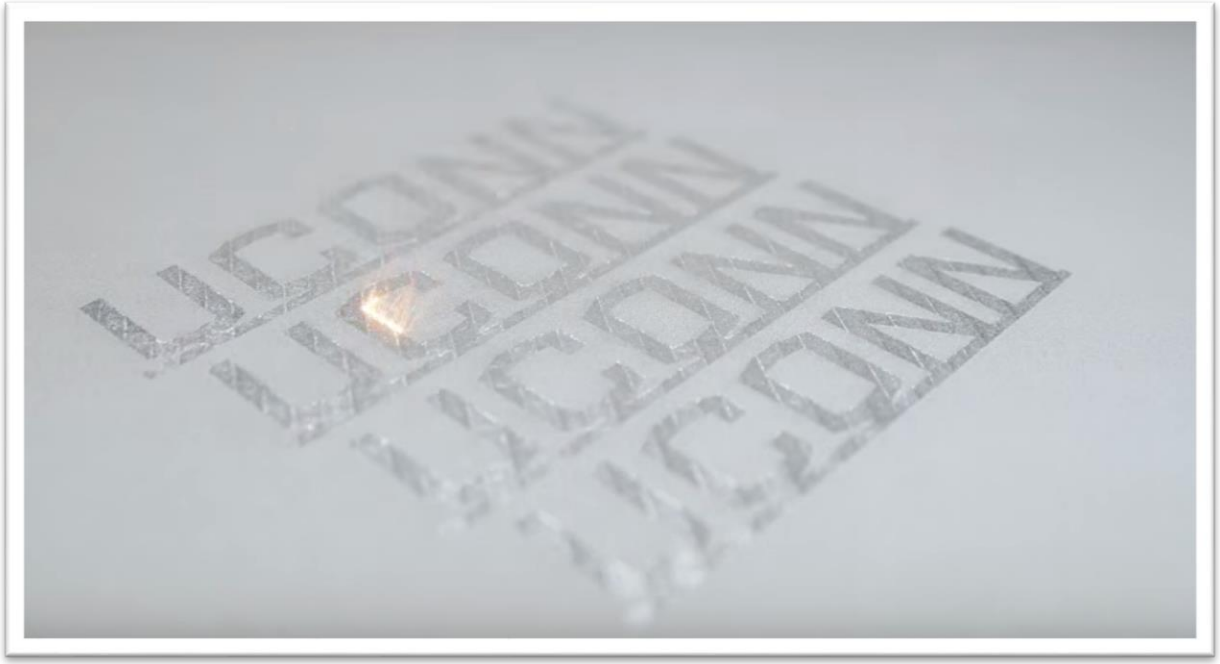
# Opportunities in Additive Manufacturing & Advanced Materials




Pamir Alpay, Rainer Hebert, Anson Ma, Steve Suib and Mun Y. Choi
University of Connecticut

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# UConn & Connecticut

- Connecticut:
  - #1: Per capita income
  - #5: R&D/GDP
  - #6: Patents/Workers
  - Home to 17 Fortune 500 companies
- Top 20 Public Research University
- Operating budget of $2.1B
- Research Exp. of $250M
- 30,000 students
- 1,800 faculty


- Points of Pride:
  - Mark Twain
  - Basketball
  - J.P. Morgan
  - Insurance
  - Igor Sikorsky
  - ESPN

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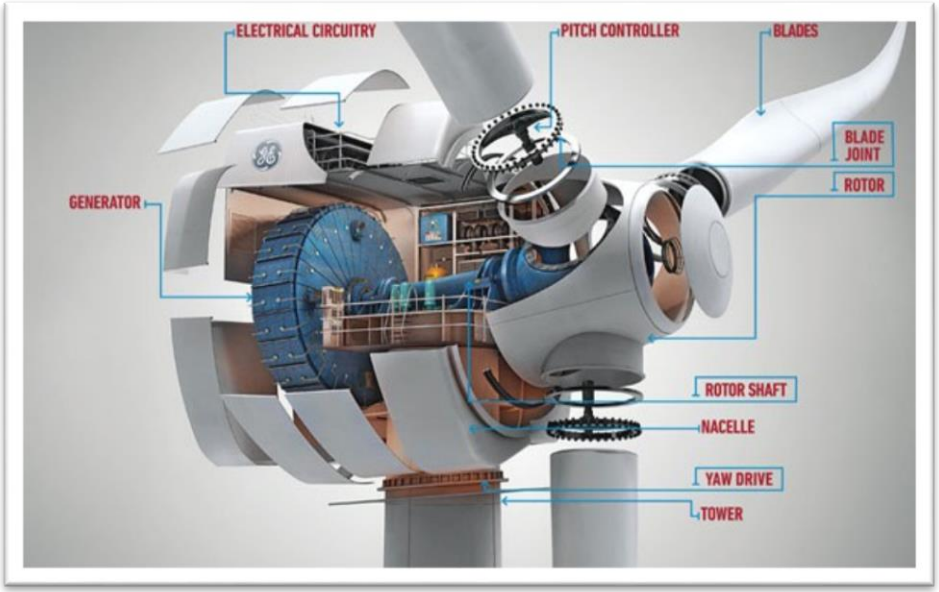
# Home to Manufacturing Innovations: General Electric

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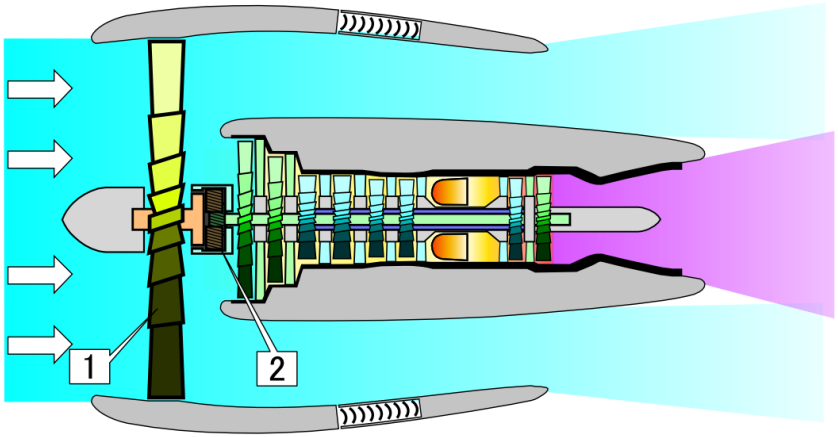
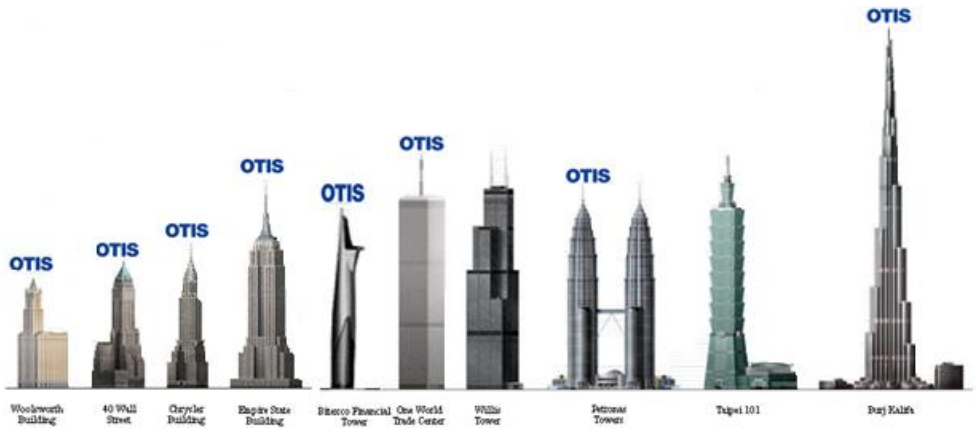
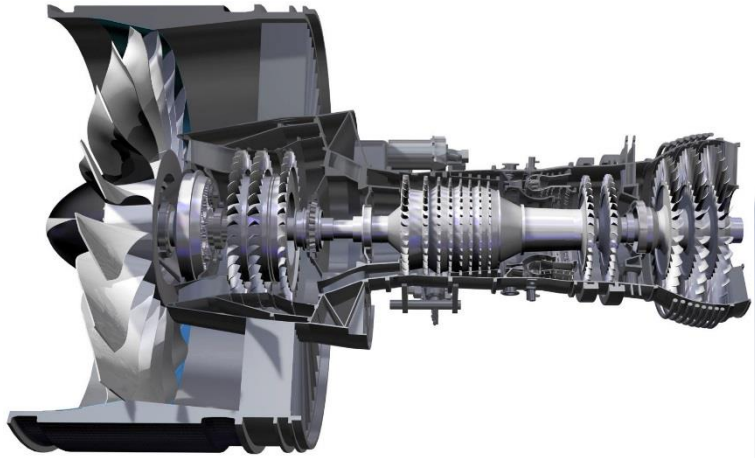
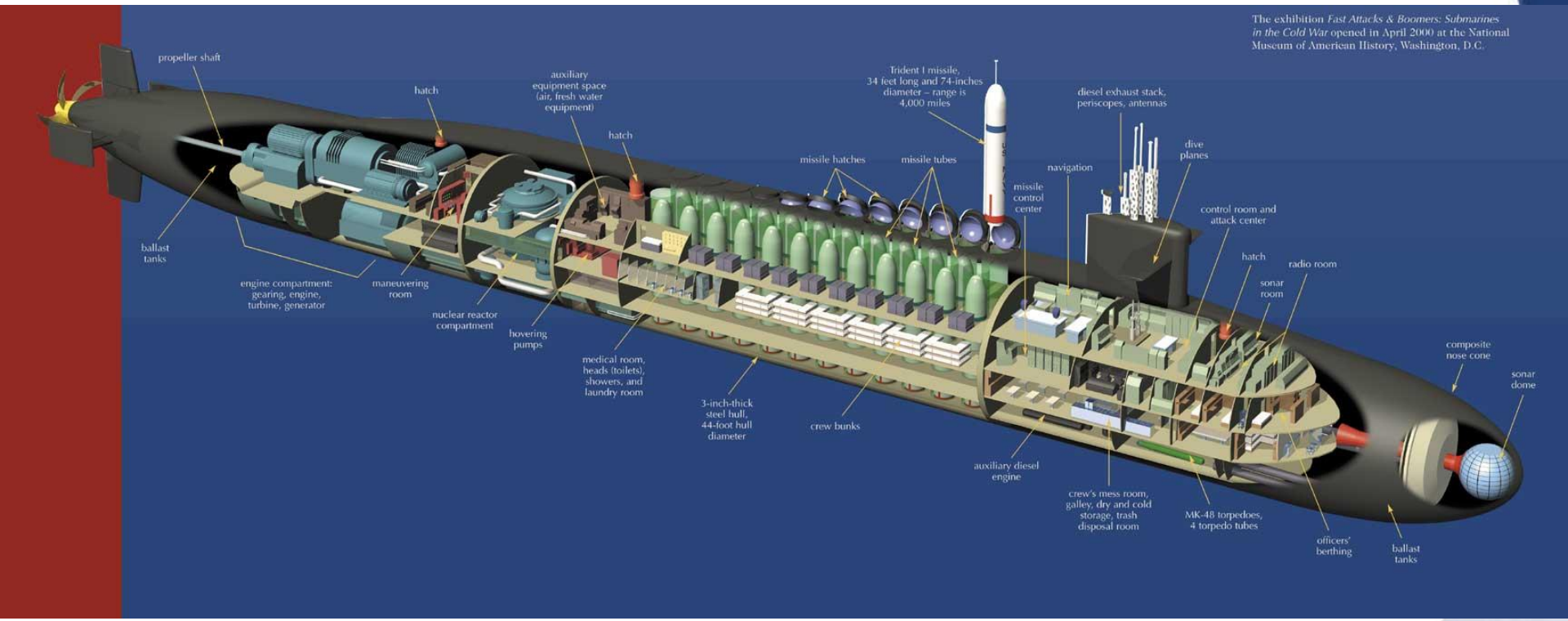
# Home to Manufacturing Innovations: United Technologies

