Additive Manufacturing

Environmental, Health and Safety Considerations

Prepared for ASSP AIHA joint meeting

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AMERICAN SOCIETY OF SAFETY PROFESSIONALS

AIHA

Protecting Worker Health

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During this session we will discuss:

Types 3D printing technologies

Safety and Health considerations

Environmental considerations

Compliance Challenges

What is Additive Manufacturing (AM)?

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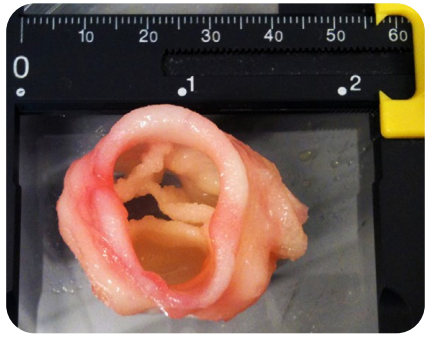

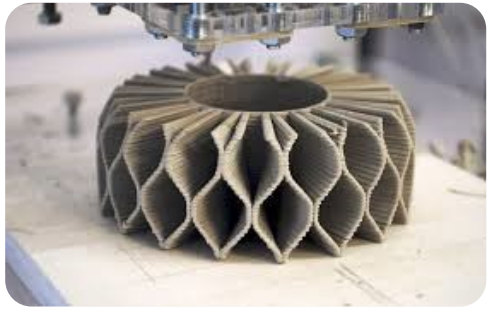

Additive Manufacturing by the Numbers…

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All Additive Manufacturing (AM) have 2 things in common

Use 3-Dimensional digital design to create a physical object

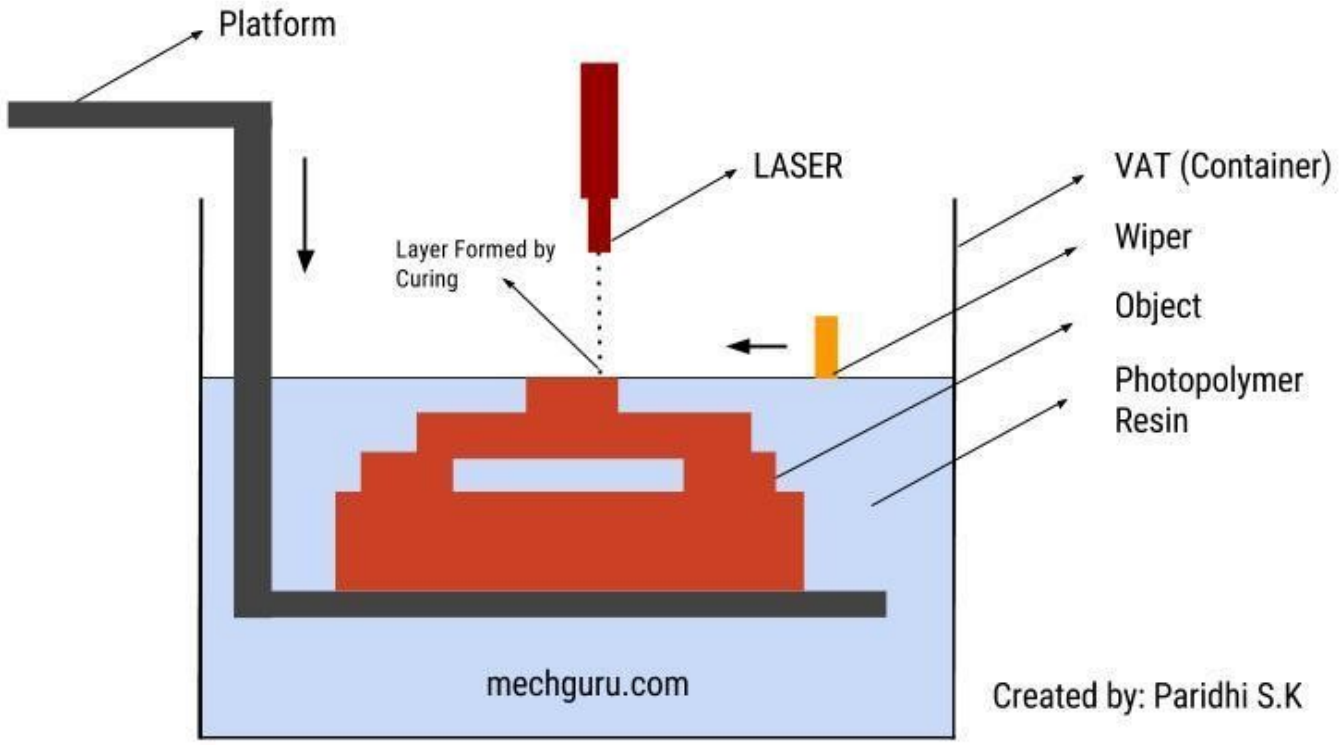
Form physical objects layer by layer

7 AM Processes are differentiated by 2 factors

Techniques used to deposit material

Ways deposited layers are bonded together

1 Vat Photopolymerization



3D Printing Technology

Technology examples

- Stereolithography apparatus (SLA)
- Digital Light Projections (DLP)

