METAL 3D-PRINTING OVERVIEW

Introduction to Additive Manufacturing (AM)

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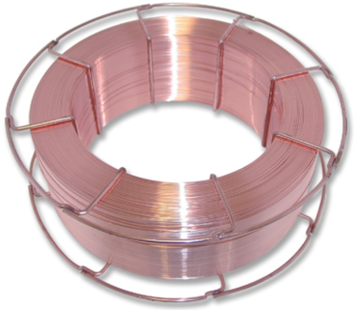
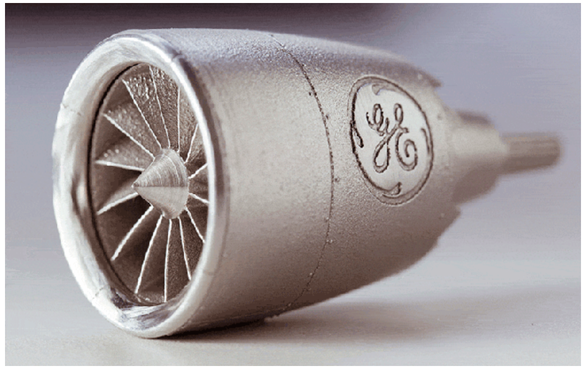
3D-PRINTING

Resource



Fabrication

Finished part



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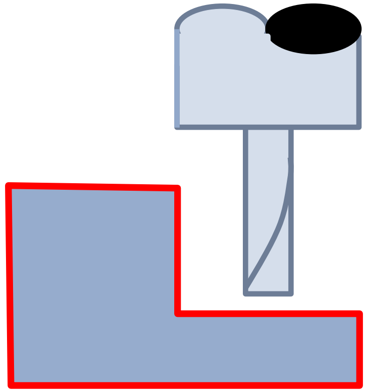
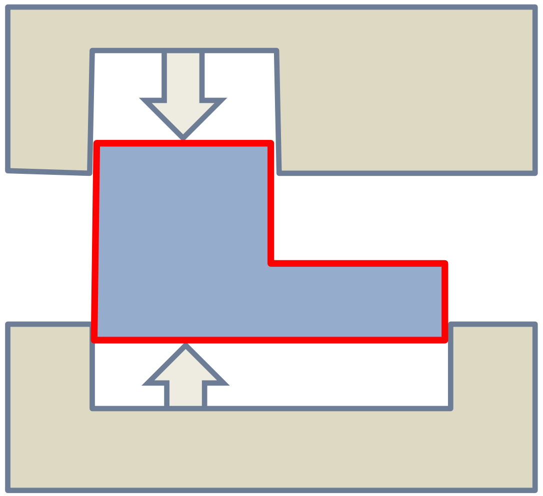
CONVENTIONAL FABRICATION VS. AM



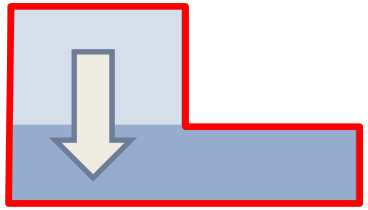
Subtractive

- milling
- drilling
- turning
- cutting
- sawing
- etc.



Formative

- bending
- forging
- forming
- injection molding
- etc.



Additive

- powder bed
- polymerization
- free form technologies
- etc.

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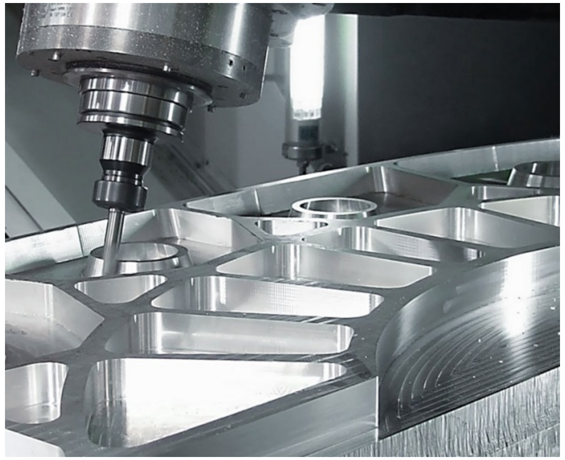
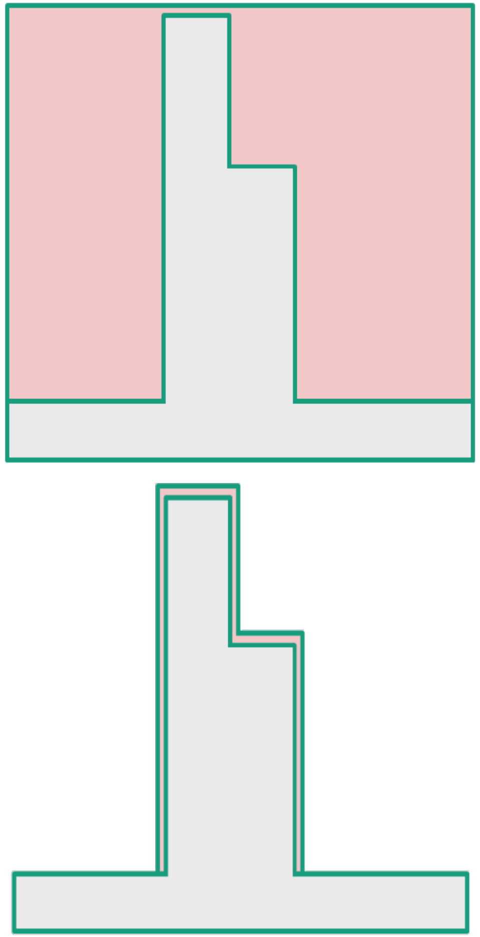
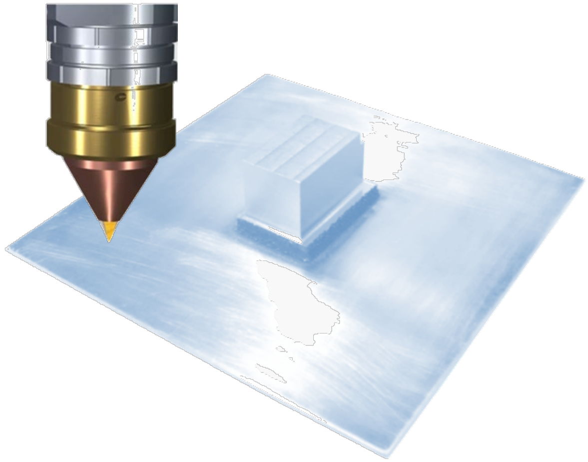
WHAT IS ADDITIVE MANUFACTURING (AM)? AKA 3D-PRINTING







- near-net shape
- material efficiency

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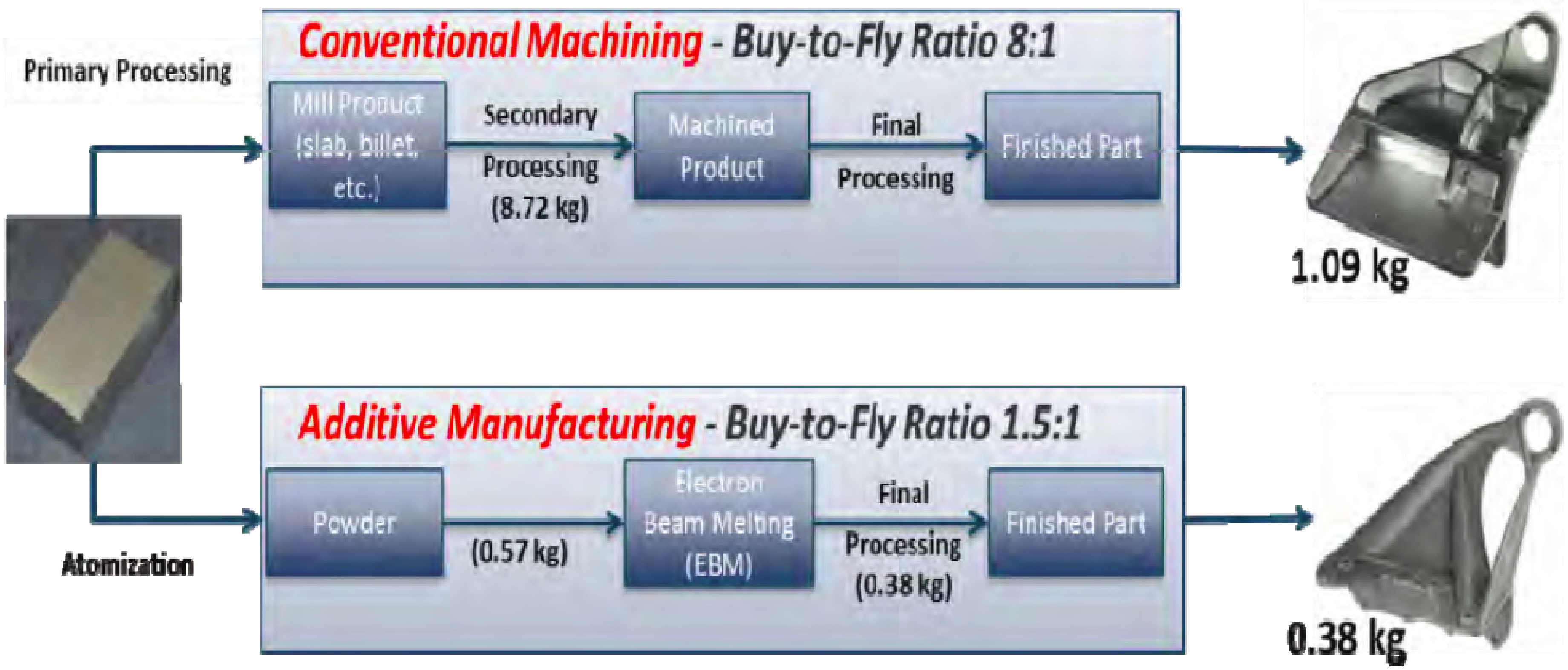
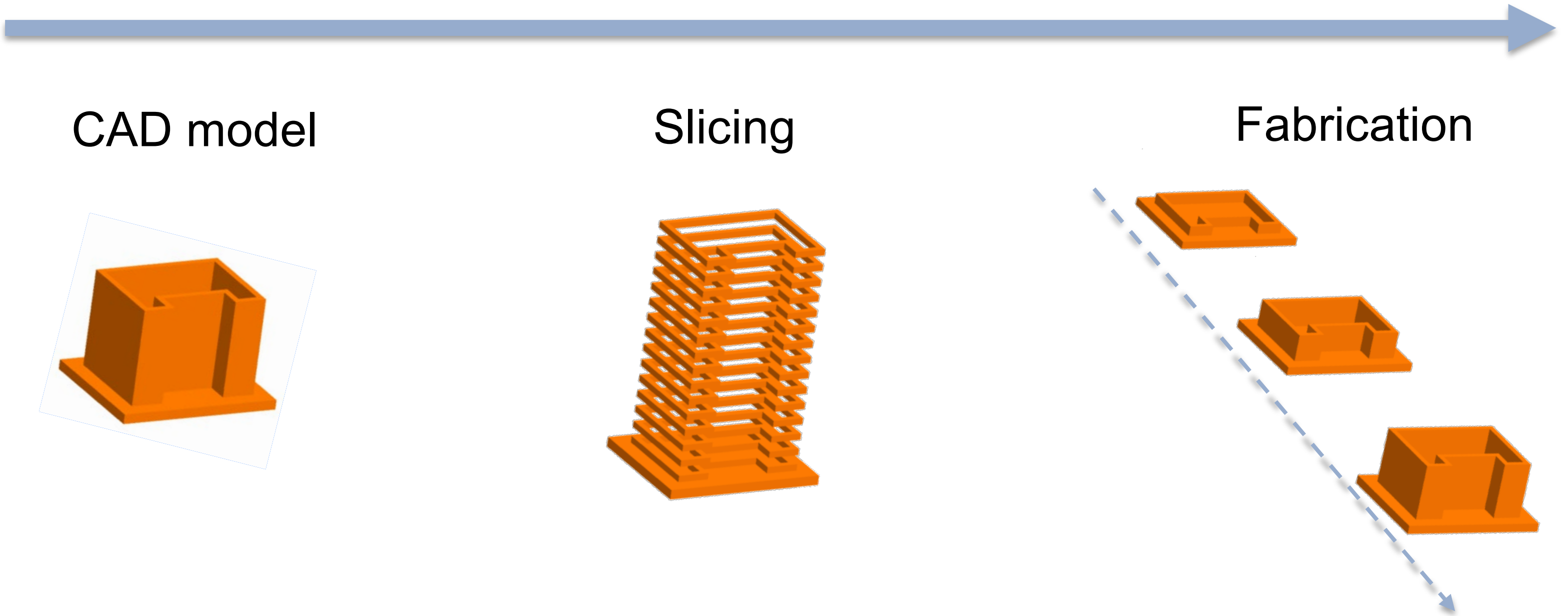
CONVENTIONAL FABRICATION VS AM



BASIC PROCESS CHAIN



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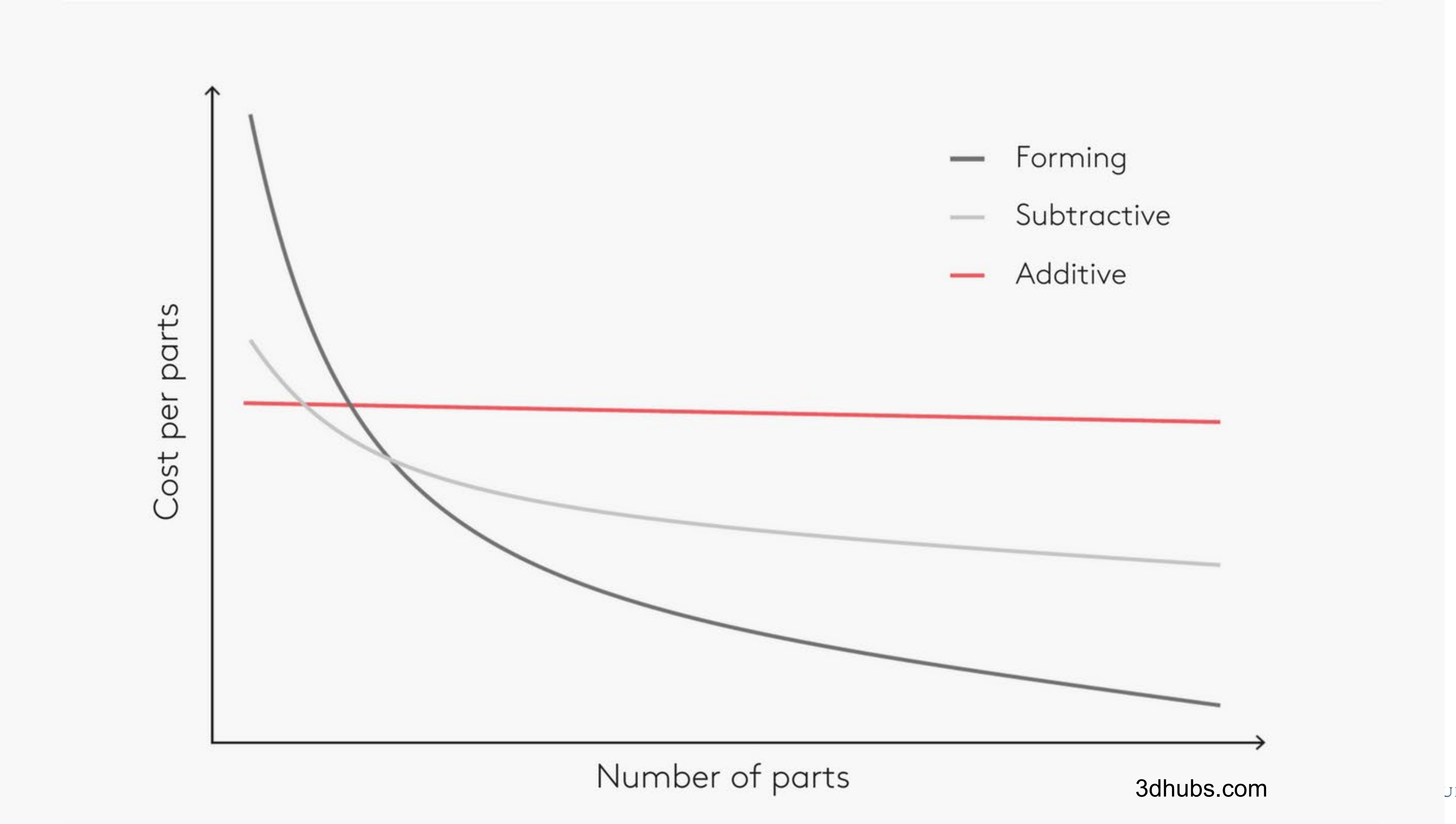
AM VS MACHINING

- CNC machining
  - Tool access and clearances
  - Fixturing
  - Can not reach all surfaces

- AM often requires support structures to be built
  - Needs removal
- Binder jetting AM techniques require no support
  - -but more post processing

SELECTING THE RIGHT TECHNIQUE



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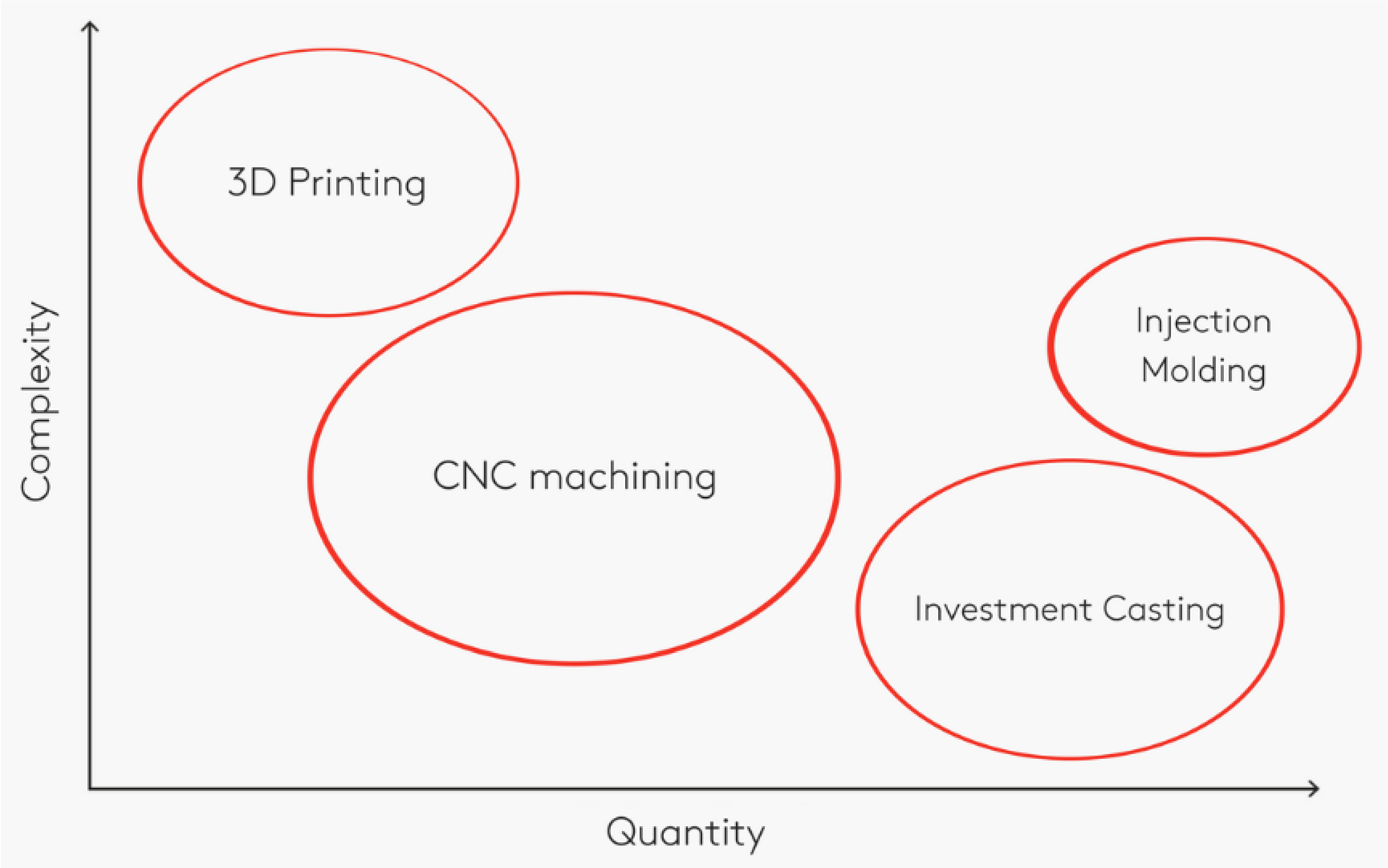
SELECTING THE RIGHT TECHNIQUE



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WHEN IS AM USEFUL?

