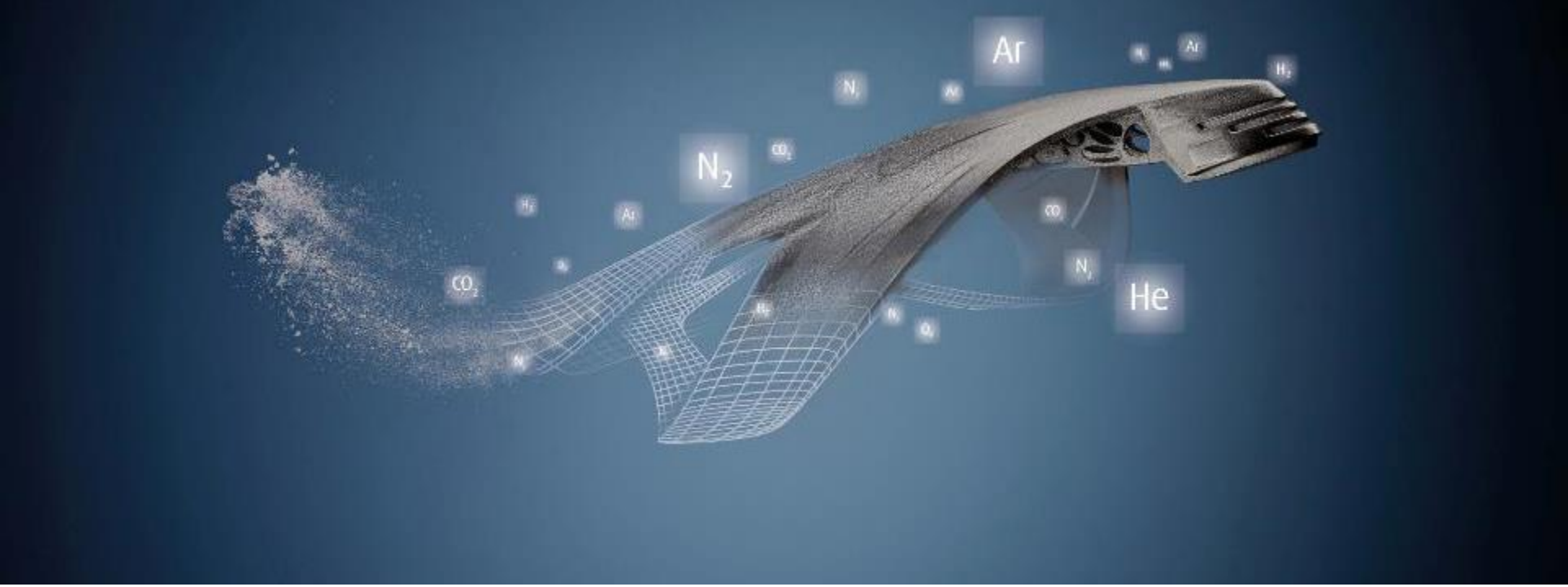


Metal Binder Jetting
Role of gases during printing and sintering

SHTE Conference 2022

Kai Zissel

Making our world more productive

Linde

Linde AM R&D – Lab in Munich

- 5 Technology Experts
- 4 PhD students

Laser Powder Bed Fusion:
- EOS M290
- TruPrint 1000
- TruPrint 3000
- Aconity Mini

Atomization:
- **Test Bench**

NEW !

Binder Jetting
- Desktop Metal P1

Material lab
- HNO, PSD, Karl Fischer, flowability
- Metallography

Self-introduction

- PhD student at Linde (4 years)
- Location: Technology Center @ Unterschleißheim
- Division: LT-GDM-AM (Pierre Forêt)
- in cooperation with Chalmers University of Technology
- Background in Material Science & Engineering (M. Sc.)

