NTRC | NANOTECHNOLOGY RESEARCH CENTER

NIOSH Activities in Additive Manufacturing and 3D Printing

CIAQ Overview October 4, 2107

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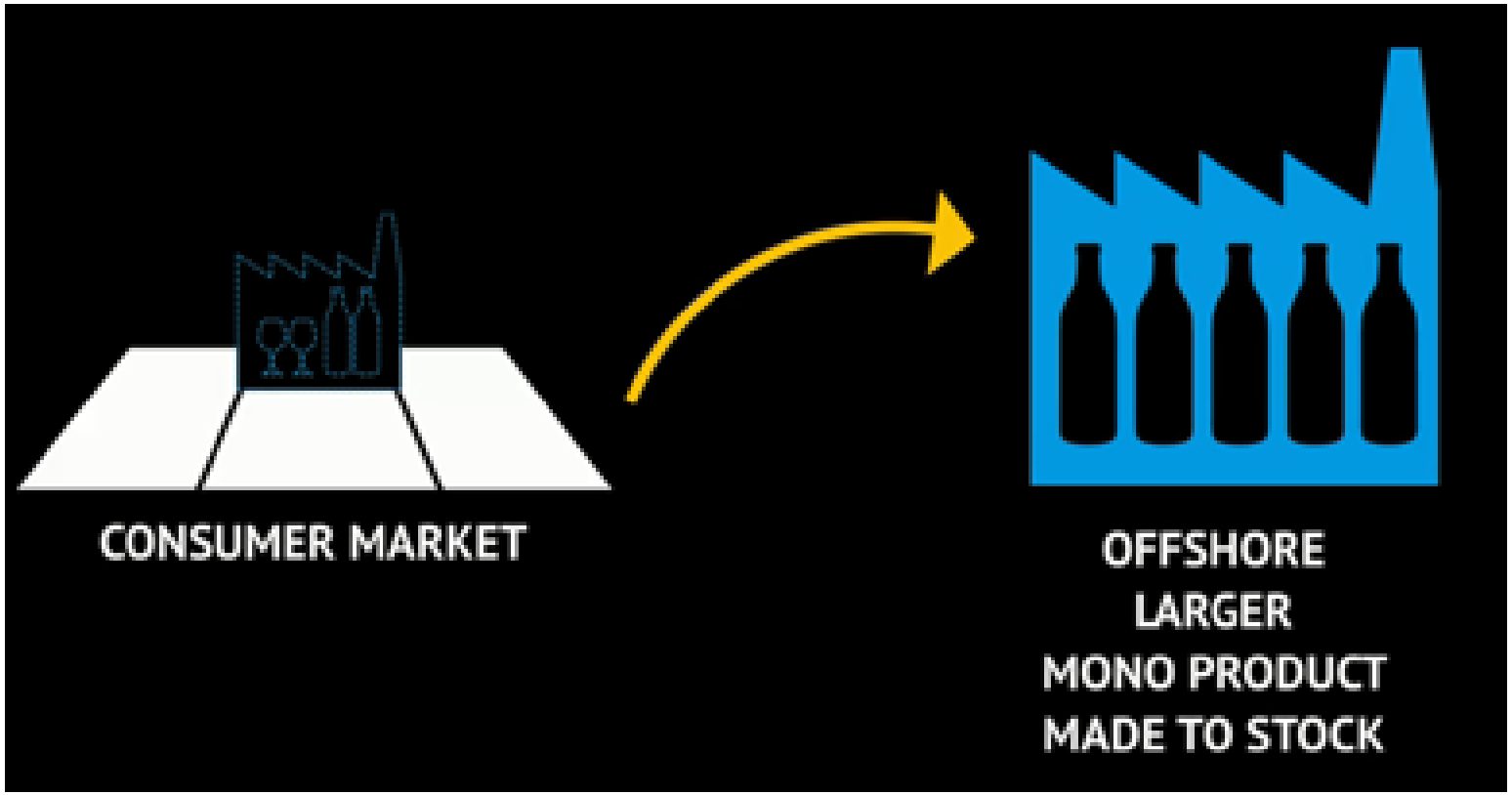
National Institute for Occupational Safety and Health

