AICA

3D Printing/ Additive Manufacturing (3DP/AM)

State of the Art in the U.S. Industry

AM/AICA Report (AMAR)

Milano – November 13, 2014

G Kassabgi

U.S. INDUSTRY
&
AM IMPACT

THE AM STRATEGIC PLAN
&
DISCUSSION

"AM in the USA" Report
The challenges to management

EXECUTIVE SUMMARY

Additive Manufacturing (AM) or 3D printing is close to 40 years old, with strong expansion since 2010. However, it is still in its infancy. It represents a tiny fraction of all the manufacturing. Originally AM was regarded as a technology for rapid prototyping, aimed at reducing the time it takes to go from the concept of a new product to its availability in the market. Current interest in AM as part of the factory has arisen from the development of a variety of industrial-grade AM processes and their related machines along with the inclusion of a growing variety of suitable materials. More work is needed. We owe a great deal for AM's status to early investments in both R&D and training in core competencies, *and* the open-source movement of the past ten years in North America, the EU, China, and Japan.

AM does not represent the third industrial revolution as some entrepreneurs and business analysts have suggested. What it could become (within the next five years, say) is a catalyst for more effective ways of doing business.

The adoption of AM in a corporation for its own production (not just for prototyping and modeling) will impact almost all aspects of its business: design and engineering, manufacturing, sales, distribution, and maintenance. The most likely scenario will be one in which AM co-exists with the traditional manufacturing process. Specifically:

● Responsibility for design and manufacturing will be spread over a wider range of contributors. IT experts will play an important role in the early stages of the design-for-AM process toward the effective use of scanners, CAD, and other reverse-engineering-related devices. Designers will inevitably need to work more closely to manufacturing and in some cases, such cooperation will require individuals to work in the same space.

● As regards sales, shipping and inventory will be downsized and/or re-organized. Instead of the traditional maintenance plan, the introduction of AM will require availability of the material/s specified by the AM process. It might lead to a situation where customers do their own repairs; this would necessitate installation of AM printer and storage of AM materials at (or near) the customer's location.

● The ROI analysis for new products will include new items such as environment, waste management, co-service providers, and a greater role over time for robotics.

● Success will ultimately depend on how well AM is integrated within the company's existing operations. It should not be seen as an absolute substitute for traditional manufacturing.

The report, maintaining a focus on business/industrial grade users/applications (versus personal usage and hobbyists) examines as well the impact the AM introduction has had or will have throughout the organization in four major areas of U.S. industry: auto/aero/transport, medicine/dentistry, housing/construction, and retail/accessories. Considering separately the activity before and after sales, AM is a challenge to management in that it:

Allows shorter development-to-market cycle
Requires, in some cases, core competency in materials at micro/nano levels
Makes higher geometric complexity feasible at lower cost
Calls for distributed design and development
Leads to hybrid manufacturing and 4D printing (medical applications)
Is an environment-friendly manufacturing process
Necessitates updated education and technical training of support staff
Ensures cost reduction in tooling, shipping, and inventory

Improves response to customers
Introduces customization as a close-to-no-cost marketing advantage
Requires new tools to protect AM digital files

Kassabgi's report concludes with an outline of considerations in preparing a long-term strategic plan for AM. Additional references are included for a continued discussion.

AM is not only about a new technology:
a more effective management of the business may be in the making.

Georges Kassabgi is an electronics engineer. He has done research in computer technology for Olivetti, General Electric, and Honeywell. He holds five U.S. patents. With a broadened scope within the industry, he became an advisor to businesses in many countries and is the author of The Legacy (2001), a collection of discussion papers on management (available at www.ugik.com).