Feedstock materials

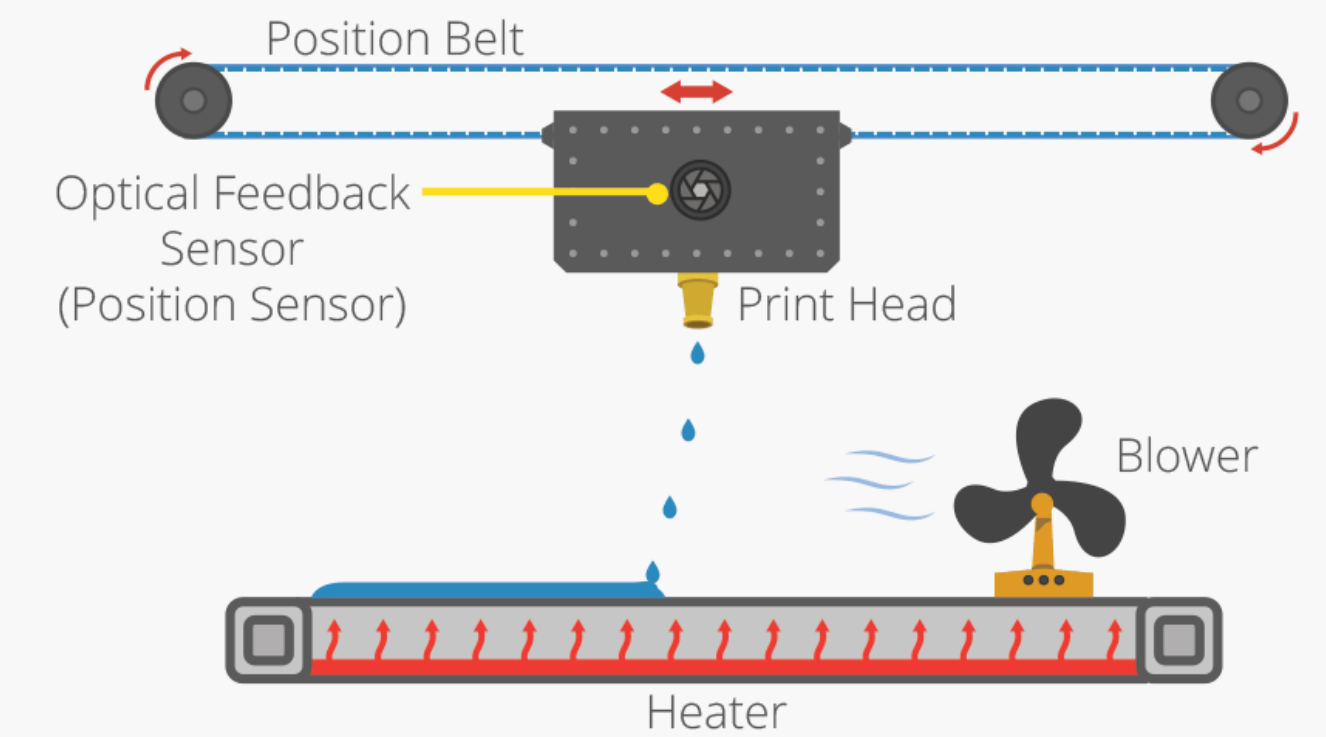
- UV curable resins
- Waxes
- ceramics

Potential Hazards

Inhalation of VOCs, Dermal exposure to resins / solvents

Ultraviolet light exposure, burns, mechanical, electrical, ergonomic

2 Material Jetting



3dprintingindustry.com/3d-printing-basics-free-beginners-guide#04-processes

Technology examples

Multijet Modeling (MJM)

