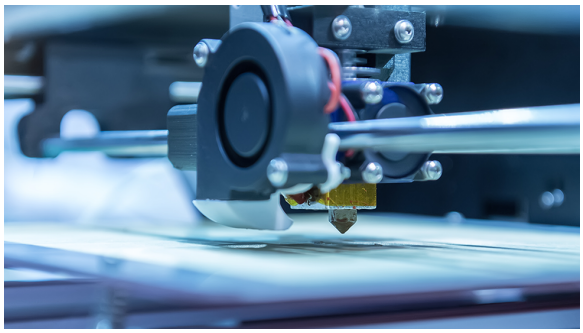
Introduction to AM

Additive Manufacturing (AM): the process and technologies utilized to create three-dimensional (3D) objects by building the object layer-by-layer with a desired material. This material (plastic, metal, and much more...) is **ADDED** in this layer fashion instead of the more commonly and older technologies of subtractive manufacturing such as milling, routing, machining, carving, etc. where material is removed from a stock shape to create the desired object.

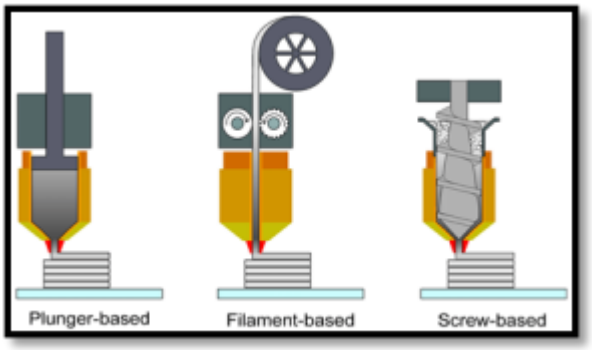
A disruptive technology that can be considered a major innovative complement to currently existing production technologies and where the design and application possibilities are almost limitless!



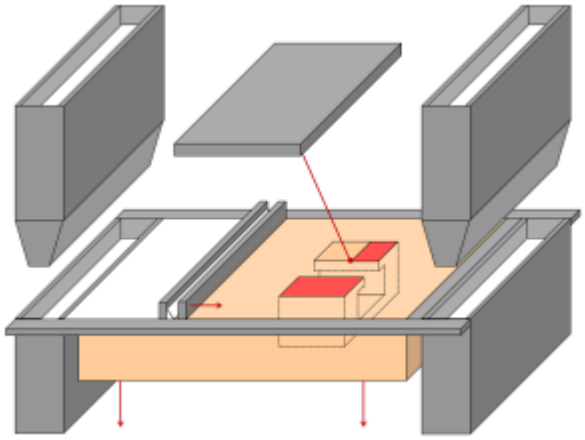
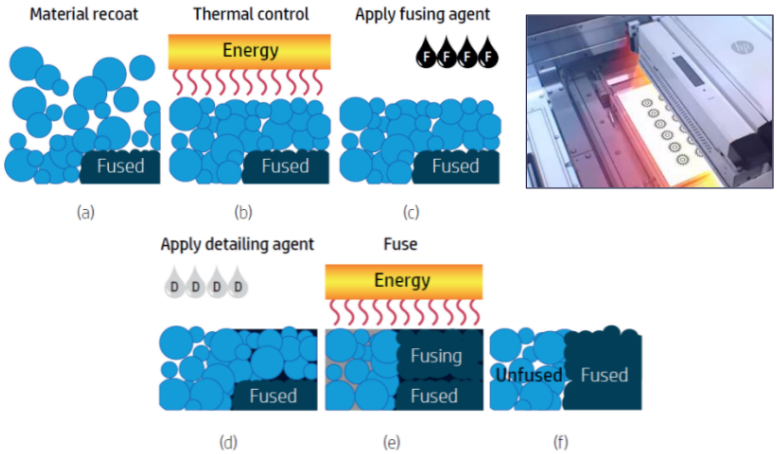
Overview of AM Technologies

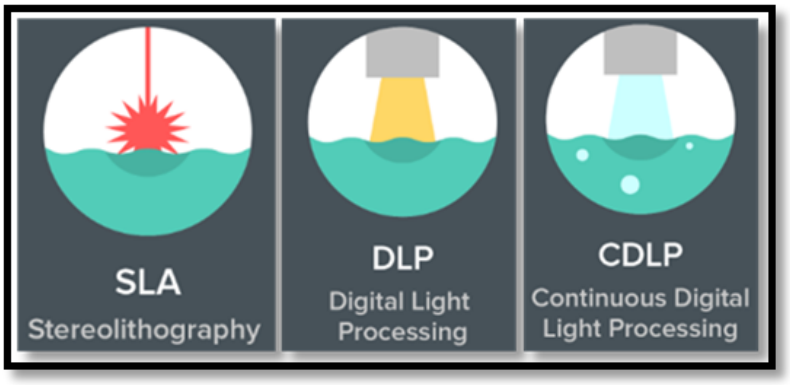
AM is a difficult process to categorize and introduce, as the number of different technologies that are considered AM are myriad and are growing exponentially very quickly. Even within what are considered the major categories, there are many different variations, some with only minute differences, but others with major modifications and innovative updates. Additionally, as such a new field of innovation, many have and are creating hybrid versions where multiple AM technologies are being combined into one process. Below are some of the major categories and a non-exhaustive list some of the more well-known subcategories.