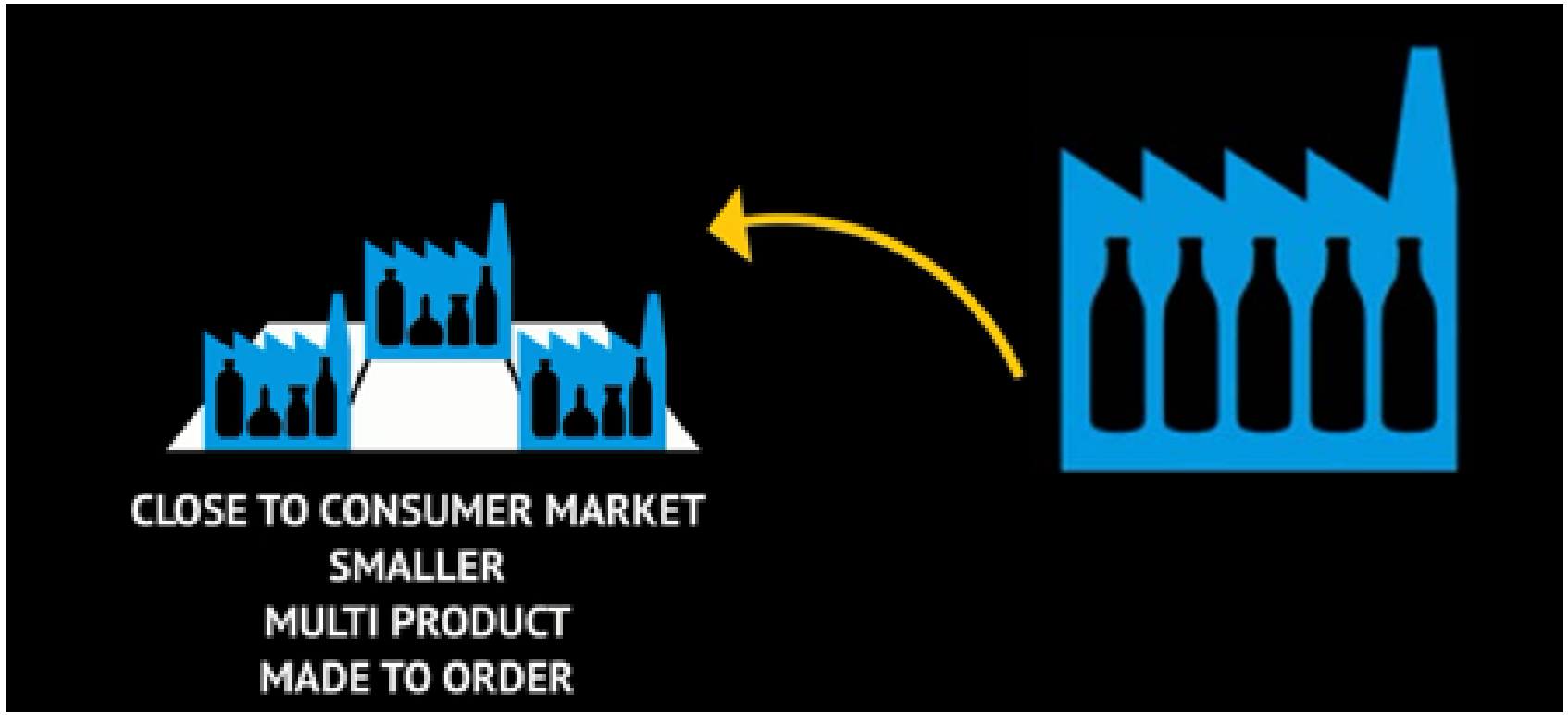
CDC Workplace Safety and Health NIOSH

Changing State of Manufacturing
Current but Fading Model



Global changes in labor and energy costs and consumer demand are changing

Emerging Manufacturing Model



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

Advanced Manufacturing

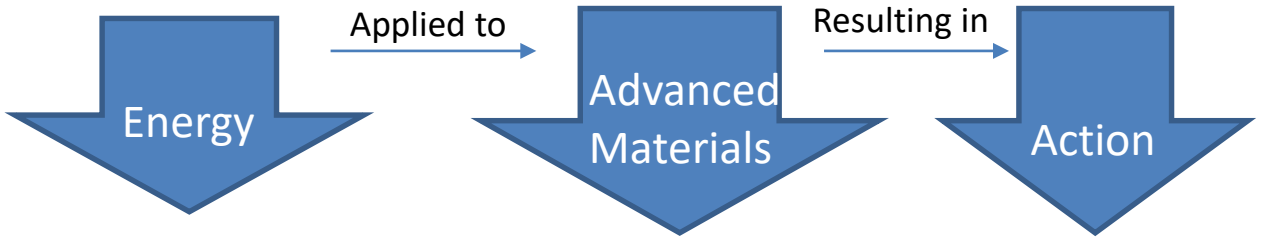
- Use of and information, automation, computation, software, sensing, and networking
- Uses cutting edge materials and emerging capabilities enabled by nanotechnology, biotechnology, chemistry, and biology.
- New ways to manufacture existing products, and the use of new and advanced technologies
- Organized in the US as Manufacturing USA

Most mature, fastest growing, applied in multiple sectors

3D Printing

What is it?