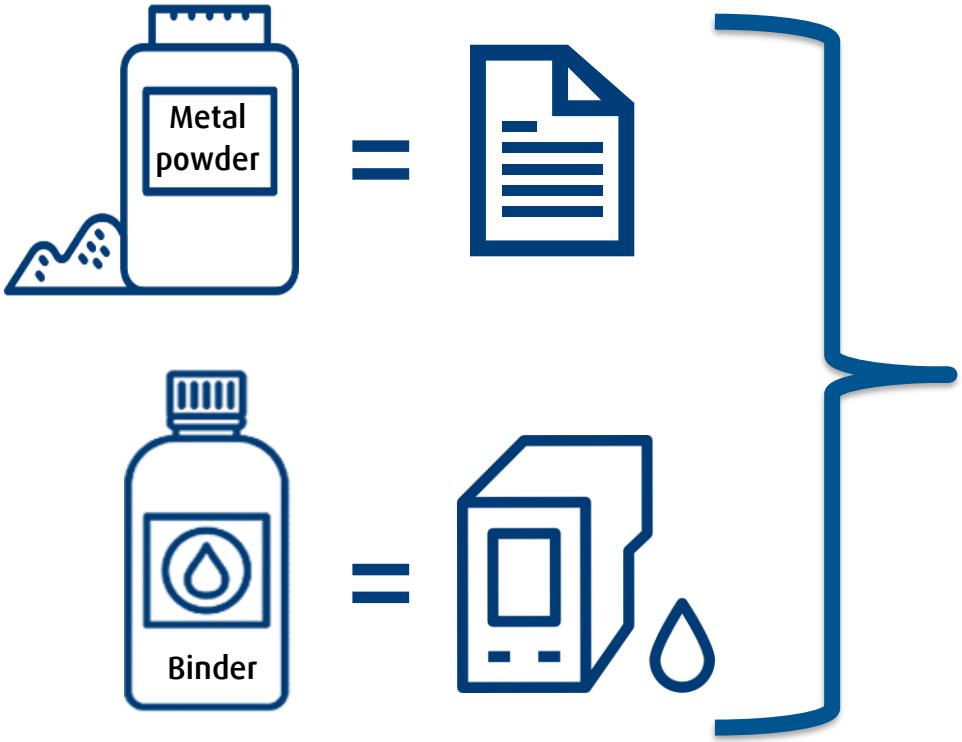
Agenda

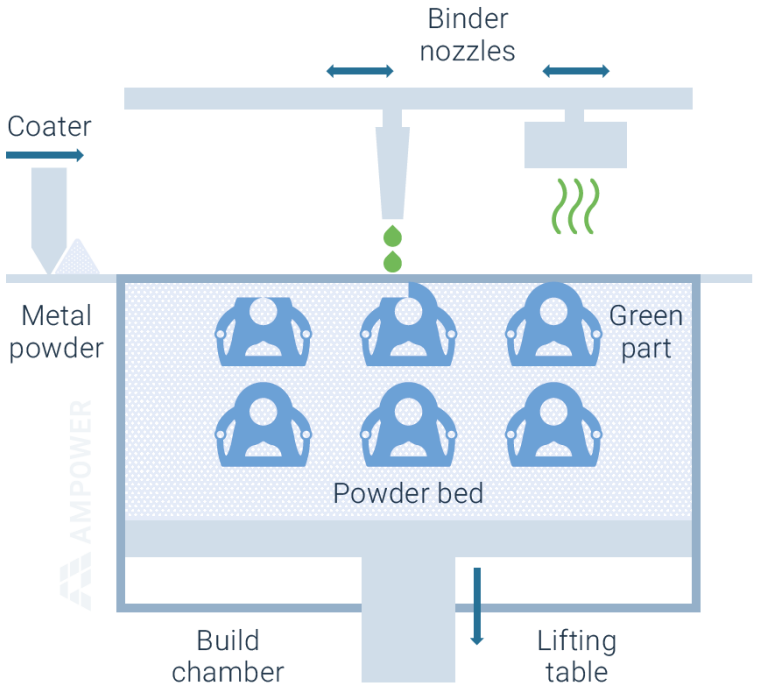
Binder Jetting – How does it work?

Why Binder Jetting? (Advantages & Limitations)

