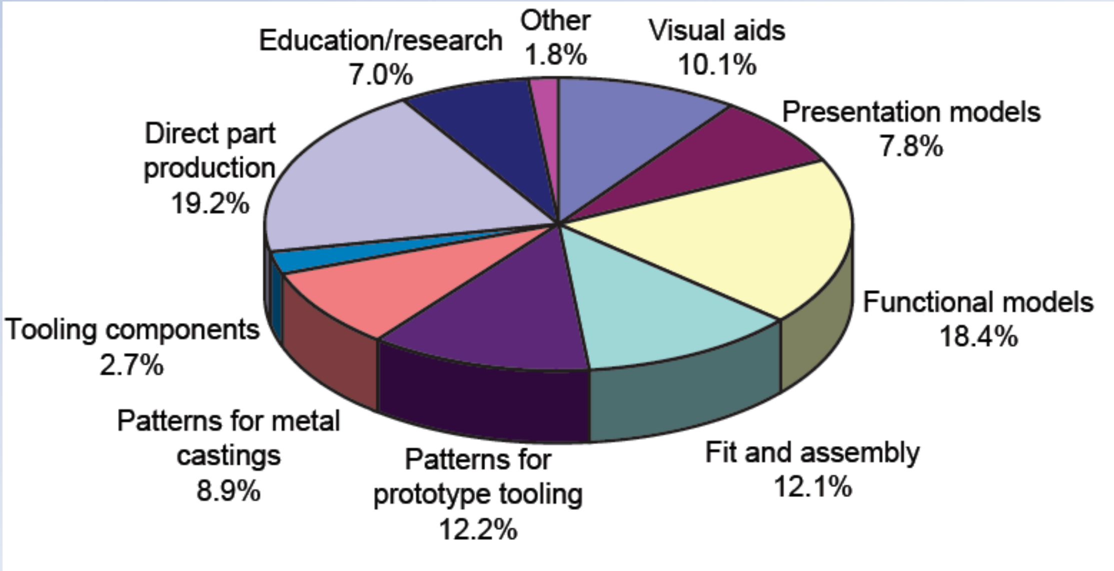


- The market for AM went up from $1.325 billion in 2010 to $1.714 billion in 2011
- AM systems and materials $834 million in 2011
- AM services $880 million in 2011
- **Products** include – AM systems, system upgrades, materials, and aftermarket products such as third-party software and lasers
- **Services** include – parts produced by service providers , system maintenance contracts, training, seminars, conferences, contract research and consulting

