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FUTURE MANUFACTURING TECHNOLOGIES
Science
With
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Benefits, challenges and cost-effectiveness of metal AM methods

17.03.2021 Kari Mäntyjärvi

IDEA TO PRINT

ARCTIC PLATFORM

▶ PRINT YOUR IDEAS IN METAL

PROJECT «FROM IDEA TO PRINTING OF METAL PRODUCTS»

ARCTIC PLATFORM FOR METAL ADDITIVE MANUFACTURING

PROJECT INFORMATION, REPORTS, EVENTS, NETWORK MEMBERS AND SAMPLES OF METAL 3D-PRINTING **CAN BE FOUND ON OUR SITE**: i2metprint.com

Kolarctic CBC

EU FINLAND NORWAY RUSSIA SWEDEN

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From Idea to Printing of Metal Products
I2P – Project

Project ID: KO4012

REGIONAL COUNCIL OF LAPLAND

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Contents:

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Metal AM vs. CNC

Metal AM is niche technology

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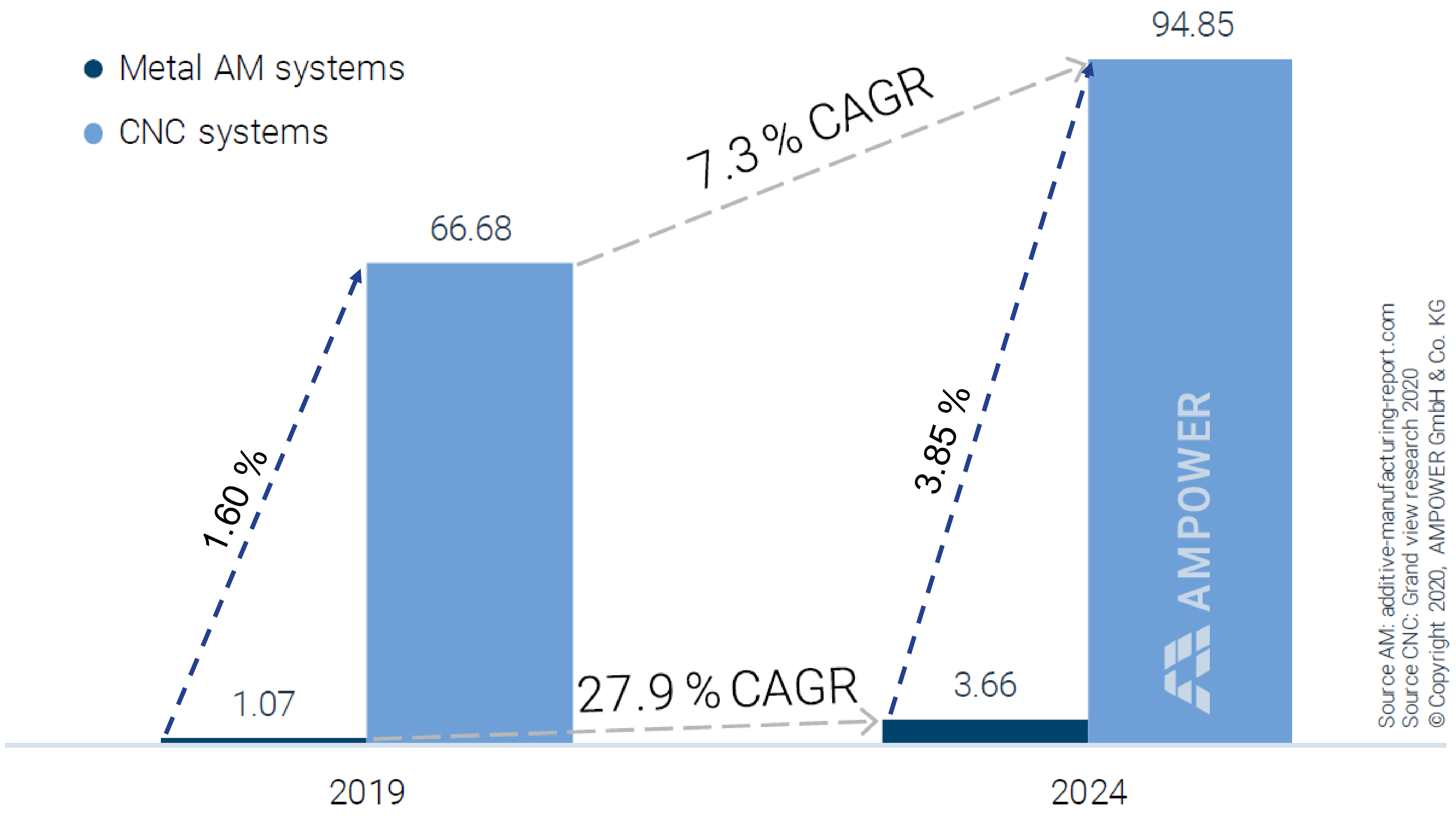
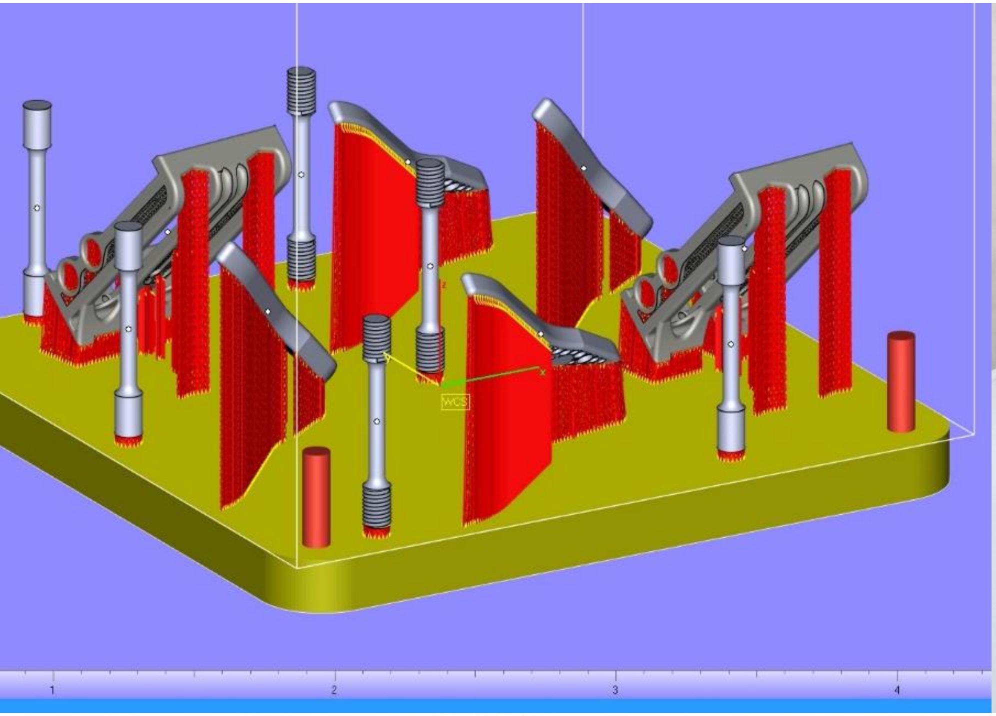
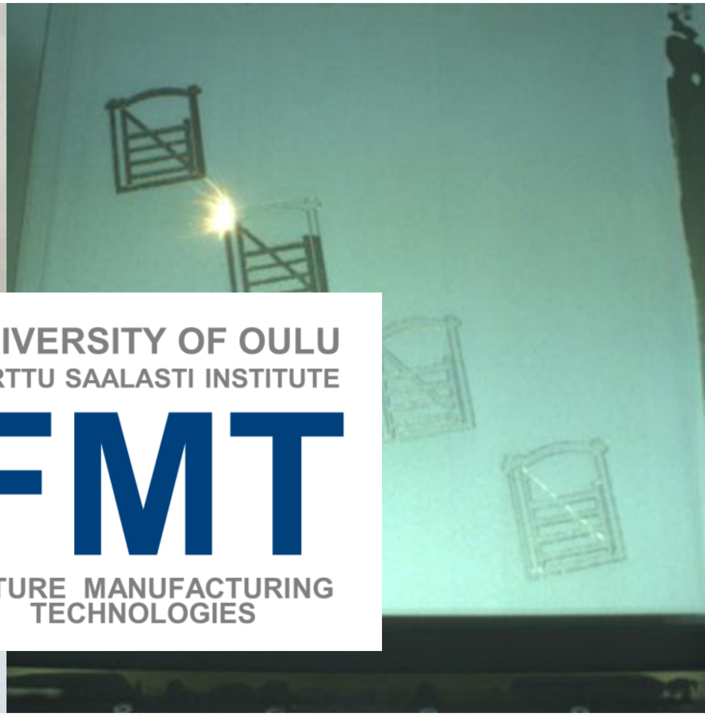
CAGR = Compound annual growth rate







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Methods overview

More than 18 different Metal AM methods!

However, one of these is by far the most used!

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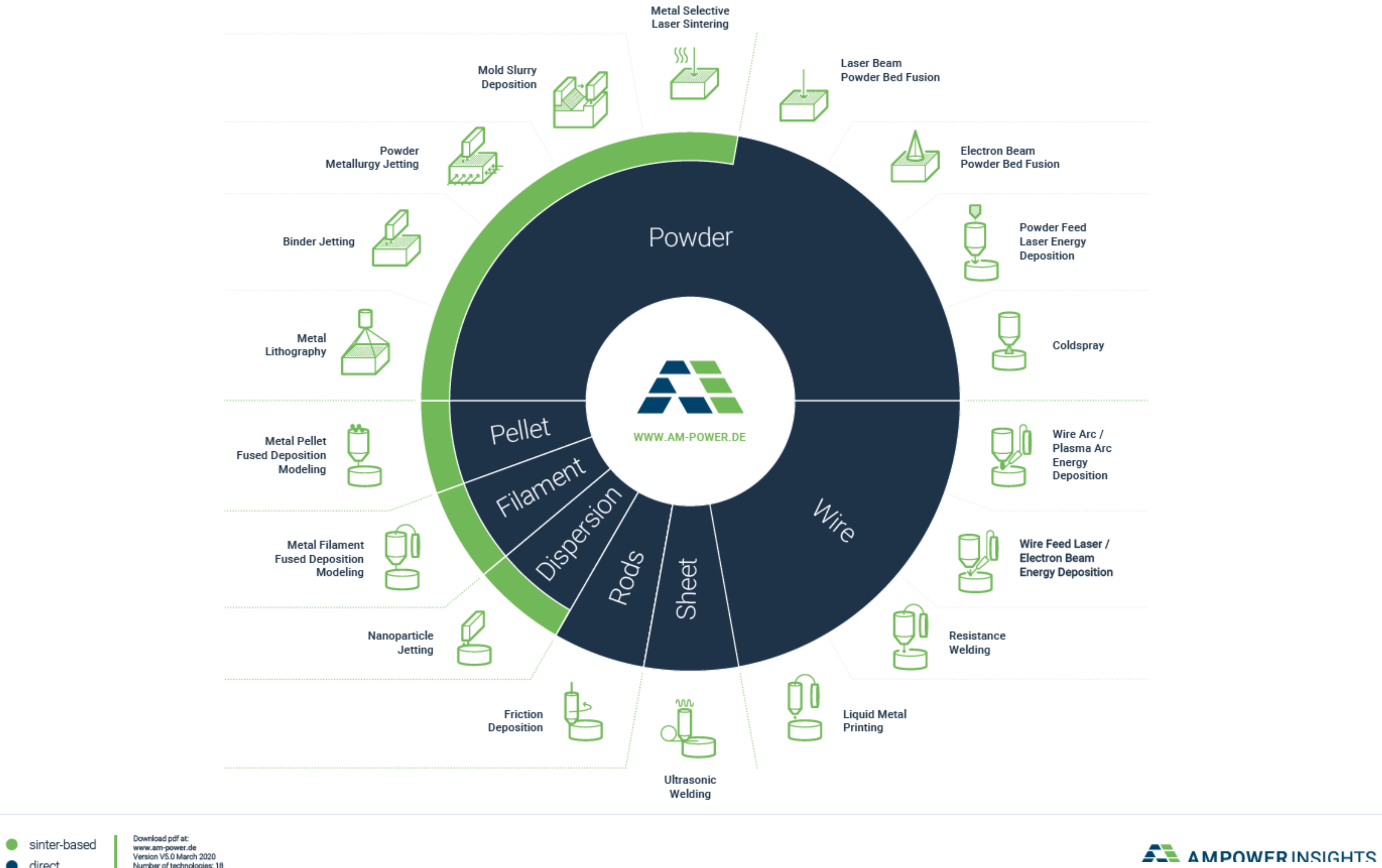
Metal Additive Manufacturing technology landscape