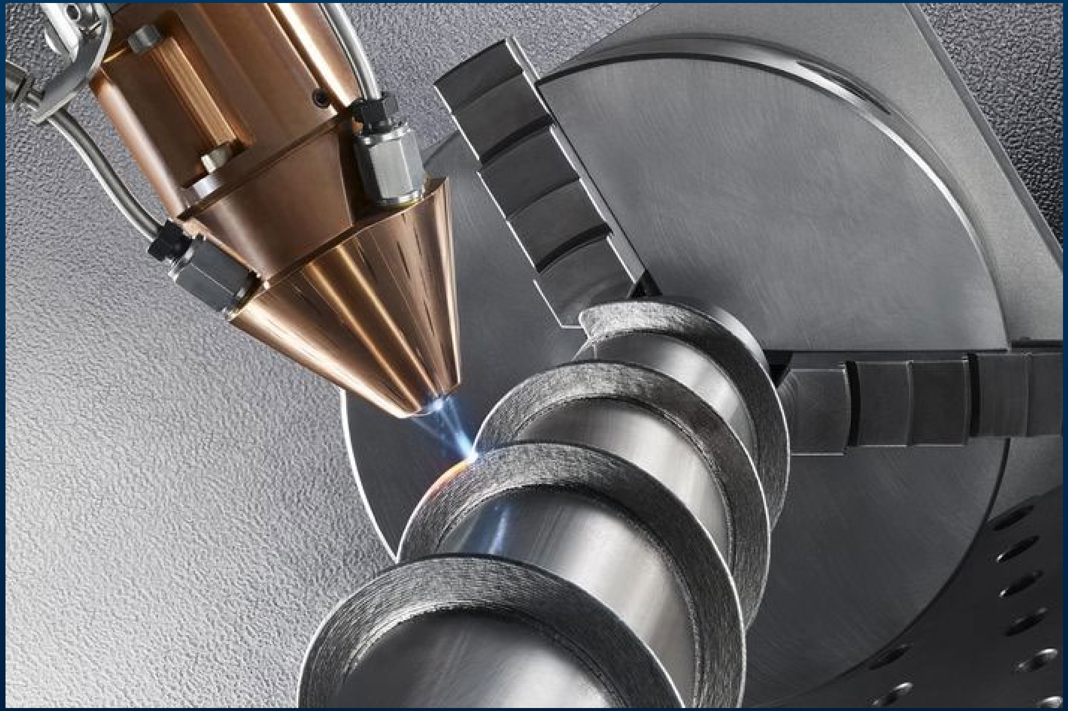
- **Multiscale structure design**
  - Advanced geometries (Structures otherwise not possible to make)
- **Topology optimization, sustainability and waste reduction**
  - Smart geometries (Saving material due to calculated force distributions)
- **Parts consolidation and inventory reduction**
  - Reduced complexity of assembling parts (fewer parts instead of many assembled), less items needed in production or storage
- **Agile manufacturing, lead time reduction and design for mass customization**
  - Reduction of the cost and leading time in producing customized parts or component improvements

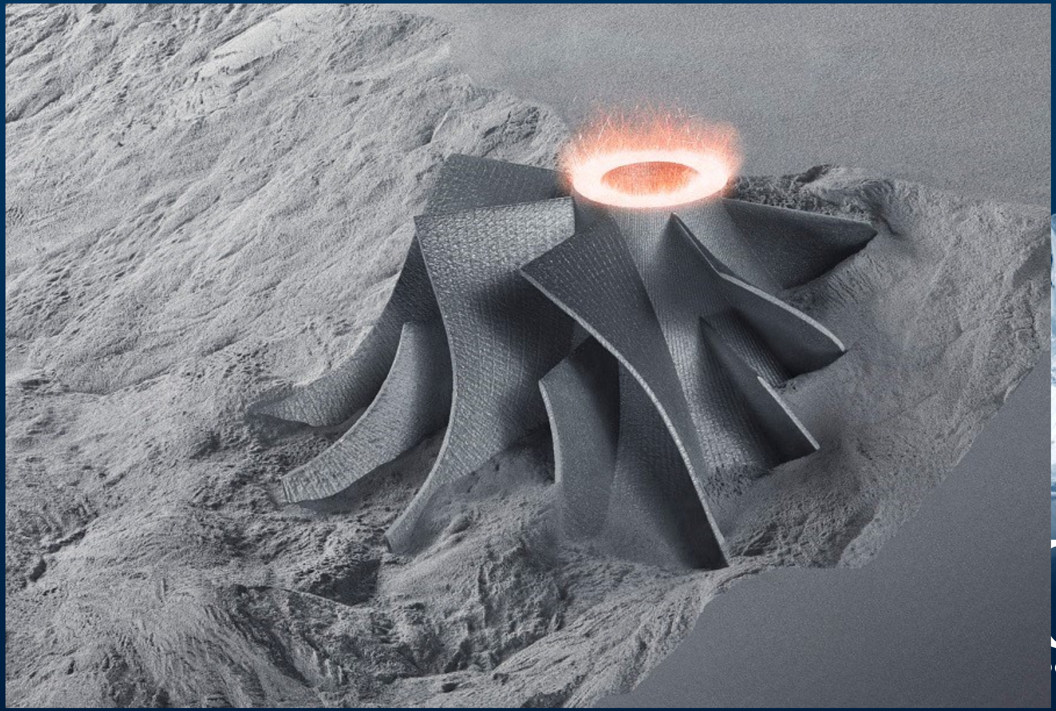
WHEN IS AM USEFUL?

- **Distributed production**
  - Produce parts where needed instead of centralized manufacturing lines, e.g. spare parts in remote locations
- **Elimination of tooling**
  - Compared to some other techniques (e.g. casting or injection molding)

METAL 3D-PRINTING OVERVIEW

AM processes (metals)



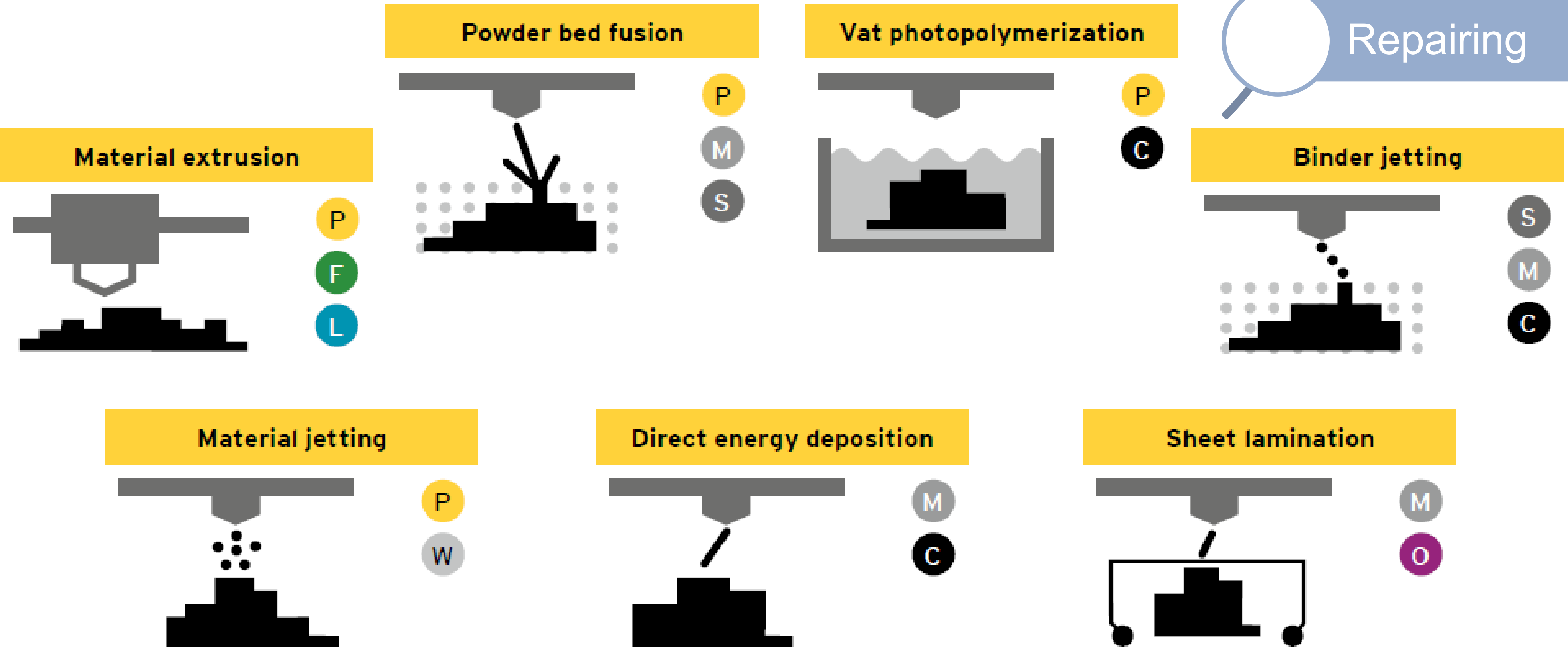


AM-PROCESS CATEGORIES

3DP sub-technologies

DED (freeform)

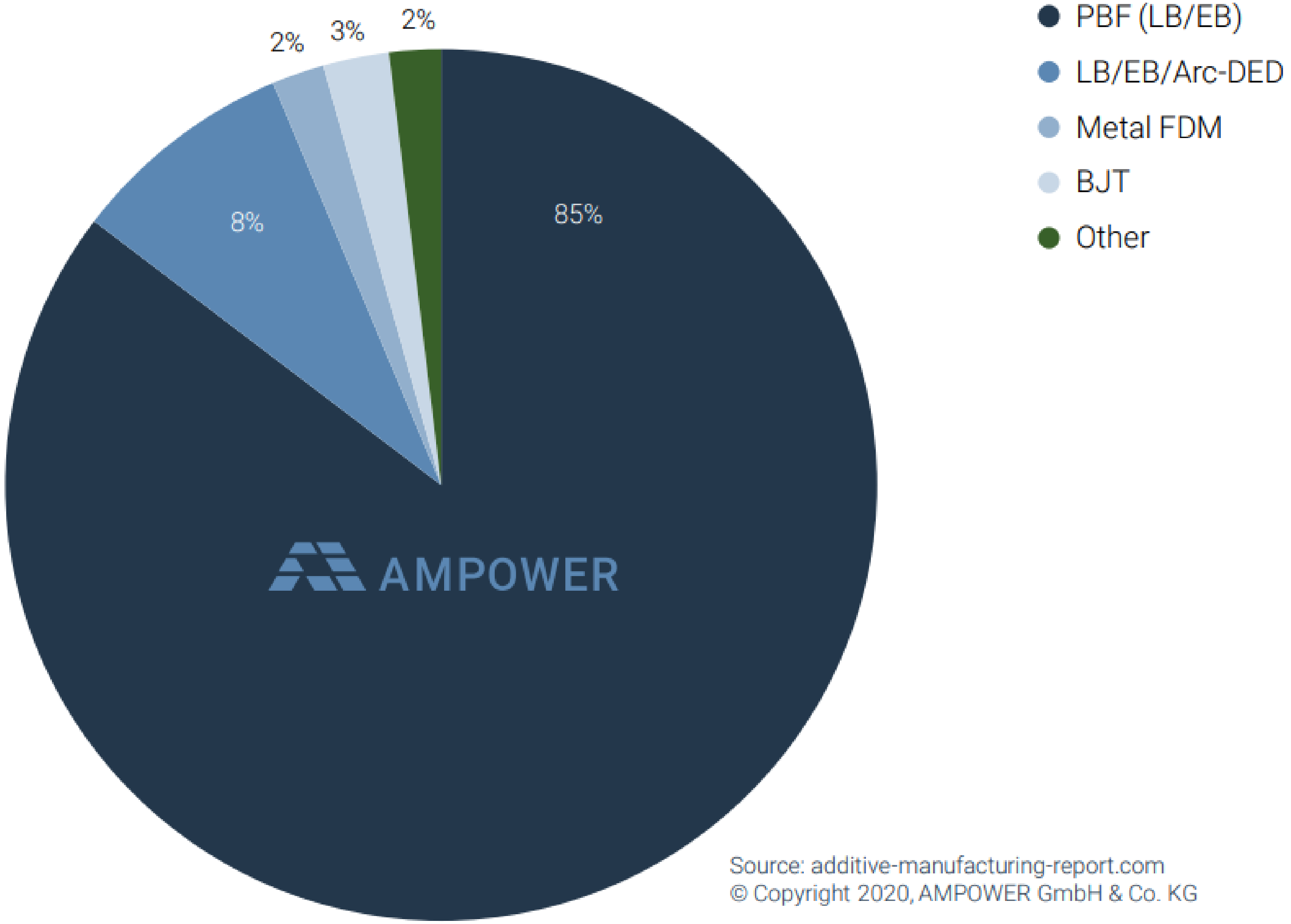
- Direct Additive Manufacturing
- Adding of functions
- Repairing



Material key: P=Polymer, M=Metal, O=Organic material, C=Ceramic, S=Sand, L= Live cells, F=Food, W=Wax

Scource: EY

SYSTEM SALES REVENUE BY TECHNOLOGY 2019



Source: additive-manufacturing-report.com

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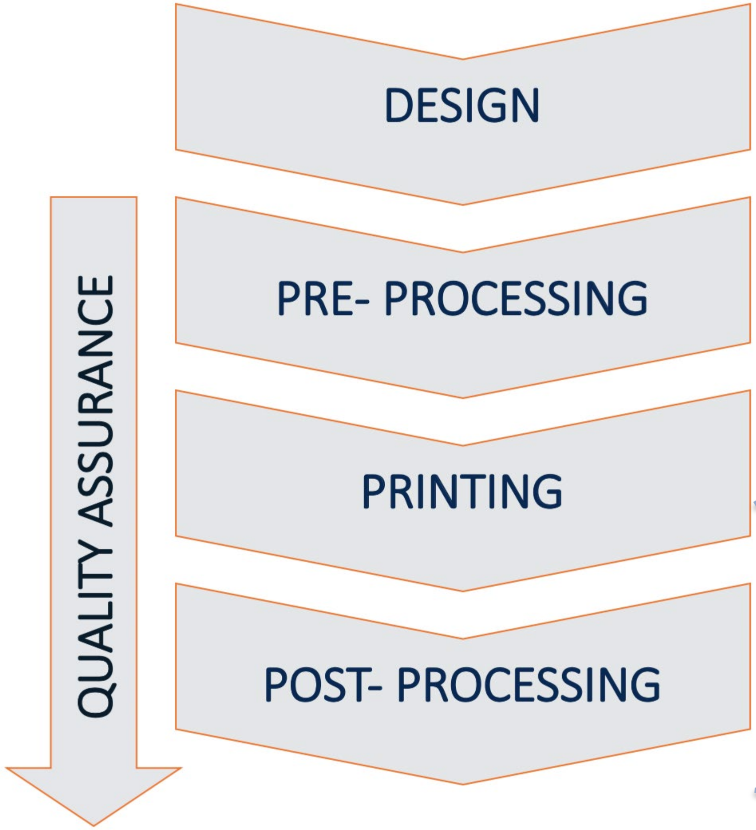
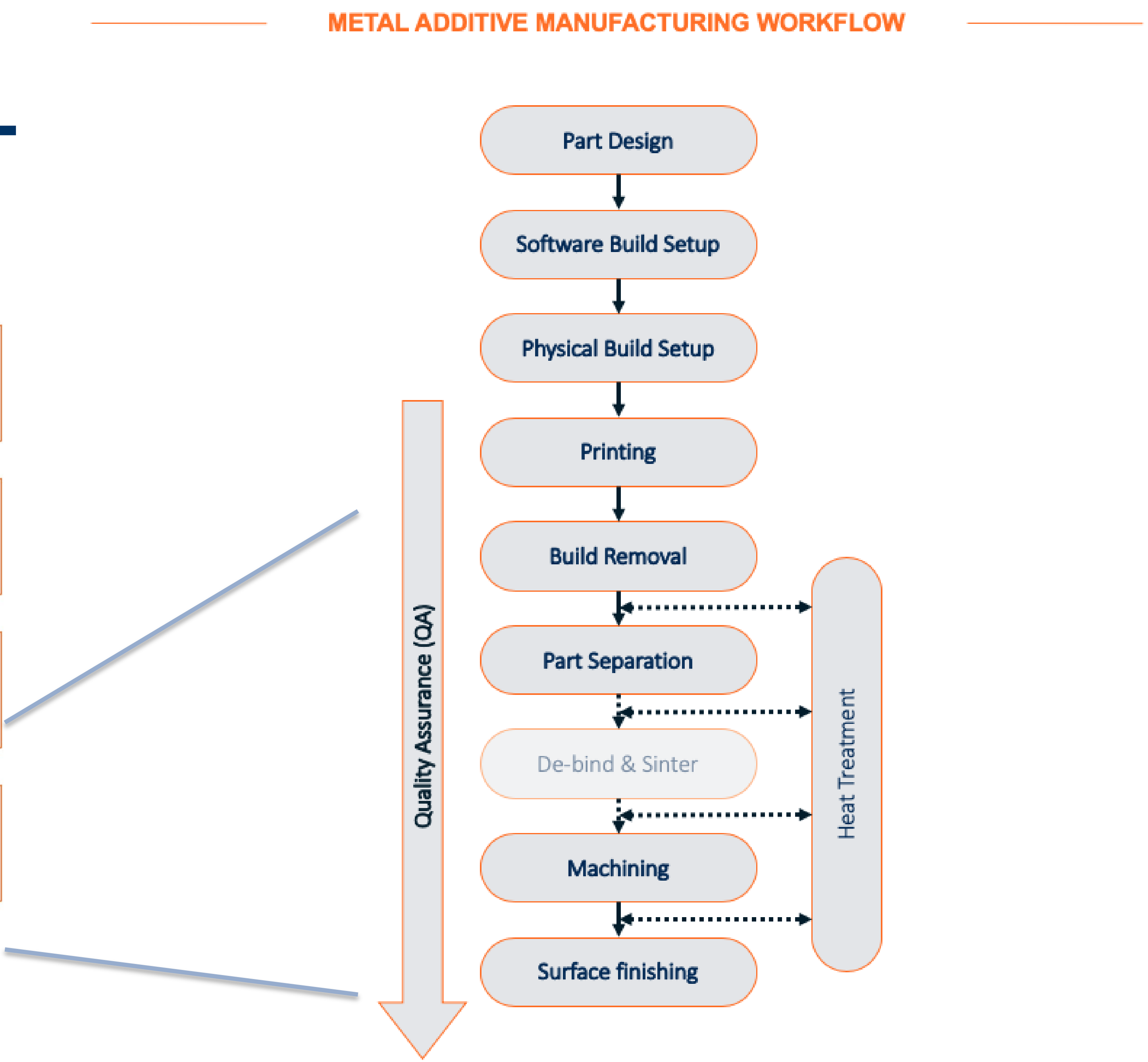
METAL