# Home to Manufacturing Innovations: General Dynamics

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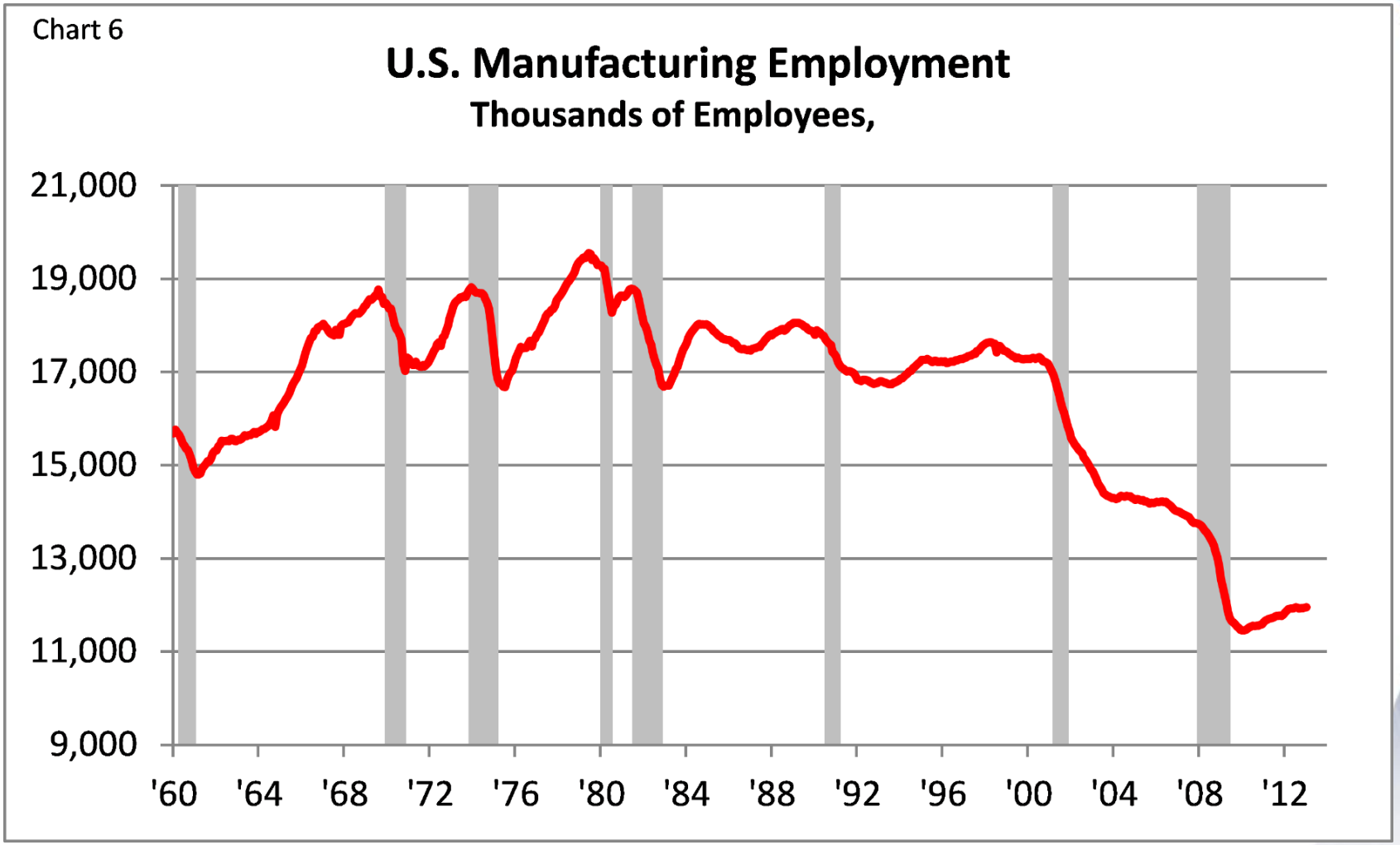
# US Manufacturing Jobs

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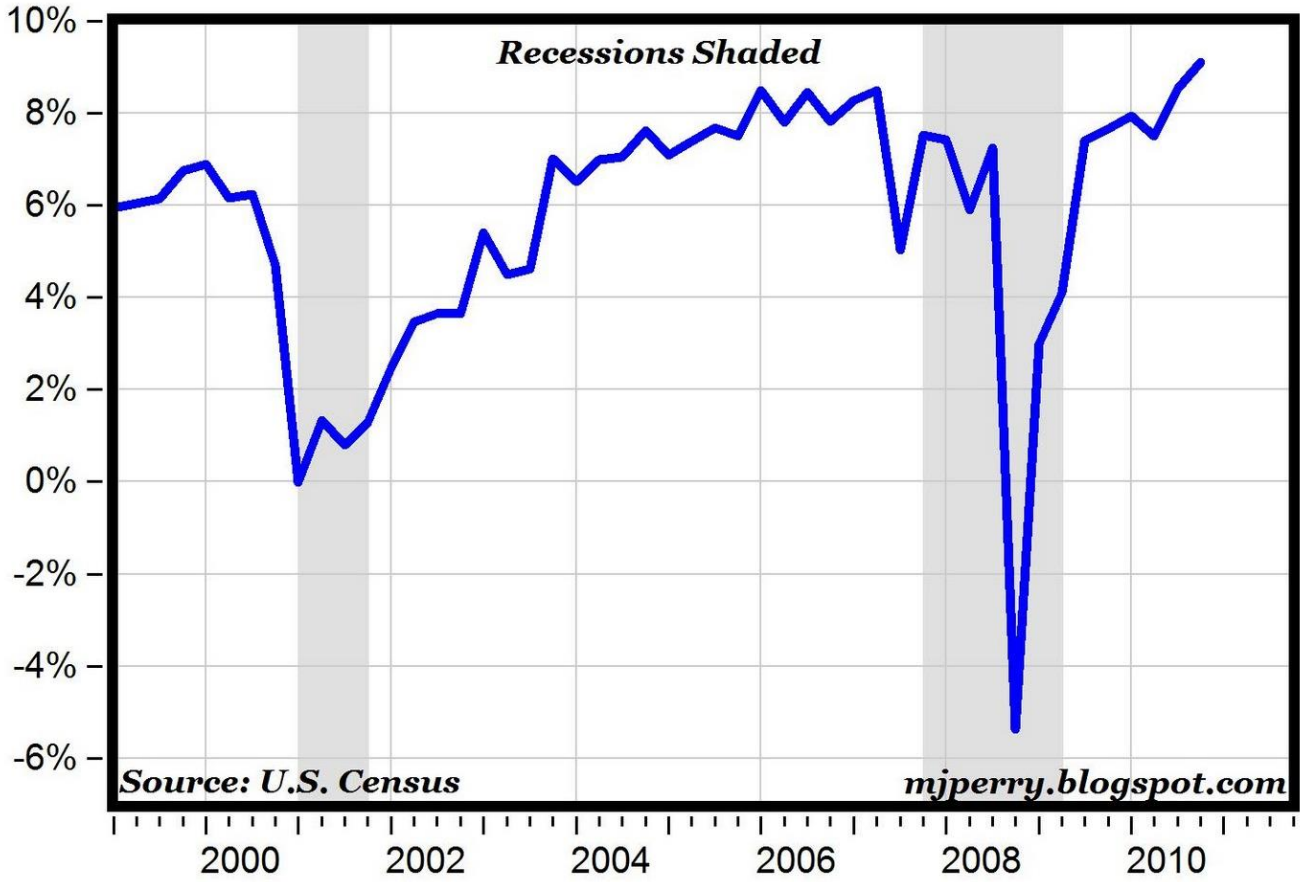
# U.S. Manufacturing Corporations After-Tax Profit Margin 1991:Q1 to 2010:Q4

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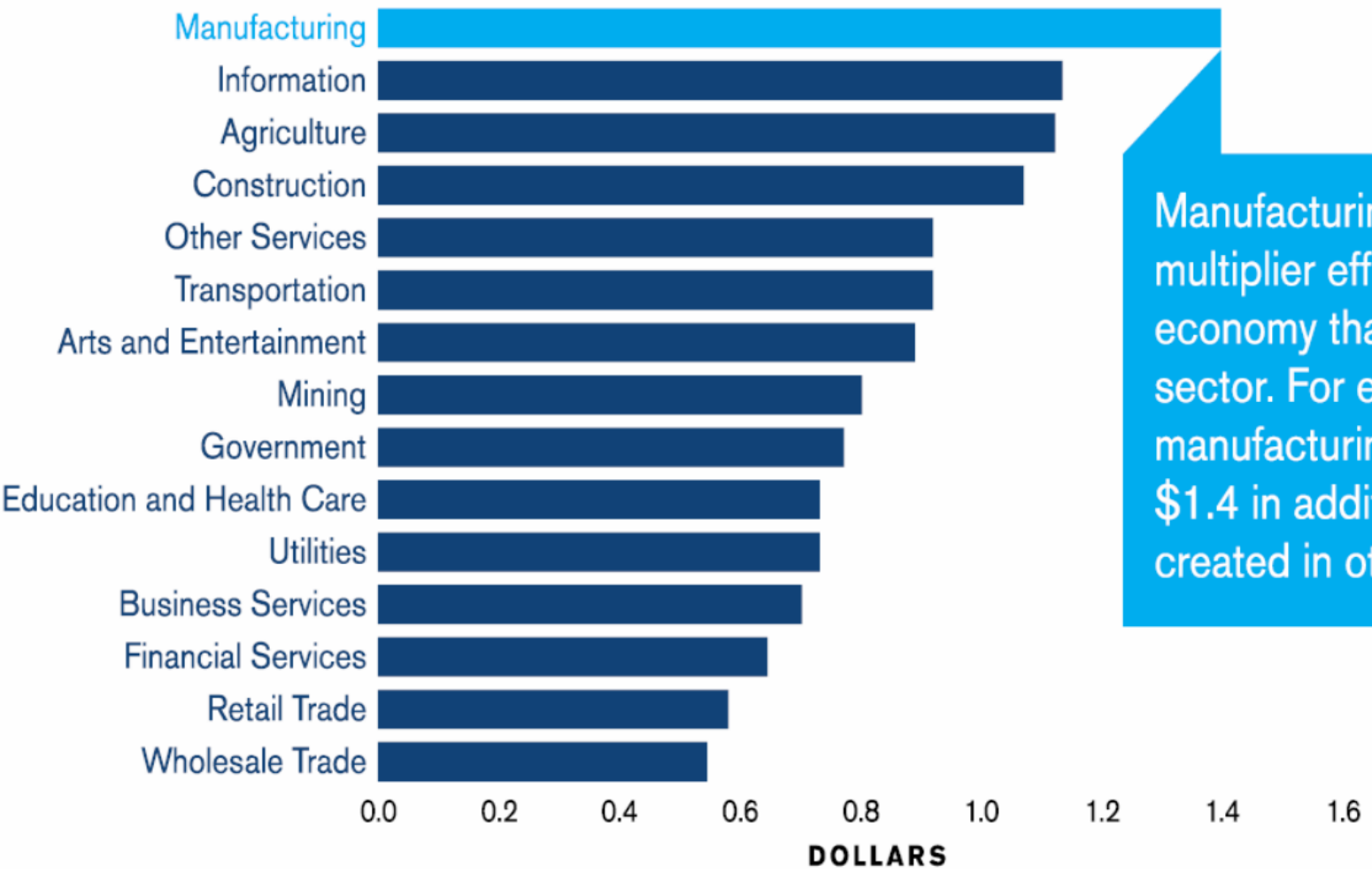
# Manufacturing's Economic Impact




Manufacturing has a higher multiplier effect on the economy than any other sector. For every $1 in manufacturing value added, $1.4 in additional value is created in other sectors.

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# Evolution of the Industrial Revolutions


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# 3rd Industrial Revolution

- Geography of supply chain will change
- On-shoring will continue:
  - Lower labor costs no longer a major factor
  - Sophistication of design will require engineers and manufacturers to work in tandem
- Startups will challenge established industry leaders
- Governments will have to evaluate practice of protecting industries with subsidies
- 'Factories' will need more engineers, IT specialists, logistics experts, marketing staff to personalize products
- Emphasis in STEM and training in creativity are key

The Economist

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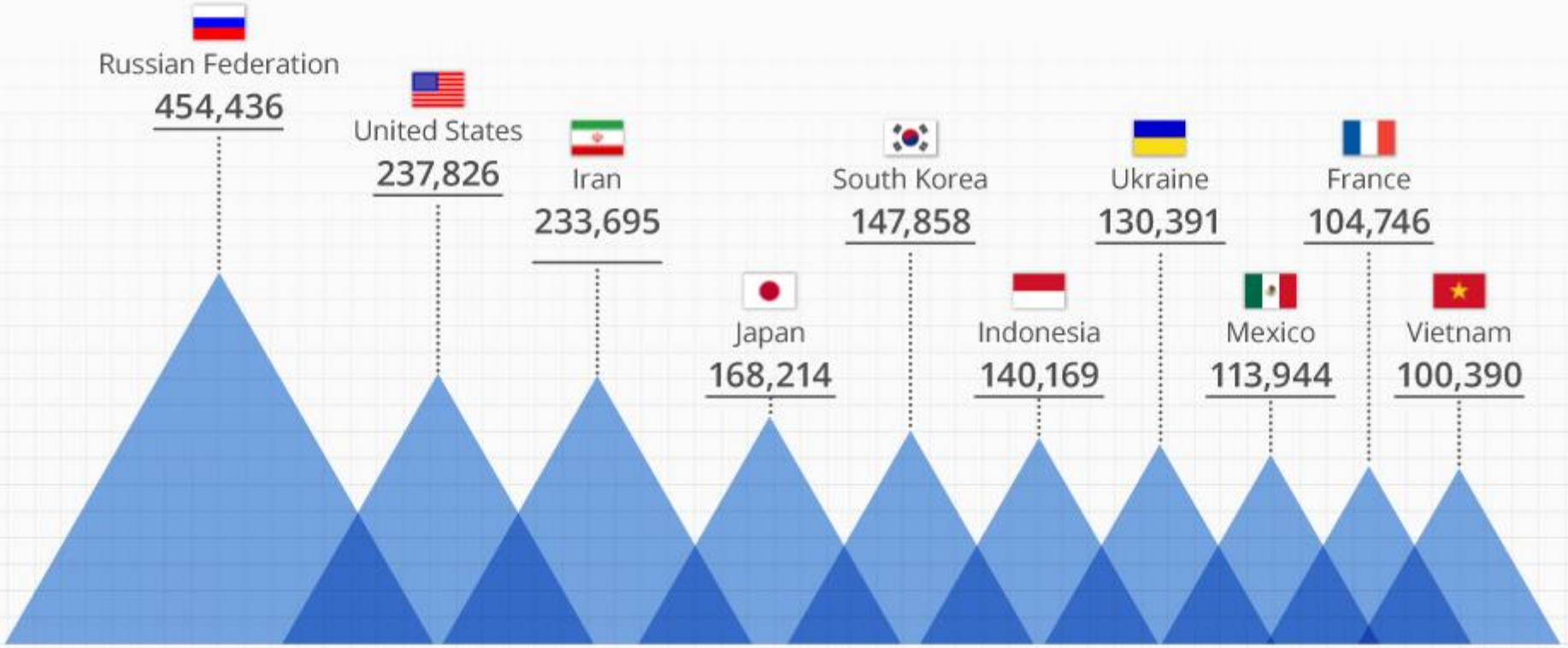
# Countries with the Most Engineering Graduates

