Re-engineering Engineering Education
- one possible scenario

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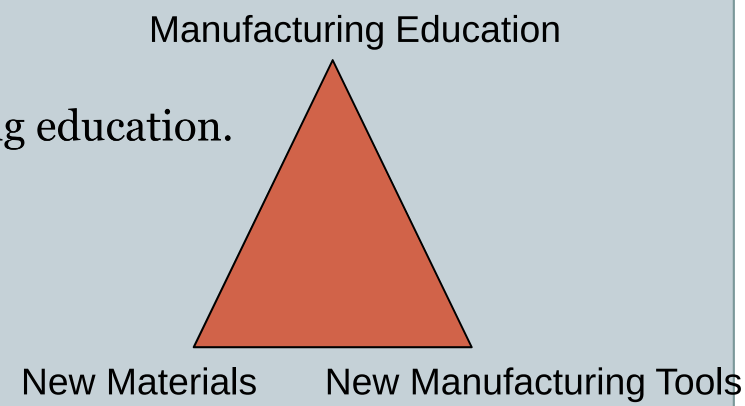

In ten years the only manufacturing left in the United States will be 1) those facilities vital to the defense industry, 2) those industries that are uniquely high-tech, 3) those that cannot absorb long-distance freight charges, and 4) those industries that service “on the spot” instantaneous demand (although even that is questionable).

Intro: Personal Motivation

- "Countries that are not manufacturing high technology goods anymore are increasingly at a disadvantage, because they do not gain the required experience from meeting the newest manufacturing challenges in the production of the latest high tech products. In other words, the loss of the manufacturing base is not a simple linear loss, it becomes irretrievable exponential as times goes on. History has shown that it is the manufacturing capability that drives the economical growth and creates wealth. Assuming that we can still market and design new products without manufacturing excellence is naïve; one cannot design without knowing the latest materials and manufacturing processes." (MM in WTEC report).

- WTEC study
- Testimony on Capitol Hill

Testimony on Capitol Hill
on the State of Manufacturing in the US April , 2005

Intro: Personal Motivation

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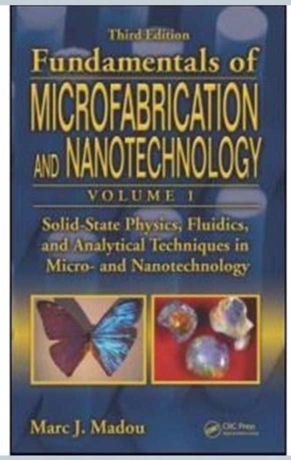
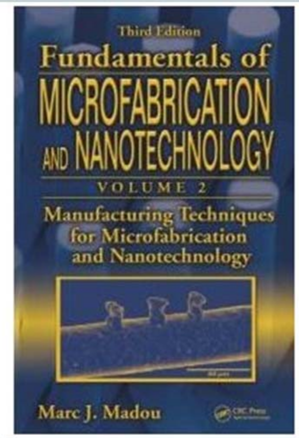
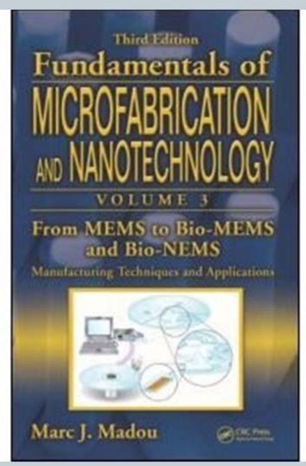
- MEMS, Nanotechnology: Federal funding in those areas leading to more profits abroad than in the US—because we cannot implement what we invent anymore.
- IP closer to a final product is much more potent.
- Describe MEMS, NEMS, 3D printing, etc as "just" other manufacturing techniques in my 3rd Edition of Fundamentals of Microfabrication
- Teach Advanced Manufacturing courses –integrate 3D printing in that class.
- Met RapidTech and brought them on the UCI campus.







Reengineer Engineering: Why?

