NTRC | NANOTECHNOLOGY RESEARCH CENTER

Sustainable Nanotechnology Organization

Moving from Nanotechnology to Advanced Manufacturing

An Opportunity for Sustainable Growth

2017 SNO Conference
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National Institute for Occupational Safety and Health

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CDC Workplace Safety and Health | NIOSH

Today's Journey

Emerging Technologies

Focus on Manufacturing

Nanotechnology's role

The role of the Workplace

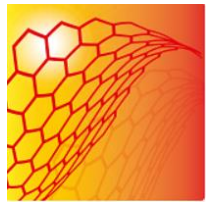
Where does Sustainability start?

The World Economic Forum ‘Top 10” Emerging Technologies

1. Nanosensors and the Internet of Nanothings

2. Next Generation Batteries

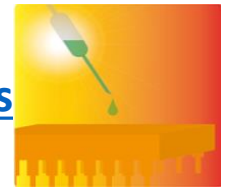
3. The Blockchain



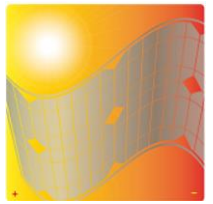
4. 2D Materials

5. Autonomous Vehicles

6. Organs-on-chips

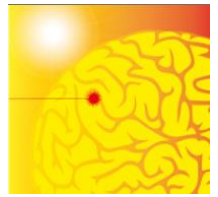


7. Perovskite Solar Cells



8. Open AI Ecosystem

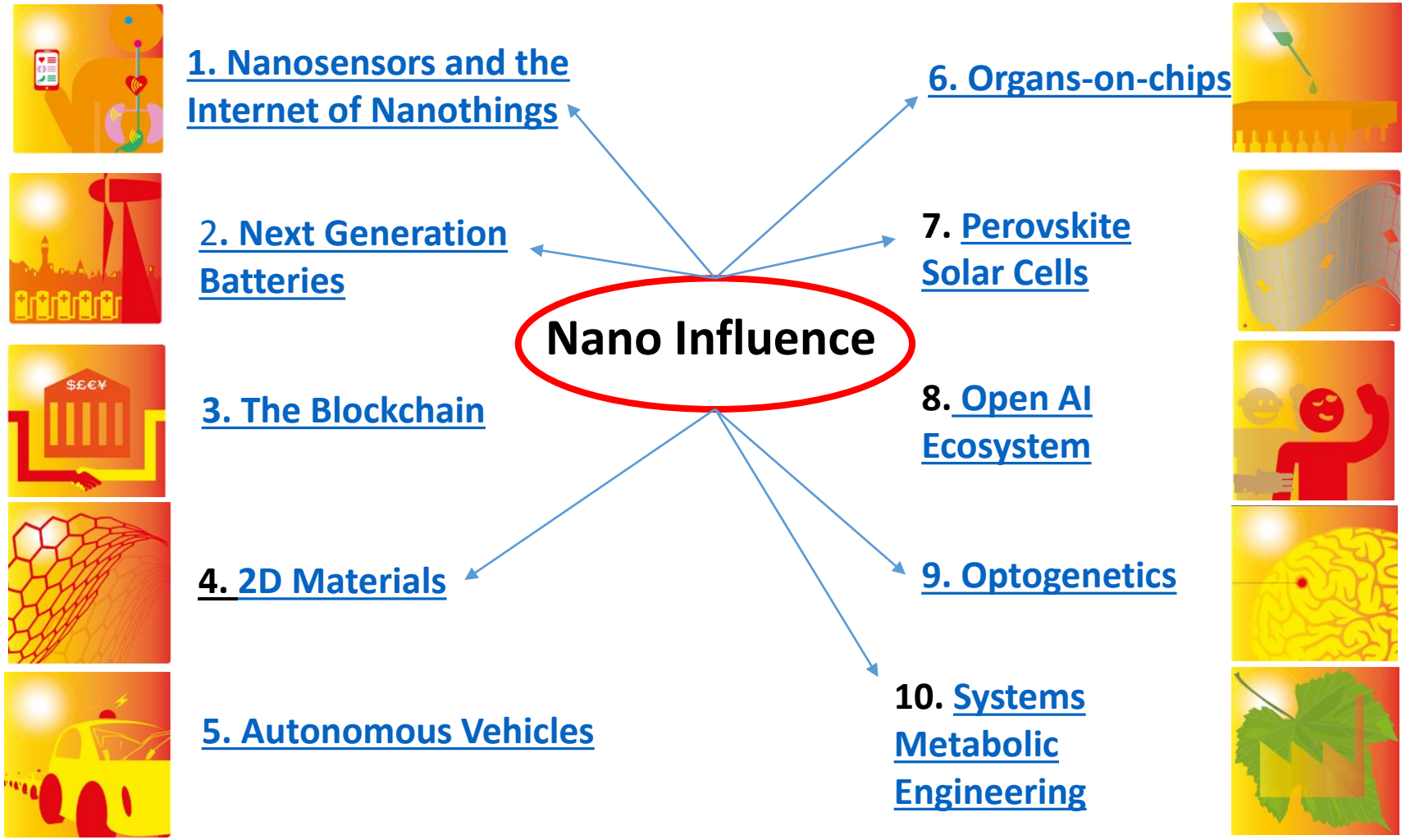
9. Optogenetics



10. Systems Metabolic Engineering

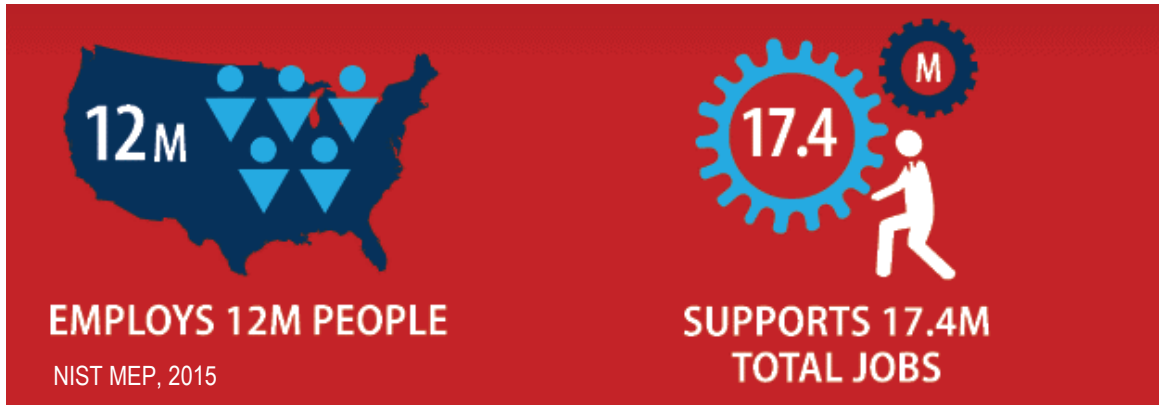
https://www.weforum.org/agenda/2016/06/top-10-emerging-technologies-2016/

The World Economic Forum ‘Top 10” Emerging Technologies



https://www.weforum.org/agenda/2016/06/top-10-emerging-technologies-2016/

Current State of US Manufacturing



Manufacturers contributed $2.17 trillion to the U.S. (NAM News)

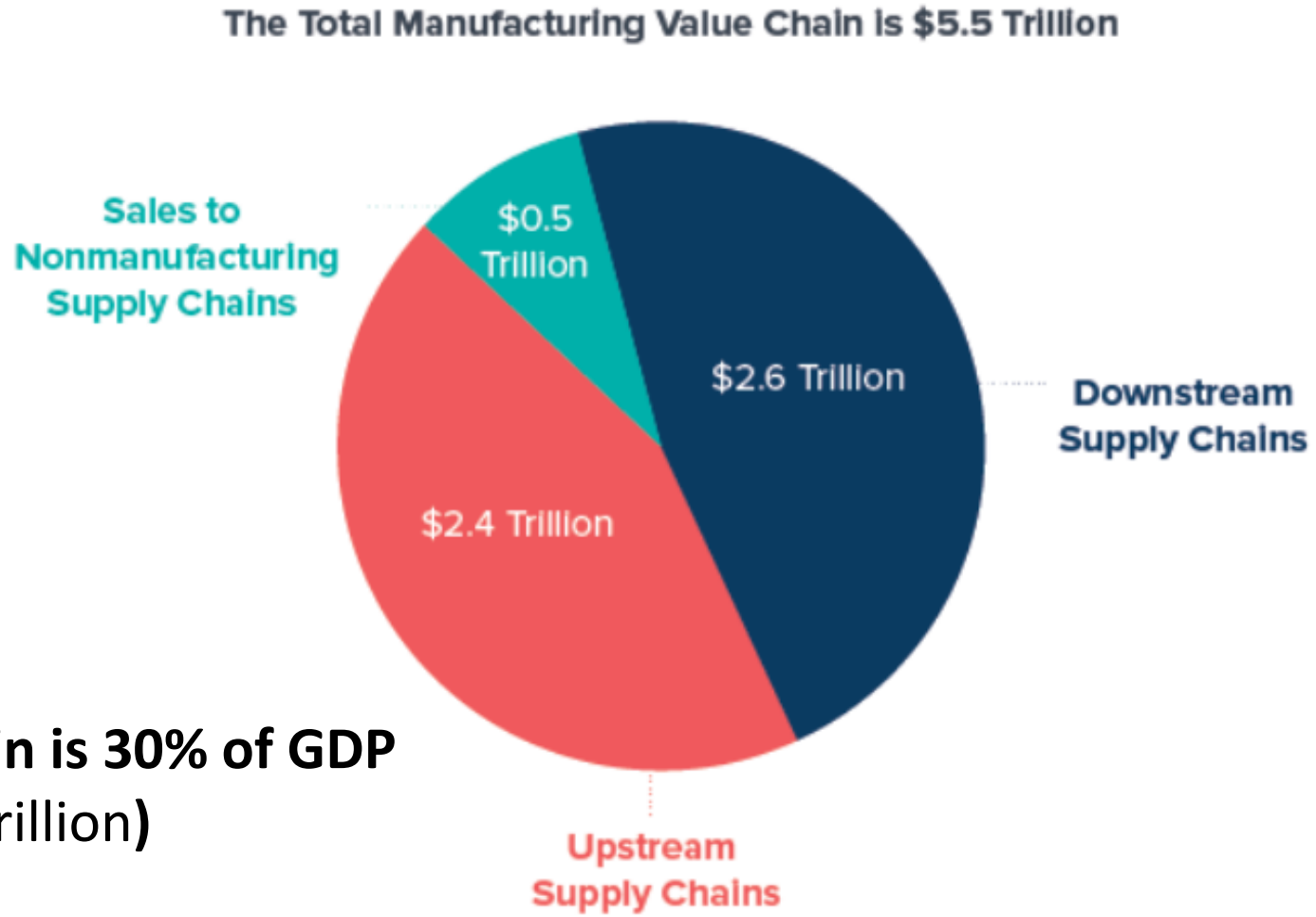
If U.S. Manufacturing were a separate country, 9th largest economy worldwide

Value of 13 % of GDP.

U.S. manufacturing fundamentals strong again: 900,000 direct jobs added since recession

This is big, but looks only at value of finished goods.

Total Manufacturing Value is Even Bigger



<u>Total</u> Value Chain is 30% of GDP
(Based on $18 Trillion**)**

Sources: MAPI Foundation and INFORUM

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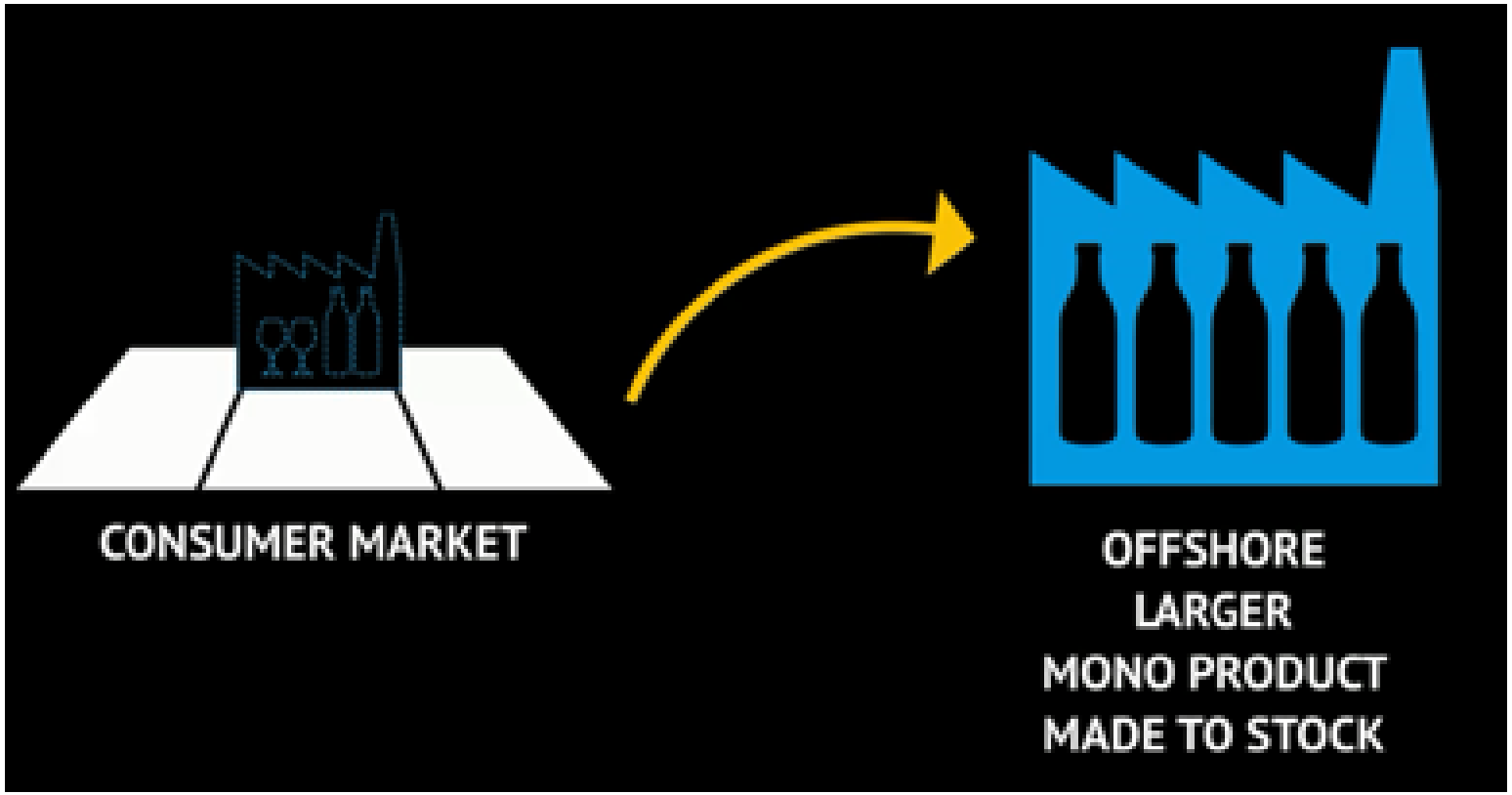
Changing State of Manufacturing
- Current Model, but Fading -



"By 2020 changes in labor, energy, and material costs will cause a rethinking"

- Emerging Manufacturing Model -

Distributed Manufacturing
Micro Factories, Home Factories
Made to Order: Just in time, Just to order , Just next door

The Manufacturing Model is Changing

How we make things is evolving from mechanical processes to information and technology based processes.