DESIGN
PRE- PROCESSING
PRINTING
POST- PROCESSING
QUALITY ASSURANCE

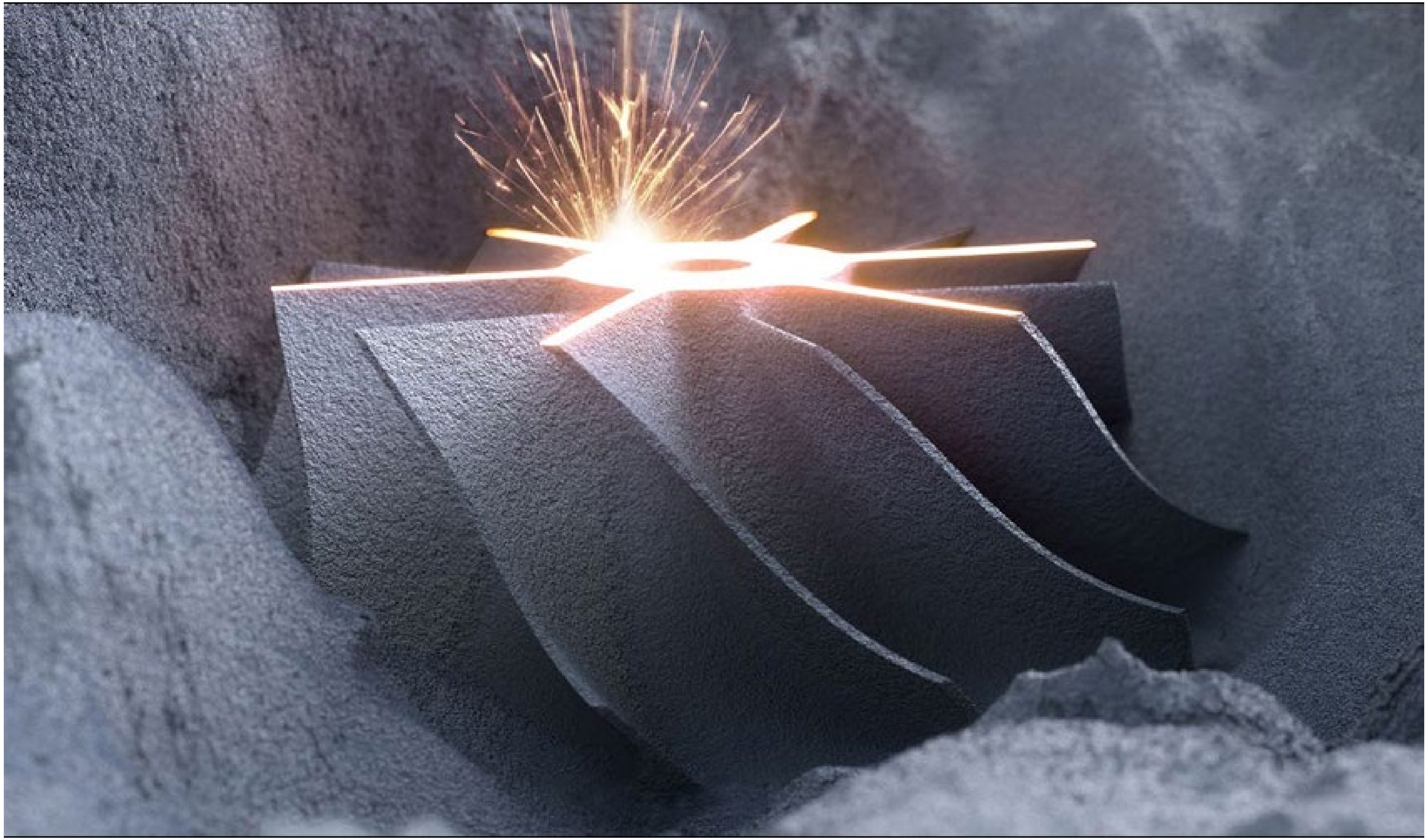


METAL ADDITIVE MANUFACTURING WORKFLOW
Part Design
Software Build Setup
Physical Build Setup
Printing
Build Removal
Part Separation
De-bind & Sinter
Machining
Surface finishing
Quality Assurance (QA)
Heat Treatment

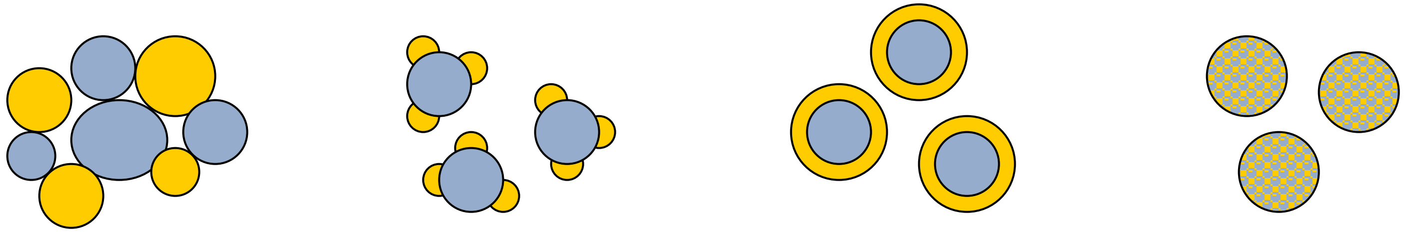
POST PROCESSING

- **Quality Assurance (QA)**
  - Not a single in step, but instead is a set of inspections, measurements, analyses and documentation performed throughout the workflow
- QA for metal AM is unique
  - The repeatability of most metal AM processes cannot be taken for granted
  - Certain processes are particularly sensitive to material input and process variables which are hard to control
  - Robust QA strategy needed
    - Software
    - Hardware
    - Materials
    - Processes monitoring

POWDER BED FUSION PROCESSES



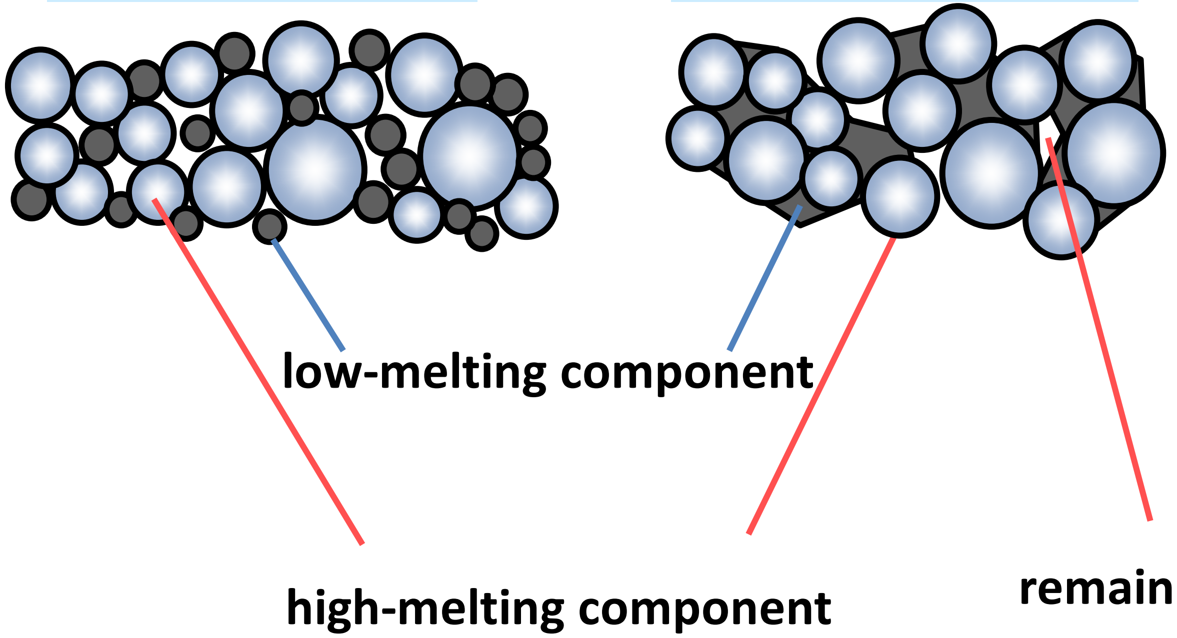
TYPES OF (SINTERING) POWDER



powder: mixed satellites coated alloyed

powder layer before sintering

powder layer after sintering



LASER POWDER BED FUSION (LPBF)
–OFTEN ALSO CALLED SELECTIVE LASER MELTING (SLM)

- Applications:
  → jewelry for individual demand in very short time

- → medicine, i. e. surgery, dentistry
  simultaneously up to 30 dental
  implants (core of teeth prosthesis)

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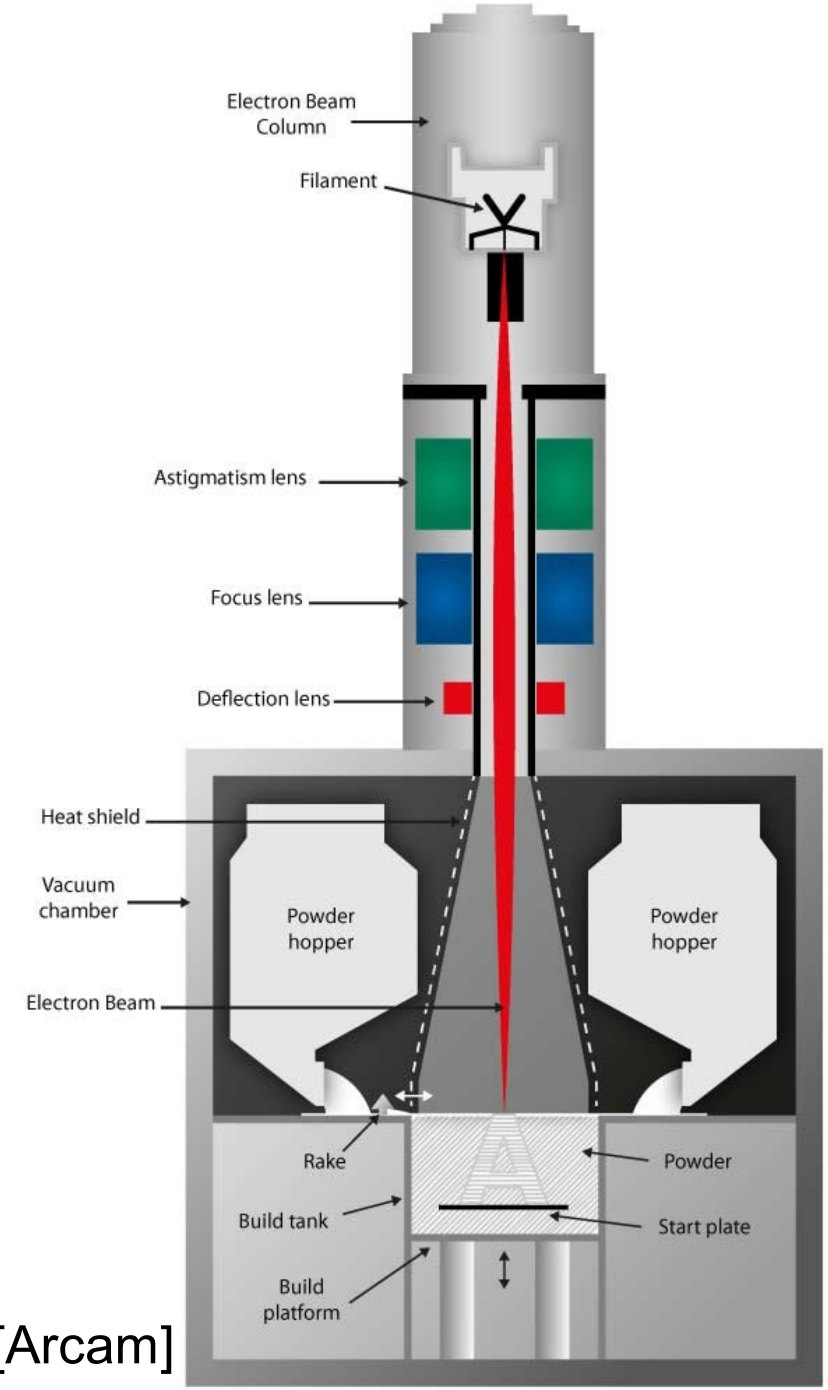
ELECTRON BEAM MELTING (EBM)

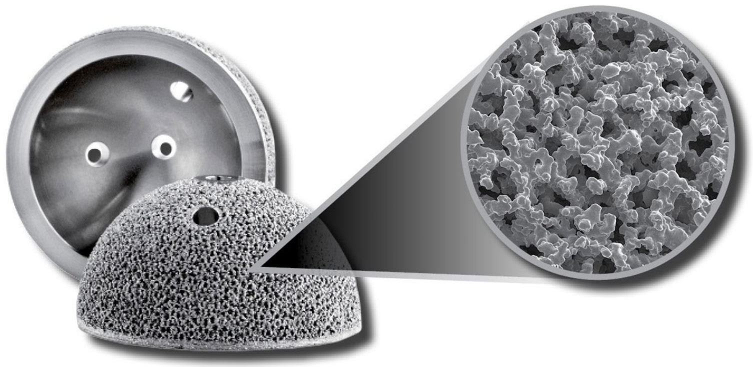
* Vacuum chamber
* Beam pre-heats powder bed before selective melting for each layer



[Arcam]

EBM APPLICATIONS – AEROSPACE AND ORTHOPEDIC IMPLANTS

Turbine blade
γ-titanium aluminide
Avio Aero



PBF FACTORIES?

[Arcam]

FREEFORM TECHNOLOGIES

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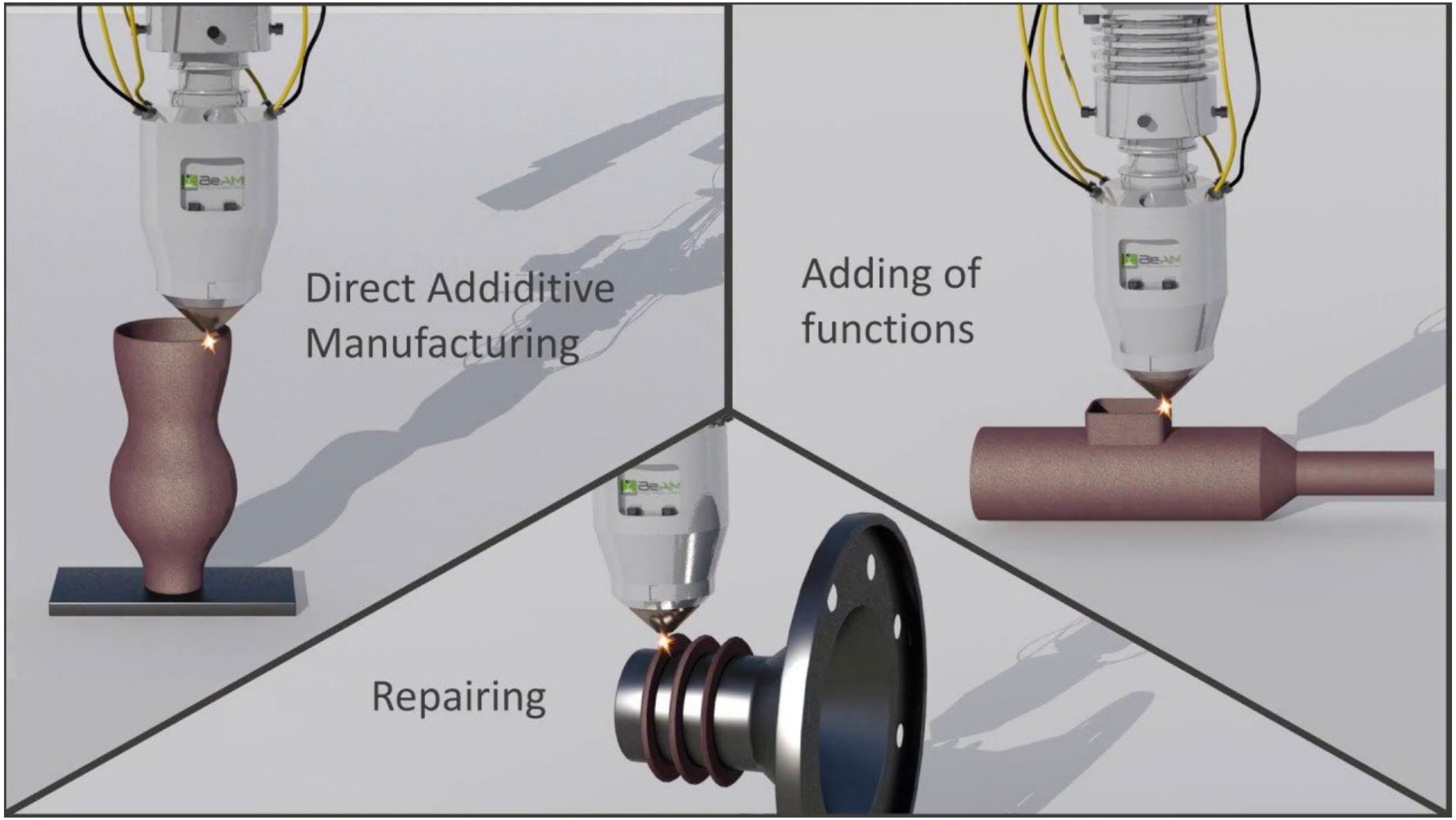
FREEFORM MANUFACTURING ASPECTS



