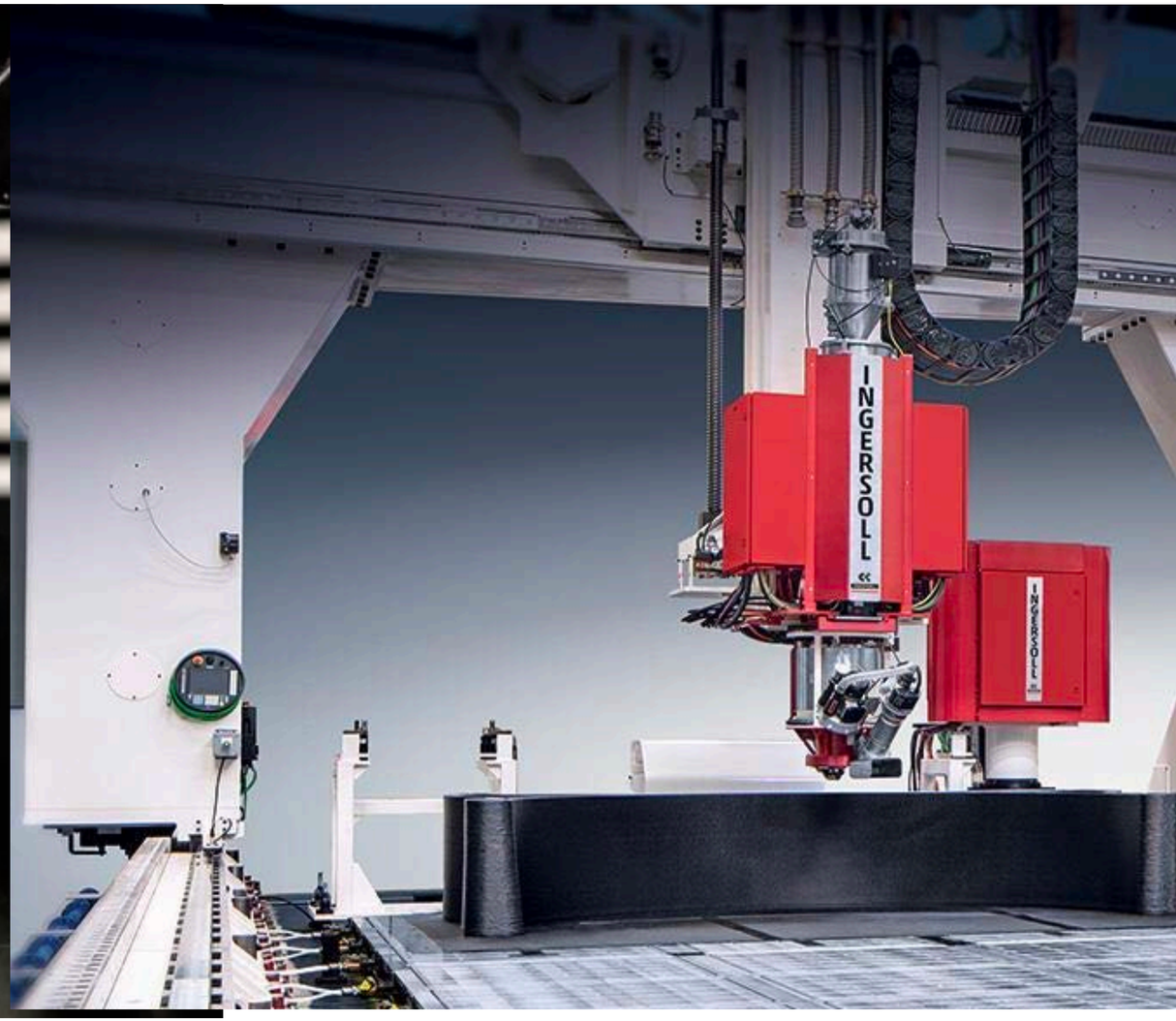
Layered Manufacturing

Additive Manufacturing



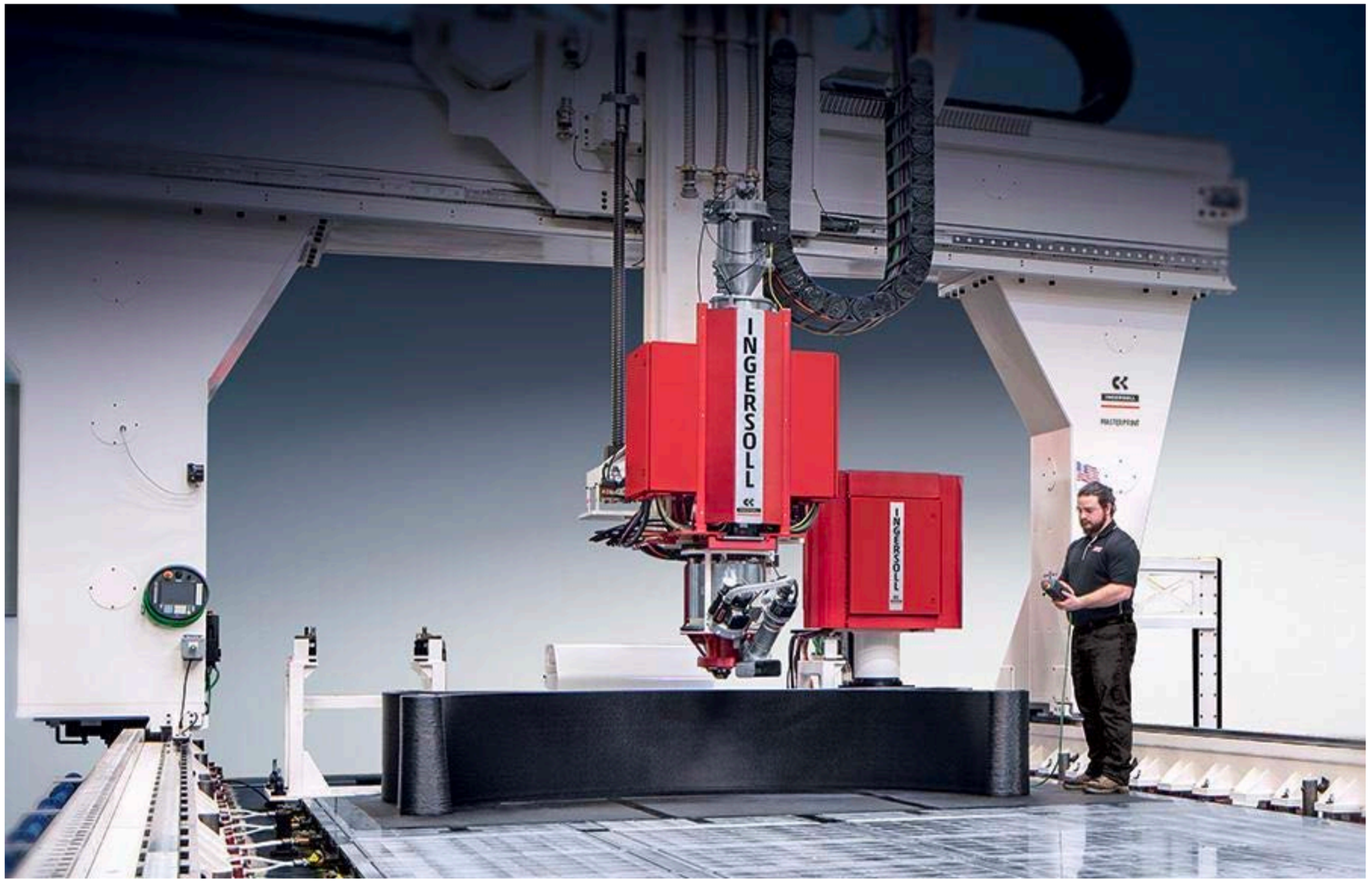
3D Printing in the Context of Manufacturing

connect to existing knowledge: formalize understanding

understand the workflow for additive manufacturing

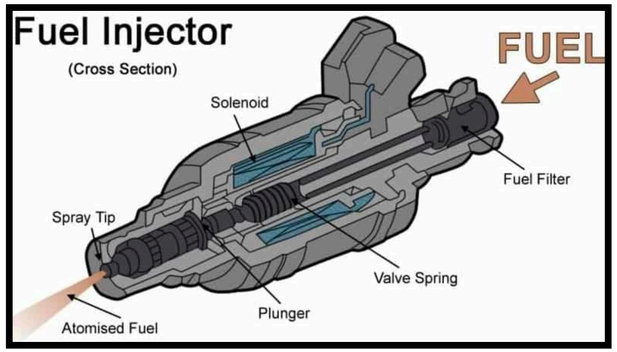
compare types of AM to understand tradeoffs

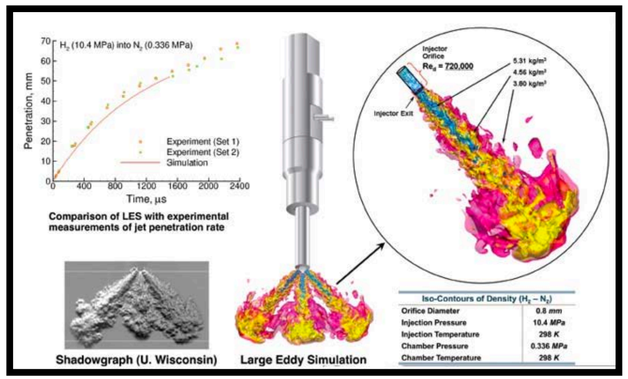
explore AM in the context of manufacturing in industry



Layered Manufacturing

Additive Manufacturing





concept — mass production — end

design

fabrication

“3D Printing”

manufacturing

manufacturing (at scale)

“Additive Manufacturing”

Layered Manufacturing

Additive Manufacturing

injection molding

thermoforming

casting

forming

machining

Forming/Casting Processes

injection molding

thermoforming

casting

forming

machining

Subtractive Processes

machining

grinding

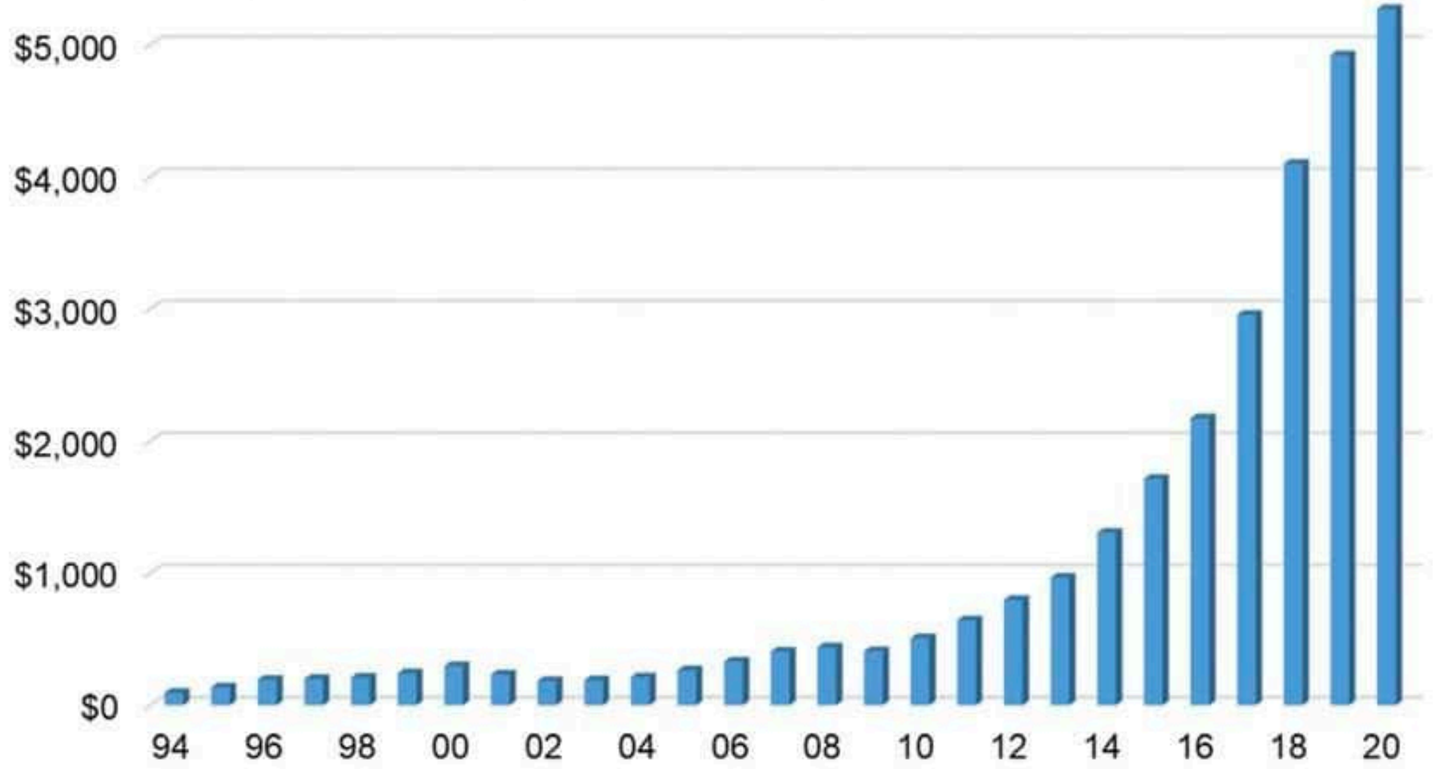
laser/waterjet

Additive Processes

there are many!

AM Growth

Production of AM parts from independent service providers in millions of dollars:



Production of AM parts from independent service providers (in millions of dollars). Source: Wohlers Report 2021

Additive Manufacturing: ~$5 billion

Global Manufacturing: ~$12 trillion

there's more to the story than direct manufacturing of parts/ products

Layered Manufacturing

Additive Manufacturing

Additive Processes

all use a **computer model** to guide the depositing of material to build a part up **layer by layer**

Extrusion

Photopolymerization

Material Jetting

Powder Bed Fusion

Additive Processes

common types on MIT's campus

Extrusion

Photopolymerization

Material Jetting

Powder Bed Fusion

Additive Processes

processes we'll be examining in more detail

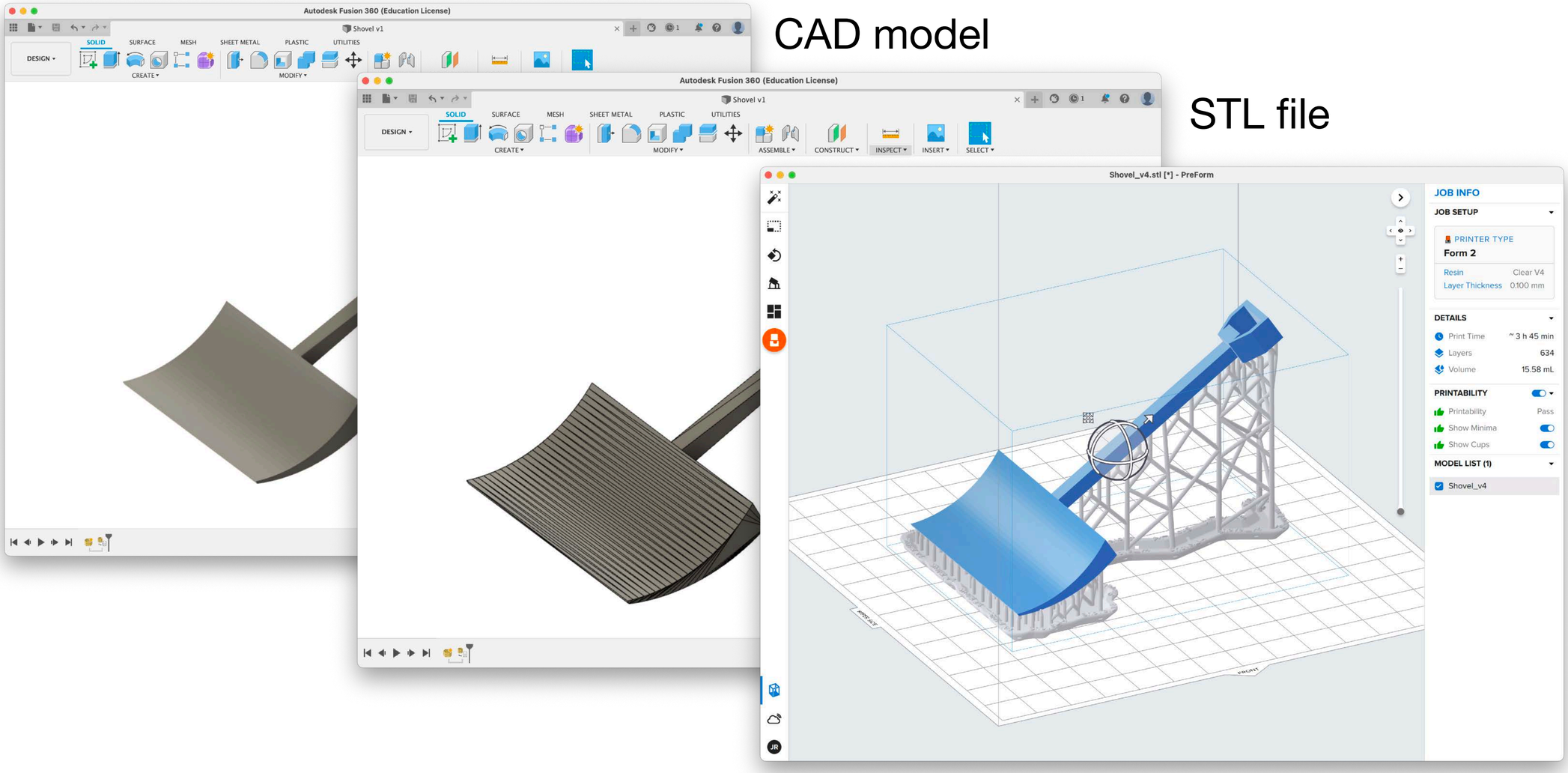
Extrusion

Photopolymerization

Material Jetting

Powder Bed Fusion

AM Workflow all processes follow a similar workflow



CAD model

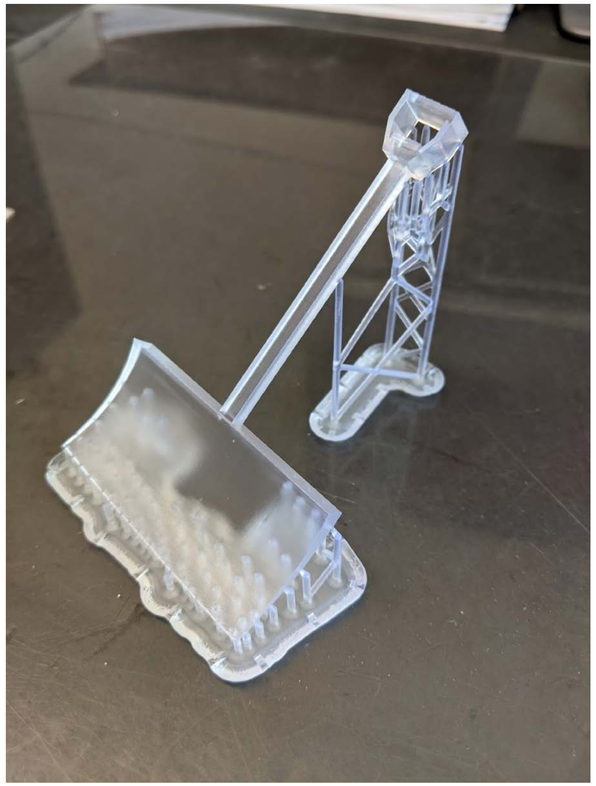
STL file

setup/
slicing/
processing

producing
and dealing
with
supports is
fundamental
to AM

AM Workflow all processes follow a similar workflow

execution



post processing +
support removal

➡ manufacturing consequences

Extrusion: Overview

Extrusion

Properties of the filament
- High buckling pressure
- High stiffness
- High rigidity