Feedstock materials

UV curable resins

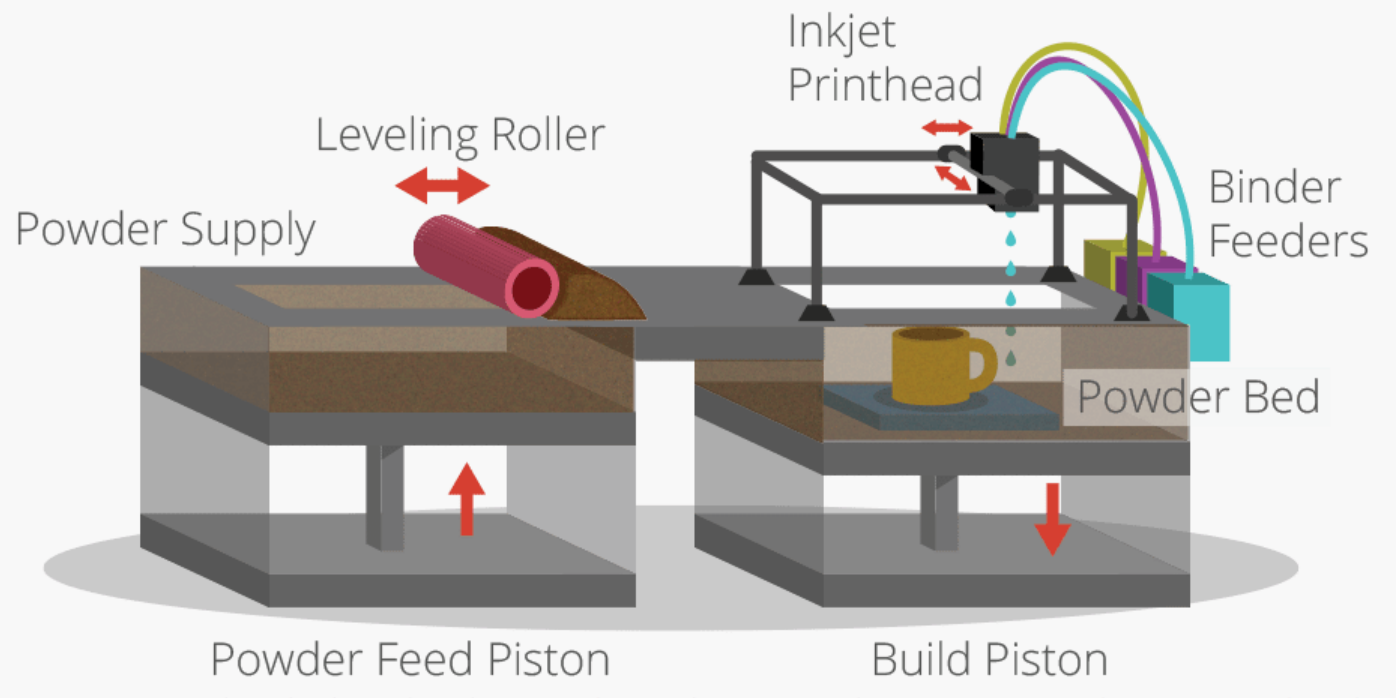
Waxes

Potential Hazards

Inhalation of VOCs, dermal exposure to resins / solvents

Ultraviolet light exposure, burns, mechanical, electrical, ergonomic

3 Binder Jetting



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Technology examples

3DP (3D printing)

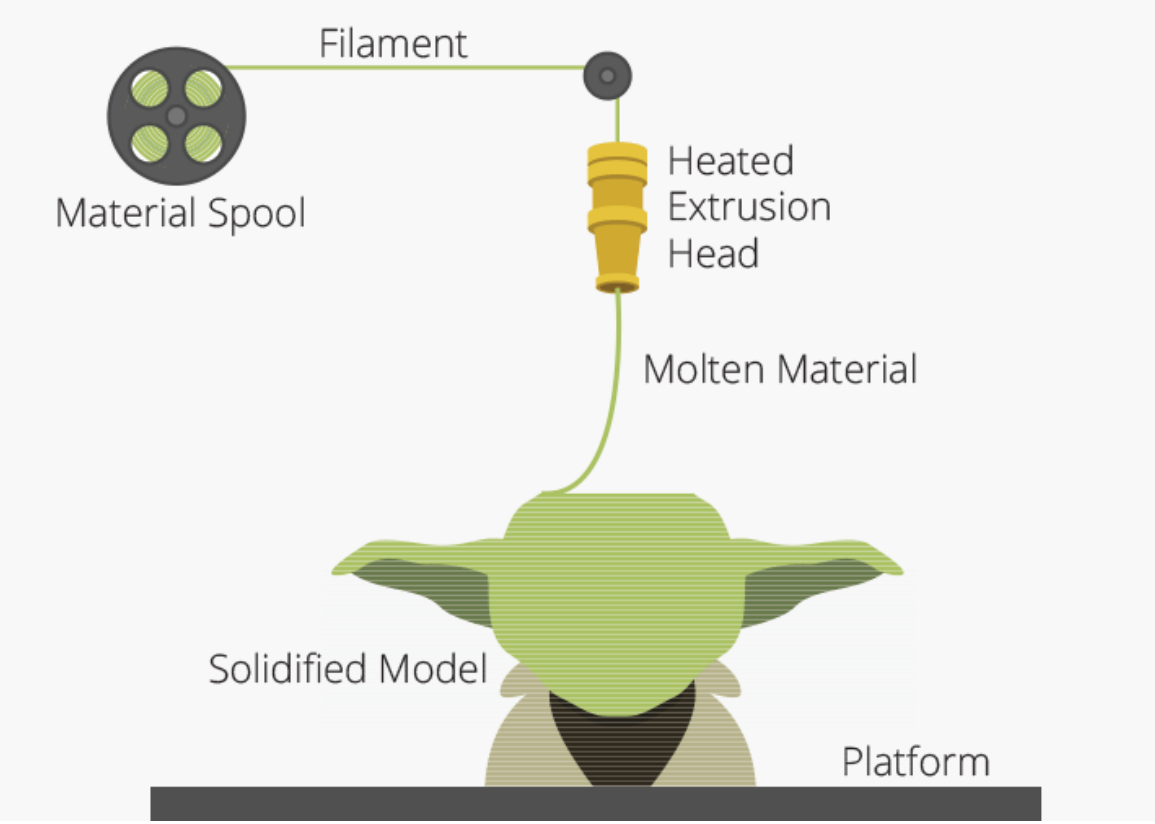
Feedstock materials

Composites
polymers
Ceramics
Metals

Potential Hazards

Inhalation/dermal exposure to powder, inhalation of VOCs, dermal exposure to binders, explosion, slips, trips, falls, ergonomic