Role of gases for the process

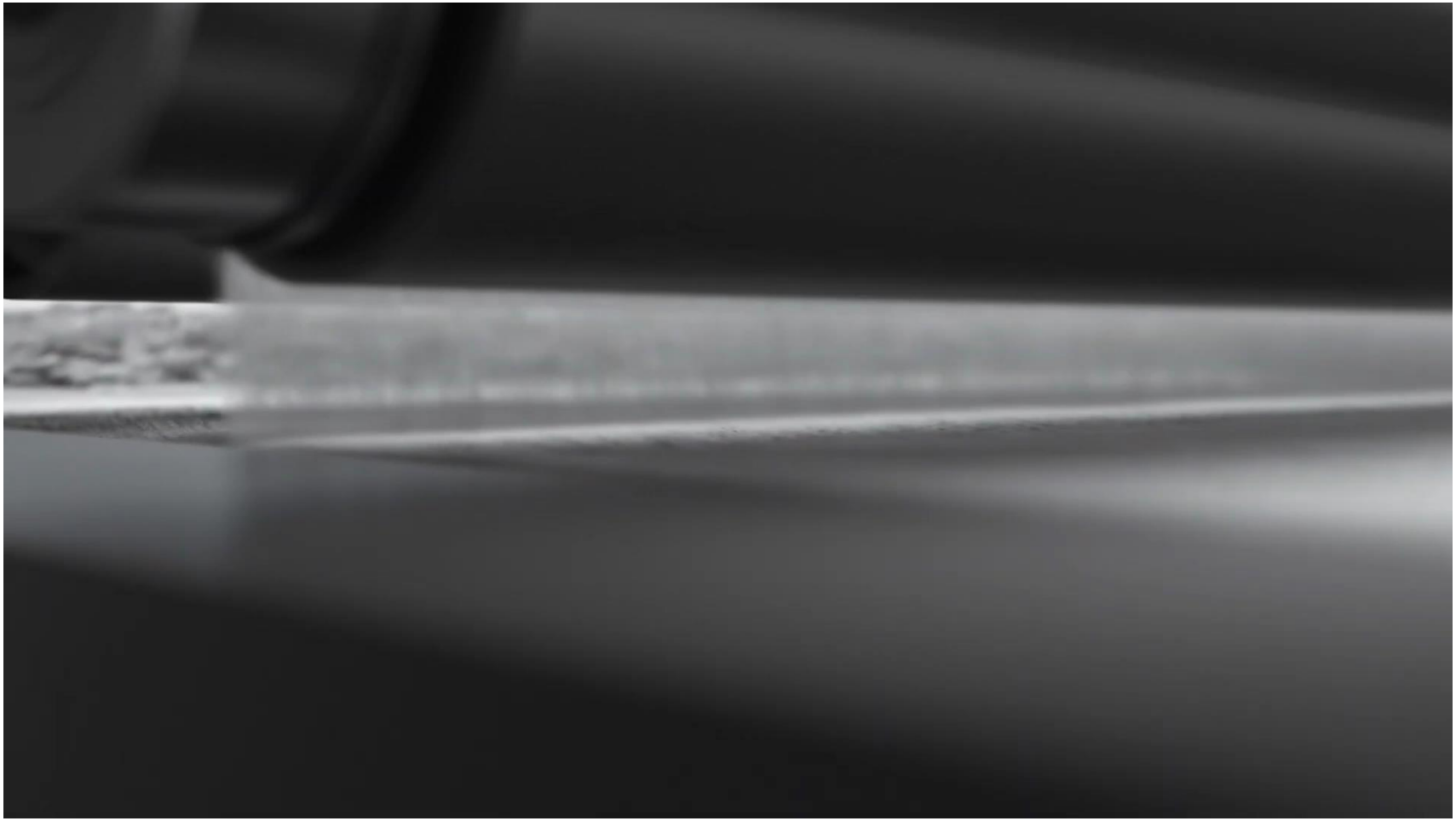
How does Binder Jetting work?