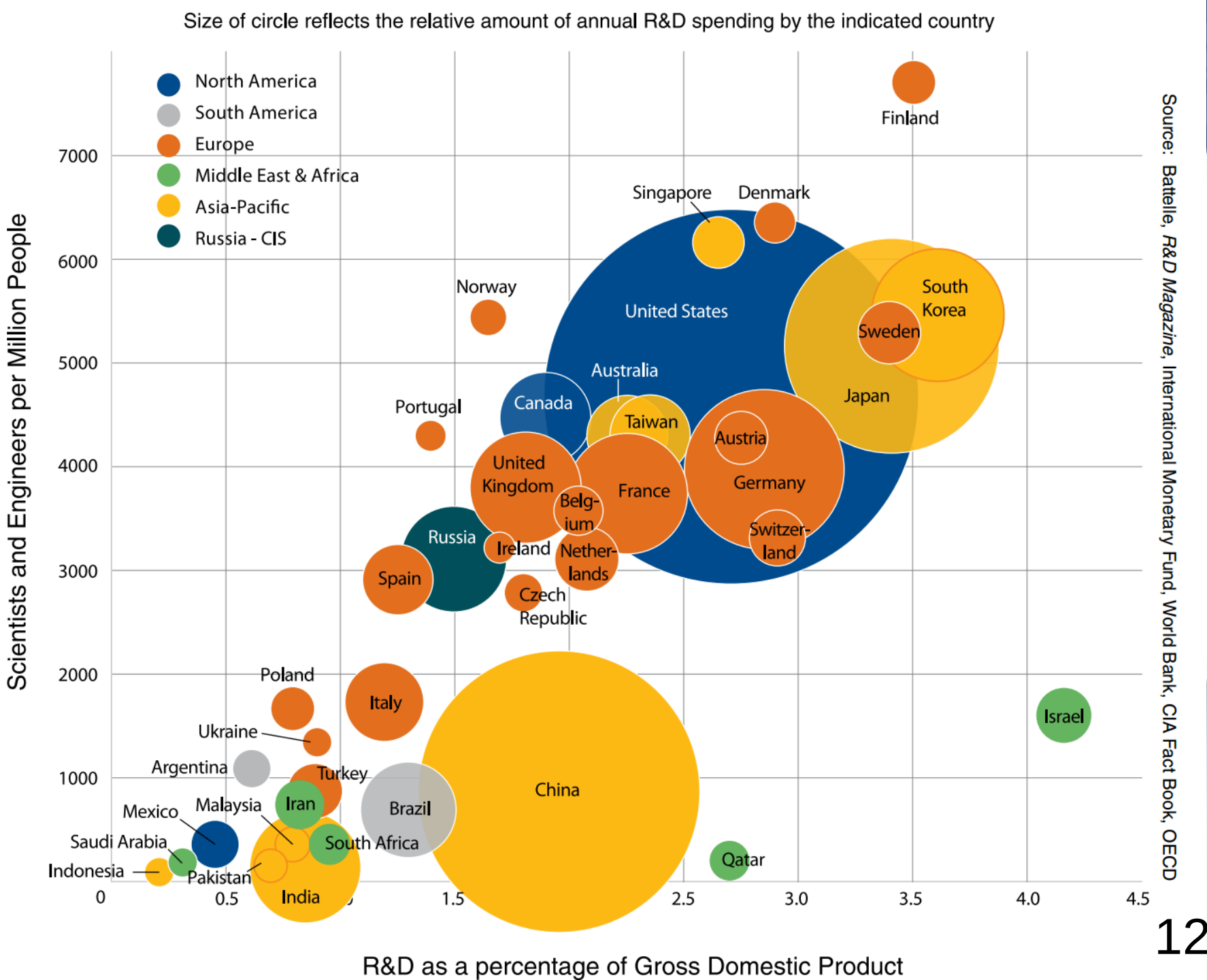



* 2015 rank out of 124 economies. No data available for China, India





Sources: World Economic Forum 2015/UNESCO Institute for Statistics


Size of circle reflects the relative amount of annual R&D spending by the indicated country
North America
South America
Europe
Middle East & Africa
Asia-Pacific
Russia - CIS
Scientists and Engineers per Million People
R&D as a percentage of Gross Domestic Product
Source: Battelle, R&D Magazine, International Monetary Fund, World Bank, CIA Fact Book, OECD
Finland
Singapore
Denmark
Norway
United States
South Korea
Sweden
Australia
Japan
Canada
Portugal
Taiwan
Austria
United Kingdom
France
Germany
Belg-ium
Russia
Switzer-land
Ireland
Nether-lands
Spain
Czech Republic
Poland
Italy
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Ukraine
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India
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2.5
3.0
3.5
4.0
4.5
1000
2000
3000
4000
5000
6000
7000

# International Research Centers

**Germany:**

- Fraunhofer Institutes (applied research, each institute topic-specific, 67 institutes, government/state/external research funding)
- Helmholtz Centers (18 cross-disciplinary research centers)

**UK:**

- Catapult (network of centers for nine major innovation themes; not-for-profit centers, collaborating with industry, universities)

**US:**

- National Network of Manufacturing Innovation (launched in 2013, initial government funding, then self-funded, over 45 institutes planned)

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# US Initiatives in Advanced and Additive Manufacturing

- Harness progress in accelerated materials/manufacturing discovery:
  - Materials genome initiative;
  - Integrated computational materials engineering;
  - Simulation of manufacturing processes for accelerated development at reduced cost;
  - Digital threading of manufacturing processes;
  - Bottom up processes promises revolutionary new material properties for additive manufacturing

**Challenges:**

- *Technical:* capture complex physics with simulations
- *Societal*: adoption barriers, new skillsets

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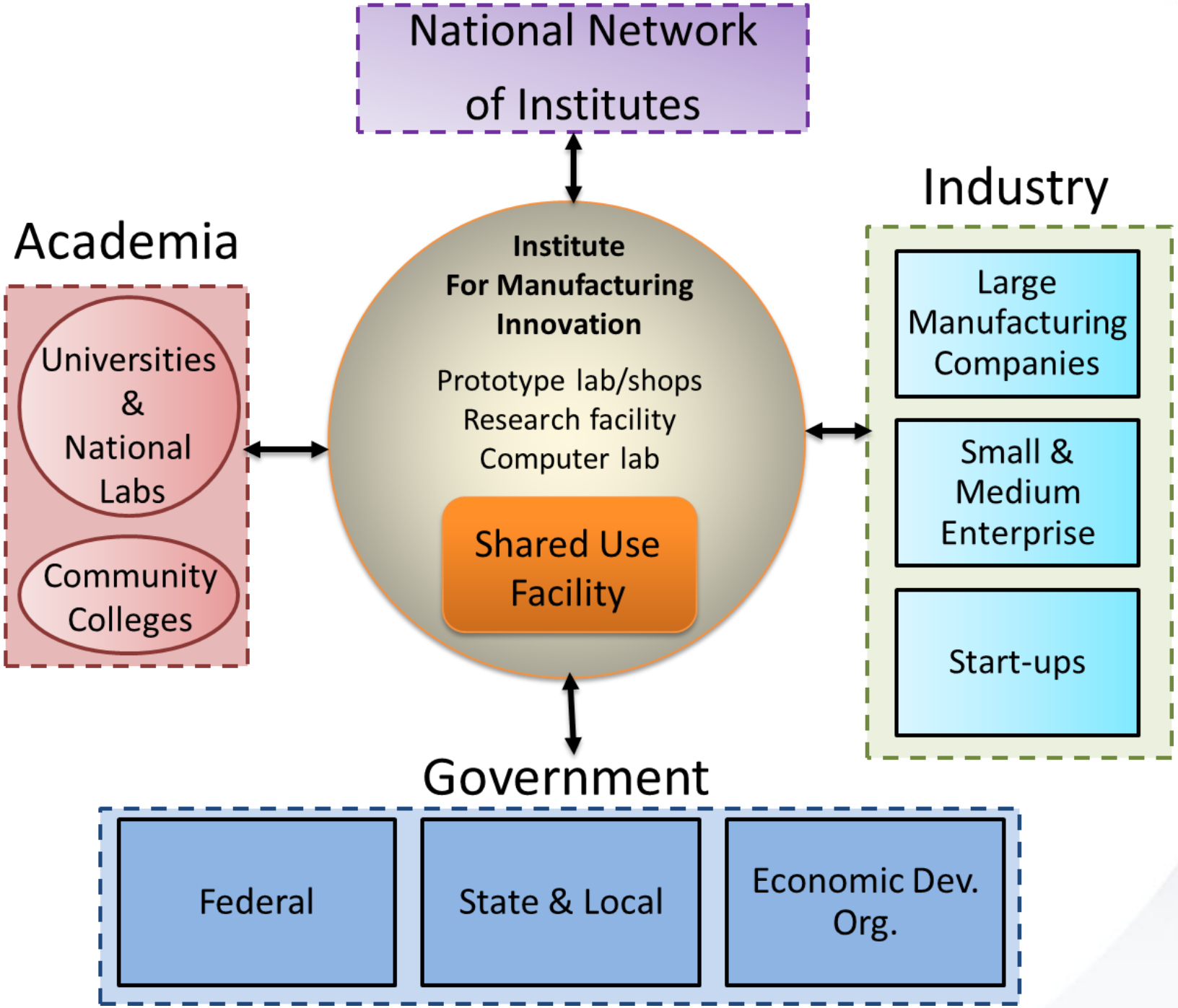
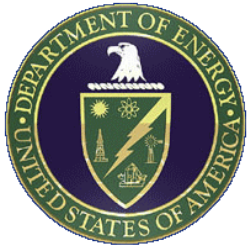
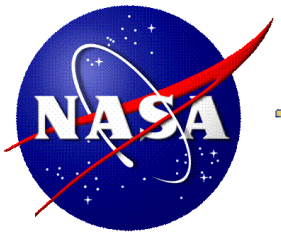

National Network of Institutes
Academia
Universities & National Labs
Community Colleges
Institute For Manufacturing Innovation
Prototype lab/shops
Research facility
Computer lab
Shared Use Facility
Industry
Large Manufacturing Companies
Small & Medium Enterprise
Start-ups
Government
Federal
State & Local
Economic Dev. Org.

# Interagency Advanced Manufacturing National Program Office *(AMNPO) – Housed at DOC / NIST*


**Executive Office of the President**









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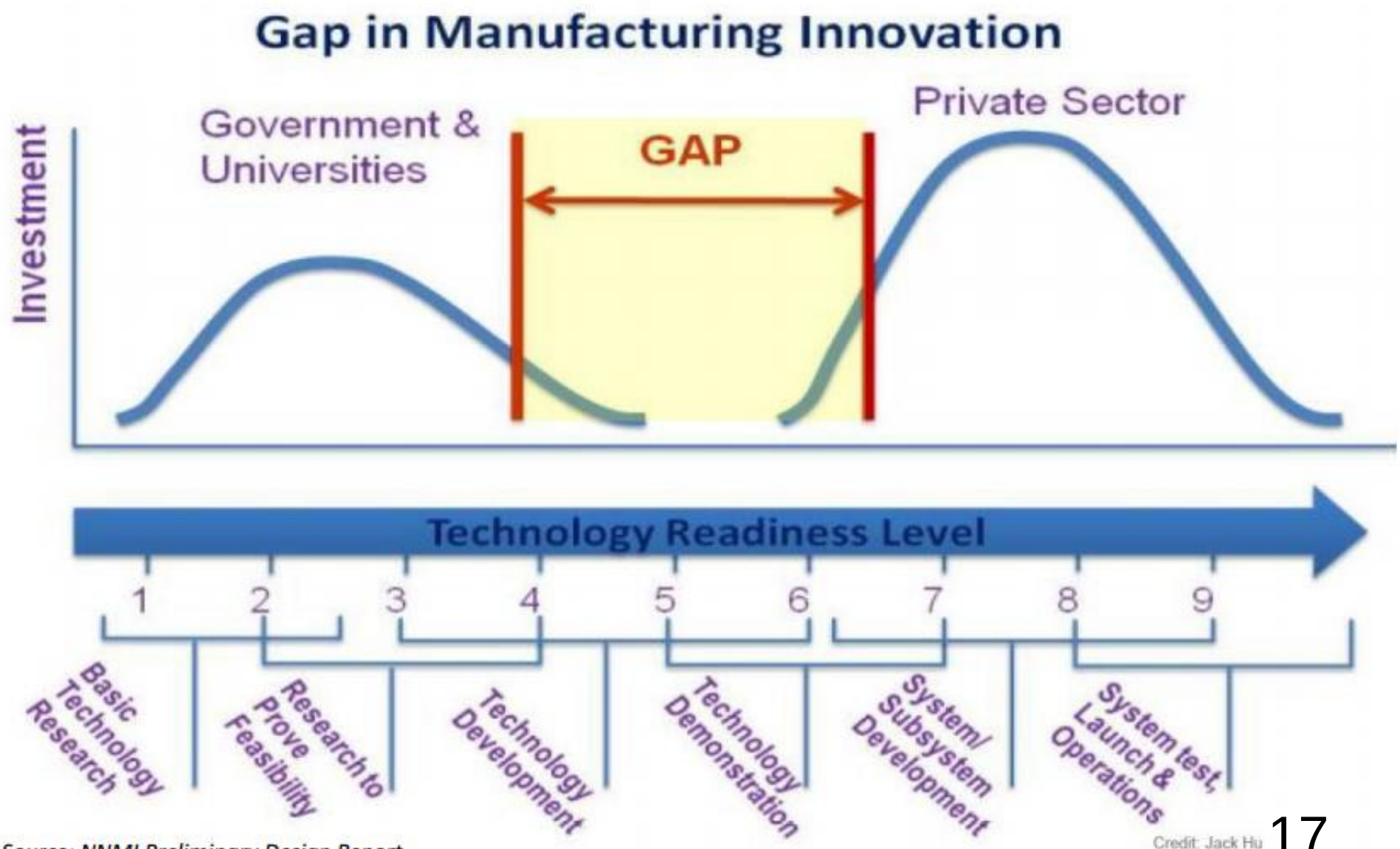
Content from Mr. Mike Molnar, Chief Manufacturing Officer, AMNPO