(November 2014)

U.S. INDUSTRY
&
AM IMPACT

■ Management Summary

■ Recent Events by Sector
&
AM Impact

■ Management Summary

AM Business is growing

Education/Training:
A Critical Success Factor

AM for your business
has to be part of a
long-term strategic plan
dealing with technology,
new life-cycle economics,
training *and* organizational
requirements/implications

The AM Industry Includes:

►*CAD+scanner+3Dprinter, network, more...*

►***AM (Build) Processes***

►***Post-processing***

►***Measurement, Finishing***

►**Materials and Suppliers**

►**Service Providers**

Design, Prototyping, and Finished Product

►**End Users**

startups (SU),
small-to-medium companies (S-M-E),
large corporations (LC),
service providers (SP),
education and training, R&D institutes (E-T-I),
personal/hobbyists

Projected Total Revenues in 2014:
~$2 B
~50% systems sales,
~50% services

- ► ~70% industrial applications
  - ~40% auto/aero, transport
  - ~20% medical, dentistry
  - ~20% housing, construction
  - ~20% retail, accessories
- ► ~20% personal/home-based
- ► ~10% education & government

2013 selling price for industrial grade AM: minimum $9K (Asiga)
maximum $5M (Sciaky)

8 major US systems manufacturers...

plus ~25+ startups...
plus service providers...
plus major R&D in universities, industry/govern.t partnerships investing in large-scale machines, integrated electronics, *and* education

2011-2013: ~30% growth (in revenues)/year

highest short-term growth in:

auto/aero, medical, retail/accessories, *and* personal/hobbyists

forecast of higher growth rates for 2013-18

business-bound applications: ~$1.5M

10% parts uniquely designed for AM
15% functional parts
40% production support, prototyping
35% presentation, models, education, research and experimenting with AM

Why AM Growth (2012-14)?

Availability of printable materials

Improved CAD/CAE software

IT expertise in design and manufacturing

Supply chain management: AM benefits

Finished goods by AM in small companies

Cost-effective customization

...

Patents expired

Education and training (Project TEAM and other programs)

The "Maker Movement"

ASTM F42 Standards

AM articles, books, research, doctoral theses, white papers by systems manufacturers...

AM Global $$$ picture:
(2014)

►USA and Canada
~40%

►EU and Israel
~35%

►Asia/Pac/Africa
~25%

...with projected global revenues to be in the $16B – $80B range by 2018

* * * *

Worldwide Manufacturing ~ $10 T
(in 2013)
AM represents <<<1%

■ Recent Events by Sector & AM Impact

4 Sectors:

►Auto/Aero, Transport

►Medical, Dentistry

►Housing, Construction

►Retail, Accessories

Auto/Aero, Transport

GE Aviation
Advanced manufacturing roadmap:
45,000 jet engine fuel nozzles 3D printed a year
https://www.ge.com/stories/additive-manufacturing
http://www.bloomberg.com/news/2013-11-12/ge-printing-engine-fuel-nozzles-propels-6-billion-market.html

ORNL (Oak Ridge, TN) **with Cincinnati Inc** has developed a large scale hybrid 3D printing and machining system

Youngstown's 'Maker City Initiative' (Ohio)
Elementary schools, public libraries, local manufacturers and local Maker spaces: focused on turning the city into a 3D-printing powerhouse.

Sciaky, Inc (Chicago) makes first official sale of giant metal 3D printer (EBAM). The firm will continue as a service provider performing welding services for the aerospace, defense, auto industries.

Local Motors' 3D printed car drives into the 21st century...

Maersk installs 3D printers on vessels

More events in Attachment A

AM IMPACT
(Auto/Aero, Transport Sector)

Shorter development cycle thanks to early adoption of rapid prototyping (form and fit testing)

Increased core competencies (including materials)

IT: an integral part of design and manufacturing

Increased geometric complexity at same cost

Reduction of tooling, inventory and shipping costs

Improved response to customers:
(a) with some manufacturing done closer to customers' facilities, and
(b) by shifting finished good transportation towards bulk material transportation

Preparing for “hybrid” manufacturing?

Benefits to the environment (lighter parts)?

Finding new anti-theft means for CAD files?

Medicine, Dentistry

Organovo (San Diego)
Proprietary three-dimensional bio-printing technology for living human tissues that are proven to function like native tissues...implanted into the human body to replace damaged or diseased tissues.

Princeton University
Using 3-D printing tools, a functional ear that can "hear" radio frequencies far beyond the range of normal human capability.