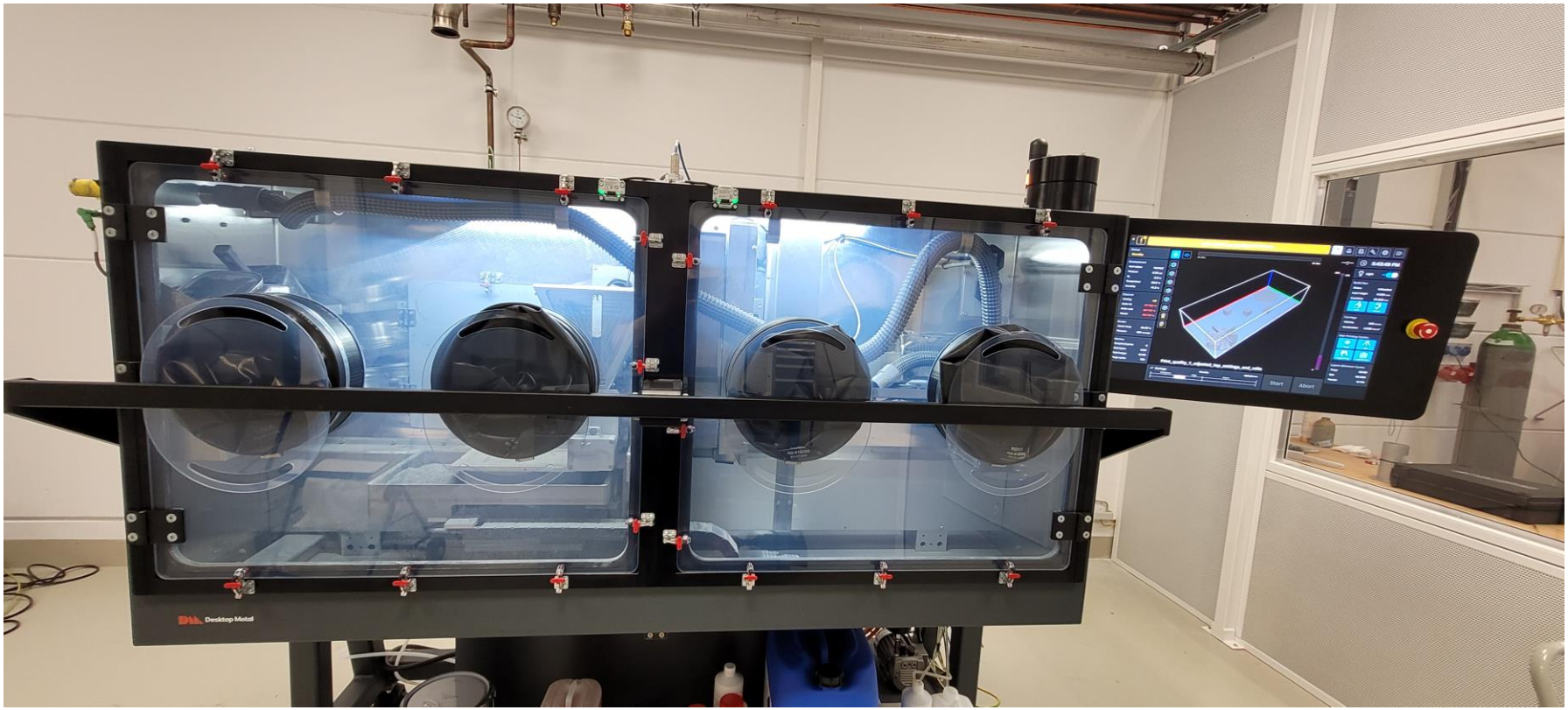
Source: ampower.eu

Binder Jet 3D printing animation



Source: Desktop Metal

Production System P1



- Build volume: 200 x 100 x 400 mm
- Build rate: 1350 cm^3/h

Production System P1 – Print chamber

Production System P1 – Printing video

Curing

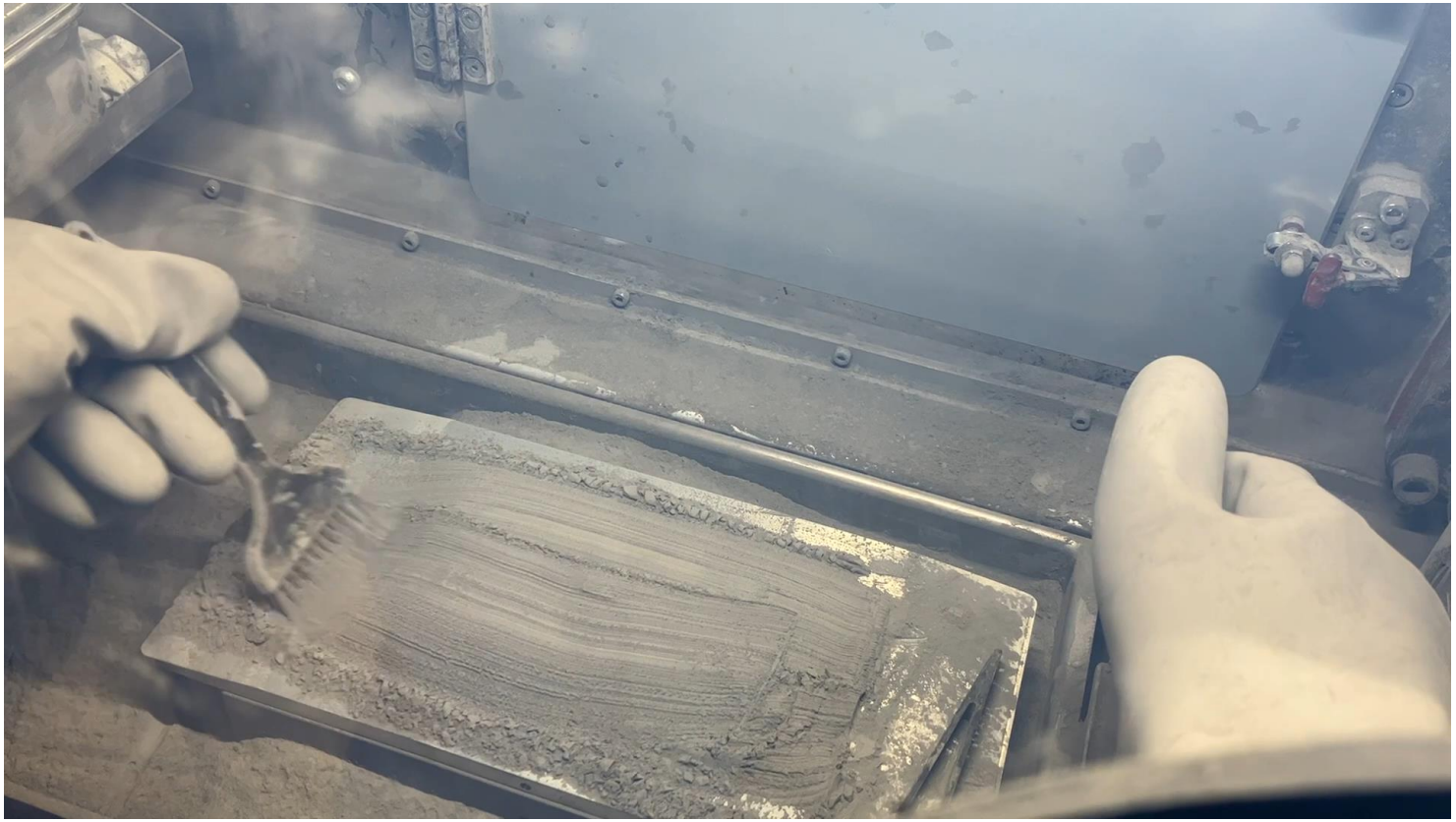
- 150 °C – 250 °C for several hours