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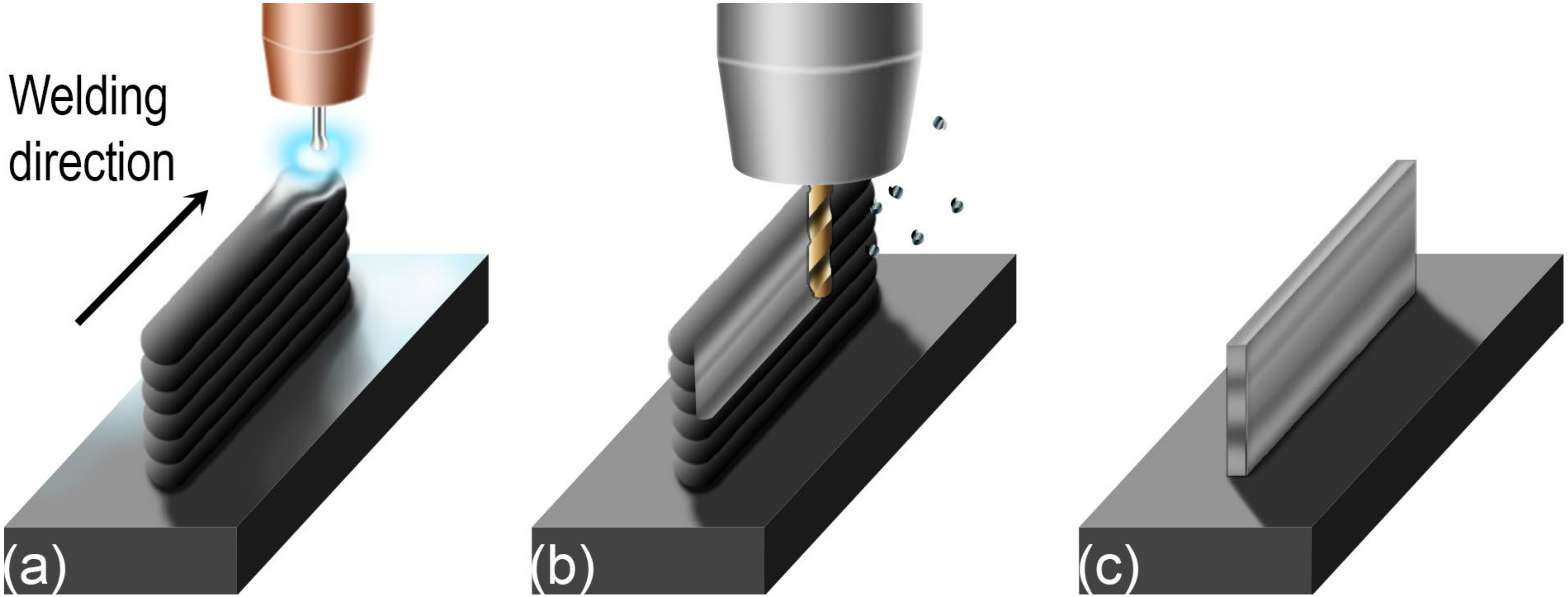
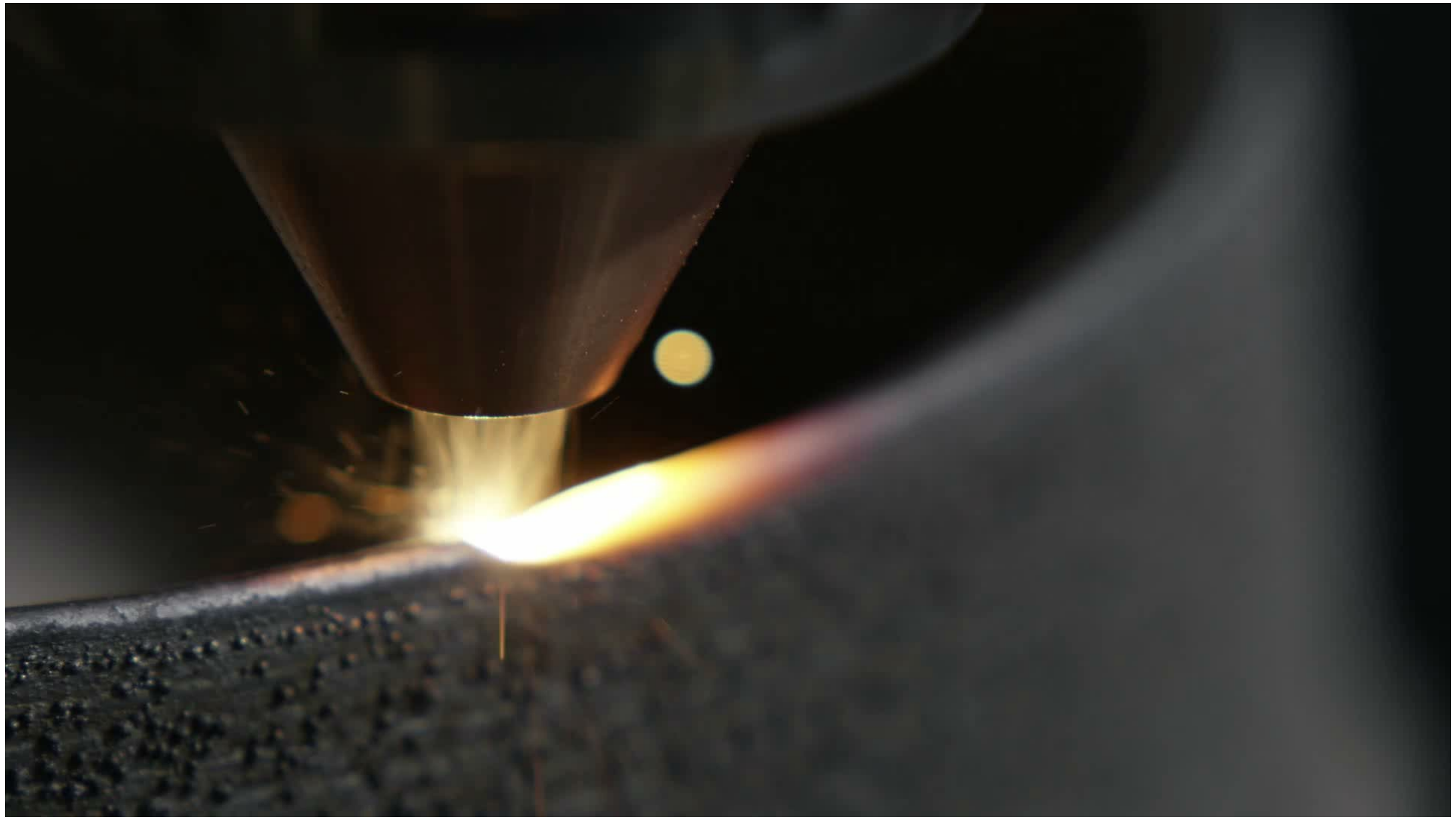
WAAM – POST PROCESSING



3D HYBRID MANUFACTURING - LASER METAL DEPOSITION & HIGH-SPEED MILLING



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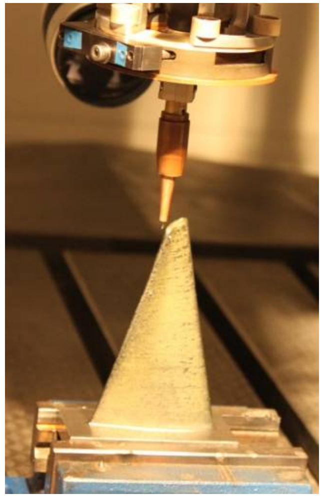
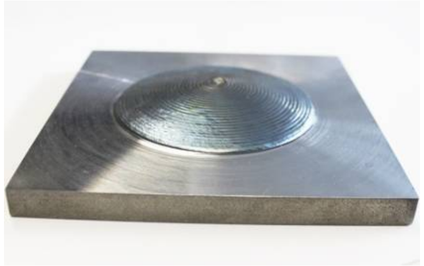
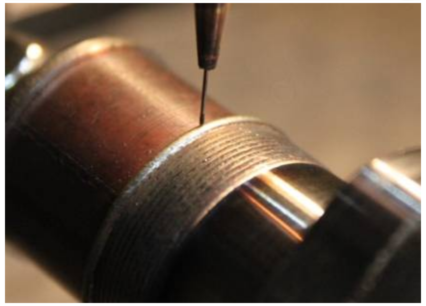
LMWD - EXAMPLES







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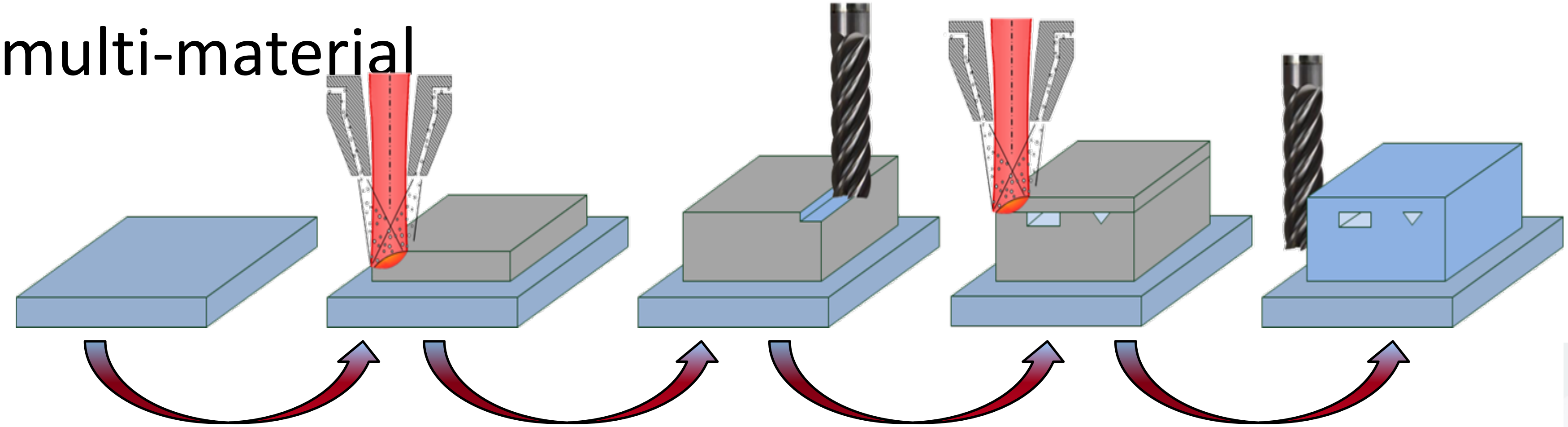
3D HYBRID MANUFACTURING - ASPECTS

- intermediate processing
  → improved accessibility **during** processing, e. g. cooling channels
- onto **free-form** substrates, e. g. repair, redesign
- direct **net shape** fabrication of complex parts → surface finish
- one clamping, reduced chuck tools → faster and high precision
- multi-material



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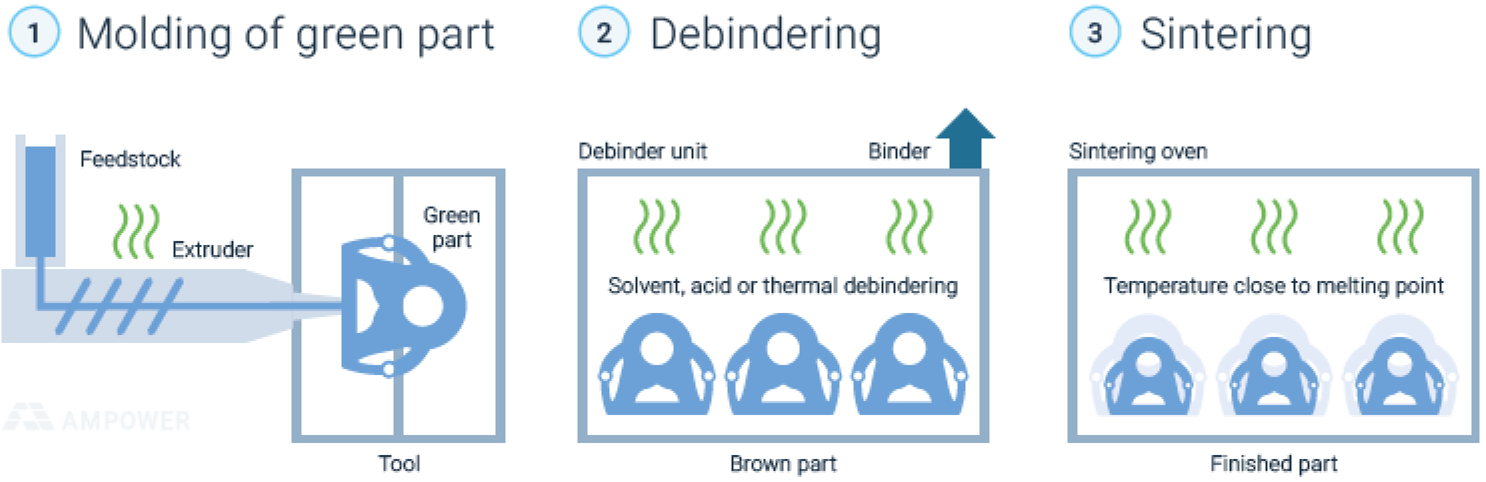
GREEN BODY TECHNIQUES

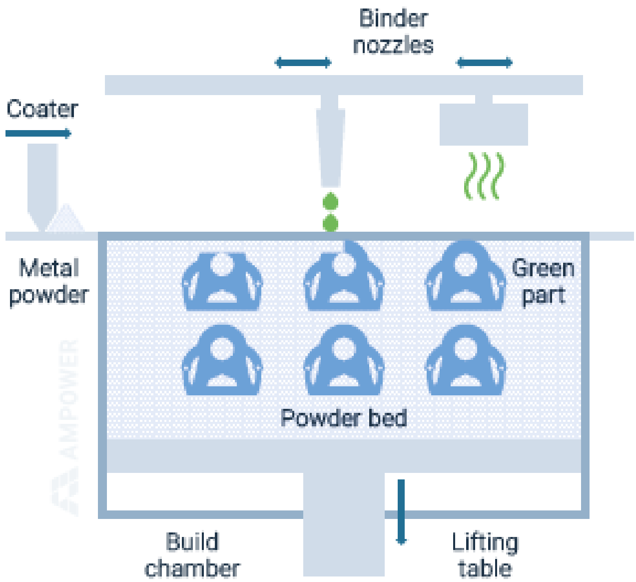
Fused deposition modeling

Binder jetting

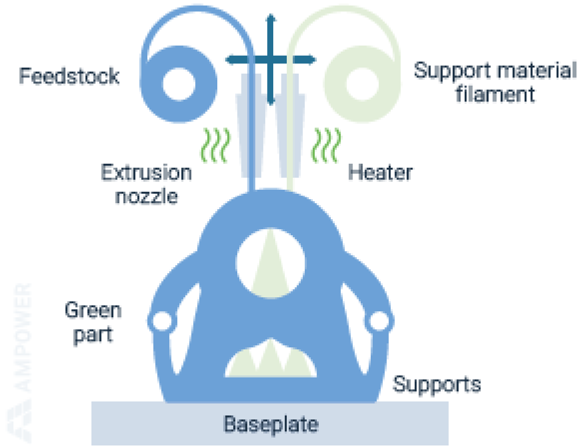
GREEN BODY PROCESSING



Binder jetting



Fused deposition modeling



Source: AMPower

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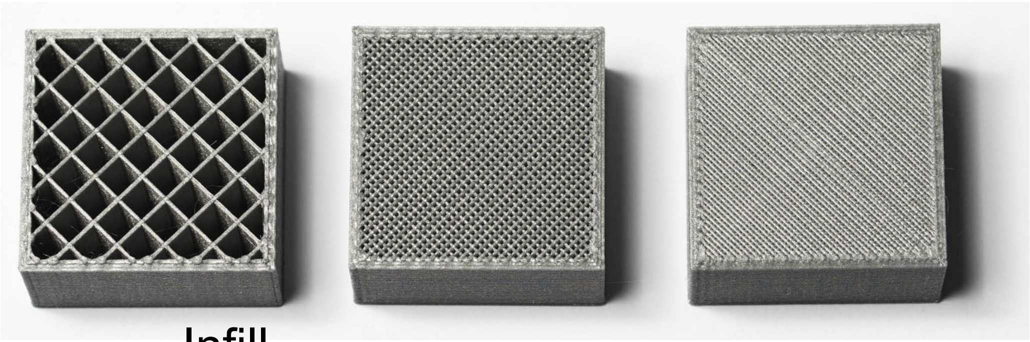
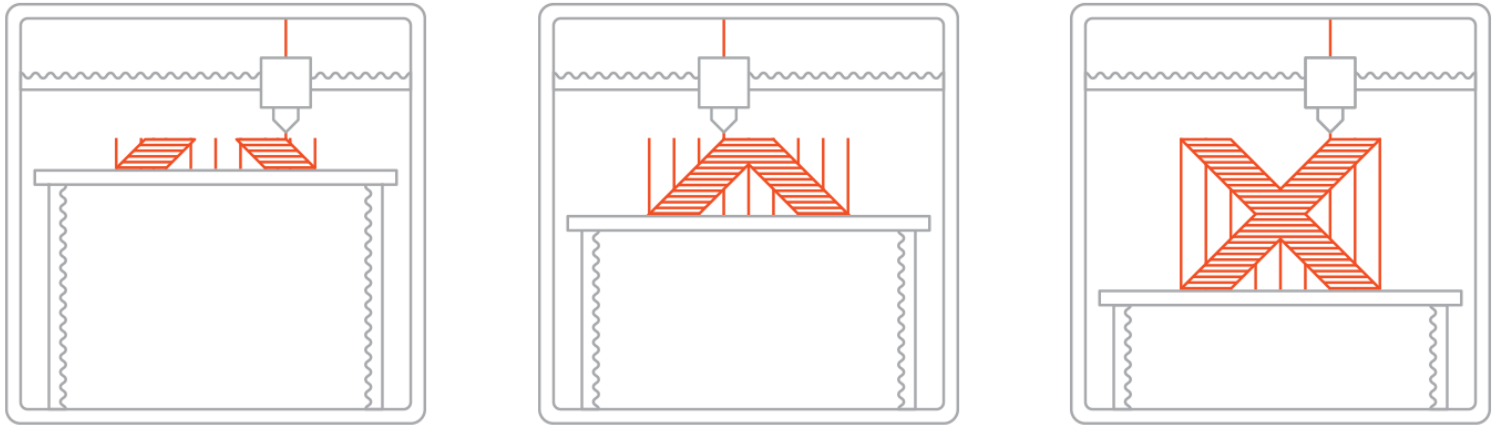
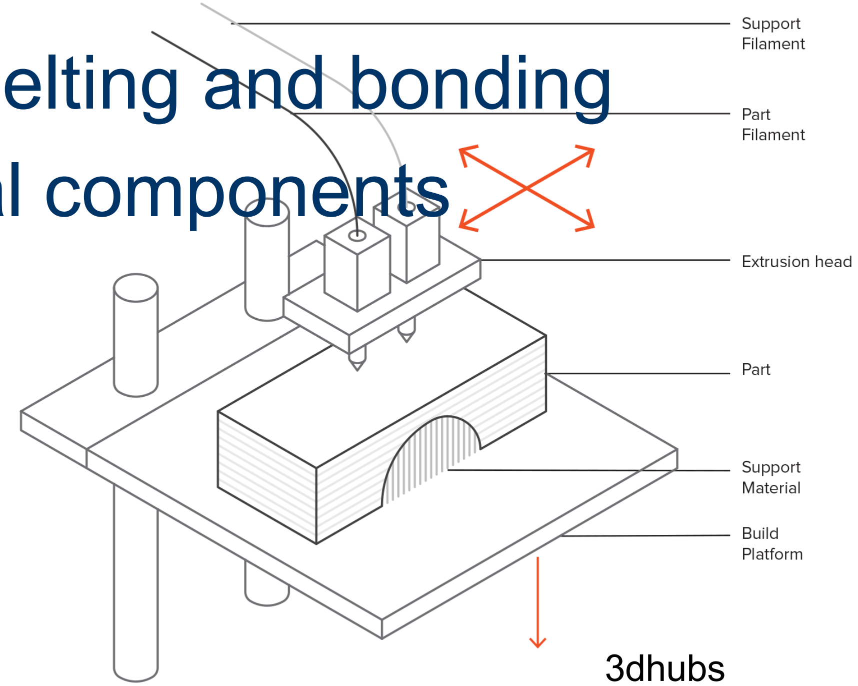
FUSION DEPOSITION MODELING (FDM)

- Most common printer (a.k.a desktop printer)
- Low cost 3D-printing
- 50-400 μm layer height
- High temperature and pressure ensures melting and bonding
- Mostly used for prototyping and non-critical components



Infill

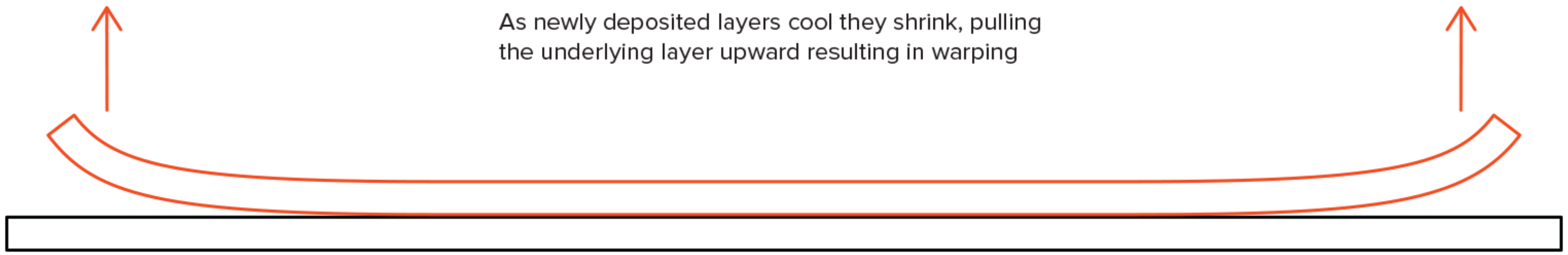




3dhubs

FDM – LIMITATIONS

- Warping
  - Large flat areas
  - Thin protruding features
  - Sharp corners
  - Material dependent, e.g. ABS
- Layer adhesion
  - Weak bond strength in z direction