Additive Manufacturing



Lasers
E-Beams
Heat

Very high and focused energy

Metals
Polymers
Bio-polymers
Nanomaterials
Ceramics
Carbon fiber

As fine powder or solid strands

Melt
Fuse
Sinter
Bond
Cure

In very thin layers to build a part

Outputs

‘Printed’ parts: medical implants to aircraft wings and building components

- and –

Ultrafine Particulate
Volatile Organics
Energy

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

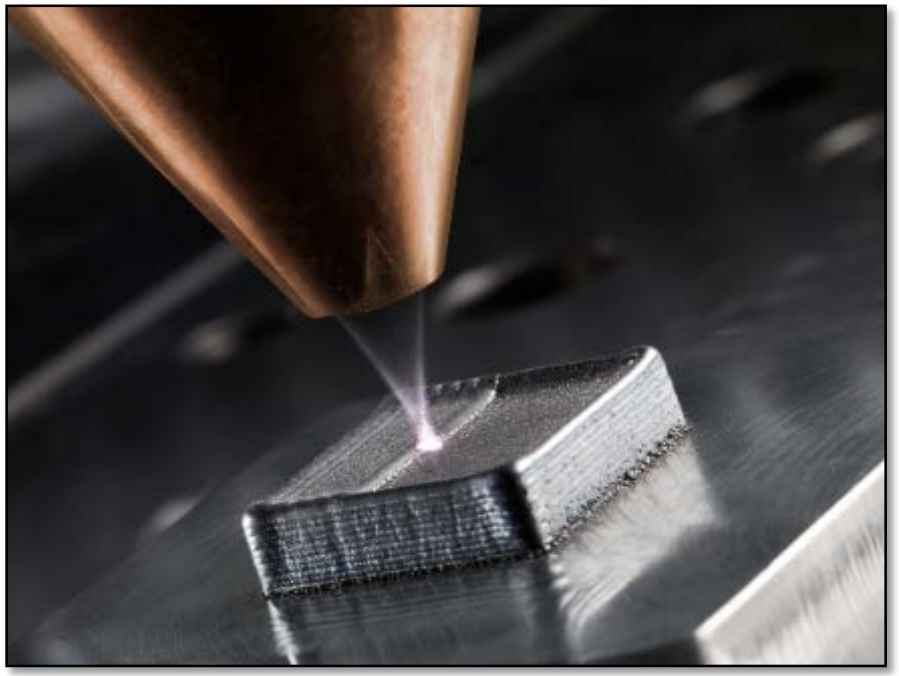
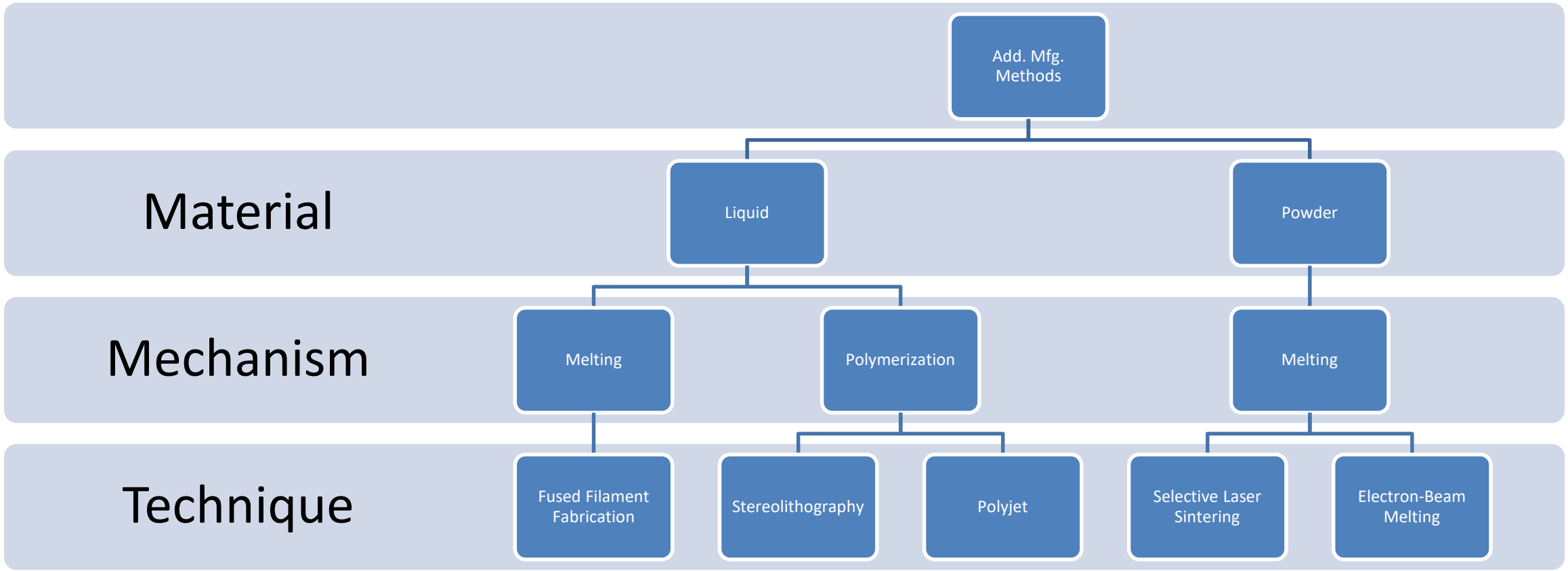