Melt rheology during extrusion
- Shear thinning behaviour
- Appropriate melt viscosity

Properties of the extrudate
- Rapid viscosity increase
- Good layer bonding

Extrusion mechanism
Should be preloaded with enough pressure to have good grip on the filament to assure continuous flow of material without grinding it

Cold-end
Should have a heat sink capable of limiting any heat escaped from the hot-end upward to the other parts of the extrusion system

Hot-end
Should provide enough heat to properly melt the extruded material at different extrusion speeds

Extrusion: Industrial 3D Printers

Extrusion

Product Life Cycle

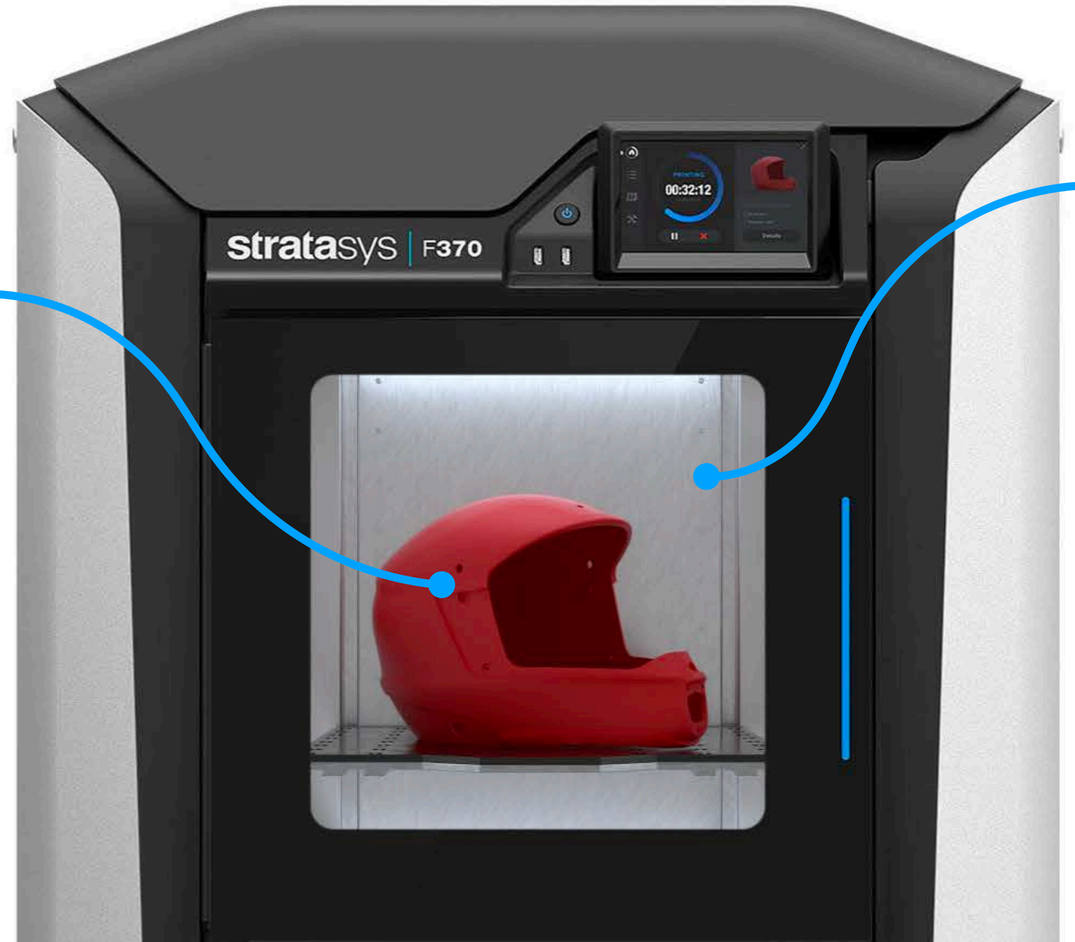
Extrusion

instrumented cartridges

ABS example

T_{melt} = 200°C

T_{ext} = 230°C



heated build chamber

T_g = 105°C

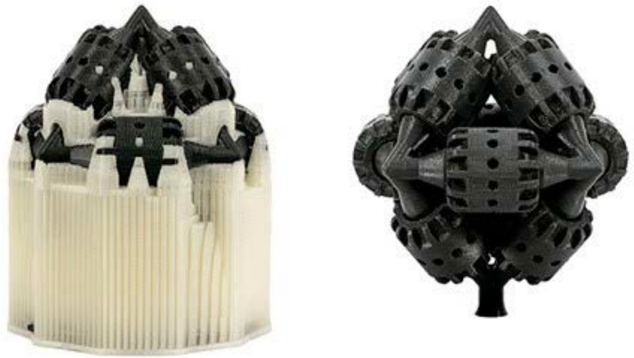
T_{hbc} = 70°C

Extrusion: Materials

several materials available

ABS: stiff, stable, tough prone to warping

PLA: easy to print, stiff, biodegradable not as tough



Nylon: strong, durable, lightweight absorbs moisture

TPU: flexible, impact resistant 3D printing a noodle…

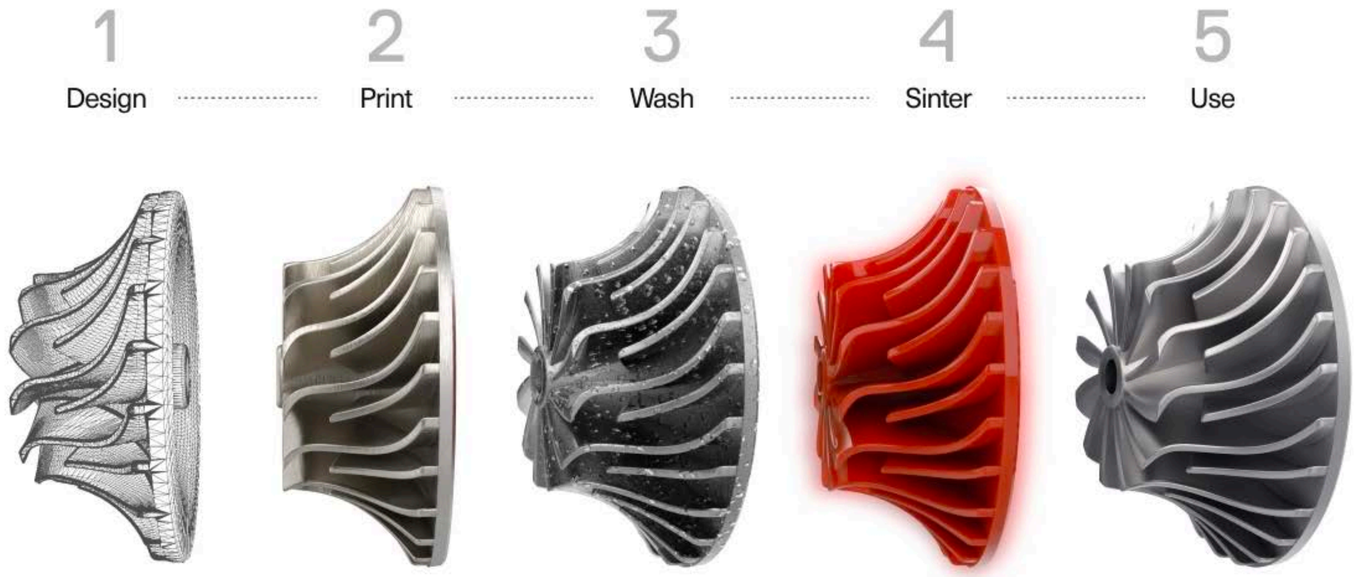
composites: extremely strong and tough requires special printers/materials

supports: breakaway or dissolvable

why polymers and not metals?