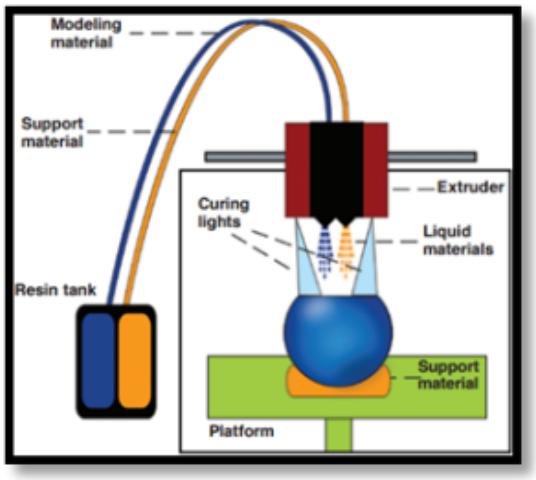
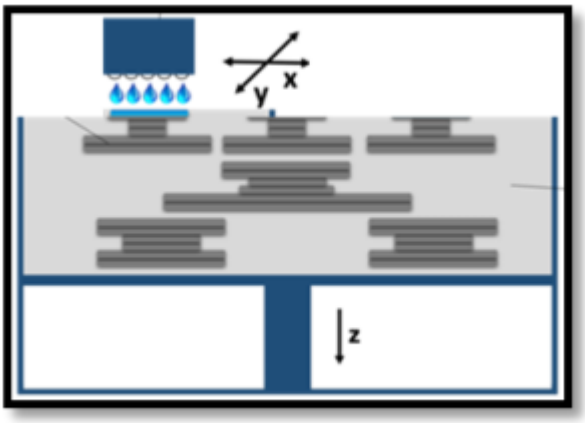
Major AM Category	Non-Exhaustive List of Included Technologies	Brief Description	Material Feedstock Form	Energy Used for Material Consolidation
Material Extrusion	Fused Filament Fabrication (FFF)	Deposit of thermoplastic filament in a layer-by-layer fashion through thermal extrusion	Filament	Thermal (sometimes additional UV or Laser)
	Fused Deposition Modeling (FDM)	Same process as FFF, but FDM is a trademarked term	Filament	Thermal (sometimes additional UV or Laser)



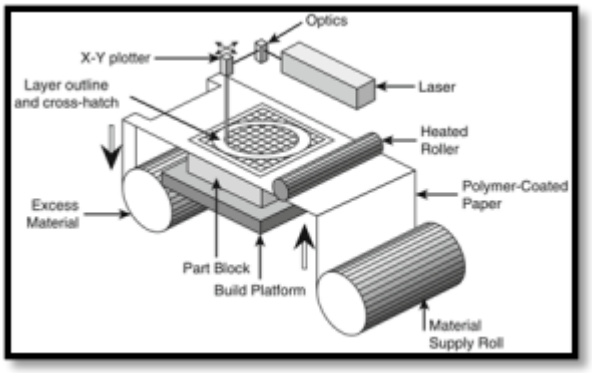
	Continuous Fiber (CF3D)	Use of continuous fiber reinforcement (either incorporated into the thermoplastic resin or applied separately) in order to gain additional mechanical reinforcement through specific designs		Continuous Fiber-Reinforced Filament	Thermal (sometimes additional UV or Laser)

Powder Bed Fusion	Selective Laser Sintering (SLS)	Application of layers of powder that are sequentially exposed to a laser that melts the current layer design. The laser penetrates multiple layers of powder to adhere the various layers together as the print progresses		Powder	Thermal and Directed Laser
	Multi-Jet Fusion (MJF)	Use of ultraviolet (UV) energy and specific application of UV-absorbing fusing agents to create thermal energy high enough to melt sequentially applied layers of powder		Powder with Liquid Additives (Spray)	Thermal and UV