Photo: Canadianmetalworking.com

Taxonomy


Material
Mechanism
Technique
Add. Mfg. Methods
Liquid
Powder
Melting
Polymerization
Melting
Fused Filament Fabrication
Stereolithography
Polyjet
Selective Laser Sintering
Electron-Beam Melting

Fused Filament Fabrication

Most commonly referred to as ‘3D Printing”

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

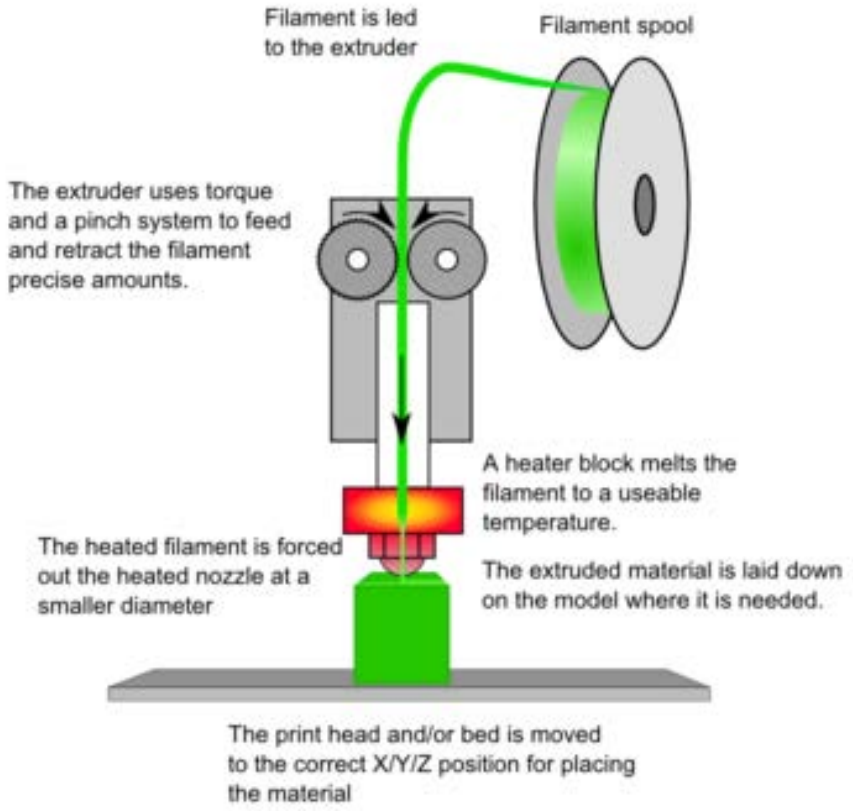
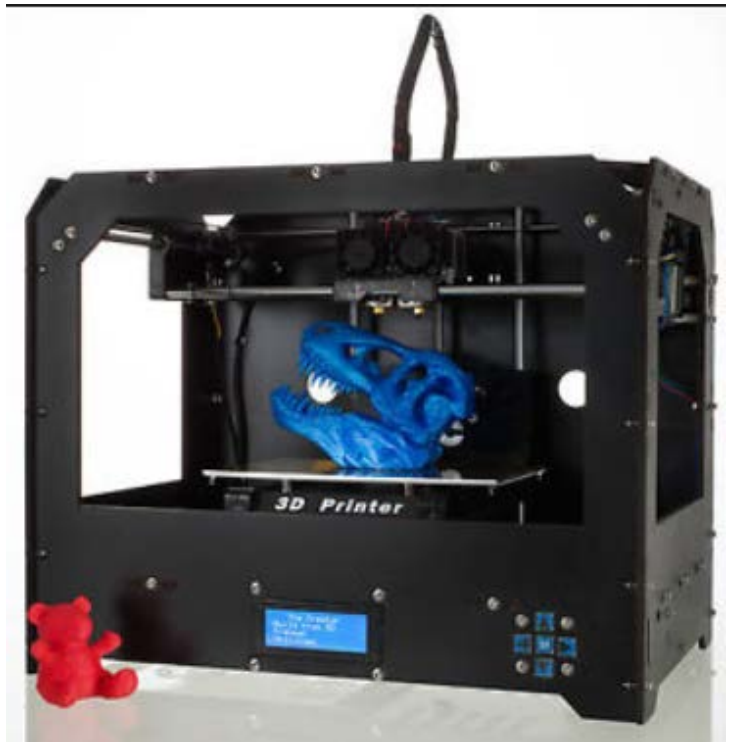