4 Material Extrusion



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Technology examples

- Fused Deposition Modeling (FDM)
- Fused Filament Fabrication (FFF)

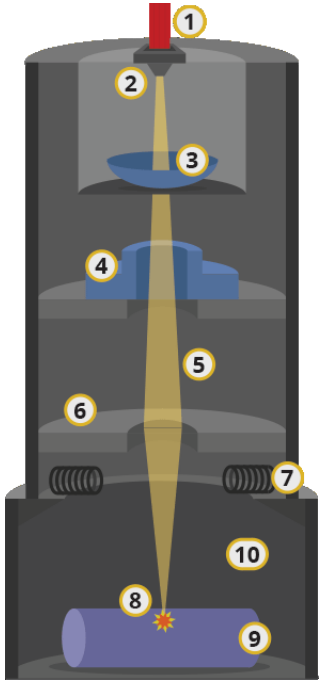
Feedstock materials

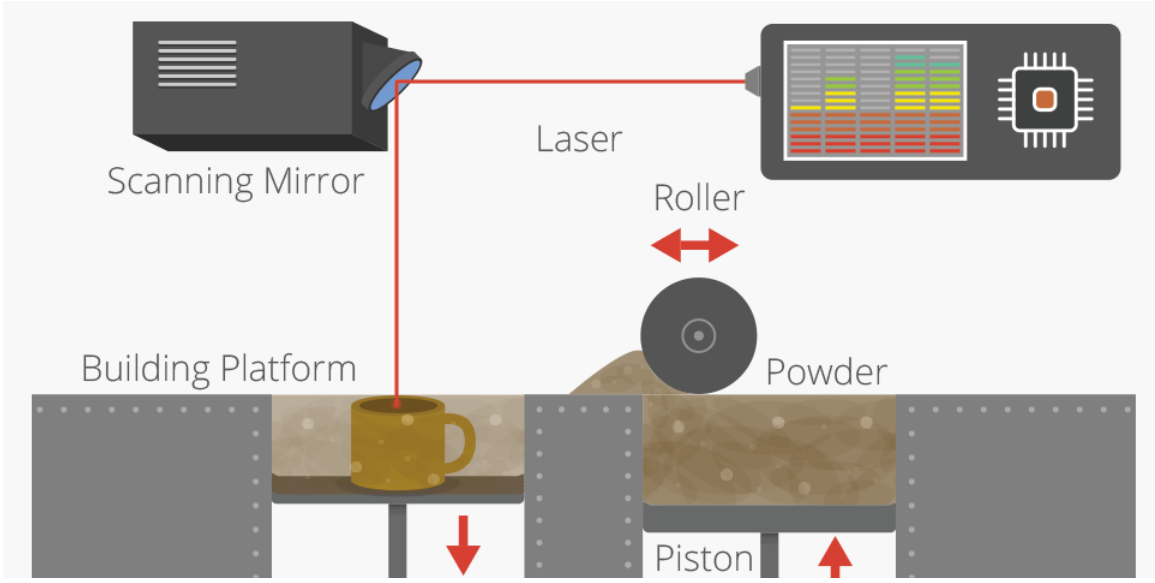
- Thermoplastics
  - polylactic acid (PLA)
  - acrylonitrile butadiene (ABS)
  - Polycarbonate (PC)
  - nylon
- Waxes
- Other material additives, including engineered nanomaterials (ENMs)

Potential Hazards

Inhalation exposure to VOCs & particulates & additives, burns

5 Powder Bed Fusion





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Technology examples

- Selective Laser Sintering (SLS)
- Select Laser Melting (SLM)
- Electron Beam Melting (EBM)