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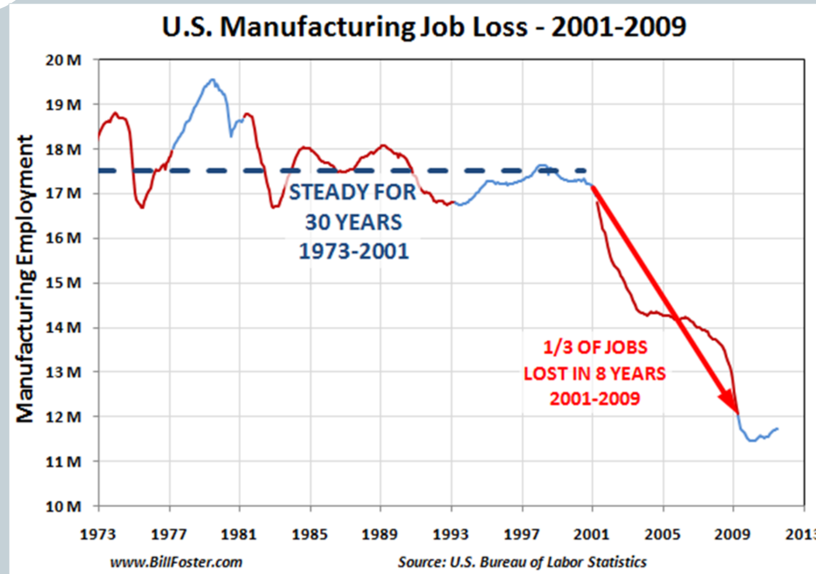
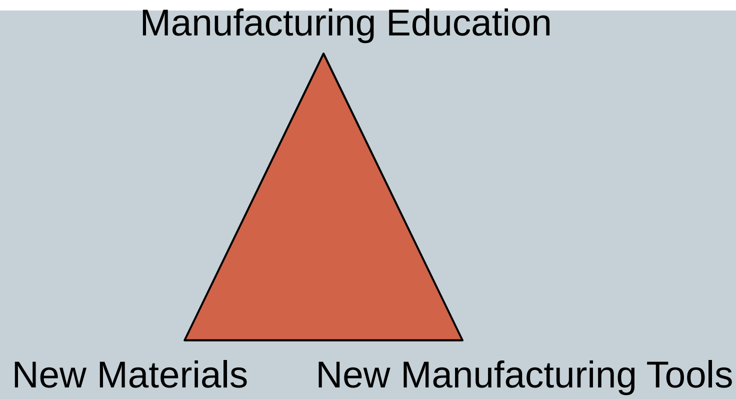
- Education:
  - Higher tuition for less value in the UC system (and I am sure also in other State schools).
  - Unequal access to education.
  - Lack of sufficiently skilled US technicians for foreign technology companies (not enough links between two-and four-year colleges).
  - The science of making things got lost in many areas.
- Systemic:
  - Indifference to employees –outsourcing.
  - Little interest in making real things.
  - Loss of manufacturing base—loss of innovation.
  - Middle class is disappearing in lockstep with loss of manufacturing.
- Future Threats:
  - If the US doesn't make the next best thing anymore we will also eventually loose our position as leaders in engineering education.
  - Gap between fewer rich and many more poor will continue to increase.
  - Security concerns.

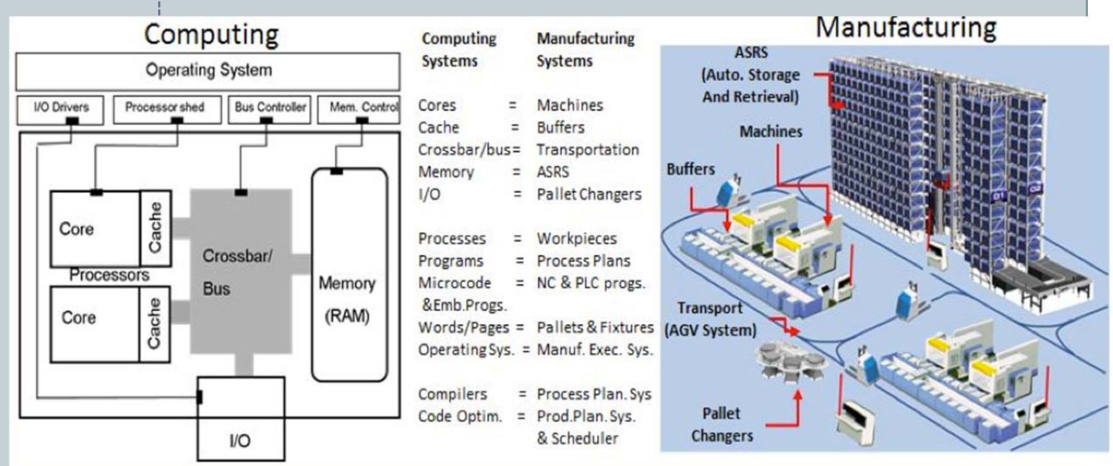


Reengineer Engineering: How?

- Invest in Manufacturing Education, New Materials and Building the Next Generation of Manufacturing Tools
- Distributed or point of need manufacturing (PC analogy) as a first trial model (bottom-up approach—Maker community, DIY, Desktop Factories, etc). See section: NOT GOOD ENOUGH!

An example of a desktop factory at AIST, Japan.





Computer systems provide a conceptual model for components and functions of scalable, flexible manufacturing systems (FMS), tools and fixtures.

Reengineer Engineering: How?

- The nonprofit RapidTech at UC Irvine offers low-cost, cutting-edge 3-D manufacturing technology for businesses and educational institutions needing to quickly design and refine prototypes.

RapidTech
NATIONAL CENTER FOR RAPID TECHNOLOGIES

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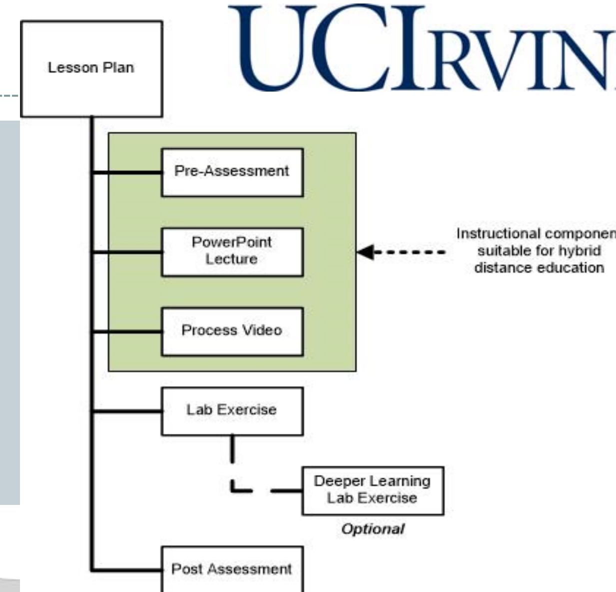

1 Jack Nobles, Boeing
2 Ryan Larson, NIKE
3 Rethia Williams, Boeing
4 Mark Kasprzak, Boeing
5 Terry Wohlers, Wohlers Associates
5 Tim Caffrey, Wohlers Associates
6 Sheku Kamara, Milwaukee School of Engineering
7 Carl Dekker, Met-L-Flo
8 Dr. Scott Johnson, Boeing
9 Harold Sears, Ford Motor Company
10 Rick Tweddell, Proctor & Gamble
11 Tim Gornet, University of Louisville

Reengineer Engineering: How?