# Manufacturing Scale-up Gap




Source: NNMI Preliminary Design Report

Credit: Jack Hu

# 1st Institute - Additive Manufacturing

- $110M Institute based in Youngstown, OH
- Simulation for additive manufacturing
- Additive manufacturing for defense and aerospace applications
- Standards development
- Project funding for small companies
- Workforce readiness
- Technology transition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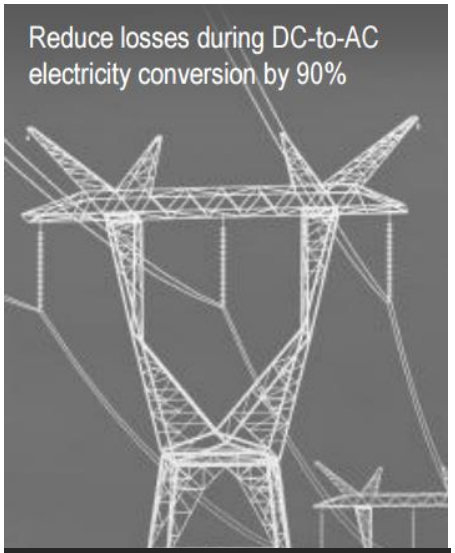
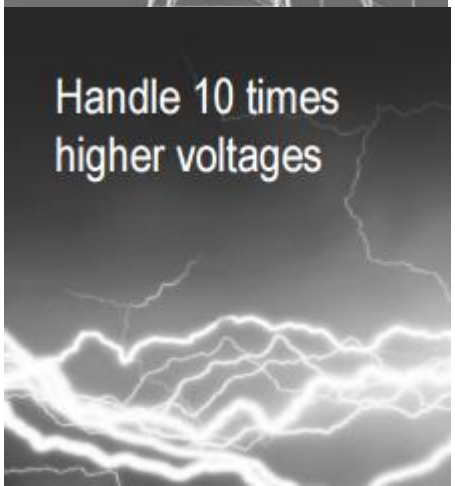
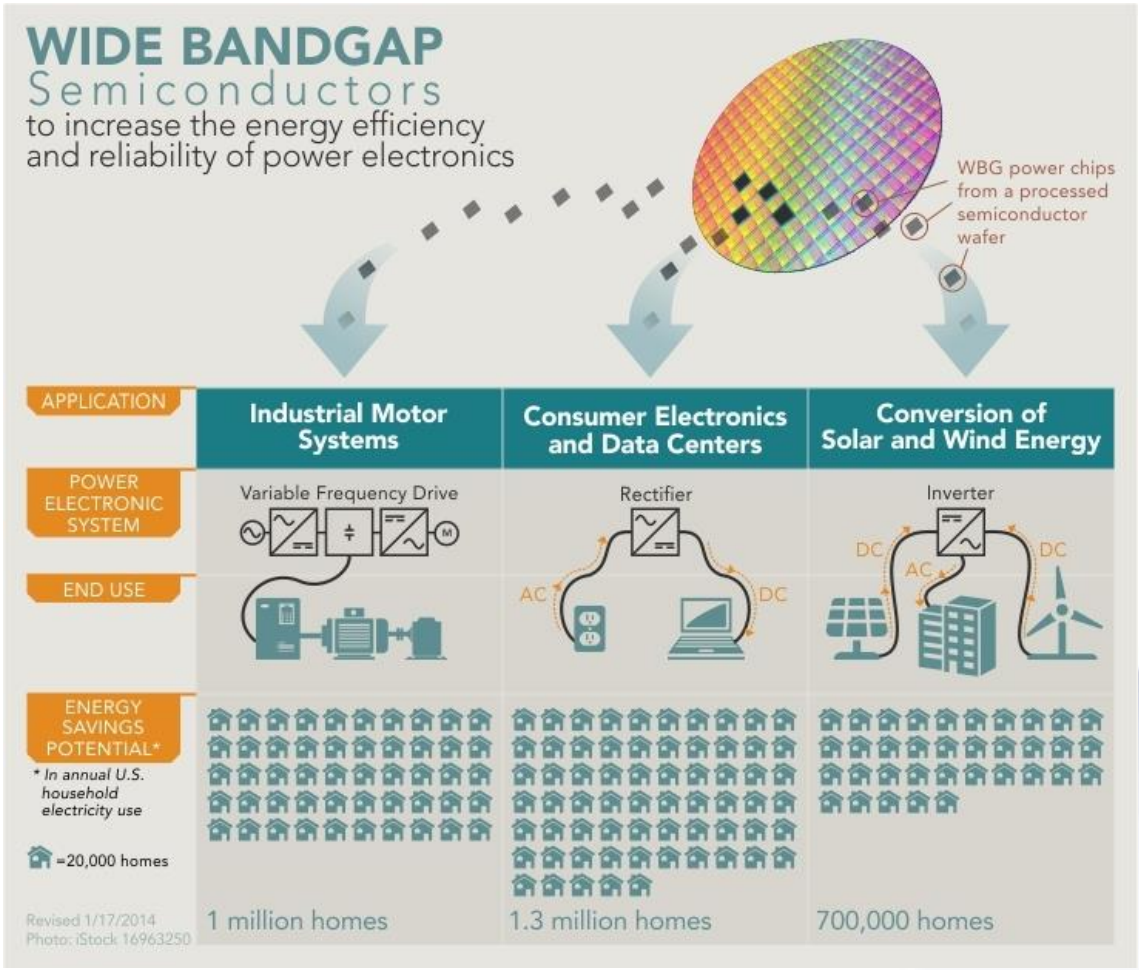
Content from http://manufacturing.gov/nnmi/

# 2nd Institute - Power Electronics

- $140M Institute based in Research Triangle, NC (NCSU)
- Large scale production of wide bandgap semiconductors, which allow power electronics to be made smaller, faster and more efficient that silicon



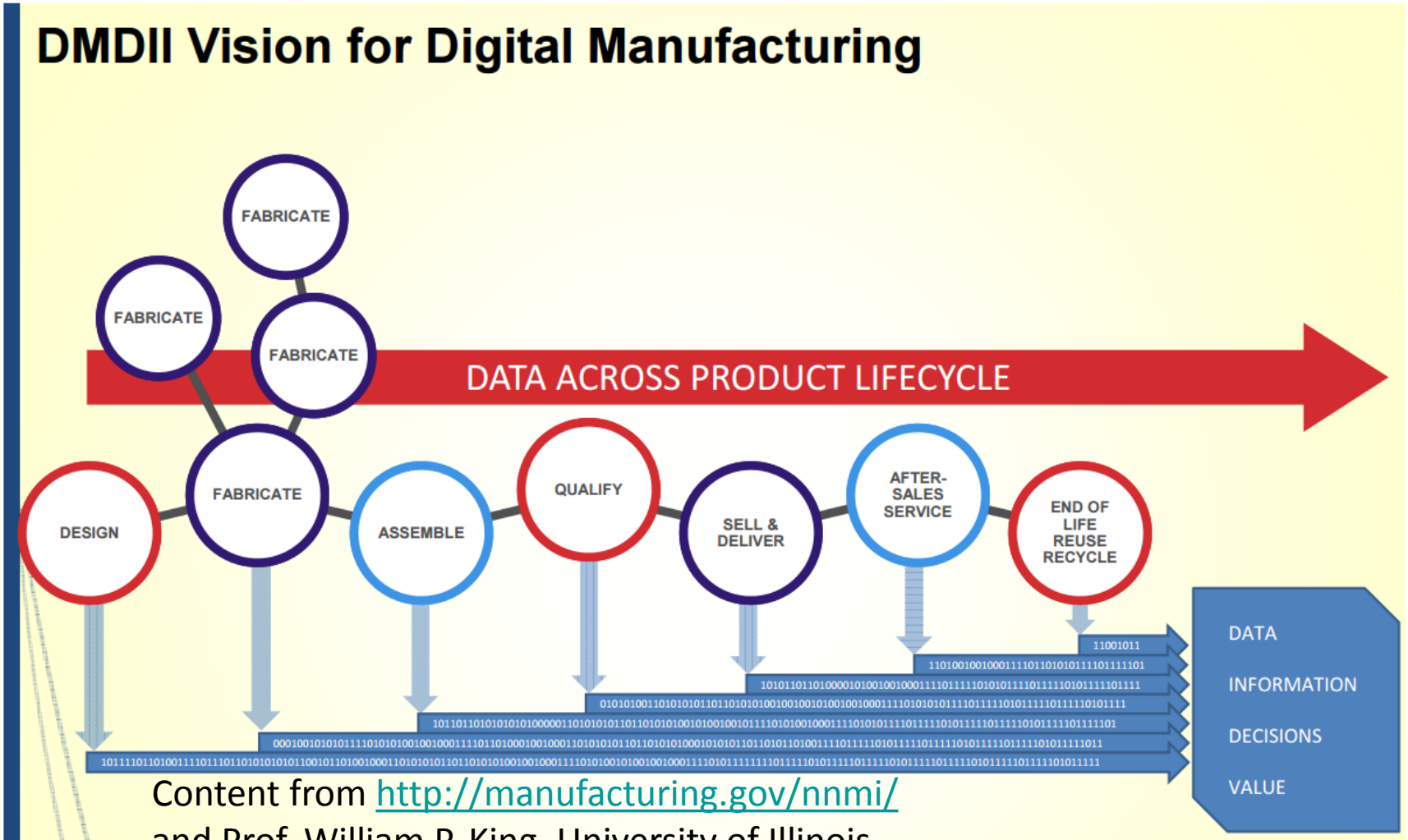




Content from http://manufacturing.gov/nnmi/

# 3rd Institute - Digital Manufacturing

- $310M Institute based in Chicago, IL (UI Labs)
- Digital links, connected factories, transparency of suppliers, data analytics for product lifecycle analysis

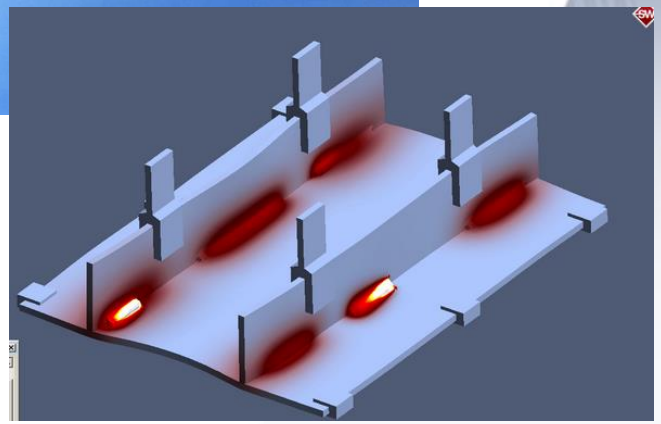



Content from http://manufacturing.gov/nnmi/
and Prof. William P. King, University of Illinois

# 4th Institute - Lightweight Metals

- $140M Institute based in Detroit, MI (Edison Welding Institute)
- Emphasis on melt process, powder process, thermo-mechanical process, coatings and joining for aluminum, magnesium, titanium and high-strength steel alloys
- Collaborations on sub-system design, component-level manufacturing, assembly (control of distortion due to heat treatment)


Content from http://manufacturing.gov/nnmi/



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# 5th Institute - Advanced Composites