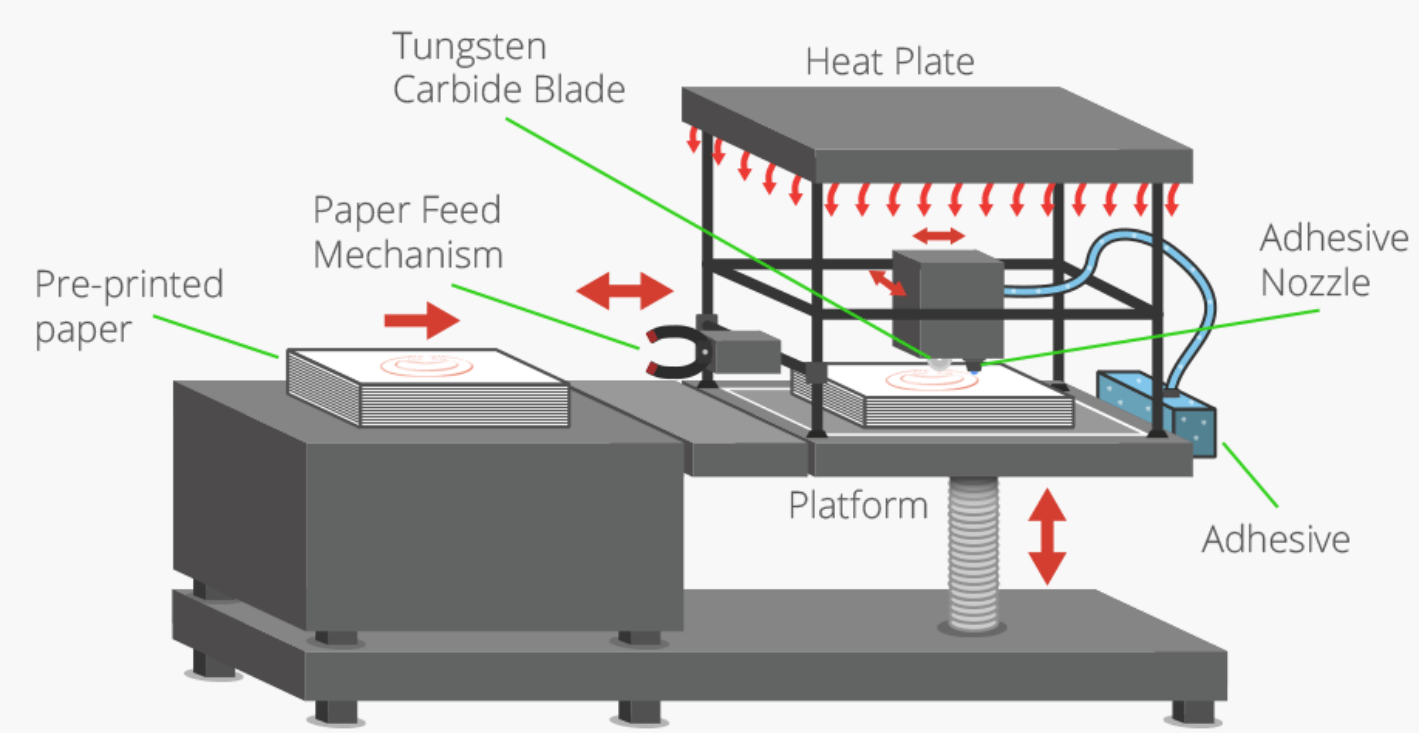
Feedstock materials

- Thermoplastics
- Metals

Potential Hazards

Inhalation/dermal exposure to powder, fumes, laser/radiation exposure, burns, mechanical, electrical, ergonomic, slip, trip & falls, explosion

6 Sheet Lamination



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Technology examples

Laminated Object Manufacturing (LOM)

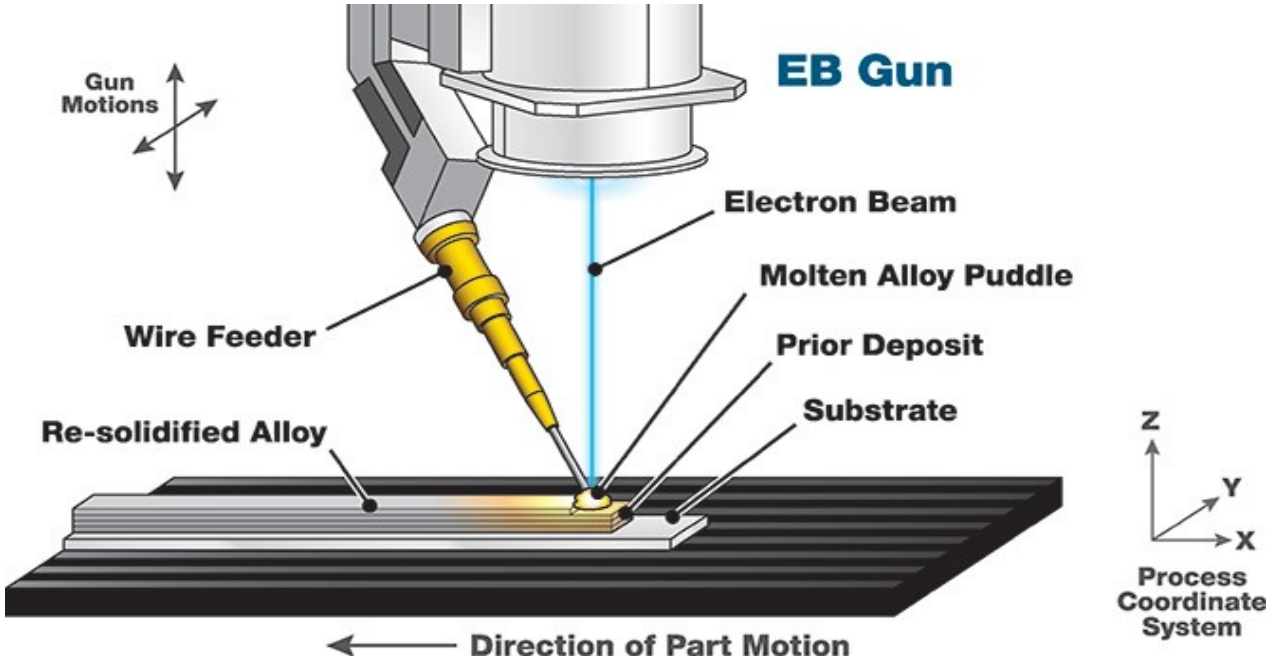
Feedstock materials

Paper
Metals
Thermoplastics

Potential Hazards

Inhalation of fumes & VOCs, laser/radiation exposure, burns, mechanical, electrical, ergonomic