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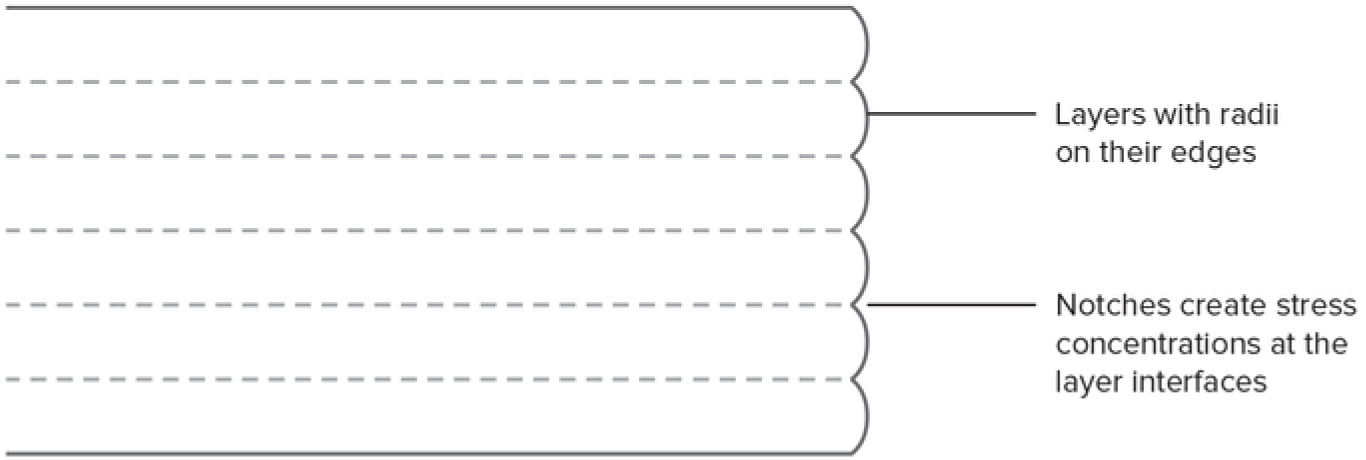
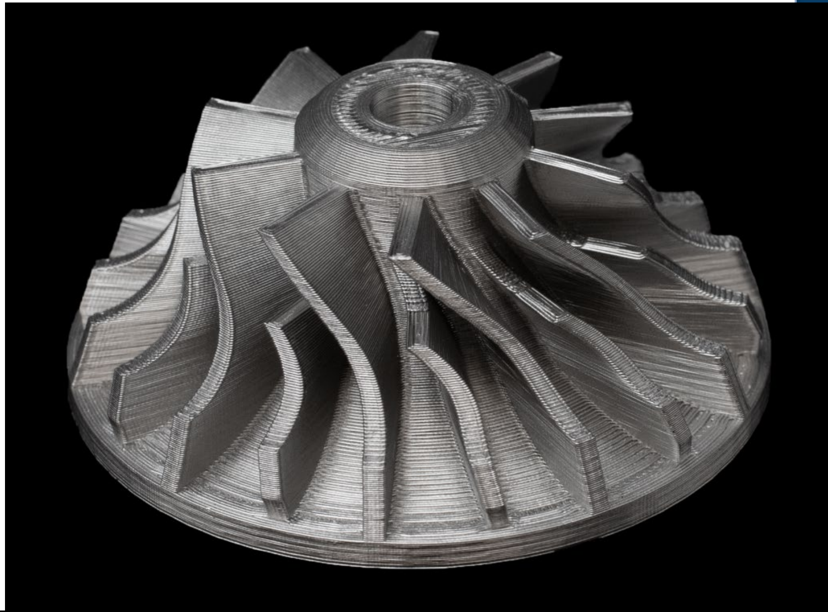
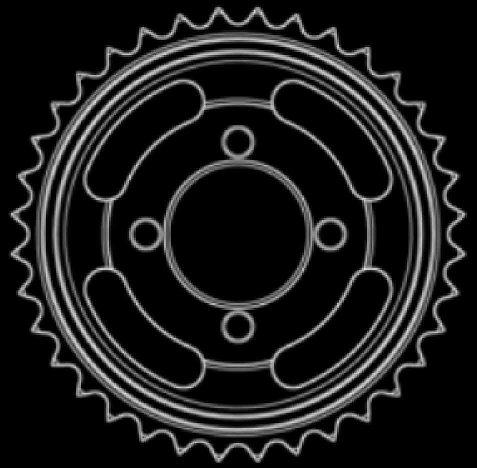


FDM – MARKFORGED METAL X

- Can print composites - infused materials in polymer wires
  - Carbon fibers (similar strength as traditional aluminium)
  - Kevlar
  - Glass fiber
- *Atomic Diffusion Additive Manufacturing*
  - Aluminium
  - Titanium?
  - Stainless steel?
  - Copper?



FDM – METAL X PROCEDURE



DESIGN

CAD your part, upload the STL, and select from a wide range of metals. The Eiger software does the rest making printing the right part easy.

PRINT

Metal powder bound in plastic is printed a layer at a time into the shape of your part. Parts are scaled up to compensate for shrinkage during the sintering process.

SINTER

Printed parts go through a washing stage to remove some of the binder. They are then sintered in a furnace and the metal powder fuses into solid metal.

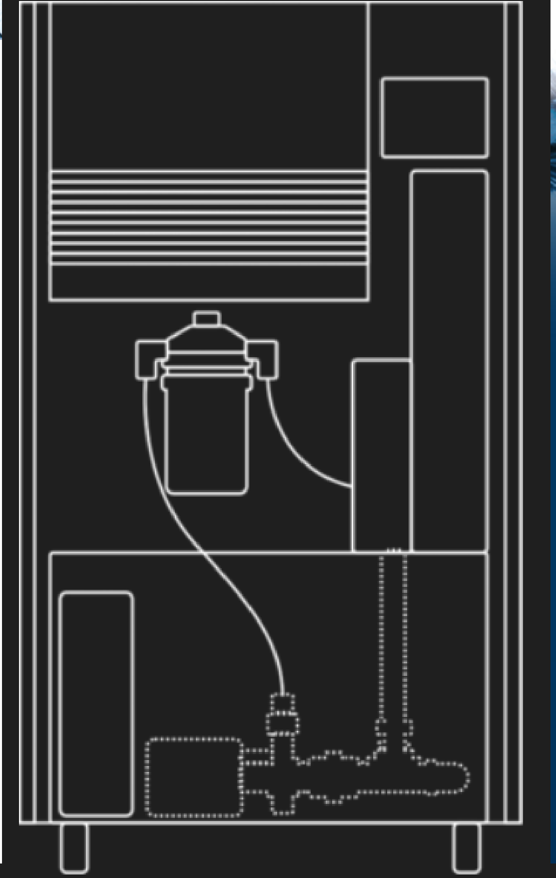
PART

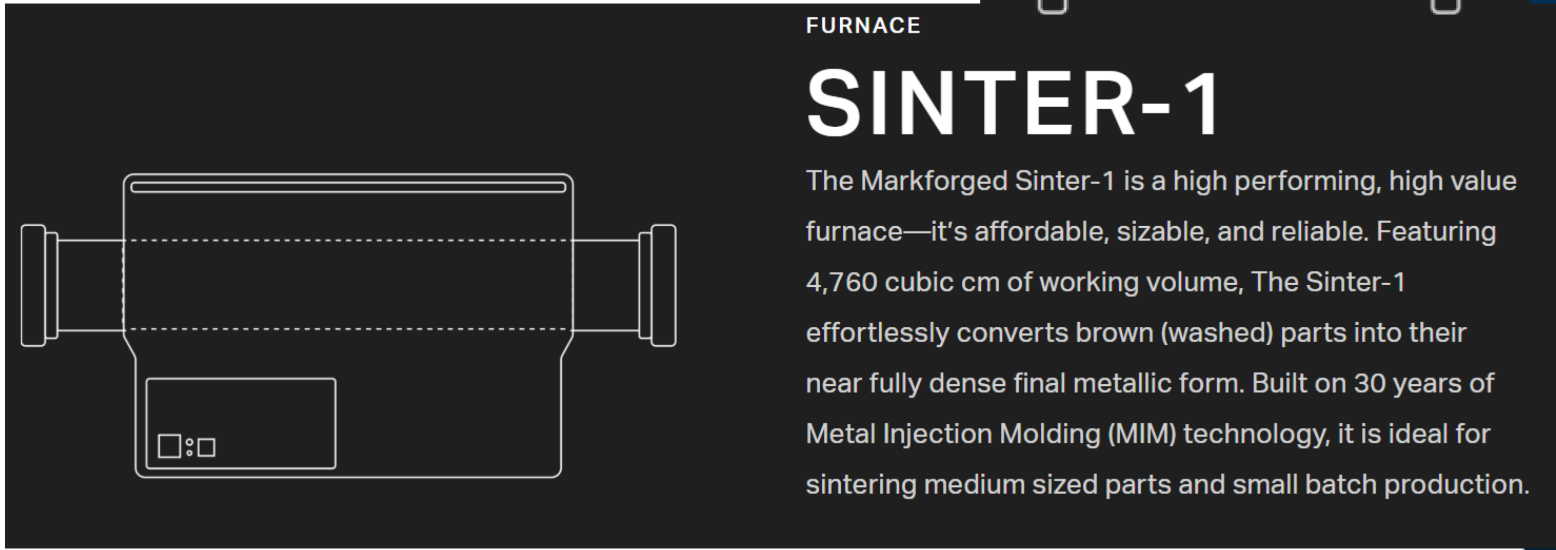
Now comprised only of pure metal, the final parts are ready for use. They can be processed and treated just like any other metal parts.

FDM – METAL X

- Post processing required
  - Washing
    - *Green part* immersed in ”specialized fluid” that removes binding material
    - Leaving part semi-porous
  - Sintering
    - Peak temperature 1300° C
- Full system cost > 130 k€

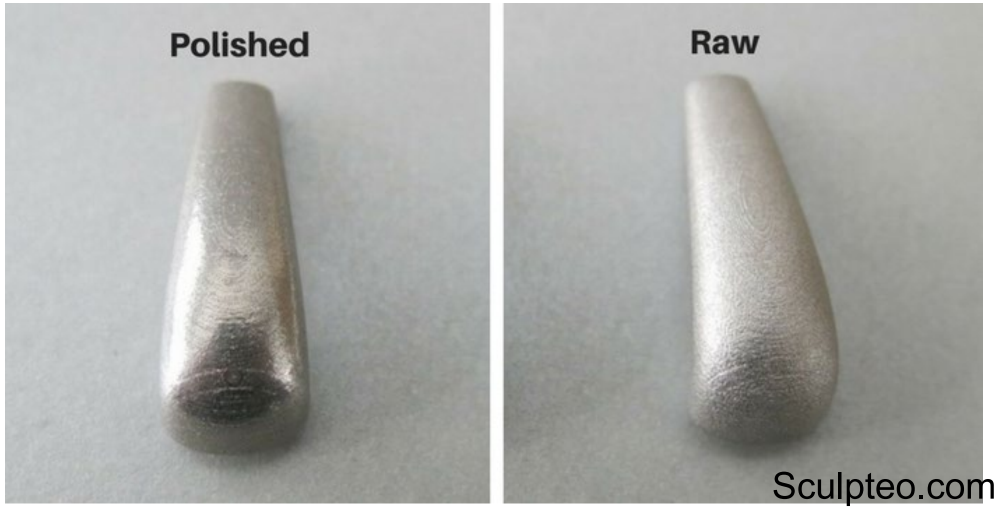
- *Not easily found info:*
  - Performance?
  - Total print cost?
  - Total time to finished part?





BINDER JETTING (BJ)

- Similar to traditional printing
- Manufacturers
  - DeskTop Metal (US)
  - Digital Metal (S)
  - ExOne (US)
  - Prodways (F)
  - HP (US?)
  - XJet
- Various applications and materials
  - Full colour prototypes
  - e.g. Plastics, ceramics
  - Sand casting and molds
  - Low-cost 3D-printing of metals



Sculpteo.com

https://www.youtube.com/watch?v=Sv17bJdVsCk

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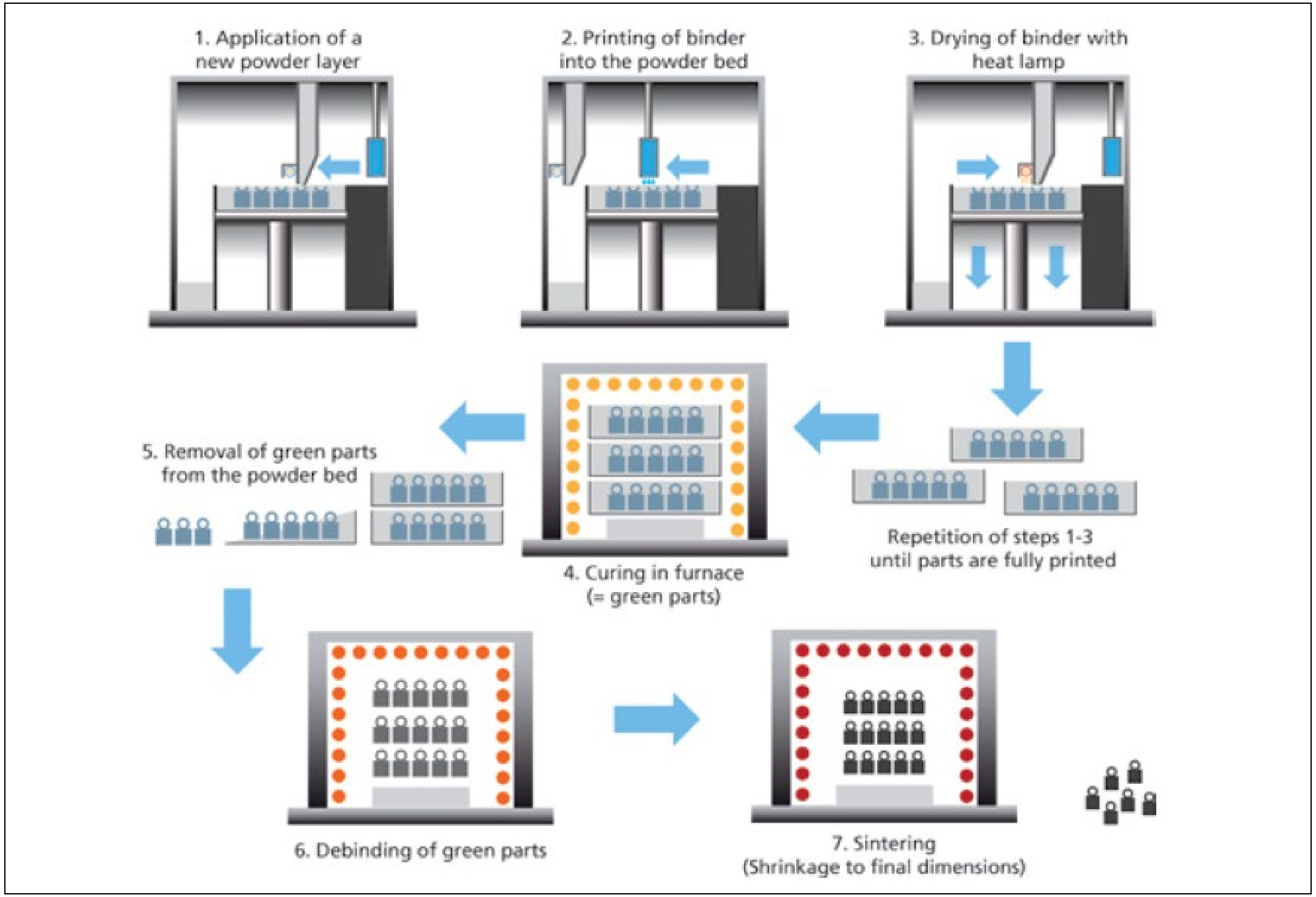
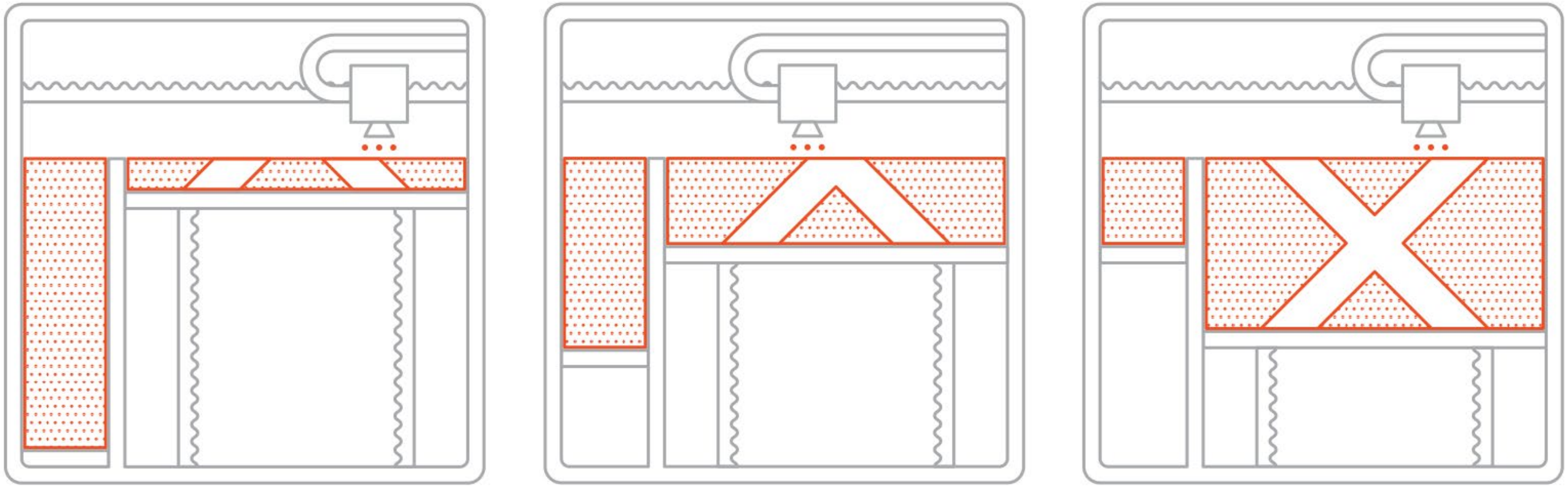
METAL BINDER JETTING AND SINTERING

- The 3D printing process is an indirect process in two steps
- Powder is agglomerated by a binder through feeding nozzle
- Green bodies fragile, requiring curing, debinding and sintering before finished



Metal Binder Jetting process (Courtesy of Fraunhofer IFAM)

BJ – PROCESS



https://www.youtube.com/watch?v=L6Rd9diIkrs

https://www.youtube.com/watch?v=wRj44e8D-xk

BJ - PROCESSING

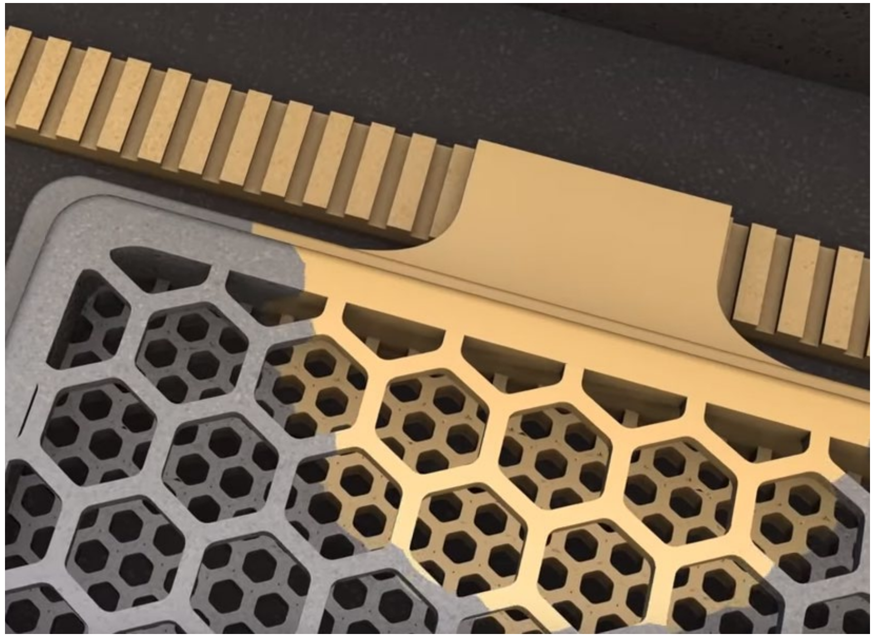
- 50-100 µm layer height
- Deformation during post-processing (sintering)

