Environment, Health & Safety
FACILITIES PLANNING & MANAGEMENT
UNIVERSITY OF WISCONSIN–MADISON

3D PRINTING/ADDITIVE MANUFACTURING SAFETY

2023

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PURPOSE

3D printing, also known as Additive Manufacturing, is the process by which a three-dimensional object is built from a computer model by laying down successive layers of material. At UW-Madison, students and researchers are finding a growing number of 3D Printing applications including electronics prototyping, modeling, Makerspace learning.
Production processes and materials vary greatly between 3D printing applications, each having its own unique set of health and safety hazards. EHS has provided safety guidelines which are detailed in this document.

3D PRINTING OVERVIEW

3D Printer Types

3D printing methods are typically organized into seven categories based on the way the material is joined:

- **Fused Deposition Modeling** – A thermoplastic filament such is melted and deposited in layers by a moving nozzle. Most low-cost, consumer-grade desktop printers use FDM
- **Stereolithography (SLA)** –Works by focusing a UV laser on a photopolymer resin, which hardens the resin in successive layers.

- **Material Jetting** – Selectively deposits droplets of feed material, such as inks, onto a build platform. When the droplets cool and solidify, the next layer is deposited on top.
- **Binder Jetting –** A liquid binder is sprayed onto a bed of ceramic or metal powder, causing it to solidify. The resulting structure is typically heated in an oven to remove the binder and fuse the remaining metal or ceramic.
- **Powder Bed Fusion** –Plastic, metal, ceramic, or glass powders are fused together using lasers or other energy source to form a solid structure.
- **Directed Energy Deposition (DED)** – A metal powder or wire is melted at the same time it is being deposited by a moving print head.
- **Sheet Lamination** – Creates 3D objects by using a laser or other sharp blade to cut and bond thin layered materials (e.g., paper, aluminum foil) together layer-by-layer.

FDM and SLA printers comprise the majority of printers at UW-Madison.

3D Printing Hazards

The hazards of 3D printing are as varied as its applications:

- **Chemical Vapors** – Plastic filaments have been shown to produce Volatile Organic Compounds (VOCs) when heated in 3D printing processes. Exposure to VOCs can headache, nausea, and eye, nose, and throat irritation. Organic solvents used in post-processing vapor baths such as alcohol and acetone vaporize readily and pose an inhalation hazard.
- **Nanoparticle Emissions** – When heated, filaments produce inhalable nanoparticles (NPs) when heated during 3D printing. Additionally, the use of NP-containing media can emit inhalable NPs into the surrounding atmosphere. The health effects of NPs are not well understood, but preliminary research suggests that inhalation is associated with cardiovascular and pulmonary diseases.
- **Corrosive Baths** – Support material can be removed by placing prints in a heated corrosive bath containing sodium hydroxide or other caustic chemicals. Exposure to these chemicals can cause serious chemical burns, scarring, and vision damage.
- **Vapor Baths** – ABS objects can be smoothed or "polished" by placing them in a closed vessel filled with a small quantity of acetone or other organic solvent, which vaporizes and reacts with the ABS plastic. These solvents are usually flammable and can cause symptoms when inhaled such as headache, nausea, and respiratory tract irritation.
- **Biological Material** – Printers using biological material can produce aerosols which may be inhaled or deposited onto nearby surfaces.
- **Heat** – Components such as UV lamps, motors, heat beds, and print heads become hot during operation and can cause burns when touched.
- **Flammability** – Fine metal powders such as aluminum, steel, and titanium can spontaneously combust under normal atmospheric conditions (known as pyrophoricity). Organic solvents like acetone used in vapor polishing can combust when exposed to a heat source. Chemicals used in bed preparation such as hairspray are flammable.
- **Inert Gas** – 3D printers sometimes use inert gases such as nitrogen or argon to create a noncombustible atmosphere in the printing chamber. Some aerosol jet printers use an inert gas as part of the aerosolization and deposition process. If inert gas is introduced

into the surrounding atmosphere, it can displace oxygen and present an asphyxiation hazard.