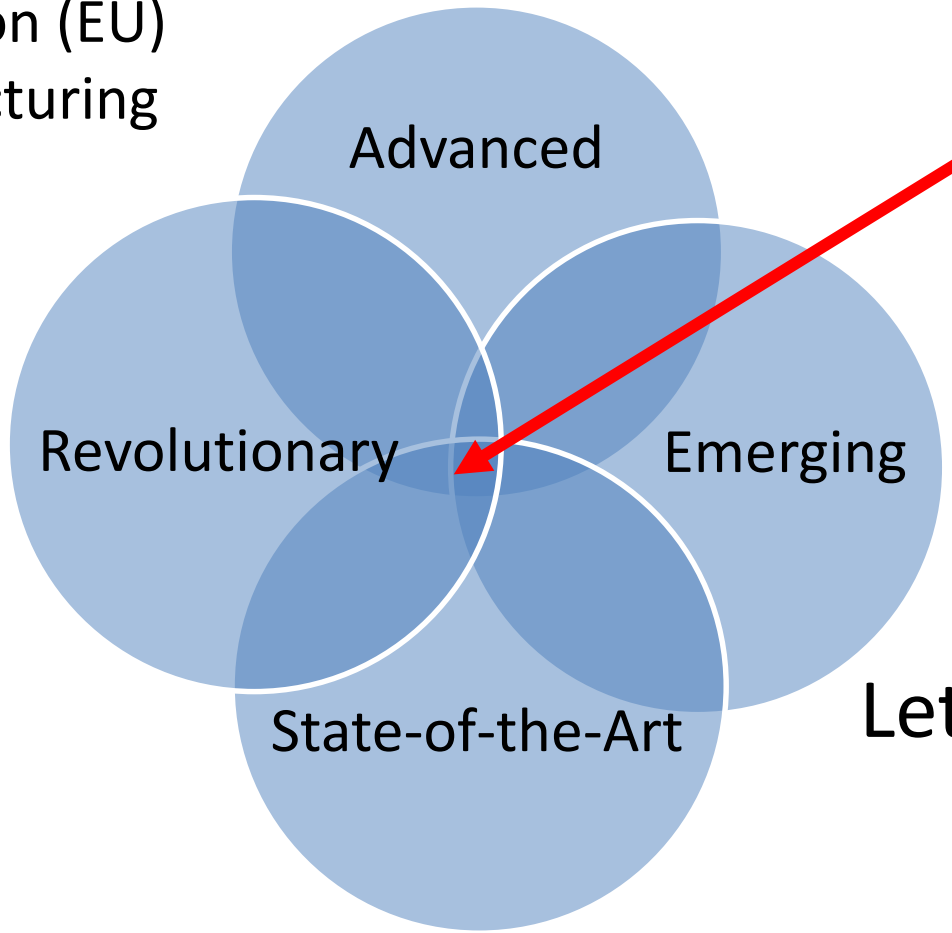
The Drivers are Changing

Speed to market, complex designs, mass customization, sustainable processes.

What do we call it?

- Advanced Manufacturing (most common)
- State-of-the-Art Manufacturing (descriptive)
- Next Production Revolution (EU)
- Next-Generation Manufacturing
- Industry 4.0 (Catching on)

21st Century Manufacturing

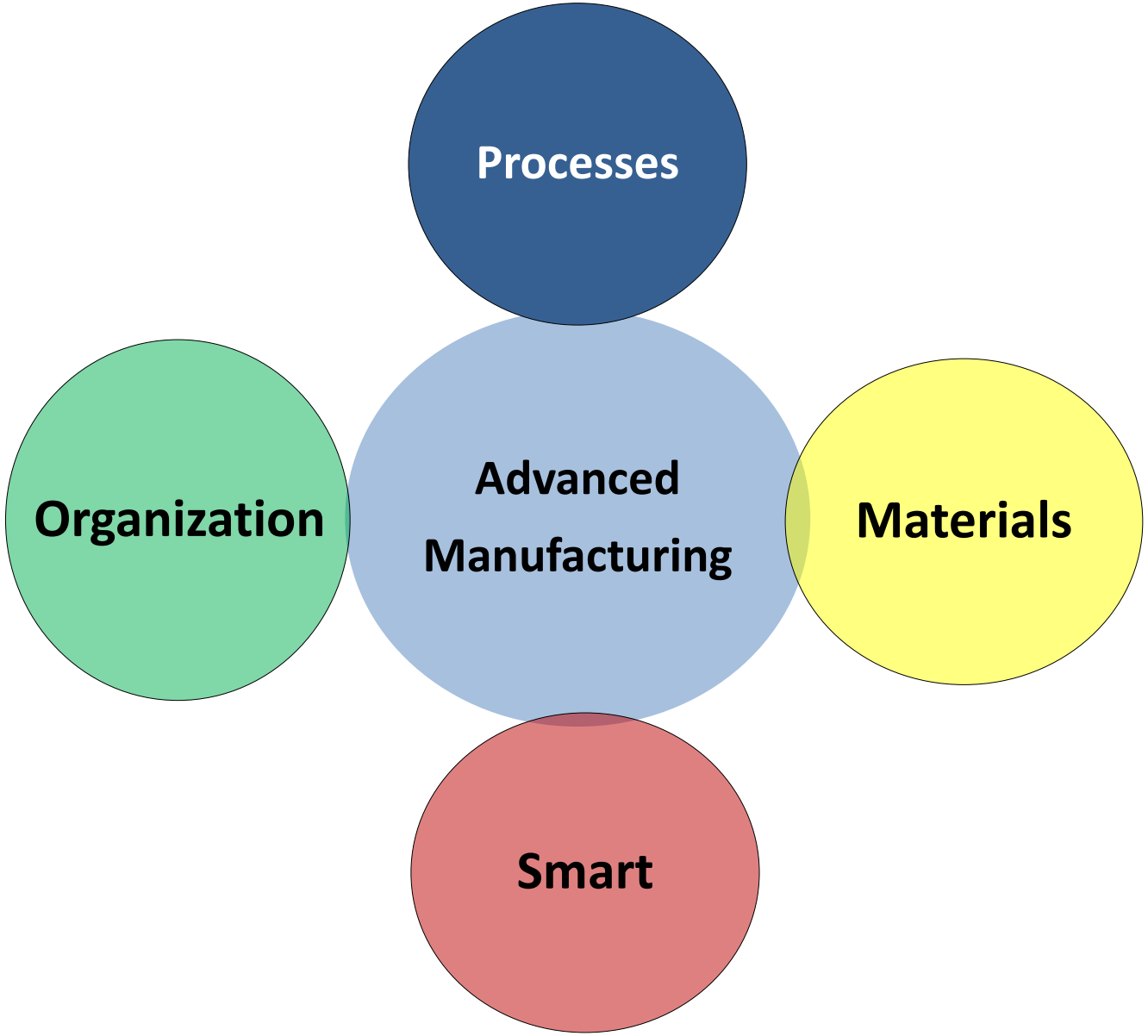


Let's call it "Advanced"

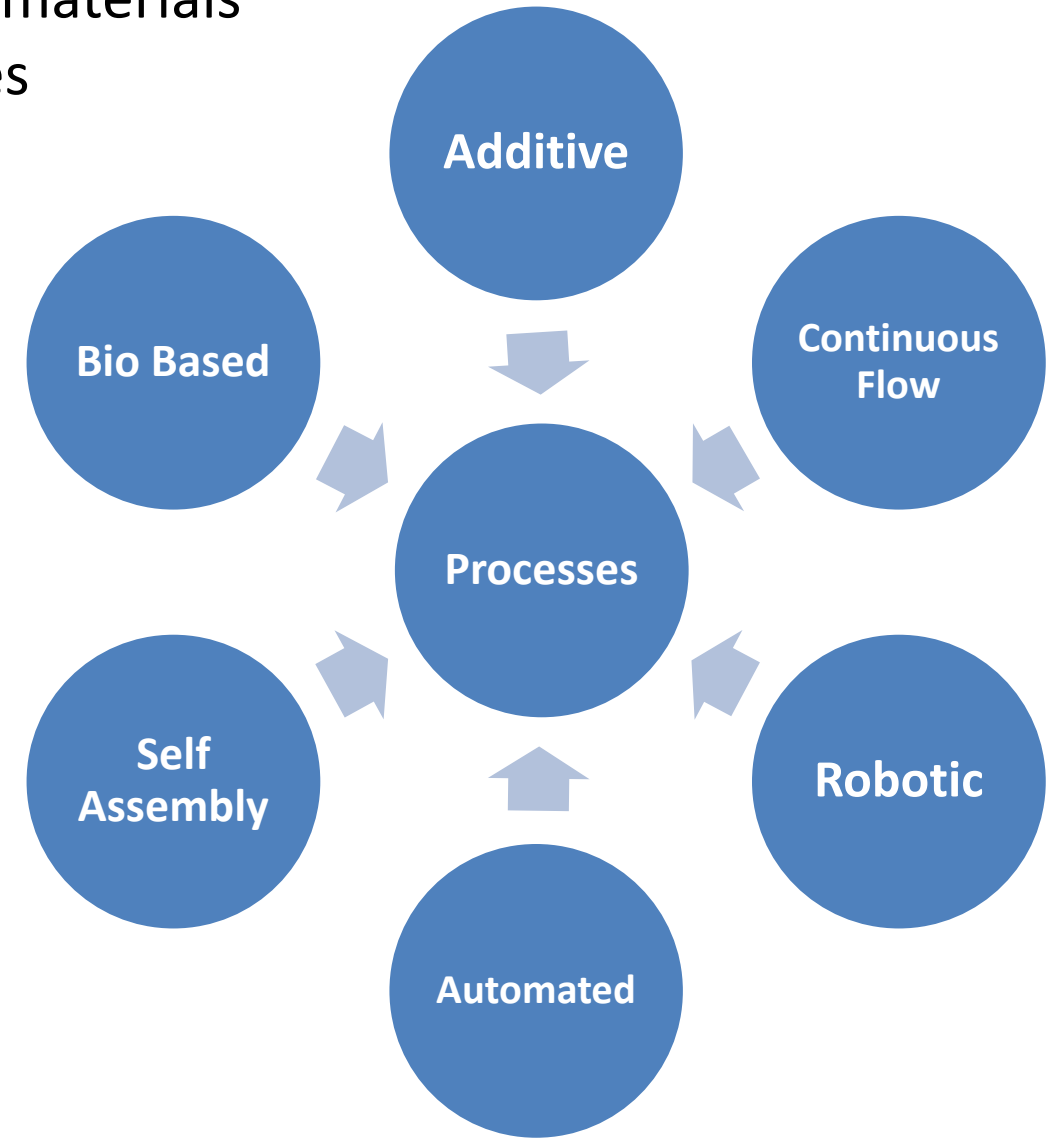
Advanced

- **Industries**
  - Conduct significant R&D; large use of STEM employees
  - Examples: ‘Super Sectors’, e.g. Aerospace, Pharma, Energy
- **Materials**
  - New, enhanced properties beyond original form; or new material
  - Designed for a specific application
- **Manufacturing**
  - High use of information, automation, modeling, and networking
  - Uses ‘cutting-edge’ chemical and biological materials, e.g.. Nanomaterials
  - New ways to make things and making new things

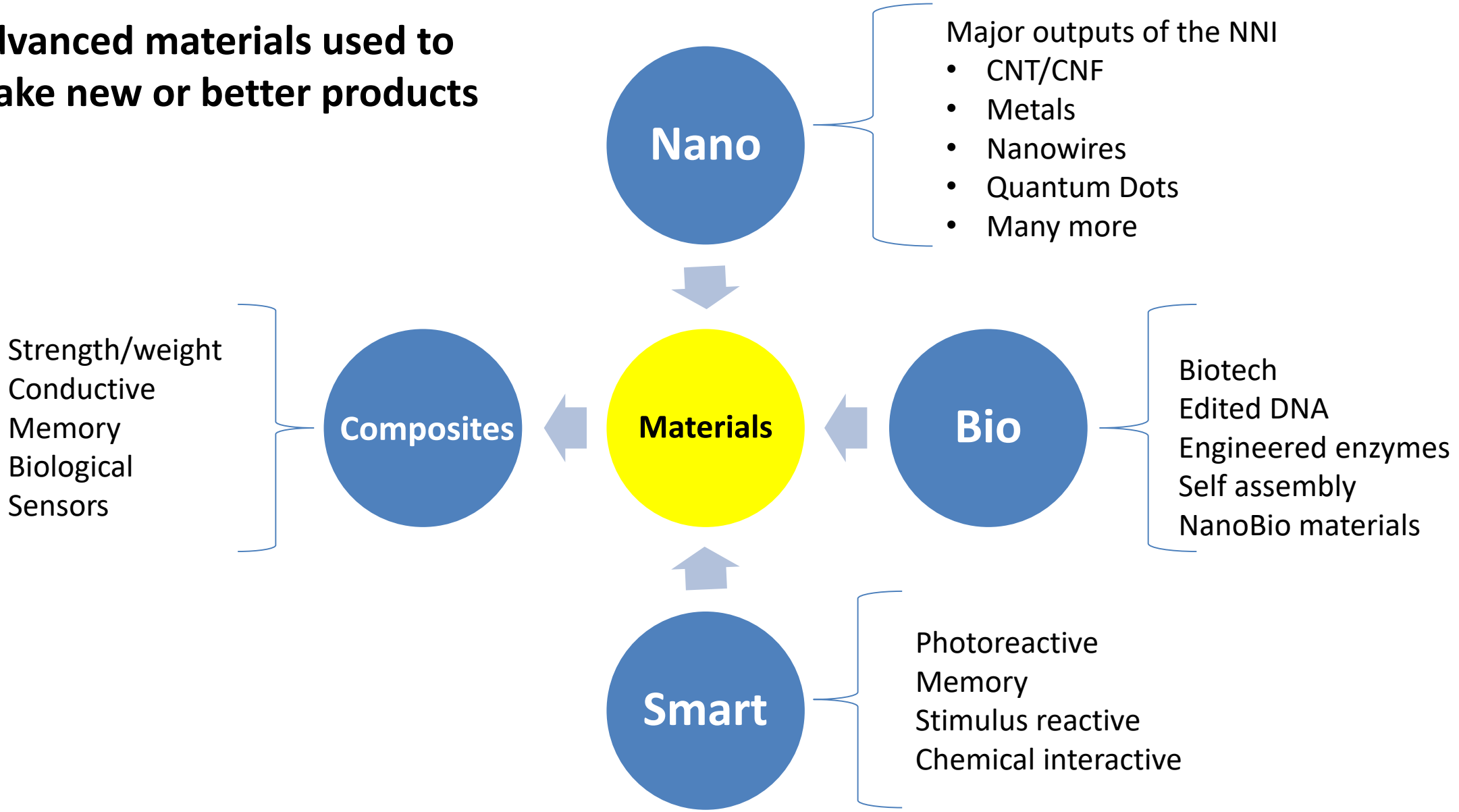
Key Attributes of Advanced Manufacturing