Cornell/Creative Machines Lab
Exploring new biological concepts for new engineering insights into biology (robotics)

FORM Labs (Boston)
10 million hearing aids. 560 million Invisalign all customized (high-value added for dentistry)

Stryker and Medtronic
Innovative orthopedic and cardiovascular products

MIT/synthetic bones
www.bostonmagazine.com/health/blog/2013/06/18/3d-printers-bone/?utm_source=iContact&utm_medium=email&utm_campaign

More details in Attachment B

AM IMPACT
Medicine, Dentistry

Teeth alignment and prosthesis: faster, more reliable
http://www.kravitzorthodontics.com/assets/pdfs/Invisalign.pdf

Customized hearing aids

Dynamic measurement foot scan

Education and training of medical support staff

Doctors can order and have delivered 3D-printed human parts... (as well as plan surgery using 3D-printed anatomical parts)?

Critical support for medical and veterinarian personnel in developing countries?

Testing new drug on functional human tissues before administering it to a living person?

Prepare for 4D Printing...(materials changing properties with changes in the environment)?

Housing, Construction

CRAFT
Center for Rapid Automated Fabrication Technologies (Los Angeles University): 3D printed house; 3D fast printing of multi-material objects.

Robot House Project,
Southern California Institute of Architecture (SCI)

NASA
http://phys.org/news/2012-07-nasa-additive-space.html

GeoFabLab
Iowa State University
http://www.news.iastate.edu/news/2014/09/15/geofablab

Cornell University
building material--interlocking ceramic bricks that are lightweight, need no mortar and make efficient use of materials.
http://www.news.cornell.edu/stories/2014/07/3-d-printing-helps-designers-build-better-brick

Home Depot

More events in Attachment C

AM IMPACT
Housing, Construction

Customization

Some reduction in shipping costs, inventory

Education and training for in-field staff (pre- and post-sales)

Benefits to environment?

Increased need for core competencies in engineering for materials at the microscopic level?

More efficient emergency services in disaster areas?

Retail, Accessories

3D KUL Factory, Omaha
3D printing shop/service. Makes prototypes, parts and other custom jobs for inventors and businesses.

Cubify (3D SYSTEMS)
3D Printers, design and development:
hub for things possible with 3D printing

Reinventing Retail
Staples, Office Depot, amazon.com, UPS

Nervous System (Boston area)
Design studio, computer programs based on processes and patterns found in nature, to create unique and affordable art, jewelry, and housewares.

FabLabs...
Thingyverse, Shapeways, and more...

MIT, AutoDesk, Stratasys, and others... for applications requiring multiple materials... and self-folding features... (4D without environment).
http://www.sjet.us/MIT_4D%20Printing.html
http://www.technologyreview.com/demo/521956/printing-batteries/

Center for Rapid Automated Fabrication Technologies (**CRAFT**), USC Los Angeles

C.Ideas
Rapid prototyping. Service provider.

Protos Eyewear
3D Printed Eyewear Tailored to fit the customer

Midwest Prototyping/ materials and services

Studio Fathom, California/ printers and services

Grafoid, Canada/ products and services (graphene)

Crescent Industries/custom injection molder and components

Kickstarter and taulman 3D/high-strength printing materials

Matter and Form 3D Scanner/compact, lightweight

OpenFabpdx.com
digital design and manufacturing/consulting

More details in Attachment D

AM IMPACT
Retail, Accessories

Reduced design' time-to-market

Incorporation of gadgetry along hyper-customization

Increased geometric complexity at same cost

Features on the basis of bio-mechanical data (shoes)
http://3dprintingindustry.com/2014/10/14/3d-shoes-design-3d-printed/?utm_source=3D+Printing+Industry+Update&utm_medium=email&utm_campaign=019ea3832d-RSS_EMAIL_CAMPAIGN&utm_term=0_695d5c73dc-019ea3832d-64478169

Decreased costs: tools, inventory and shipping

Education and training of sales staff

Design and development may become distributed?

Multi-material prototypes for testing?

Plastic waste converted into 3D printing filament?

Counterfeiting of CAD files?

HP 3D Printer? Dell 3D Printer? Google.com?

THE AM STRATEGIC PLAN

► Rationale for adopting AM in your organization

► Business opportunities

► Core competencies

► Factors limiting adoption of AM

► Case studies (for further analysis)

Rationale for adopting AM in your organization

Some components in your product line cannot be cost-effectively produced by traditional manufacturing process alone, especially if in metal.