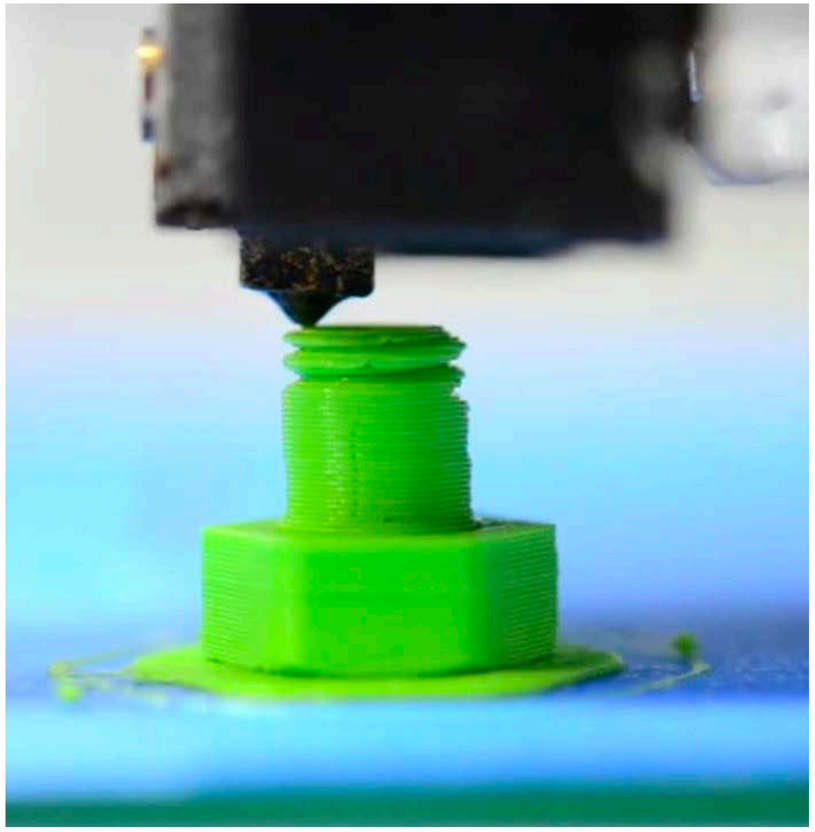
Extrusion: Materials

polymers vs metals BPE: Bound Powder Extrusion



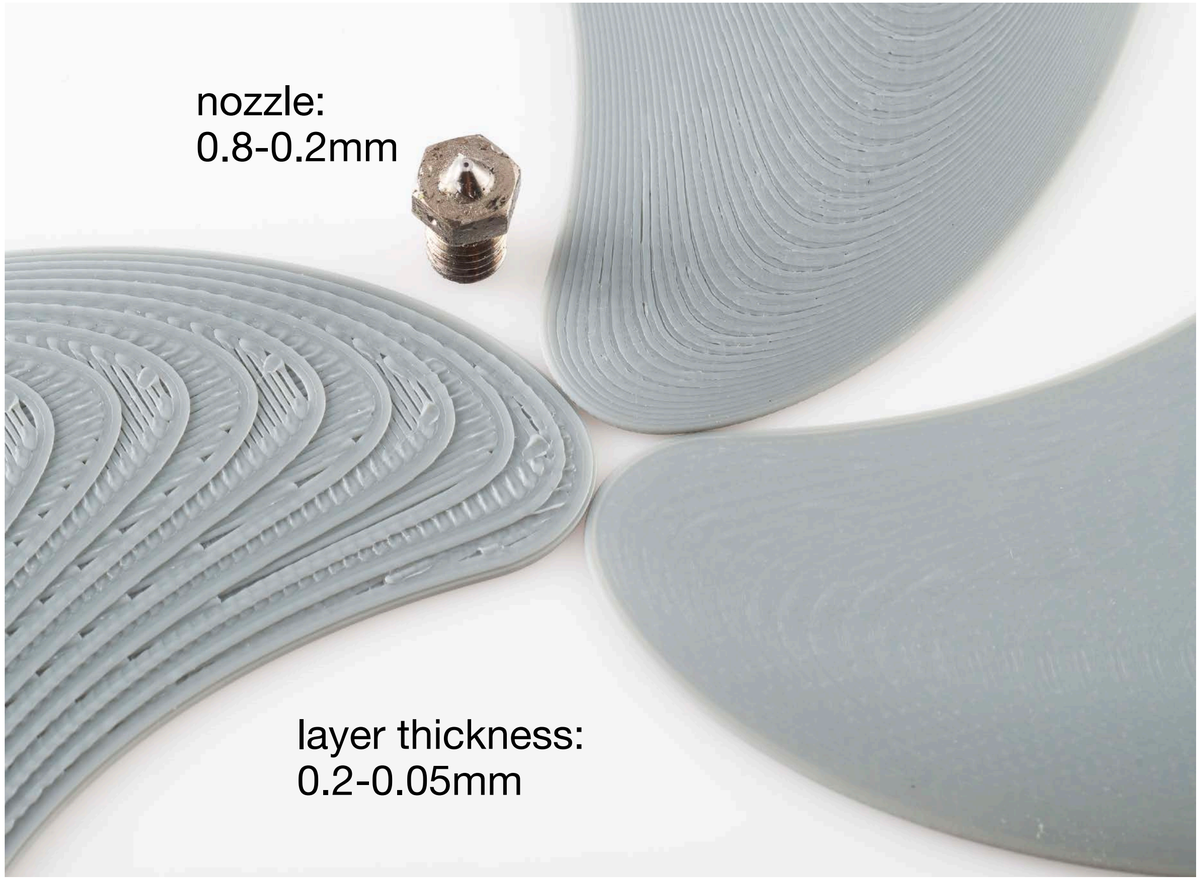
Extrusion: Tradeoffs

single point process - nozzle moves to entire volume



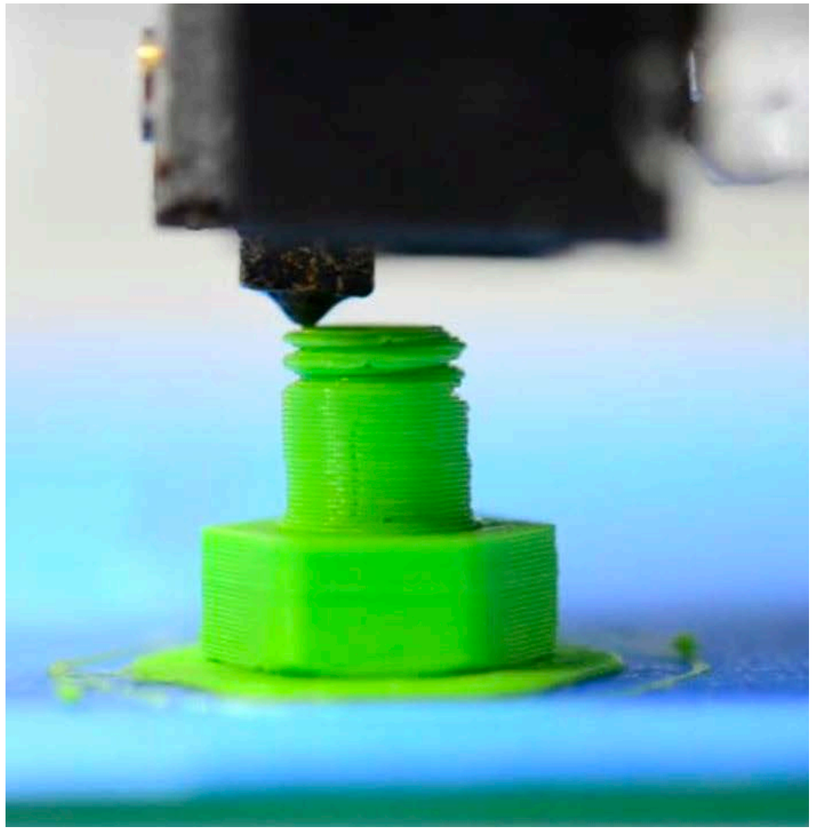
Quality

resolution: surface finish, speed tradeoff

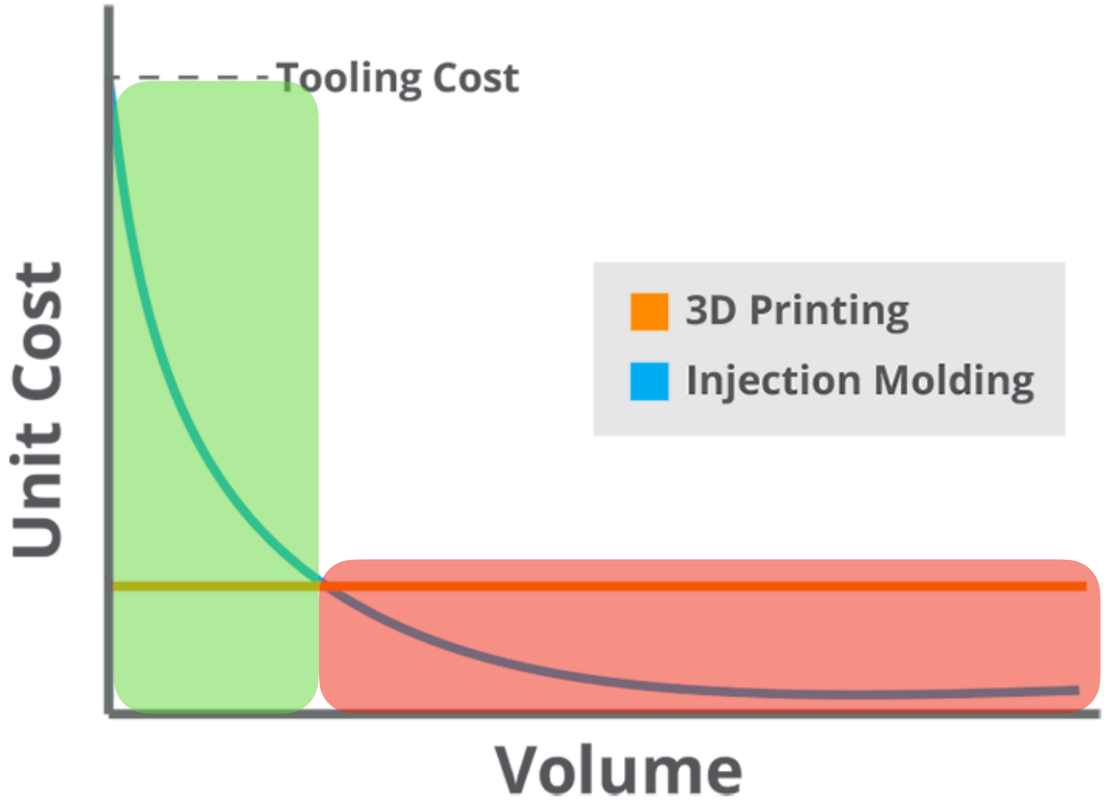


Extrusion: Tradeoffs

single point process - nozzle moves to entire volume

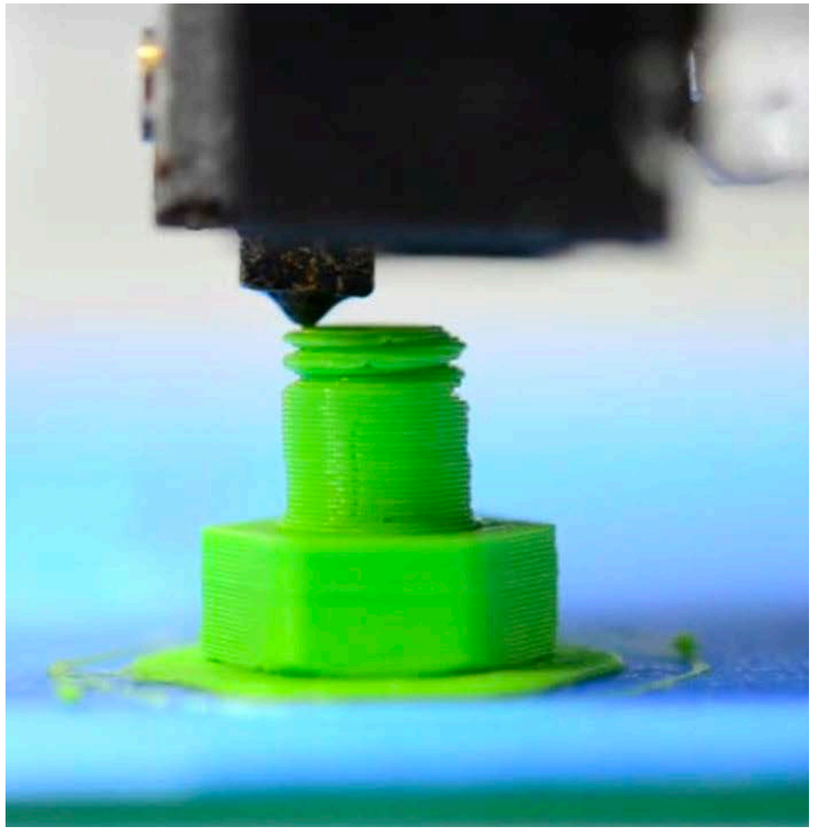


Cost



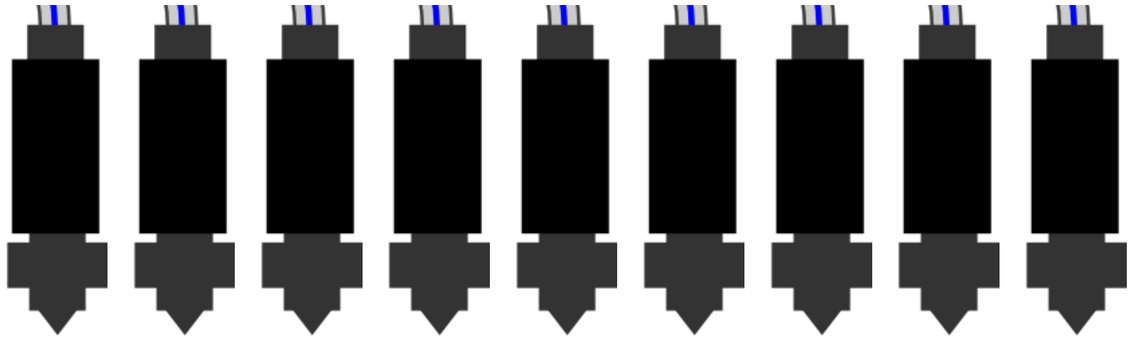
Extrusion: Tradeoffs

single point process - nozzle moves to entire volume

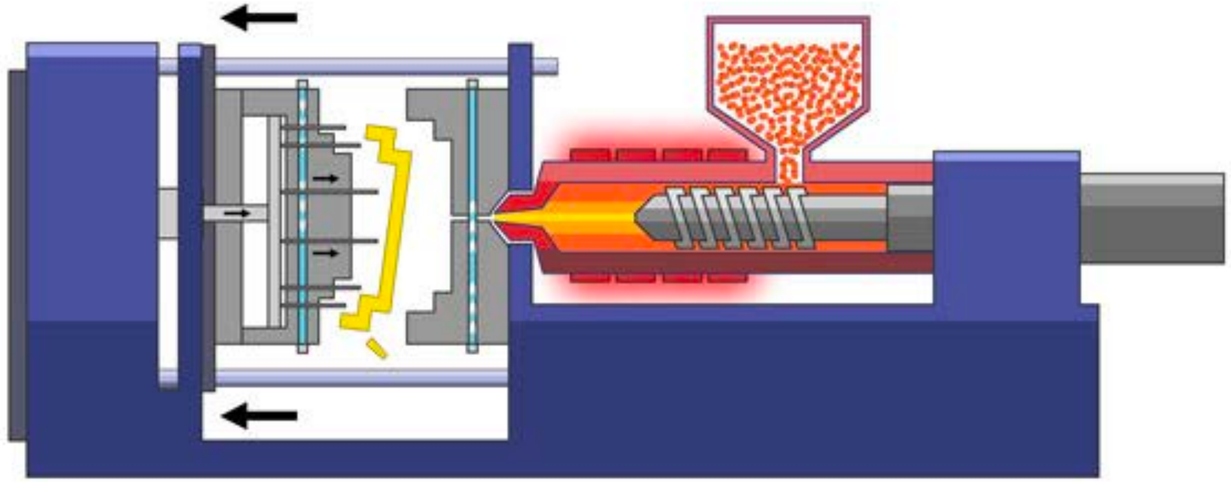


Rate limited by single point

whole layer at once?

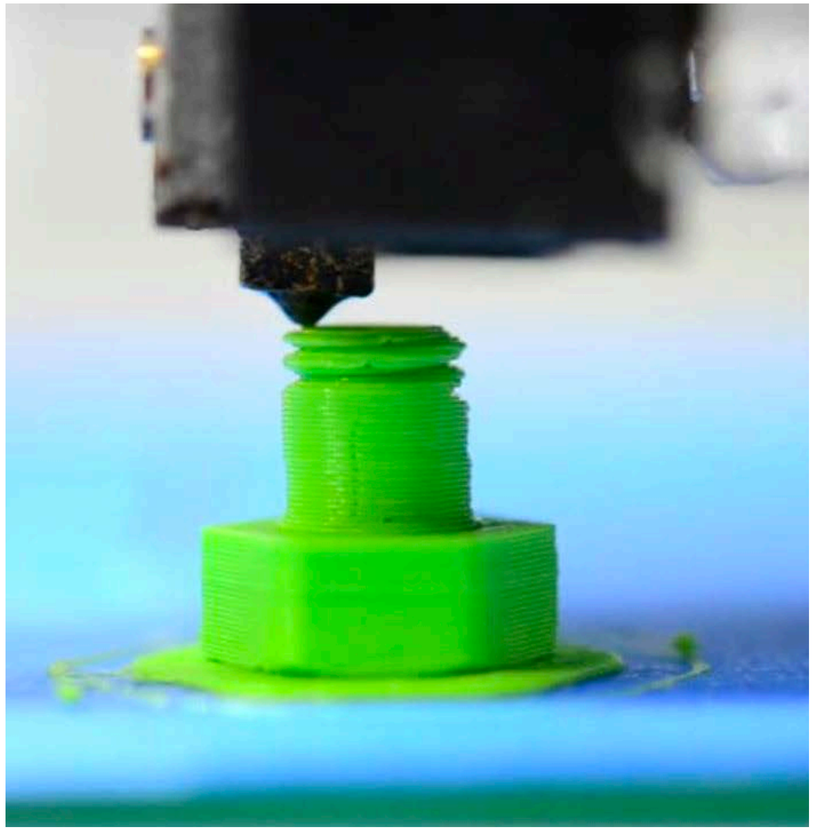


whole part?



Extrusion: Tradeoffs

single point process - nozzle moves to entire volume



Quality **Cost** **Rate**

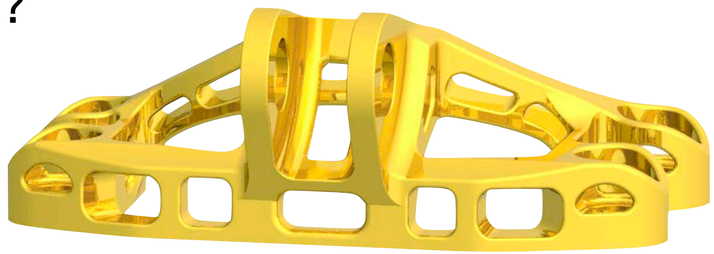
?

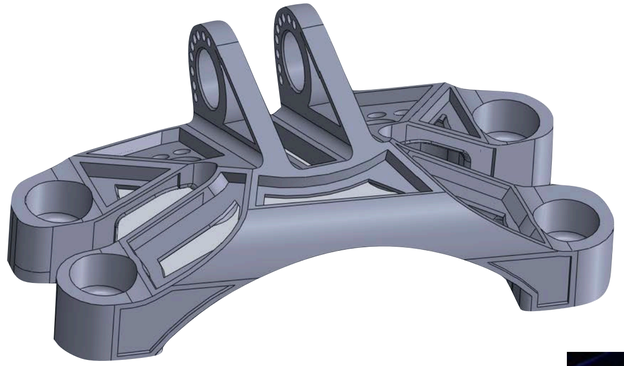
Flexibility

Layered Manufacturing

Additive Manufacturing

GE Jet Engine Bracket Challenge what does this flexibility get you?





as you increase complexity: new parts become possible

GE Jet Engine Bracket Challenge what does this flexibility get you?

traditional manufacturing processes:

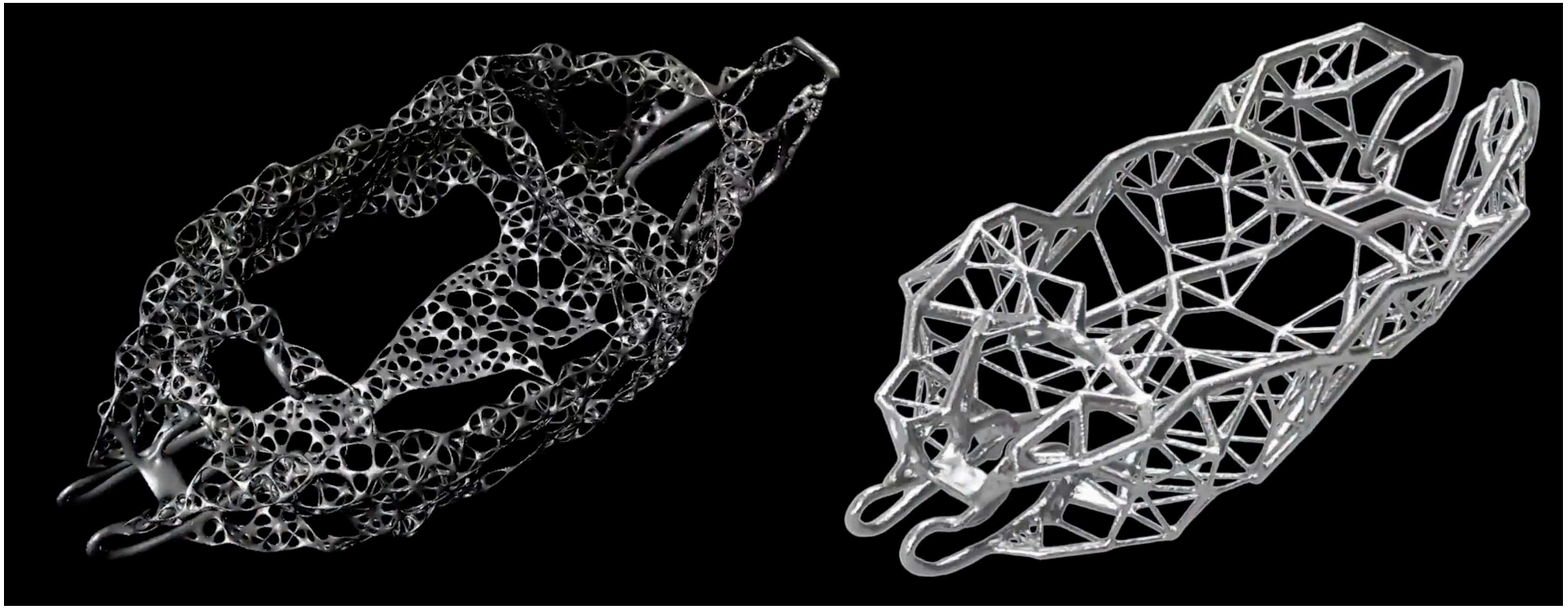
- longer production
- more expensive
- might be impossible

additive:

- faster production times
- lower production cost
- more designs are possible

complexity is free
(sometimes more than free)

Flexibility: Complexity



complexity ➡ higher performance (sometimes, not always!)

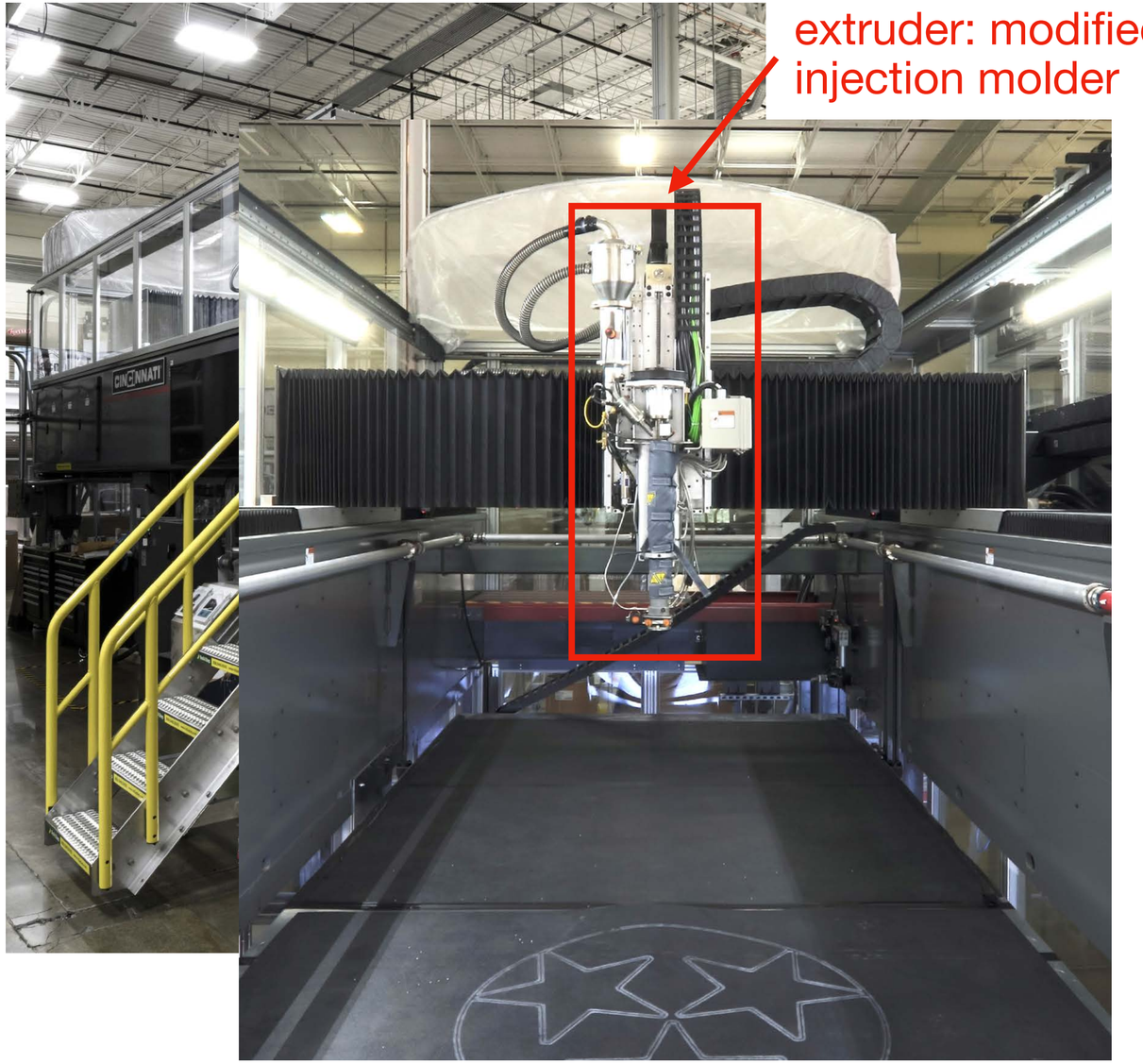
Extrusion: Going Big

where else besides directly making parts? tooling

extrusion: easy to scale up

Oak Ridge National Lab

Big Area / Large Format Additive Manufacturing



Additive Engineering Solutions

Typical LFAM Layers

Layer Dimensions: 1"+ wide x 0.25" thick

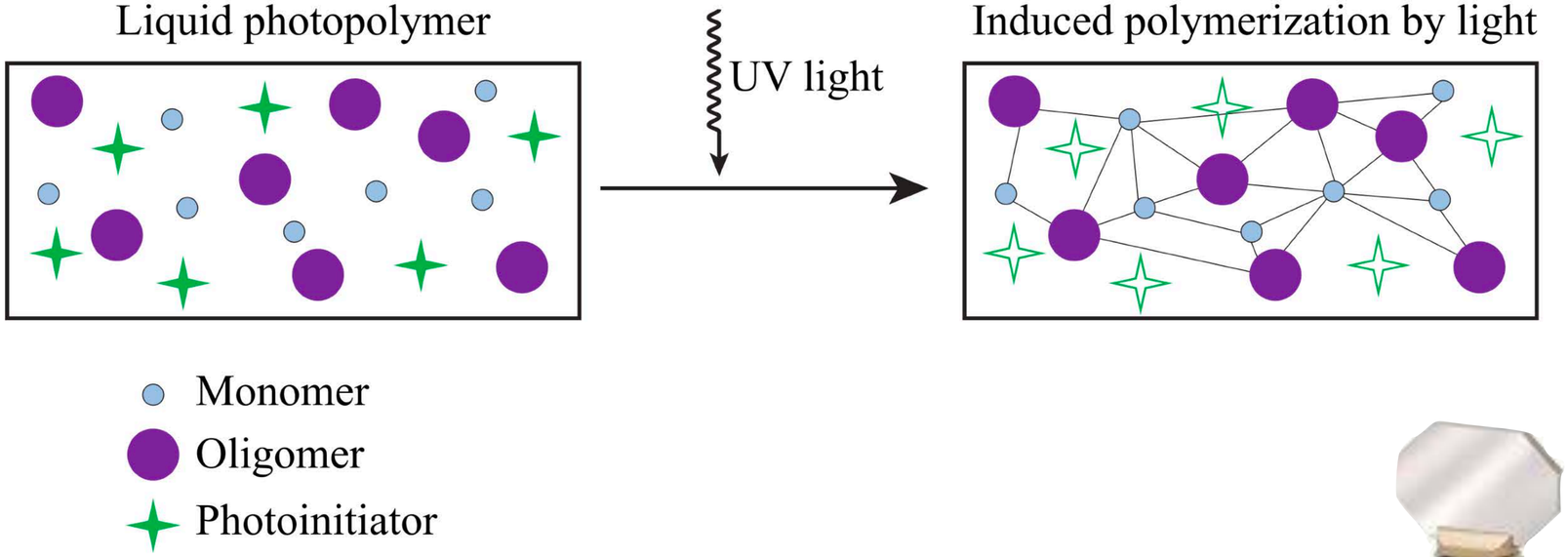
Results: approximately 0.250"- 0.500" to final dimensions

how to get tighter tolerances?