At least 18 different Metal AM methods



Source:
https://additive-manufacturing-report.com/

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Metal Additive Manufacturing technology landscape

The shape of the raw material

Source: https://additive-manufacturing-report.com/

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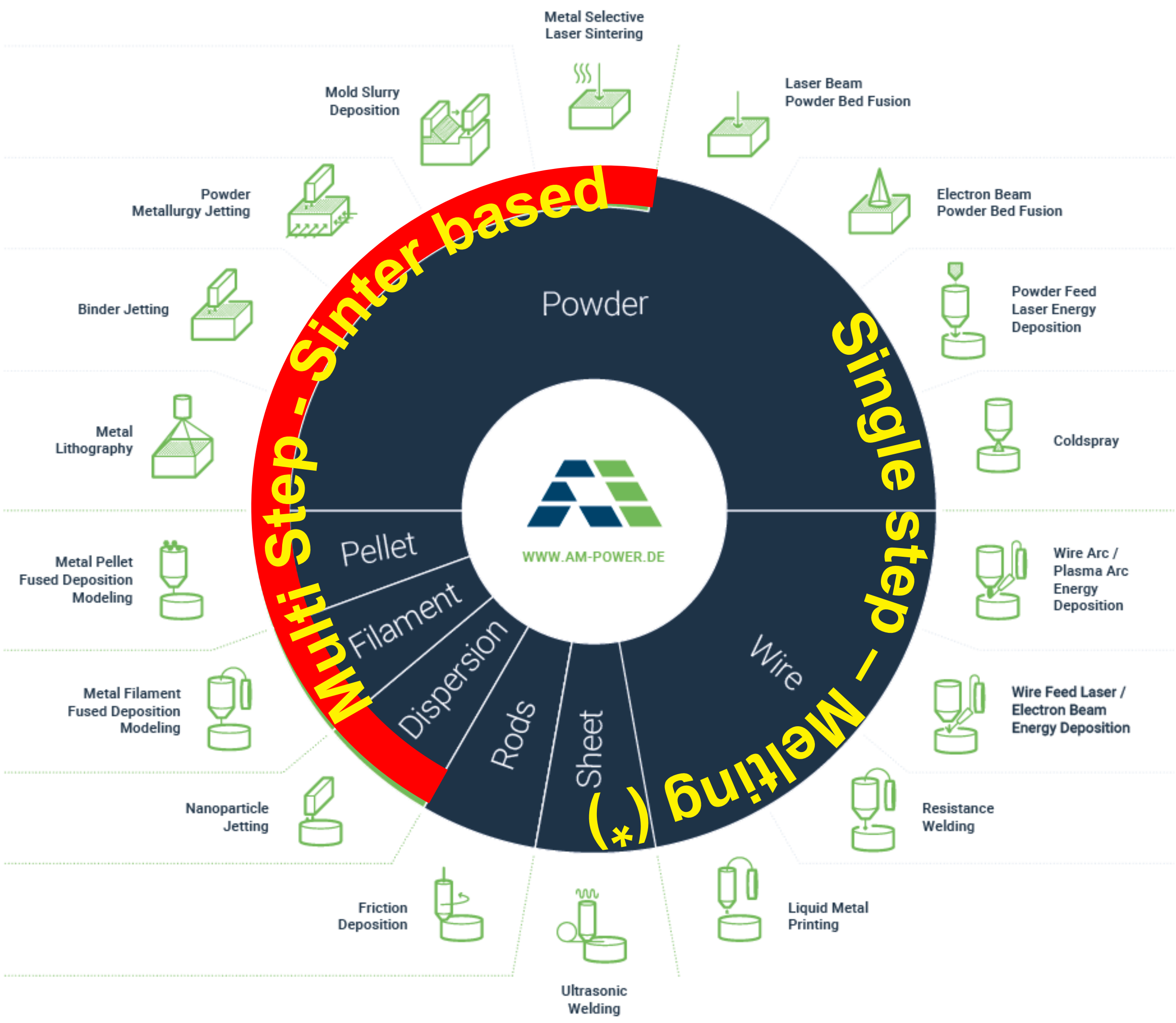
Metal Additive Manufacturing technology landscape

Formation of a metallic bond



sinter-based
direct

Download pdf at:
www.am-power.de
Version V5.0 March 2020
Number of technologies: 18
Number of suppliers: 140

(*) Also joining by mechanically intermixing

AMPOWER INSIGHTS

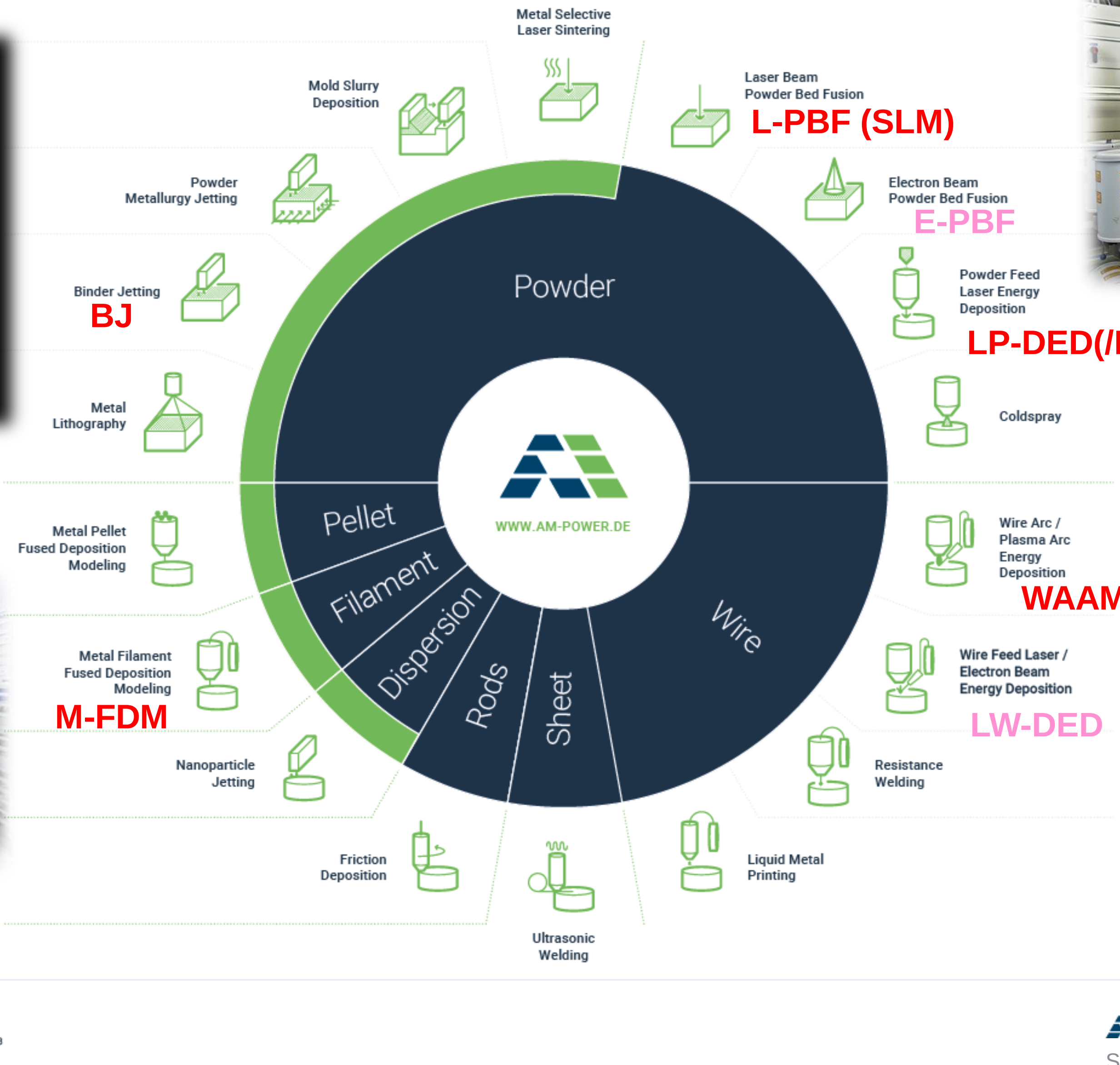
Source: https://additive-manufacturing-report.com/

Metal Additive Manufacturing technology landscape

Currently the most interesting methods

Source: https://www.exone.com/en-US/3D-printing-systems/metal-3d-printers

Source: https://www.desktopmetal.com/products/studio



Source: https://www.sciencephoto.com/media/593358/view/wire-arc-additive-manufacturing

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Source: https://additive-manufacturing-report.com/