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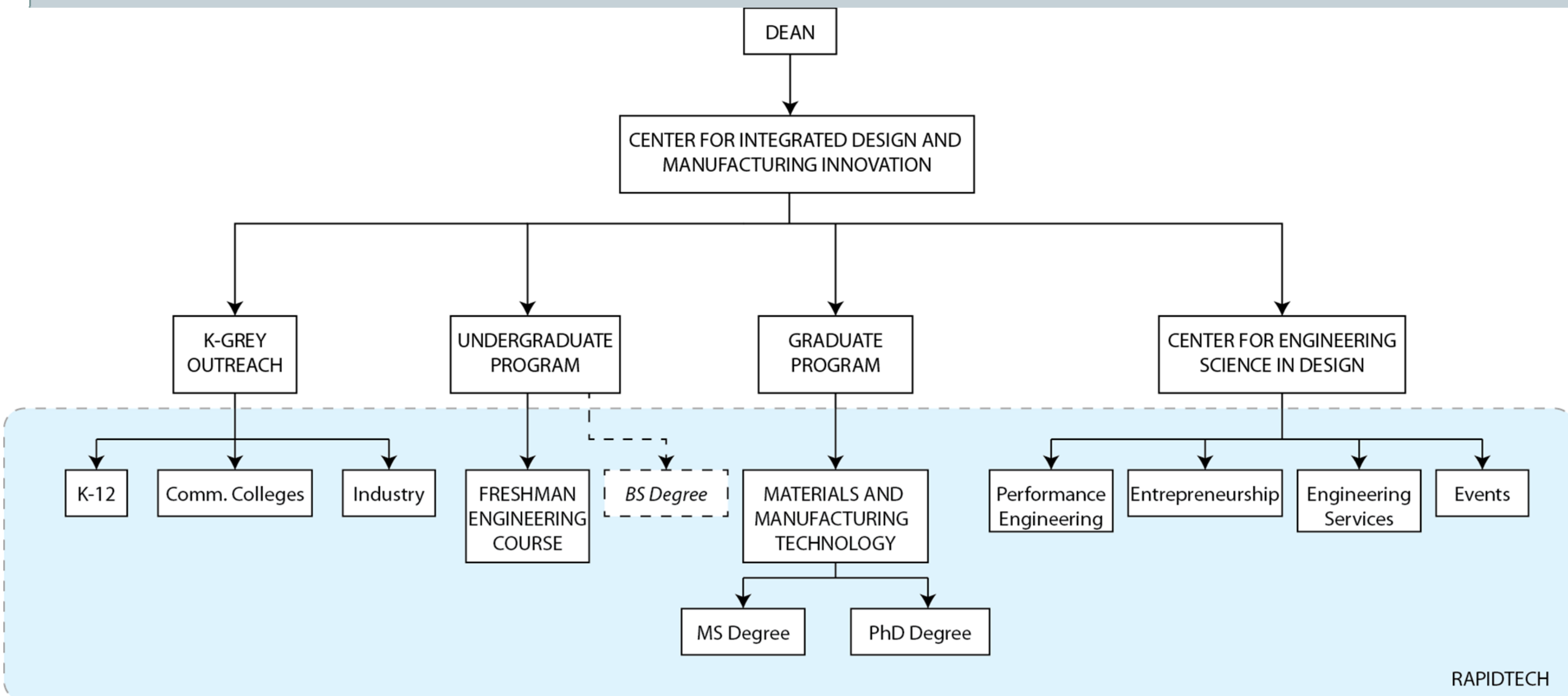
- Bringing RapidTech on the UCI campus. Major benefits:
  - UCI Engineering students are actually making things again! See video at the end of this lecture.
  - Community College students get trained and integrated in UCI research projects—transfer students.
  - Shorten the design to prototyping/product loop helps in UCI research projects.
  - Our project engineering competitions became much more fun and competitive.
  - My Advanced Manufacturing Class (Eng 165/265) has now a practicum in 3D printing
  - K to Gray (incumbent and re-entrant): connect four year colleges with community colleges that are in turn better integrated with K-12.
  - Connection to Industry has grown stronger for UCI and RapidTech.
  - Workforce retraining on the newest manufacturing equipment and processes can occur much faster as 2-year and 4-year colleges have an area of overlap.
  - Research opportunities in developing the next 3D printing equipment – again connecting 2 year and 4-year colleges better.
- Now can we scale this for the US and make it a permanent feature: UCI, CNMI, NNMI

Reengineer Engineering: How? UCI



Reengineer Engineering: How? CNMI

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- California Network for Manufacturing Innovation

- In March 2013, the California Network for Manufacturing Innovation™, Inc. (CNMI) was formally established as a non-profit corporation for the purpose of promoting manufacturing competitiveness in California through a collaboration of industry, national laboratories, technical assistance, government agencies, <u>academia, workforce and economic development organizations</u>. CNMI is designed to create a unified voice and plan to create programs and physical centers for California's small and medium-sized manufacturers to have access and use advanced manufacturing technology to help them grow and compete in the global marketplace.