- **Electric Shock** – Unguarded electrical components and damaged power cords can result in electric shock.
- **Mechanical Hazards** – Hands and fingers can get pinched by moving printer components while in operation. CNC post-processing of metal parts presents mechanical and noise hazards.
- **Ultraviolet Light/Lasers** – Eye exposure to the UV lights used in SLA printers can cause temporary or permanent vision loss. Directed Energy Deposition and Powder Bed Fusion printers often use powerful Class 4 lasers which can cause permanent eye injury from direct or reflected light.

GENERAL SAFETY PROVISIONS

- Before operating a 3D printer, ensure you are familiar with the correct, safe operation of the printer.
- Always follow the manufacturer's instructions on printer setup and usage.
- Safety Data Sheets for materials used with 3D printers should be reviewed prior to use. Employees and students should have access to electronic or printed copies.
- Never bypass safety controls or defeat interlocks once the printing process has started. This will decrease the risk of exposure to hand/finger pinches from moving parts and reduce air contamination.
- Do not place flammable liquids near 3D printers. The heated components of 3D printers can cause the flammable liquid to catch fire.
- If the manufacturer offers enclosures or exhaust ventilation kits, they should be purchased. When hazardous/volatile materials will be used/created during print runs, they printer(s) must be exhausted to building ventilation.
- Never work alone when using hazardous chemicals. It is permissible to work alone if using consumer grade printers that use solid media.
- Know the locations of emergency equipment relevant to the hazards of your printer, such as fire extinguishers and eyewash stations.

Signage

Rooms containing any quantity of hazardous chemicals should have a current and accurate lab door emergency card. These door cards provide first glance information to an emergency responder. They allow responders to ensure they are prepared for whatever may be in the lab and warn responders who may not be adequately protected from the listed hazards not to enter. They also provide necessary contact information for custodians or others who may find or hear something amiss in the lab after hours.

Chemical Storage

Chemicals should be stored in a designated, labeled chemical storage cabinet. **Do not store flammable substances like resin polymers, rubbing alcohol, and acetone in non-rated**

refrigerators/freezers. This can cause an explosion. Large bottles of chemicals should be stored no more than two feet from floor level.

If multiple types of chemicals will be stored in the same cabinet, refer to UW-Madison's Chemical Safety Guide to determine if they are compatible for storage. If chemicals are determined to be incompatible, contact EH&S Chemical Safety Office for further guidance.

Spill Procedures

Keep a chemical spill kit in locations using chemicals. FDM printers using solid media do not require a spill kit. Spills under one liter may be cleaned up using the chemical spill kit. For spills over one liter, contact EHS for cleanup at chemsafety@fpm.wisc.edu.

Training

All individuals operating 3D printers should receive the following training, and training should be documented (topics covered, date, employee names and signatures)

- Chemical Safety: The OSHA Laboratory Standard and Disposing of Hazardous Chemicals.
- Site Specific Training with PI or lab manager
- Laser Safety (If handling un-enclosed lasers, such as during assembly and maintenance)

FUSED DEPOSITION MODELING

Hazards & Safety Practices

VOCs and Nanoparticles—When plastic filament is heated, it produces volatile organic compounds (VOCs) and nanoparticles that can be inhaled. All FDM users are encouraged to use an enclosure.

PLA filaments may be used without ventilation or enclosure. A local exhaust or filtered enclosures are usually required to use other filament types such as ABS, PMMA, PETG, and nylon. If using filaments other than PLA, please contact Campus Renovation Services to determine an appropriate ventilation setup. When hazardous/volatile materials will be used/created during print runs, printer(s) must be exhausted to building ventilation.

Flammable Chemicals—Organic solvents like ethanol, isopropyl alcohol, and acetone used in bed preparation can catch fire upon contact with heat.

When cleaning with flammables, use a wetted towel rather than a spray bottle. Aerosolized flammables can catch fire upon contact heated components.

Containers 750mL in size or smaller can be kept on working surfaces, away from heat sources. Larger containers should be stored in a designated chemical storage area.

Sharps—Removing support material using sharp instruments like razors and clippers can cause cuts and abrasions. Handle sharp instruments with care and know the location of a first aid kit.

Electrical—Assembly and maintenance of printers can expose electrical components capable of causing shocks. Always assemble and disassemble according to manufacturer instructions. Ensure the power cable does not fray.

Heat—FDM printers use multiple heated components like print nozzles and print beds. Only handle components that are cool.