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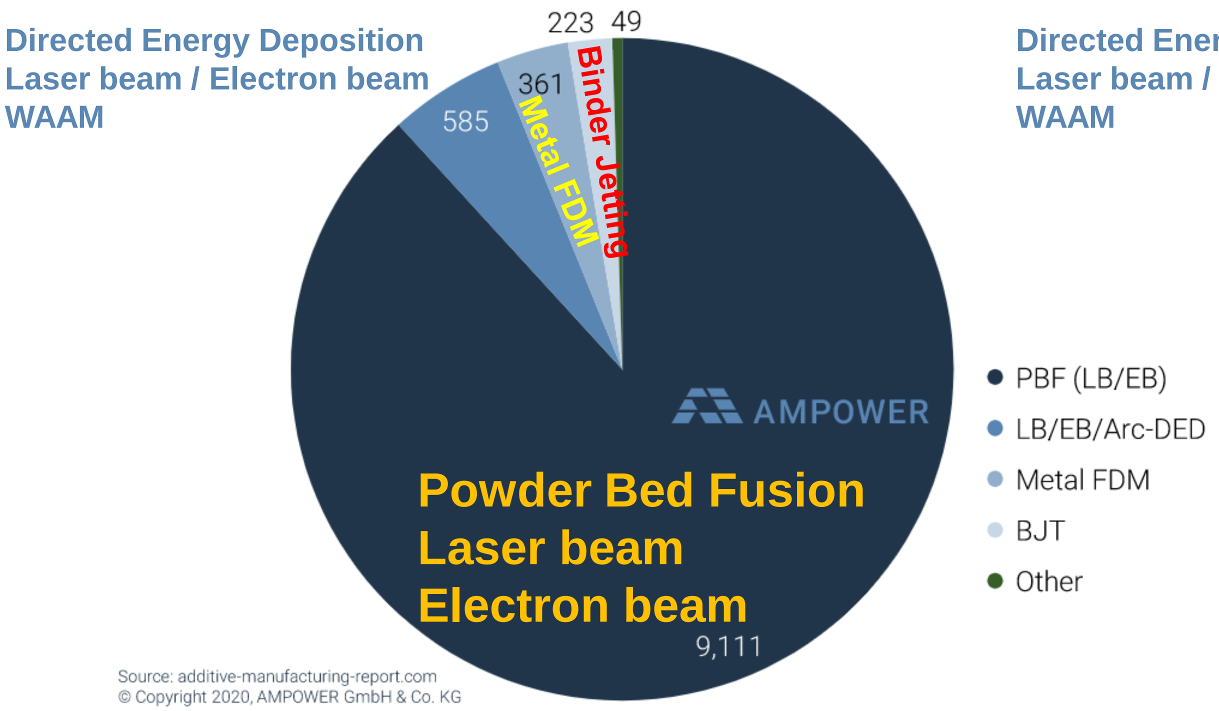
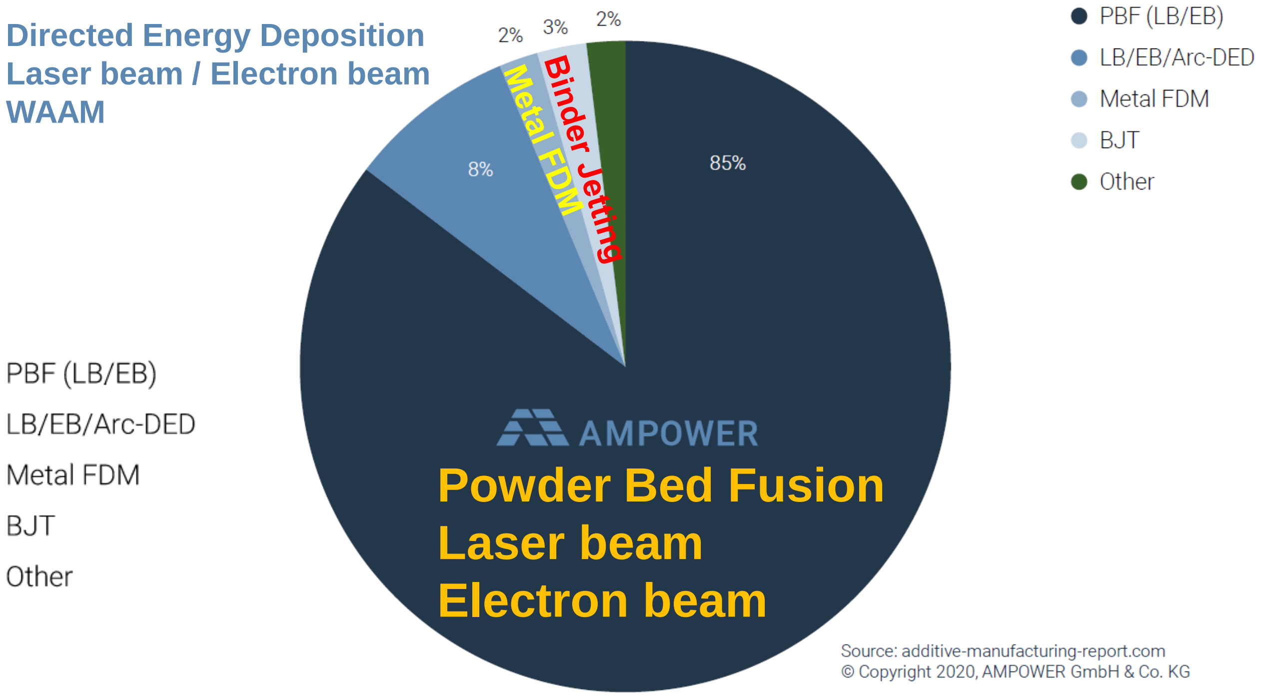
Installed base by technology 2019 [units]



System sales revenue by technology 2019



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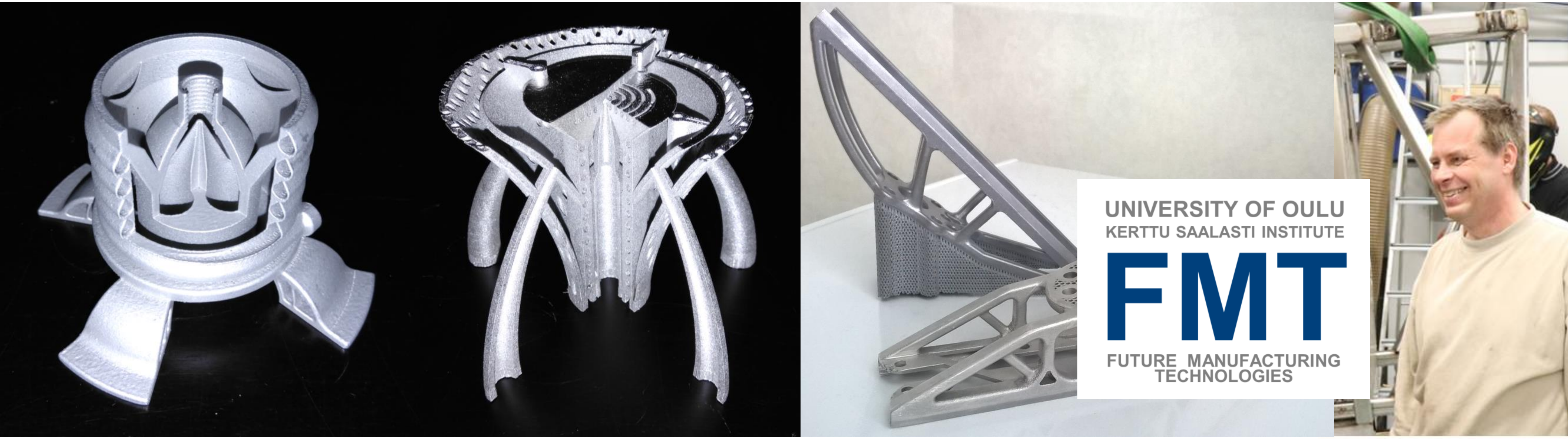
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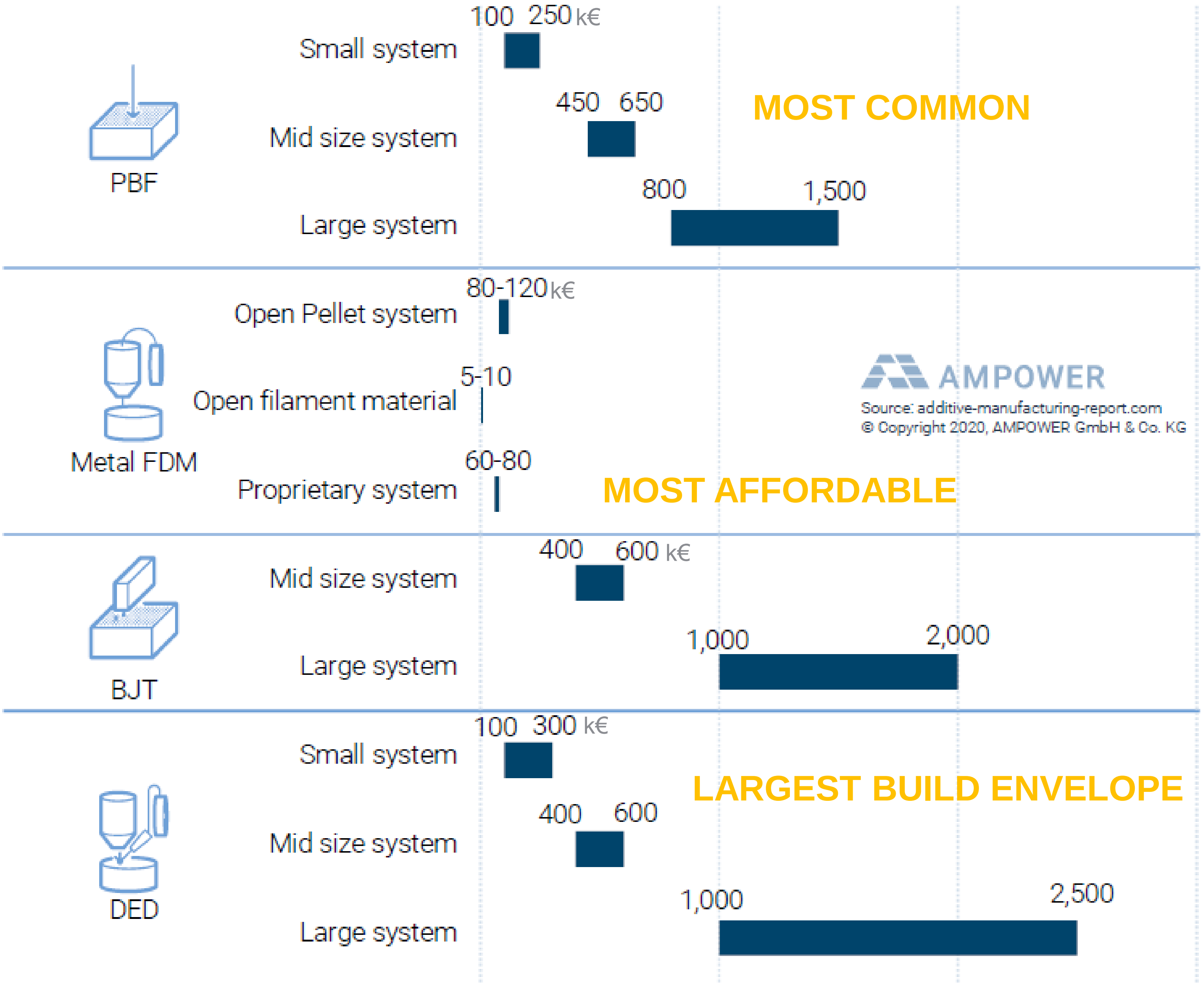
Cost-effectiveness

Investment cost and build envelope



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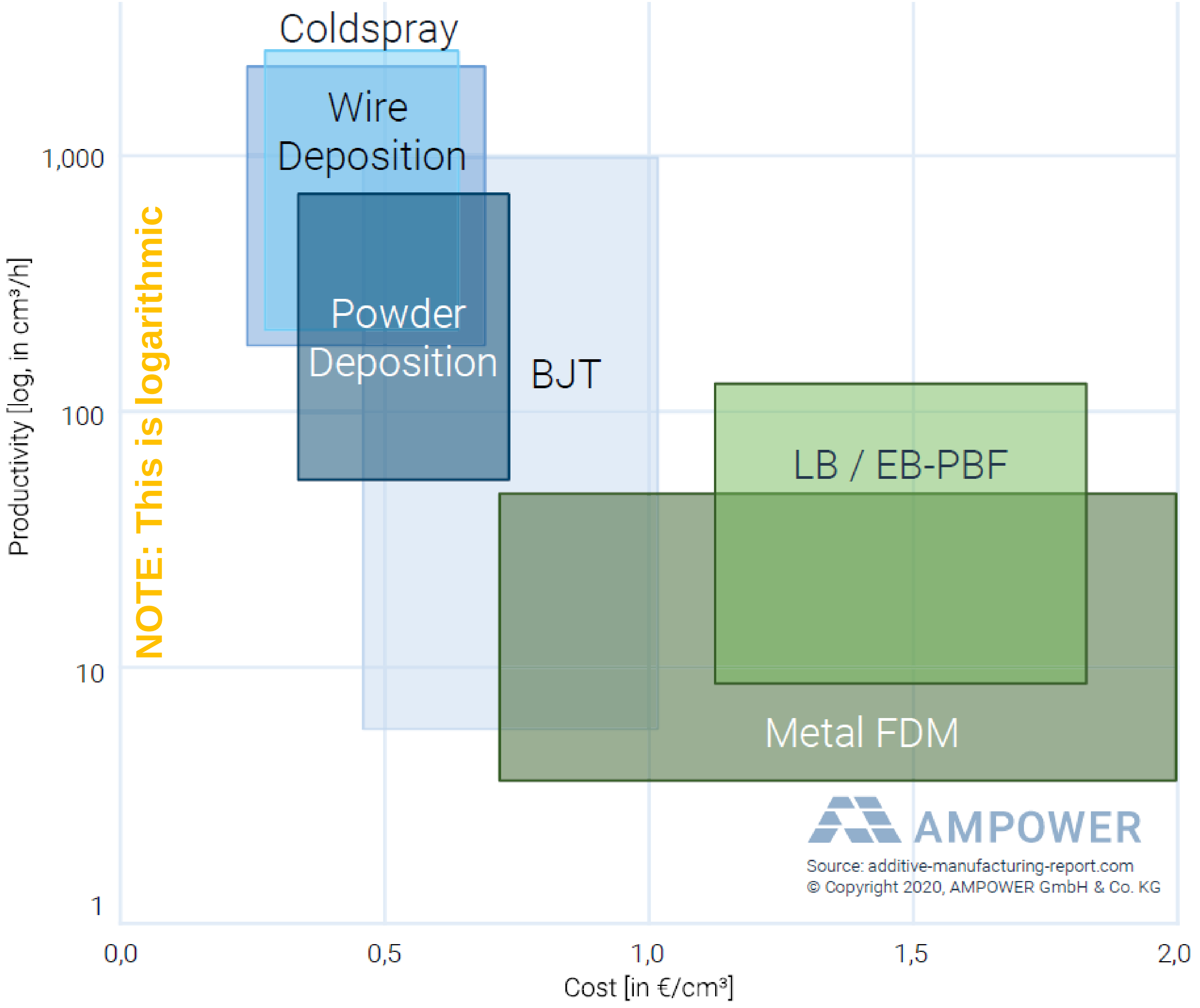
Build rate vs. cost