- Mission of CNMI: CNMI provides leadership in California to foster innovation that will enhance the global competitiveness of the manufacturing sector.

Reengineer Engineering: How? CNMI

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- Principles of Collaboration
  - Designed as a statewide program
  - Focused on Small and Medium-sized manufacturers
  - Built to be an inclusive organization
  - Led by working groups concentrating on industry, workforce, technology and communications/policy
  - Driven by transparency in communications

Reengineer Engineering: How? NNMI

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- This program is a National model
- We will need this anyways as the the National Network Manufacturing Institutes (NNMIs) start producing new technologies that need to be incorporated in the students curricula
- Along this line we are launching the Advanced Manufacturing Project for Learning in Focused Innovation (AMPLiFI) program.
- This program seeks to create a flexible technician education framework that draws on the experience of RapidTech to prepare the nations technical workforce for the advanced manufacturing technical occupations of the future.
- The proposed framework will be developed and piloted for curricula focused on Additive Manufacturing (AM) in a manner that it is broadly applicable to technician education programs in other technical areas.
- In addition, the framework and associated knowledge, skills and competencies will be built around broadly accepted national and international standards (e.g. ASTM, ISO, etc.) in order to ensure broad industry recognition and acceptance

AMPLiFI Year 1

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- Goal 1
  - Develop technician education modules in advanced manufacturing suitable for infusion into existing technical education coursework
- Goal 2
  - Verify the efficacy of the framework through development of support for focus group workshops to promote open dialog regarding implementation at the Community College level

AM: Not Good Enough

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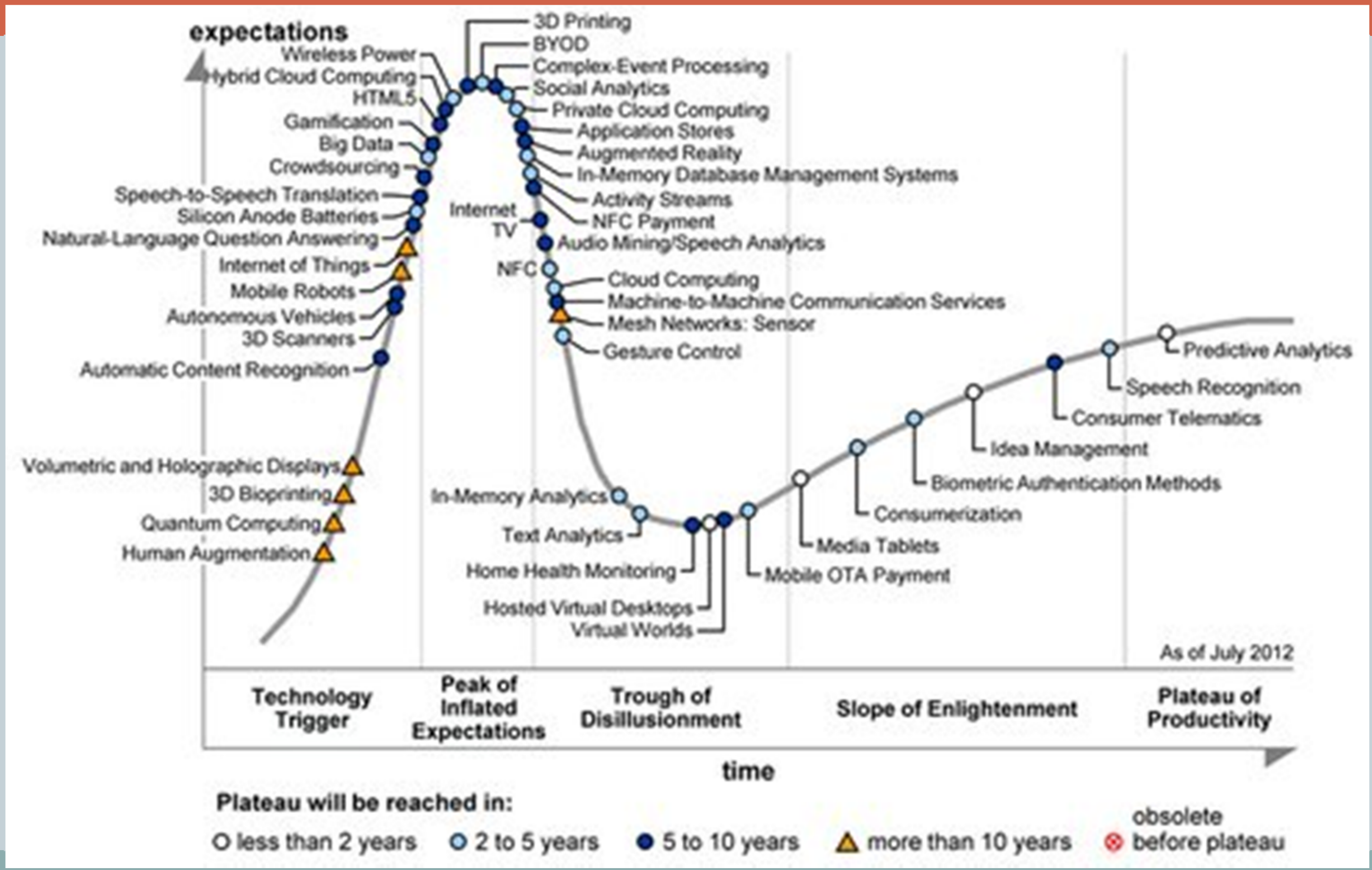
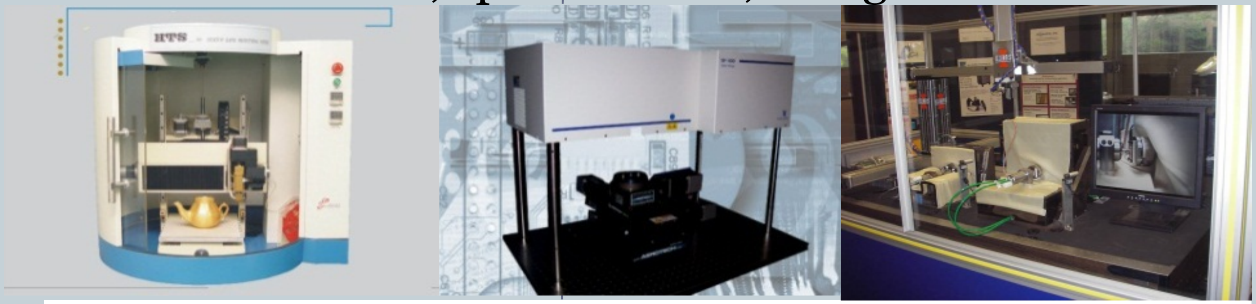
Word of caution: Tech Consultancy Puts 3D Printing at Peak of "Hype Cycle"