Post-Processing Baths

Support material may be removed by submerging prints into a bath which can contain water or a caustic solution. All liquids used in these baths should be disposed of as hazardous waste via EHS, including water. Special safety precautions should be taken when using caustic baths to remove support material. The alkaline chemicals used in caustic baths can cause chemical burns and permanent blindness. The following PPE should always be worn when using the caustic bath:

- Long pants
- Closed-toe shoes
- Laboratory coat
- Nitrile gloves that cover the cuffs of the lab coat
- Splash goggles
- Chemical-resistant apron

Ensure that PPE is kept in good condition. Regularly check PPE for cracks, holes, and signs of wear.

A functioning eyewash station must be kept within 10 seconds or 55 feet of an alkaline bath. Keep the eyewash station unobstructed and easily accessible. Plumbed eyewashes must be tested weekly and recorded.

Use instruments such as tongs when adding and retrieving objects from the bath. Never add or remove objects with your hands, even with gloves on. It is permissible to add and remove objects while the bath is being agitated if no splashing is observed and all PPE is worn. It is permissible for the bath to operate unattended.

Never use the caustic bath alone. In the event of an eye exposure, use the eyewash immediately and have another employee call 911. In the event of a skin exposure, wash for 15 minutes under tepid water and have another employee call 911.

Caustic powder/liquid concentrates should be kept in a dedicated chemical storage cabinet with “Chemical Storage Area” and “Corrosive Material” labels placed conspicuously on the outside of the cabinet.

Place used liquid in EHS-provided plastic containers (carboys), complete the Waste Pickup Tag, and contact EHS for waste pickup Never pour caustic solution down the drain. When mixing a new caustic bath, fill the container with water first and slowly add the caustic powder/liquid second.

Dispose of hazardous material waste using the EHS Chemical Disposal request form

STEREOLITHOGRAPHY

Hazards & Safety Practices

Flammable Resins—The resins used by SLA printers are usually flammable. They should be kept away from heat sources and stored in a flammable-safe storage cabinet. Wear disposable nitrile gloves while handling resins.

Sharps—Removing support material using sharp instruments like razors and clippers can cause cuts and abrasions. Handle sharp instruments with care and know the location of a first aid kit.

Ultraviolet Light—SLA printers use UV lasers, lamps, or other UV light sources that can cause eye damage. Interlocks must never be defeated, and UV-blocking enclosures should always be kept in place during operation. If removing the enclosure or defeating the interlocks is required for maintenance, UV-blocking safety glasses must be worn. Work should take place in a location with the fewest people in the direct line-of-sight to minimize potential exposures. EHS must be notified if the light source needs to be exposed for assembly, maintenance, or other procedure. The lab/shop where a UV source is being used must be signed appropriately. Contact the Office of Radiation Safety for assistance.

Electrical Hazards—Assembly and maintenance can expose electrical components capable of causing shocks. Always assemble and disassemble according to manufacturer instructions. Ensure the power cable does not fray.

Post-Processing—Prints that have not been cured and have residual resin should be handled with nitrile gloves. UV ovens are often used to cure finished prints. EHS must be contacted if users plan to make a DIY curing oven. Post-processing baths using organic solvents should be kept away from heat sources.
Used liquid should be disposed of as hazardous waste via EHS.

BINDER JETTING & POWDER BED FUSION

Binder jetting and powder bed fusion are typically more hazardous than FDM and SLA. Following UW-Madison safety policies and manufacturer instructions are essential.

Metal Powders

All metal powders of any composition and particle size should be treated as hazardous, including alloys and mixtures containing non-metallic substances. Metal powders should be used with great caution.
Personal exposure can cause chronic health effects, and improper handling can result in fire or explosion.

The following safety practices should be followed for any operation handling or producing metal powders:

- Conduct activities in a manner minimizes the release of airborne dust and the possibility of spillage. When cleaning small parts, utilize a fume hood to reduce opportunity for exposure.
- A Class D fire extinguisher must be present. Contact Fire and Life Safety for assistance.
- Only use vacuums designed for use with metal powders. Conventional vacuums can cause fire or explosion. Vacuums should be electrically grounded.
- Never let machines operate unattended.