7 Directed Energy Deposition



4e Revolution, Metal 3D printing: Airbus selects printing by electron beam

Technology examples

Laser Metal Deposition (LMD)

Electron Beam Additive Manufacturing (EBAM)

Feedstock materials

Metals

Potential Hazards

Inhalation/dermal exposure to powder, fumes, laser/radiation exposure burns, mechanical, electrical, explosion, slip trip & falls, ergonomic

Robust Hazard Assessments are critical to safe manufacturing using 3D printing technologies

Health hazards

Physical hazards

To properly assess risk, you need to:

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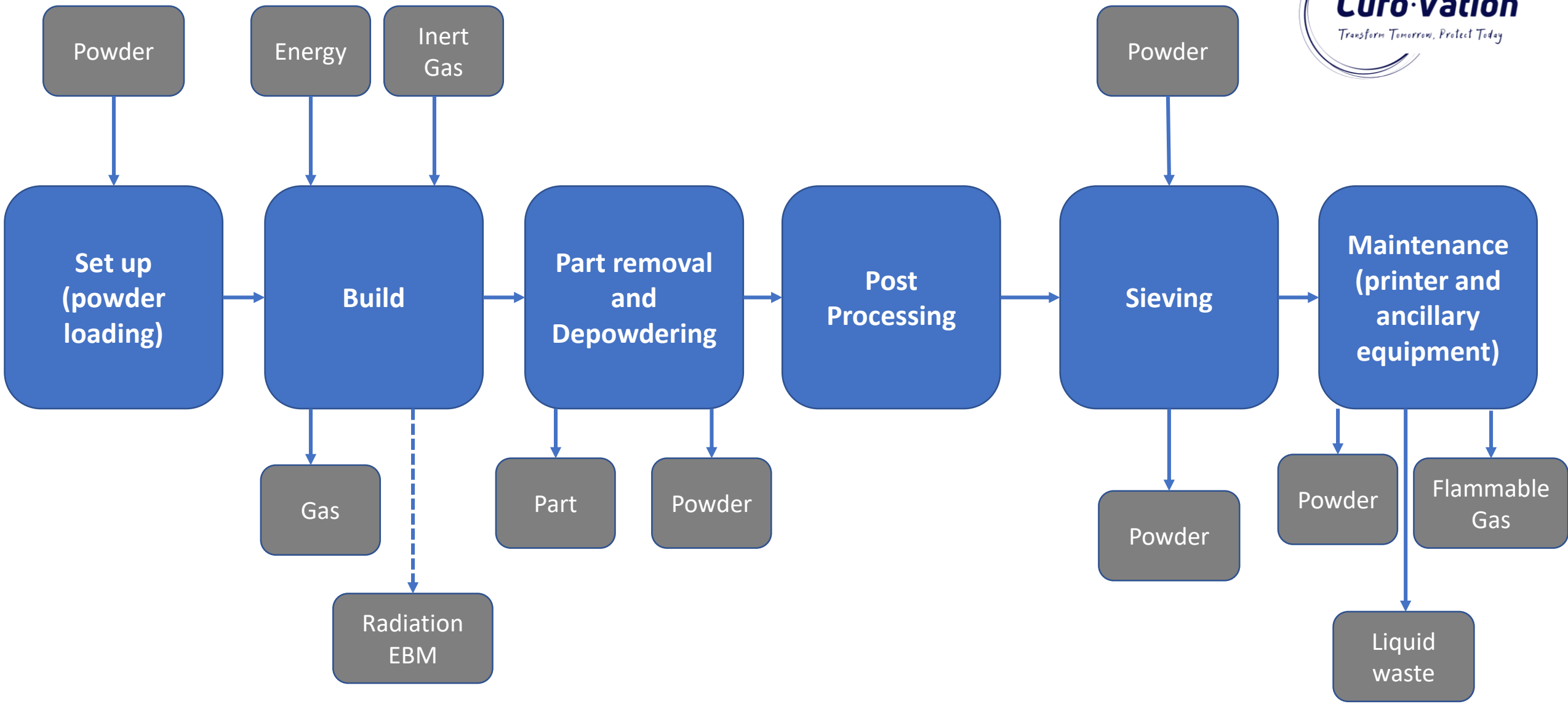
1. Know your printing technology and materials
2. Know your manufacturing process
   - Pre and Post processing, Routine and Non routine machine maintenance
   - Ancillary equipment safety
3. Facility design
   - Building code compliance, HVAC, material storage
4. Validate