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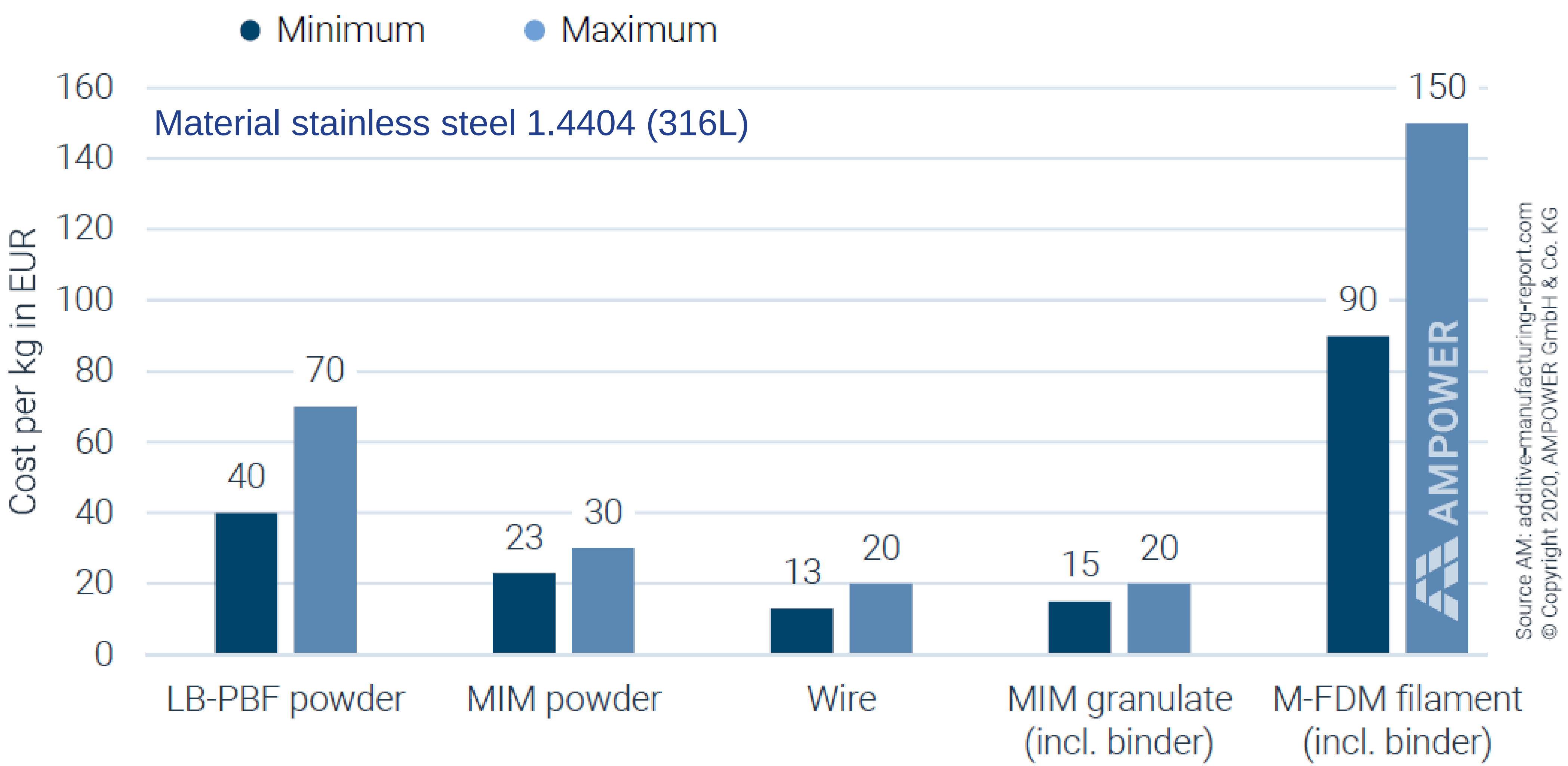
Wire is most cost-efficient material!



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Effect of production volume on unit price

Part Volume	44	cm^3	Part X	161	mm
Support Volume	10	cm^3	Part Y	45	mm
Stock Material	0	cm^3	Part Z (build direction)	45	mm
Material Group	Steel-base		Quantity	1 / 10 / 100	parts

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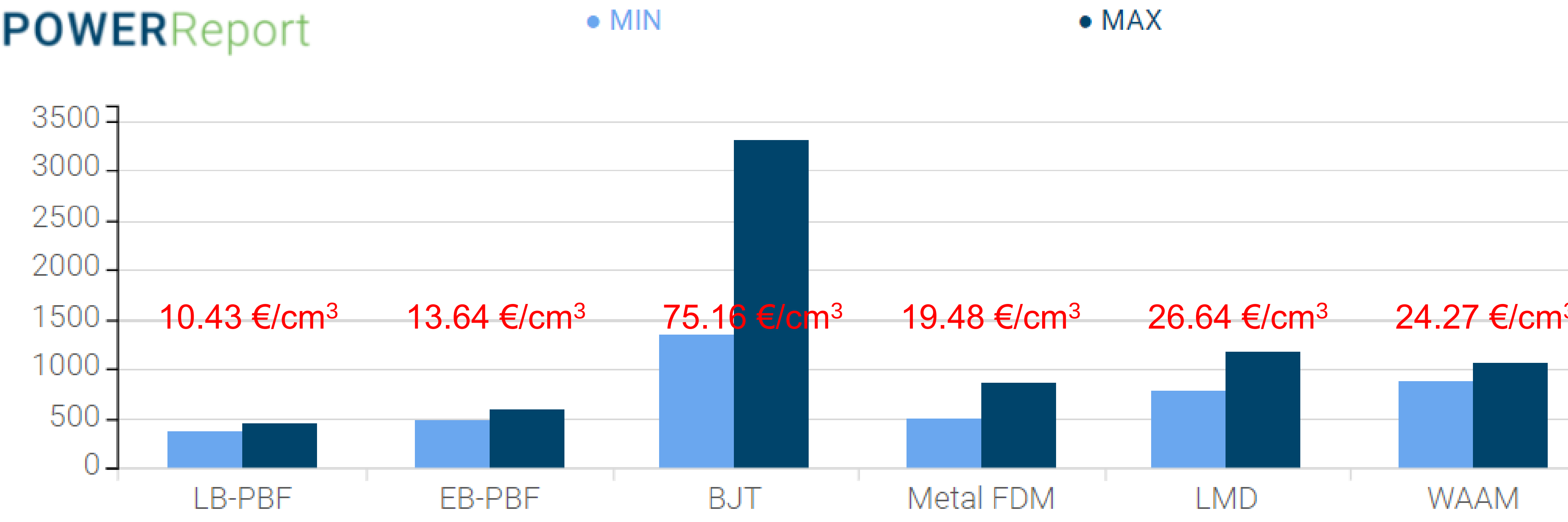
https://additive-manufacturing-report.com/cost-calculator/

Part Volume	44	cm³	Part X	161	mm
Support Volume	10	cm³	Part Y	45	mm
Stock Material	0	cm³	Part Z (build direction)	45	mm
Material Group	Steel-base		Quantity	1	parts

Cost per Part in €

AMPOWERReport



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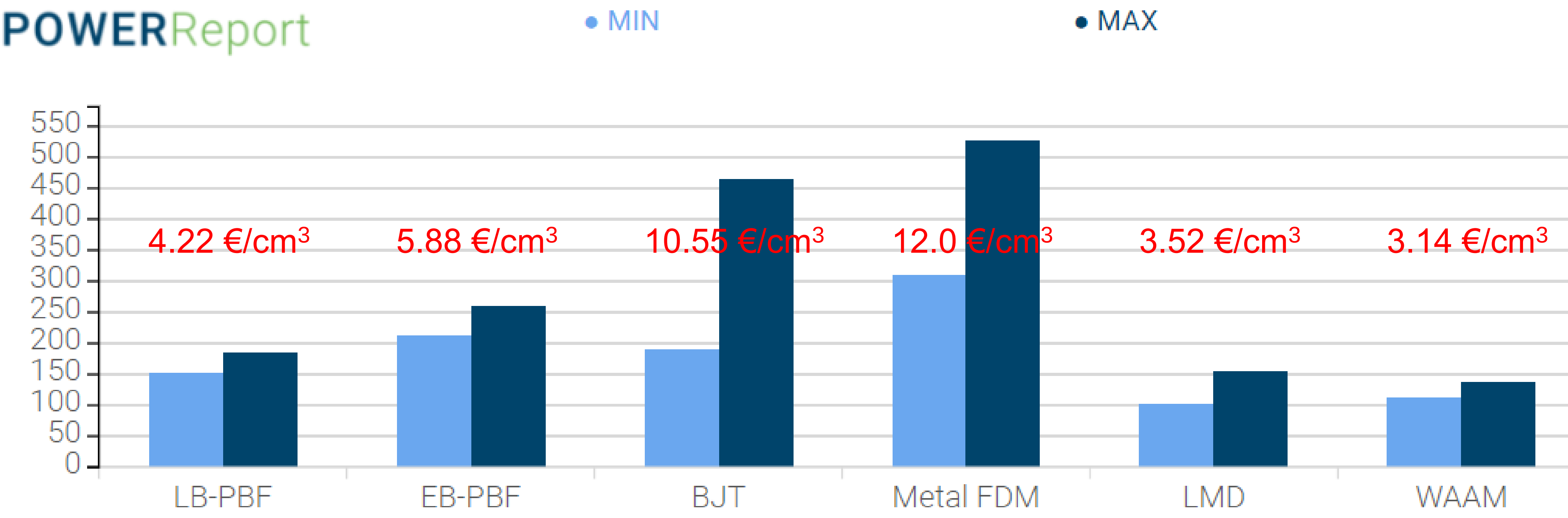
https://additive-manufacturing-report.com/cost-calculator/

Part Volume	44	cm³	Part X	161	mm
Support Volume	10	cm³	Part Y	45	mm
Stock Material	0	cm³	Part Z (build direction)	45	mm
Material Group	Steel-base		Quantity	10	parts