Vat Polymerization	Stereolithography (SLA)	Curing of photopolymer resin in a vat via the application of a laser		Liquid	Directed Laser
	Digital Light Processing (DLP)	Similar to SLA, but exposing the entire layer at once to the laser source		Liquid	Laser
	Continuous Liquid Interface Production (CLIP) or Continuous Digital Light Processing (CDLP)	Similar to SLA, but utilizing a film/liquid interface to make the process continuous and faster than traditional SLA		Liquid	Laser
PolyJet		Application of a curable photopolymer resin (followed by curing) directly onto a print bed one layer at a time	blocked URL	Liquid	Laser

Jetting	Material Jetting	Spraying of photocurable liquid droplets onto a print platform. After application of UV energy, the droplets are cured, allowing for the next layer to be subsequently sprayed		Liquid Spray	UV
	Binder Jetting	Use of a sprayed binder materials (photocurable) to "glue" powder particles together, layer-by-layer, into the designed part		Powder with Liquid Additives (Spray)	UV

Composite Hybrid Techniques	Additive Fusion Technology (AFT)	Hybrid filament process where continuous fiber-reinforced filament is printed into the designed object. The object is then exposed to high pressure and heat to completely consolidate the layers and remove any voids		Various	Thermal and Pressure

	Sheet Lamination	Use of applied polymer powder or films to reinforcing fabric sheets. These composite fabrics are then exposed to either thermal energy or a laser to melt the polymer, consolidating it with the fabric. Following this, the individual layers are cut from the fabric, applied layer-by-layer to assemble the final part, and then exposed to heat and pressure to consolidate the layers		Various	Thermal and Pressure

AM Applications and Uses - Why Use AM?

While AM can be used for almost limitless applications and purposes, there are four major areas and a few considerations where AM is considered to be ideal:

1. **Prototyping:** Part production, from design to final production, can be an extremely expensive process. For polymers, this can include purchase of new equipment, tools, molds, etc. Iterative design steps could mandate that multiple versions of the part and required tooling be created and tested. AM is a way to significantly shorten the process and reduce costs. By utilizing AM to design and rapidly produce a prototype part, many of the time-consuming and expensive design steps can be eliminated. Depending on the part and material chosen, these **rapid prototypes** can also be considered **functional prototypes** and tested in real-world applications to validate the design. Then, once the design is vetted and finalized, there would only need to be one subsequent step to obtain and produce all final equipment and tools needed for ramped production.
2. **Tooling:** AM can be an extremely valuable way to produce customized tools and jigs. There are many real-world examples where a specific tool is necessary that either does not currently exist or is needed in a short period of time that precludes being able to obtain the tool through traditional routes. As extreme examples, AM is currently being highly examined for use in locations where keeping large stocks of tools is not feasible, such as space, on ships, and in remote locations. In these situations, keeping a common feedstock material that can be printed into the necessary form is more feasible. Additionally, there are many instances where a highly customized tool or jig that currently does not exist is required. AM is ideal for creation of these tools and can be created very rapidly, even if multiple iterative design steps are required to perfect the design.
3. **Low Volume (But Rapid) Production:** While AM cannot currently compete with more established polymer processing techniques (like injection molding) for large production purposes, there is a cost and time benefit comparison to be made in favor of AM for small-series production. Equipment for part production can be extremely expensive and may not make sense for certain applications where low volume is required. In these cases, AM is ideal because customized and non-reusable equipment is not necessary and only requires intelligent design of the part. This kind of paradigm shift in production can be particularly advantageous in markets such as **healthcare and aerospace** where low volume production is fairly common.
4. **High Customization:** On a similar note, AM is extremely ideal for highly customized parts. Instead of using relatively wasteful subtractive manufacturing in order to produce parts that are slightly different for each part or production run, AM can be used to directly print each customized part.
5. **Other Considerations:**
    a. **Waste Reduction:** Compared directly to subtractive manufacturing, where waste is considered very high even with some recycling techniques, and compared to traditional polymer processing techniques where waste is still present (like the sprues and runners of injection molding), there is very little waste when utilizing AM. This is especially true with some of the AM technologies, like FFF, where waste can be virtually zero. Material is normally used only in the part itself.
    b. **Complexity:** As a result of building the part up instead of down (subtractive manufacturing), parts can be made as complex as imagination, the technology, and printer are capable. With subtractive engineering, the more complex designs are usually paired with extreme difficulty and drastically increased costs. With AM, "complexity is free," as the complexity of the part is designed from the beginning with no extra time required to create the complexity. There will be some design requirements to follow per each technology, but if within those requirements, complexity is almost limitless.
    c. **Part Consolidation:** Due to the ability to print complex shapes that may be impossible by any other polymer processing technique, some other post-production steps may also be able to be eliminated. This is especially true in part consolidation or assembly steps. In many cases, certain parts can be printed already assembled or as one entire part. This can save time and costs in production.