- Crosslinking of polymer chains

→ Binder hardens

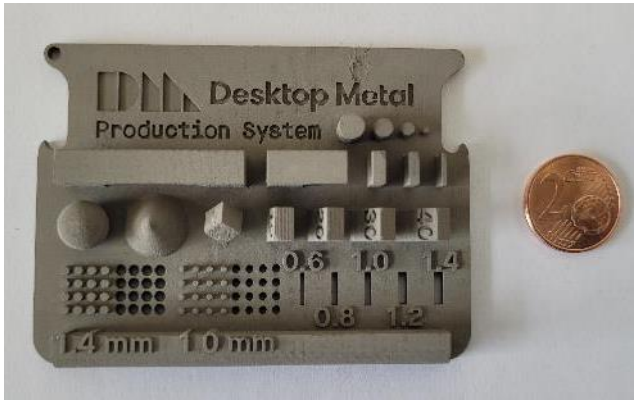
- Evaporation of binder (mostly water)

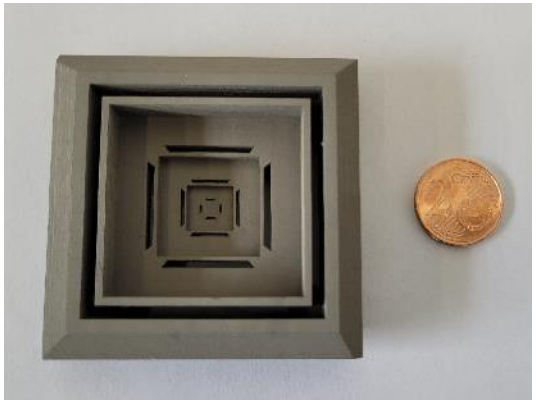
Depowdering

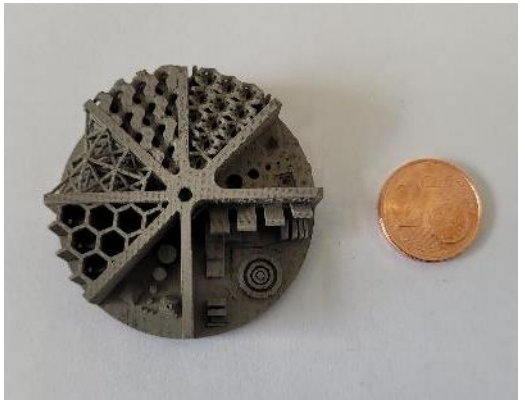


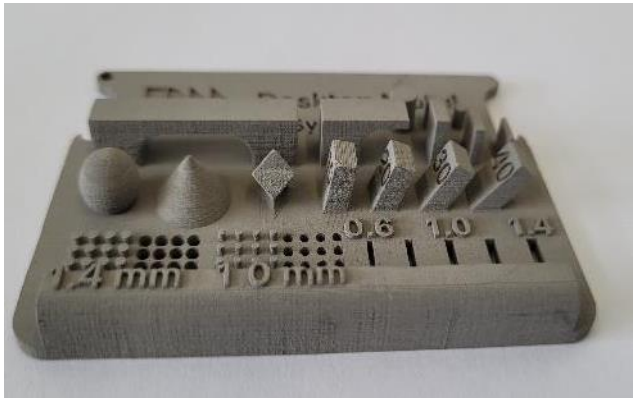
- Risk of breaking fine features
- Part should be big enough to find