- $250M Institute based in Knoxville, TN (University of Tennessee)
- Develop technologies that will (within 10 years) make game-changing advanced fiber-reinforced polymer composites
- Applications include lighter turbine blades, high-pressure tanks for hydrogen vehicles, stronger airframes and nautical applications

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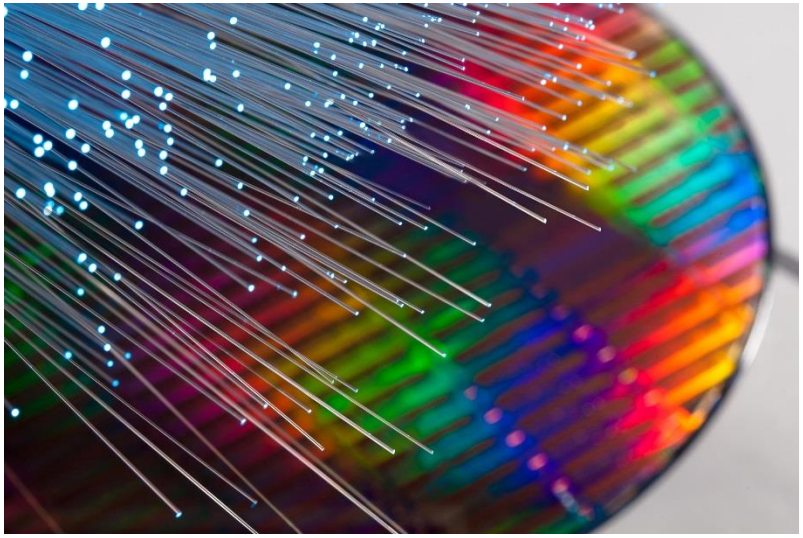
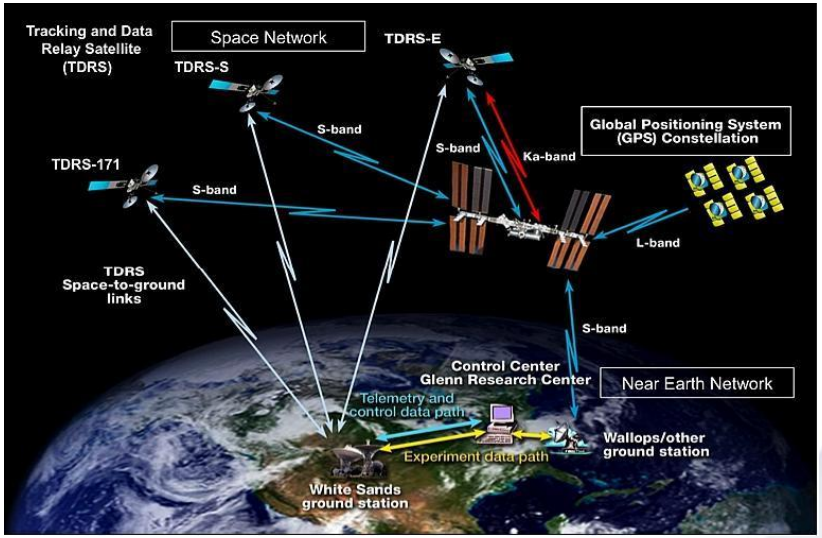
Content from http://manufacturing.gov/nnmi/

# 6th Institute - Integrated Photonics NNMI

- $610M Institute based in Albany, NY (State University of NY)
- Ultra high-speed transmission of signals for the internet and telecommunications
- New high performance information-processing systems and computing
- Compact sensors for medical advances in diagnostics and treatments
- Multi-sensor applications for urban navigation to space communication and quantum information sciences



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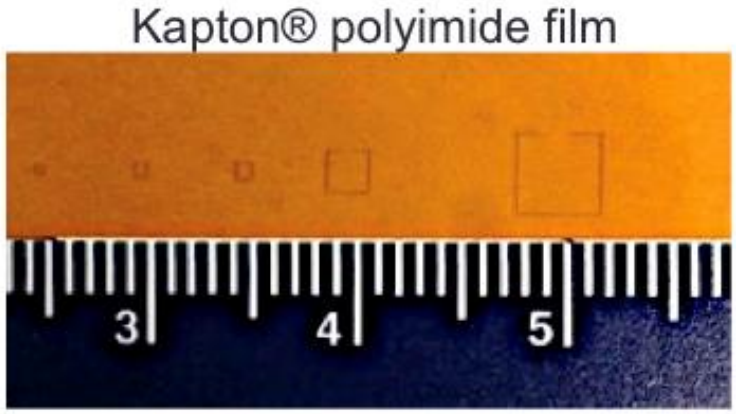
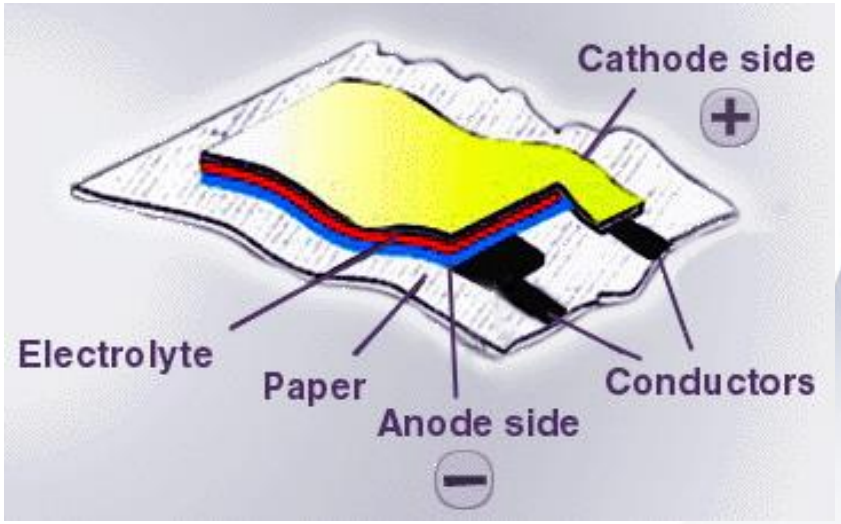
Content from http://manufacturing.gov/nnmi/

# 7th Institute – Flexible Electronics NNMI

- $171M Institute based in San Jose, CA (FLEXTECH Alliance)
- Scale-up:  Conductive and active inks and pastes, novel substrates that are flexible and stretchable
- Thinned device processing: Leading ultra-thin slicing and thinning of silicon integrated circuits and sensors
- Device/sensor integrated printing and packaging: High speed automated pick and place for precision placement of ultra-thin silicon devices, merging the high-performance printing industries for interconnects and data lines

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Content from http://manufacturing.gov/nnmi/

# UConn's Emphasis in Manufacturing & Materials

# $172M Innovation Partnership Building
# $95M Engineering & Science Building

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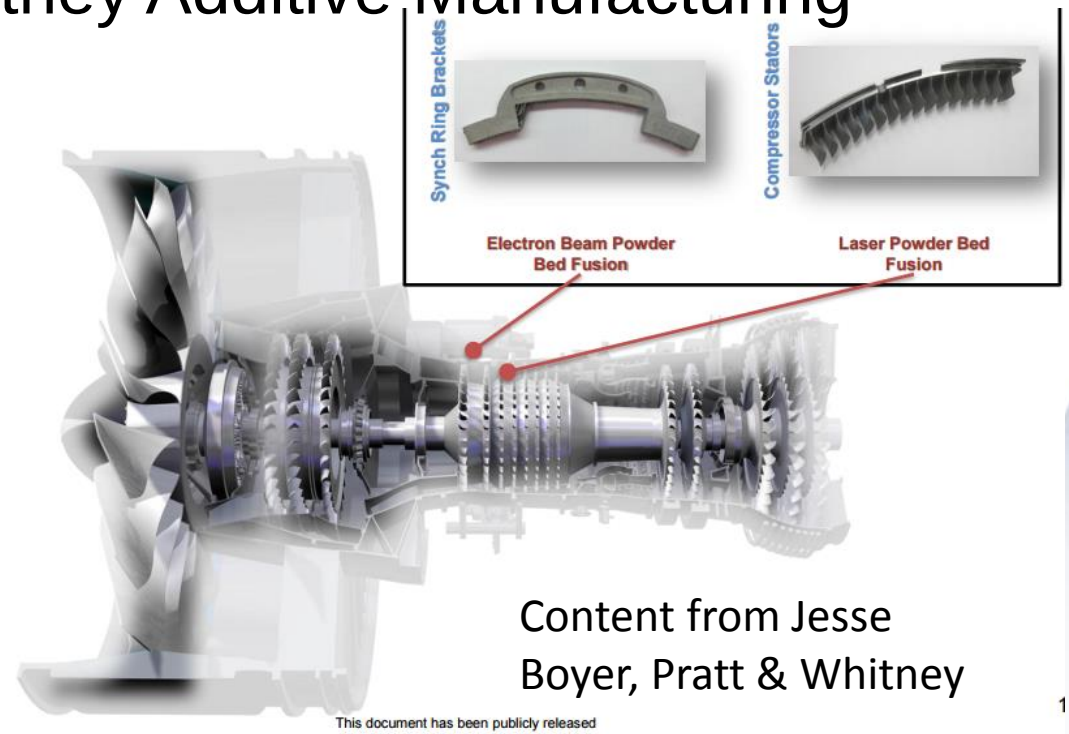
# Industry Partnerships

- $7.5M GE Center for Electrical-Protection Technologies
- $7.2M Fraunhofer Center for Energy Innovation
- $10M United Technologies Institute for Advanced Systems Engineering
- $7.5M Pratt & Whitney Additive Manufacturing ter




Content from Jesse Boyer, Pratt & Whitney

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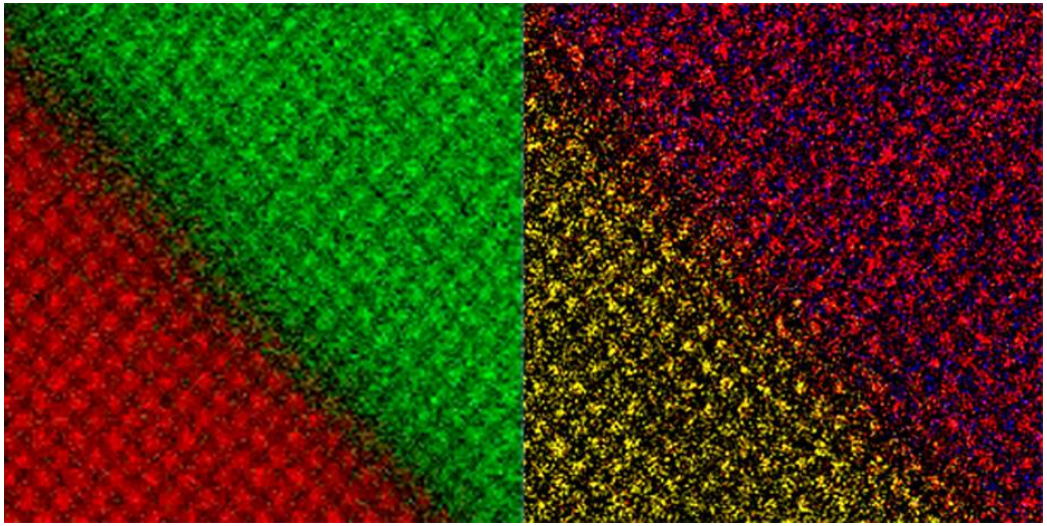
# $25M UConn-FEI Microscopy Center