Cost per Part in €

AMPOWERReport



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Part Volume	44	cm³	Part X	161	mm
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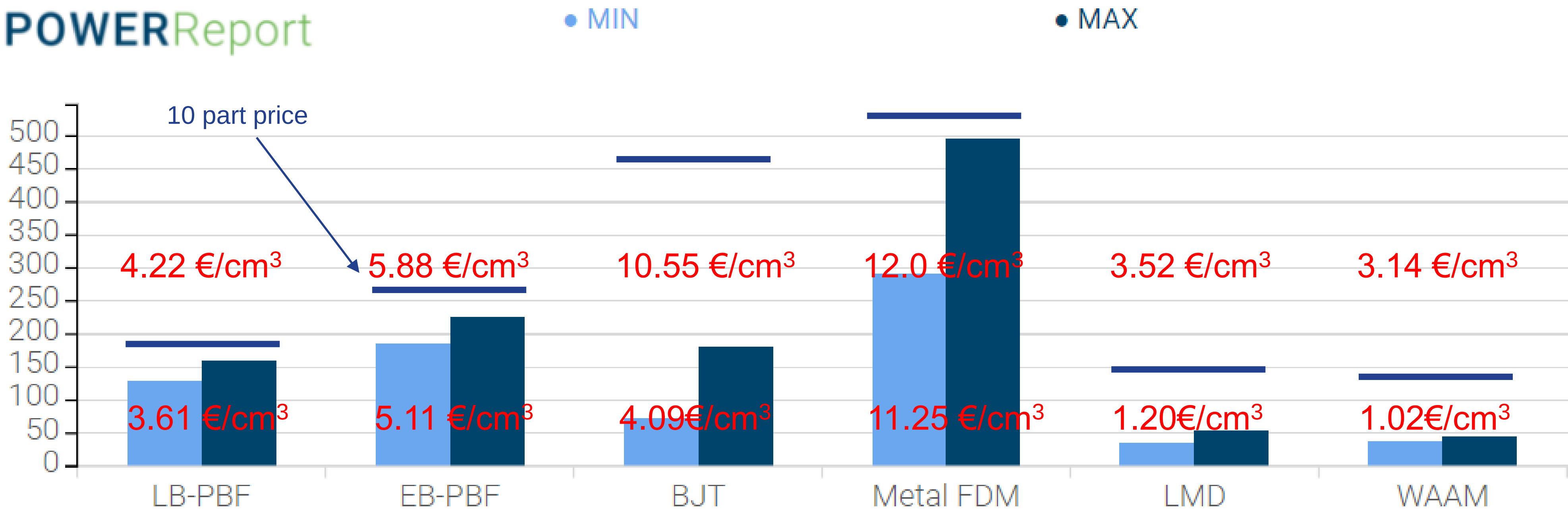
Cost per Part in €

AMPOWERReport



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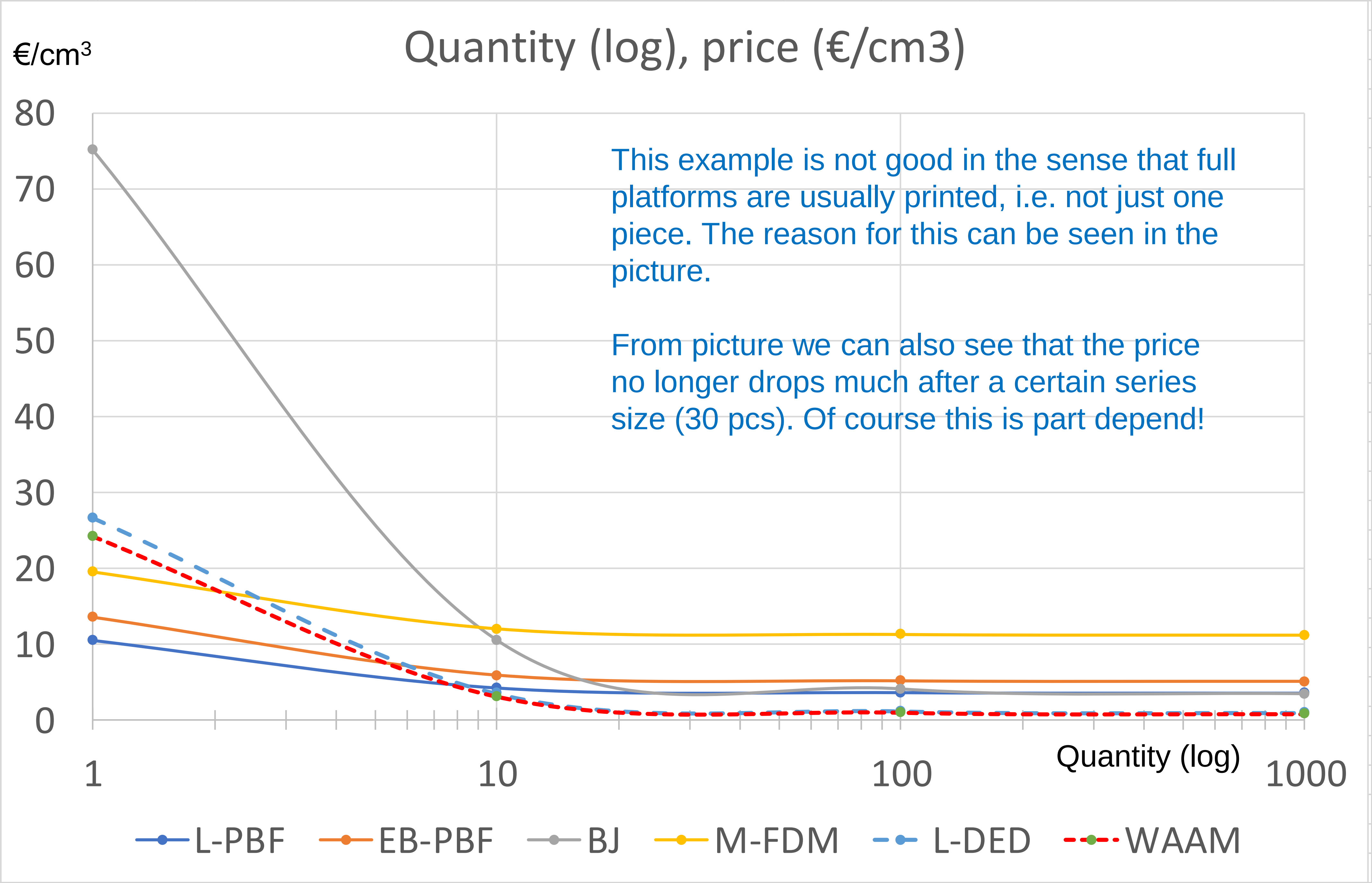

Quantity (log), price (€/cm3)
€/cm3
80
70
60
50
40
30
20
10
0
1
10
100
1000
Quantity (log)
This example is not good in the sense that full platforms are usually printed, i.e. not just one piece. The reason for this can be seen in the picture.
From picture we can also see that the price no longer drops much after a certain series size (30 pcs). Of course this is part depend!
L-PBF
EB-PBF
BJ
M-FDM
L-DED
WAAM

Cost-effectiveness

– Adding the material brings cost!
- Time is money! – more volume to print more it takes to print and more costs 😂
- The parts should be designed to be as light as possible
- Complex geometry does not increase costs if it does not increase the volume of the part

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Cost-effectiveness

– Pre- and Post-Processing:

- Wohlers report 2020: ”70% of the cost of metal AM parts comes from pre-and post-processing”
- Pre-Processing: work-preparation, making sure the printer settings are correct, tasks related to starting printing (10-30%)
- Post-Processing: From the printed part to the finished part. Fixture removal, heat treatments, machining, surface preparation etc (10-50%)

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Method comparison

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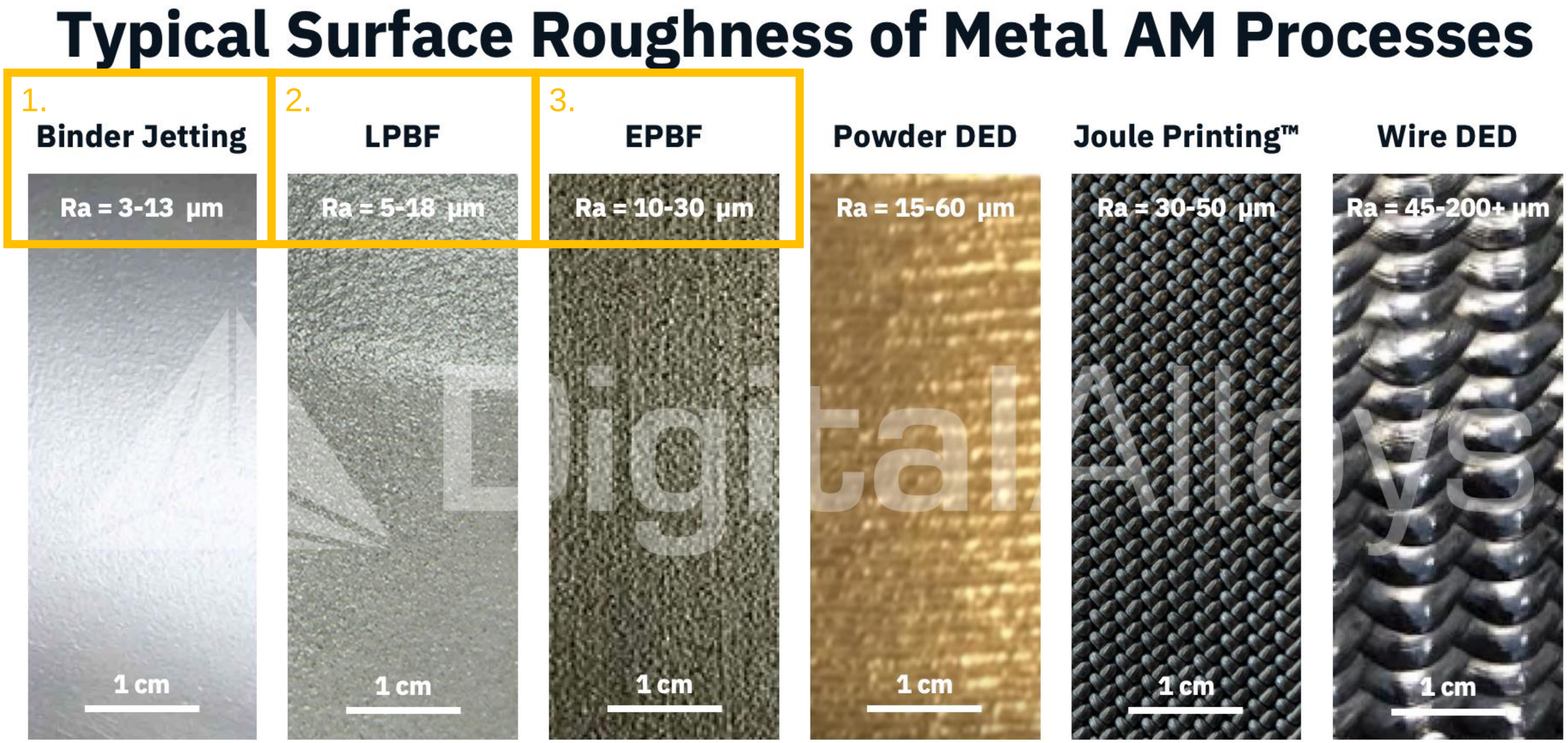
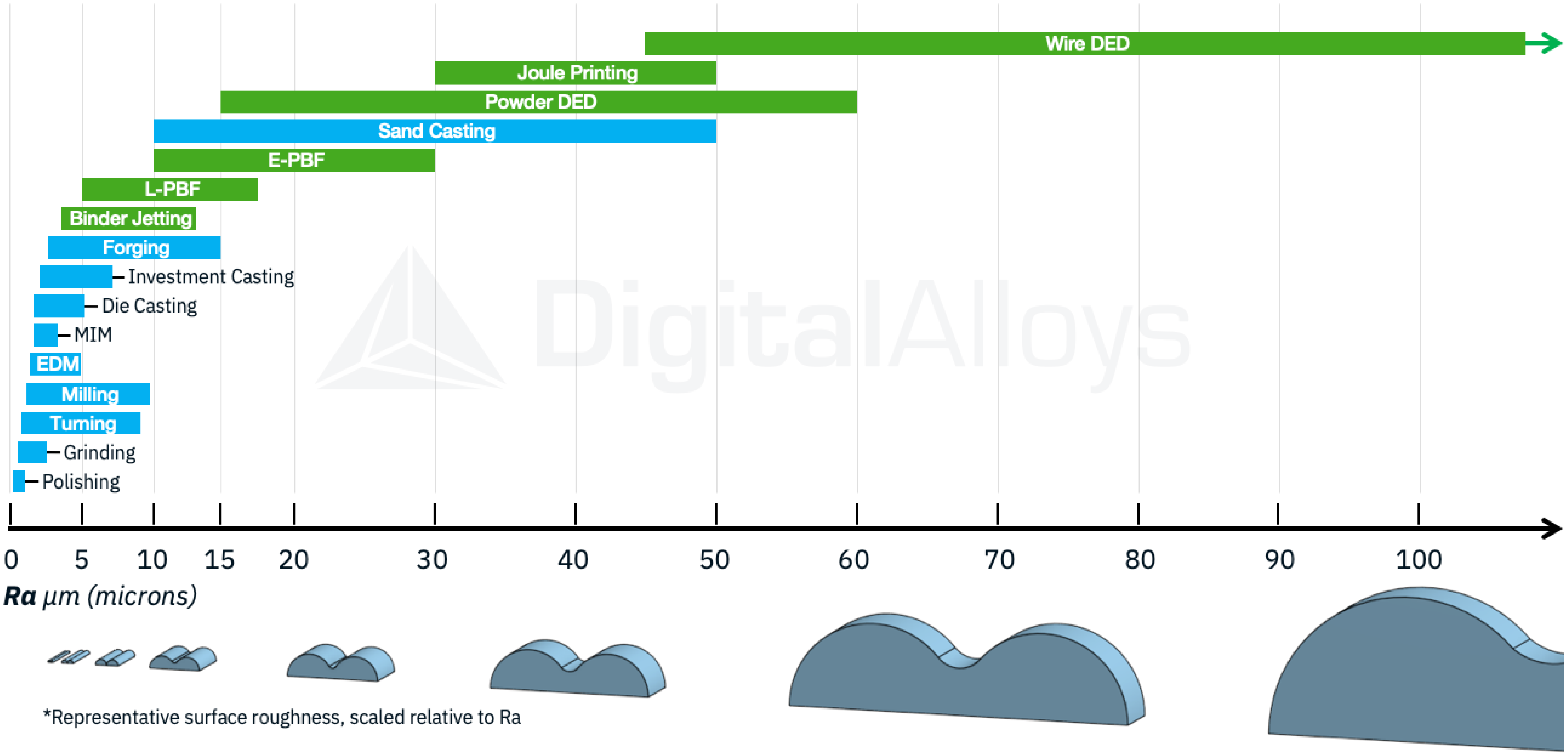
Comparison: Surface Roughness