AM : not Good Enough

- Additive manufacturing alone will not provide the solution for future advanced manufacturing ! For that novel multi-physics, multi-material, multi-length scale new manufacturing tools are required: desktop integrated manufacturing platforms (DIMPs).
- Example: Desktop manufacturing stations have been the goal of at least three disparate communities: 1) materials scientists for additive manufacturing, 2) micro-technology scientists for mask-less lithography, and 3) mechanical engineers for micro-manufacturing centers.
- However, these stations include a limited set of processes in narrow application domains and lack shared standards, specifications, or algorithms.



Desktop manufacturing stations: (Left) Typical Rapid Prototyping Machine (Guangzhou Comac); (Middle) SF-100 ELITE Maskless Lithography System (Intelligent Micro Patterning); and (Right) First U.S. Micro-factory at UIUC .

AM : not Good Enough

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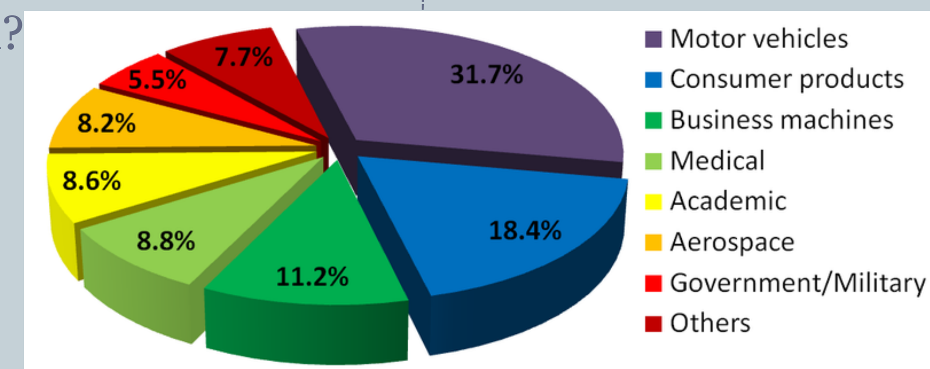
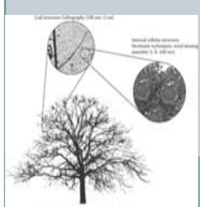
- Prototyping (90 %)
  - Concept models
  - Architectural models
  - Disney characters
  - Movies—or is that real and thus manufactured?
  - Etc

- Manufacturing (10%)
  - Implants and custom medical devices
  - Aerospace parts
  - Pilot scale production of lab equipment
  - Molds .. A Stradivarius ?