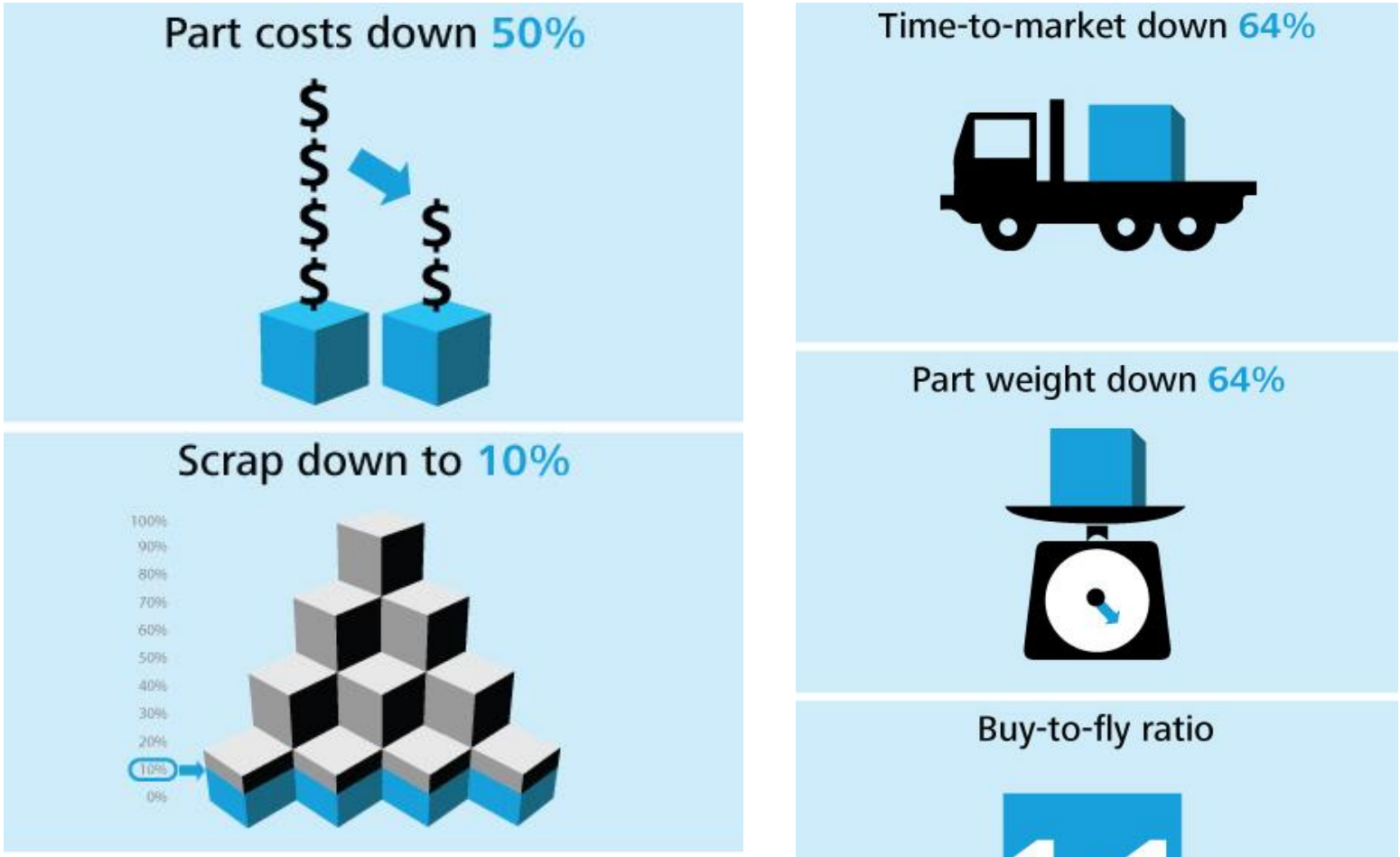
- **Themis Titan** –Atomic Scale S/TEM
- **Talos 200** – S/TEM EDS
- **Verios** – ESEM
- **Teneo** – SEM
- **Helios 460F1** – Focused Ion Beam/SEM
- **Helios PFIB Dual Beam** – Plasma Focused Ion Beam/Field Emission SEM

Atomic resolution chemical map of $GdScO_3/SrTiO_3$ interface showing the elemental distribution of Sc and Ti. The EELS signal (left) and the EDS signal (right) is simultaneously acquired.

*Sample courtesy: Dr. M. Luysberg, Ernst Ruska Centrum, Germany*

# Benefits of Additive Manufacturing

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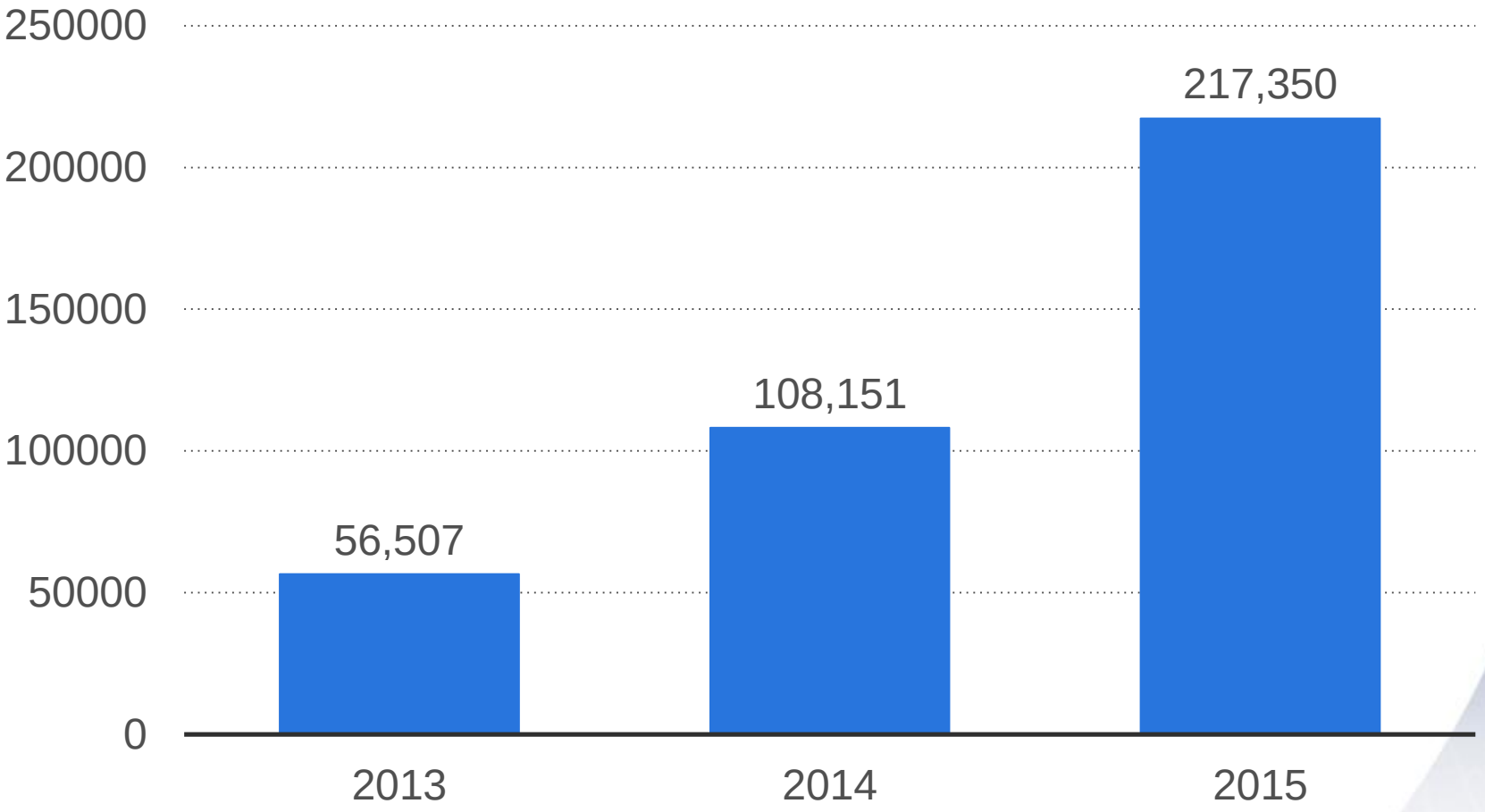
# Global Shipments of Industrial 3D Printers from 2013 to 2015

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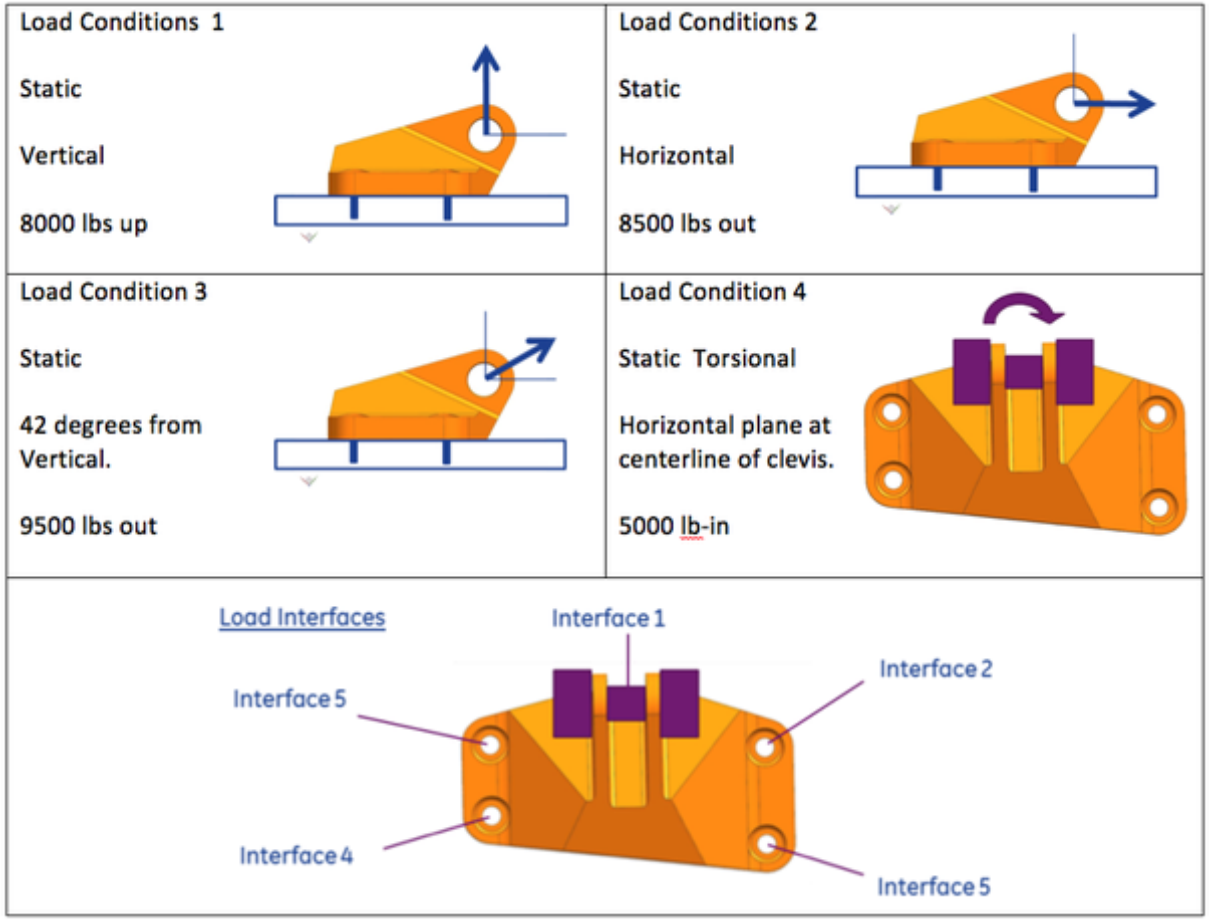
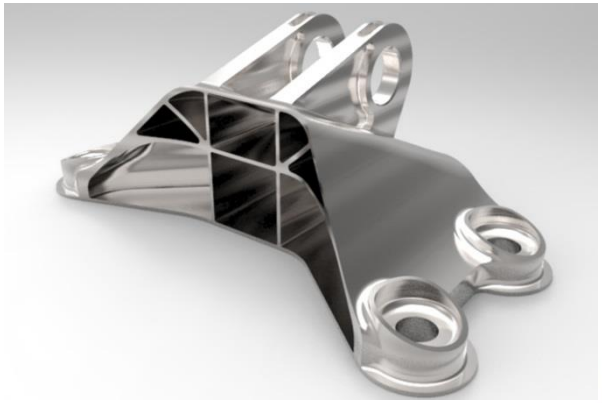
statista

# Crowd-Sourcing Solutions for AM

- GE Jet engine loading bracket weighs 2 kg
- An international challenge was launched to design and build a replacement bracket that maintains load specs but with reduced weight



- Winning entry weighed 0.32 kg (84% reduction)

# Committed to Additive Manufacturing

- Fuel nozzle for GE Leap Engine comprised of 20 different components
- Newly designed and additively manufactured nozzle is a single part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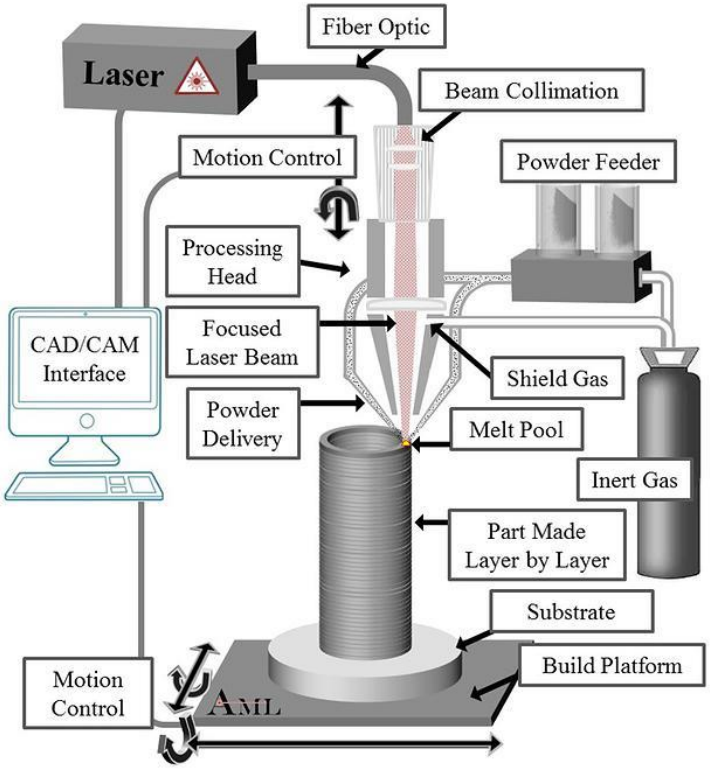
# Key Techniques in Additive Manufacturing