1. Recoating of powder bed
2. Cariage with inkjet nozzles passes over the powder bed
   1. Binder agent (glue)
   2. Coloured binder possible
3. Platform lowered

- After printing, part needs to be cured and afterwards cleaned
  - For metals, sintering is also necessary

BJ – BENIFITS

- Room temperature building in air atmosphere
- Large build volumes (up to 2200x1200x600 mm)
- No support structures needed
  - Not affected by thermal effects, e.g. warping
- Entire build volume can be used
  - Suitable for low-medium batch production
- High powder re-usability
- Short lead times between builds compared to PBF systems



- Metal components at low price
  - Stainless steel (bronze infiltration)
  - Stainless steel (sintered)
  - Tungsten carbide (sintered) - cutting tools

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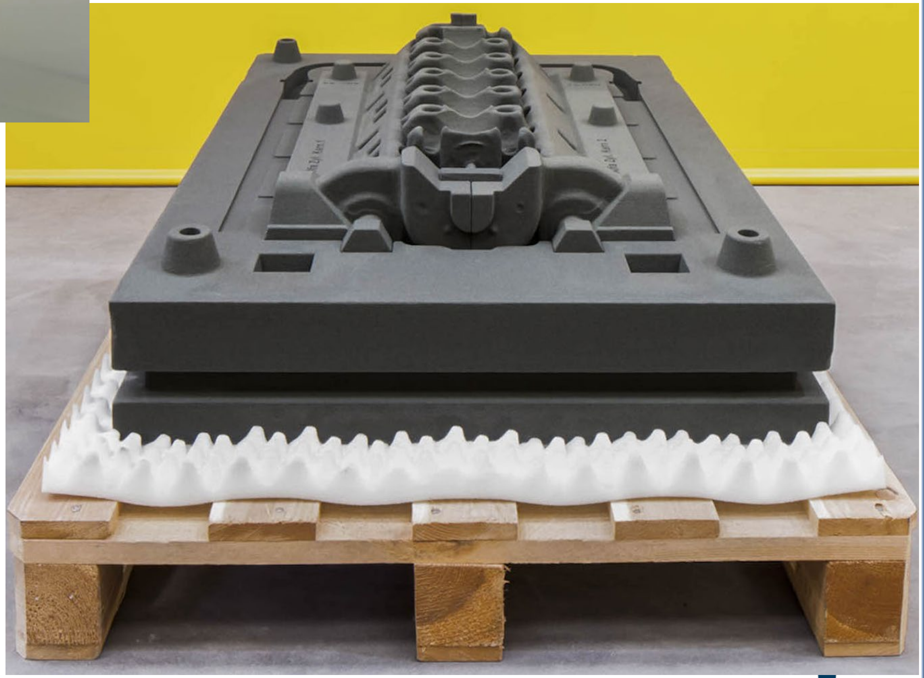
BJ - CONSTRAINTS

- Part size limited to 50 mm (due to post processing steps)
- Accuracy and tolerances difficult to predict (geometry dependent)
- Components shrink 0.8-2% during infiltration and ~20% during sintering
- Lower mechanical properties of metal components
  - Stainless steel (bronze infiltration) - ~10% porosity
  - Stainless steel (sintered) ~3% porosity
  - Only rough details possible
    - Brittle in green state and fracturing during post processing

APPLICATIONS

- Colour printing
  - Sandstone or PMMA powder
- Sand casting cores
- Metal printing
  - Up to 10x more economical
  - Though comparison reveals:

	MJF	SLS
Cost for one-off part	Average: $46.28 Minimum: $25.71	Average: $46.45 Minimum: $26.79
Cost per part for 30 parts	Average: $28.75 Minimum: $19.00	Average: $25.85 Minimum: $19.48
Lead time	Average: 4 days Top hub: 2.9 days	Average: 7 days Top hub: 5.2 days



Multi-part sand casting assembly used to cast an engine block. Image courtesy of ExOne

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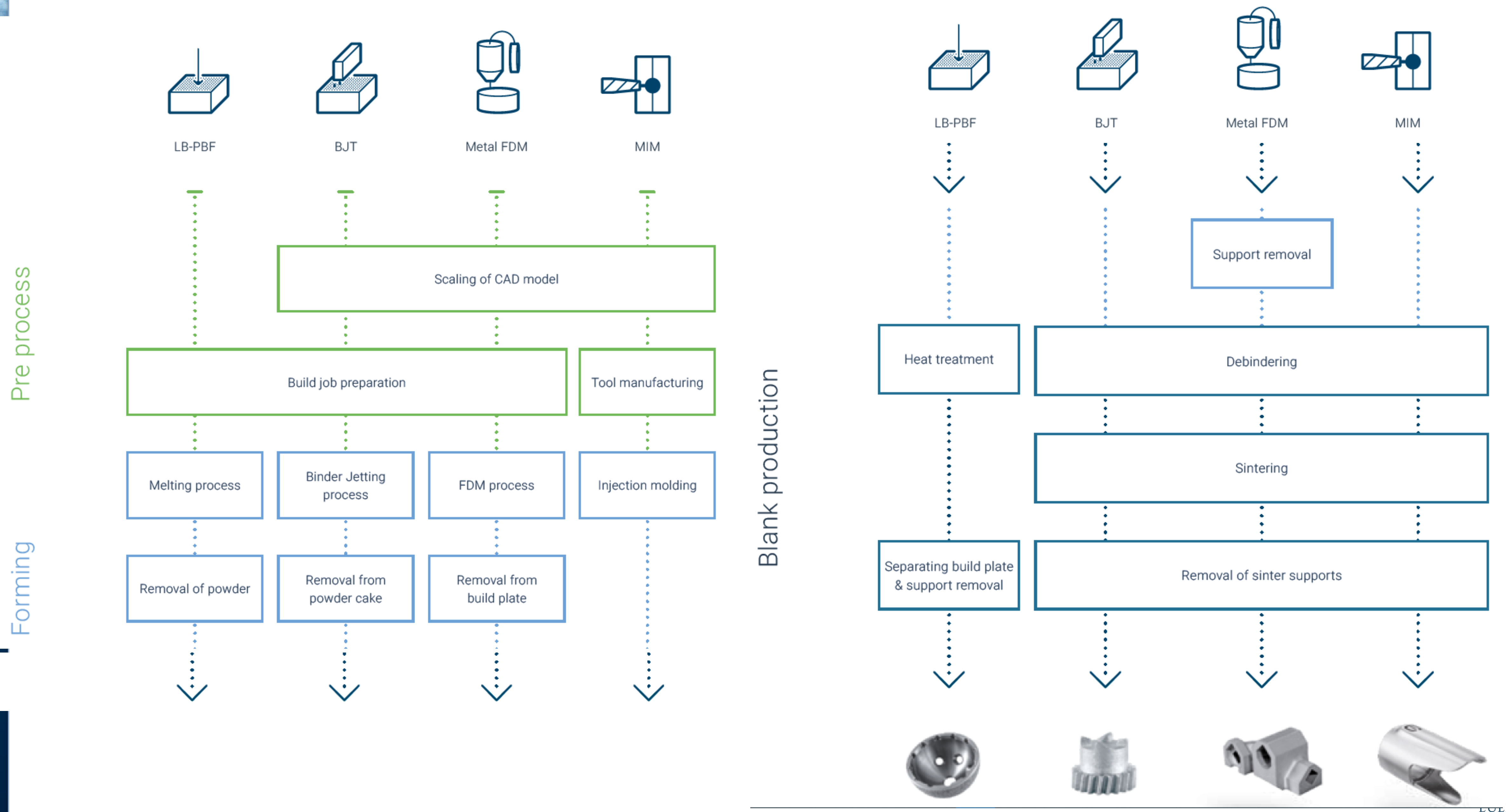
AM PROCESS COMPARISON

Go to the AM-power web-page for more information:

https://am-power.de/en/
https://additive-manufacturing-report.com/table-of-contents/

https://am-power.de/en/insights/insights-tools-additive-manufacturing-cost-calculator/



(MIM = Metal Injection Molding)

Source: AMPower

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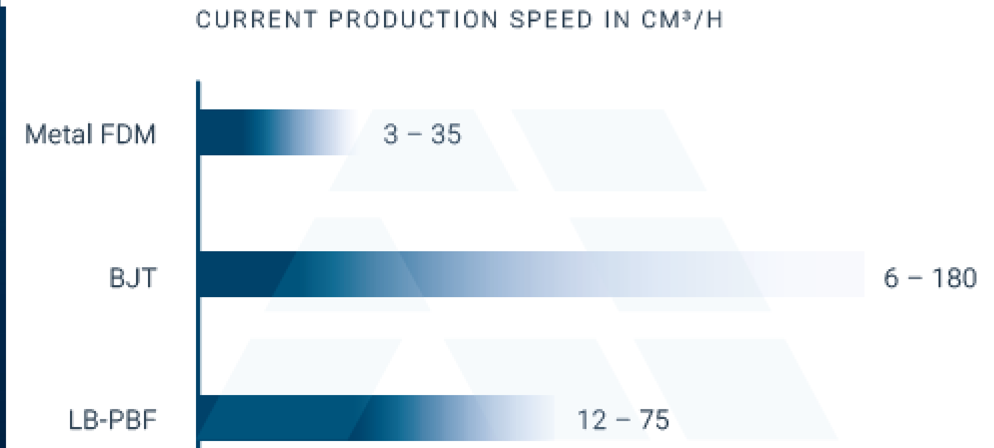
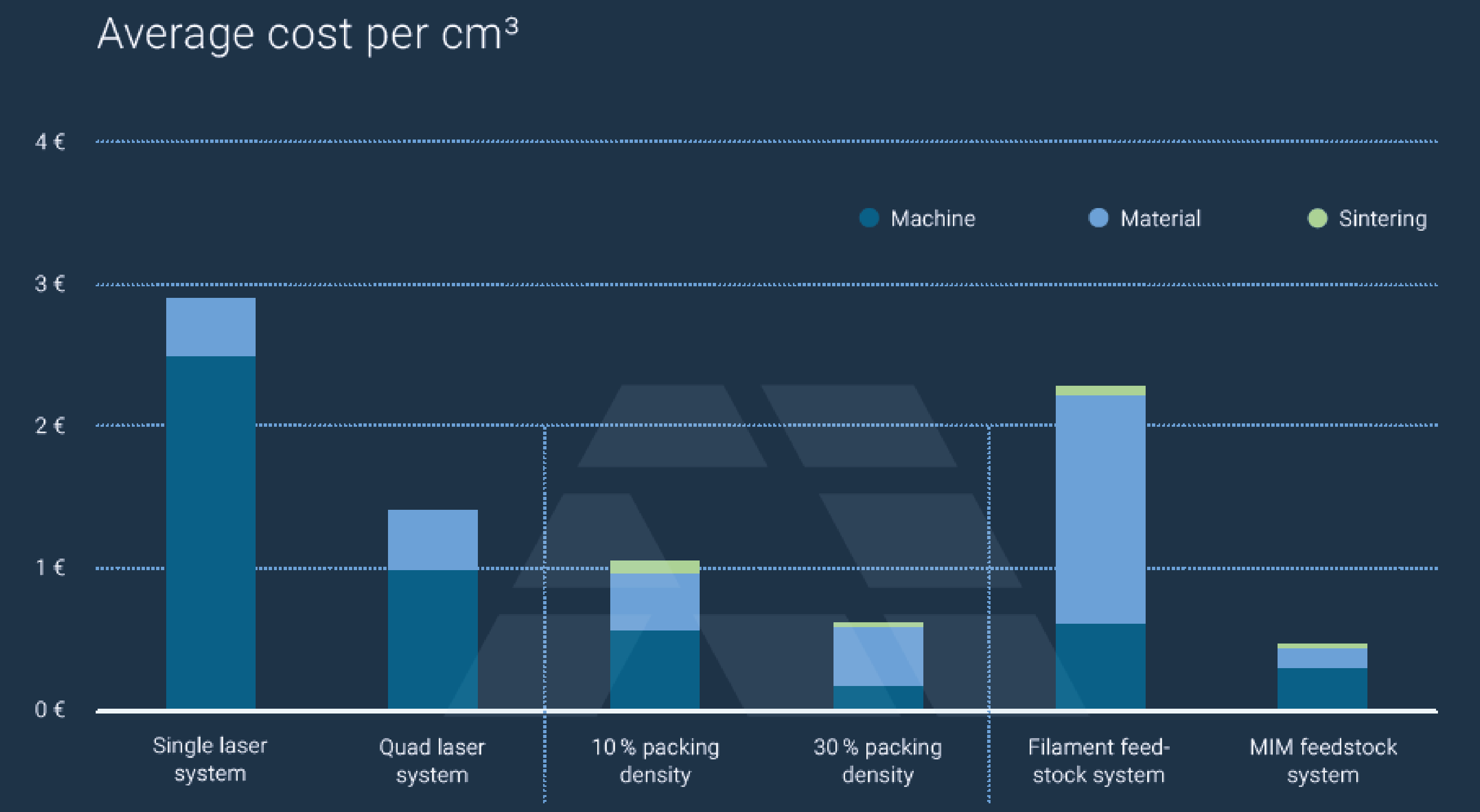
COST AS THE GAME CHANGER





Source: AMPower

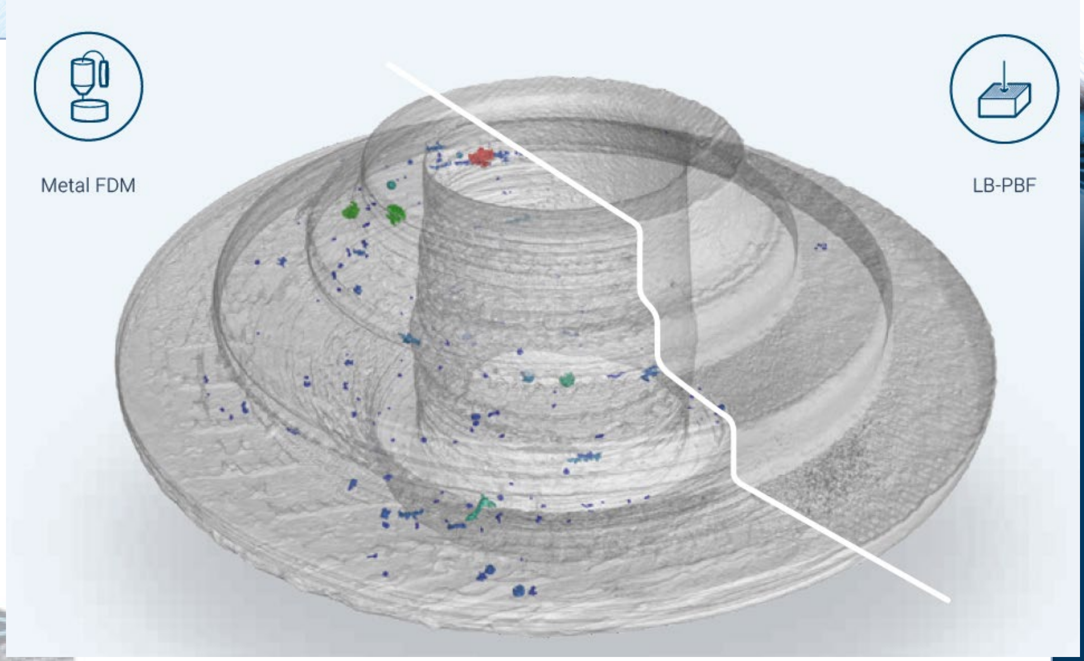
AVAILABLE MATERIAL TYPES

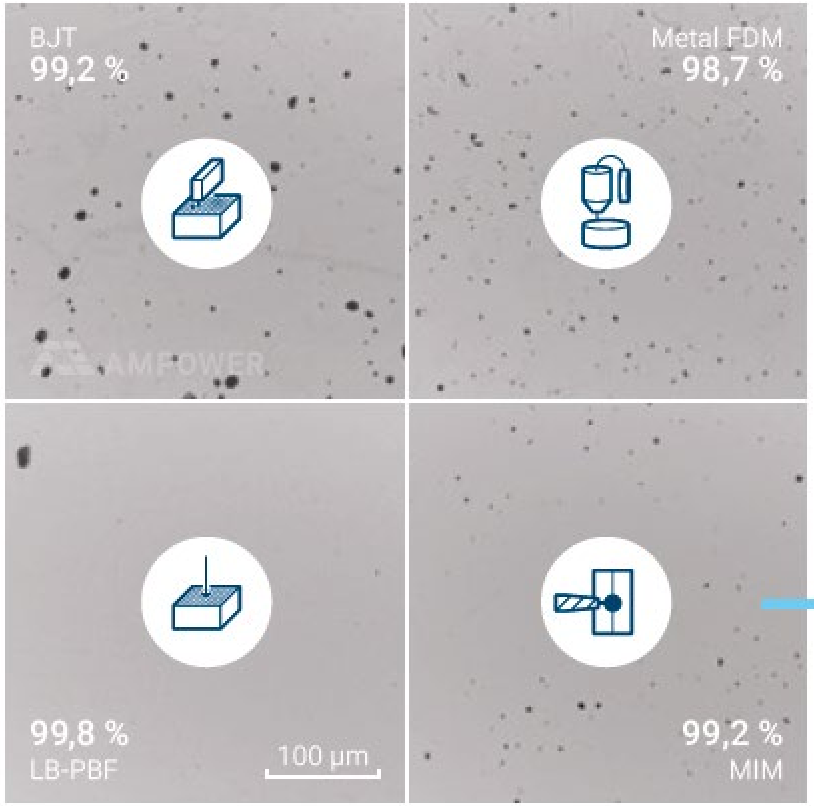
	LB-PBF	BJT	Metal FDM	MIM
Stainless steel	●	●	●	●
Tool steel	●	○	○	●
Super alloy	●	○	○	●
Titanium	●	●	○	●
Aluminum	●	◌	◌	◌
Copper/Bronce	○	○	●	●
Carbide	○	○	●	●

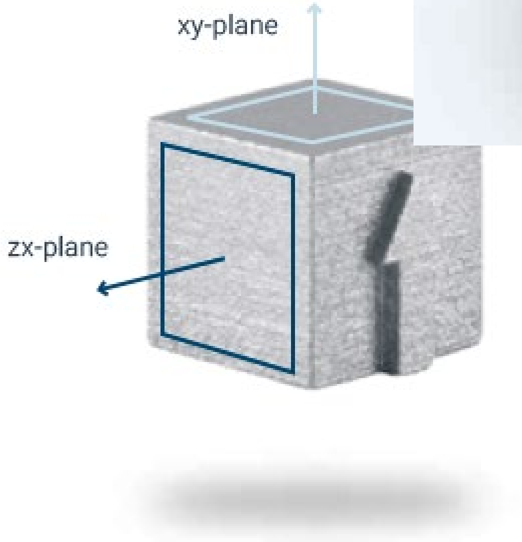
● Available ○ Under development ◌ Inherently difficult

Source: AMPower

MATERIAL DENSITY







Typical density values of MIM parts range between 95 to 97 %. The examined MIM specimen exhibits exemplary high quality with density of above 99 %.