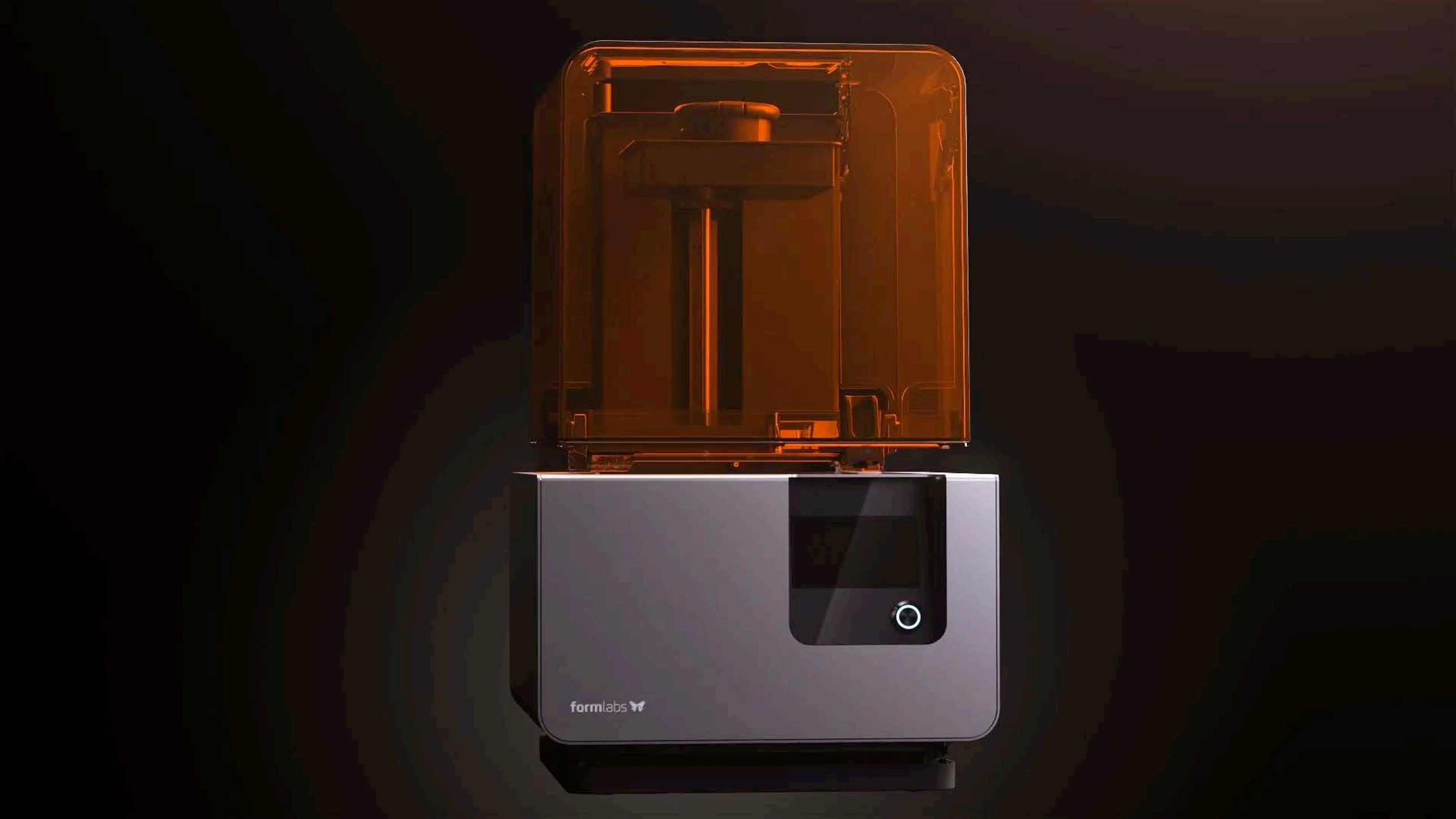
AM + CNC machining

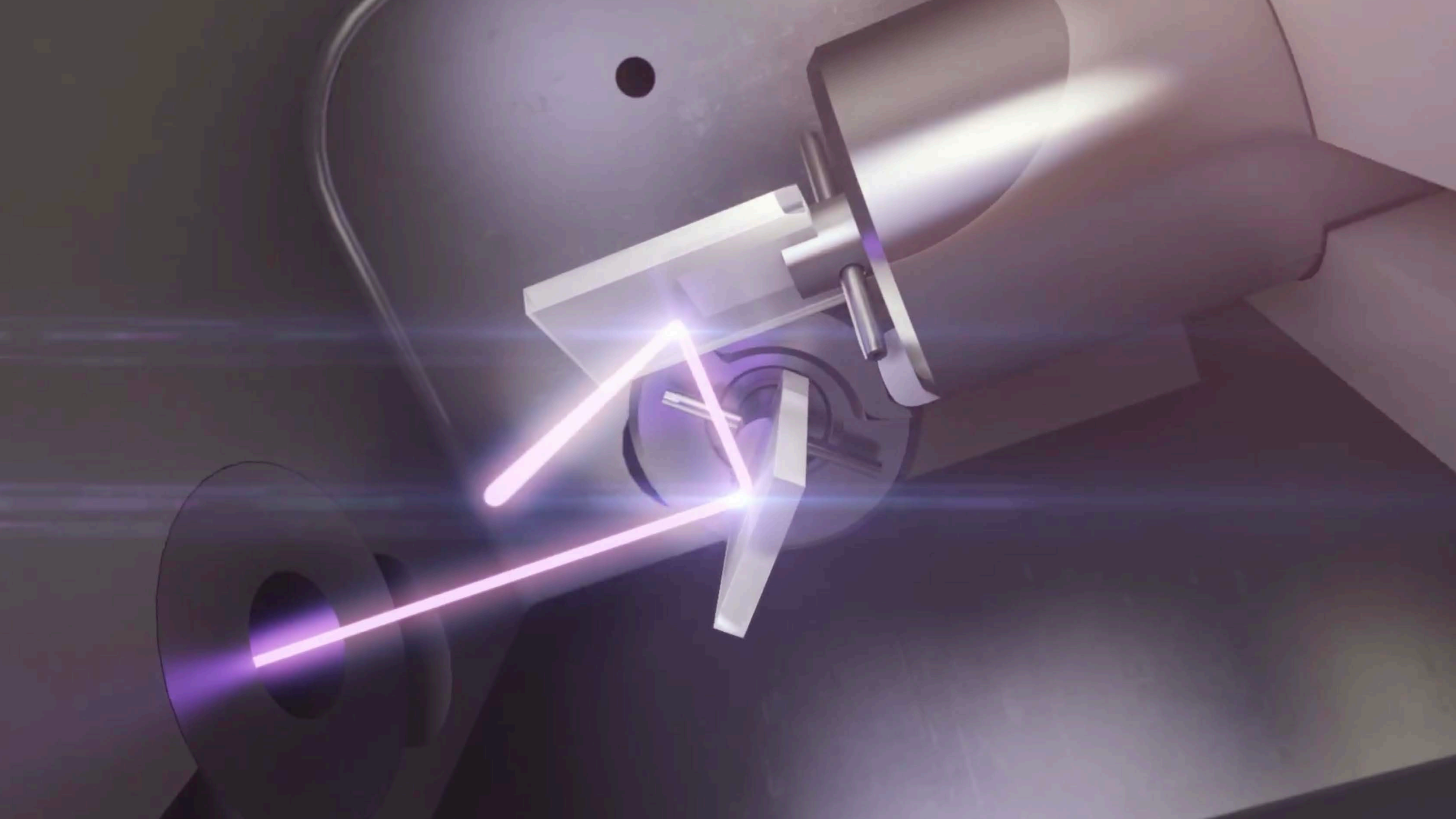
Photopolymerization: Curing Resins SLA: Stereolithography