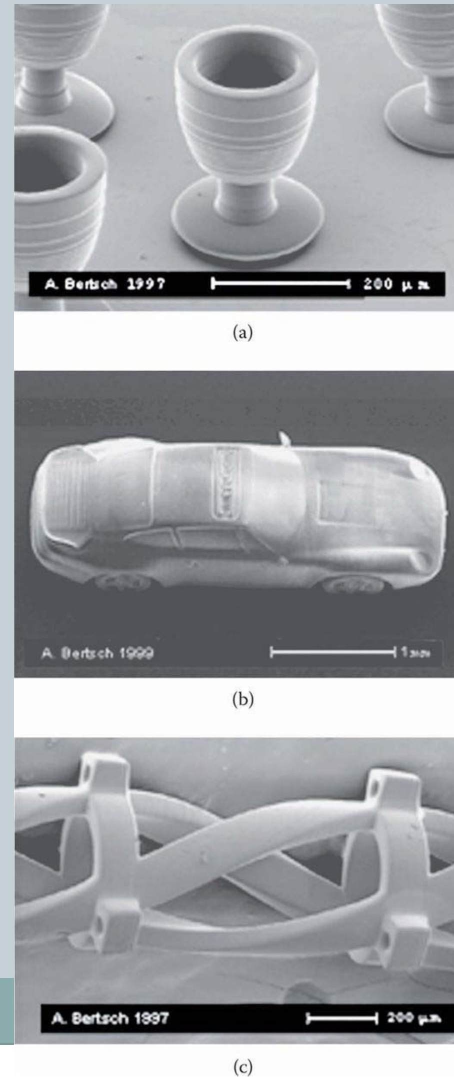
Multi-Length Scales

- Micro-stereolithography, derived from conventional stereolithography, was introduced by Ikuta in 1993.
- Whereas in conventional stereolithography the laser spot size (voxel) and layer thickness are both in the 100-μm range, in micro-stereolithography, a UV laser beam is focused to a 1–2-μm spot size to solidify material in a thin layer of 1–10 μm.
- The monomers used in SLA and micro-stereolithography are both UV-curable systems, but the viscosity in the latter case is much lower (e.g., 6 cPs vs. 2000 cPs). In micro-stereolithography the viscosity should be as low as possible for optimal flat layer formation because high surface tension hinders both efficient crevice filling and flat surface formation in the microscale.



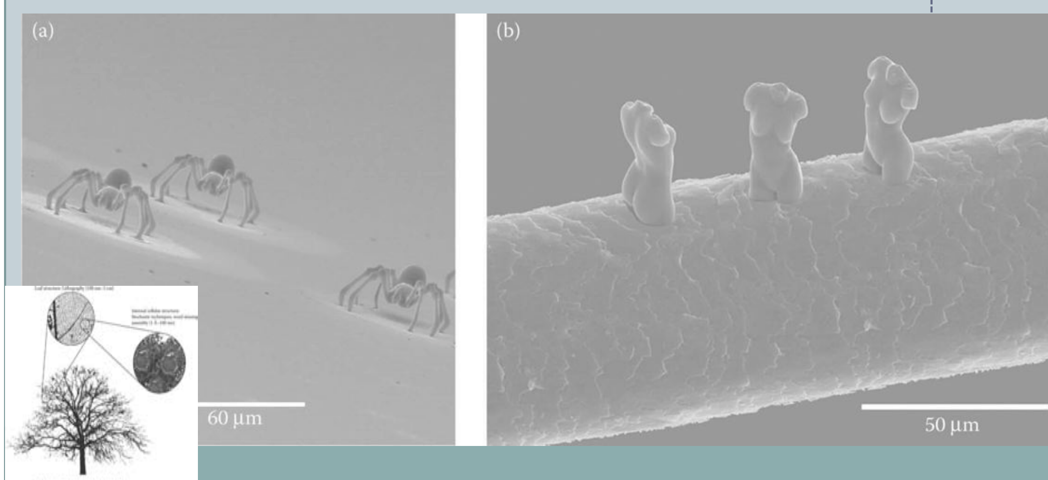
Multi-Length Scales

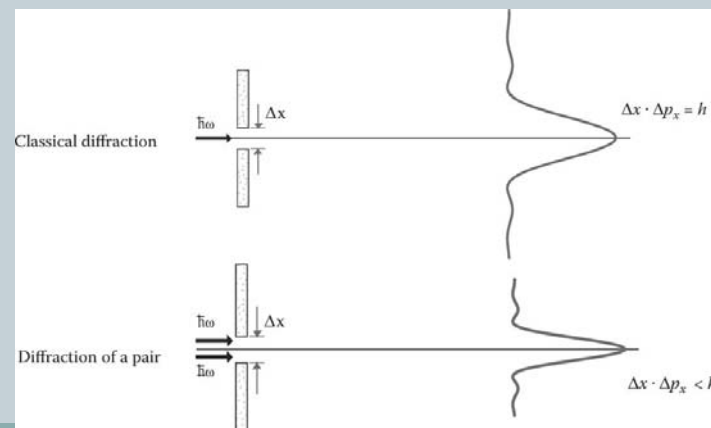
- The application of rapid prototyping (RP) techniques to MEMS and NEMS requires higher accuracy than what is normally achievable with commercial RP equipment.
- Laminated object manufacturing (LOM), fused deposition modeling (FDM), and selective laser sintering (SLS) all must be excluded as microfabrication candidates on that basis.
- Only stereolithography has the potential to achieve the fabrication tolerances required to qualify as a MEMS or NEMS tool.
- Latest enhancements that have made it an attractive option are high-resolution micro- and nanofabrication methods.



Multi-Length Scales

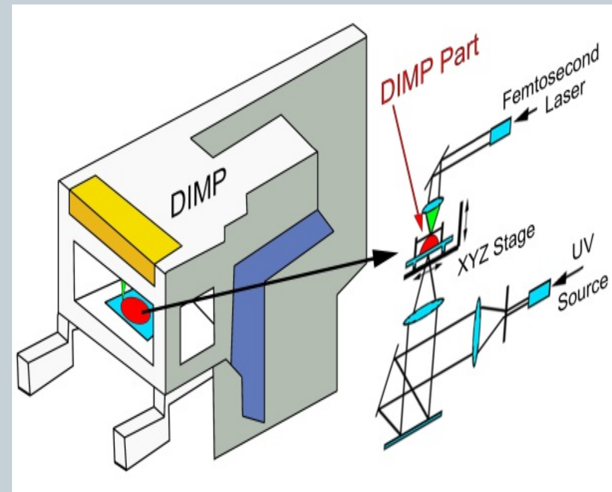
- Another difference resides in the fact that in micro-stereolithography the solidified polymer is light enough so that it does not require a support as is required for the heavier pieces made in SLA.
- Yet a further refinement is to use two-photon lithography. An entangled photon pair comes out from a point of the object plane, undergoes two-photon diffraction, and results in twice narrower point spread function on the image plane.
- A useful hybrid manufacturing station would thus combine SLA with two-photon polymerization (2PP).