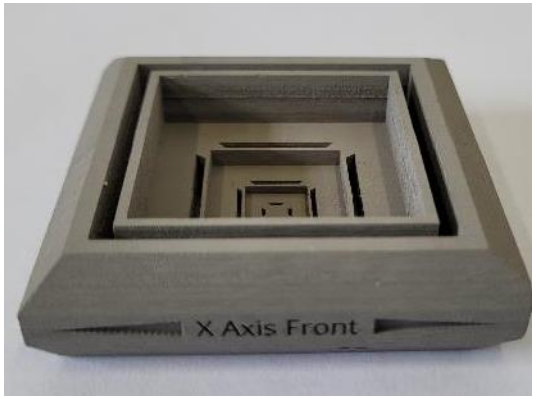
Green parts (after Curing)

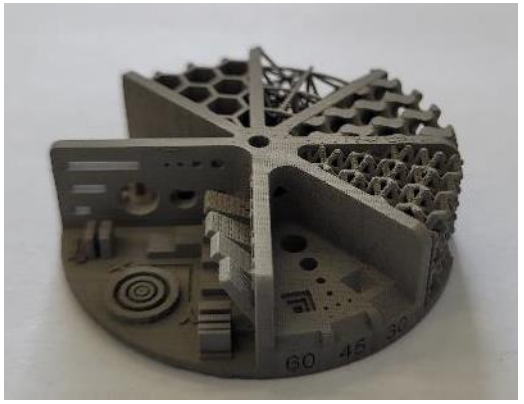




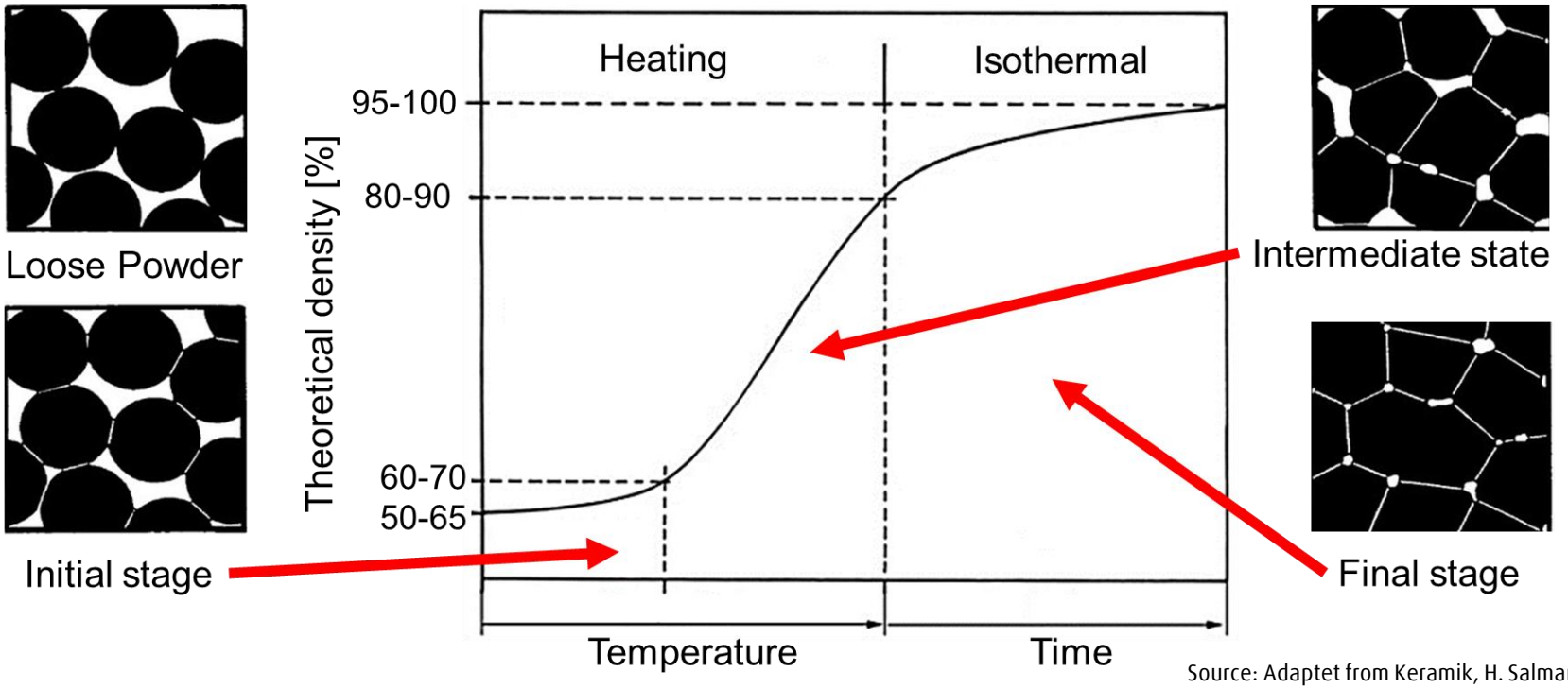




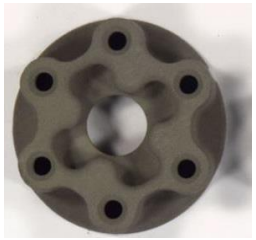




Debinding & Sintering



Source: Adaptet from Keramik, H. Salmang, 1982



Source: gknpm.com

~ 20 % shrinkage

Source: gknpm.com

Multi-step process