Source: https://www.digitalalloys.com/blog/surface-roughness/

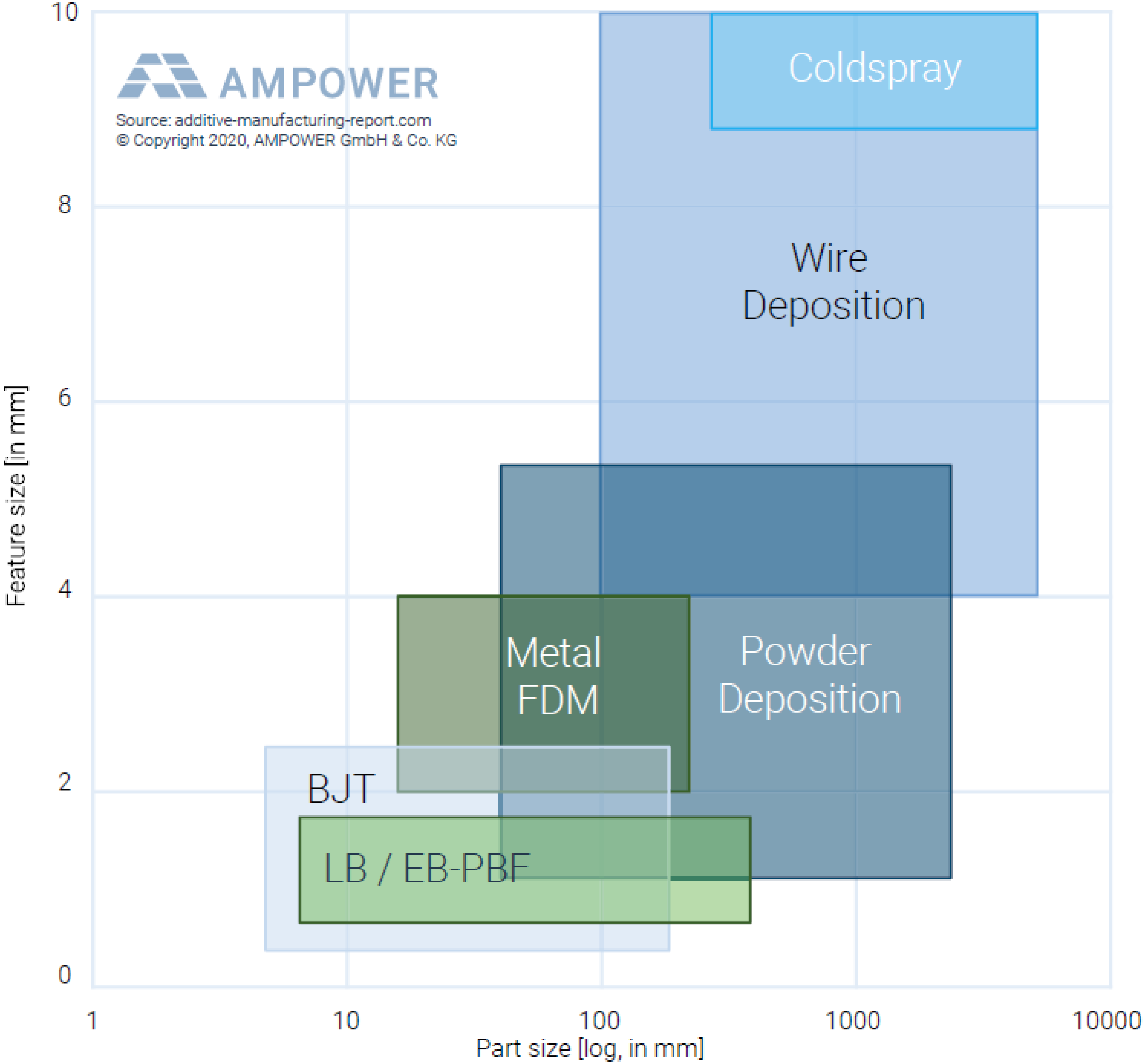
Typical Surface Roughness of Metal AM & Conventional Processes



*Representative surface roughness, scaled relative to Ra

Source: https://www.digitalalloys.com/blog/surface-roughness/

Part size vs. feature size



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Comparison: Accuracy

Metal AM Process	Typical XY Resolution (µm)	Typical Z Resolution (µm)
Binder Jetting	20 – 65 (400-1200 DPI)	50 – 100
PBF	**20** – 200	**20** – 200
Powder DED	100 – 1,000 (0.1 – 1 mm)	100 – 1,000 (0.1 – 1 mm)
Joule Printing™	500 – 1,000 (0.5 – 1 mm)	500 – 1,000 (0.5 – 1 mm)
Wire DED	2,000 – 50,000 (2 – 50 mm)	1,000 – 10,000 (1 – 10 mm)
Metal FDM	50-500	50-500

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Source: https://www.digitalalloys.com/blog/surface-roughness/

Comparison: Fatigue test specimens
“Can this be done by method X?”

L-PBF – YES (and done)
E-PBF – YES
L-DED – NO (an exception exist)
WAAM – NO!
BJ – NO
M-FDM – NO or possible

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Benefits and drawbacks

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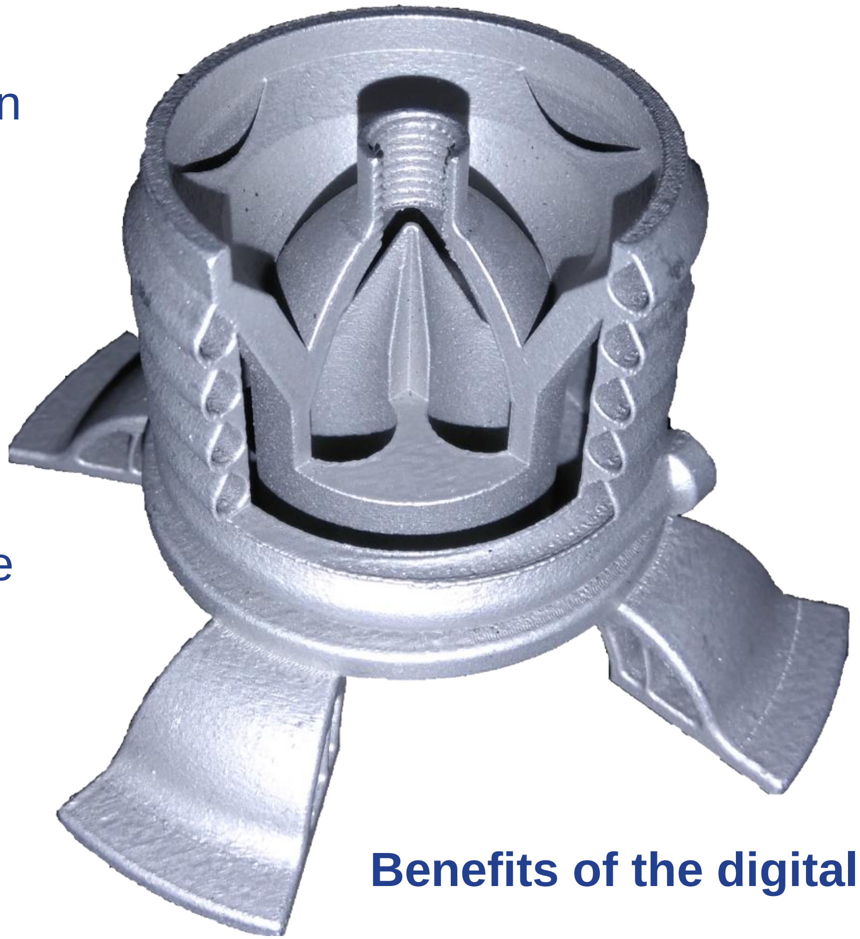
General benefits of Metal AM

DESIGN and GEOMETRY
- Freedom of geometry
  - Flexibility and freedom of design
  - More possibilities to product optimization
    - Topology, flow path, weight, lattice structures, etc.
  - Reduce part count:
    - Assembly to one part
    - Multifunctionality parts
  - Little or no restrictions that come from manufacturing technology
- Customization freedom
- Fast Design and Production
  - Rapid prototyping



MANUFACTURING
- No tooling – no tooling costs
- On-demand manufacturing
  - Inventory reduction
- Reduced lead times
- Reduction of material waste
- Possibility to make parts no other machine can do
- Lower manufacturing costs (in some cases)
  - In metal AM, complexity is free
- Metal 3D printing cost per part is the same at low and high volumes
- Mass customization

Benefits of the digital manufacturing

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Benefits of Digital Manufacturing

1. Increased efficiency through automated data exchange
2. Lower production and maintenance costs
3. Faster throughput at all levels of the value chain
4. Better understanding at critical decision points
5. Increased quality: Uninterrupted data flow, quality assurance by simulation
6. Faster pace of innovation
7. Real-time visibility of the effects of changes to product and production

Drawbacks of Metal AM

- Slow and expensive methods
- Modest accuracy compared to machining
- Technical immaturity in non - PBF methods
- Restricted build size (in some methods)
- Lot of need for post processing in several methods
- Methods require a lot of skills and knowledge