State of the Industry: Industry and Application



2011 AM use by industry

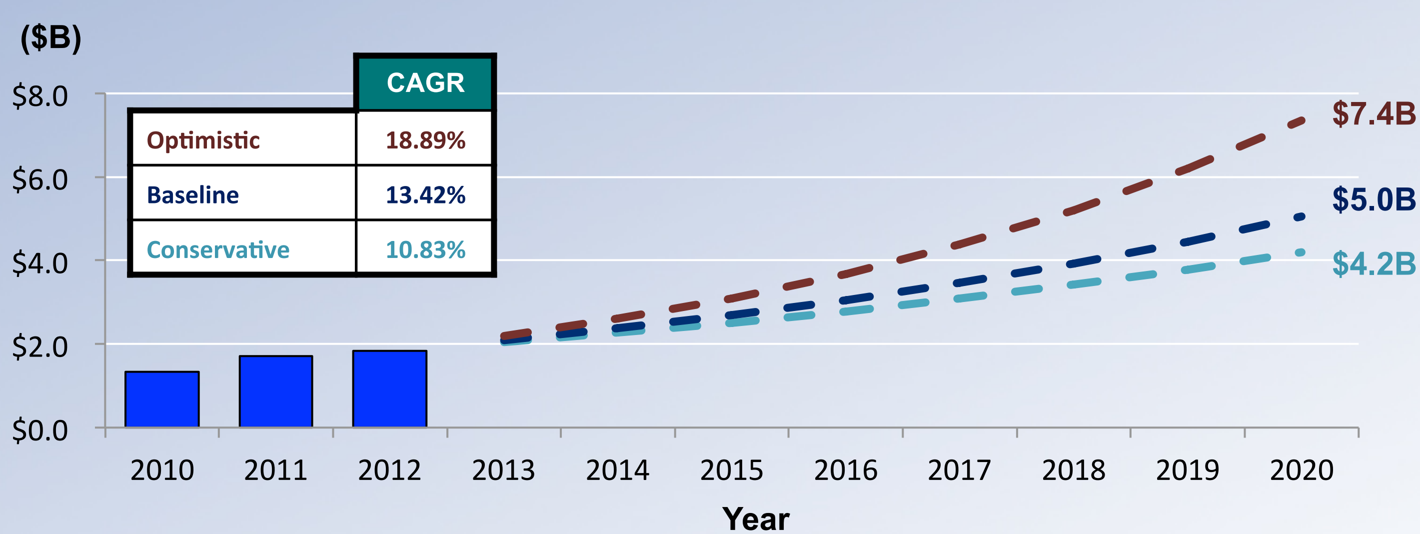


2011 AM use by application

State of the Industry: Trends

- Experts estimate current market penetration of AM technology is 8% (translates to a potential current market size of $21B)
- By 2019, the industry is expected to surpass the $6.5 billion mark
- Includes industrial equipment sales, personal printer sales, AM materials, service providers, etc.

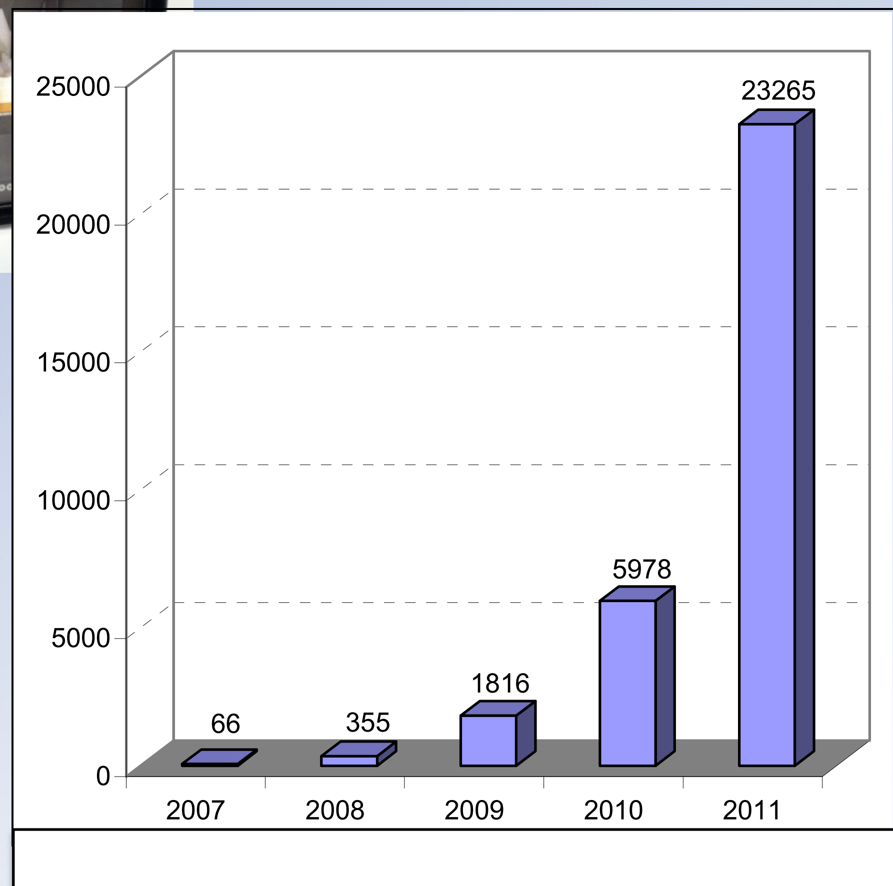
Market Size and Projected Growth in Global AM



The Personal Printing Revolution

$500-$2000

- **Low Cost**
- **High Interest**
- **Quality?**



Similar Trends expected for Metal Additive Technologies?

State of the Industry: Trends

1. **Serious Manufacturing** – Moving past rapid prototyping
2. **New Industry Standards** - As of May 2012, 4 AM terminology standards have been published by ASTM, with many others in development
3. **Advances in metals** - A range of metals with properties on par with wrought and casting processes
4. **Lightweight, strong parts** – AM has enabled Topology Optimization design approach
5. **New design tools** – The emergence of basic design tools is allowing non-professionals to create parts and products
6. **Explosion of new businesses** – The advancement of AM is creating vast opportunities for individual entrepreneurs
7. **Expiration of key patents –** As the industry ages, patents will expire (e.g . Fused Deposition Modeling – FDM and Selective Laser Sintering – SLS)
8. **New types of machines** – The invention and development of new AM process technology is ongoing.