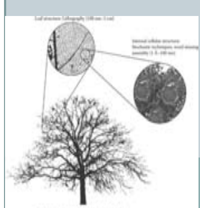


Multi-Length Scales

- Stereolithography (SLA) Integrated with Two-Photon Polymerization (2PP). SL is an additive manufacturing process in use on thousands of machines. Constraints on laser spot size, polymer chemistry, and control limit SLA to manufactured features on the order of 100 microns. 2PP uses similar materials but relies on laser cross-linking. A part's upper size is limited to about 100 microns, which has relegated 2PP to research lab curiosity status. Integrating these two manufacturing techniques could create human-scaled parts with micron-scale tolerance and submicron-scale surface finish. A desktop HYMAP (hybrid manufacturing platform) is called a DIMP (Desk top Integrated Manufacturing Platform



HYMAP that integrates SL and 2PP.



Multi-Materials

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- Materials in AM today:
  - Thermoplastics (FDM, SLS)
  - Thermosets (SLA)
  - Powder based composites (3D printing-3DP)
  - Metals (EBM, SLS)
  - Sealant tapes (LOM)
- Functional parts:
  - FDM (ABS and nylon)
  - SLS (thermoplastics, metals)
  - EBM (high strength alloys, Ti, stainless steel, CoCr)
- Non functional parts:
  - LOM, 3D Printing, marketing and concept protos.
- As new materials are introduced more functional devices will be made (perhaps 30-40% by 2020).

Multi-Materials

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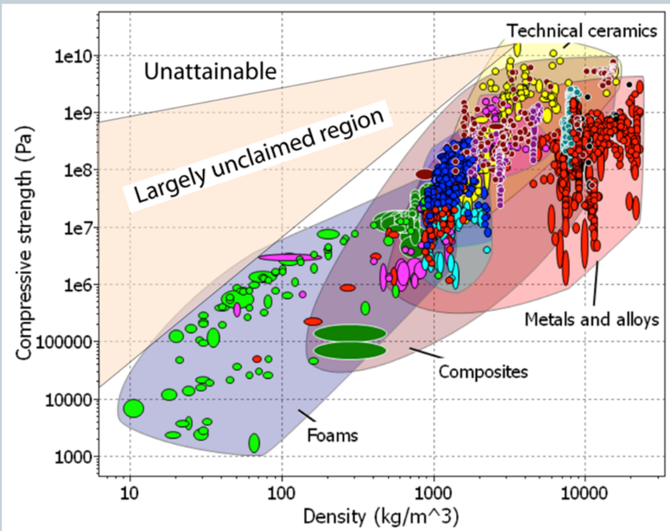
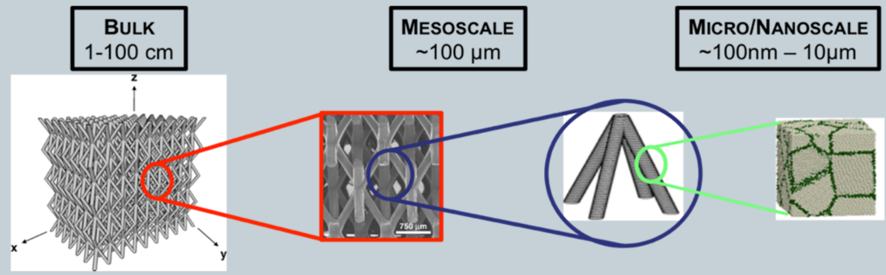
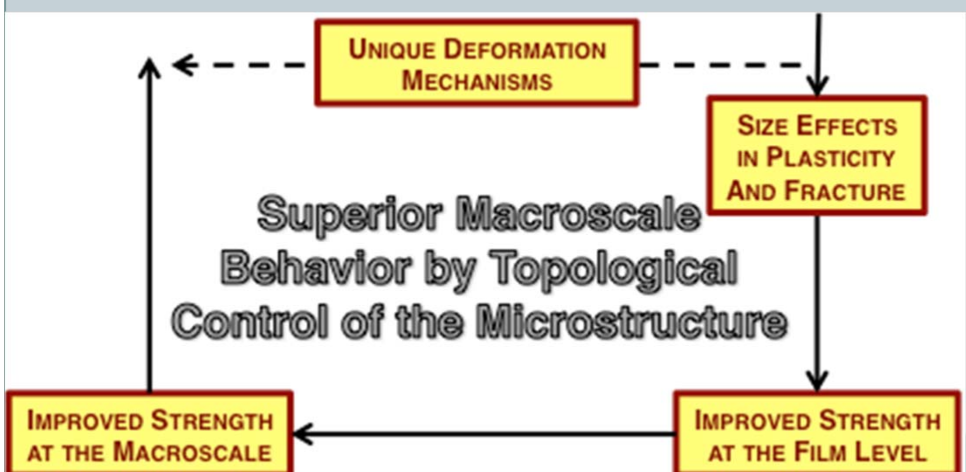
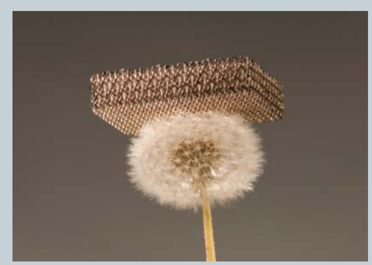