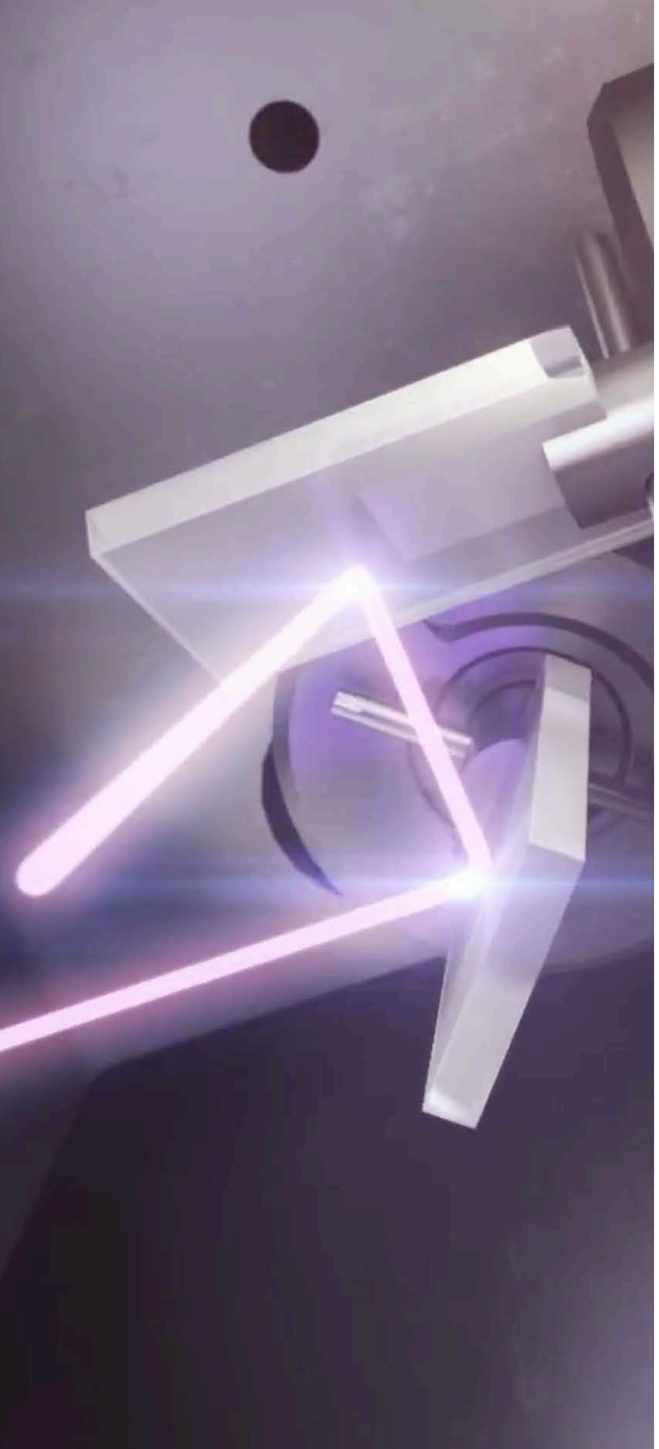
Photopolymerization

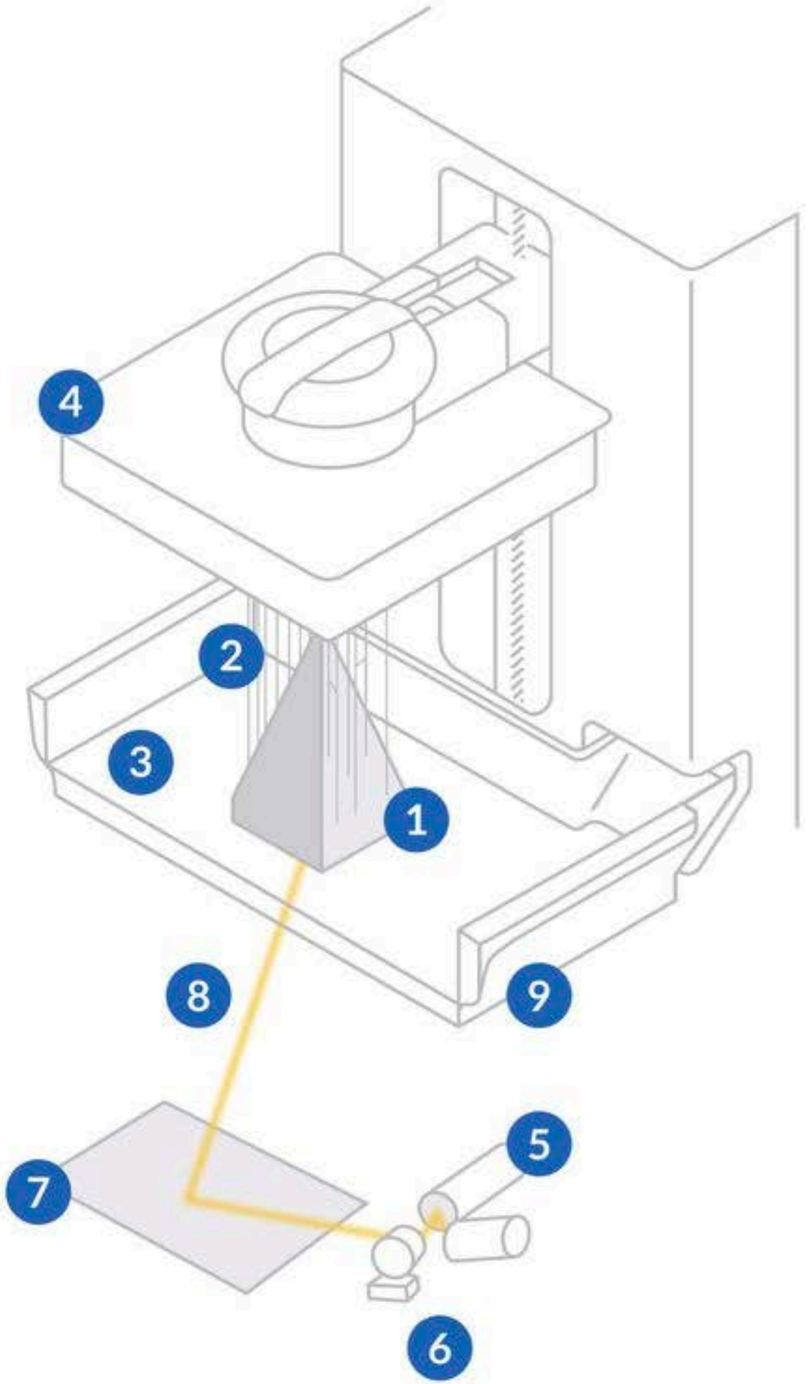


single point: laser directed by galvanometers and mirrors


formlabs



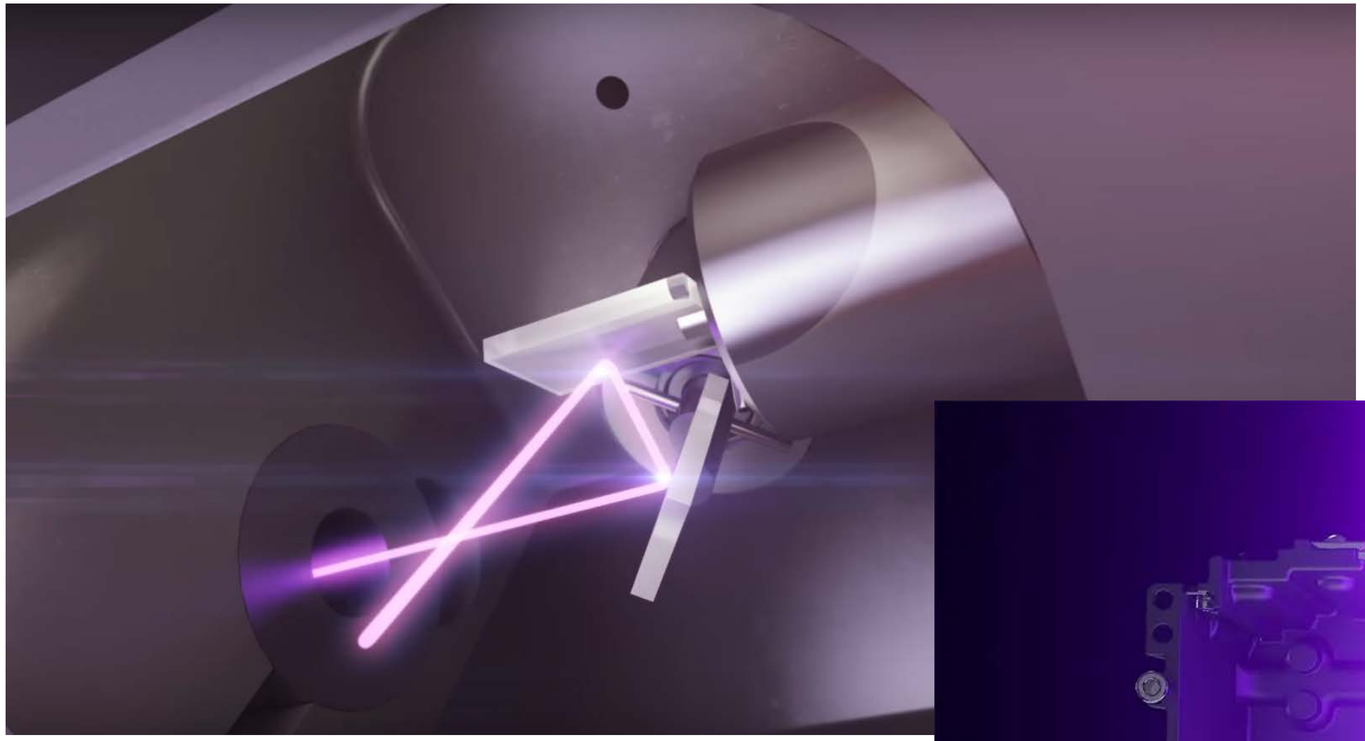




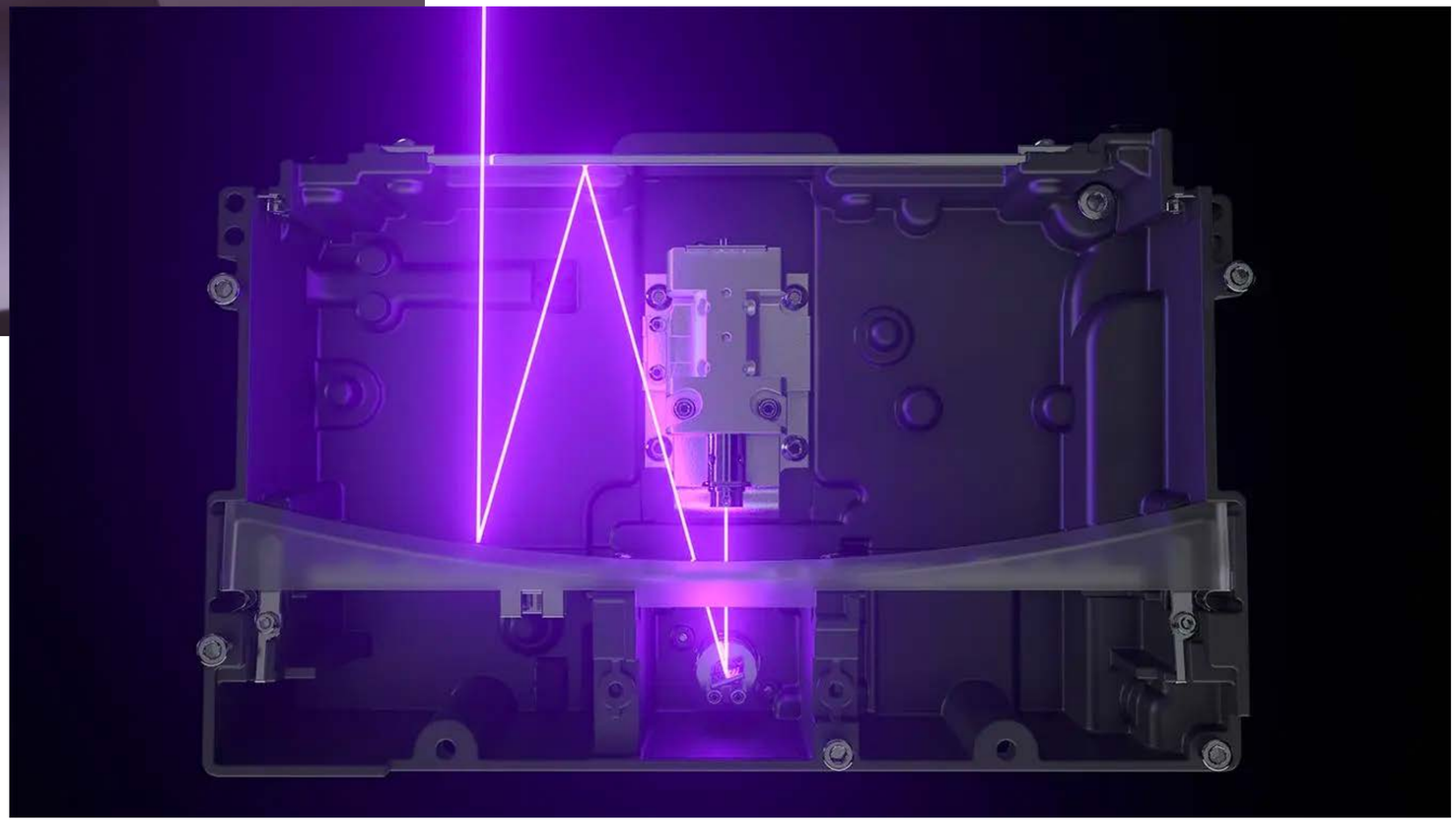
Upside-Down (Inverted) SLA

1. Printed Part
2. Supports
3. Resin
4. Build Platform
5. Laser
6. Galvanometers
7. X-Y Scanning Mirror
8. Laser Beam
9. Resin Tank

Form 2



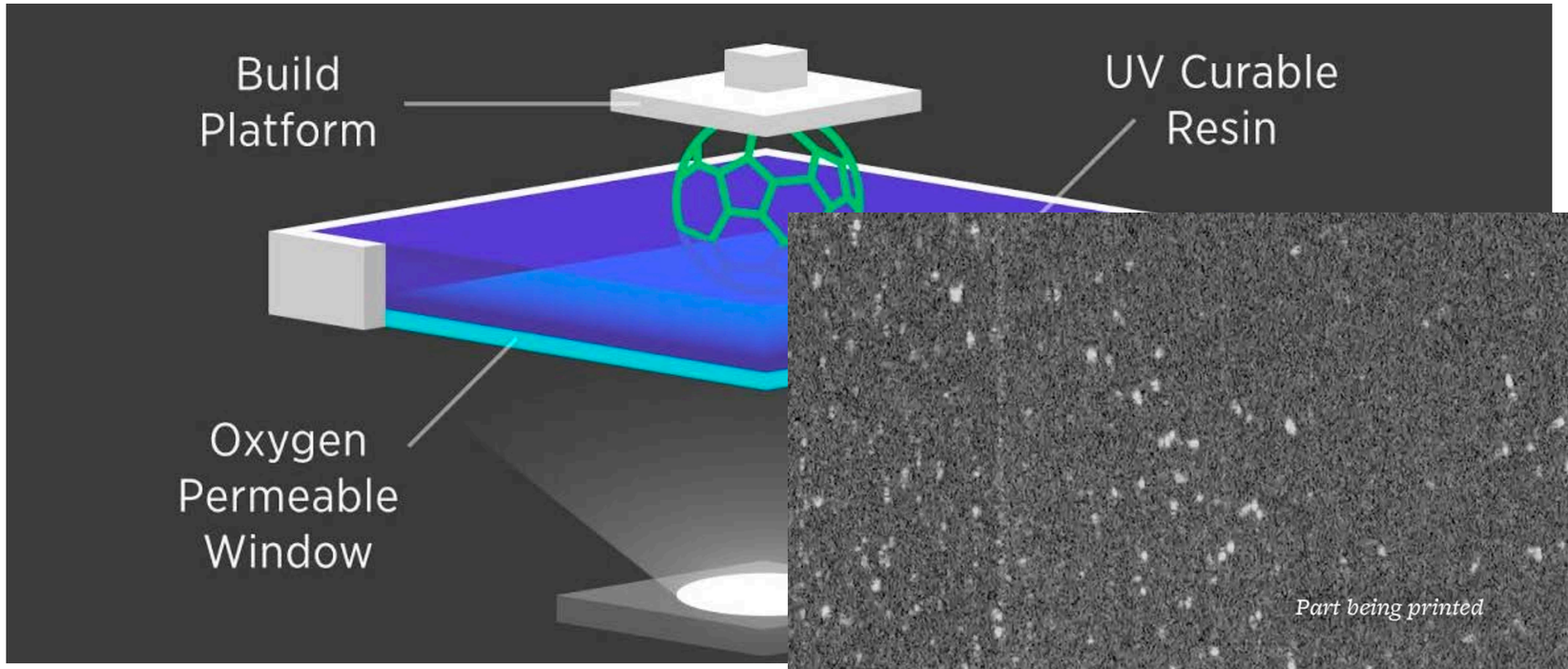
Form 3

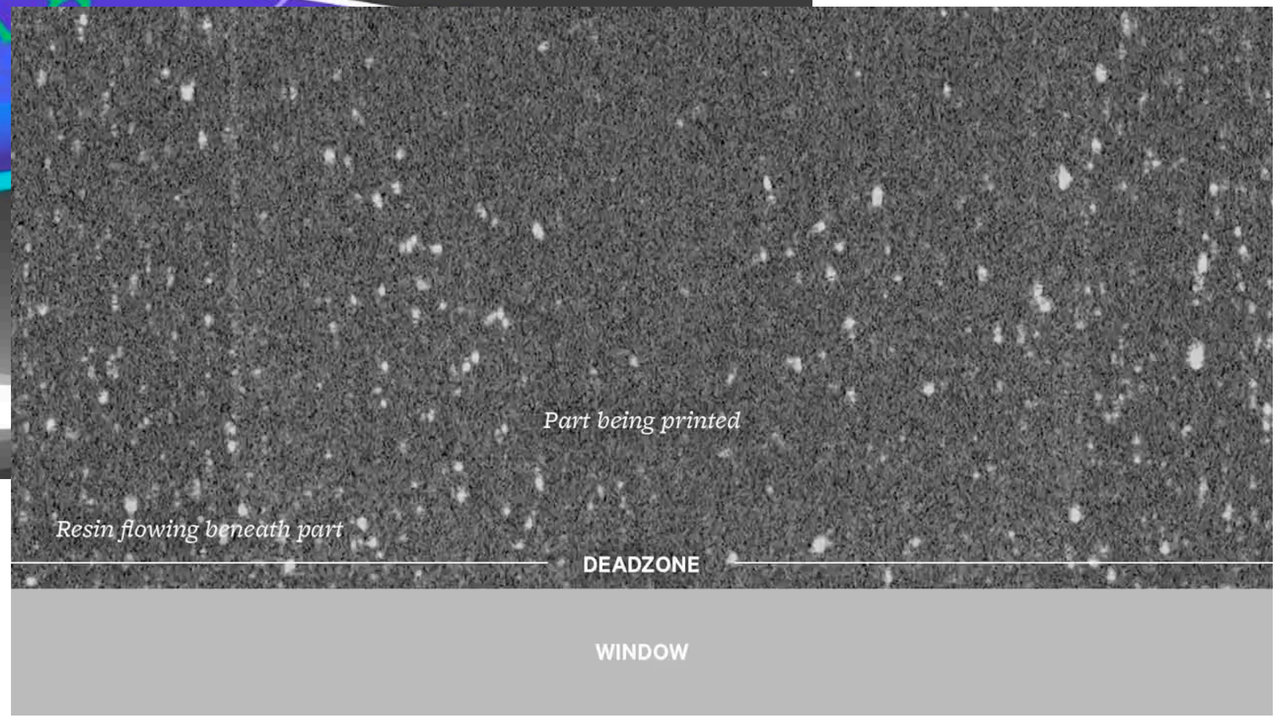


Photopolymerization: Full Layer Curing

DLP: Digital Light Projection

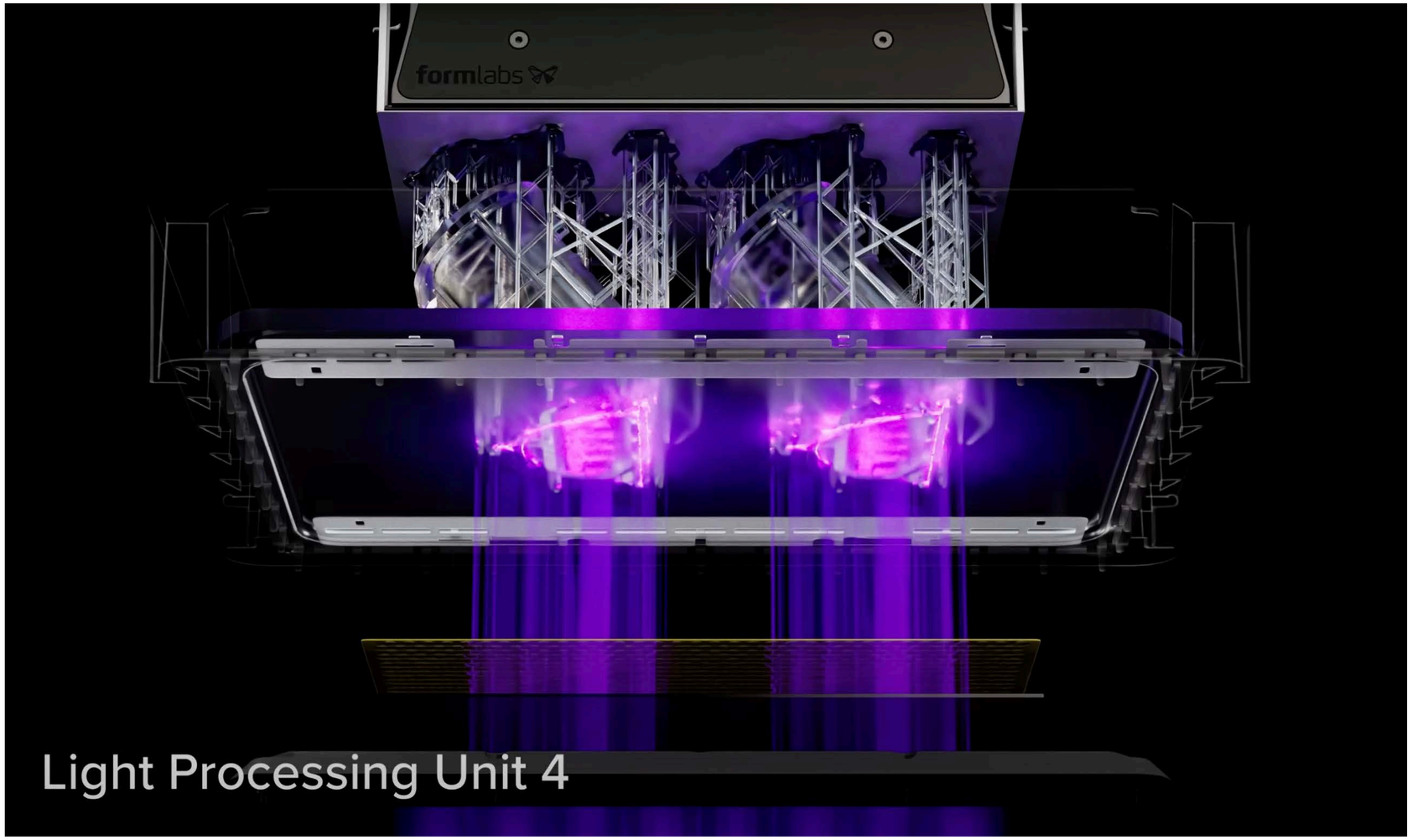
CLIP: Continuous Liquid Interface Production





continuous ➡ more isotropic

Photopolymerization: Full Layer Curing

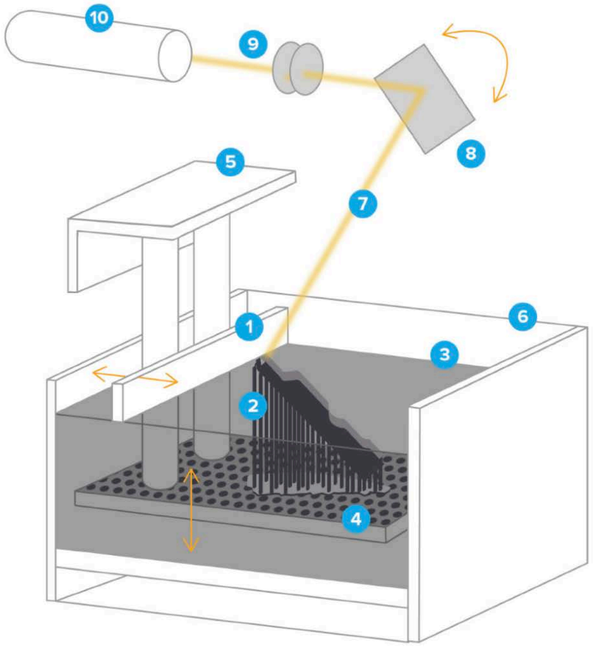


Form 4

Layered Manufacturing

Additive Manufacturing

Photopolymerization: Scaling moving a light beam is easier than moving an extruder



Right-Side Up SLA

1. Sweeper
2. Printed Part
3. Resin
4. Build Platform
5. Elevator
6. Resin Tank
7. Laser Beam
8. X-Y Scanning Mirror
9. Lenses
10. UV Laser