State of the Industry: Technical challenges

- **Process control and modeling**
- **Increased build volume**
- **Increase build rate (deposition rate)**
- **Thermal stress management (residual stress)**
- Rapid qualification - validation and certification procedures and standards
- Materials characterization and availability
- Cost reduction
- Design tools
- Part features and finish – reduce post processing

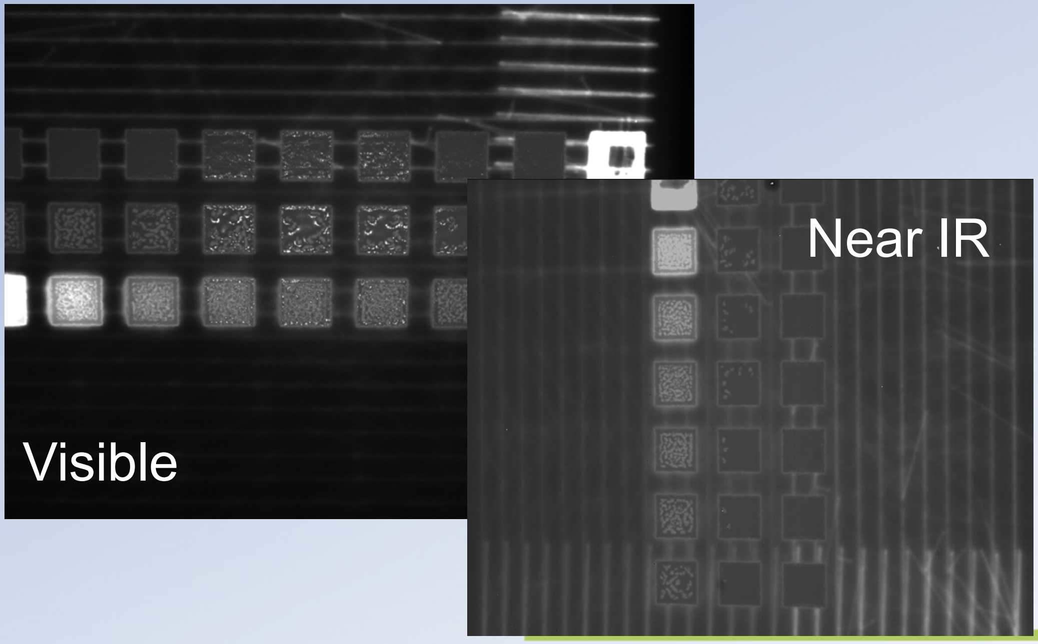
Additive Manufacturing R&D

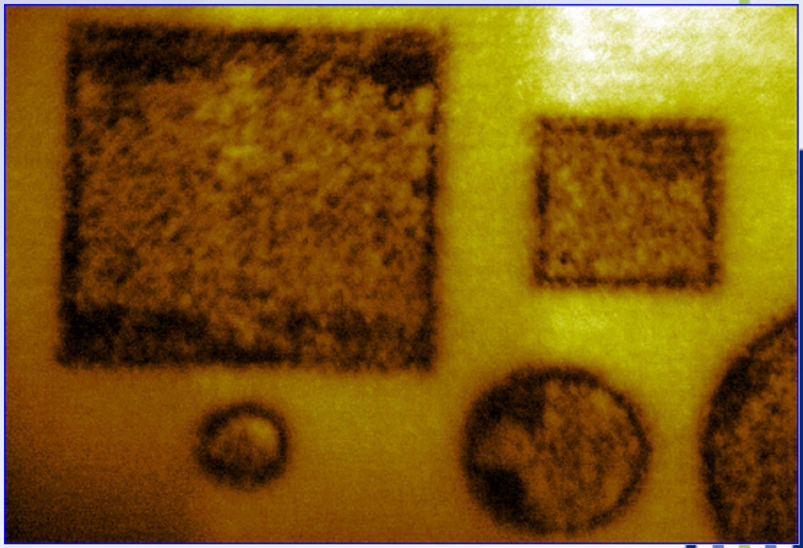
- **Developing advanced materials**
  - Titanium alloys, Ni superalloys, stainless and ultra high-strength steels
  - High-strength, carbon-reinforced polymers
- **Implementing advanced controls**
  - In-situ feedback and control for rapid certification and quality control
- **Understanding material properties and geometric accuracy**
- **Exploring next-generation systems to overcome technology barriers for manufacturing**
  - Bigger, Faster, Cheaper
  - Integrating materials, equipment and component suppliers with end users to develop and evolve the supply chain

In-Situ Process Monitoring

- Ability to understand defects, porosity and material behavior in each layer deposited (repair)
- Several methods examined for both R&D Environment and for cost effective manufacturing solution