You need to reduce the number of parts, and waste.

Design-for-AM training and planning: (a) to have parts according to function and usage, *not* as required by the subtractive manufacturing process; (b) to ensure higher efficiency in the use of materials; (c) to manufacture at point of demand or consumption; (d) to select materials and process for quality and cost optimized products.

CIO/IT expertise is in design/manufacturing

Hybrid (subtractive + additive) manufacturing and robotics are of potential interest for better ROI.

...

Your long-term strategic plans include training on core AM competencies in materials and processes.

You value the importance of life-cycle costs for improved supply chain as well as cooperation between design, development, and manufacturing/maintenance.
Noteworthy: AM life-cycle costs include items not usually considered with traditional manufacturing (e.g. recycling+ costs, environment, distributed development, and more).

Keeping in mind that...

"Design for AM" tools and knowledge need to be accessible to a broad range of designers manufacturing technicians. More research and engineering is needed for AM to be called an "industrial revolution".

It does not cost more to produce complex components, therefore, parts with higher geometric complexities can be obtained at same manufacturing prices as basic components. For instance, (a) increase shock absorption or improve heat dissipation via 3D, and (b) customize with special features for clients willing to pay.

In essence: Print what your business requires
versus
what the manufacturer is capable of producing

Some AM materials are not recyclable.

AM is to be implemented, with the objective to ensure beneficial changes are obtained in engineering and manufacturing as well as in pre- and after-sales activities .

online white papers/info of interest:

CSC review of 3D Printing opportunities/challenges
http://lef.csc.com/assets/3705

Design rules and detail resolution for SLS 3D printing
http://www.shapeways.com/tutorials/design_rules_for_3d_printing

SLS (selective laser sintering) Accuracy study
https://www.solidconcepts.com/resources/white-papers/sls-accuracy-study-austin-tx-april-2009/

design-for AM: recent article
http://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/8659/New-Design-Optimization-Possibilities-with-Additive-Manufacturing.aspx

parameter setting
https://www.dropbox.com/s/sztdsf2kw5p6i0m/EOS-quality-tradeoffs.pdf

http://www.imp-obj.com/

http://www.forecast3d.com/

AM life-cycle costs case report:
http://www.forbes.com/sites/airbus/2014/07/15/how-adding-a-new-dimension-to-airplanes-is-delivering-parts-on-demand/

more white papers available at systems manufacturers websites

What are the biggest market and business opportunities for AM?

Rapid/low-cost production of tools for manufacturing
http://www.cs.berkeley.edu/~sequin/CAFFE/cyberbuild.html

Low volumes, with focus on customization

Complex geometries for performance

Parts that are sole sourced or with long lead times

Parts or products for operations in remote locations

Improved functionality at a lower weight/cost

Taking part in large-scale supply chains

Reduction of substantial import/export fees

Many laser-sintering patents are set to expire in 2014

Printers in the middle price range ($50K-500K) are under development: that will help achieve complete printing systems with higher application usage/performance (at a lower cost).

Core competencies for AM

● Effective usage of CAD, reverse engineering, scanners, digital cameras, networks... in support of design-for-AM

● Distributed design/engineering and manufacturing

● Post-processing for each process/material

● Supply chain management (AM life-cycle costs)

● Material properties (nano/micro structures, thermal management, internal sensors, perform-in-process inspection,...) so as to expand (a) the range of materials while reducing their cost; (b) multiple-materials options in same machine; and (c) the capability to print very large objects.

Note 1: ensuring that adhesion between (metal) layers will be consistent remains a challenge.

Note 2: According to engineering.com the number of ads requiring technicians/workers with AM-related skills increased 103 % since August 2013

Factors limiting adoption of AM

*Limited training (at both the national and company levels) in**:** design-for-AM, materials, manufacturing process, logistics*

Materials too expensive (re monopolies)

Large machines too expensive

Time-to-print too long

Not-yet-available updated, simpler-to-use or more-automated software for CAD/CAE so as to make design-for-AM broadly accessible

Not effective post-processing steps may eliminate the advantages of low inventories, short-lead times, and on-demand production

Legal issues not-explored yet: will consumer have the right to replicate a product they own? will they be allowed to create their own spare parts?