Image source: Spiritdude, 2012.

Desktop 3D Printing



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

Selective Laser Sintering

Most often referred to as “Additive Manufacturing”

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

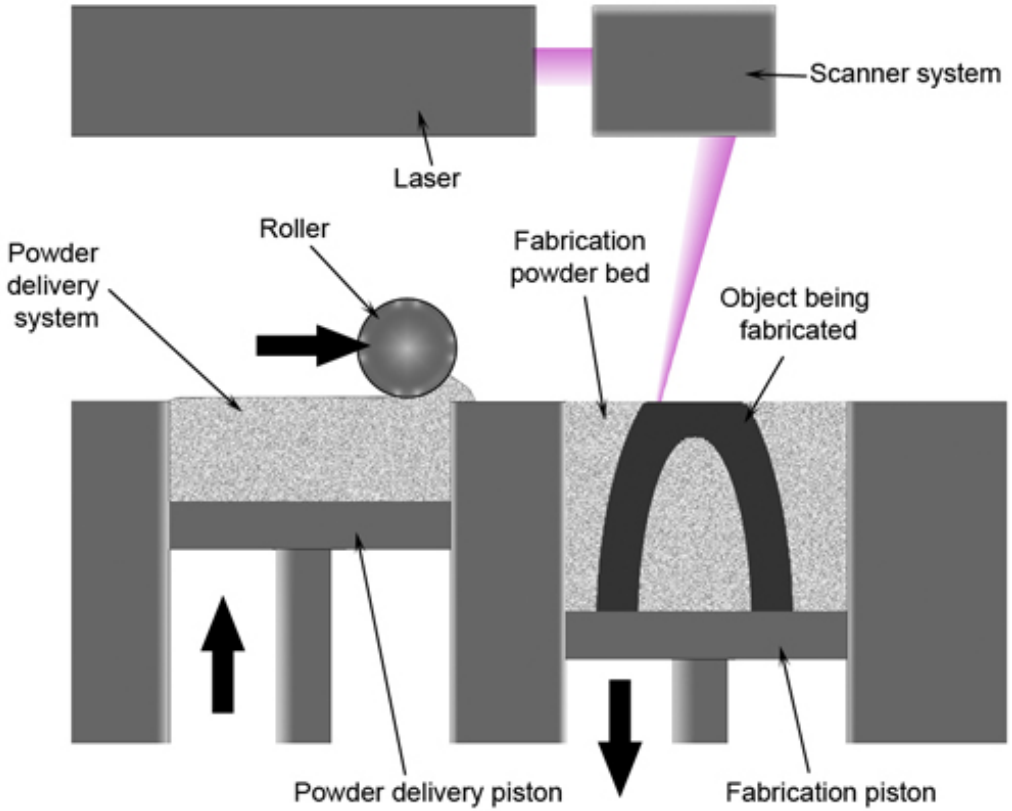


Image source: Materialgeeza, 2008.