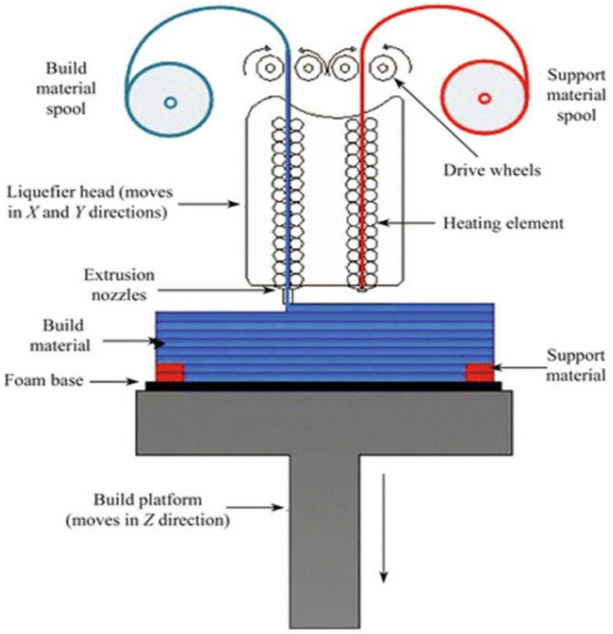
The following Personal Protective Equipment should be worn when handling metal powders:

- Long pants
- Closed-toe shoes
- Laboratory coat
- Nitrile, butyl, or neoprene gloves that cover the cuffs of the lab coat
- Safety glasses, safety goggles, or full-face respirator
- Half-face or full-face respirator with P100 filters

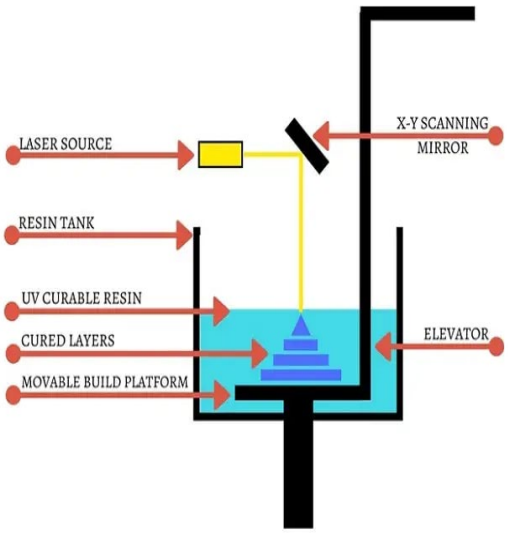
Closed containers may be handled without PPE. E-mail the EHS Occupational & Environmental Safety Office for assistance with respirators.

Lasers/Radiation

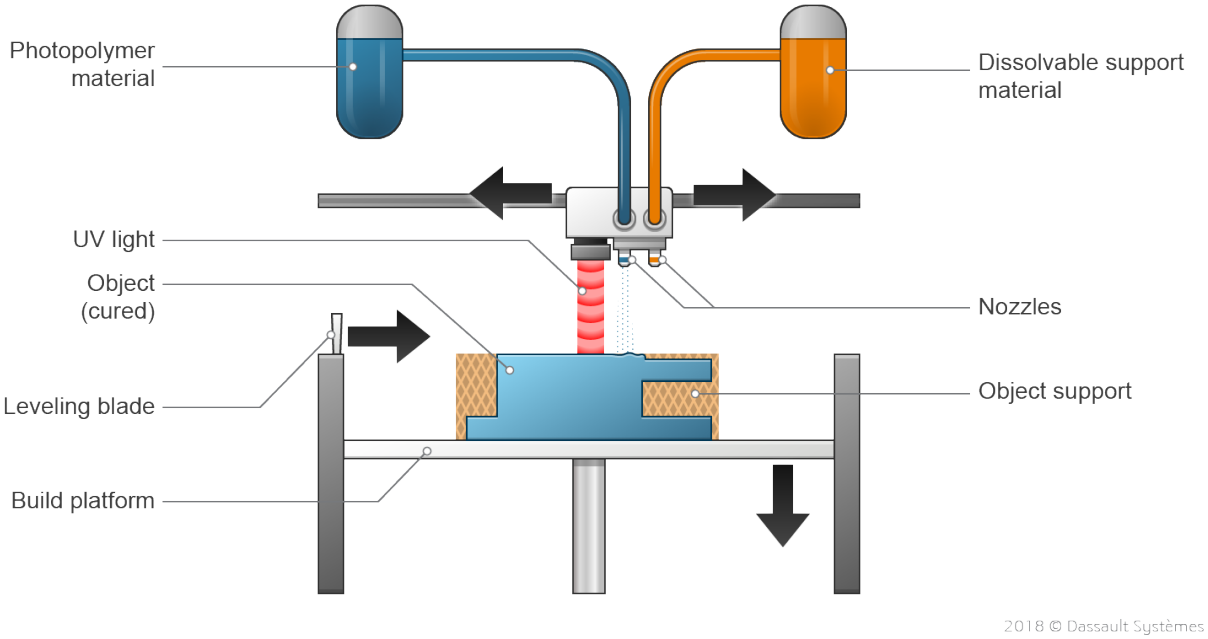
Energetic radiation such as lasers and electron beams can cause significant injury. Contact EHS Laser Safety at 608-219-6963 or lasersafety@wisc.edu to determine appropriate control measures.