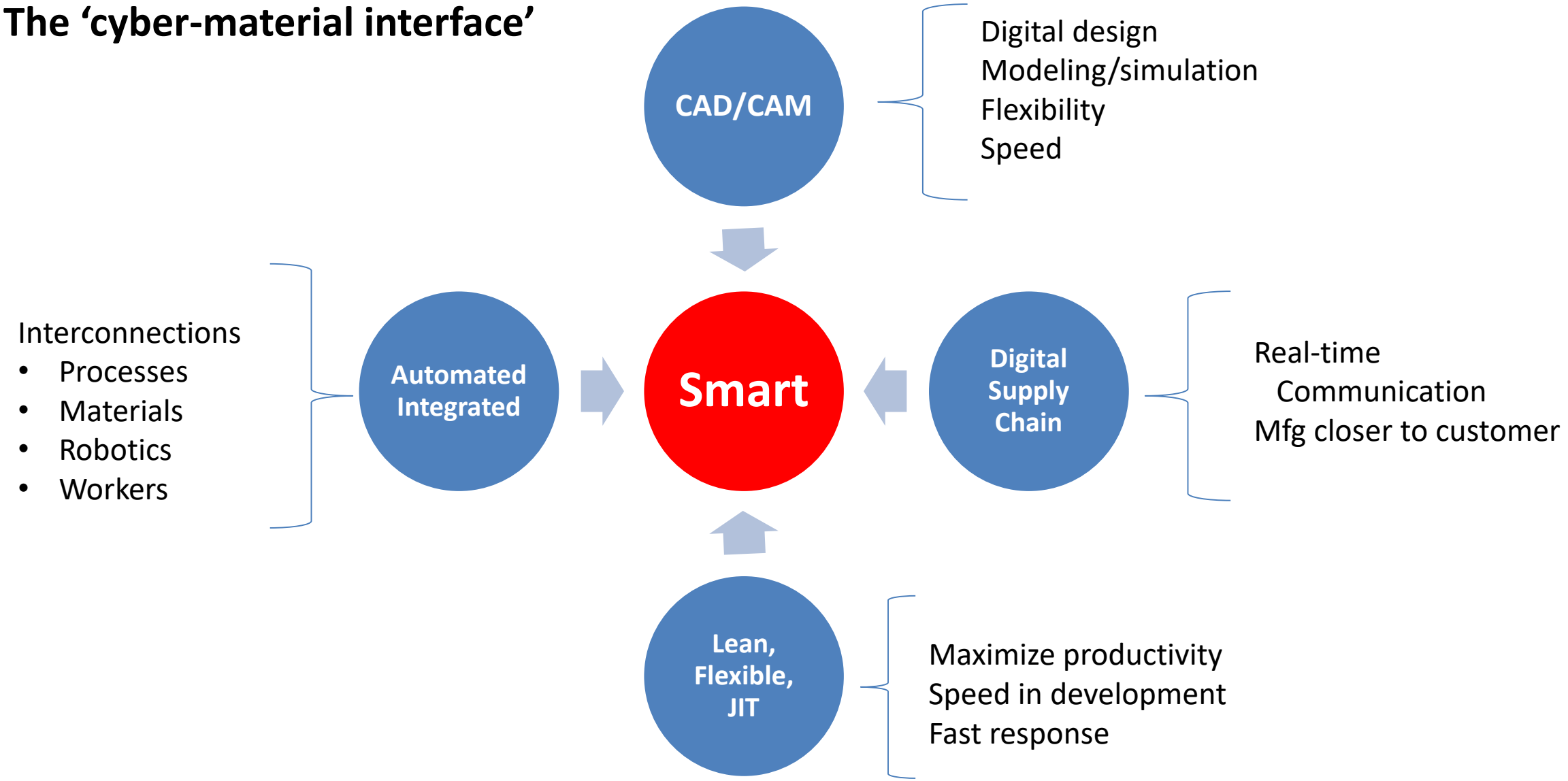
New ways of combining materials and controlling processes



Advanced materials used to make new or better products



The ‘cyber-material interface’



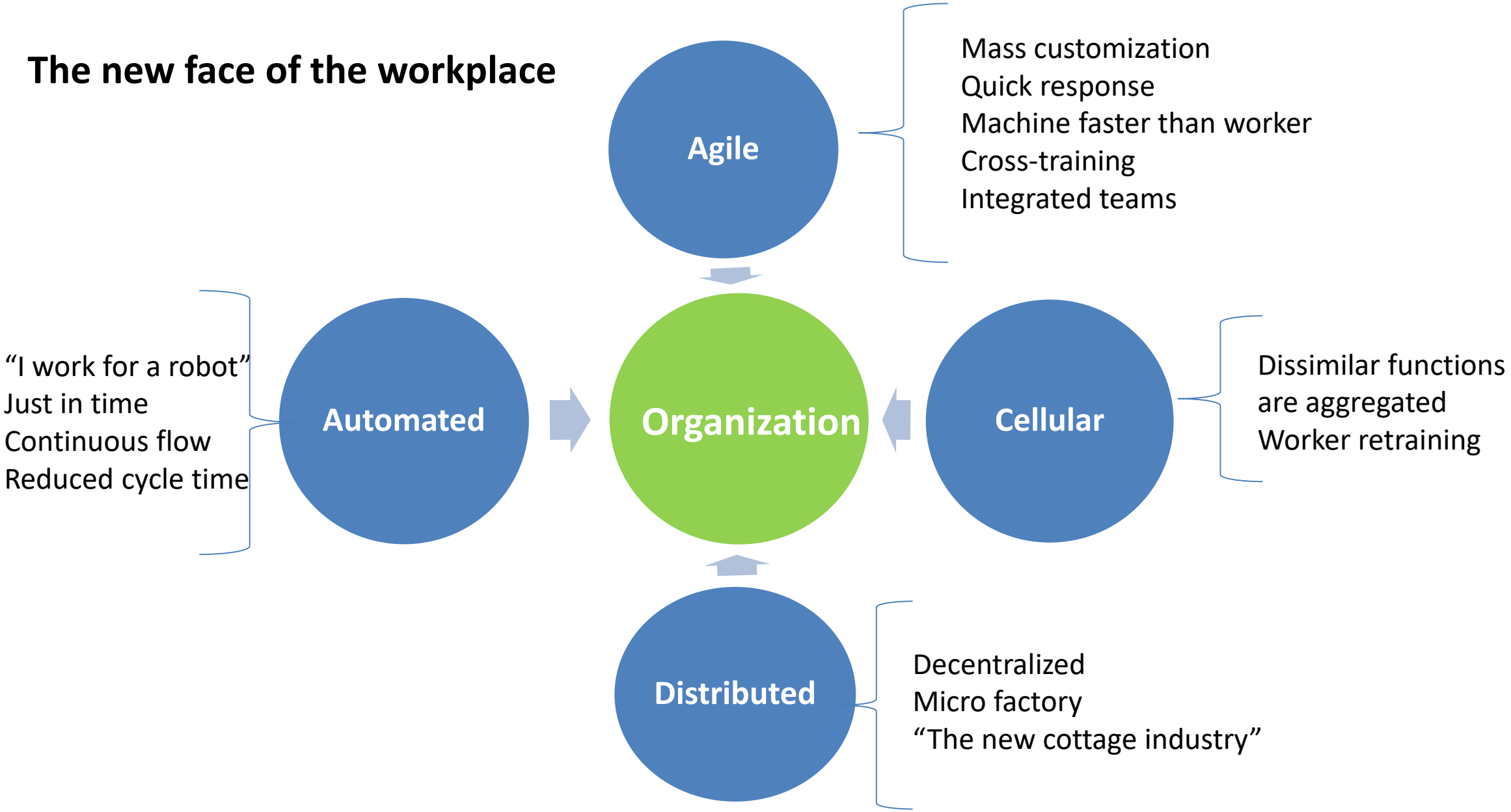
The Cyber-Physical Interface

- Multiple sensing events (thousands/second?) during production: process and environmental conditions.
- Digital interface with process: VR, AR, Collaboration
- Sensors for human performance, exposures, etc.

"You want data? You can't handle the data!".....can you?

Informatics as an EHS skill?

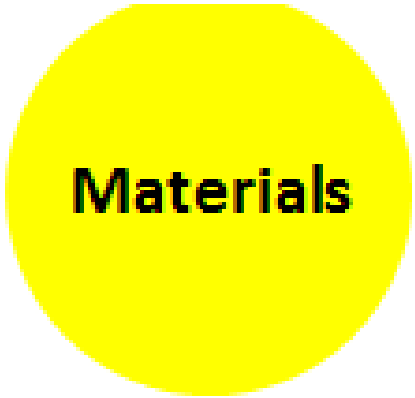
The new face of the workplace



The Big Shift: ‘Nano to Advanced”

Convergence, convergence, convergence

- Nano manufacturing: focus on commercialization (not new)
- Nano is mainstream and not always a separate theme
- Advanced Materials quickly displacing “Nanomaterial”
- Advanced Manufacturing seen as direct outlet for Nano
- Growth of Advanced Manufacturing
- Nanotech, Biotech, Emerging Tech, Manufacturing Tech



Converging US Initiatives

Nanotechnology: Nanomaterial Science

Brings us…

Advanced Materials

Nanomaterials, Nano-bio Functional materials, and more

Many Moving into…

Advanced Manufacturing Technology

Defining Advanced Material

Advanced Materials: all new materials and modifications to existing materials specifically engineered to have novel or enhanced properties for superior performance over conventional materials, critical for the application under consideration.

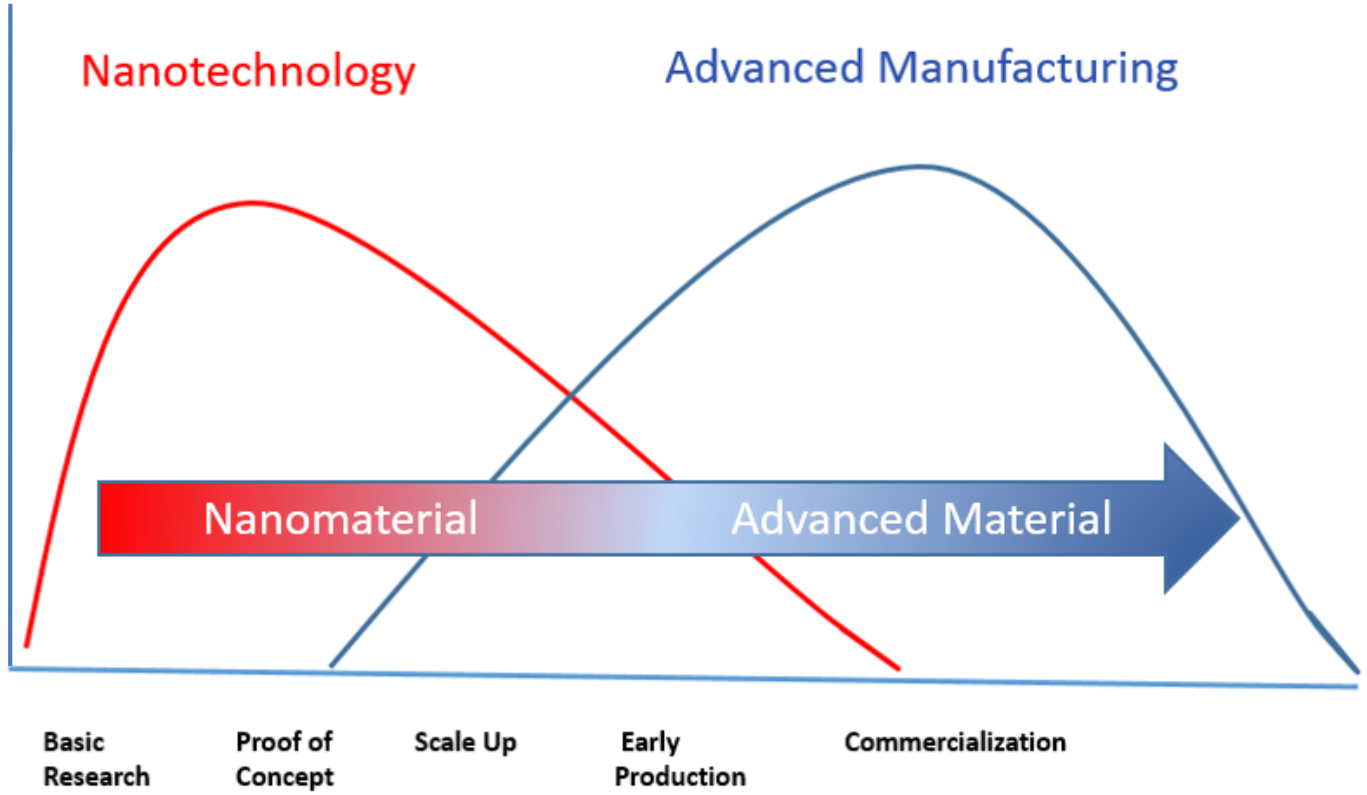
Nano (Advanced) Material

~~Advanced~~ Nano Materials refers to all new materials and modifications to existing materials that are specifically engineered in the 1 to 100 nm scale to have novel or enhanced properties that result in superior performance relative to their bulk counterparts that allow for novel applications ~~conventional materials~~, ~~that are critical for the application under consideration~~.

-Question-

Do the unique characteristics of Advanced Materials create an uncertain risk profile and the potential to adversely impact health, safety, and the environment?

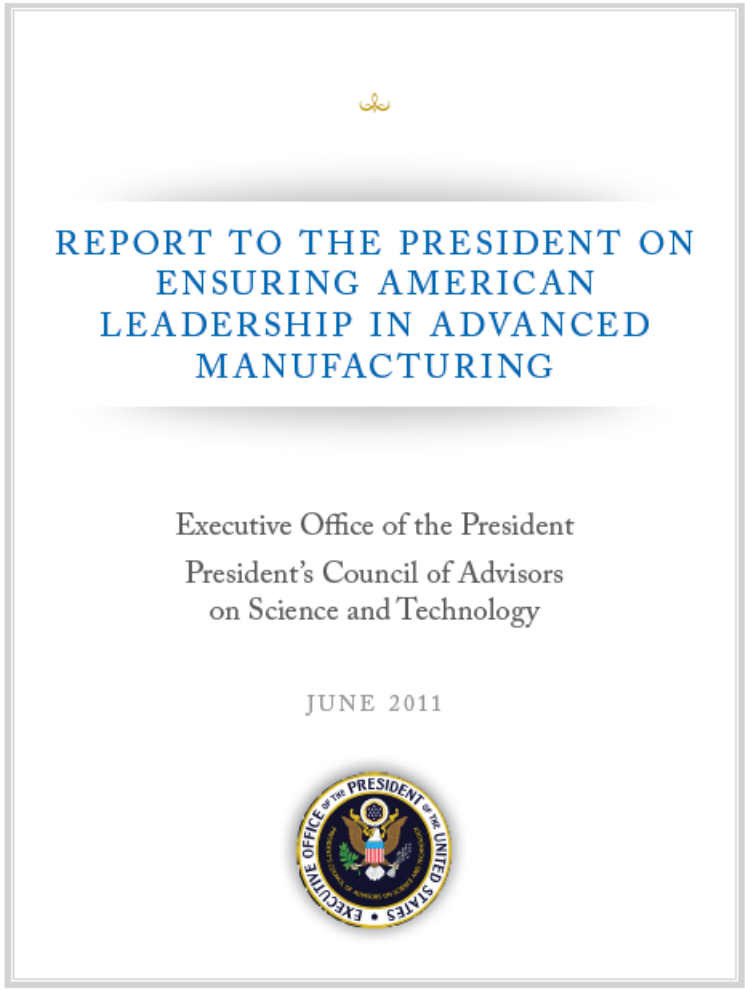
Evolution of Advanced Materials and Manufacturing



Material, Process, and Product Life Cycle

Advanced Manufacturing

- Additive manufacturing
  - 3D Printing, Rapid Prototyping, Layering and Deposition, Selective Laser Sintering
- Synthetic Biology
  - Manufacture biological substances from engineered biological systems
- Advanced materials
  - Nanoscale carbon materials
  - Nano-enabled medical diagnostic devices and therapeutics
- Next-generation optoelectronics
- Flexible electronics