Additive manufacturing

- Photo credit: 3dprintingindustry.com

This is also a 3D Printer

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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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

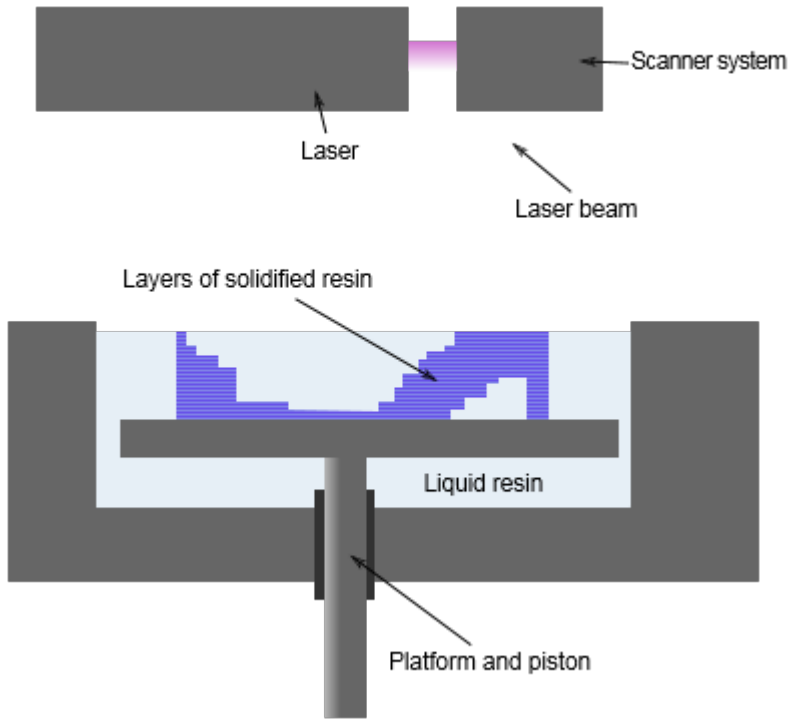


Image source: Materialgeeza, 2008.

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

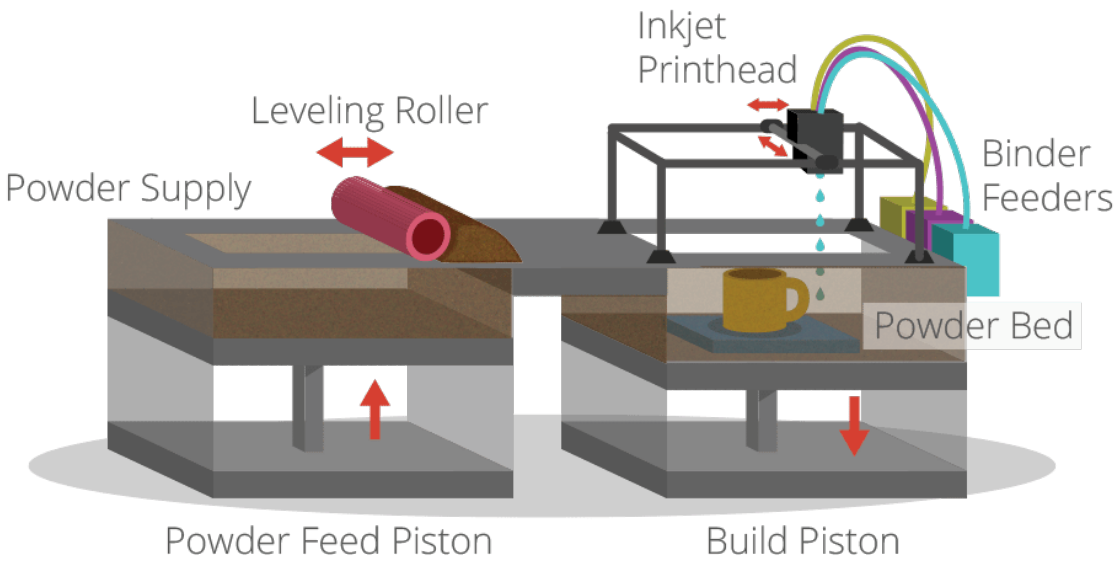
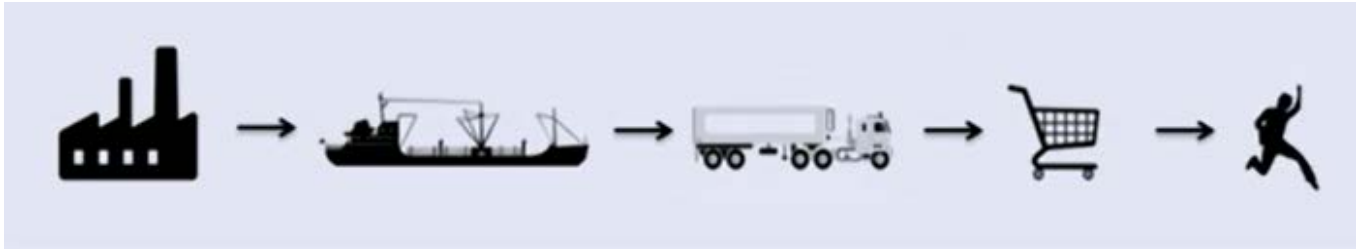


Image source: 3DPI's Beginner's Guide to 3D Printing, 2013.