Video of High-Speed IR





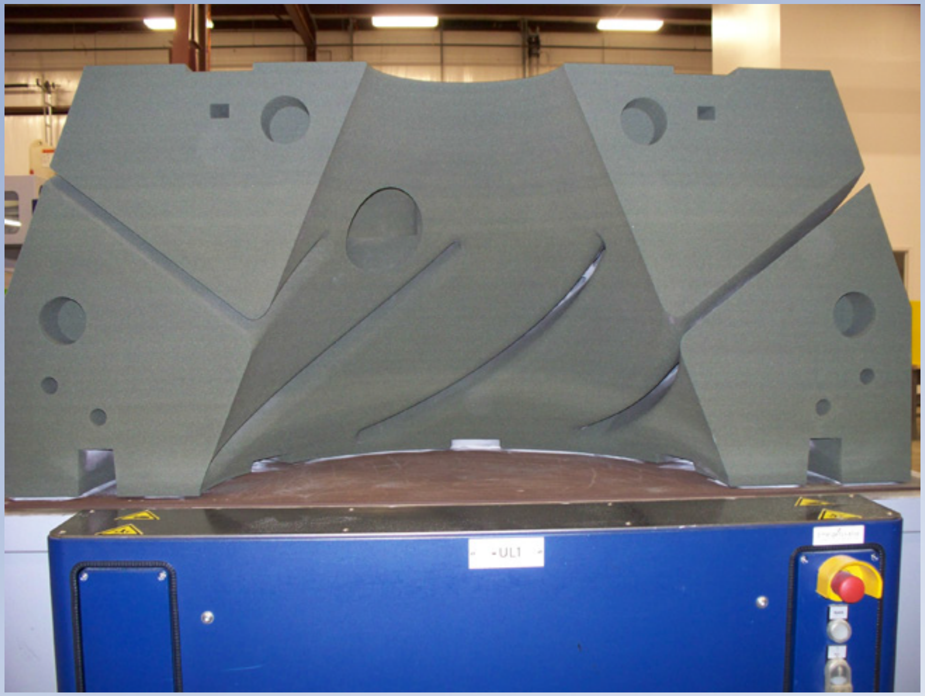
Applications

"… in our lifetime, at least 50% of the engine will be made by additive manufacturing."