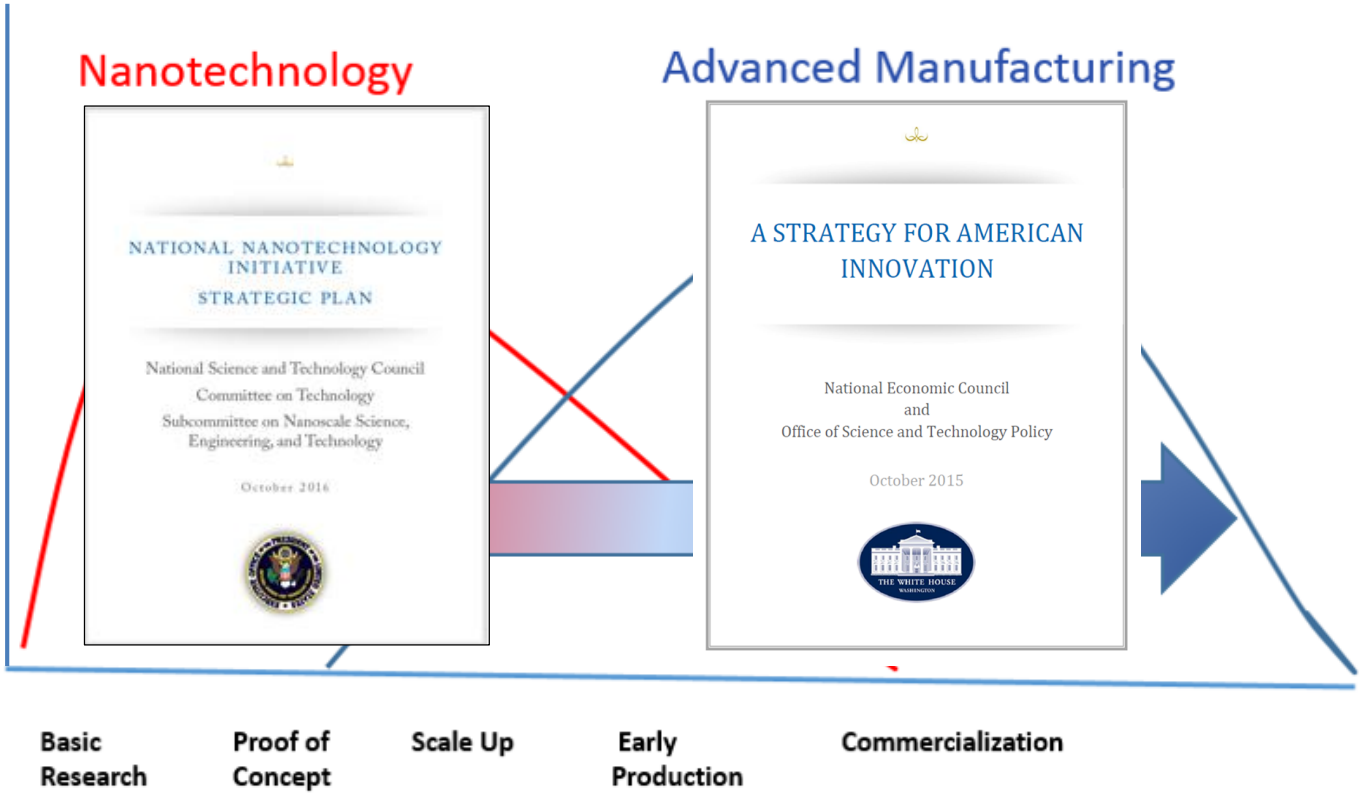

REPORT TO THE PRESIDENT ON ENSURING AMERICAN LEADERSHIP IN ADVANCED MANUFACTURING

Executive Office of the President
President's Council of Advisors on Science and Technology

JUNE 2011

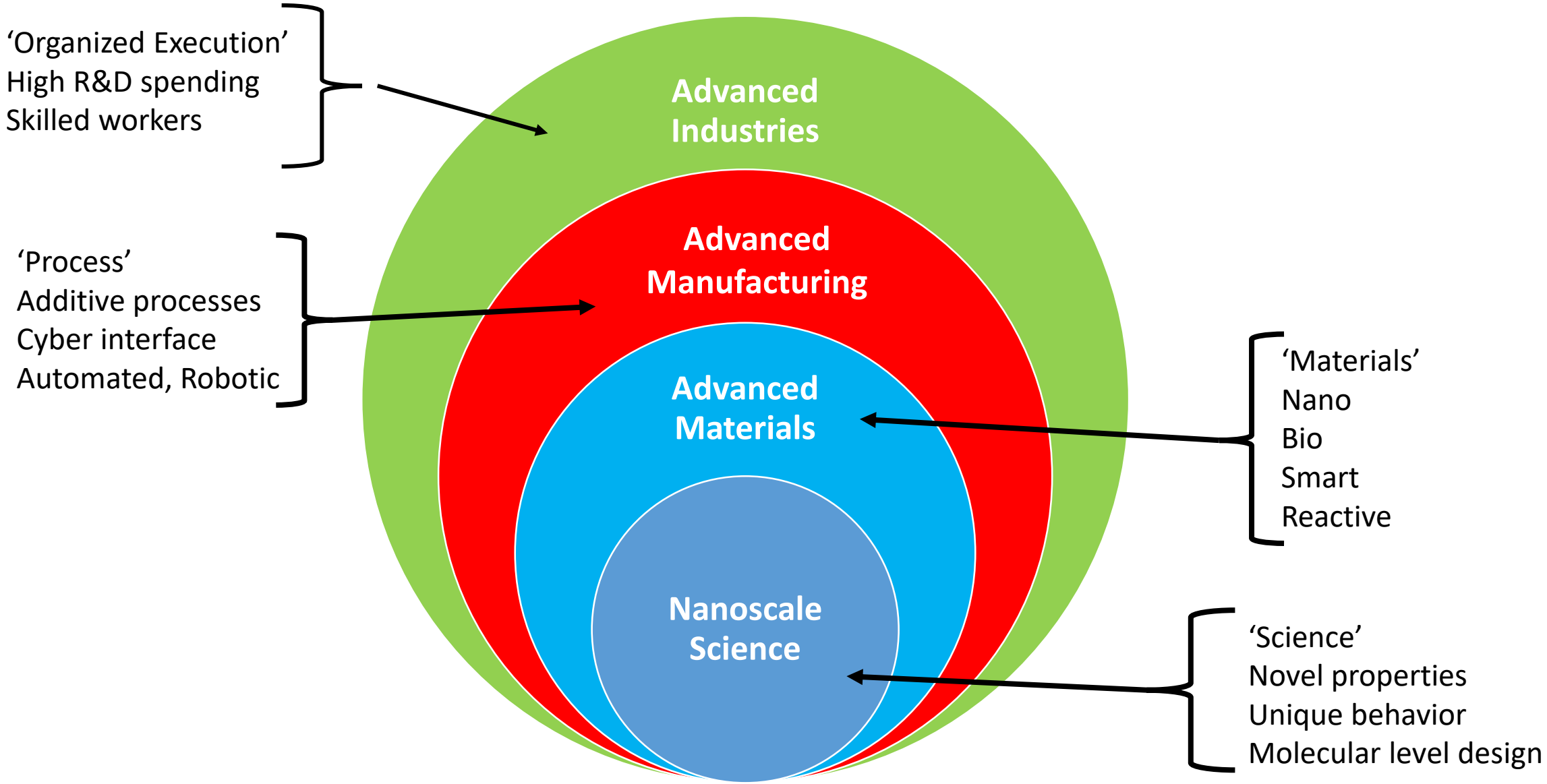
US Strategy to Promote Advanced Materials and Manufacturing

Overall Investment

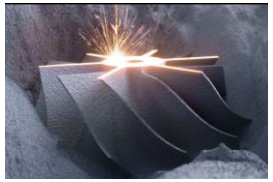


Material, Process, and Product Life Cycle

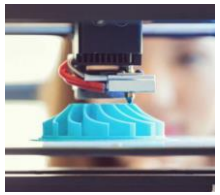
Advanced Industries, Manufacturing, and Materials



Processes & Products

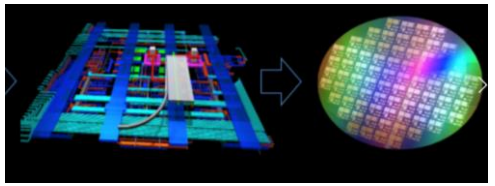


Additive Manufacturing



3D Printing

Functional Fabrics



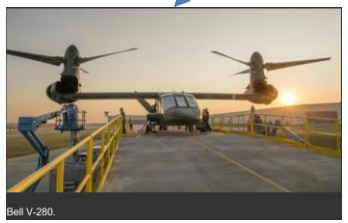
Photonics

Flexible Sensors

"Advanced Manufacturing"

Robotics

Light Weighting



Advanced Composites

Clean Energy

Engineered Biology

Some processes and some products.

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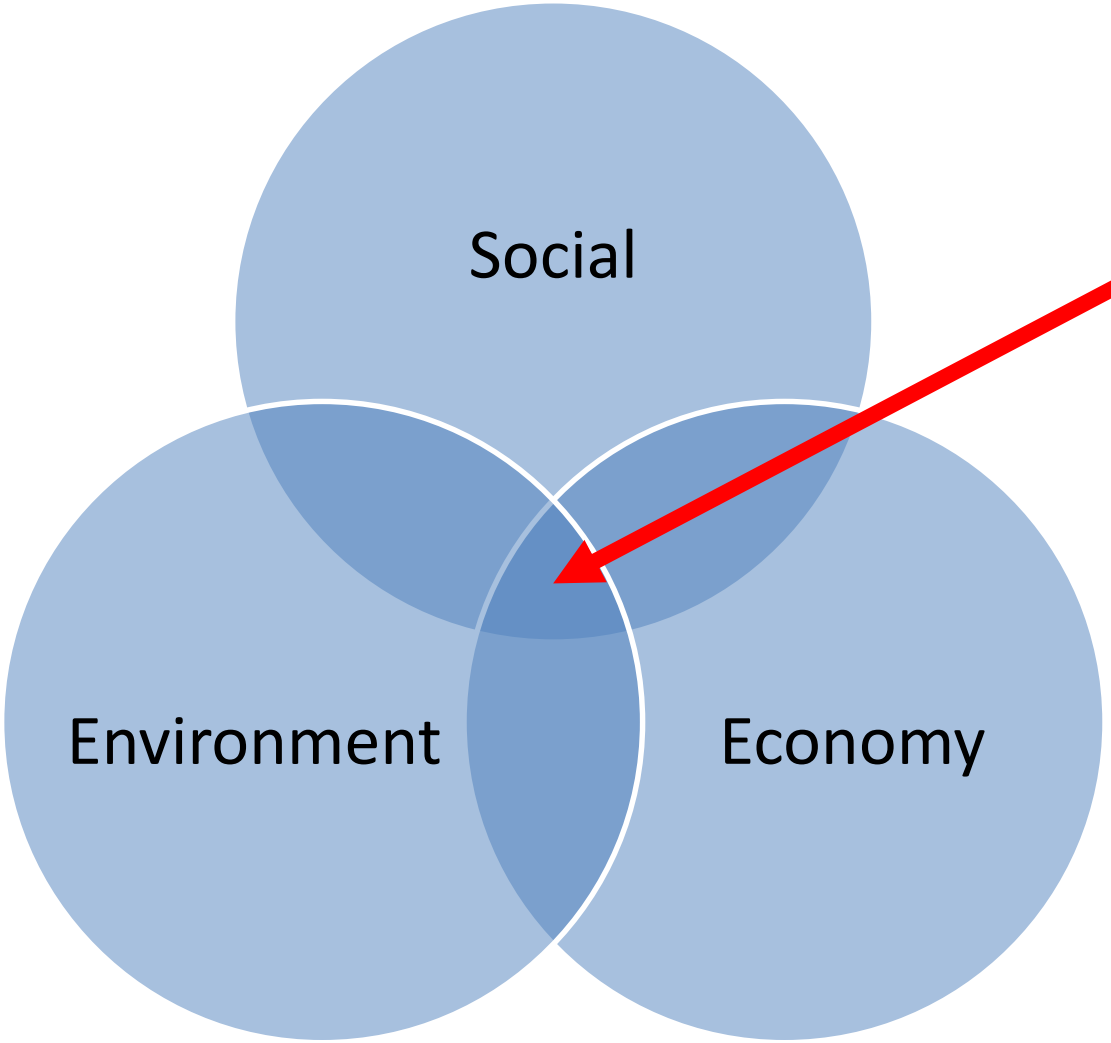
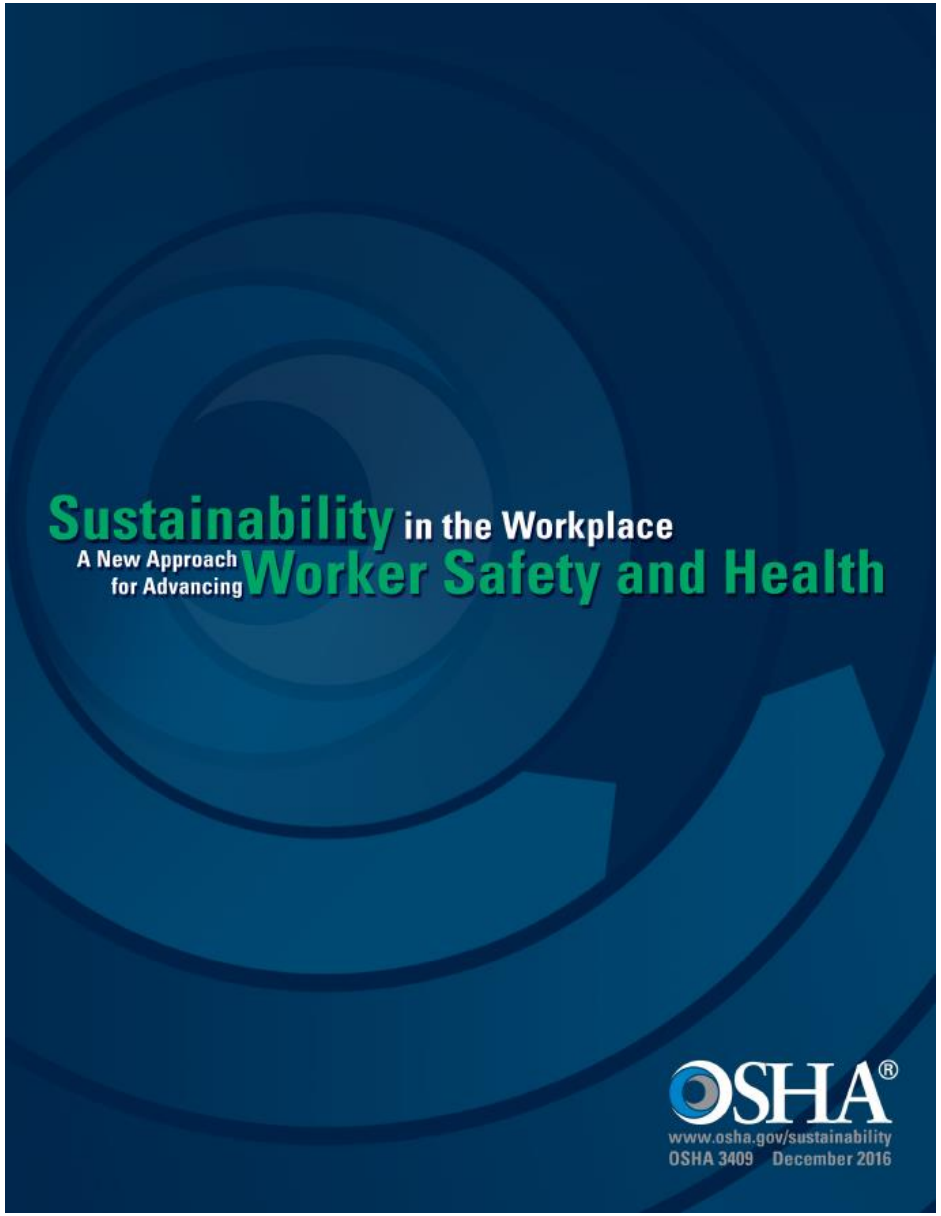


Sustainability

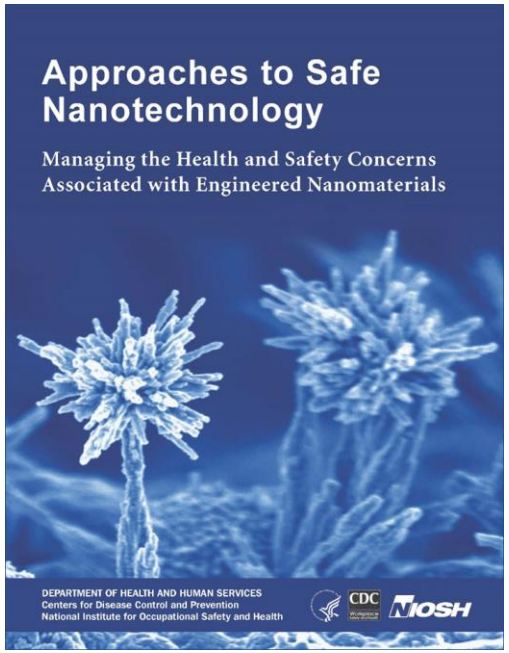
The Workplace is an important element the Social component.