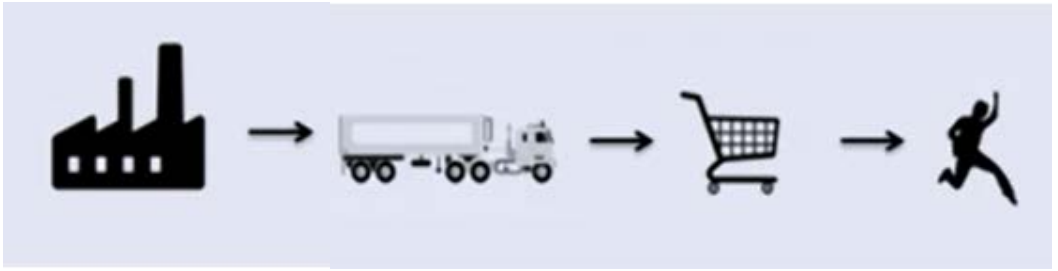
What is the Impact of 3D Printing?

Production

Consumption



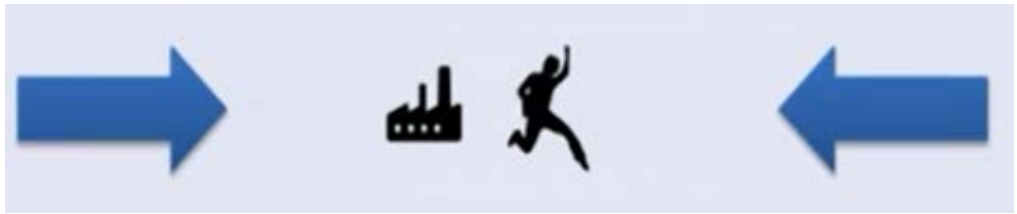
Old Model



Evolving Model

Cottage, Close to Home, Custom Made

3D Printing is accelerating this model



Manufacturer as Consumer
Consumer as Manufacturer

NIOSH Approach

- Use current Nanotechnology Research Center resources, experience, and presence with partners
- Conduct lab and field evaluations of emissions and controls
- Bring the ‘lab to the field’ for most realistic picture of emissions

NIOSH Nanotechnology Research Center (NTRC)

- Increase understanding of new hazards, exposures, and related health risks
- Expand understanding of the initial hazard findings
- Support the creation of guidance documents and best practices
- Support epidemiologic studies for workers in these fields
- Assess and promote national and international adherence with risk management guidance

NTRC Field Team – Advanced Materials and Manufacturing Technologies Activities

On site assessments to gain real world insight to potential exposures, develop mitigation strategies, and develop and share best practice guidance that support safe development and commercialization

Lab Studies: Background

- Fused deposition modeling (FDM) 3-D printers
  - Extrude thermoplastic filament through heated nozzle
  - Heating thermoplastic polymer → chemical emissions
- Numerous factors may influence emissions
  - Printer (design, operating temperature, etc.)
  - Consumable (additives, colorants, composition, etc.)
- Little understanding of actual 'as used' emissions
  - Chamber studies
  - Gather "real-world" data from field studies

Field Study Methods

- **Combination of traditional industrial hygiene methods and newly developed sampling techniques**
  - Personal and area air sampling for Total Particulate, Respirable Particulate, with TEM
  - Volatile Organic Compounds, or other potential exposures of interest.
  - Chemical and or gravimetric analysis
  - TEM/SEM sampling for identification, sizing and morphology
- **Direct Reading Instrumentation for particle counts, sizing, classification**
  - CPC, OPS, DustTrak , Nano Scan, FMPS, EPLI,

Additional NIOSH Studies

- **In Progress**
  - NTRC Advanced Materials and Manufacturing Field Team
    - LCDR Kevin L Dunn
  - Chemical Emissions from a Desktop 3-Printer
    - Dr. Alexander Stefaniak et al (CDC/NIOSH/RDH)
  - “Emissions and Controls”-Lab into the Field
    - CDR Duane Hammond (CDC/NIOSH/DART)
- **Proposed**
  - **Pulmonary and Cardiovascular Responses to Aerosolized Emissions from 3-D Printers**
    - Yong Qian et al **(**CDC/NIOSH/HELD**)**
    - Larger scale lab-based emission studies