Piracy once a 3D design is shared online?

How will certain stores manage/promote their 3D Printing services offering?

AM remains a complex technical process with challenging problems in performance and cost... especially if core competencies are not fully available

intellectual inertia

CASE STUDY (qualitative): complex multi-material stand-alone part

	Subtractive Manufacturing	**Additive Manufacturing**
Concept/ Design	centralized, by hand; high performance many prototypes	with many contributors using CAD and scanner; higher performance (potential) one or two prototypes
	long lead time-to-final	relatively shorter lead time-to-final
Production	new tooling, molds, hand assembling, and minimum finishing: all energy- and waste-intensive	AM materials preparation AM-based assembly and for-AM-post-processing: some low-energy, and all minimum-waste
	time-to-produce 1: short	time-to-produce 1: relatively longer
	cost= f(total quantity) customization adds cost	cost same for all units customization adds no cost
Marketing/ Distribution	Standard distribution; product inventory high	AM next to customer; inventory: materials only
Repair	high cost	low cost
...		
Implementation	in-house	via AM service provider if first AM product (optional)
	ROI standard	ROI taking into account features of AM process from design/engineering through maintenance/repair as well as waste and repairs

Example: jewelry via cooperation with AM system manufacturer

Jenny Wu's 3D-Printed Jewelry Inspired by Geometry and Organic Movement

Stratasys has collaborated with architect and designer Jenny Wu, of Oyler Wu Collaborative, on her first 3D-printed jewelry collection.

The LACE collection is a line of 3D-printed wearable designs, including necklaces and rings, inspired by line-based geometry and intricate, organic movement, which stand out as bold statements on the body. The leading LACE design is the Tangens necklace. This necklace will be available in black, white or translucent material.

Wu said, “I wanted to design a range of jewelry that could be avant-garde yet wearable, and approached it from my architectural heritage of spatial and line-based geometries to form a bold but soft spectacle for the body."

Wu has also collaborated with Solidscape, a Stratasys subsidiary, to produce the Papilio ring, which evokes the beautiful fluttering movement of a butterfly wing. Solidscape’s MAX^2 3D Printer was used to deliver high precision and a refined surface finish – ideal for small jewelry items.

CASE STUDY: Hearing Aids in the US

	Traditional Manufacturing	**Additive Manufacturing**
Pre-process with patient	cast of ear; adjustments: model is ordered after numerous iterations	3D scan of ear; technician uses virtual image to create fit ear-aid shell
patient is back at home	wax impression; new cast; long process in lab (days or weeks)	hearing aid is AM printed (2-to-6 hours)
Inspect/install with patient	alignment, final inspect electronics installed	electronics installed
	custom shell delivered typically after ten days	custom shell delivered typically after 2-4 days

2 million custom hearing aids delivered in 2013

90% were AM printed

AM process shorter than traditional process by 50-80% (depending on patients)

…

http://www.forbes.com/sites/stevebanker/2013/10/15/3d-printing-revolutionizes-the-hearing-aid-business/

DISCUSSION

Documents ─

─ AM 40-year history: an overview
─ Processes + Process/Material relationship + materials info
─ Major AM machine manufacturers (US)
─ R&D current activities

─ Books and more reading references

─ Attachments (re additional "Recent Events and AM Impact")

AM 40-year history: an overview

1972
CAD software allows the saving of digital files that can be 3D printed

1979
a precursor of Selective Laser Sintering is patented but not commercialized

1980
DARPA (Defense Advanced Research Projects Agency) sponsors several AM studies

1986
Charles Hull invents/patents stereo lithography and founds the 3D Systems company

mid-1990s
3D Systems commercializes SLA (Stereo Lithography Apparatus) for photopolymers

MIT develops inkjet 3D printing process for powders (plaster and starch)

1999-2002
first AM applications in medicine, sponsored by Wake Forest Institute for Regenerative Medicine

Many European and Asian countries get directly involved in developing their AM technology

The FabLab network is established (goal: at least one FabLab every 700,000 people)