Application – Tooling

Soluble Tool Material

Application – Energy
Large Scale Printed Casting Cores



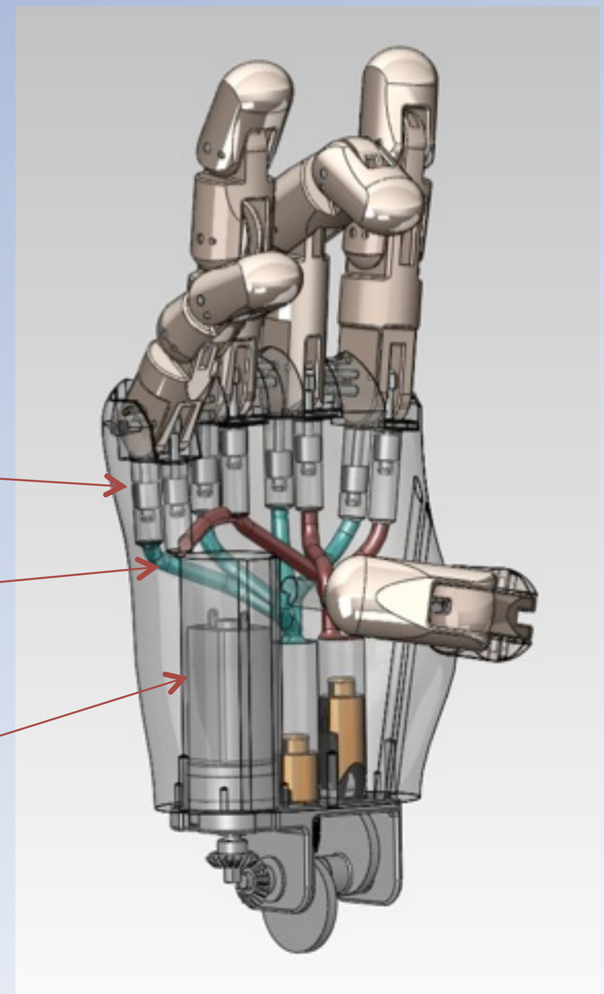
Enabling Next Generation Robotics

Additive Manufacturing

Pistons integrated into structure

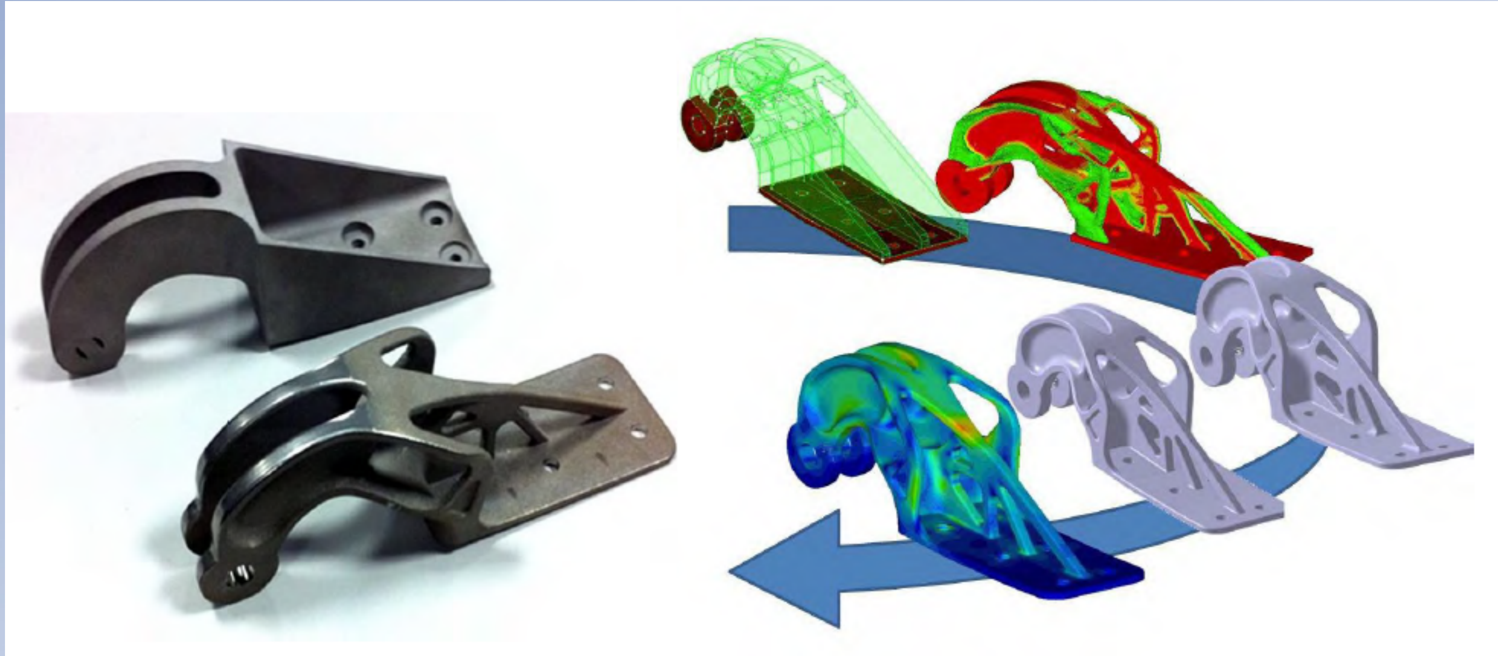
Curved fluid passages

Integrated motor and pump



- Titanium made using E-beam AM (operating pressure 3000 psi)
- Integrated pump, fluid passages and pistons with mesh for weight reduction

Functional and Technology Adapted Product Design



- Nacelle hinge bracket
- Weight reduction by 64%
  918g -> 326g

Additive Manufacturing: Why – energy & cost

Case studies for Additive Manufacturing: Aerospace Brackets

WHY?

Initial adoption of AM in aircraft has begun by targeting less critical components e.g. cabin brackets affix cabin structures (kitchens, lavatories, galleys, etc.) to primary airplane structure and are less critical.

CASE STUDIES

1. Avoiding machining: Cost savings to manufacture – same bracket by AM uses 95% less material resulting in more than 50% cost savings.

2. Optimized design: Results in bracket that is 65% lighter, saving manufacturing materials and resulting in use phase energy savings.