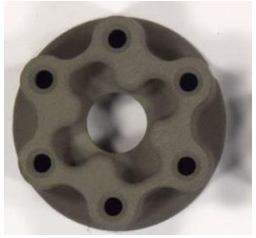
Printing → Curing → Depowdering → Debinding & Sintering

Source: exone.com

Source: nabertherm.com

Source: 3dprintingcenter.net

Source: hubs.com



Source: gknpm.com

~ 20 % shrinkage

Source: gknpm.com

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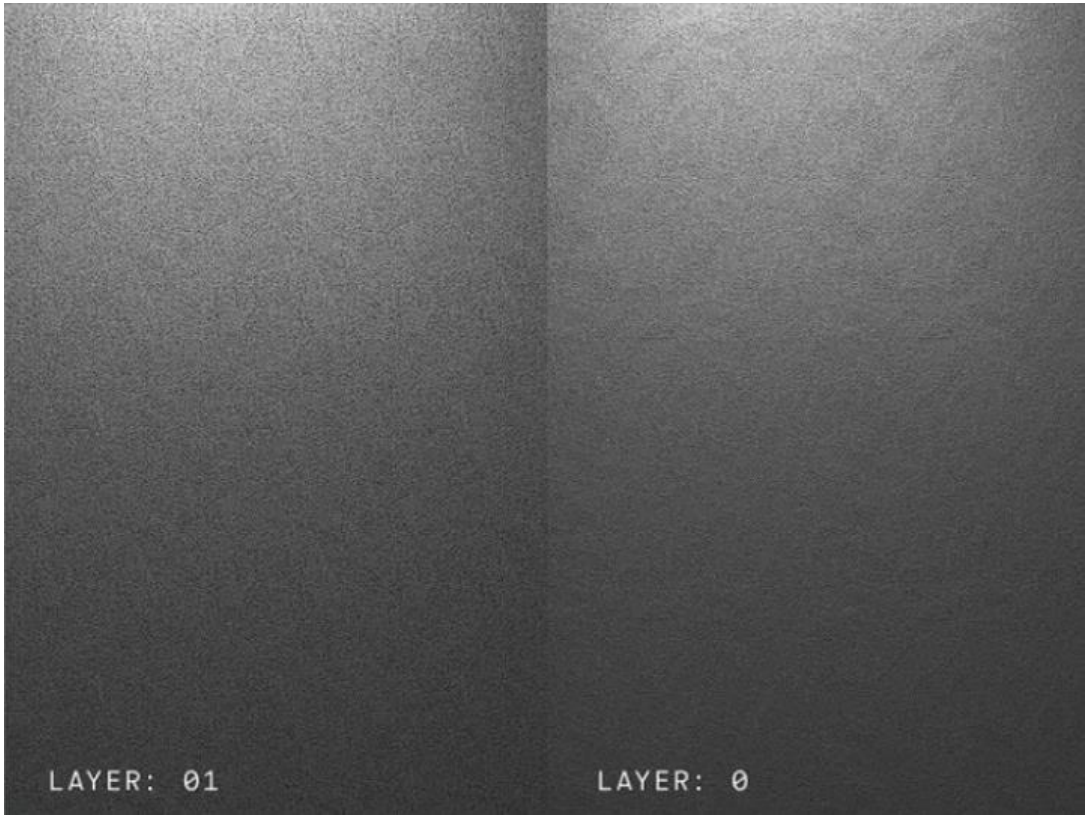
Binder Jetting – How does it work?