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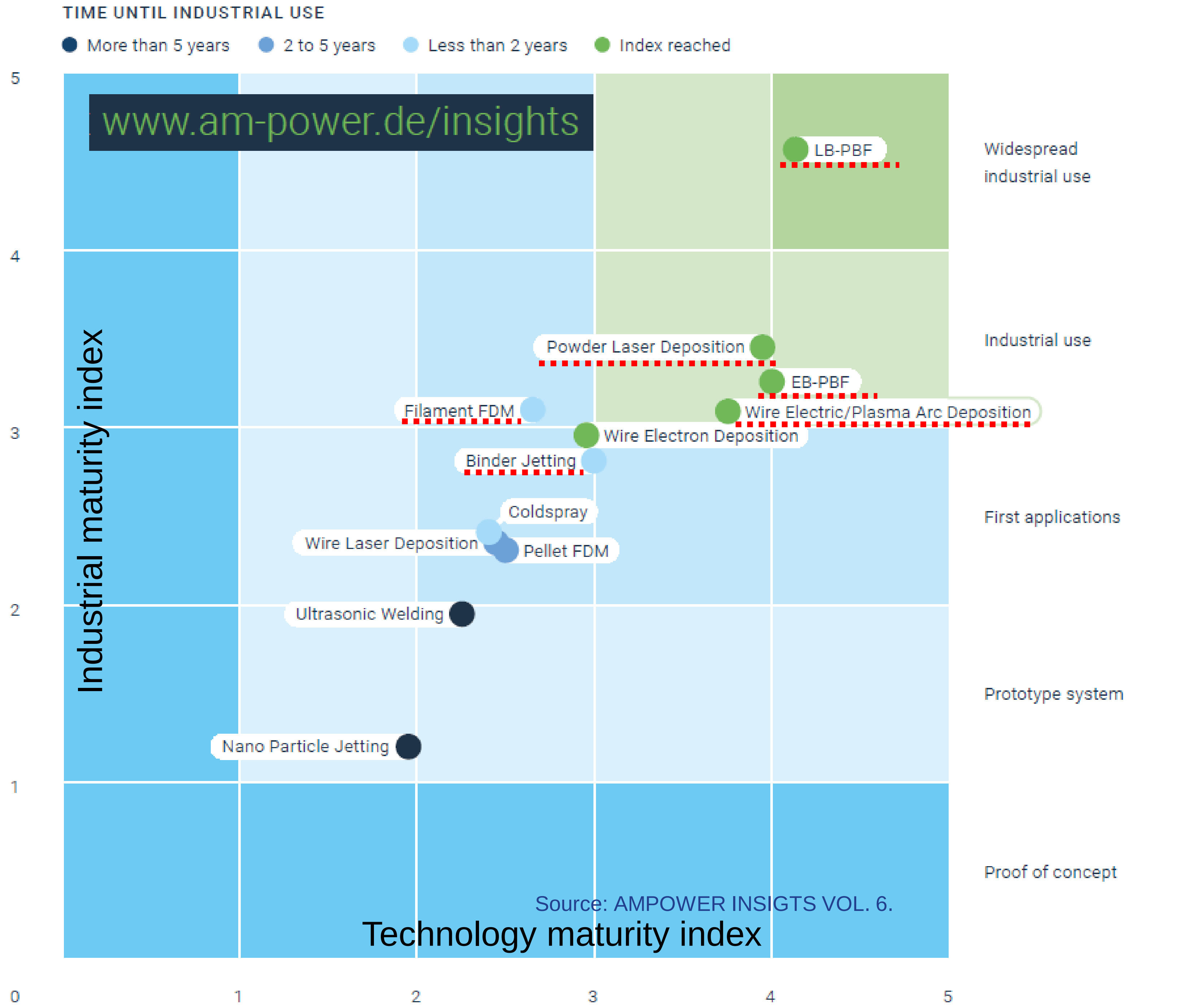
MATURITY



TIME UNTIL INDUSTRIAL USE
More than 5 years
2 to 5 years
Less than 2 years
Index reached
www.am-power.de/insights
LB-PBF
Powder Laser Deposition
EB-PBF
Wire Electric/Plasma Arc Deposition
Filament FDM
Wire Electron Deposition
Binder Jetting
Coldspray
Wire Laser Deposition
Pellet FDM
Ultrasonic Welding
Nano Particle Jetting
Industrial maturity index
Technology maturity index
Source: AMPOWER INSIGTS VOL. 6.
Widespread industrial use
Industrial use
First applications
Prototype system
Proof of concept
0
1
2
3
4
5

Pros and Cons - Powder bed fusion (PBF)

Generally:

- Most mature AM technology
- Lot of machine suppliers
- Public knowledge widely available
- Established supply chain
  - Plenty of commercial printing service providers

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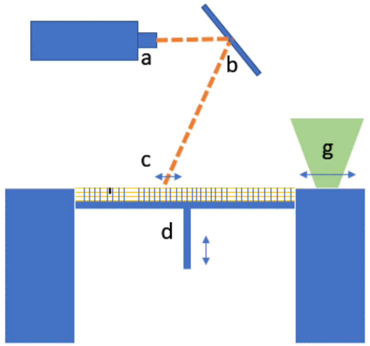
Pros and Cons - Powder bed fusion (PBF)

Pros:

- Fine resolution
- High repeatability and reproducibility
- Good mechanical properties
- Wide range of materials
- High freedom of design

Cons:

- Not enough public data on the fatigue resistance of materials
- Relatively slow method
- Geometric limitations due need of support structurers
- Anisotropy



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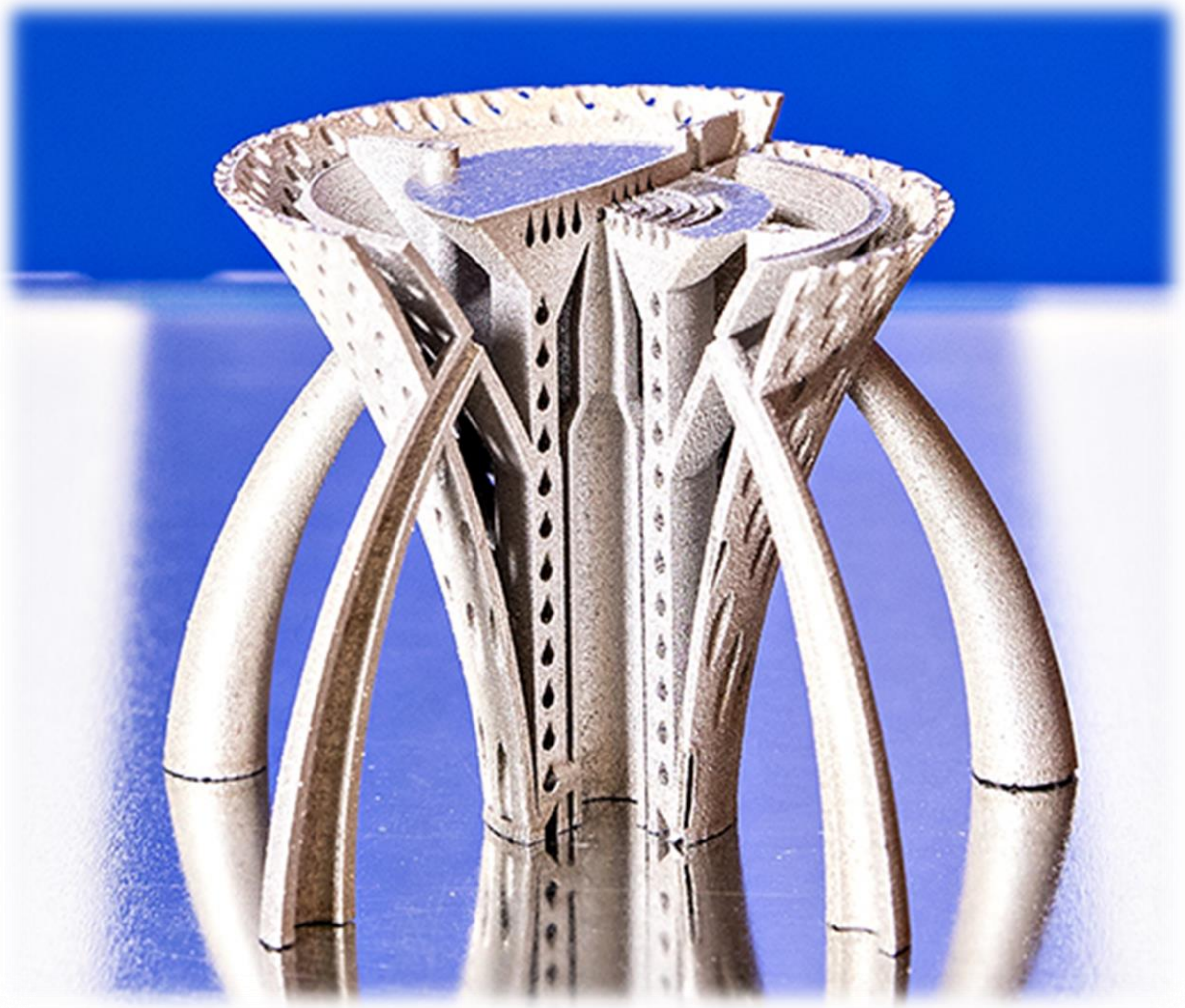

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Pros and Cons - DED (Directed Energy Deposition)

Generally:

- Laser powder DED is the most common DED method
- Wire Arc Additive Manufacturing is becoming more common
- Relatively inaccurate methods, accuracy is done by machining
- Cladding, repair of components and near net-shape parts for end part production
- Some, not many, machine providers
- Supply chain in development phase

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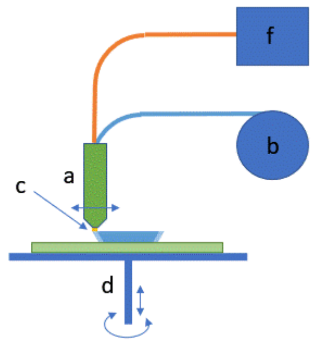
Pros and Cons - DED (Directed Energy Deposition)

Pros:

- Possible to make BIG parts
- High build rate
  - 2-3 times higher comparing LB-PBF
- Flexible machine technology
- Highest resolution for DED technologies
  - Specialized working heads allow resolutions below 1 mm

Cons:

- Incomplete Work preparation software
- Cooling time decreases productivity



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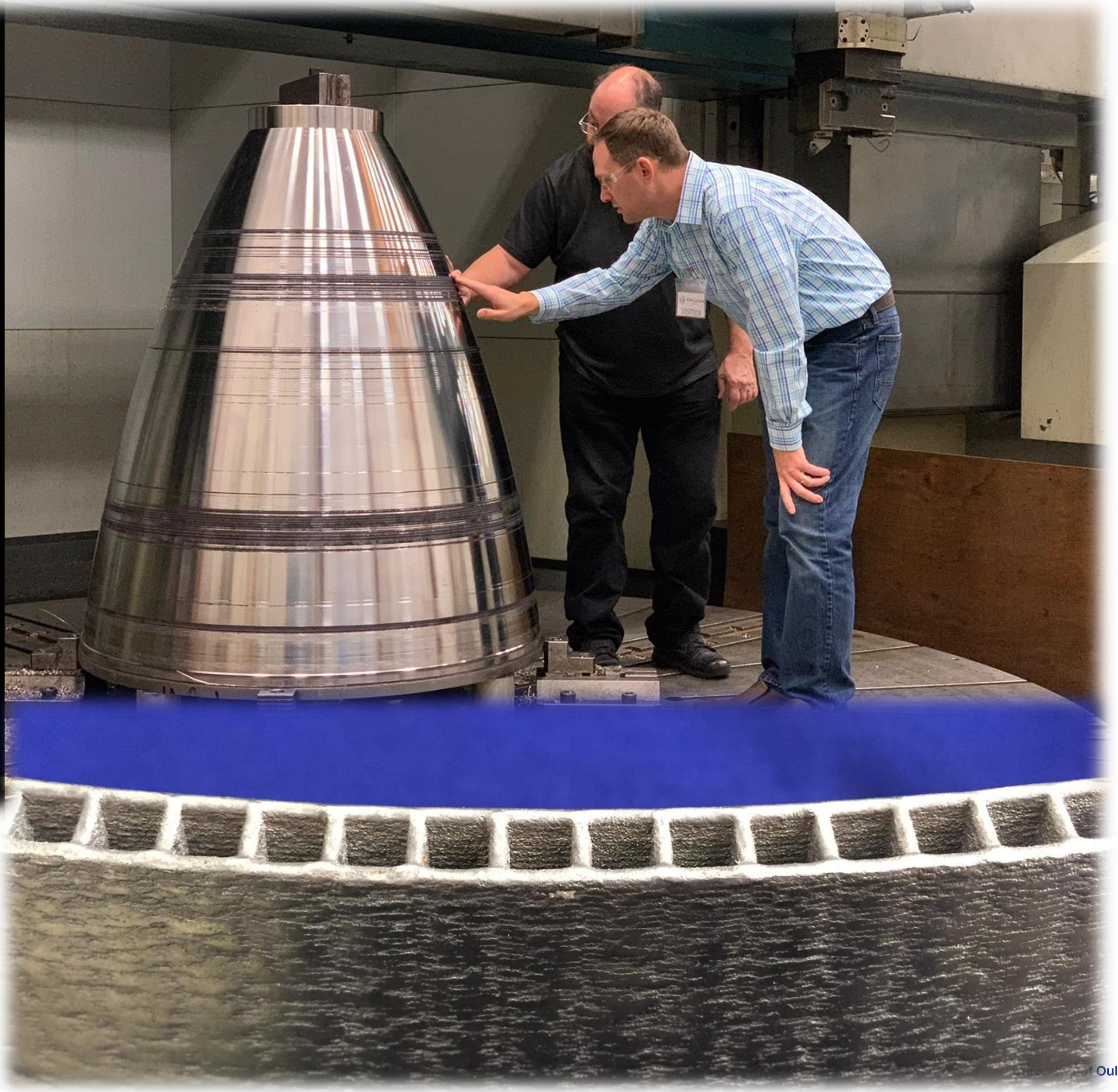