Conventional Process

12 g

1.09 kg

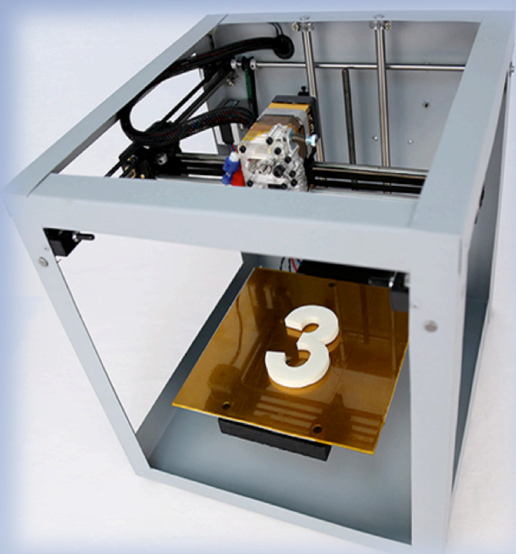
Additive Process

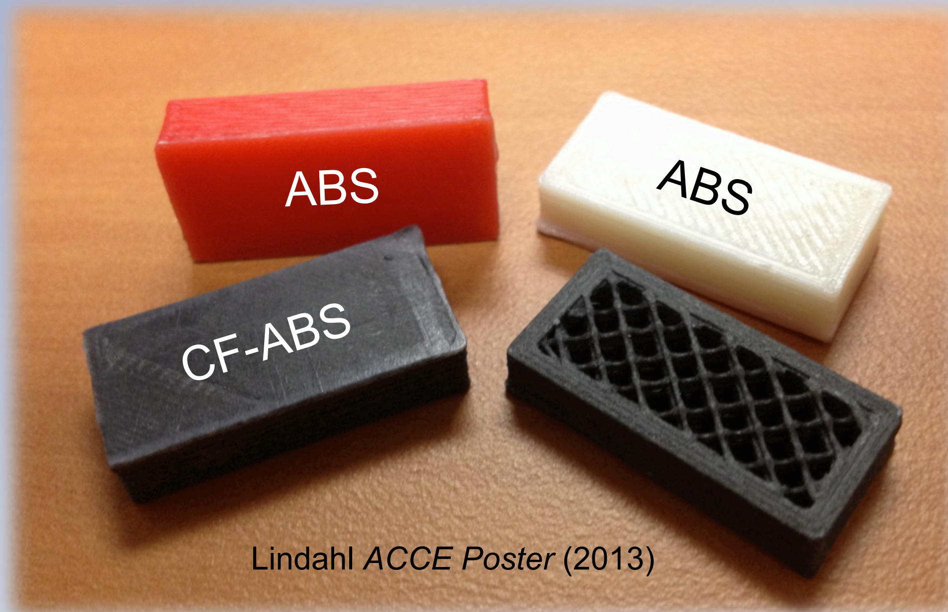
12 g (identical)

0.38 kg (optimized)

Carbon Fiber FDM Composites

- Compounded filament printed on table top unit (modified)
- 10-15% CF by weight



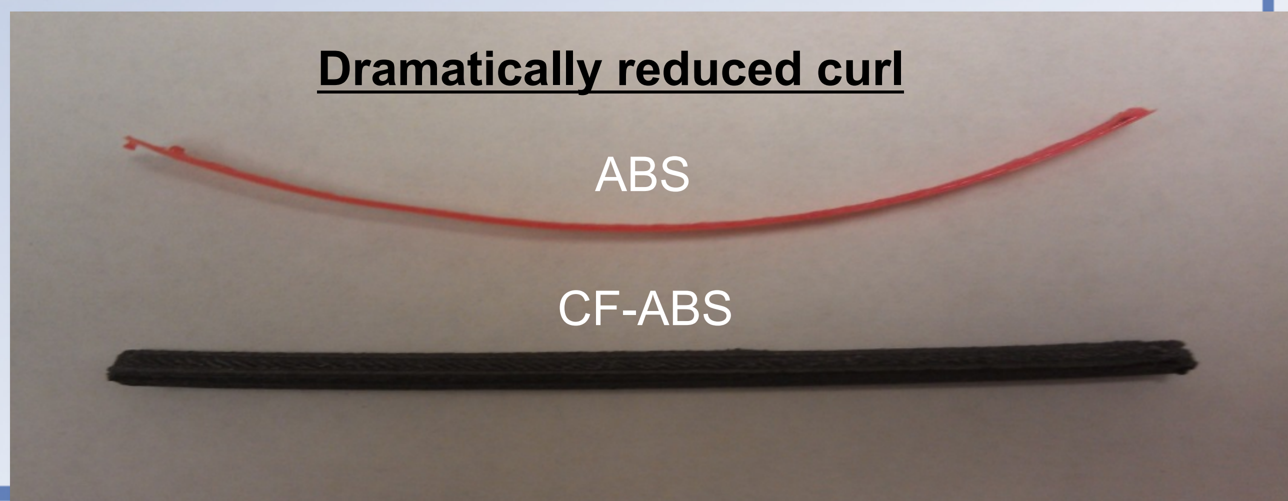


Lindahl *ACCE Poster* (2013)