## Directed Energy Deposition

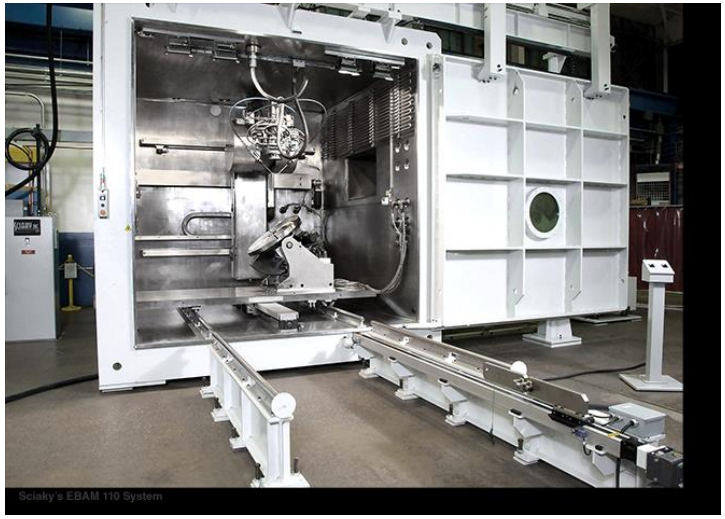
*From Optomec and*
*www.additivemanufacturinglaboratory.com/*

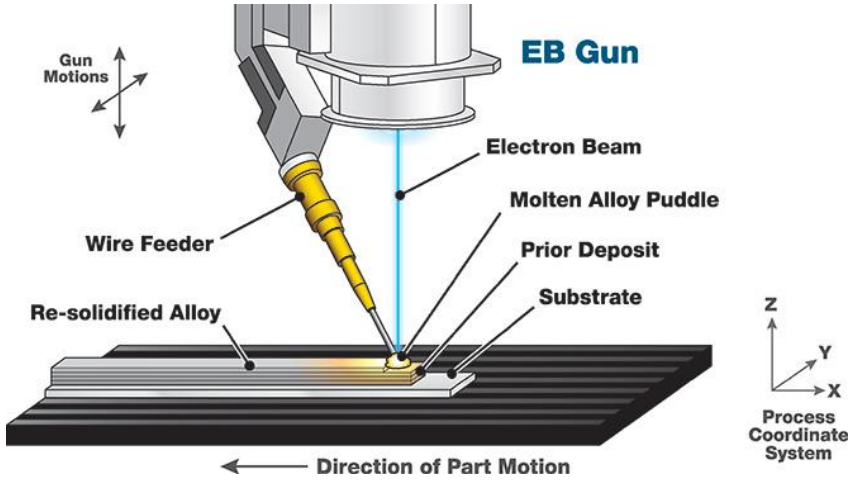



- Powder is fed into laser beam, melted onto substrate
- Deposition rates of pounds per hour (~70 $cm^3$/hr)
- Useful for tall/big structures
- Details of 500 microns
- Adding features to or repairing existing parts

# Key Techniques in Additive Manufacturing

## Electron beam wire deposition

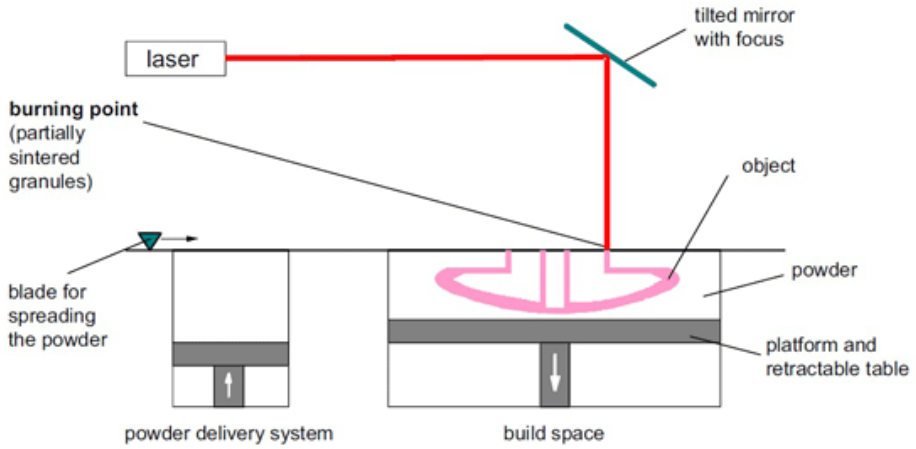



- Wire is fed into electron beam, melted onto substrate
- Deposition rates of tens of pounds per hour
- Useful for tall structures, used for Ti-alloys, refractory alloys
- Applications:
  - Tooling applications requiring high strength surfaces
  - Joining of dissimilar metals (different melting points & thermal conductivity

# Key Techniques in Additive Manufacturing

## High-energy powderbed technologies

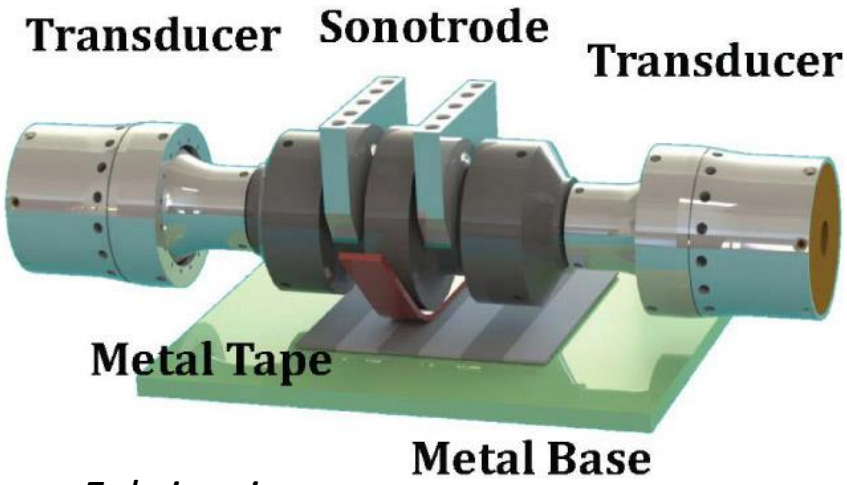



- **Laser Beam Sintering**
- **Electron Beam Melting**

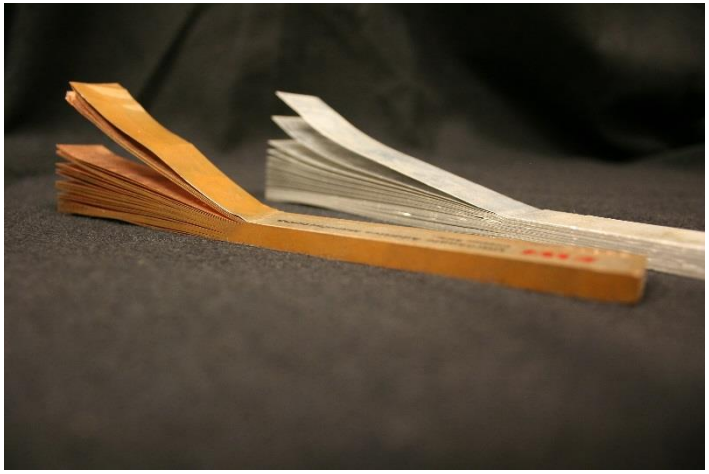
- Powder raked/rolled onto build plate
- Laser-/electron-beam melting powderbed
- Largest build volume: 500mm X 500mm X 500mm
- Build speed of ~20 $cm^3$/hr
- Details of 40 microns
- Commercial machine manufacturer: Arcam (electron-beam), EOS, 3DSystems, SLM Solutions, Concept Laser, Realizer, Renishaw
- Applications:
  - Fuel nozzles, turbine blades, biomedical implants

# Key Techniques in Additive Manufacturing

## Ultrasonic additive manufacturing




*From Fabrisonics*



- Ultrasonically-driven (20,000 Hz), friction based bonding of foils
- Solid state only, no liquids involved
- Particularly useful for embedding thin foils/sensors
- Applications
  - Joining of materials at lower temperatures
  - Embedding of functional electronics to structural elements

# P&W Additive Manufacturing Innovation Center

EOS 270 Direct Metal Laser Sintering Machine (DMLS)

*Photo: Nozzle-guide vane segment for jet engine made of IN718*


(www.eos.com)

Build volume:
210 mm x 210 mm x 170 mm

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# P&W Additive Manufacturing Innovation Center

Arcam A2X *Electron beam melting technology, used with Ti-6Al-4V powder, Inconel-718 powder*

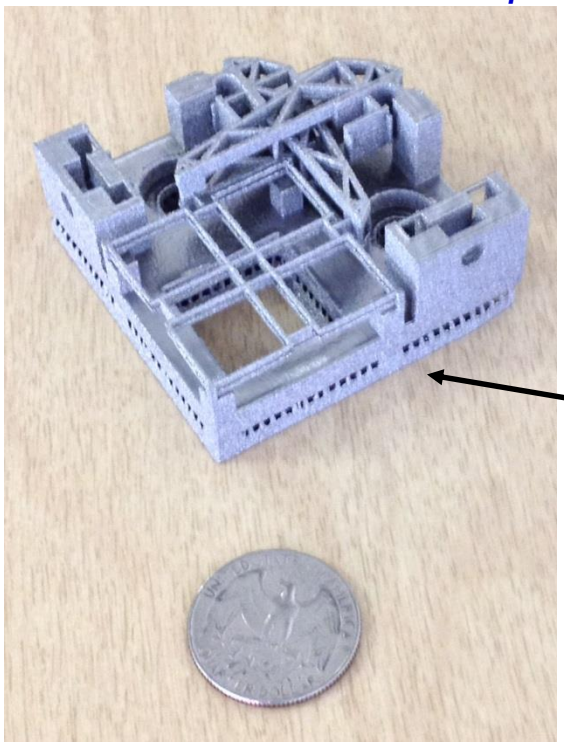

*Photo: piezo-electric transducer driven titanium actuators*

Build volume: 200 mm x 200 mm x 340 mm

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# P&W Additive Manufacturing Innovation Center

3DSystems ProX-300: installed May 2015
500 W laser, 250 mm x 250 mm x 300 mm build volume


Materials:
Currently: 17-4 PH stainless steel,
Near future: aluminum alloys

*Photo: impeller*

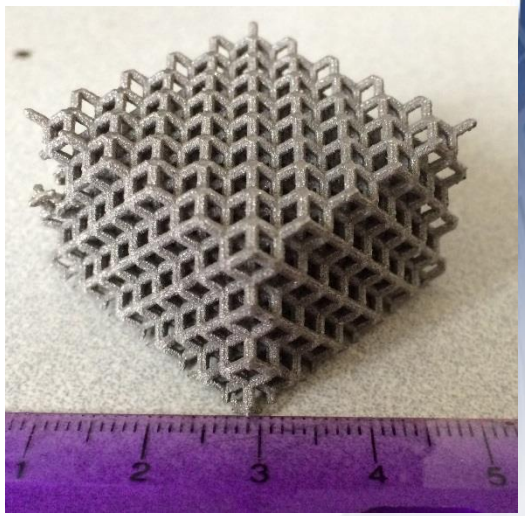

*Photo: lattice structure*

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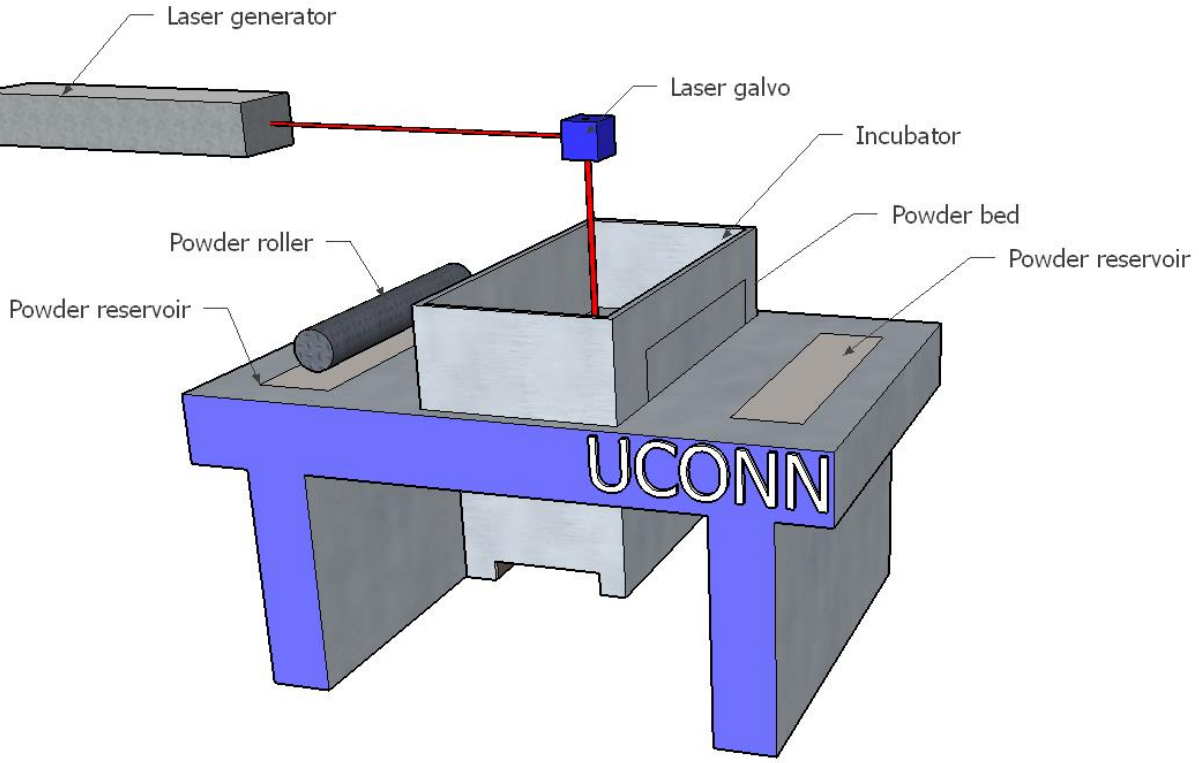
# Advanced Manufacturing Testbed

