Moving from Nanotechnology to Advanced Manufacturing
An Opportunity for Sustainable Growth

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Charles L. Geraci, Jr. PhD, CIH, FAIHA
Associate Director, Nanotechnology and Advanced Materials
National Institute for Occupational Safety and Health
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/
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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

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

Value of 13% of GDP.

This is big, but looks only at value of finished goods.
Total Manufacturing Value is Even Bigger

The Total Manufacturing Value Chain is $5.5 Trillion

- $2.6 Trillion Downstream Supply Chains
- $2.4 Trillion Upstream Supply Chains
- $0.5 Trillion Sales to Nonmanufacturing Supply Chains

Total Value Chain is 30% of GDP (Based on $18 Trillion)

Sources: MAPI Foundation and INFORUM
“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)

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

- Processes
- Advanced Manufacturing
- Materials
- Organization
- Smart
New ways of combining materials and controlling processes
Advanced materials used to make new or better products

Nano

Major outputs of the NNI
- CNT/CNF
- Metals
- Nanowires
- Quantum Dots
- Many more

Composites

Strength/weight
Conductive
Memory
Biological
Sensors

Bio

Biotech
Edited DNA
Engineered enzymes
Self assembly
NanoBio materials

Smart

Photoreactive
Memory
Stimulus reactive
Chemical interactive

Materials

Advanced materials used to make new or better products
The ‘cyber-material interface’

- **CAD/CAM**: Digital design, Modeling/simulation, Flexibility, Speed
- **Automated Integrated**: Interconnections
  - Processes
  - Materials
  - Robotics
  - Workers
- **Digital Supply Chain**: Real-time Communication, Mfg closer to customer
- **Lean, Flexible, JIT**: Maximize productivity, Speed in development, Fast response
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

- **Agile**
  - Mass customization
  - Quick response
  - Machine faster than worker
  - Cross-training
  - Integrated teams

- **Automated**
  - "I work for a robot"
  - Just in time
  - Continuous flow
  - Reduced cycle time

- **Cellular**
  - Dissimilar functions are aggregated
  - Worker retraining

- **Distributed**
  - Decentralized
  - Micro factory
  - "The new cottage industry"
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?
Material, Process, and Product Life Cycle

Evolution of Advanced Materials and Manufacturing

Overall Investment

Nanotechnology
Advanced Manufacturing

Nanomaterial
Advanced Material

Basic Research
Proof of Concept
Scale Up
Early Production
Commercialization
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
US Strategy to Promote Advanced Materials and Manufacturing

Overall Investment

Material, Process, and Product Life Cycle
Advanced Industries, Manufacturing, and Materials

‘Organized Execution’
High R&D spending
Skilled workers

‘Process’
Additive processes
Cyber interface
Automated, Robotic

‘Materials’
Nano
Bio
Smart
Reactive

‘Science’
Novel properties
Unique behavior
Molecular level design

Advanced Industries

Advanced Manufacturing

Advanced Materials

Nanoscale Science
Some processes and some products.
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
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.
OS&H Activity and Collaborations along the Life Cycle

1. Discovery, scale up, pilot phase
2. Raw Material Production
3. Consumer Product Manufacturing
4. Consumer Use
5. Product End of Life
6. Industrial Emissions
7. Human Population and Ecological Exposure
8. Recycle
9. Landfills
10. Incinerators

- Worker Exposure
- Consumer Exposure
- Worker Exposure
- Industrial Emissions
- Human Population and Ecological Exposure
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 and 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

SEM

TEM-Bright Field

Industrial life cycle scenarios

- Personal Breathing Zone
- Prep for *in vivo*
- Sampling Lines
- Nanocomposite Sample
- Internal View
- Constant-Force Feeder
- Sanding Belt
- Boat for Particle Collection
- Filter Sampler

??
Example Occupational Life Cycle

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Example Occupational Life Cycle
Connecting the Key Exposure Assessment Elements

- Epidemiology
- Toxicology Assessment
- Exposure Assessment
- Exposure Metrics
- Biomarkers
- Dose metrics

Courtesy of M Schubauer-Berigan and M Dahm
Green Chemistry Opportunities for Nanotechnology

- Better Yield
- Reduce Solvent
- Renewable Feedstocks
- Safe by Design
  - Materials
  - Processes
- Lower Energy Needs
Nanotechnology: ‘Green Impact’ on Industry

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

- 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

Quick case study: America Makes
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).

• Photo: Fabricatingandmetalworking.com

Photo: Canadianmetalworking.com
Four Basic Categories of Additive Manufacturing

- **Fused Filament Fabrication (FFF)**
- **Selective Laser Sintering (SLS)**
- **Stereolithography**
- **Powder Bed Inkjet Binding**
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

Selective Laser Sintering

Operation:
1. Chamber filled with N\textsubscript{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

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

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

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

Building envelope: 800 x 400 x 500 mm³ (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
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," Etienne says. But additive allows you to get sophisticated and reduces costs at the same time. This is an engineer’s dream." Image credit: Adam Santaniello for G3 Reports.
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)
- nSiO₂ (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?
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