Larger Scale Laboratory Emissions Test Chamber

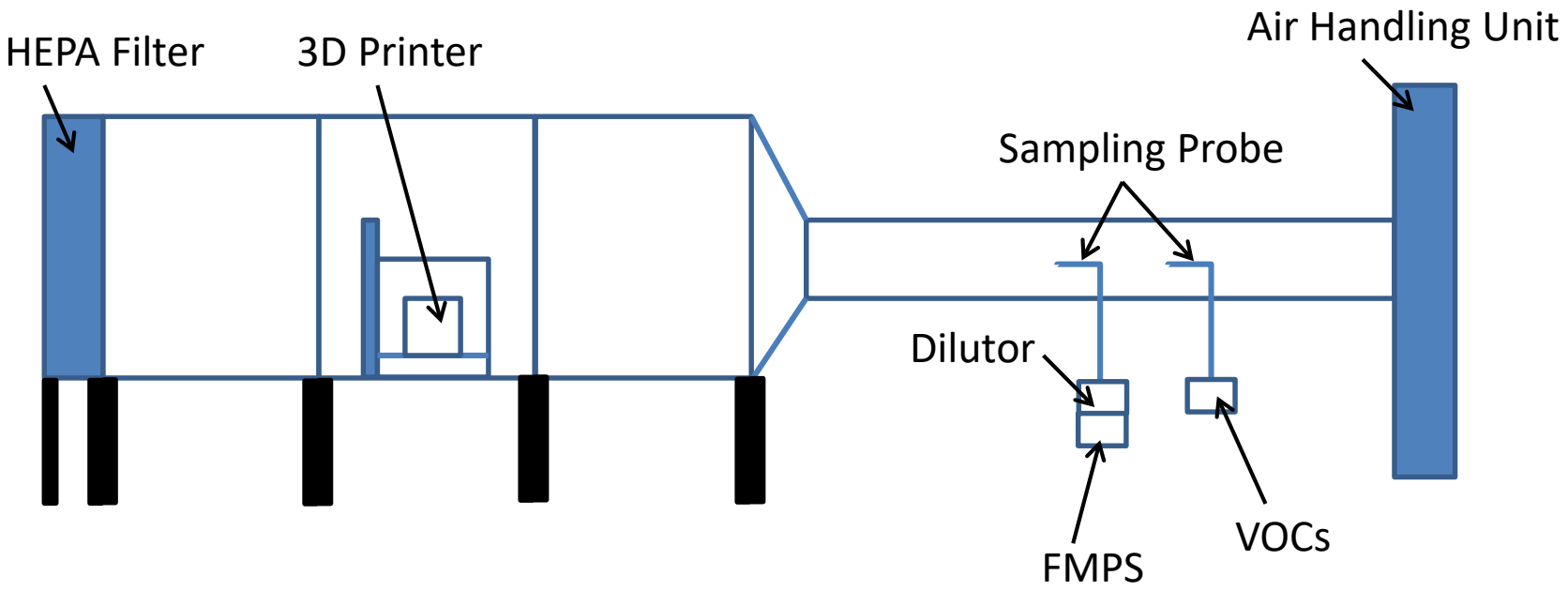


Photo and Diagram Credit: Chaolong Qi (NIOSH)

Laboratory Emissions Test Chamber

NTRC Field Team Activities

- Currently have **five** commercial, **two** equipment manufacturer, and **two** university partners for Additive Manufacturing & Advanced Materials collaborations
- FDM
- SLS
- SLA
- Polyjet
- Wide variety of feed stocks from metal powders, thermoplastics, with and without nanomaterials added

Bringing the lab to the field

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Engineering Control Studies

- Specific Aim 1: Conduct field studies to better understand existing engineering controls used to contain industrial 3D printer emissions.

- Specific Aim 2: Evaluate the effectiveness of engineering control techniques for containing industrial 3D printer nanoparticle emissions and develop new approaches as needed.

- Specific Aim 3: Conduct laboratory evaluations of engineering controls and containment techniques for a variety of common desktop and industrial 3D printers that are known to emit nanoparticles.

Closing Thought

What we hope to gain is the combination of solid laboratory and field based research to help guide the rapid and responsible development of emerging technologies.

Thank you!

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www.cdc.gov/niosh/topics/nanotech

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