Source: AMPower

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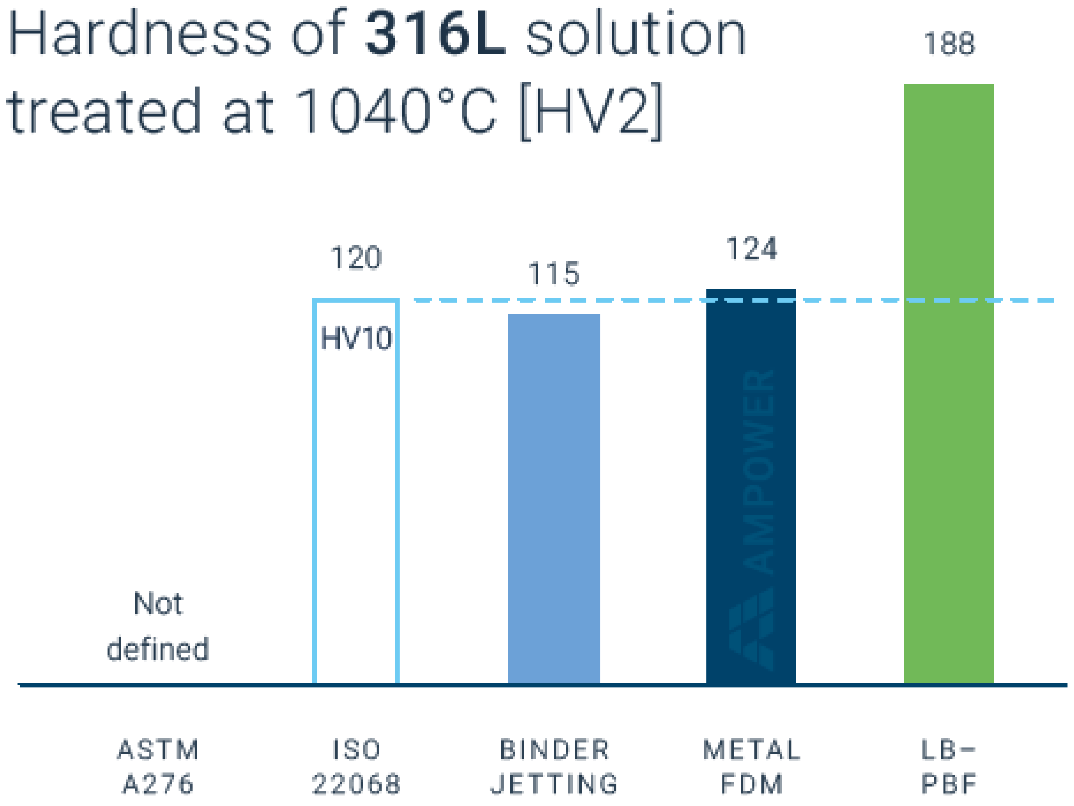
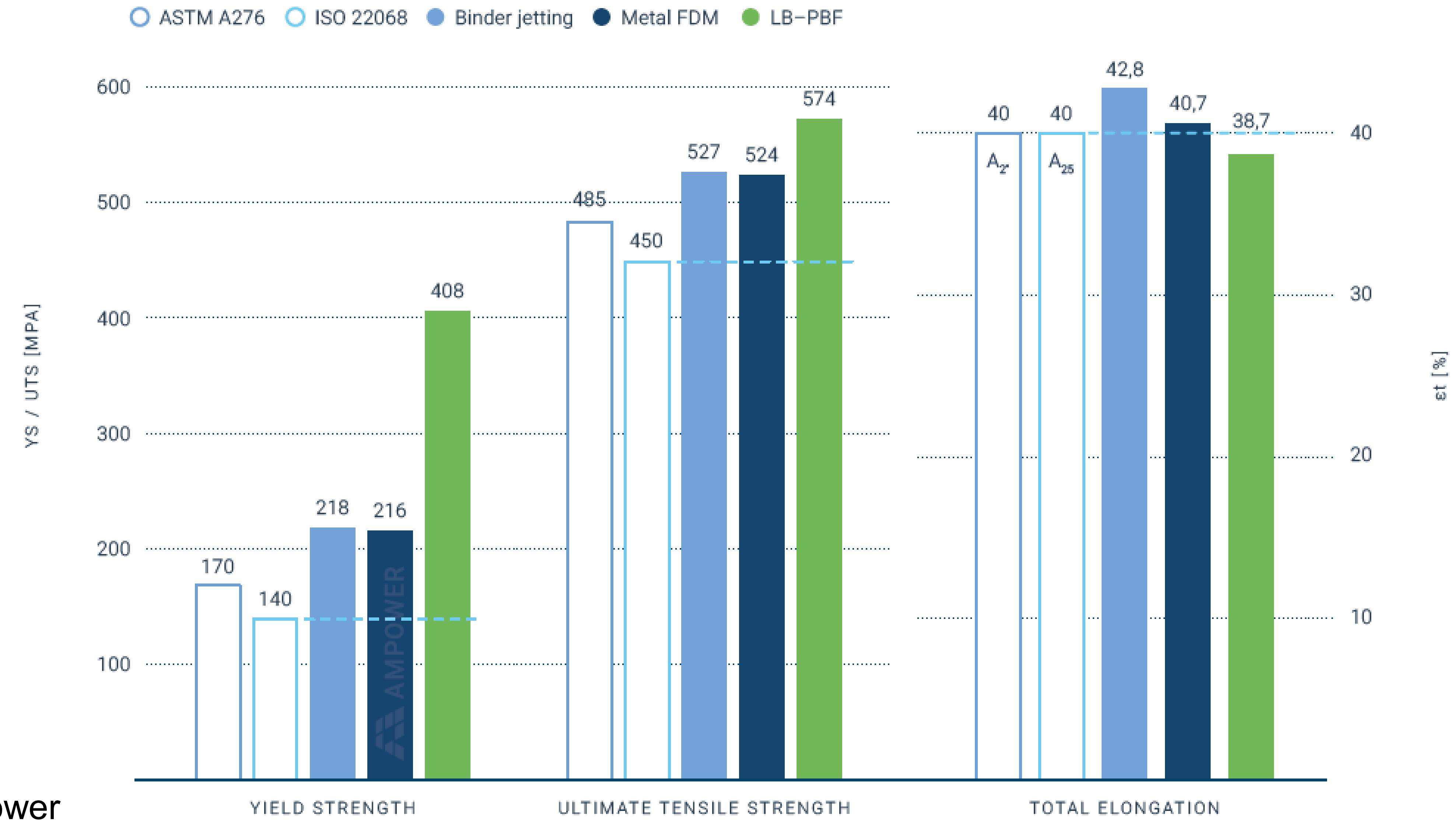
MATERIAL PROPERTIES – TENSILE STRENGTH AND HARDNESS



Sinter-based AM technologies achieve hardness close to the defined requirement for MIM alloys according to ISO 22068.
Decrease in hardness below the value described in the standard might be attributed to the additional solution treatment and/or accumulation of porosity.

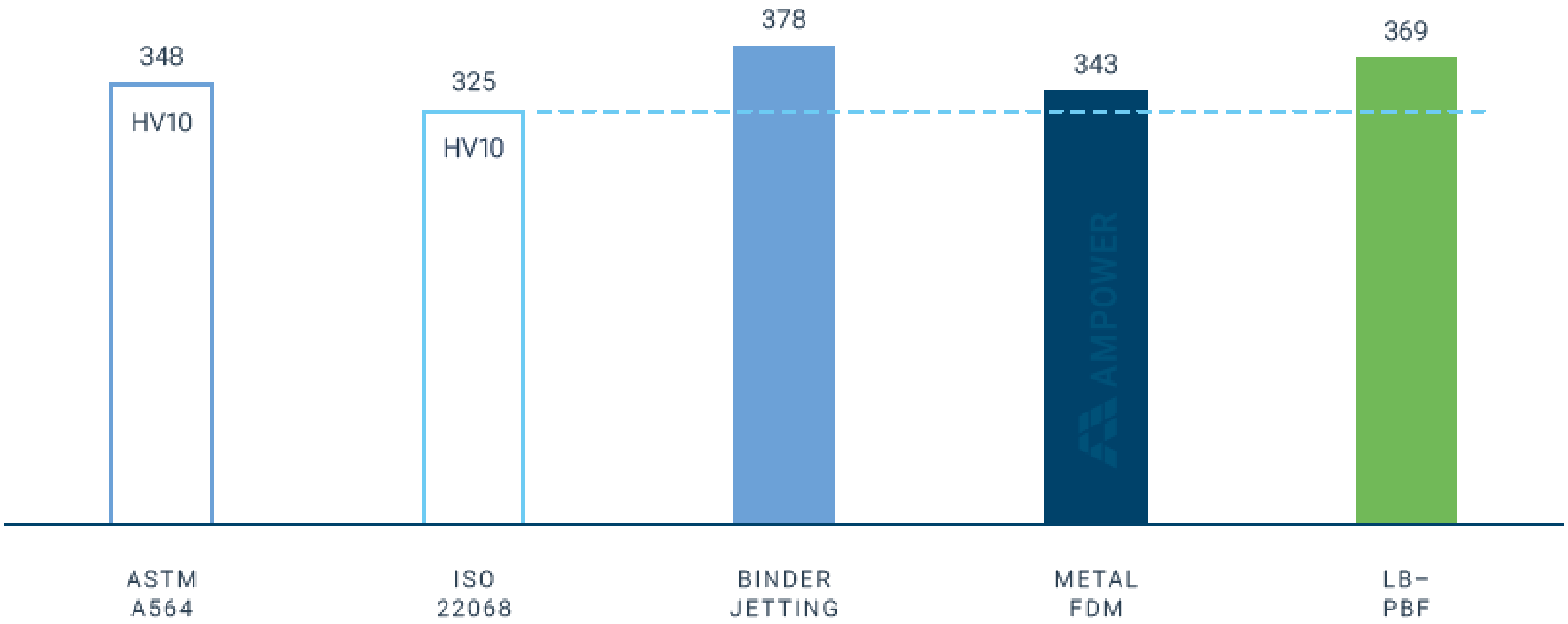
Source: AMPower

TENSILE PROPERTIES OF 316L SOLUTION TREATED AT 1040° C



Source: AMPower

HARDNESS OF 17-4PH HARDENED TO H1025 [HV25]



Source: AMPower

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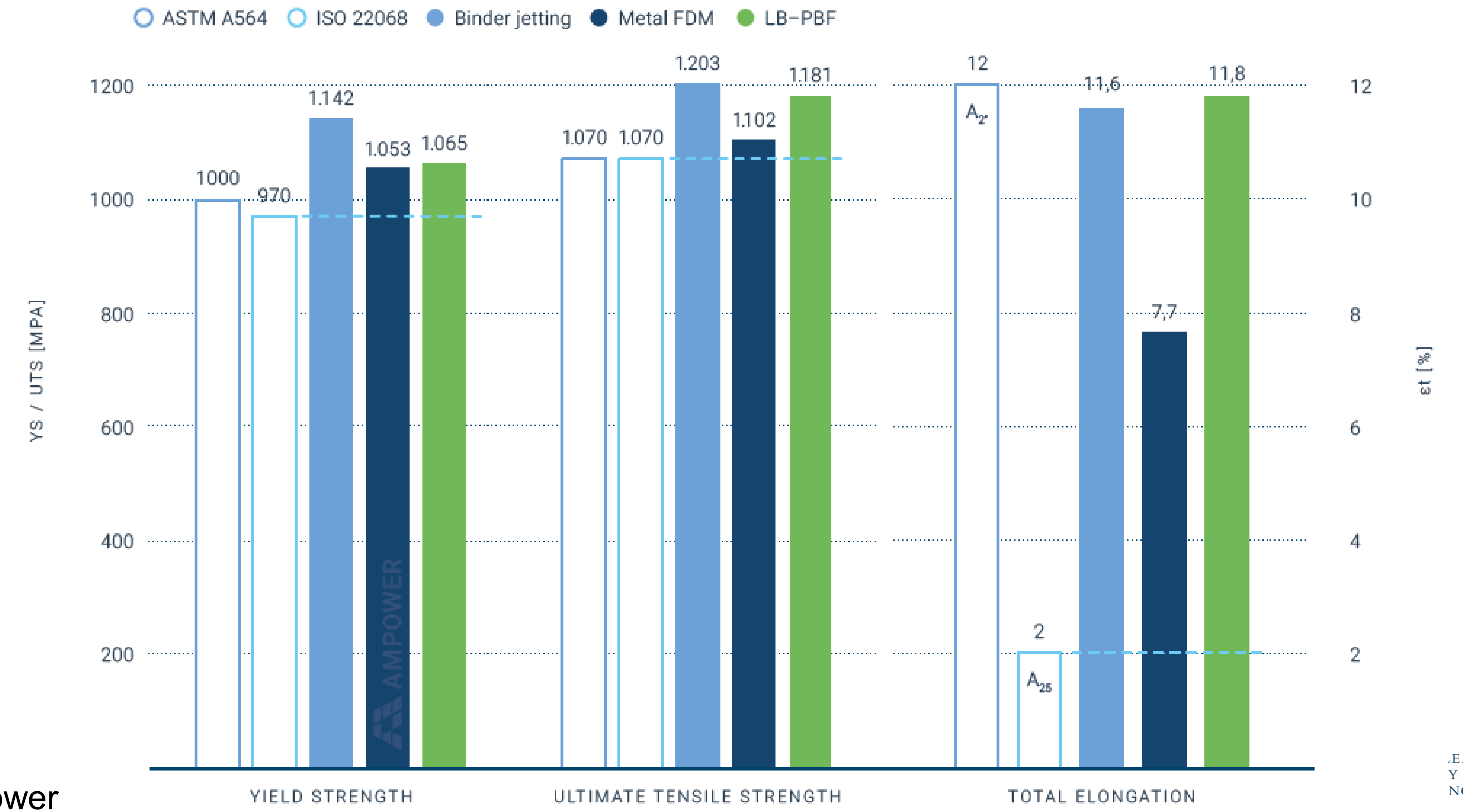
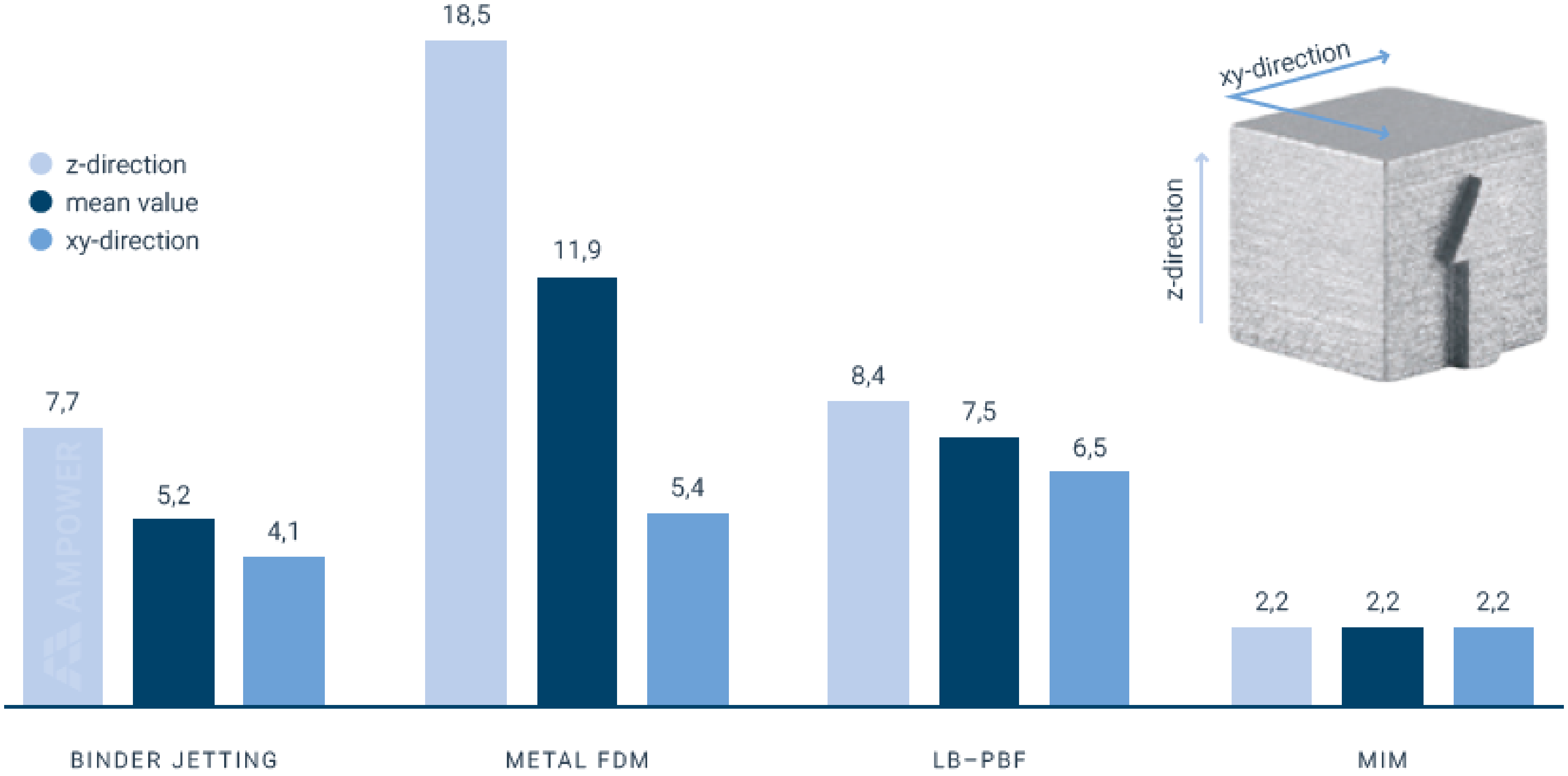
HARDNESS OF 17-4PH HARDENED TO H1025 [HV25]