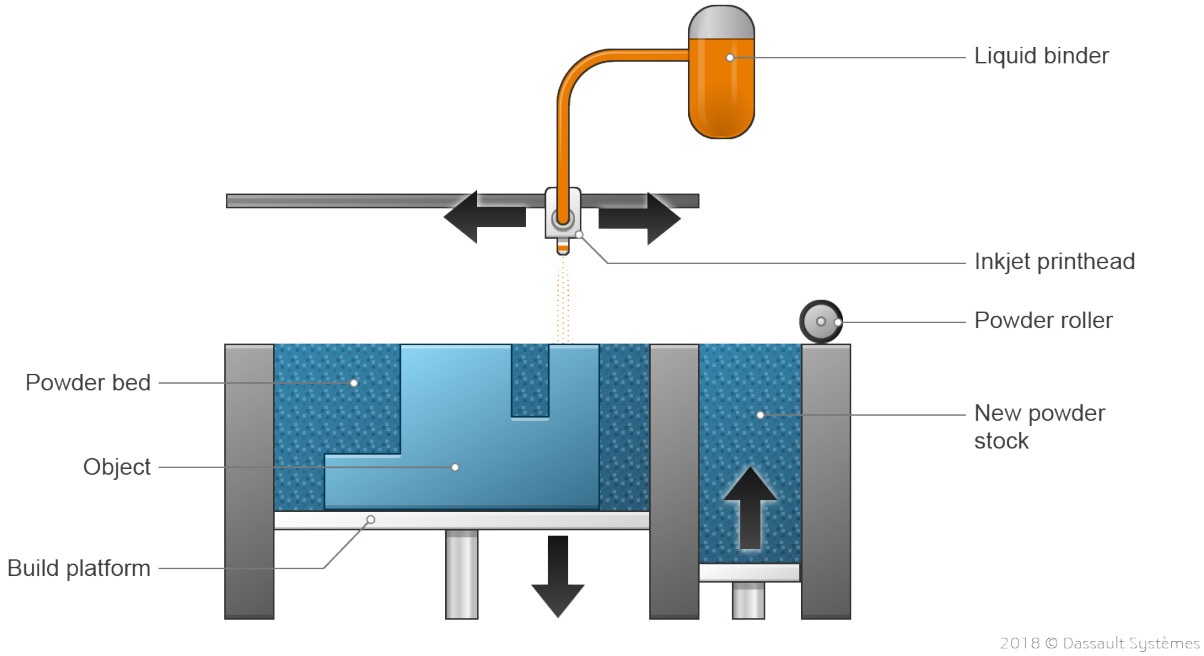
Fused Deposition Modeling



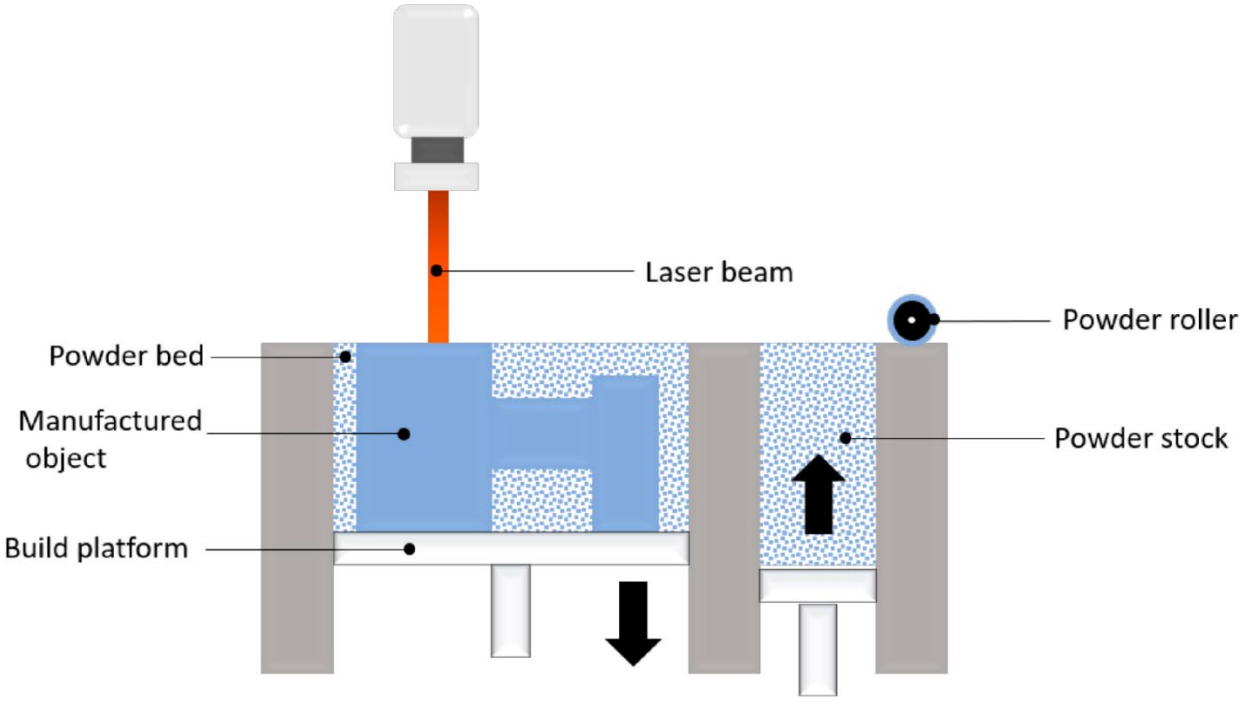
Stereolithography



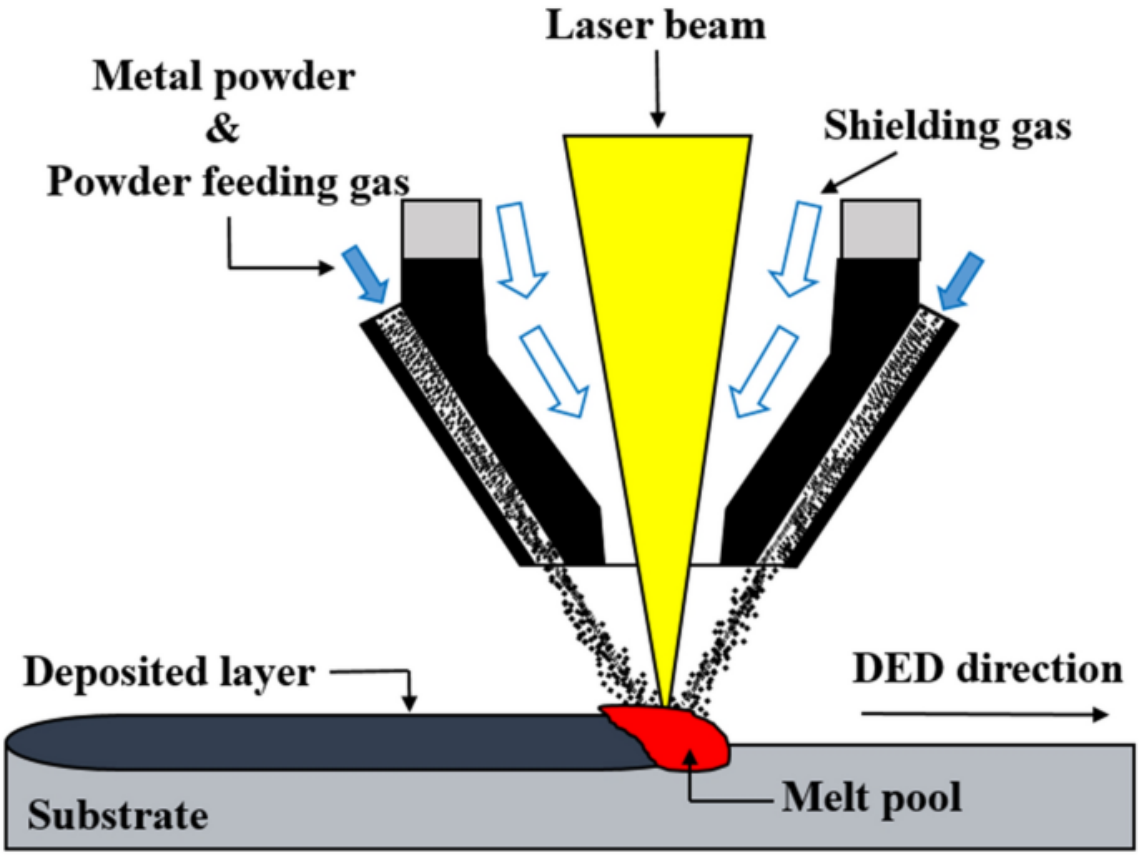
Material Jetting