Sample Process… Powder Bed Fusion (metals)

Health Hazards

Physical Hazards

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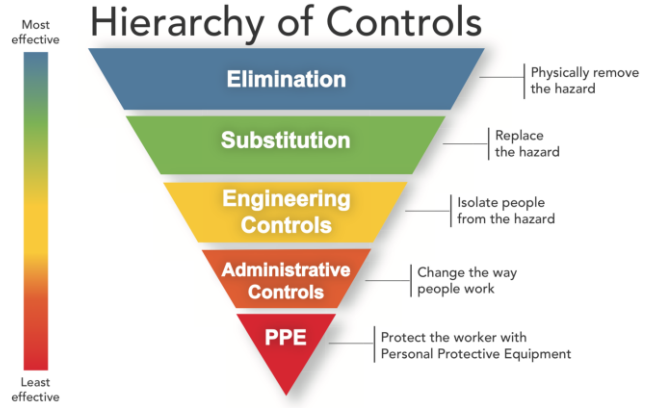
- ❑ Chronic Exposure to Metal Powders
- ❑ Sensitization Potential
- ❑ Asphyxiation risk from inert gas
- ❑ Nonionizing radiation risk – class 4 laser but enclosed and class 1
- ❑ Ionizing radiation – EBM registration as X-ray cabinet
- ❑ Non-routine task such as HEPA filter change, sieve cleaning



Sample Process… Powder Bed Fusion (metals)

Physical Hazards

- Combustible Dust - Typical powder particle size distribution is in the range of 10-70 microns for the laser powder bed fusion process.

- Fire Protection
- Ergonomics
- Confined Space
- Gas Cylinder Handling
- Electrical Safety / LOTO
- Slips, trips, ad falls

Sample Process… Powder Bed Fusion (metals)

Health Hazards

- ❑ Dermal sensitization potential from photopolymers such as acrylates
- ❑ Decomposition fumes
- ❑ VOC and nuisance odors
- ❑ Caustic handling

Physical Hazards

- ❑ Burns from hot parts
- ❑ Post –processing
- ❑ Ergonomic
- ❑ Mechanical
- ❑ Electrical
- ❑ Slips, trips, falls

Processes using Polymers

Health Hazards

Physical Hazards

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Identification

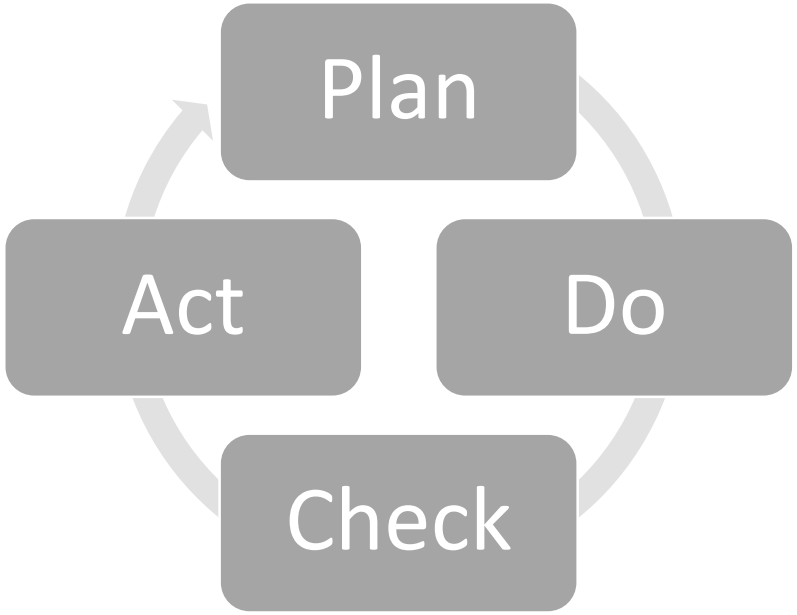
- SDS and process
- Combustible Dust Characterization
- Material Handling

Evaluation

- Compare to standards
  NIOSH, OSHA, ACHIH, NFPA 484

Control

- HVAC
- Housekeeping
- Work practices & personnel hygiene



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OSHA News Release - Region 1

U.S. Department of Labor

Please note: Information in some news releases may be out of date or may no longer reflect OSHA policy.