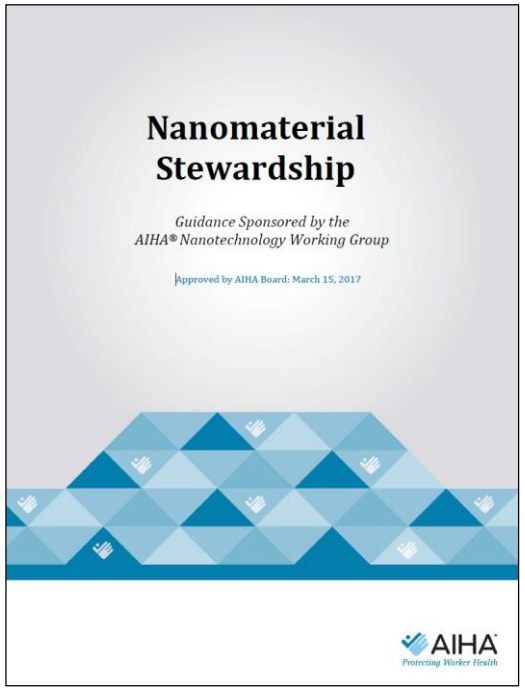


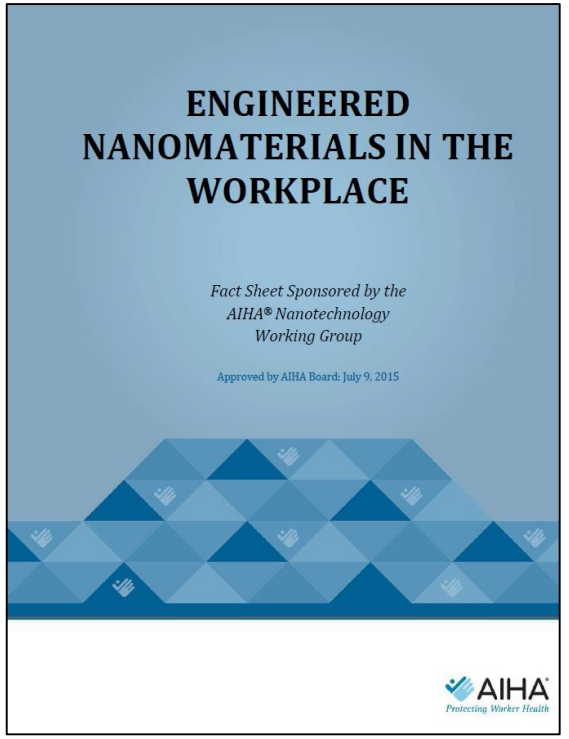
“Sustainability Starts in the Workplace”

- New Technologies are developed in the R&D Workplace
- First human interface
- First opportunity for safer design
- Human health hazard evaluated
- Control of emissions
- Design of safer processes and products

Recognition of the need for good OS&H practices







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OS&H as a ‘Sustainability Translator’

Nanotechnology

Research and guidance that supports responsible development.

Translation &
Reapplication

Advanced Materials and Manufacturing

Explore potential implications on worker health.

Guidance that supports rapid and responsible development.

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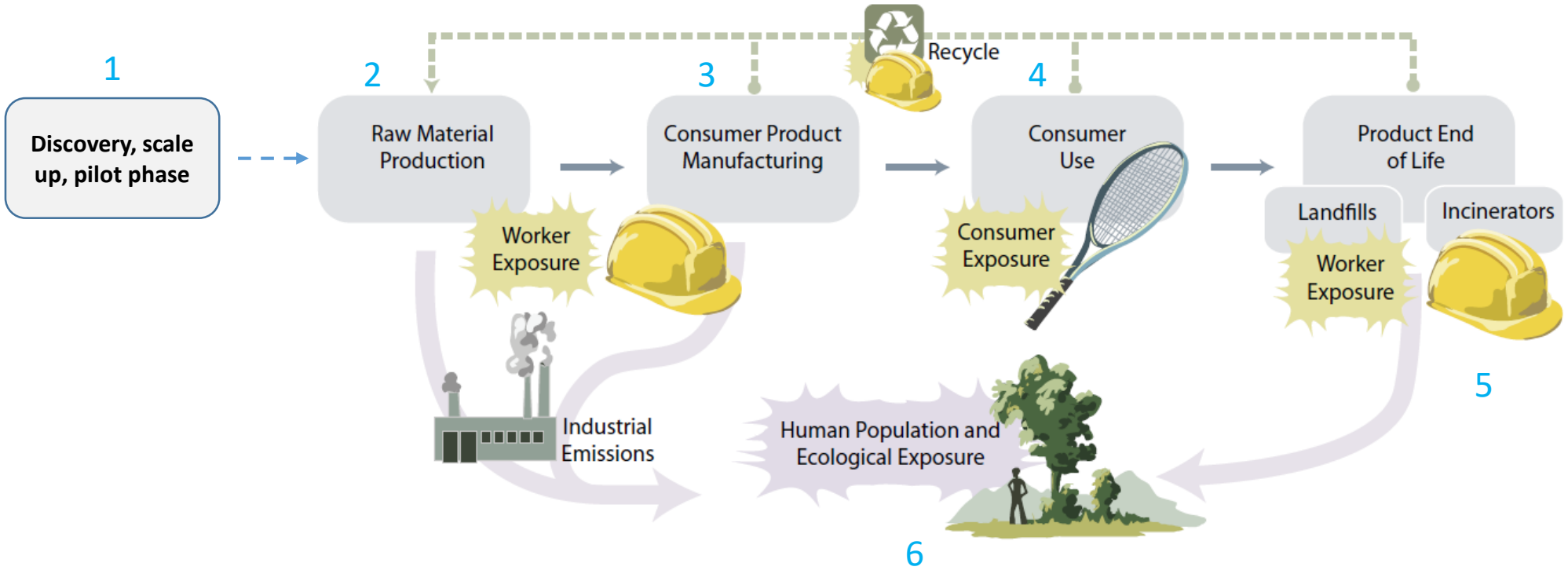
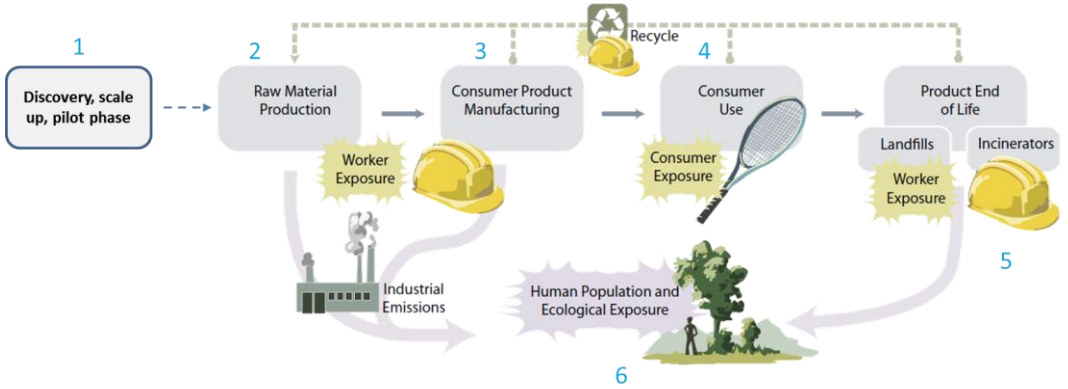
OS&H Activity and Collaborations along the Life Cycle



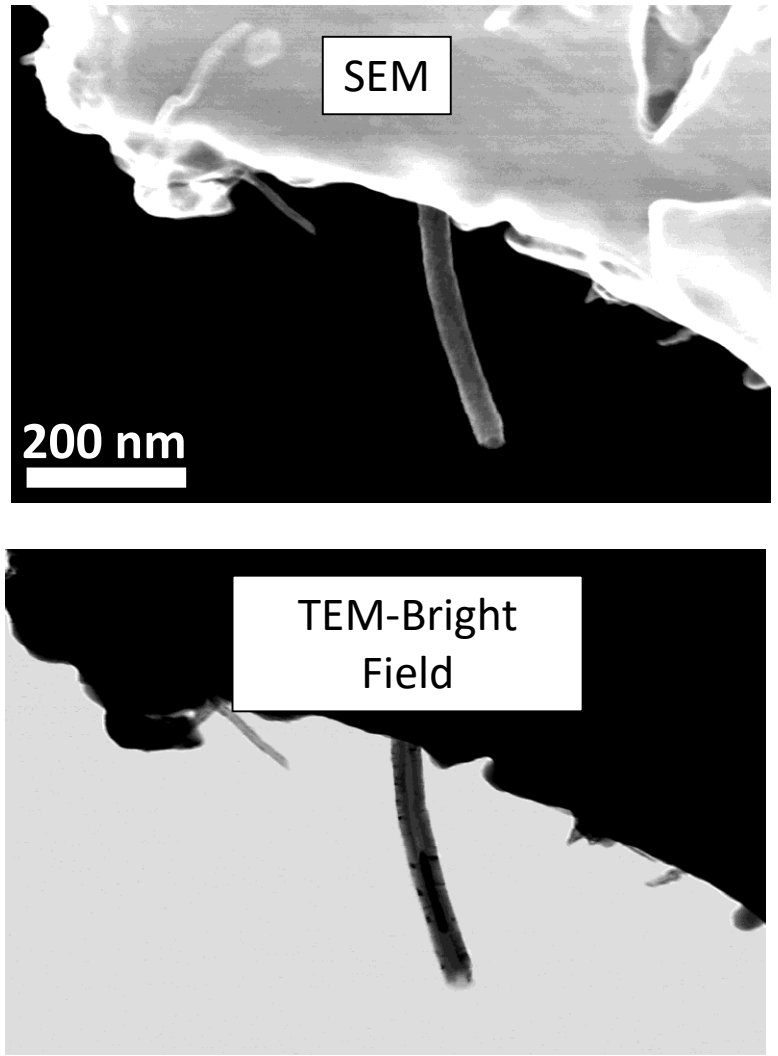
OS&H Research Activity and Collaborations along the Life Cycle



1. Evaluate toxicology of new ENM, develop hazard profiles, conduct dose-response risk assessment, evaluate lab safety and controls, metrology
2. Evaluate material handling, conduct exposure studies, evaluate practices
3. Reapply containment an control technologies, evaluate and mitigate exposures, worker health considerations
4. Share toxicology, exposure and risk assessment, metrology capability with partner agencies and stakeholders
5. Evaluate exposure and risk scenarios, controls
6. Share general knowledge from occupational setting

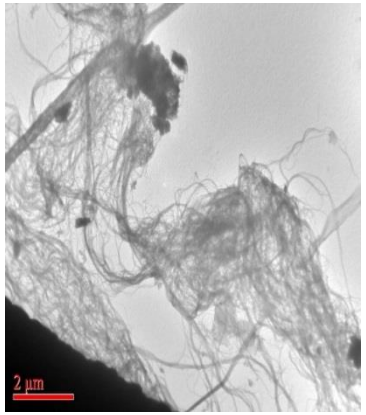
Occupational Life Cycle

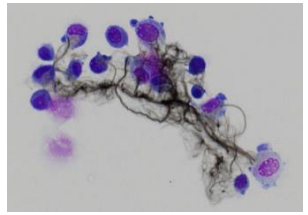
- As-produced MWCNT
- Post-coated MWCNT
- Composite



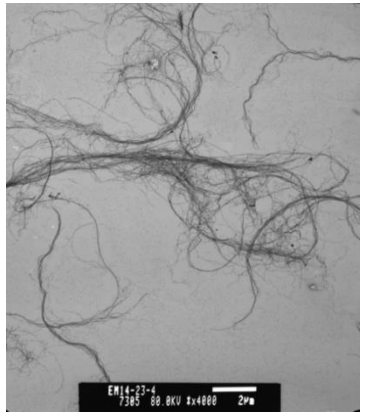
Hirt S et al., J Nanopart Res 15:1504, 2013

