Overview of Additive Manufacturing and Potential Occupational Hazards

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The National Institute for Occupational Safety and Health

The U.S. Federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness.

Mission: To develop new knowledge in the field of occupational safety and health and to transfer that knowledge into practice.
Market Impact of AM

$7.3 Billion (21% CAGR)
## Comparative Advantages

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Traditional Manufacturing</th>
<th>Additive Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials Options</td>
<td>Vast</td>
<td>Small, but growing</td>
</tr>
<tr>
<td>Quality Control</td>
<td>High</td>
<td>Varies</td>
</tr>
<tr>
<td>Throughput</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Scalability</td>
<td>High</td>
<td>Low (parallelization)</td>
</tr>
<tr>
<td>Tool requirements</td>
<td>Multiple</td>
<td>Single</td>
</tr>
<tr>
<td>Maximum Complexity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Process Modification</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
<tr>
<td>Waste material generation</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Labor Pool</td>
<td>Existing</td>
<td>Training</td>
</tr>
</tbody>
</table>
Benefits of AM/3DP

**Development**
- Computer-Aided Design (CAD)
- Rapid iteration & prototyping
- More innovation space

**Products**
- Novel geometries
- More complex parts
- Efficiently use high-cost materials
- Customization

**Logistics**
- Lower material use
- Fewer tools
- Just-in-Time fulfillment
- Distributed manufacturing
PROCESSES
The Basics

- Computer-Aided Design (CAD)
- Feedstock material
- Selective x-/y-axis binding
- Stepwise vertical (z-axis) build
- Post-Processing
Materials & Feedstocks

- Liquid Resin
- Solid Plastic
- Metal Powder

... or any permutation thereof.
... or something else entirely.
Binding/Joining Mechanisms

Curing  Heat/Cooling  Cementing
Taxonomy

Additive Manufacturing

- Liquid Feedstock
  - Vat Polymerization
  - Material Jetting
- Solid Feedstock
  - Material Extrusion
  - Sheet Lamination
- Powdered Feedstock
  - Directed Energy Deposition
  - Powder-Bed Fusion
  - Binder Jetting

- Stereolithography
- Digital Light Processing
- Fused-Filament Fabrication
- Selective Laser Melting
- Electron Beam Melting
- Selective Heat Sintering
Material Extrusion

- **Build Material**
  - Thermoplastic

- **Feedstock Form**
  - Solid filament

- **Selector**
  - Deposition nozzle

- **Binding Mechanism**
  - Melting
Powder Bed Fusion

- **Build Material**
  - Metal/Plastic/Ceramic

- **Feedstock Form**
  - Powdered

- **Selector**
  - Laser

- **Binding Mechanism**
  - Sintering / Melting
Vat Polymerization

- **Build Material**
  - Photopolymer resin

- **Feedstock Form**
  - Liquid

- **Selector**
  - UV Laser/Projector

- **Binding Mechanism**
  - Curing
Binder Jetting

- Build Material
  - Metal/Plastic/Ceramic

- Feedstock Form
  - Powdered

- Selector
  - Printer Head

- Binding Mechanism
  - Adhesion/cementing
Post-Processing

Removing material
- Wet-chemistry
- Powder evacuation
- Manual removal

Retreating
- Annealing
- Curing

Finishing
- Sanding/Polishing
- Texturing
- Coating
POTENTIAL HAZARDS
AM requires a Holistic Approach to Risk Management

- **Materials**
  - Toxicity
  - Safety
  - Formulation

- **Environment**
  - Transport/Storage
  - Contamination
  - Organization

- **Process**
  - Energy/Mechanism
  - Consumables
  - Support Processes
# Process, Post-Process, and Support Process Hazards

**Process**
- UV Light, Lasers, Radiation
- Fire/explosion
- Cutting injuries
- Compressed gases

**Support Processes**
- Ergonomic concerns
- Falls & falling objects
- Crushing injuries
- Burns

**Post-Processing**
- Ergonomic concerns
- Cutting & grinding injuries
- Chemical exposures
- Burns

**Machine**
- Electrical shock
- Noise generation
- Heat generation
- Crushing injuries
Materials & Hazards

### Polymers
- Acrylonitrile-butadiene-styrene
- Polylactic acid
- Propylene fumarate
- Poly(vinyl alcohol)
- Polystyrene

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

### Metals
- Aluminum
- Titanium
- Steel
- Superalloys

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

### Particle Emissions

### Outgassing/VOC Emissions

### Dermal Toxicity

### Reactivity

### Flammability

### Combustibility

**Specific formulation**

**Process-induced changes**

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[Images of CDC and NIOSH logos]

[Logo of NTRC, NanoTechnology Research Center]
Environment

Transport & Storage

Waste Management

Workspace Ventilation & Airflow

Area Contamination

Robotics & Automated Systems

Scheduling

Psychosocial Stresses
Example Hazards

Thermoplastic Extrusion
- Burns
- Particulate emissions
- VOC emissions
- Post-process chemical use

Stereolithography
- Chemical dermal contact
- VOC emissions
- Post-process exposure
- Ergonomic hazards

Aluminum Laser Sintering
- Fire/explosion
- Powder inhalation
- Powder dermal contact
- Ergonomic hazards

Plastic Binder Jetting
- Fire/explosion
- Powder inhalation
- VOC Emissions
- Post-processing
AM users and knowledge will vary

Users may differ in terms of ...

- Budget for OSH activities (controls)
- Expertise (in both OSH and additive manufacturing)
- Synergistic exposures
- Demographics
- Communication preferences
- Decision-making structure
- Safety culture
Safe AM requires Communication

Safety Officers
- Hazard identification
- Risk assessment
- Safety controls

Designers
- Product application
- Material properties
- Process principles

Operators
- Build operations
- Support operations
- Practicalities
SUMMARY
Additive Manufacturing ...

Is substantially impacting multiple market sectors

Includes many materials and processes

Hazards will vary significantly based on particulars

Requires rapid and responsible development
NIOSH Performs On-Site Research

• Over 100 visits (65 sites)

• Uses existing methods

• Evaluate processes & personal exposures

• Provide Guidance and recommendations

• Seeking more partnerships and collaborations!
References & Image Sources

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Thanks for your time!

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