X. Chen, A. Ma, R. Hebert

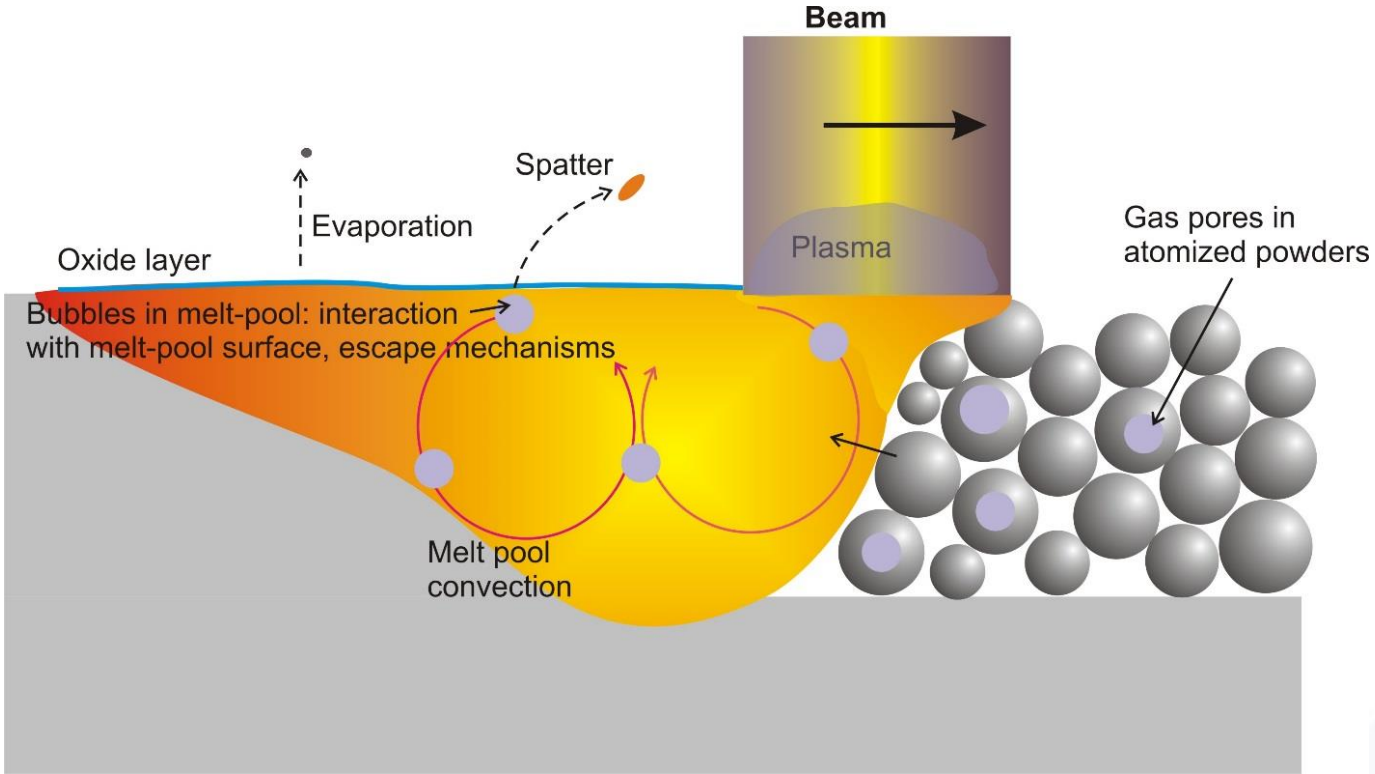
- UConn Selective Laser Sintering (SLS) test bed
- To develop an open-source powder bed fusion AM (PBFAM) machine as a test bed for fabricating polymers, metals, and ceramics.
- The test bed will enable researchers access to key parameters in the manufacturing process, discover problems hidden in commercial “black box” systems



# Pratt & Whitney sponsored project

R. Hebert, P. Alpay, A. Dongare, J. Hancock and L. Ladani

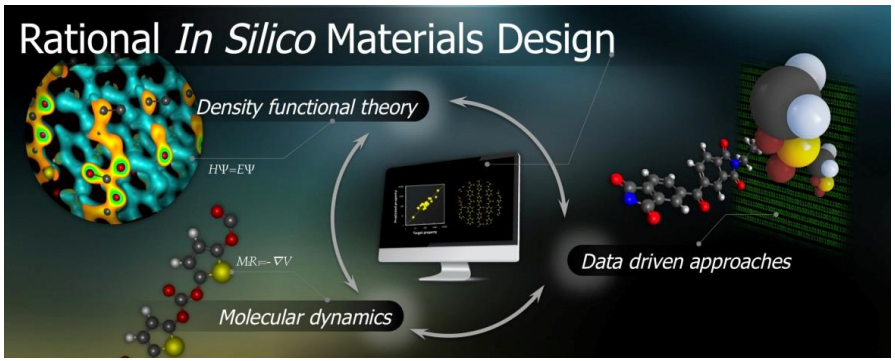
- Focus on laser-powder bed interaction
- Subproject 1: measurement of laser beam characteristics (power, beam size)
- Subproject 2: impurity effects on viscosity, surface tension; powder bed homogeneity;

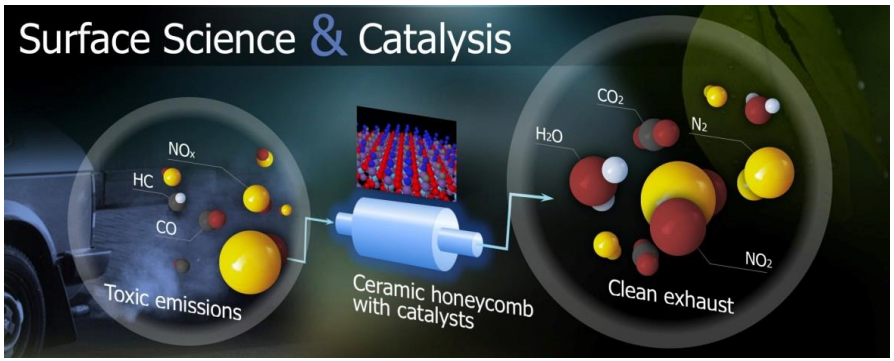


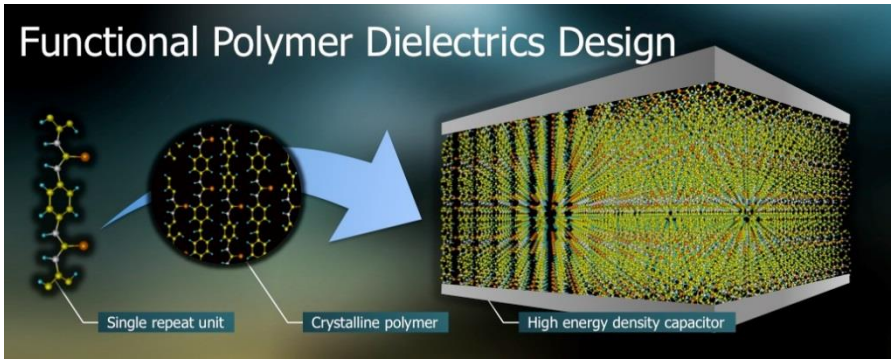
# $7.4M DOD Rational Materials Design Project

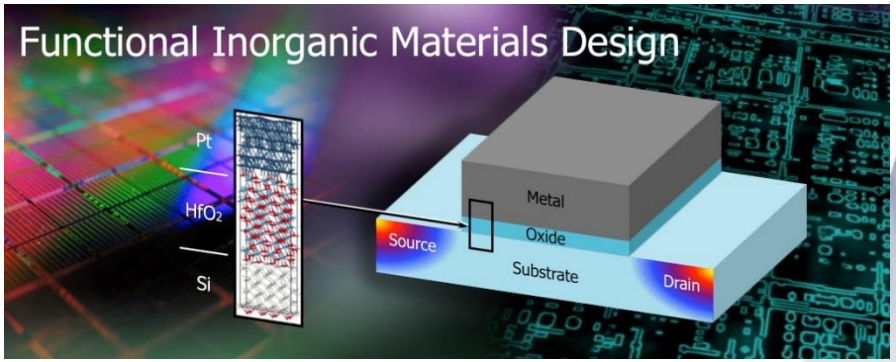
Rampi Ramprasad

## Through Quantum Mechanical Computations & Data Mining

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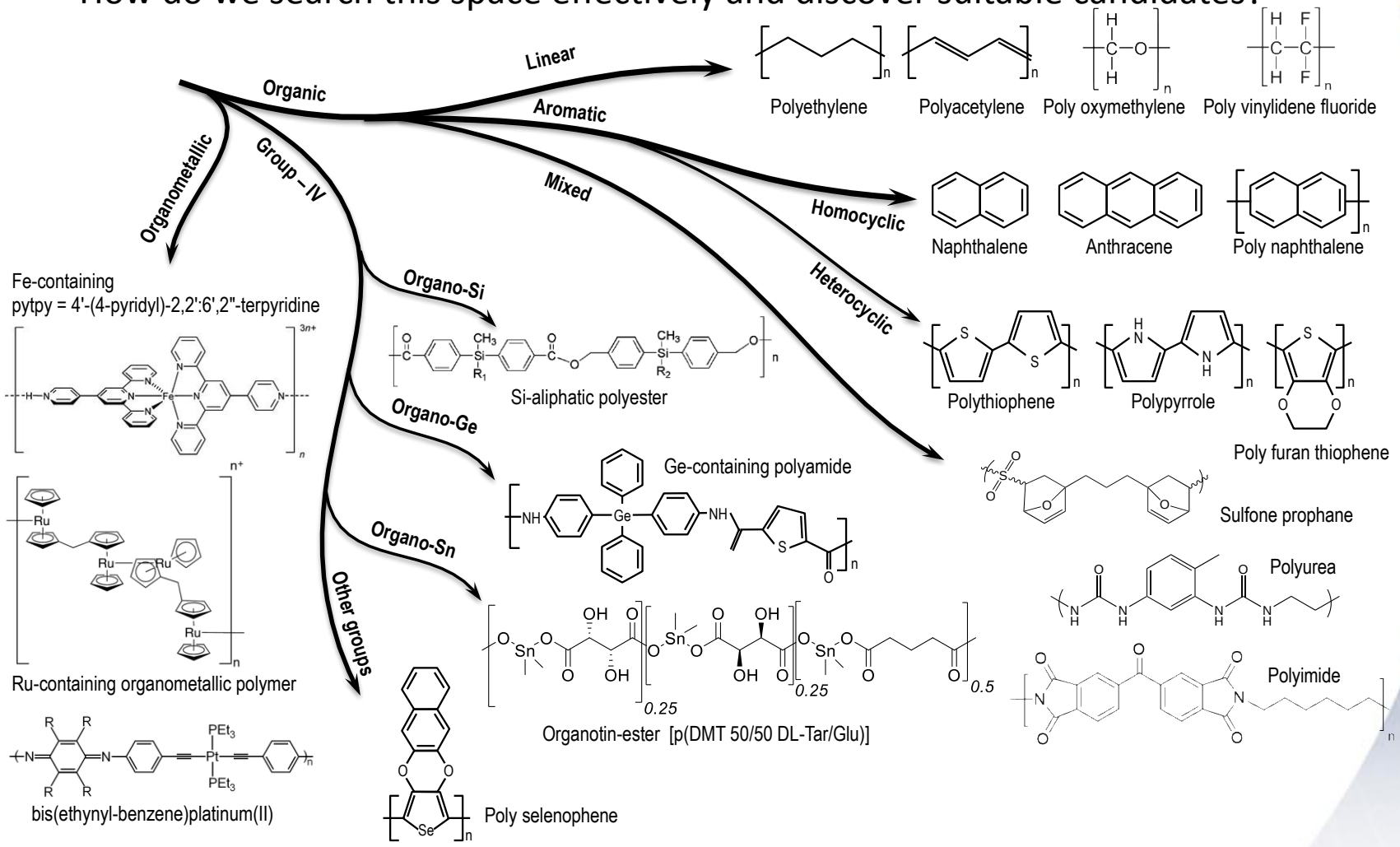
# The Polymer Chemical Universe is VAST!

How do we search this space effectively and discover suitable candidates?

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# Observations

- Create structures that cannot be created using conventional methods (e.g., functionally graded materials)
- On-site manufacturing where components are needed
- Buy to fly ratio close to one
- Leap in component development with new, AM-specific alloys
- Repeatability and reproducibility
- Currently only single component inspections exist
- Understanding complexity of process
- Low spatial resolution
- Slow throughput

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