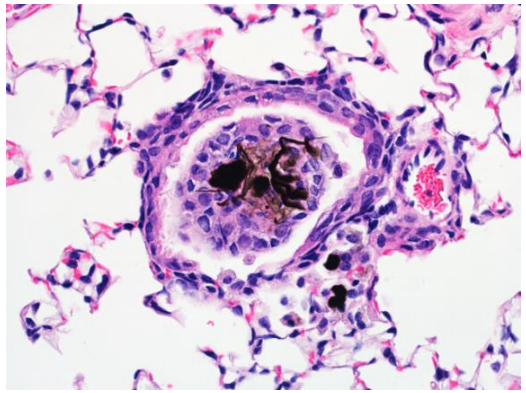
Personal Breathing Zone



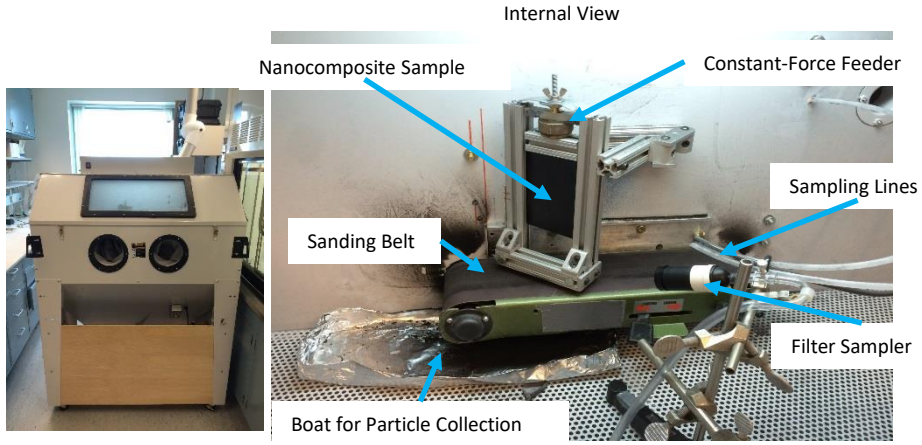


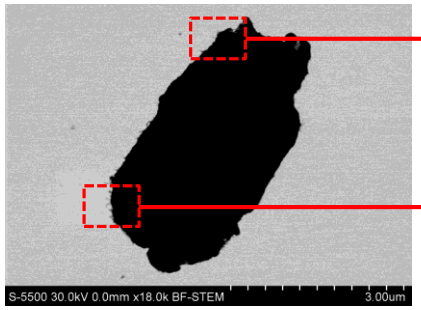
Prep for *in vivo*

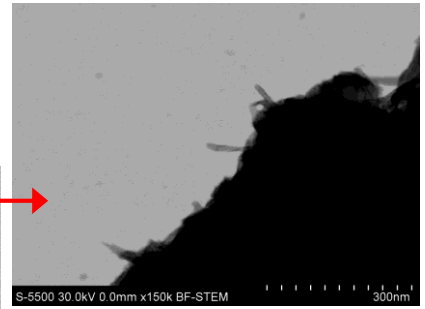


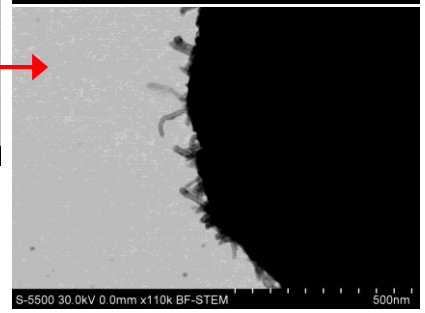


Industrial life cycle scenarios









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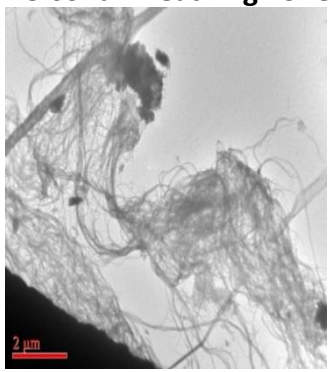
Example Occupational Life Cycle

As-produced MWCNT

Post-coated MWCNT

Composite

Personal Breathing Zone



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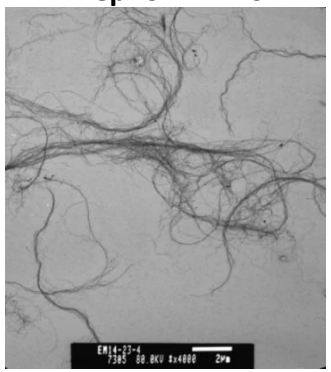
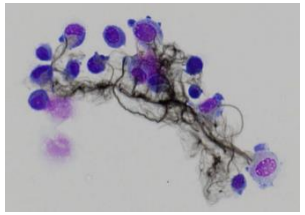
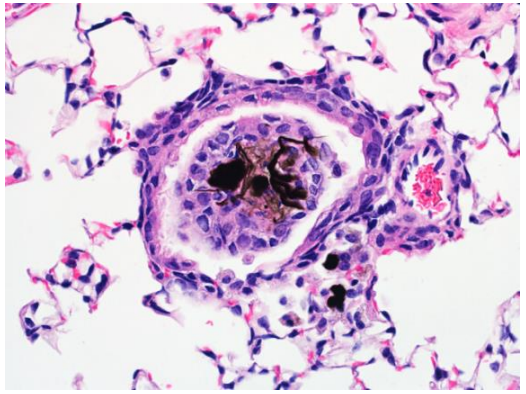
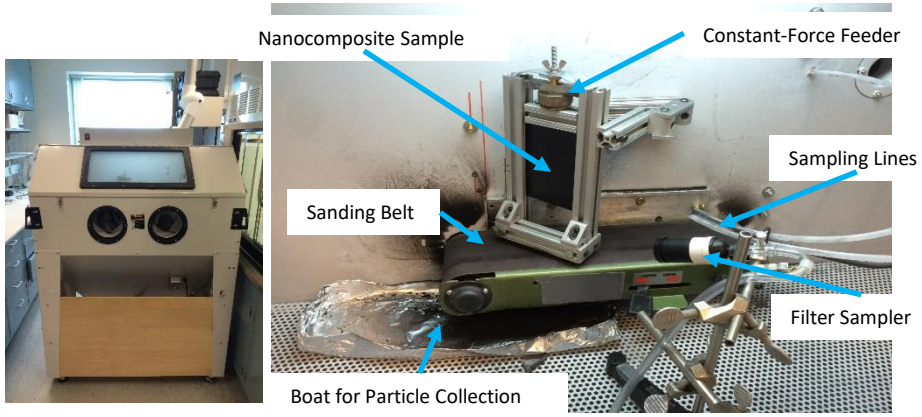
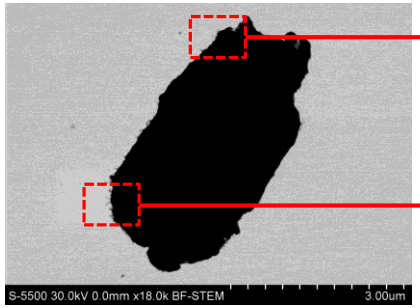


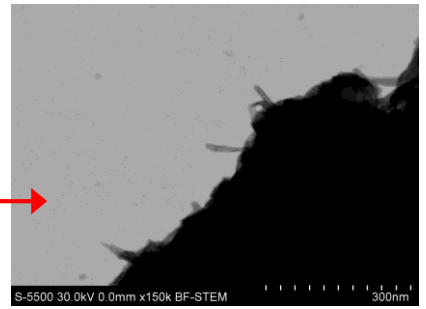


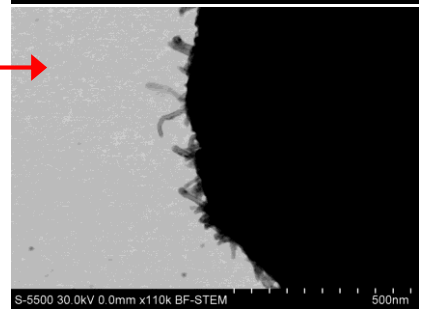


Internal View









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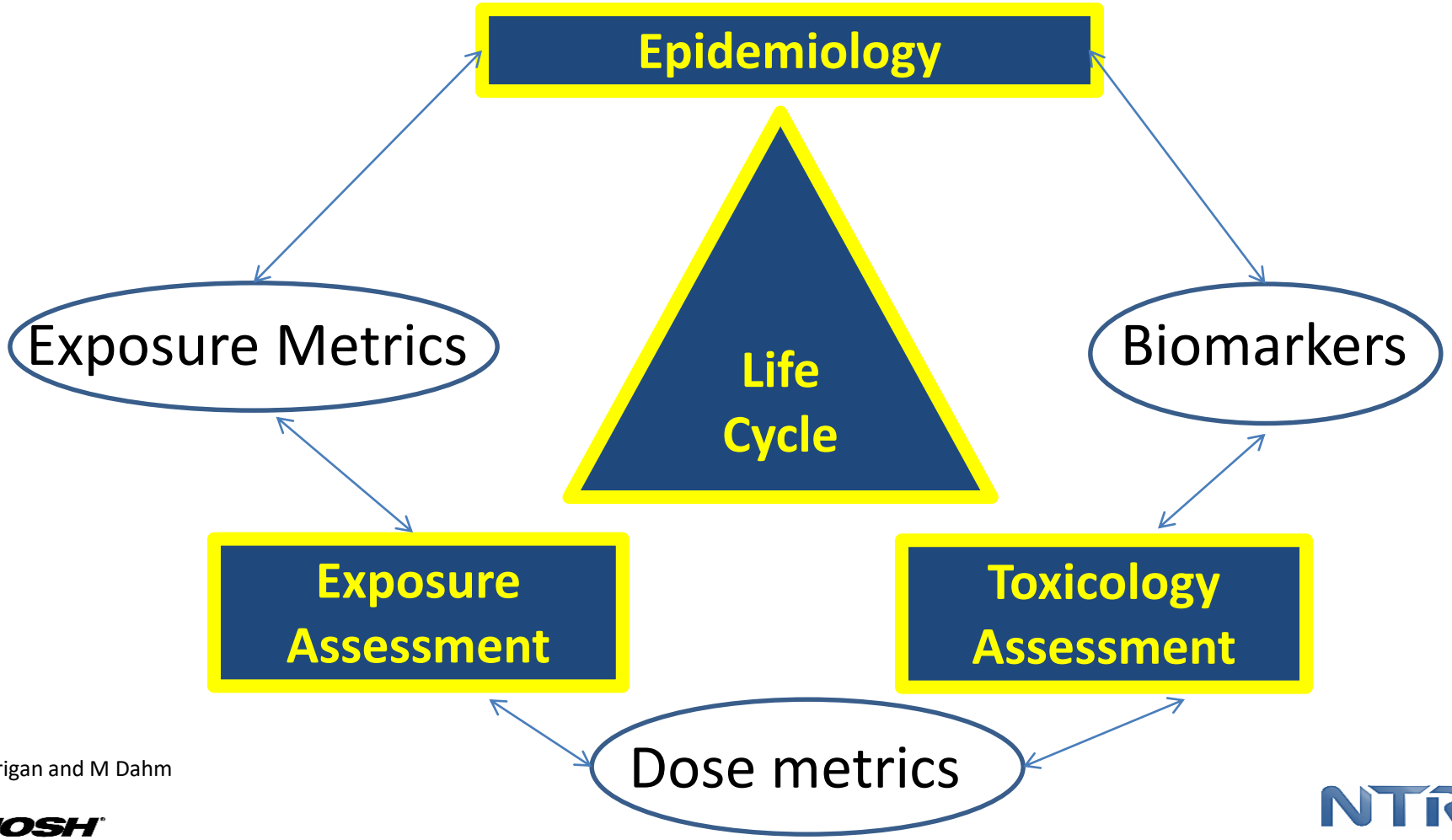
Connecting the Key Exposure Assessment Elements



Courtesy of M Schubauer-Berigan and M Dahm

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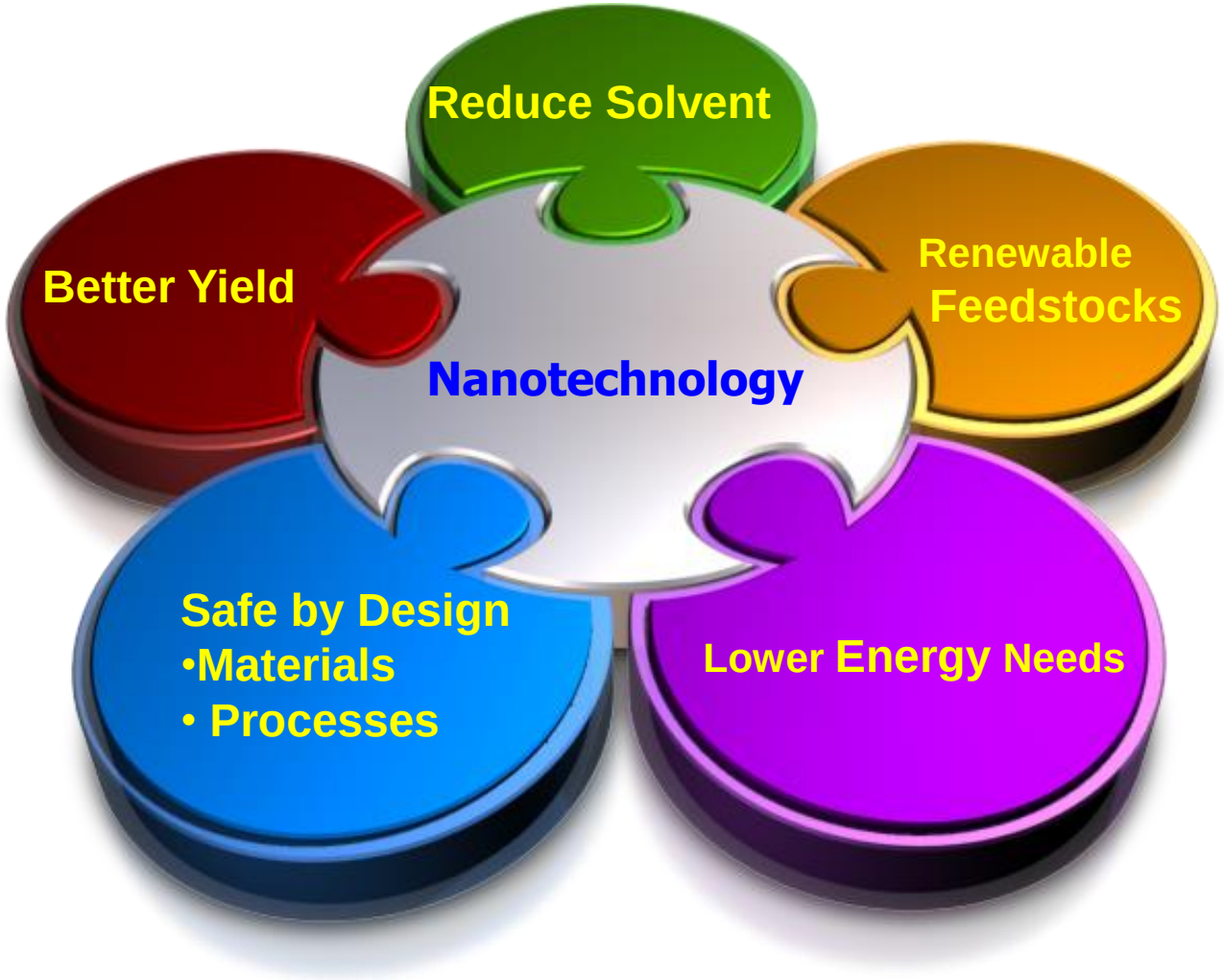
Green Chemistry Opportunities for Nanotechnology



Nanotechnology: 'Green Impact' on Industry

Agriculture	More efficient, targeted delivery of plant nutrients, pesticides. Newer application techniques and tools
Automotive	Lighter, stronger, self-healing materials: Manufacture and assembly of nano-enabled components
Biomedical	Targeted therapeutics, enhanced detection, new structural materials. Accelerated growth in biologicals and SynBio
Energy	More efficient fuel cells, solar collectors, generation, transmission and storage. Insulation
Environmental	New pollution control and remediation tools, sensors
Food	New safety sensors, food preservatives, nutrient additives
Materials	Self-cleaning glass, stain resistant, stronger materials, body armor, construction
Water	New purification approaches: filtration, treatment

Organized approach in the US

Manufacturing USA℠

Quick case study

Tissue Fabrication

Functional Fabrics

Integrated Photonics

Additive Manufacturing

Advanced Robotics

Digital Manufacturing

Advanced Composites

Lightweight Manufacturing

Flexible Hybrid Electronics

Manufacturing Biopharmaceuticals

SiC and GaN Semiconductors

Molecular Level Process Maximization

Sustainable Manufacturing

Smart Sensors Digital Processes

What is additive manufacturing/3D printing?

Joining materials to make objects from 3D model data, usually layer upon layer (ISO/ASTM 52900:2015….Formerly ASTM F2792).