Region 1 News Release: 14-817-BOS/BOS 2014-073
May 20, 2014
Contact: Ted Fitzgerald Andre J. Bowser
Phone: 617-565-2075 617-565-2074
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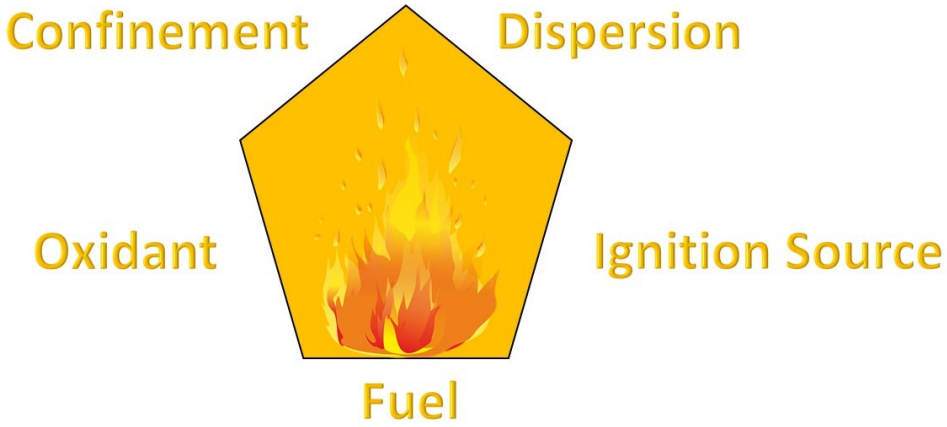
After explosion, US Department of Labor's OSHA cites 3-D printing firm for exposing workers to combustible metal powder, electrical hazards
Powderpart Inc. faces $64,400 in penalties

ANDOVER, Mass. – Powderpart Inc., a Woburn 3-D printing company, was cited by the U.S. Department of Labor's Occupational Safety and Health Administration for one willful and nine serious violations of workplace safety standards. The inspection followed an explosion and fire on Nov. 5, 2013, which inflicted third-degree burns on a company employee.

OSHA's Andover Area Office found that the company failed to prevent and protect its workforce from the fire and explosion hazards of reactive, combustible* metal powders, such as titanium and aluminum alloys, which are used in the company's three-dimensional printing process.

"The fire and explosion hazards when working with titanium and aluminum are established, particularly when the materials are in powder form," said Jeffrey Erskine, OSHA's area director for Middlesex and Essex counties. "Just as it's easier to start a campfire with kindling than with logs, it's easier for a metal fire to start when you're working with metal powder that is as fine as confectioner's sugar."

Powderpart failed to eliminate known sources of potential ignition and follow pertinent instructions from equipment manufacturers, and did not alert the Woburn Fire Department to the workplace presence of hazardous materials. Additionally, Powderpart located an employee workstation and flammable powders next to an area with explosion potential.



NFPA 484, 2019 Edition
Chapter 13 Additive Manufacturing

- Dust Hazard Assessments
- Facility Construction
- Material Handling and Storage
- Provisions for Emergency Shutdown
  - E-stop
  - Auto shutdown for loss of purge gas, high temp, loss of vacuum
- Shipping and Handling
- AM Equipment Operations
  - Equipment & personnel grounding and bonding
- Fire protection
- Employee Training

Environmental Considerations

Challenges for the EHS professional

Waste Management

- Broad range of waste
- RCRA & State
- Highly variable waste streams
- Unique physical properties

Air & Wastewater permitting

- Dust Collectors
- VOC emissions
- Federal and Sate HAPS
- Sanitary , industrial waste, stormwater
- Cooling water discharges
- Metal finishing – post processing

Filter Disposal

- “condensate” – highly reactive metal generated from laser sintering
- Filter changes are considered one of the most hazardous activities in AM
- Requires “treatment” to safely handle and manage the waste

***On the bright side, consider*:**

Carbon footprint

Less material waste

What about consumer and nonindustrial applications?

November 2018: UL Chemical Safety and Georgia Tech study

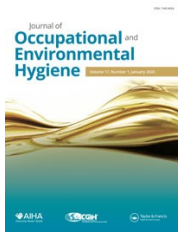
- Many desktop 3D printers generate ultrafine particles (UFPs) while in operation. UFPs may pose a health concern. Emissions of nanoparticles and may be inhaled and penetrate deep into the human pulmonary system.
- More than 200 different volatile organic compounds (VOCs), many of which are known or suspected irritants and carcinogens, can be released while 3D printers are in operation.
- Factors including nozzle temperature, filament type, filament and printer brand, and filament color, affect emissions while extrusion temperature, filament material and filament brand

Feb 2019 ANSI/CAN/UL 2904 - published

- Defines measurement and assessment protocols for emissions of particles and volatile chemicals from diverse 3D printers, print media, and print applications.
- Standard applies to freestanding 3D printers that are typically found in schools, offices, libraries, homes, and other non-industrial indoor spaces,

References and Great Resources

The Free Beginner's Guide
https://3dprintingindustry.com/3d-printing-basics-free-beginners-guide#04-processes



Journal of Occupational and Environmental Hygiene, Potential Occupational Hazards of Additive Manufacturing, April 2019, Gary A Roth, Charles L. Geraci, Aleksandr Stefaniak, Vladimir Murashov, John Howrd,

UL News, https://www.ul.com/news/ul-chemical-safety-and-georgia-institute-technology-release-pioneering-3d-printing-research

Journal of Manufacturing Science and Engineering, Additive Manufacturing: Current State, Future Potential, Gap and Needs, and Recommendations, February 2015, Yong Huang, Ming C. Leu, Jyoti Mazumder, Alkan Donmez.

4e Revolution, Metal 3D printing: Airbus selects printing by electron beam

3D Printing Technology