2005
Adrian Bowyer of University of Bath founds RepRap, an open-source initiative

2006
First SLS (Selective Laser Sintering) is commercialized

First 3D printer for multiple materials

2008
Shapeways starts co-creation service and community

2009
Organovo starts with first AM blood vessel

2011
First 3D printers for gold and silver

2012
The America Makes (NNMI) starts: a national hub for AM technology and workforce education/training

2013
NASA launches zero-gravity 3D Printer

The AM Process*

1. CAD (fully described external geometry output in STL)
2. STL conversion to AM machine
3. File transfer to AM machine
4. AM machine setup (settings related to build parameters, material constraints, energy...)
5. Build (an automated process)
6. Remove (supports, other parts)
7. Post-process (parts may require cleaning, painting, etc.)
8. Application (parts may require additional treatment such as priming, surface finish)
9. Maintenance: AM machines are fragile, require monitoring, under controlled environment, certain materials might need special attention or have limited shelf life, regular test patterns might be applicable.

* from: "Additive Manufacturing Technologies" by Gibson, Rosen, Stucker (2010)

The 7 processes (ASTM F42 Standard)

1. Material jetting (POLYJET)

> droplets of build material (typically, photopolymers or wax-like for investment-casting patterns) are jetted to form an object

> often use multi-nozzle print heads with technology which atomizes nanoparticles-sized print materials (metal and non-metal), enabling the printing of electronic circuits

2. Binder jetting (3DP)

3 dimensional printing

> liquid bonding agent is jetted to join powder materials

3. Material extrusion (FDM/FFF)

fused deposition model/fused filament fabrication

> material, typically thermoplastic, (filaments or droplets), is dispensed through a nozzle and each layer bonds to the previous layer i.e. solidifies

> support structures (also filament extruded) are critical

> this is the largest installed base of AM systems (including personal 3D printers)

4. VAT photopolymerization/STL/SLA
(stereolithography)
> material (photo sensitive liquid resin) is cured layer after layer by light-activated (UV) polymerization

5. Sheet lamination (LOM, laminated object manufacturing**)**
> sheets (metals, plastics, or paper) are bonded to form an object

6. Powder bed fusion (SLS/SLM)
> thermal energy (laser) is used to selectively fuse regions, layer by layer, of a powder bed (SLS, selective laser sintering is like an ink-jet printer/ SLM selective laser melting, when rather than fusing the powder material, the powder is melted at high temperatures)
>EBM, Electron Beam Melting is similar to SLS but with an electron beam

7. Directed energy deposition (LENS, laser engineered net shaping**)**
> focused thermal energy (laser) is used to fuse materials (metals) by melting as deposition occurs
> also called “laser cladding” and “blown powder AM”... capable of depositing more than one material simultaneously... suitable for adding material to an existing part as in repair

>>> layer thickness: minimum 0.05mm/SLS, Max 0.250mm/FDM

Process/material relationship:

Materials	AM Process
Polymers (and blends)	Material extrusion, Material jetting, Binder jetting Vat photopolymerization, Lamination, Powder bed fusion, Directed energy deposition
Metals	Binder jetting, sheet lamination, Powder bed fusion, Directed energy deposition
Graded/hybrid metals	Sheet lamination, Directed energy deposition
Ceramics	Binder jetting, Vat photopolymerization Powder bed fusion
Investment casting patterns	Material jetting, Binder jetting, Vat photopolymer. Powder bed fusion
Sand molds, and cores	Material extrusion, Binder jetting, Powder bed fusion
Paper	Material extrusion, Sheet lamination

AM Materials 2014

Status ~$520M

photopolymers... ~50%
thermoplastics (solid)... ~40%
metals... ~10%

AM more efficient in the way materials are used *versus* injection molding which wastes a significant proportion of raw materials...
Comparison of energy consumption: AM energy requirement dedicated to the product in most cases is much higher.