Subtractive Manufacturing

- Photo: Fabricatingandmetalworking.com

Additive Manufacturing

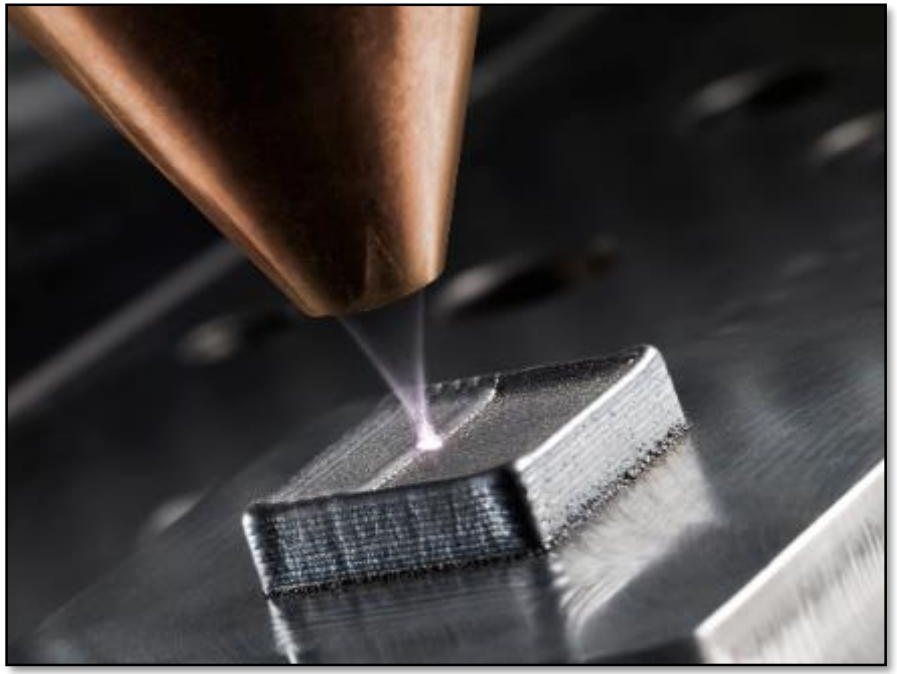
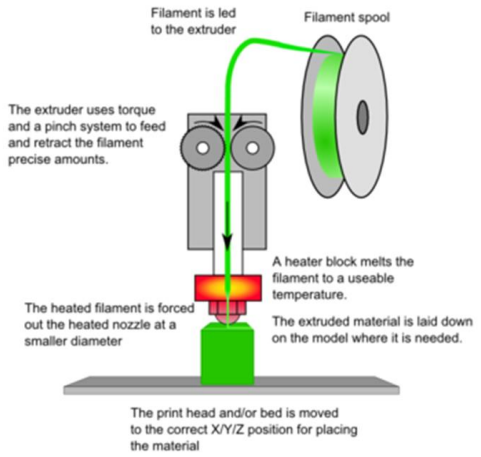


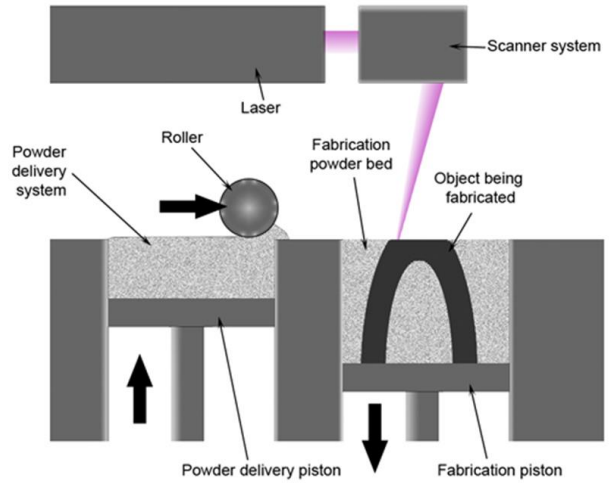
Photo: Canadianmetalworking.com

Four Basic Categories of Additive Manufacturing

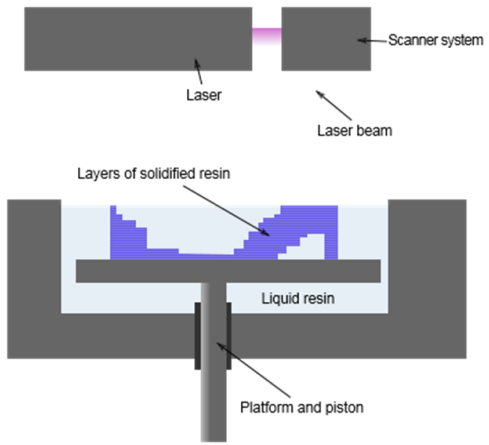
Fused Filament Fabrication (FFF)



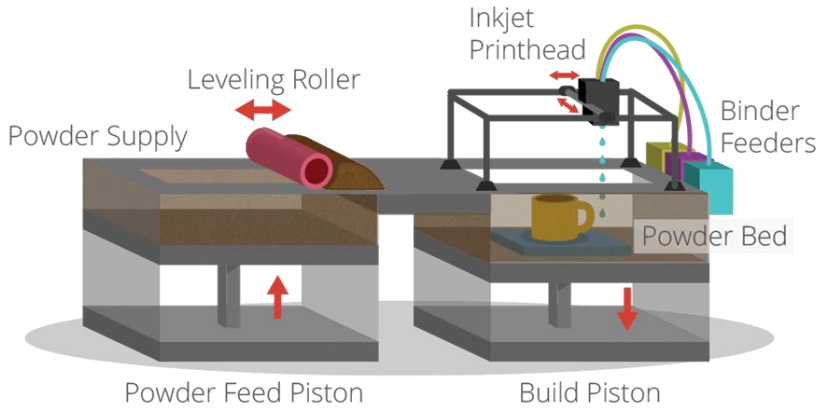
Selective Laser Sintering (SLS)



Stereolithography



Powder Bed Inkjet Binding



CDC Workplace Safety and Health NIOSH

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Fused Filament Fabrication

Operation:

1. Thermoplastic heated in print head.
2. Print head scans platform, deposits plastic.
3. Thermoplastic cools and solidifies.
4. Platform lowers or print head raises. Subsequent layers add height.

Key Aspects:

- Inexpensive (< $1,000)
- Poor resolution
- Thermoplastics only; additives (including nanomaterials) are being explored
- Most common consumer 3D printing technology

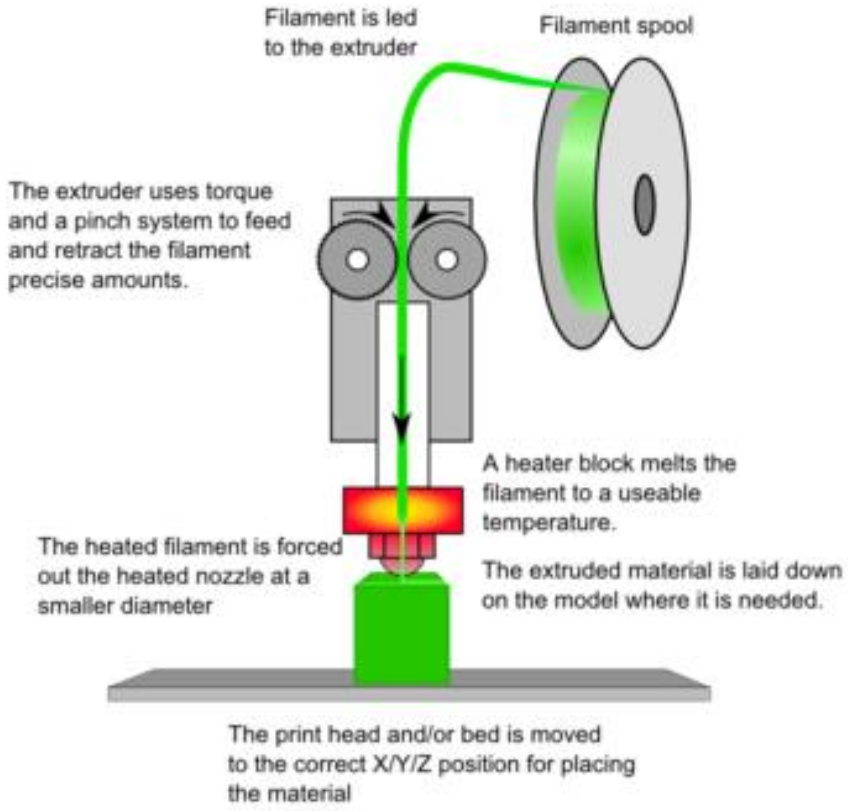


Image source: Spiritdude, 2012.

Selective Laser Sintering

Operation:

1. Chamber filled with N_2, temperature raised.
2. Powder rolled across platform.
3. High-power laser scans platform, bonding particles.
4. Elevator lowers. Steps 1 & 2 repeated to add subsequent layers.
5. Excess powder can be reclaimed & reused.

Key Aspects:

- Extremely expensive (> $1,000,000)
- High resolution (sub-micron)
- Materials-flexible (metal, plastic, ceramic)
- Most venerable metal-printing method

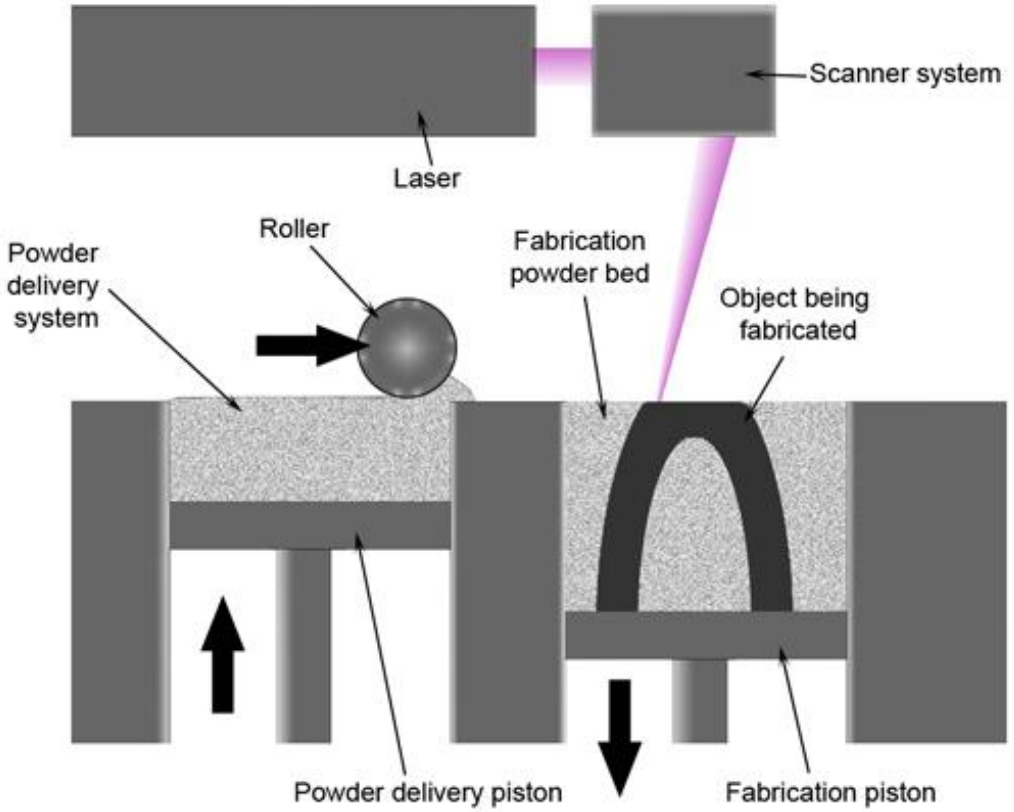


Image source: Materialgeeza, 2008.

Stereolithography

Operation:

1. Photopolymer resin added into chamber. Elevator platform raised just below surface.
2. UV Laser scans surface, curing exposed resin.
3. Elevator lowers, allowing successive layers.
4. Final product removed for additional post-curing. Remaining resin can be reclaimed.

Key Aspects:

- Photopolymers only
- Usually single material
- Strength inconsistent
- High resolution

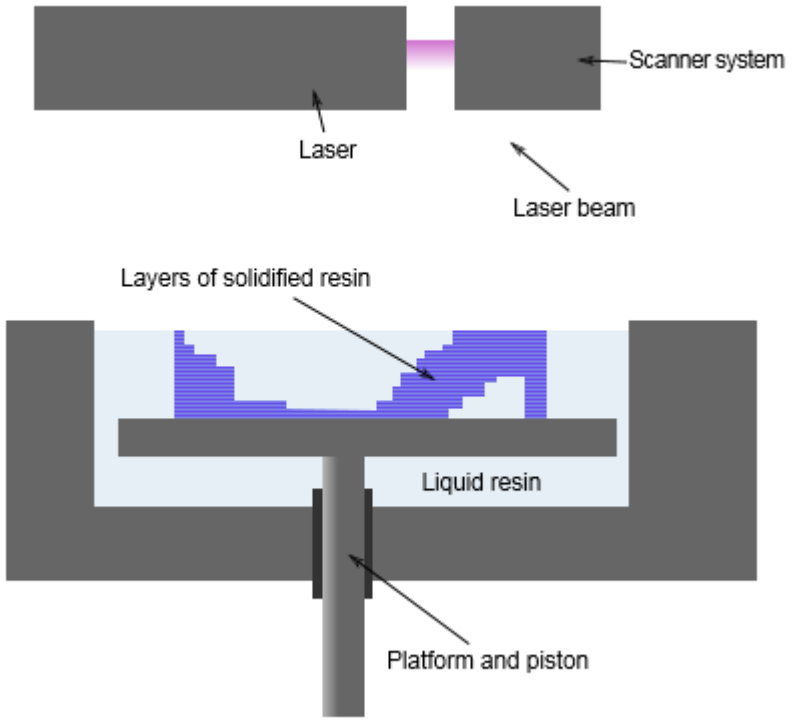


Image source: Materialgeeza, 2008.

Powder Bed Inkjet Printing

Operation:

1. A platform is covered in powder by a roller.
2. A print head scans the surface, depositing a binder in a selected pattern to solidify areas.
3. The chamber lowers, allowing the deposition of addition powder and solidifying successive layers.