Photopolymerization: Scaling

scaling down: 2 Photon Polymerization

0.2 micron feature width, **sometimes smaller**

Photopolymerization: Materials

Many resins available

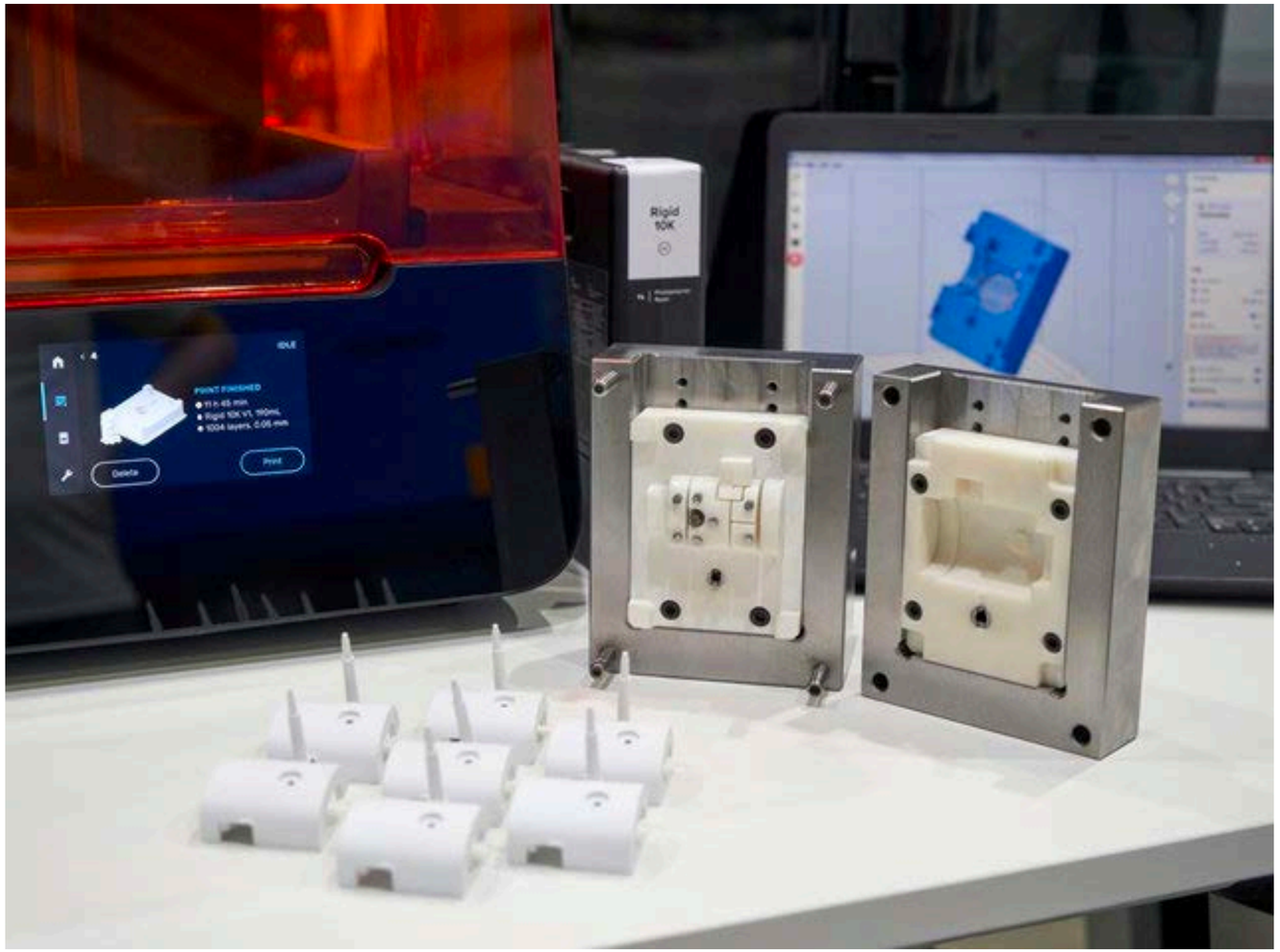
clear

flexible

stiff

temperature resistant

Photopolymerization: Materials & Complexity



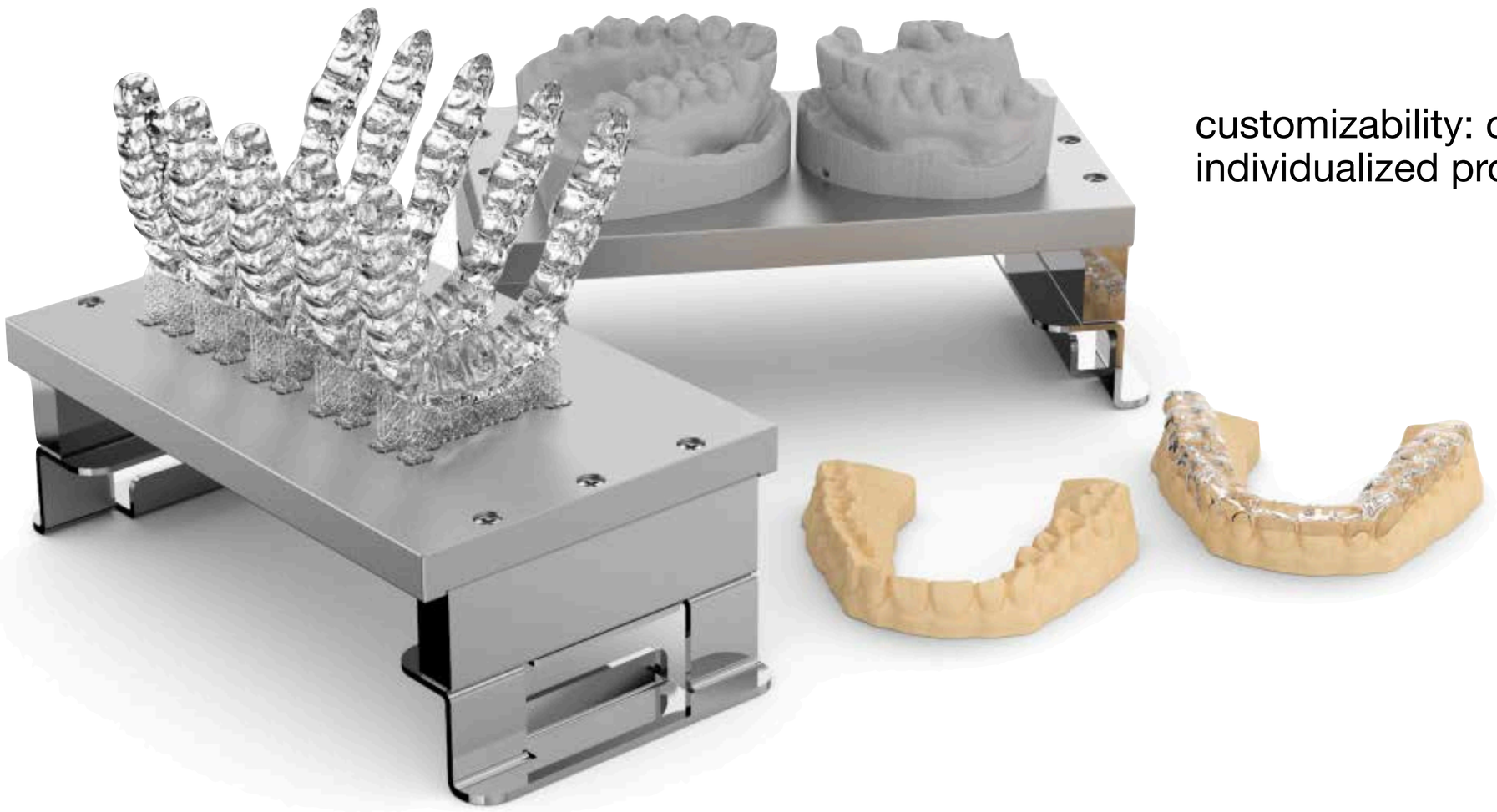
high stiffness + temperature resistant resin:

tooling for small batch injection molding

what are the tradeoffs?

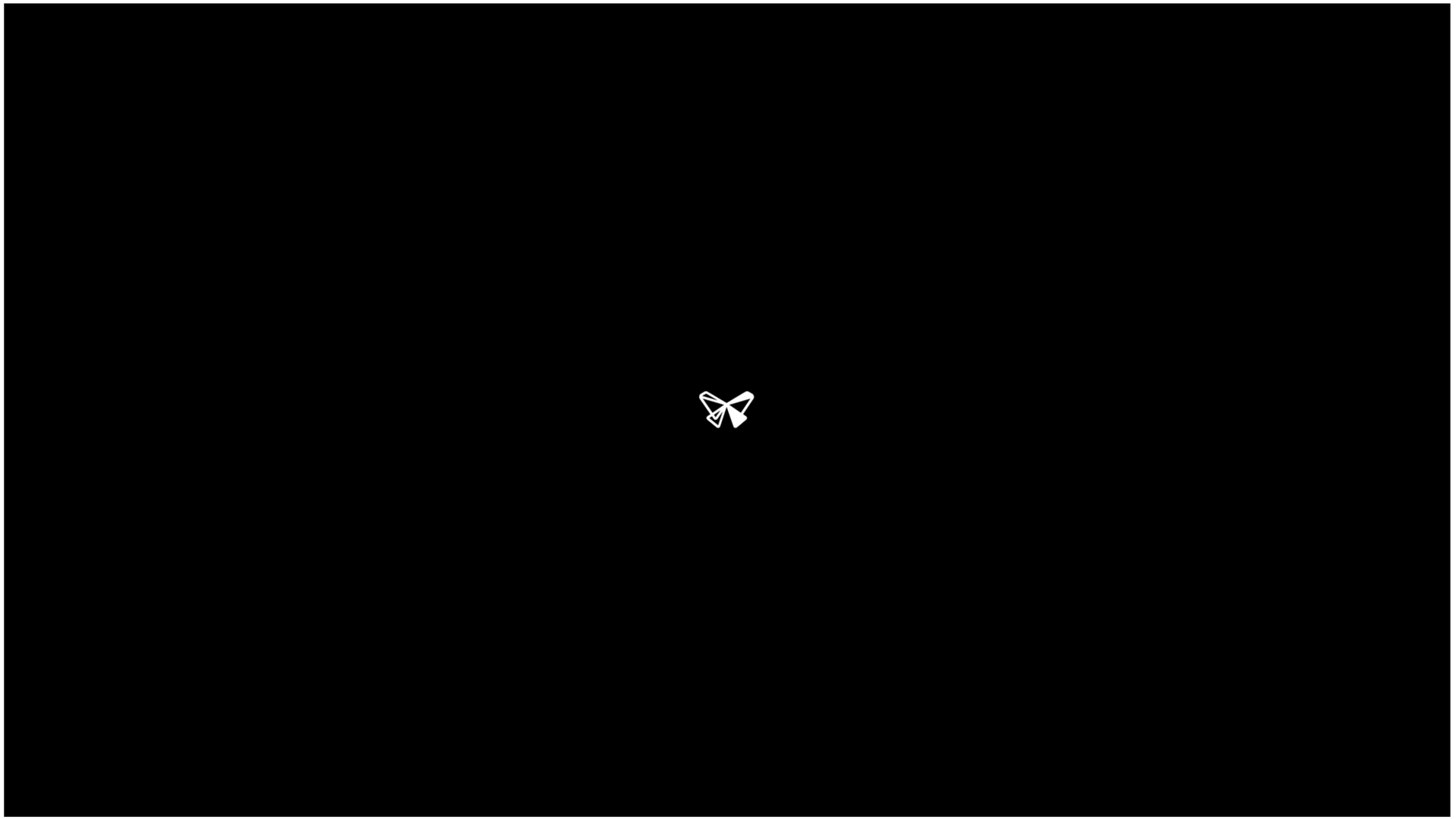
why machine molds in 2.008?