Materials with Controlled Microstructural Architecture

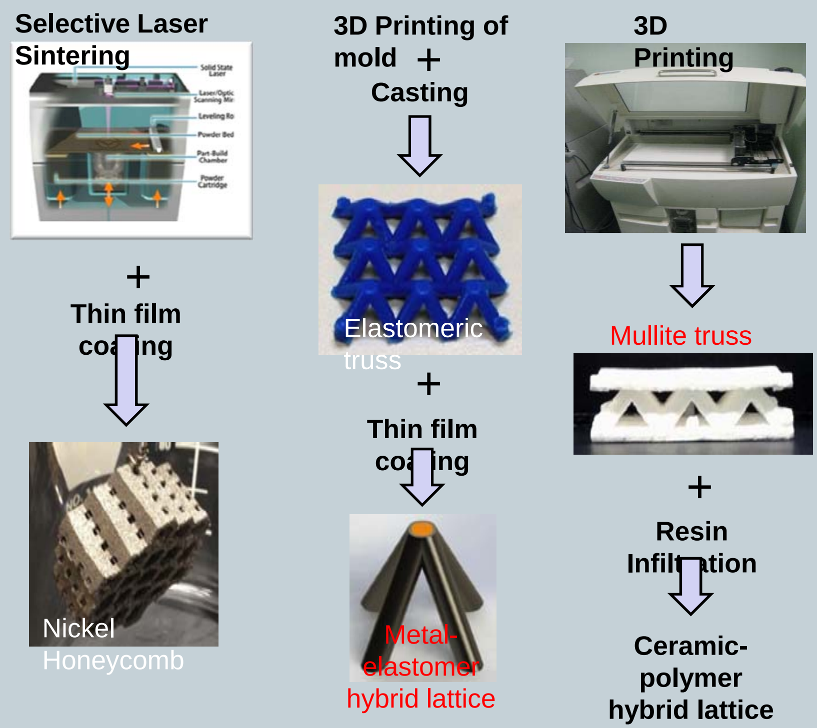


T.A. Schaedler, A.J. Jacobsen, A. Torrents, A.E. Sorensen, J. Lian, J.R. Greer, L. Valdevit, W.B. Carter, **Ultralight Metallic Microlattices**, *Science*, Nov 18 (2011)

Multi-Materials

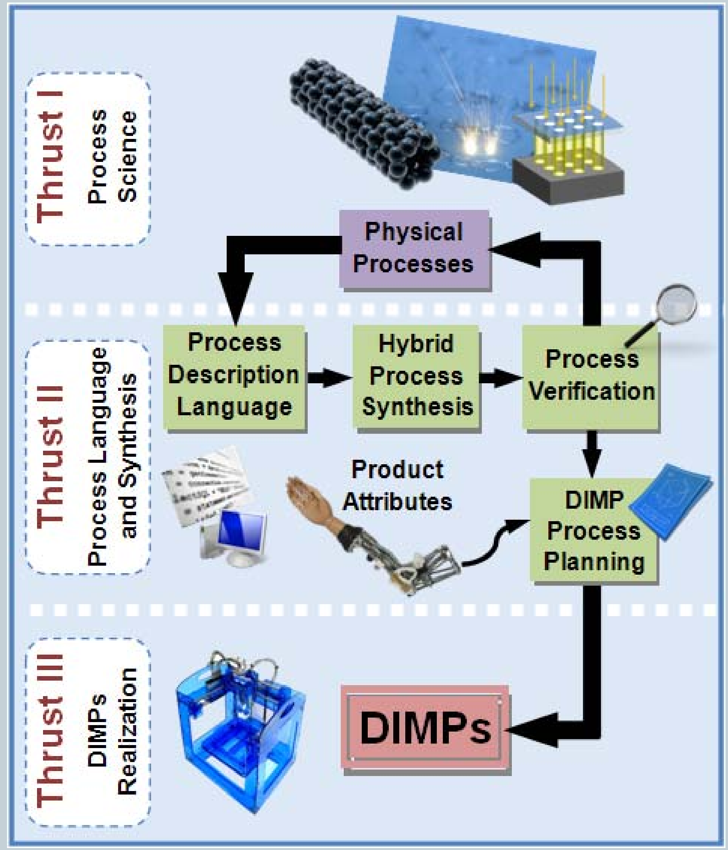
- Beyond periodic lattices (e.g., density gradient)
- All types of composites
- Wide dimensional bandwidth (nano to micro)

Digital Manufacturing



Multi-Physics

- We aim to: (1) formulate a unifying computer language able to describe manufacturing processes from the many different process domains; (2) develop an effective suite of software tools to interactively assist in synthesizing new hybrid processes; (3) use computer algorithms and simulation tools as well as the results from process hybridization experiments to evaluate the performance and correctness of the newly synthesized processes; and (4) organize hybridized processes in a process- planning software tool to initiate the building of Desktop Integrated Manufacturing Platforms (DIMPS) (see http://dimps.eng.uci.edu).



Building DIMPS

Conclusions