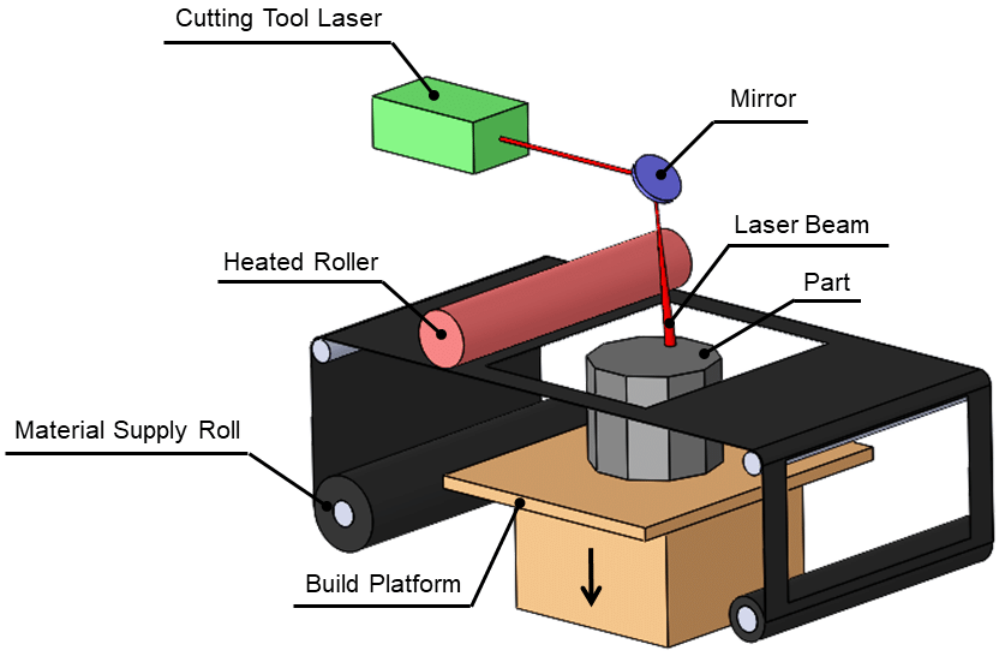
Binder Jetting



Powder Bed Fusion



Directed Energy Deposition



Sheet Lamination/Lamination Object Manufacturing

Additional Resources

Underwriters Laboratory (UL) 200B Guidance Document: Safe Use of 3D Printing for Institutions of Higher Education

The National Institute for Occupational Safety and Health (NIOSH): 3D Printing Safety at Work / Additive Manufacturing/3D Printing