Flexibility: Biocompatible Resins



customizability: can make individualized products

Rate: Manufacturing Cells



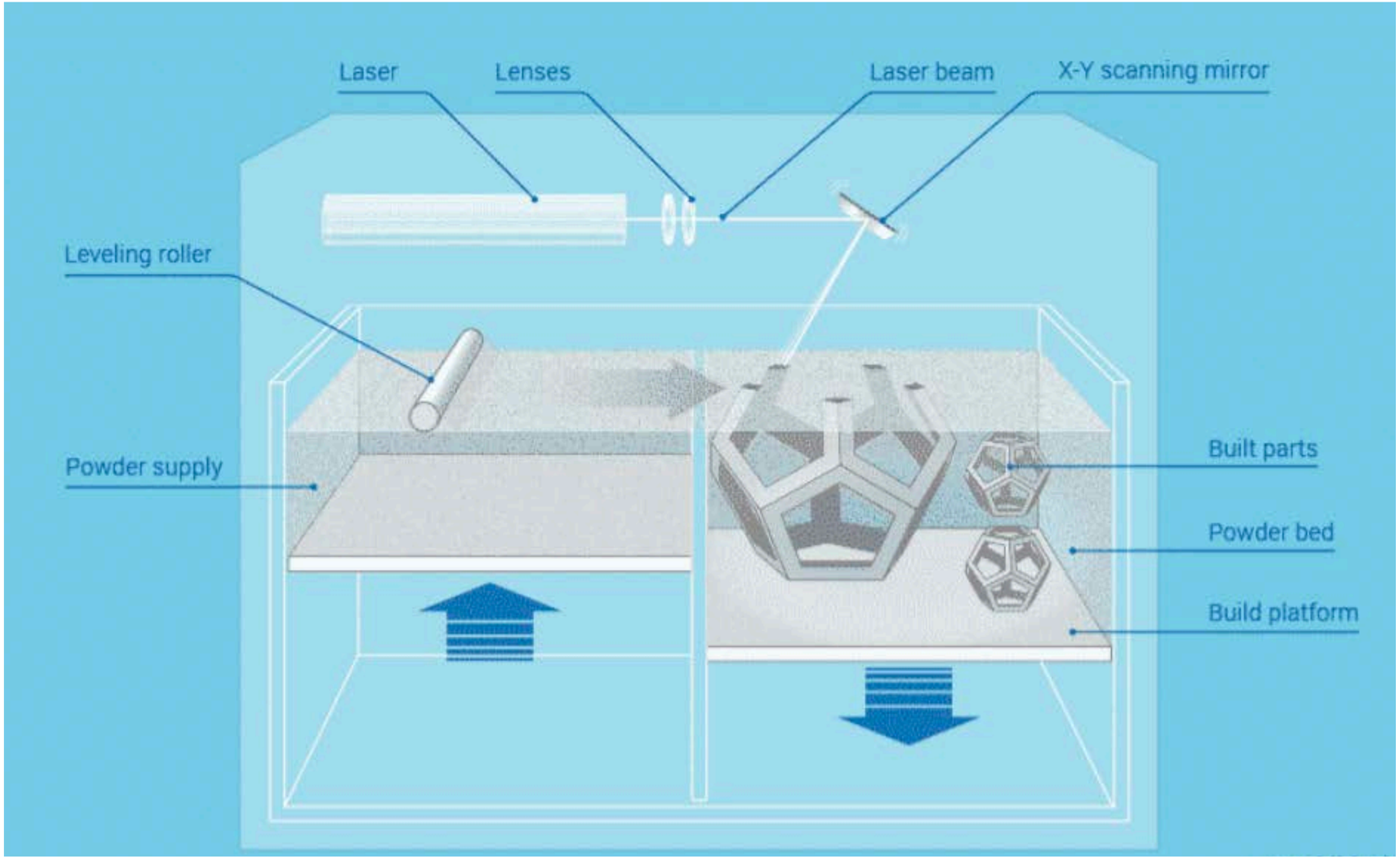
Powder Bed Processes

Powder Bed Fusion

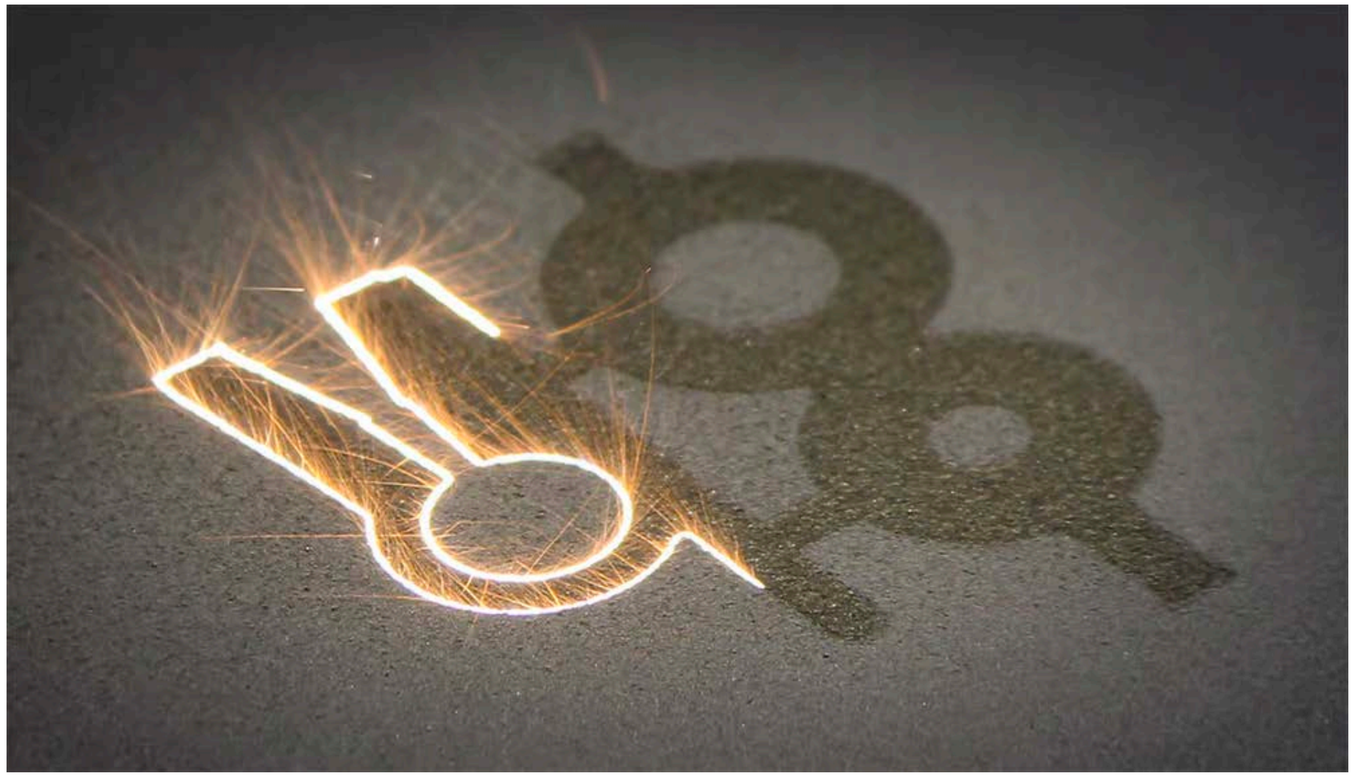
metals and polymers

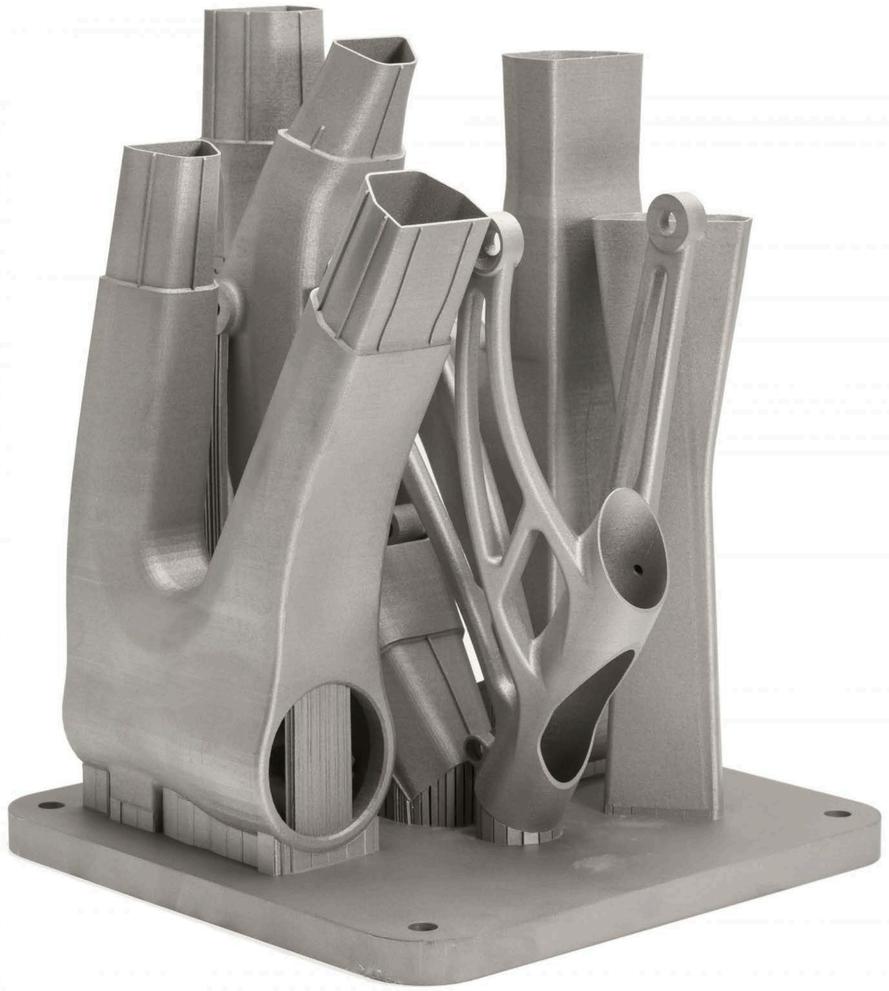
SLS: Selective Laser Sintering

SLM: Selective Laser Melting



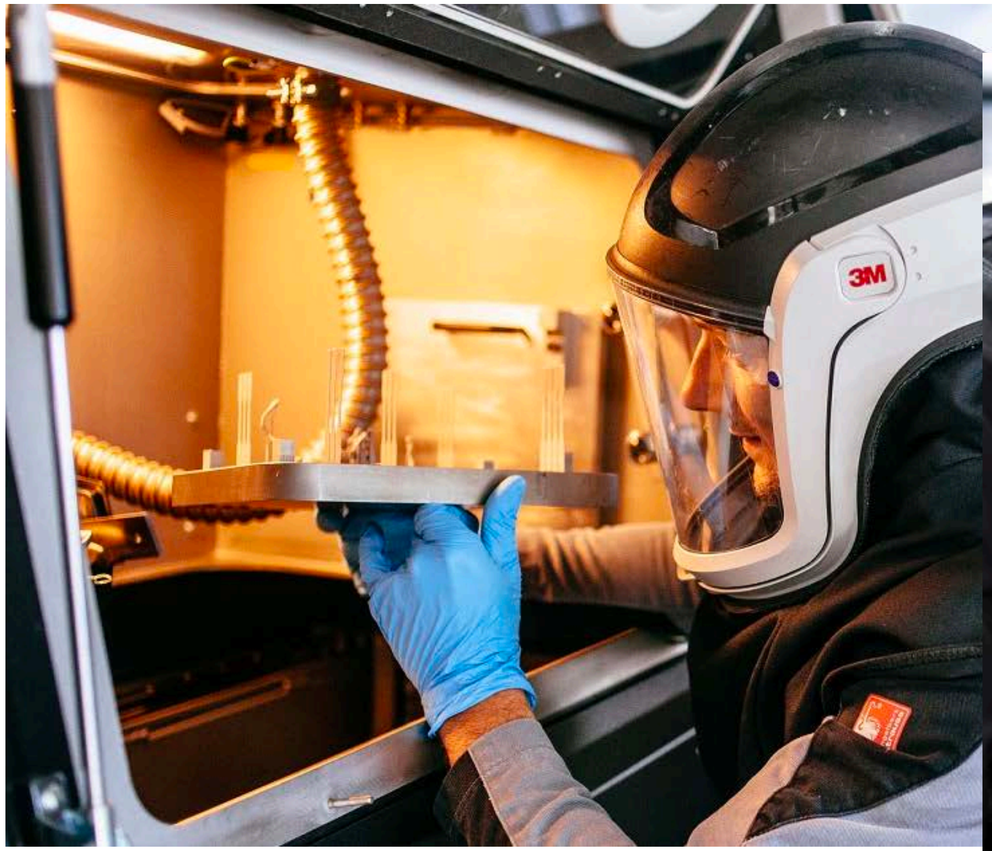
Powder Bed Processes: Metals



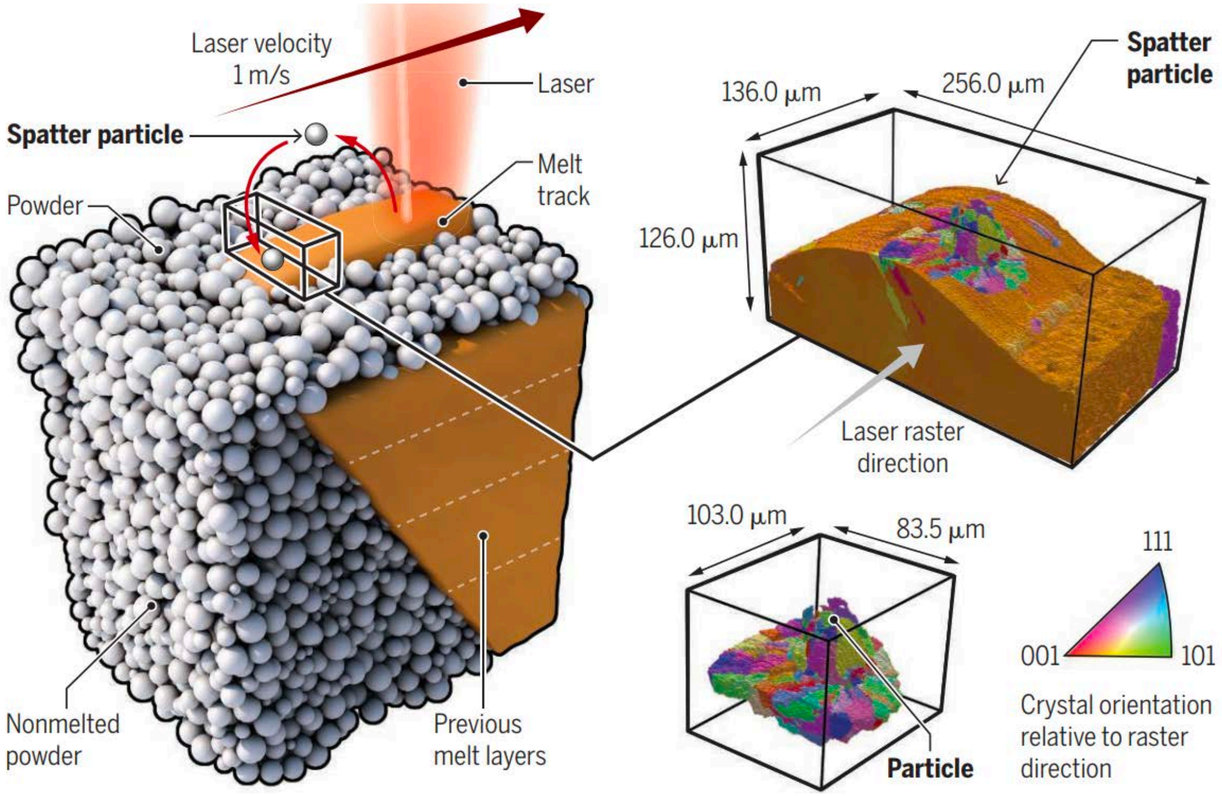


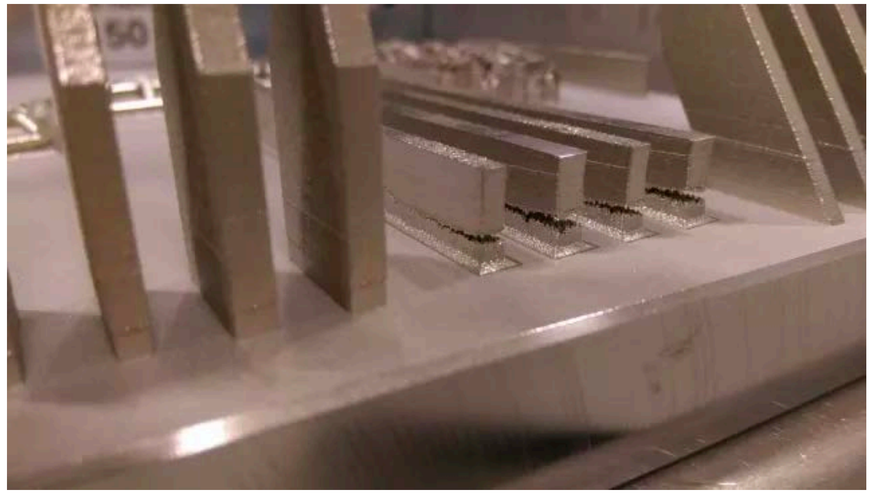
why don’t we see more on MIT’s campus?

Powder Bed Processes: Safety



Powder Bed Processes: Challenges





cracking/warping (residual stress)

surface finish + part integrity

“Researchers Successful in Reducing Spatter-Induced Defects in Metal 3D Printing”

Powder Bed Processes: Metal Examples

GE Fuel Nozzles

# of parts from 20 to only one, while weight cut by 25%, 30% cost savings

manufactured 100,000 so far by AM

GE operates a facility with 40 metal 3D printers

de-risking supply chain

other tradeoffs?

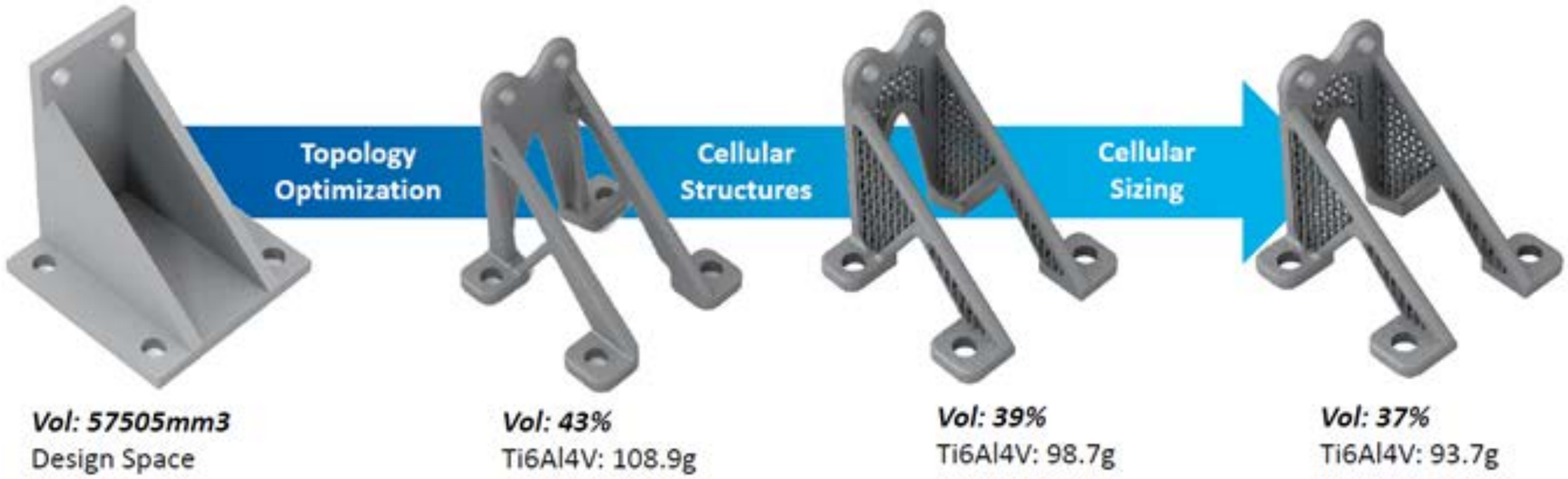
casting parts analysis

10 month conversion to 3D printing vs 12-18 months to cast

35% savings in cost

GE Bleed Air Adapters

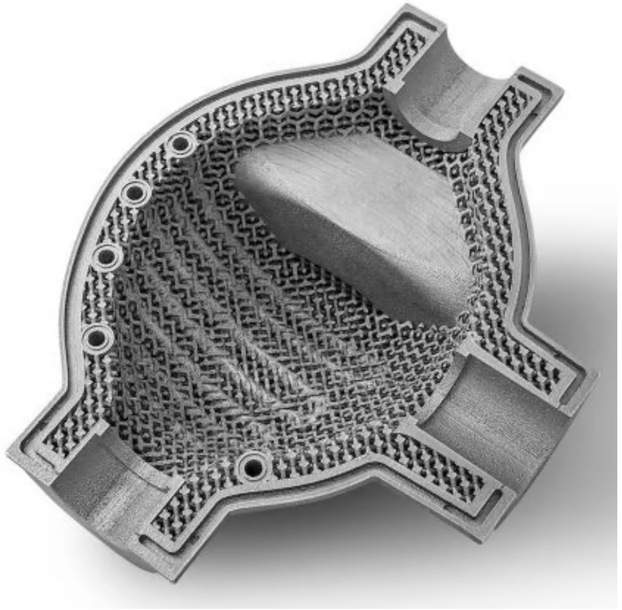
Powder Bed Processes: Complexity ➡ Performance