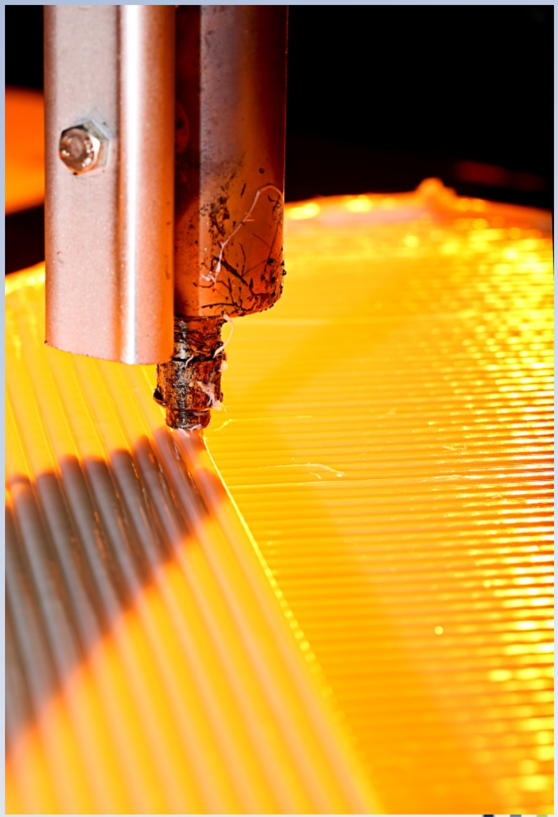
<u>CF-ABS</u>

2x strength

4x stiffness

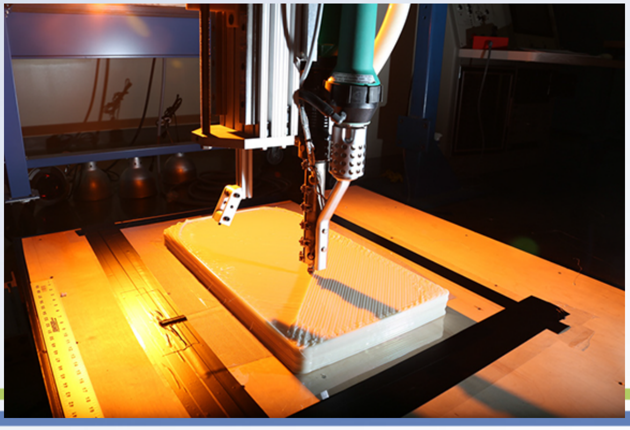


Big Area Additive Manufacturing (BAAM)



- Collaboration between ORNL and Equipment Manufacturer
  - Multiple-robot coordination (8' x 8' x 8' gantry, multiple degree of freedom Robot)
  - Materials – low CTE, high strength materials
  - Deposition – new methods of deposition and control

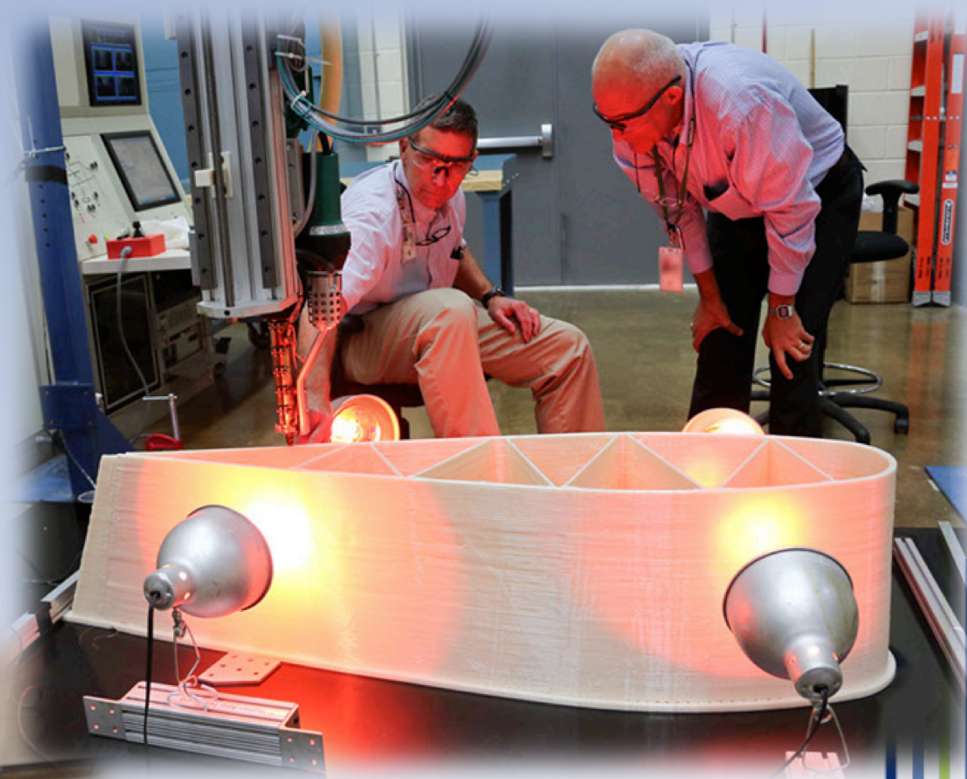
- Pellet-to-Part: Enables manufacturing of large components using pelletized feed.