Challenges & Opportunities

Market Forecast: high growth

Major AM machines manufacturers in the US

Company	Technology
3D Systems	Binder/metal jetting, powder bed fusion, photoplymerization film transfer imaging, not yet ASTM standard
Sciaky	Directed energy deposition EBDM (electron beam direct manufacturing, with wire instead of powder)
Optomec	Directed energy deposition, Material jetting+ Direct write
Fabrisonic	Sheet lamination
ExOne	Binder jetting
Asiga	Vat photopolymerization
Stratasys	Material extrusion, Material jetting,
SolidScape	Material jetting
DDM Systems	Large area photopolymer.n (2015)

R&D references

America Makes (NNMI), established in 2012

First Institute opened 08/2013
95 members, as of April 2014
Hub for AM technology *and* workforce education

NASA Langley Research Center (development of previously impossible/complex parts)

Air Force Research Laboratory

DARPA

AM Consortium (Columbus, Ohio)

ASTM International Committee F42 (Standards)

Project TEAM (Technician Education in Additive Manufacturing)

NSF (National Science Foundation) Basic Research on Existing AM Technology, with Carnegie Mellon University (Pittsburgh, Pennsylvania) with North Carolina State University, Wright State University, and Pratt & Whitney.

NSF Research on Meso, mocro, and nano Scale Technology with University of Michigan (Ann Arbor), **North Carolina State University**, and Rensselaer Polythechnic Institute (Troy, New York)

National Institute of Health

Oak Ridge National Laboratory (ORNL) and Cincinnati, Inc
http://www.ornl.gov/ornl/news/news-releases/2014/ornl-cincinnati-partner-to-develop-commercial-large-scale-additive-manufacturing-system--

Lawrence Livermore National Laboratory (Livermore, California), **LLNL**

UT, Austin, *and* Keck Center at Paso (UTEP)

Maker City Initiative (Youngstown University, Ohio)

MIT

Tennessee Tech University

Pearson Educational Company

Rapid Prototyping Center at **Milwaukee School of Engineering**

National FabLab Network: to establish at least one FabLab every 700,000 people...to empower the next generation of entrepreneurs/innovators... to help students build the STEM (Science, Technology, Engineering, Math) skills

RapidTech at UC Irvine

Honeywell Aerospace (Tempe, AZ)
Developing a new directed energy deposition process called IFF (ion fusion formation): for metal parts, using plasma welding torch.
Using both powder and filament for large aluminum parts

Flexible Robotic Environment (Rapid City, South Dakota)
Developing a laser-based directed energy deposition with six degrees of freedom and 300-watt fiber laser.

iRobot

Optomec and Aurora Flight Sciences and Stratasys
complete airplane wings, including electronics and sensors for small drones

Harvard School of Engineering and Applied Sciences
building block of tiny lithium ion batteries as printable inks
developing bio-inks to make living tissues... with new ink (for blood) which melts as it cools, not as it warms

Michigan Technological University (MTU)
Delta robot printers and open-source

Xerox PARC inks for circuits, antennas, tags...

Books and references

"Additive Manufacturing Technologies"
by Ian Gibson, David W Rosen, Brent Stucker
(2010)

ASTM Standards F42

AMUG
www.additivemanufacturingusersgroup.com/index.htm

http://cba.mit.edu/people/index.html

ibm supply chain management:
http://www-935.ibm.com/services/us/gbs/bus/html/gbs-making-change-work.html
http://www-01.ibm.com/common/ssi/cgi-bin/ssialias?infotype=PM&subtype=XB&htmlfid=GBE03163USEN#loaded

...

online magazines:
TCTmagazine.com
ScienceDirect
Engineering.com

ATTACHMENT A
More Events for Industry Sector
Auto/Aero, Transport

BOEING
Boeing and Lotus join forces to advance AM processes and materials

FORD

Hyperloop Transport
intercity aerospace transport

Lockheed Martin

JCL at the Center for Automotive Research Management briefing seminars: a printer for 12 different materials, 20 different components, assembled all at once...smart surfaces that can perform additional functions...

PARC moves closer to 3D Printing electronic components within objects (chiplets)

TiCycles (Portland, Oregon) used AM with pure titanium to create tubes and other parts of the frame

Avante Technology's Advanced Composite Filament FilaOne (advanced thermoplastic)

Adobe's New Photoshop CC updated with more 3D printing features

MarkForg3D: the revolutionary Mark One 3D printer is the first one to print continuous carbon fiber.