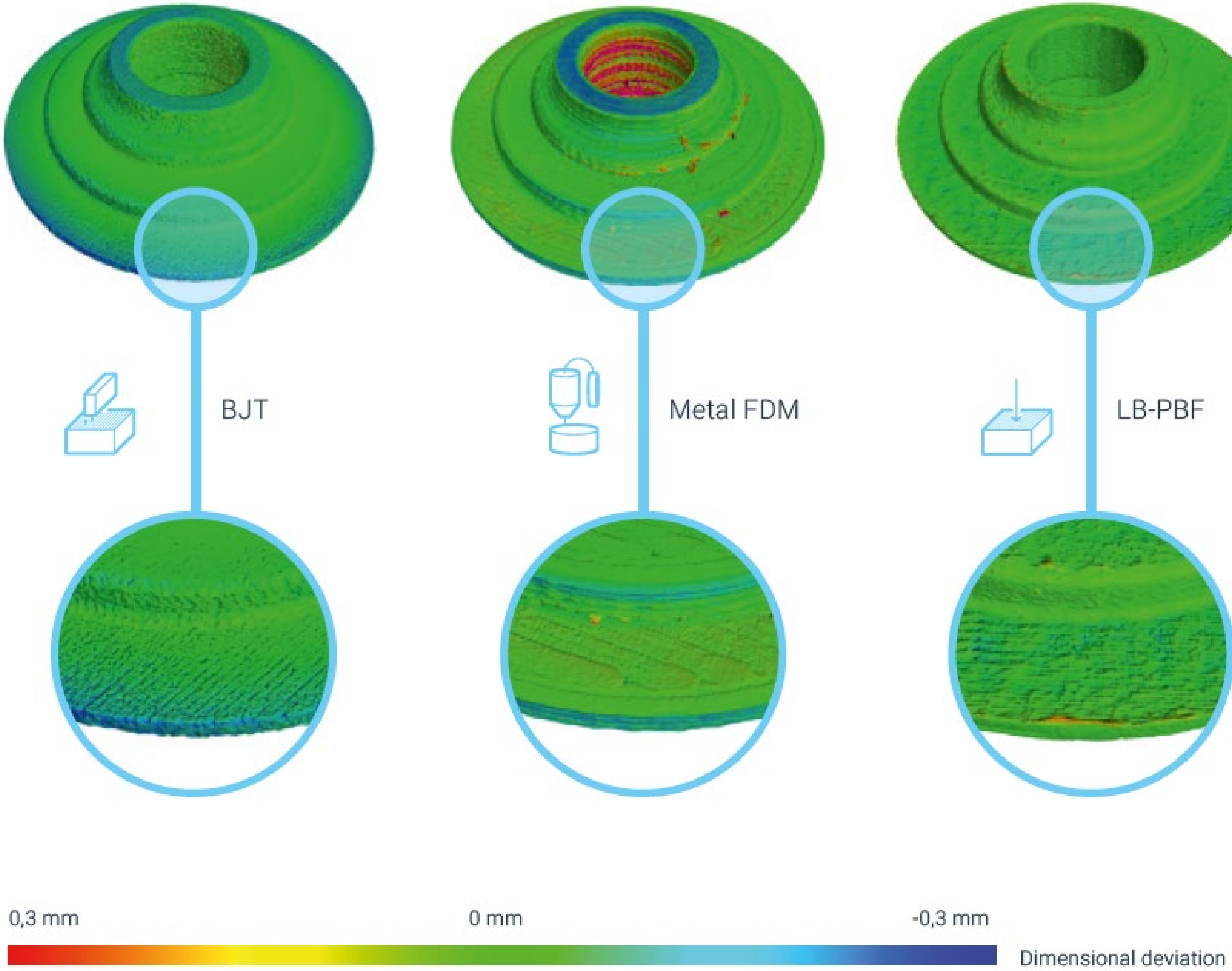
Source: AMPower

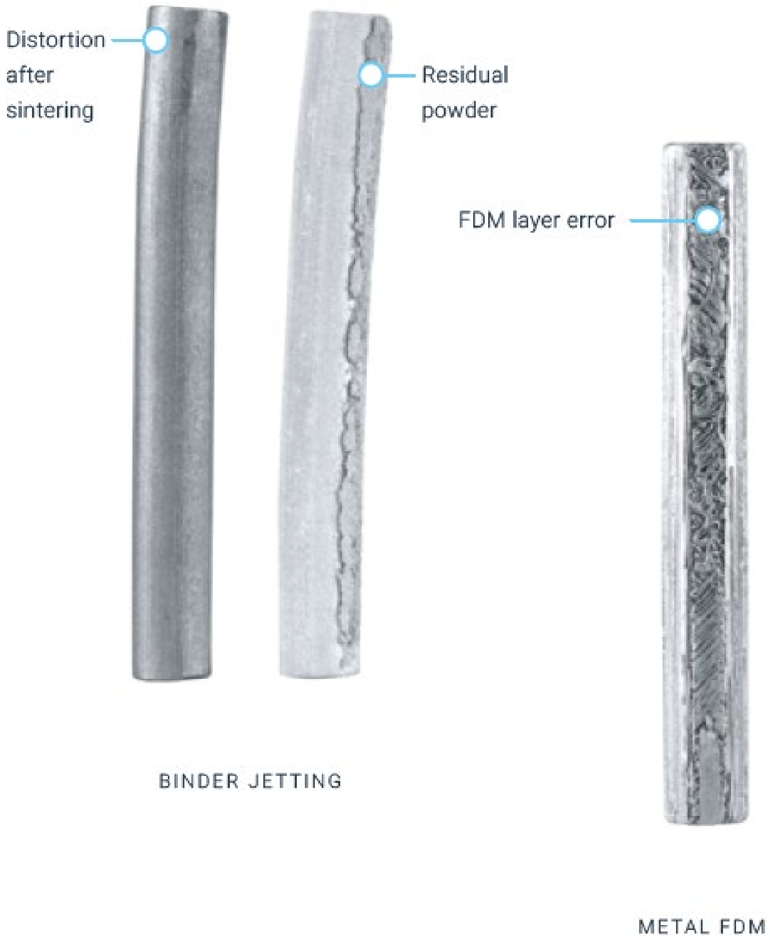
ARITHMETIC AVERAGE ROUGHNESS R_A AS BUILD IN MM



Source: AMPower

DIMENSIONAL VARIATION





Source: AMPower

DESIGN GUIDELINES FOR PROCESS SELECTION
(DFAM FOR EACH PROCESS)

	BJT	METAL FDM	LB-PBF
5-50 mm part size suited	●	●	●
50-500 mm part size suited	○	◑	◕
0,5-2 mm thickness suited	●	◑	◕
3-10 mm thickness suited	◕	◕	●
10-50 mm thickness suited	○	○	◕
Thickness jump possible	◑	◑	◕
Hollow body printable	◕	●	◕
Lattice structures possible	◕	◔	●
Support free design	●	◑	◔

	BJT	METAL FDM	LB-PBF
Surface quality	●	◔	◕
Part shrinkage under control	◕	◕	●
Part distortion under control	◔	◔	◑
First time right potential	◑	◑	◕

High ● ◕ ◑ ◔ ○ Low

Source: AMPower

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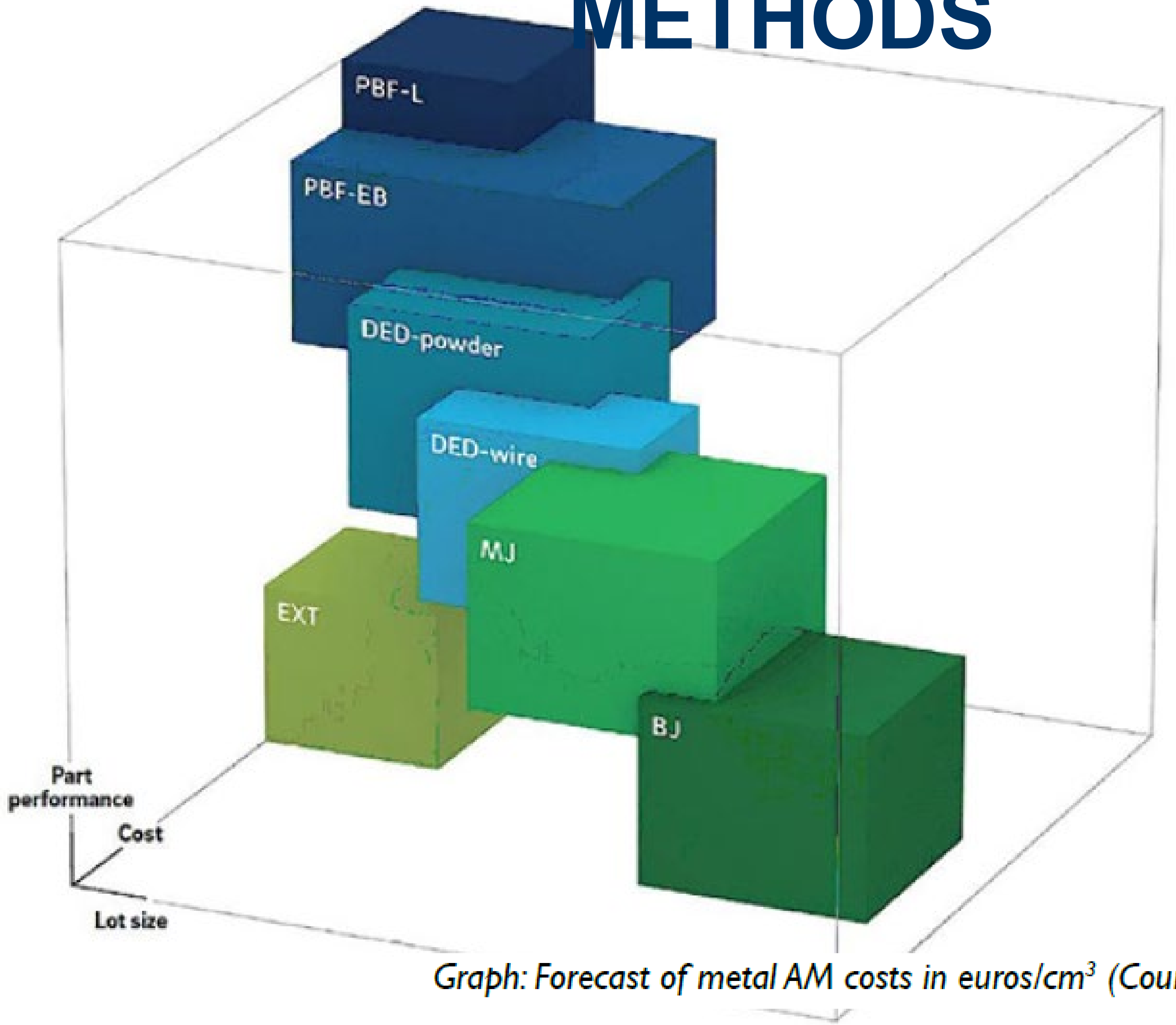
COST/PERFORMANCE COMPARISON OF AM METHODS



Graph: Forecast of metal AM costs in euros/cm³ (Courtesy of Roland Berger)

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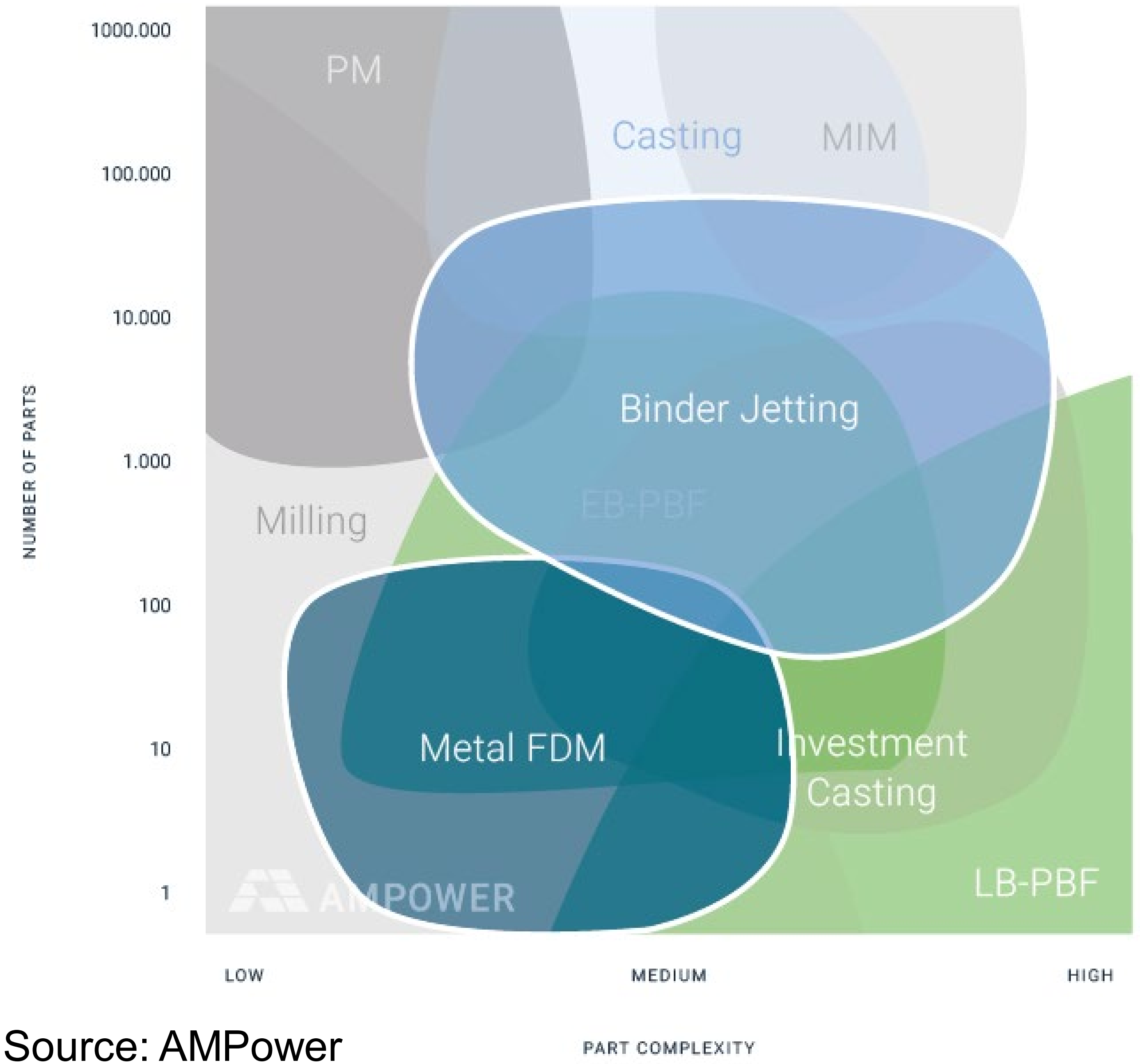
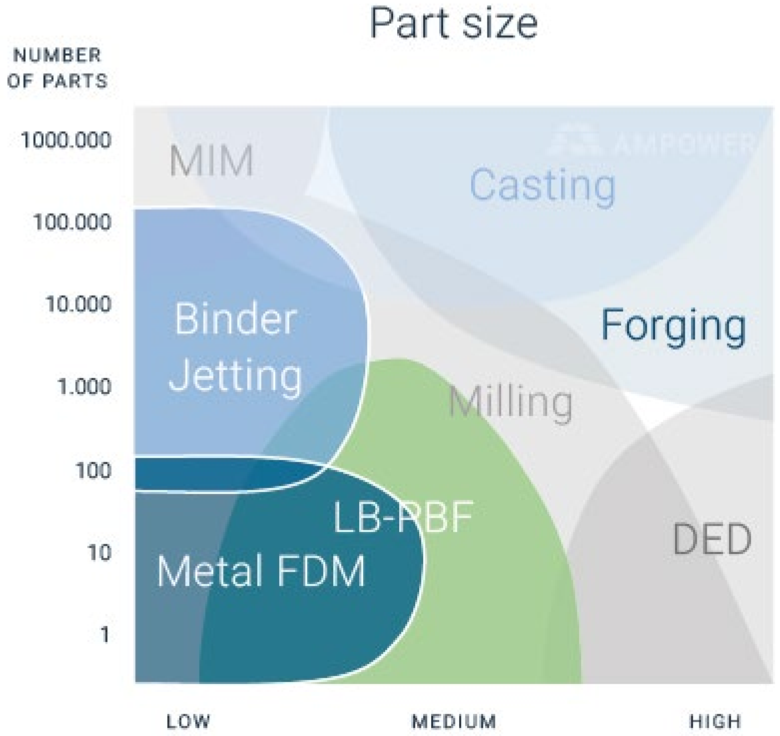
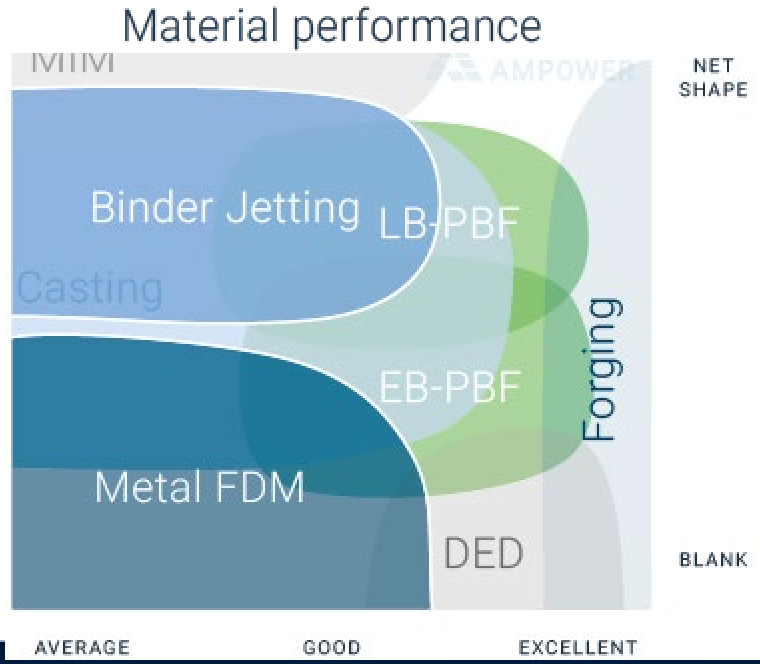
PROCESS SELECTION MAP







Source: AMPower

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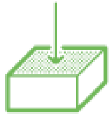
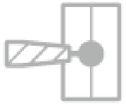
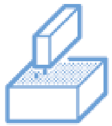
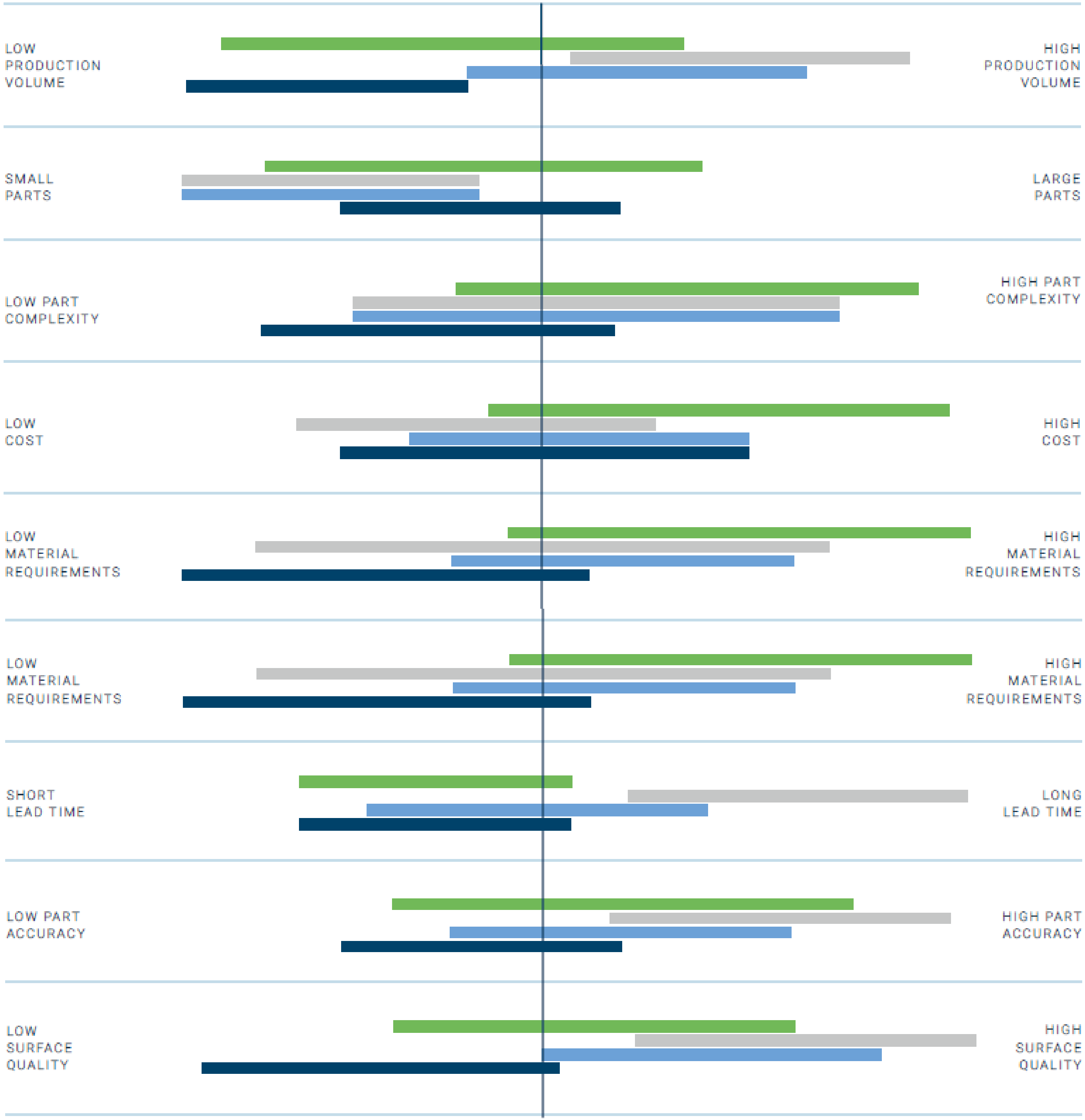
PROCESS SELECTION IDENTIFICATION MAP


LB-PBF


MIM


BJT


Metal FDM



Source: AMPower

THANKS FOR YOUR ATTENTION

Questions?

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