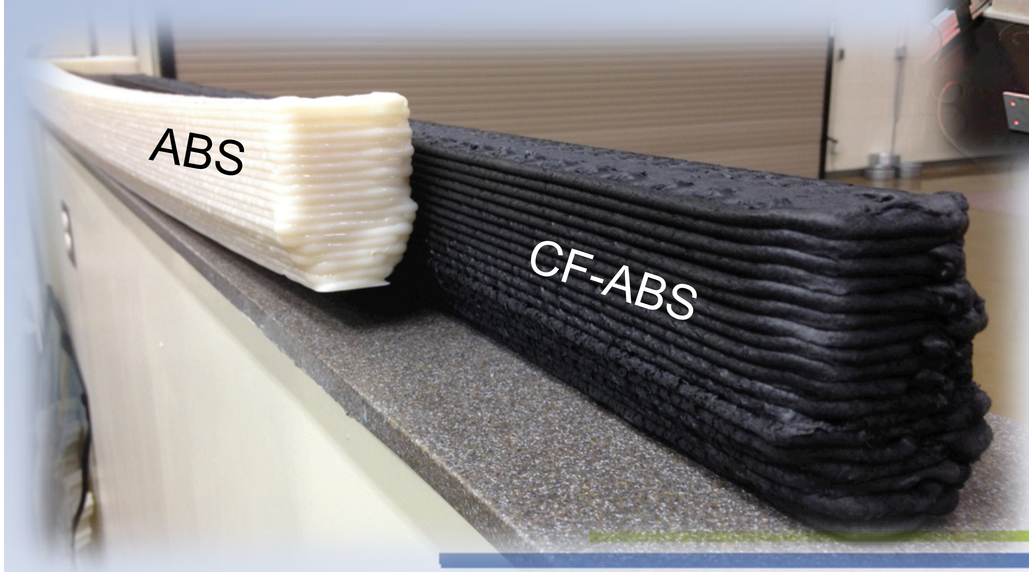
Big Area Additive Manufacturing (BAAM)

Large scale deposition system

- Unbounded build envelope
- High deposition rates (~20 lbs/h)
- Direct build components
- Tools, dies, molds

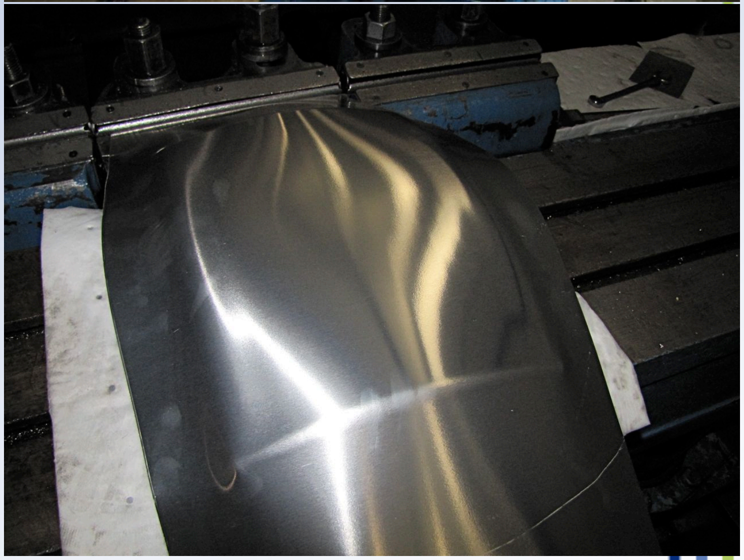


Carbon fiber material reduces warping out of oven



Example: Stretch Form Tooling

- Tool Details
  - Size 10” x 13” x 2.5”
  - 2” crown w/ multiple contours
  - Tool Material – ULTEM 9085
- Successfully Formed
  - Alloy 2024-0
  - Thickness 0.050” up to 0.100”
- Notes
  - Surface pressures are minimal
  - Tool can be optimized to minimize build times and cost
  - PC is a viable alternate material depending on alloy, thickness and tool build styles



Questions?

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