Arcam AB's New 3D Printer garners interest from aerospace companies

RedDOT, a Seattle-based company that designs HVAC systems for heavy commercial and military vehicles makes tough nylon parts with FDM

University of Texas at Austin, Carolyn Conner Seepersad, Mechanical Engineer Department

Ai Design, teaming with RedEye, uses 3D printing to customize vehicles

ATTACHMENT B
More Events for Industry Sector
Medical, Dentistry

Envisiontec

Washington University

NOVA Copy

Columbia University (Tissue Engineering and Regenerative Medical Lab)

Journal of the America Pharmacists Association

Orthopedics

Hearing aids

Align

Groupe Gorge'...

DARPA projects

Scripps Clinic

http://www.economist.com/news/technology-quarterly/21598322-bioprinting-building-living-tissue-3d-printer-becoming-new-business

Johnson & Johnson partners with Organovo to 3D print living tissues

Phantoms for Medical Imaging and Computational Validation Applications:

3D Printing Photopolymers: An Emerging Source of Antinomy (metal, poisonous like arsenic) to the Environment.

The researchers' primary purpose was to explore an efficient and versatile method of merging electronics with tissue. The scientists used 3-D printing of cells and nanoparticles — with an off-the-shelf printer purchased off the Internet — followed by cell culture to combine a small coil antenna with cartilage, creating what they term a bionic ear.

Center for Rapid Automated Fabrication Technologies (CRAFT), USC LosAngeles

Austin Biotech

University of Michigan

Printing the Human Body
20 June 2014, *Silicon Hills*
http://www.siliconhillsnews.com/2014/06/20/printing-the-human-body/

exoskeleton, tailor-made at a significant lower cost + increased quality of life for patient (disorders affecting posture and movement)

Center for Rapid Automated Fabrication Technologies (**CRAFT**): to develop the science and engineering needed for rapid automated fabrication of objects of various size out of a variety of materials including polymers, metals and alloys, ceramics and composites such as concrete at various sizes ranging from meso-scale to mega-scale objects. Application areas include biomedical, automotive, space industry, and building construction industry blending fundamental engineering research with the development of engineered systems; partnerships with materials, equipment, construction, architecture, real estate, software and manufacturing industries; incorporating environmental, regulatory, labor and economic expertise and interdisciplinary graduate and undergraduate education.

ATTACHMENT C
More Events for Industry Sector:
Housing, Construction

Voxeljet
industrial scale sand-casting, prototyping

C.ideas
rapid prototyping
17 machines, 24 materials

DESIGN ROBOTICS GROUP (Harvard)

MIT Material Based Design Computation

ATTACHMENT D
More Events for Industry Sector
Retail, Accessories

SPEED swimsuits, goggles

TREK bicycles (parts)

Modern Meadows leather

Mobile phone covers plastic, metals

US Army's 3D printing clothing could increase flexibility and mobility through 3D printing... combining different advanced materials and reduce the number of seams for added comfort and durability

Clark, San Diego - based company, Mr. Speakers of Dan Clark...for over-the-ear headphones...the best closed headphones ever created ...3D printed...we realized there were technical things we could do with a 3D printer that we just couldn't do with injection molding.

Shapeways launches additional precious metals for 3D printing

Jewelry Replicator...American Pearl takes photo of old jewelry and turns them into 3D digital models

Continuum = Create new products and services for existing businesses

Precious M80 Direct Metal Laser Sintering (DMLS) System (EOS + Cooksongold)

MIT, Autodesk, Stratasys, and more join in multimaterial shape changing out of 3D printers:
http://www.sjet.us/MIT_4D%20Printing.html
http://www.selfassemblylab.net/
http://kokompe.cba.mit.edu/
http://mtm.cba.mit.edu/

amazon teams up with Mixee Labs

Have an idea? Need a prototype or model?
3D printing impacts nearly every industry—from manufacturing to health care to fashion. Is your business using 3D printing technology to save time and lower costs?
White Clouds
South Ogden, UT 84405 USA

ATTACHMENT F

AM Events in Food

Cornell University
Creative Machines Lab

NASA

ORD Solutions, Canada

Rova 3D

Foodini

Candy Confectionery 3D Printer

ChefJet

Universal Paste Extruder

fab@home

Modern Meadows
cultured leather and meats which requires no animal slaughter and much lower inputs of land, water, energy and chemicals

AM IMPACT

Food

Distribution in developing (poor) countries

Logistics

HP 3D Printer?

Dell Printer?