Materialize: bracket example

common complexity increase for metal part in aerospace

Powder Bed Processes: Complexity ➡ Performance

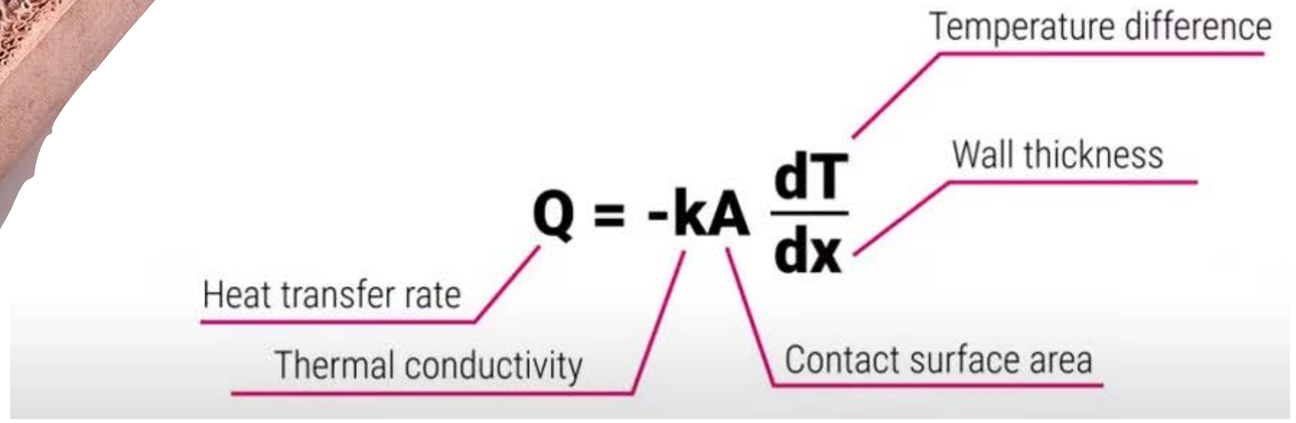


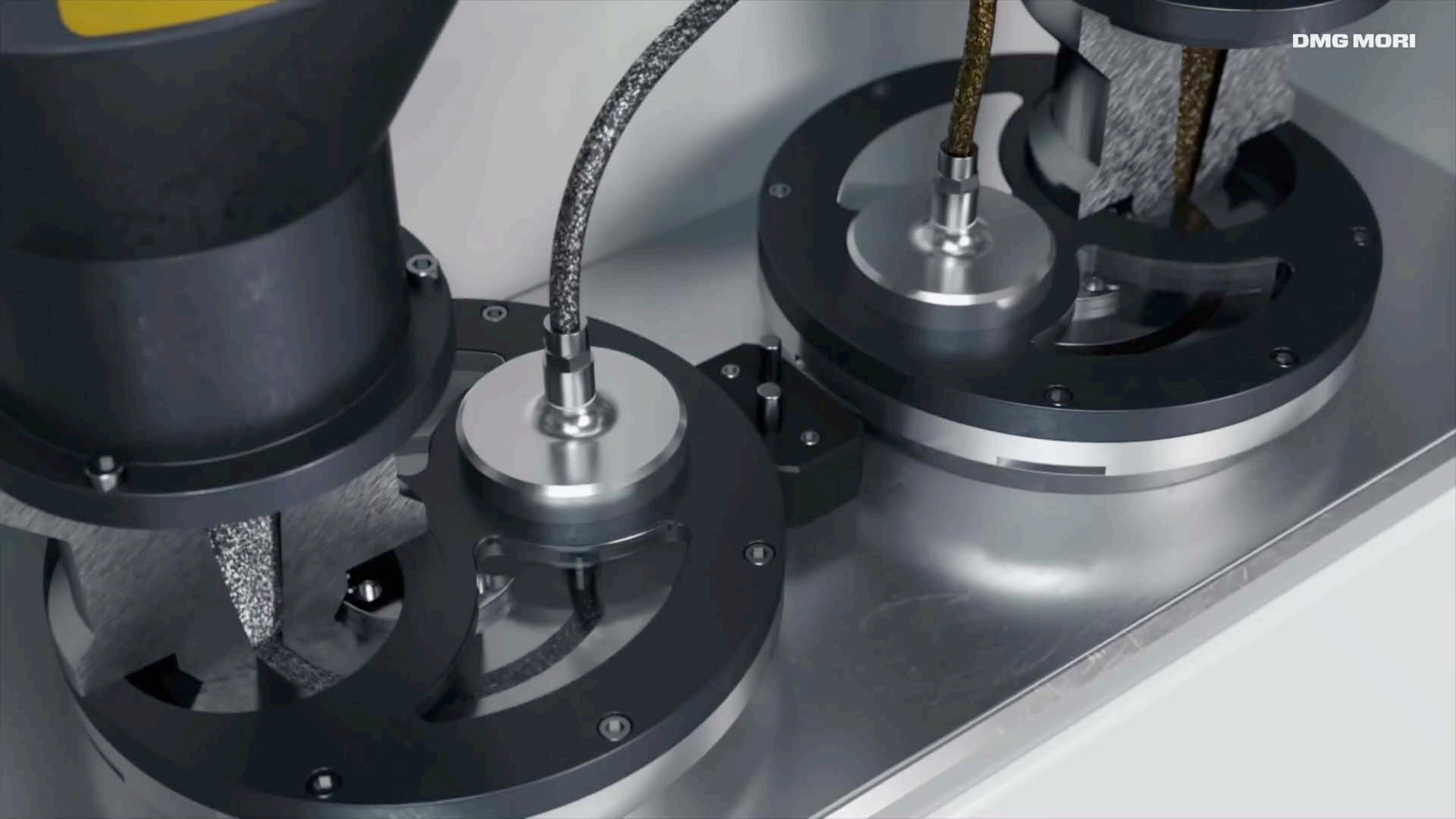
FIT AG

heat exchangers

Heraeus

nTopology




DMG MORI

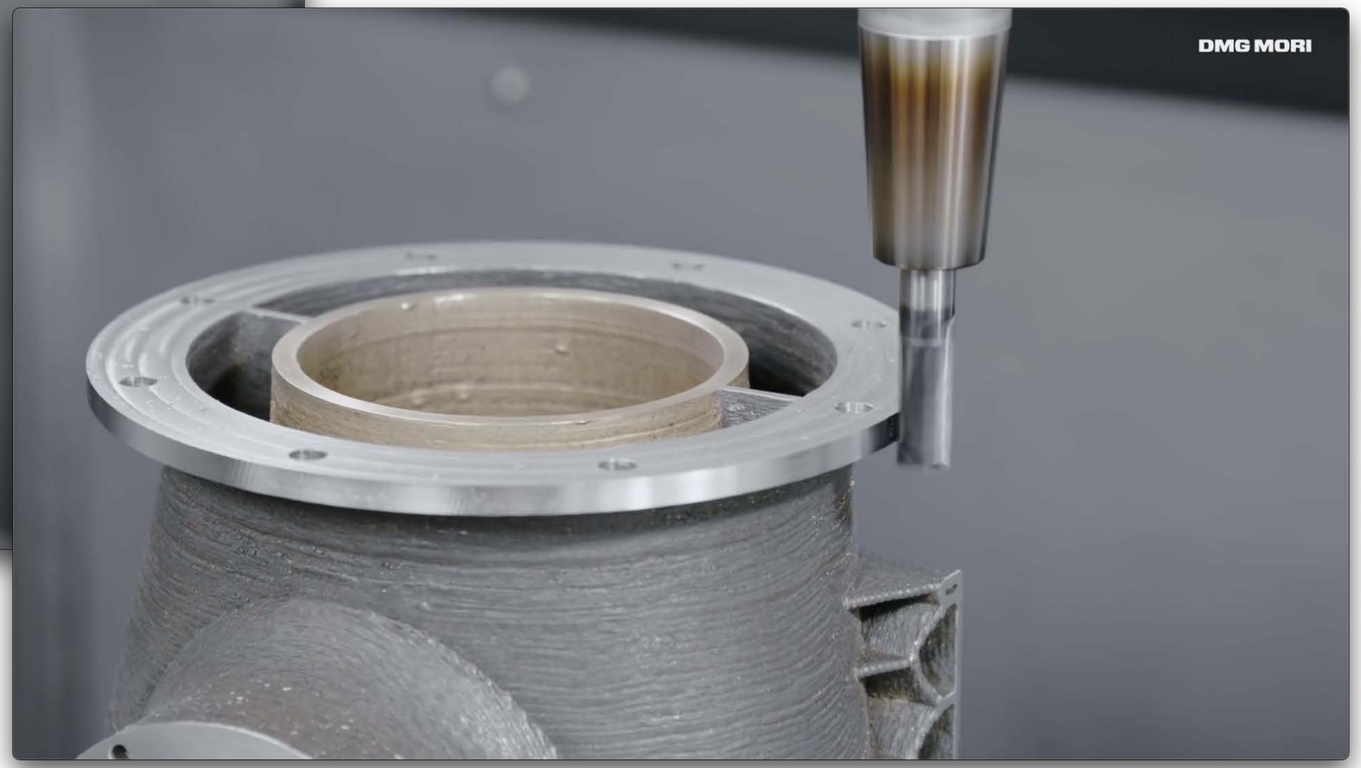
Layered Manufacturing

Additive Manufacturing

Hybrid Metal 3D Printing

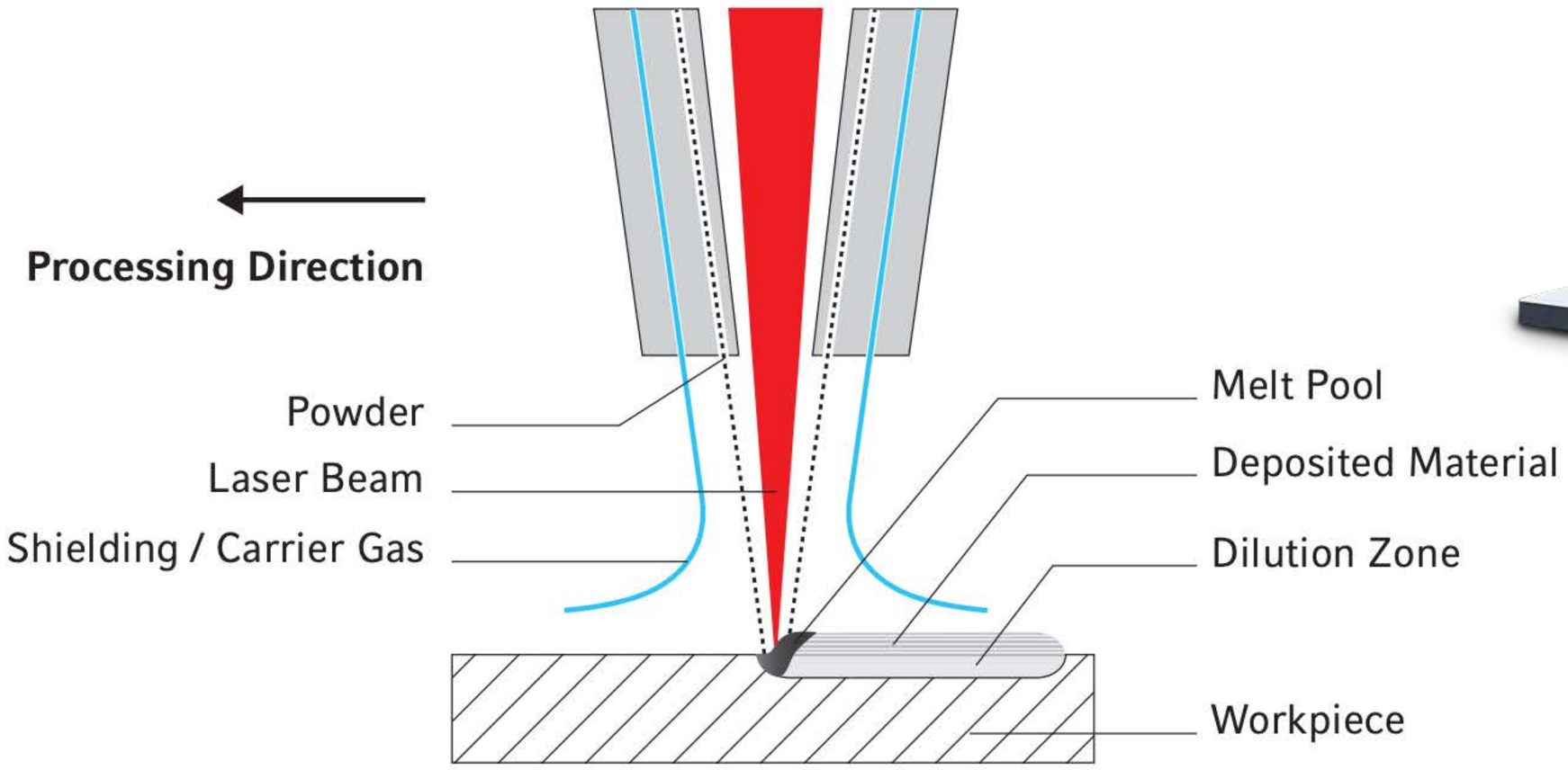
laser deposition welding

machining

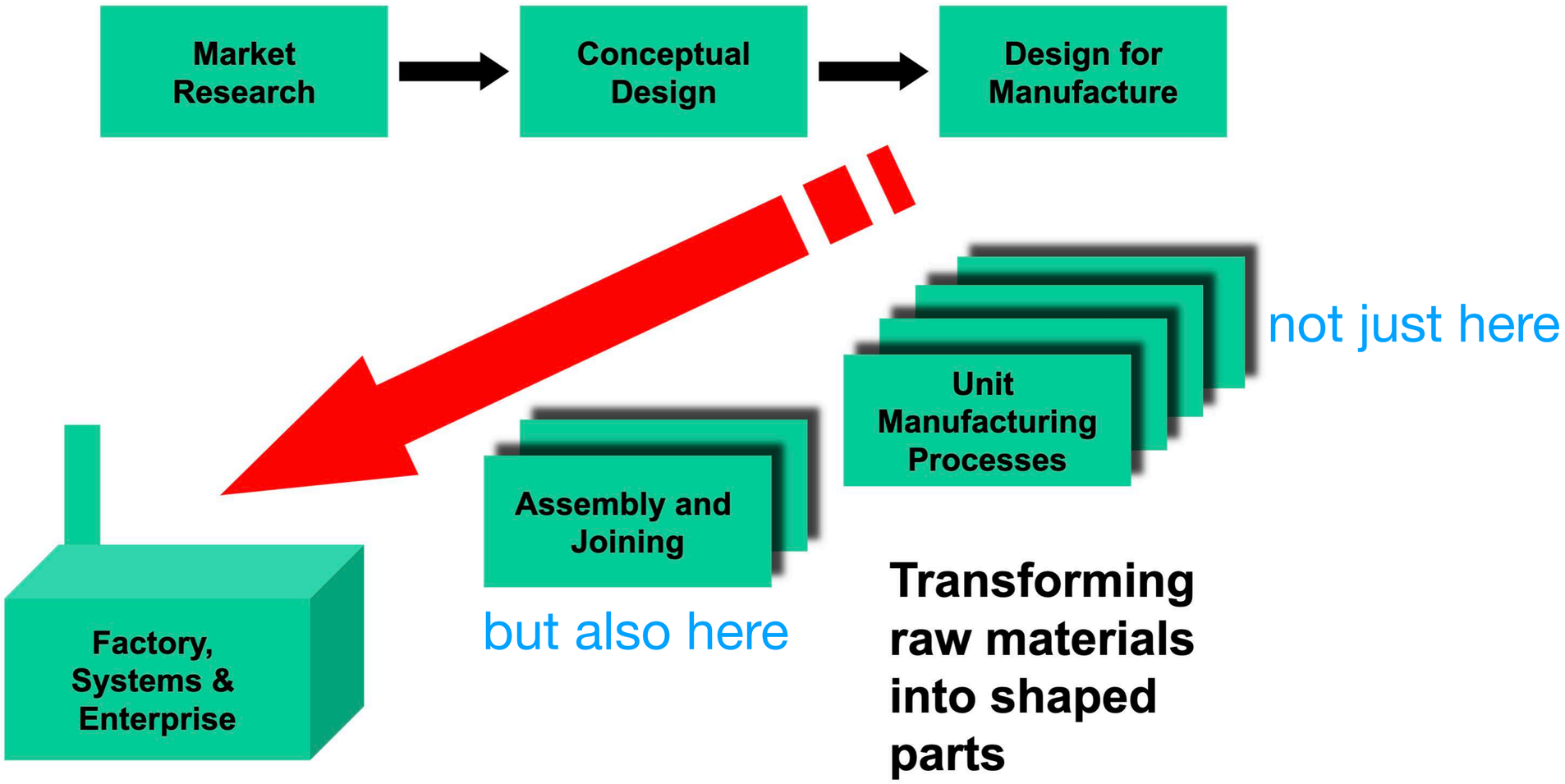


cost: size of VF-2 is around $2.5 million

Laser Deposition Welding



AM in Other Parts of Manufacturing



AM in Other Parts of Manufacturing: Assembly & Joining

BMW: assembly jigs

human ergonomics necessitates complex geometries

weight reduction important for fatigue

customization/iteration are easy and fast

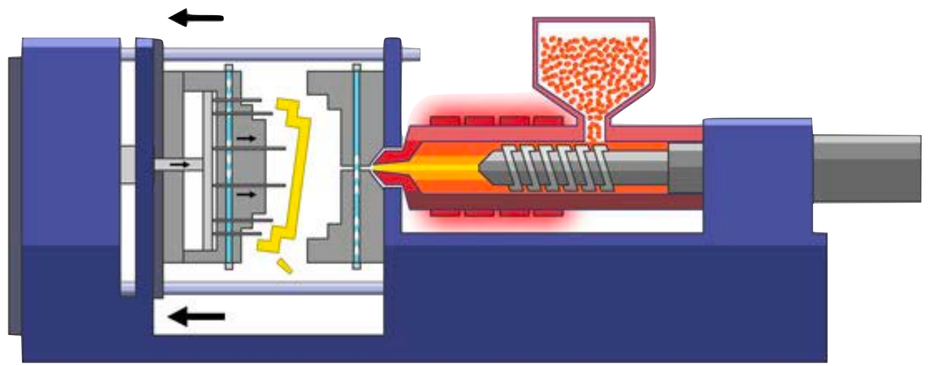
occasional cost reduction

AM in Other Parts of Manufacturing: Service & Maintenance

out-of-production models:
low demand, low volume

huge number of
possible parts from
many product lines

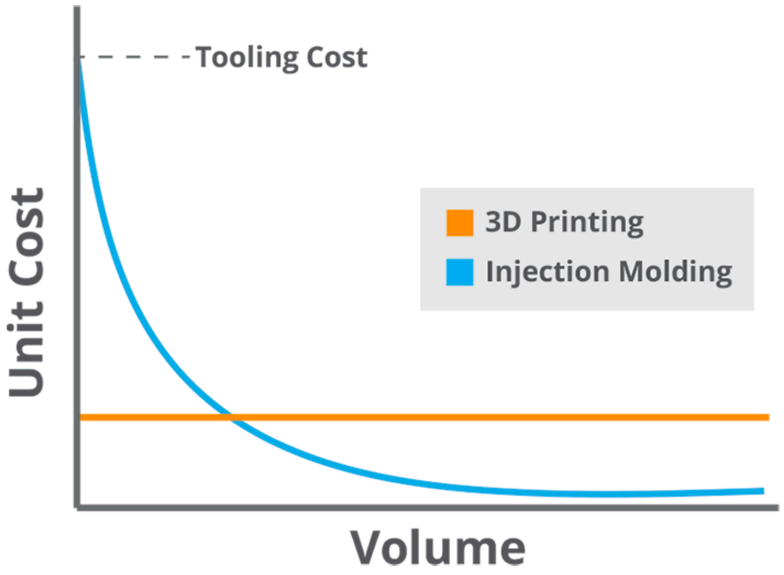
AM in Industry: Summary



relationship to traditional manufacturing:

investment in tooling: ⬆Quality, Rate, Cost

AM: ⬆Flexibility: Complexity, Performance



complexity is more than free

and can lead to higher performance

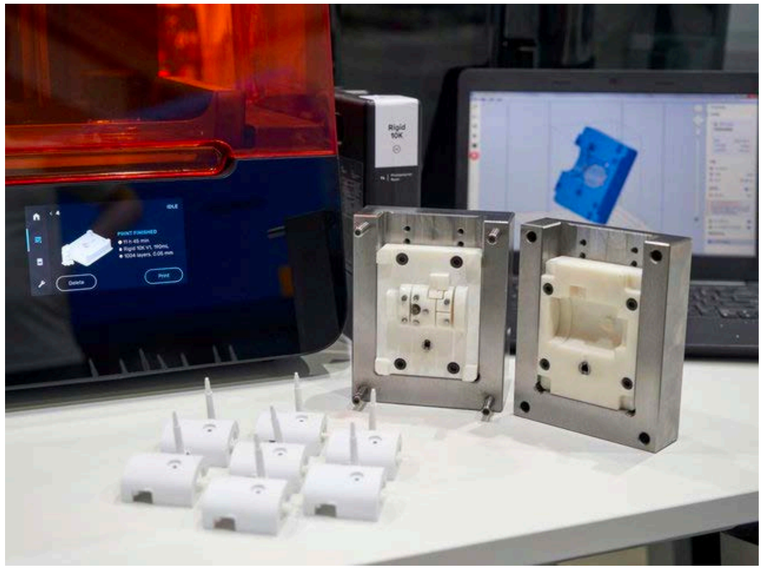
AM in Industry: Summary

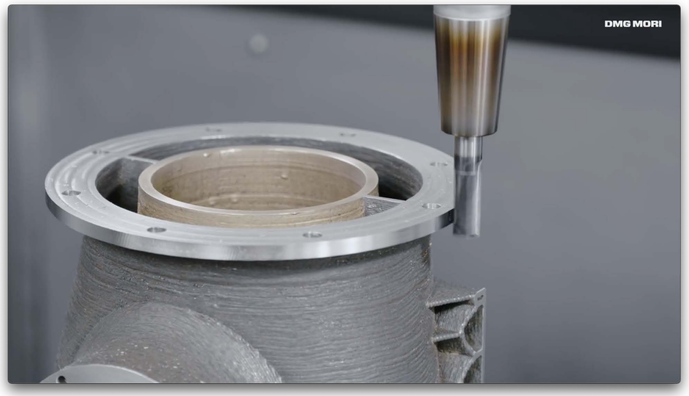
multiple parts can be combined, simplifying process plans

supply chain shortcuts

AM in Industry: Summary

you can make tooling to improve traditional processes

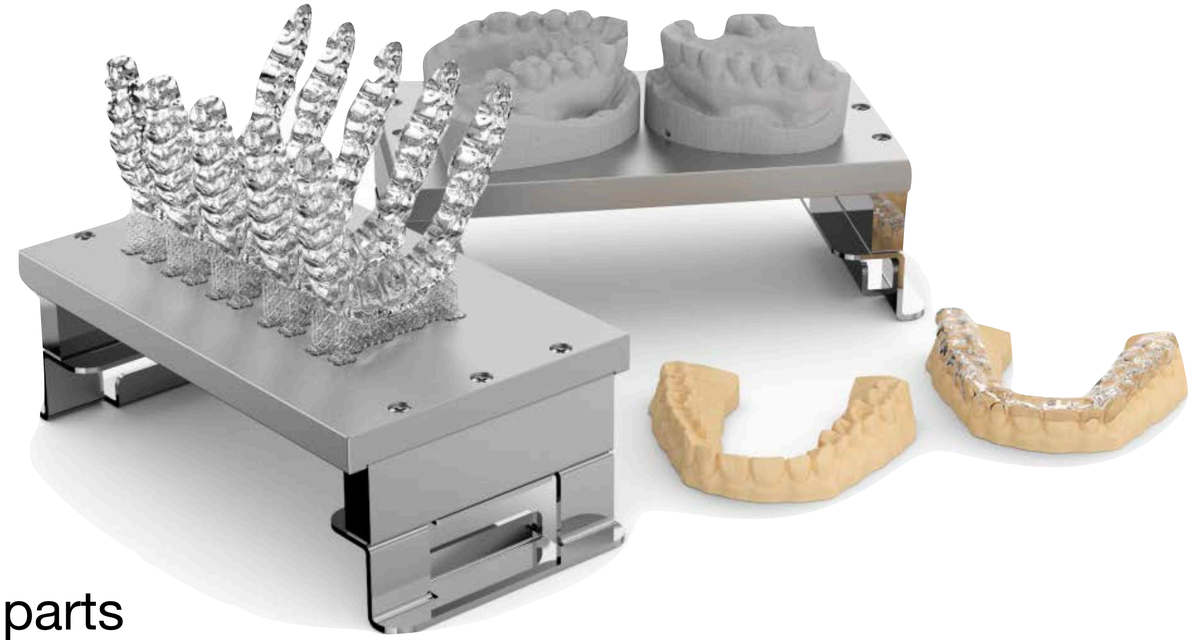




or combine AM to make new parts and improve traditional processes

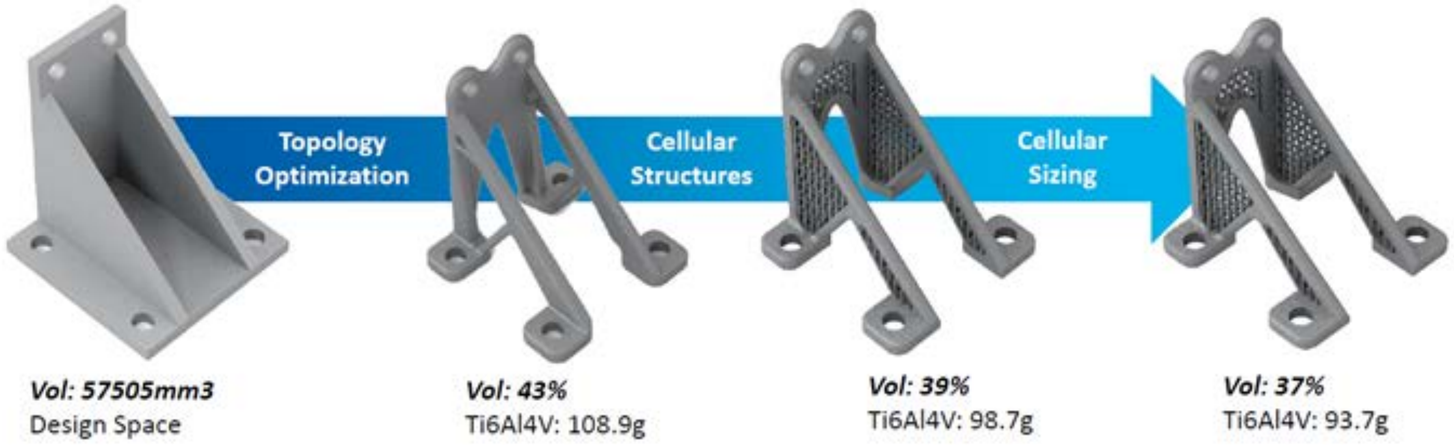
AM in Industry: Summary

you can support
products for longer



or offer customized parts
directly to customers

What still needs to improve?



processes are slow, expensive, and quality can be improved

design tools can be cumbersome

data management in a factory setting is difficult

education: cutting edge information needs to be disseminated to industry

who’s going to do all this work?

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2.008 Design and Manufacturing II

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