Key Aspects:

- Extremely high throughput
- Amenable to differing materials
- Inexpensive
- Low-strength products

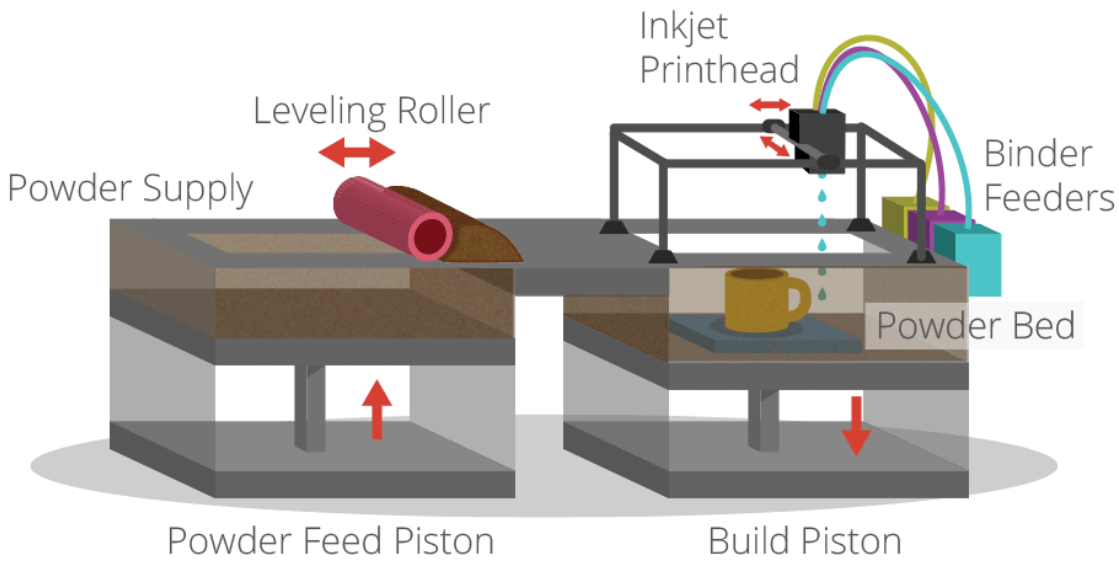
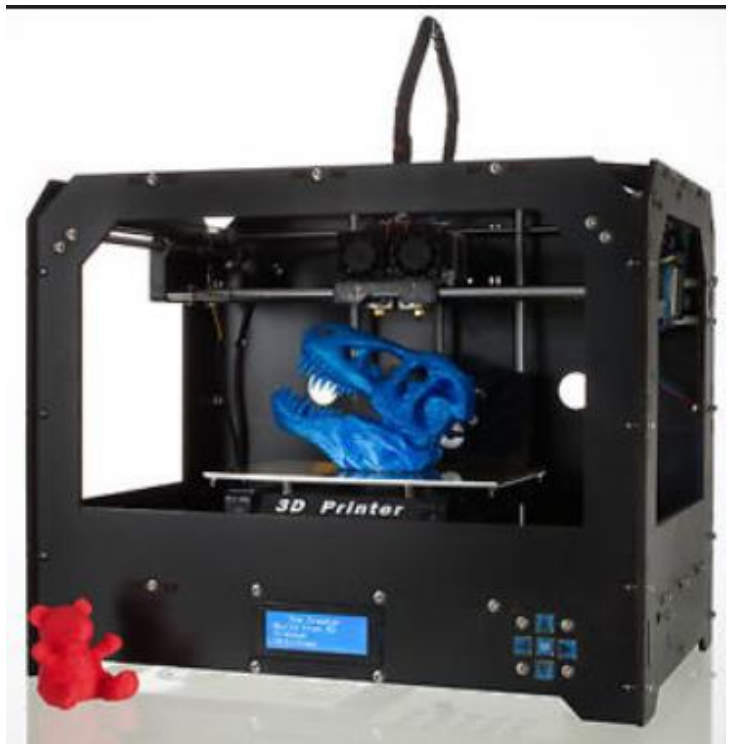


Image source: 3DPI's Beginner's Guide to 3D Printing, 2013.

Desktop 3D Printing



- Readily available
- Multiple polymer strands available
- Custom ‘at home’ strand compounding
- Prices dropping, units getting larger

This is also a 3D Printer

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Is this a ‘3D Printer’?
Sorry, this is Additive Manufacturing

Building envelope: 800 x 400 x 500 mm^3 (x,y,z)

(a 6 cu ft build volume)

Laser system: Fibre laser 2 x 1 kW (cw)

Hundreds of pounds of metal powder per charge.

Metal and Metal Alloy blends vary based on application

Rethink risk management?

- EHS, Security, Response Issues
- Uses pure (pyrophoric) Aluminum
- Up to 400 lb per charge
- Warehouse feedstock for 10 charges
- Emission, exposure, waste

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More than simple parts or prototypes

Above: The 3D printed nozzle combined all 20 parts into a single unit, but it also weighed 25 percent less. "In the design of jet engines, complexity used to be expensive," Ehteshami says. But additive allows you to get sophisticated and reduces costs at the same time. This is an engineer's dream." Image credit: Adam Senatori for GE Reports

The Blade Supercar

Modern Manufacturing

- Photo credit: 3dprintingindustry.com

Possible Hazards of Additive Manufacturing

Safety

- Lasers
- Radiation (Electron beams)
- Asphyxiation
- Heat & Burns
- Explosions

Health

- Metals
- Organics
- Particulate
- Nanomaterials
- Noise

Materials of Interest (not exhaustive)

Polymers

- Acrylonitrile-butadiene-styrene
- Polylactic acid
- Propylene fumarate
- Poly(vinyl alcohol)
- Polycarbonate
- Polyethylene
- Polystyrene

Solvents

- Dimethyl fumarate
- Isopropanol
- Acetone
- Methyl Ethyl Ketone
- 2-Butanone

Metals

- Ti-6Al-4V
- IN 625 & IN 718 (Ni, Cr)
- 17-4 PH stainless steel
- Cobalt chromium

Nanomaterials

- nFe (steel sintering)
- nAg (sintering, conductivity)
- nCB, CNT (conductivity, stiffness, tensile strength)
- $nSiO_x$ (polymer strength)

Preliminary exposure-related studies

- Nanoparticles above background levels detected in vicinity of several commercially available, desktop, 3D printers while printing ABS and PLA (Stephens et al. 2013)
- Five FFF printers with several different feedstocks all generated detectable nanoparticle and VOC emissions, varying with different printer and feedstock (Azimi *et al.*, 2015)
- Another study verified FFF was found to generate nanoparticles of the deposition material and create detectable VOCs (Kim *et al.*, 2015)
- Filament selection (Yi et al. 2016) and temperature (Stabile et al., 2016) significantly affect the size and concentration of particle emissions.
- Few studies of non-FFF techniques

Product, Culture, Workplace

Different Business Models, Sizes, & Uses

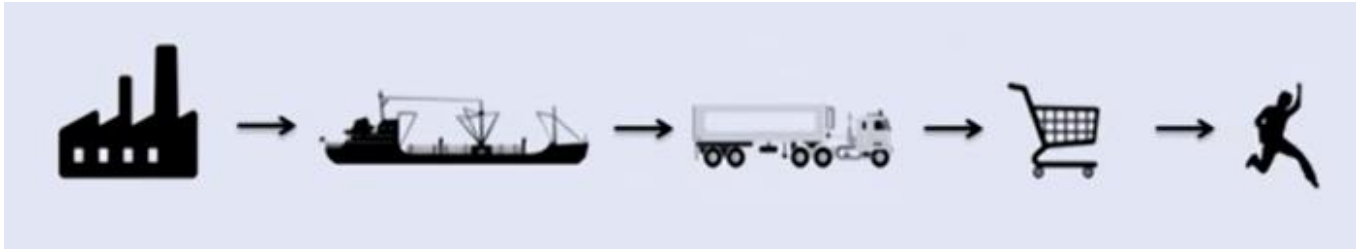
- Primary Production
- Prototyping
- Just-in-Time Production
- Service Bureaus
- Small Business

Different answers to critical questions…

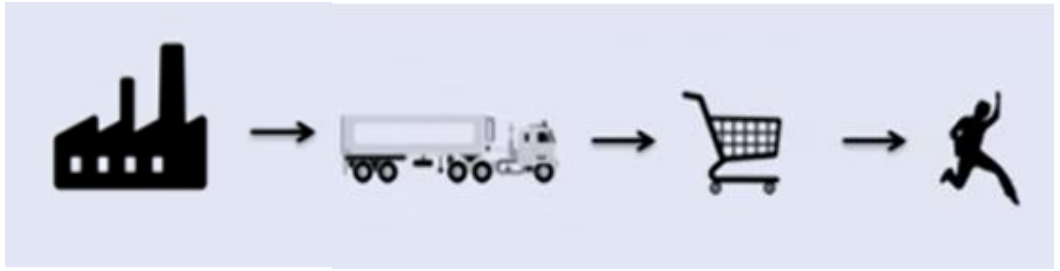
- Typical worker education?
- Pace of process/material change?
- Transfer of materials & products?
- Flow of information?
- Dedicated OSH expertise?

Impact of 3D Printing on the Supply Chain

Production Consumption



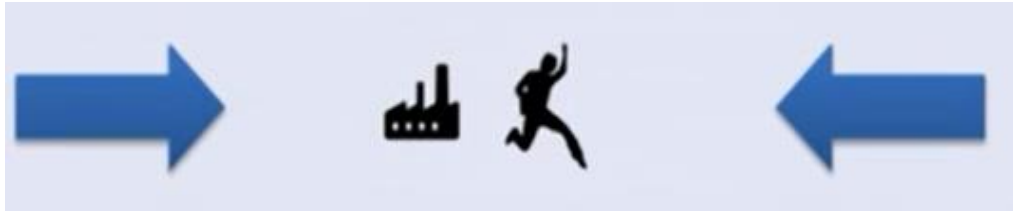
Old Model



Evolving Model

Cottage, Close to Home, Custom Made, Maker Spaces

3D Printing is accelerating this model

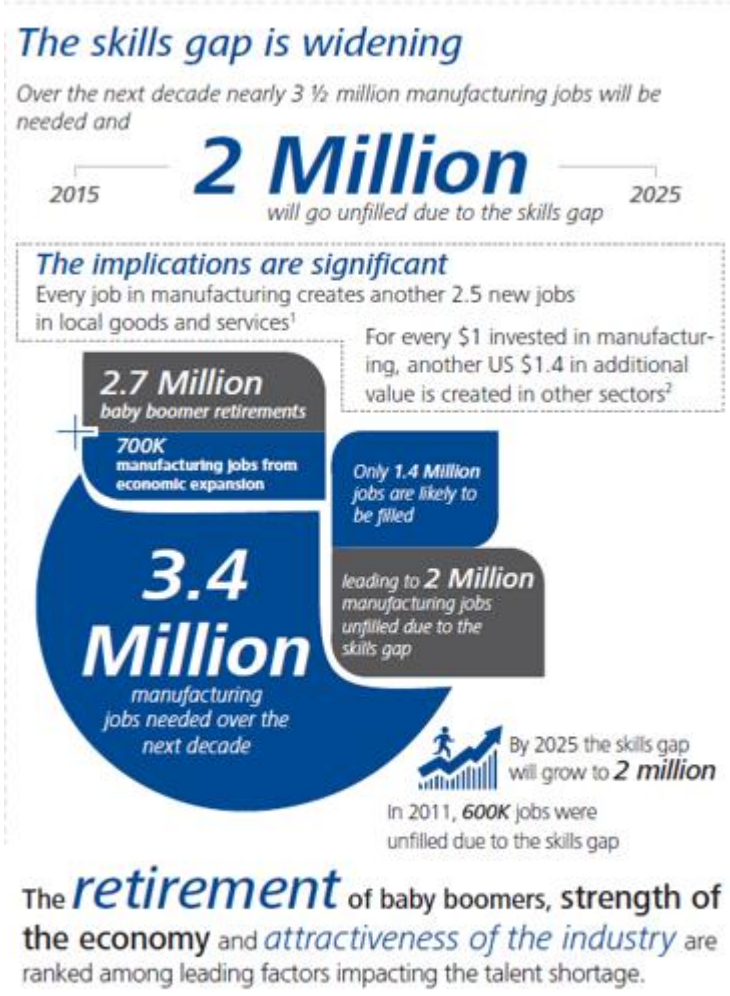


Manufacturer as Consumer
Consumer as Manufacturer

Summary of Additive Manufacturing

- Will impact many market sectors
- Many different materials and process categories
- Each material and process poses distinct hazards
- More data needed on hazards, exposures, controls

Over the next decade nearly **3 1/2 Million** manufacturing jobs need to be filled
The skills gap will result in **2 Million** of those jobs being unfilled



Will health, safety, and sustainability be part of workforce development?

Deloitte. Institute

NIOSH

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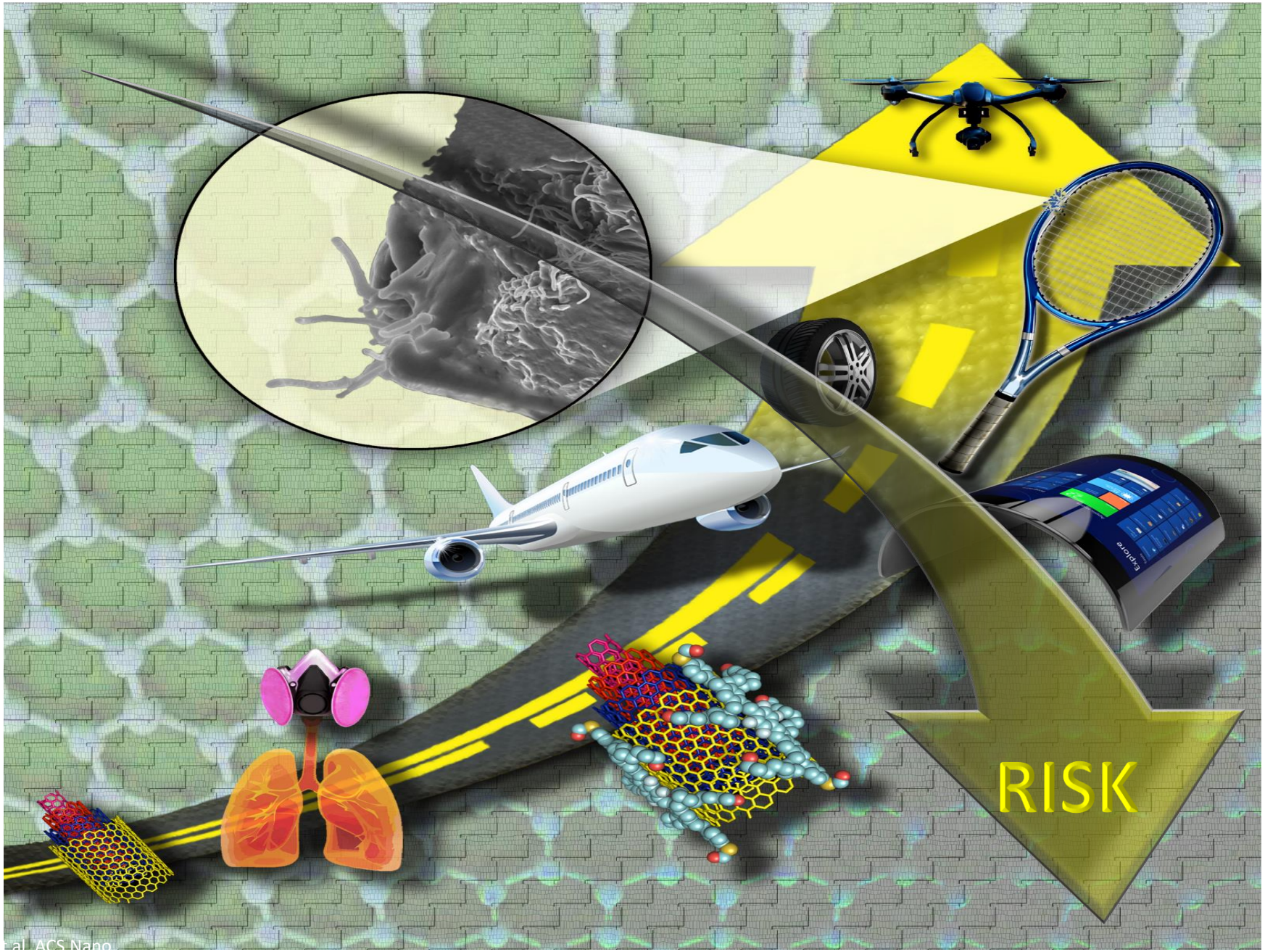
Advances in Nanotechnology and Manufacturing feel like this…..

Work on Sustainability should not feel like this!



EHS

- Support growth
- Help minimize risk

Thank You!

cgeraci@cdc.gov