Source: https://www.nasa.gov/centers/marshall/news/releases/2020/future-rocket-engines-may-include-large-scale-3d-printing.html

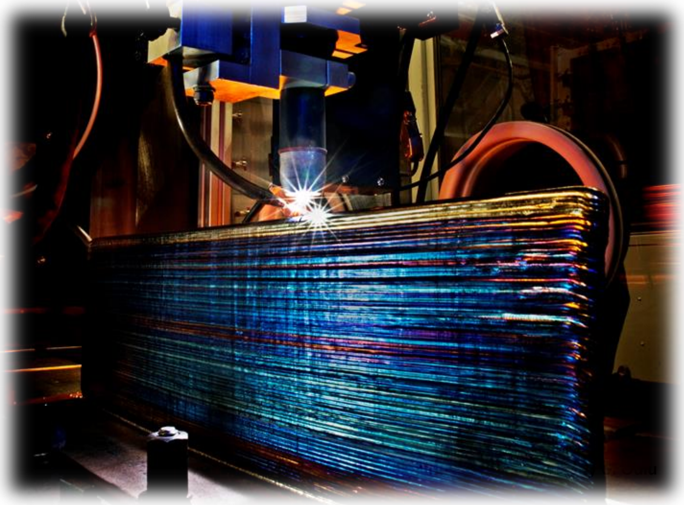
Pros and Cons - WAAM (Wire Arc Additive Manufacturing)

Pros:

- Relatively inexpensive hardware
- Possible to make big parts
  - Almost unlimited part size
- High build rate
  - Deposition rates of up to 4 kg/h
- Flexible machine technology
- Highest resolution for DED technologies

Cons:

- Incomplete Work preparation software
- Low resolution
- High thermal gradients



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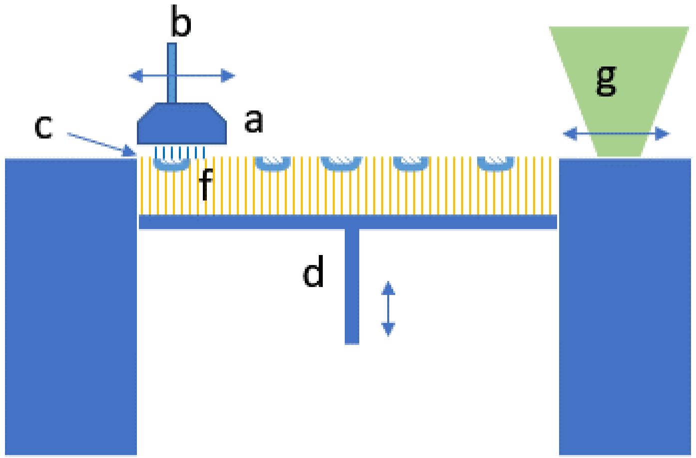
Source: https://www.damen.com/-/media/new-corporate-damen/images/news/2017/11/worlds_first_class_approved_3d_printed_ships_propeller_unveiled/waampeller.jpg?rev=52387b3360274e28ac90e513e8ab4781

Pros and Cons - Binder Jetting

Generally:

- A relatively new method entering the mark
- Suited for small part sizes in the range between 5 to 50 mm
- A multi-step process, the metal joint is based on sintering



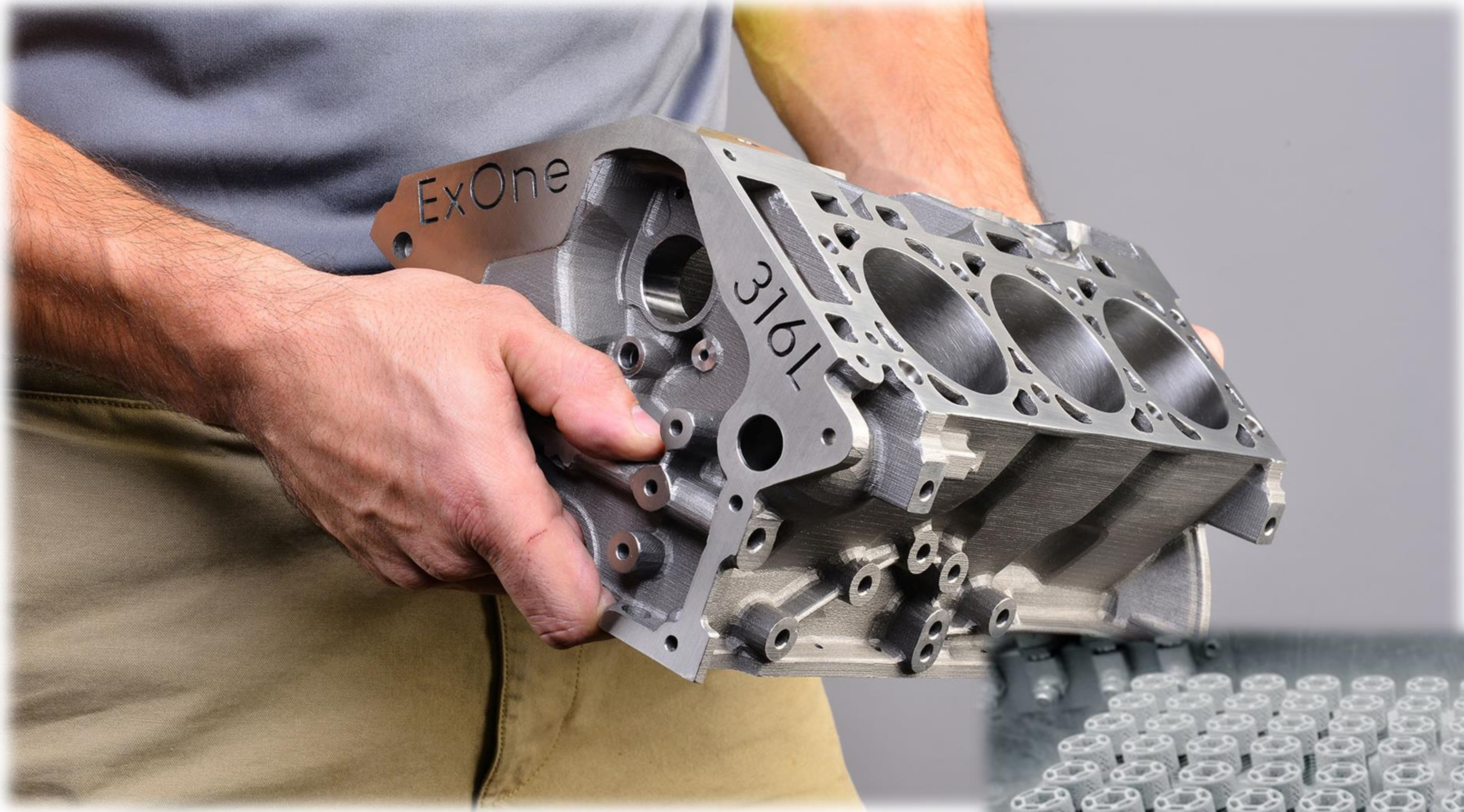
Pros and Cons - Binder Jetting

Pros:

- Low cost method
- No need for support structures
- Relatively good surface quality (Ra of 3 µm to 5 µm)
- Parts equally strong in all directions

Cons:

- Sintering has many unknown effects and have low first time right availability
- The shrinkage of parts is from 18 % to 21 %, z-direction has highest shrinkage
- Distortions may exist
- Limited material selection
- Modest knowledge base



Source: https://www.exone.com/getattachment/fce3082b-e121-410c-922c-f370a95a8093/hero-image-for-bj-landing-page1.jpg

https://amfg.ai/wp-content/uploads/2019/07/Metal-binder-jetting-Image-credit-Digital-Metal.png

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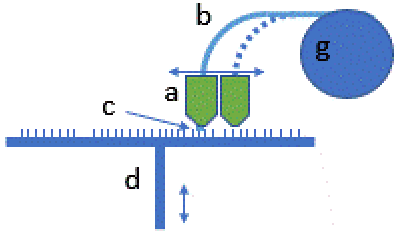
Pros and Cons - Metal FDM (Fused Deposition Modelling)

Generally:

- A relatively new method
- A multi-step process, the metal joint is based on sintering
- Small part sizes up to 100 mm are easier to fabricate
- Thicknesses from 3 mm to 10 mm most suitable
- For quick production of simple parts
- Inexpensive hardware
- SLOW (MarkForged example)
- Printing 1-5h , Washing 12-72 h and Sintering 17-31h --> 31...105 h



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Pros and Cons - Metal FDM (Fused Deposition Modelling)

Pros:

- Low cost method
- Own material for support structures
- Not as accurate as L-PBF
- Can print materials that cannot be processed in other metal AM technologies

Cons:

- Sintering has many unknown effects and have low first time right availability
- Geometric limitations
- Distortions may exist
- Limited material selection
- Modest knowledge base

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Source: https://www.desktopmetal.com/industries


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Outlook and Challenges

Outlook and Challenges

- Utilizing the methods is not simple!
- The designer needs to adopt a new way of thinking
- Finding suitable applications requires knowledge and insight
  - The situation is easiest when we have a problem for which Metal AM brings a solution
  - There are a fairly many different limitations to AM methods that need to be known
- A cost-effective solution requires that the advantages of AM methods can be widely exploited

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Outlook and Challenges

– It is known that in a few years we will have several different technically ready metal AM methods.
- The need for knowledge and expertise is not diminishing
- It is likely that metal AM cost efficiency will increase
– At present, insufficient information is available on the fatigue resistance of parts printed by different methods (and materials)

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Conclusions

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Conclusions 1/3

- More than 18 metal AM methods and L-PBF is mostly used!
- DED methods (LP-DED/LMD, WAAM) are becoming more common and there are coming low cost methods like binder jetting and Metal FDM
- Challenge is that finding suitable applications requires knowledge and insight

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Conclusions 2/3

– L-PBF is most mature method
– WAAM is most cost efficient method

– Time is money!
- Use as little material as possible
- If geometric complexity degeases material it also reduces printing costs

Conclusions 3/3

- I2P project is here for you 😀
- To increase knowledge and awareness of the possibilities of 3D printing of metals in the northern region
  - By organizing events to share information about the 3D printing of metals
  - By providing companies information and assistance in utilizing 3D printing of metals
- Intensify cross-border cooperation in research and industrial exploitation of 3D printing of metals.
  - By making efficient use of know-how and equipment located in different countries
  - By maintaining of arctic collaboration forum for 3D printing of metals
- Are you or is your company interested in 3D printing of metals and would you like to get more information about metal AM? The experts of the I2P project serve companies in Northern Ostrobothnia and Lapland regions in matters related to 3D printing of metal.

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Thank you for your kind attention!

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