Why Binder Jetting? (Advantages & Limitations)

Role of gases for the process

Binder Jetting – Productivity



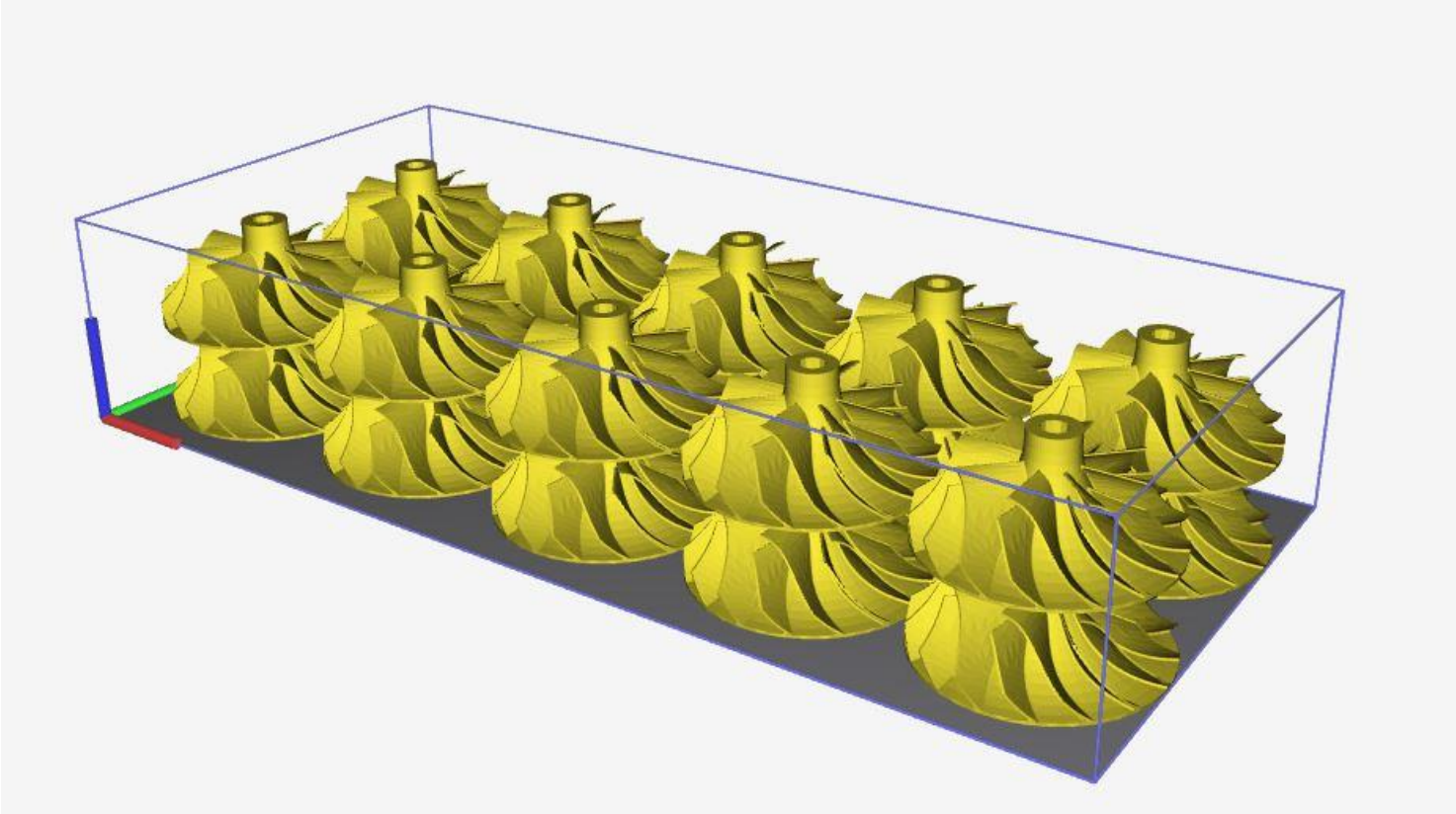
Source: Desktop Metal

EOS M400:
up to **100** cm3/h*

Production System P50:
up to **12.000** cm3/h*

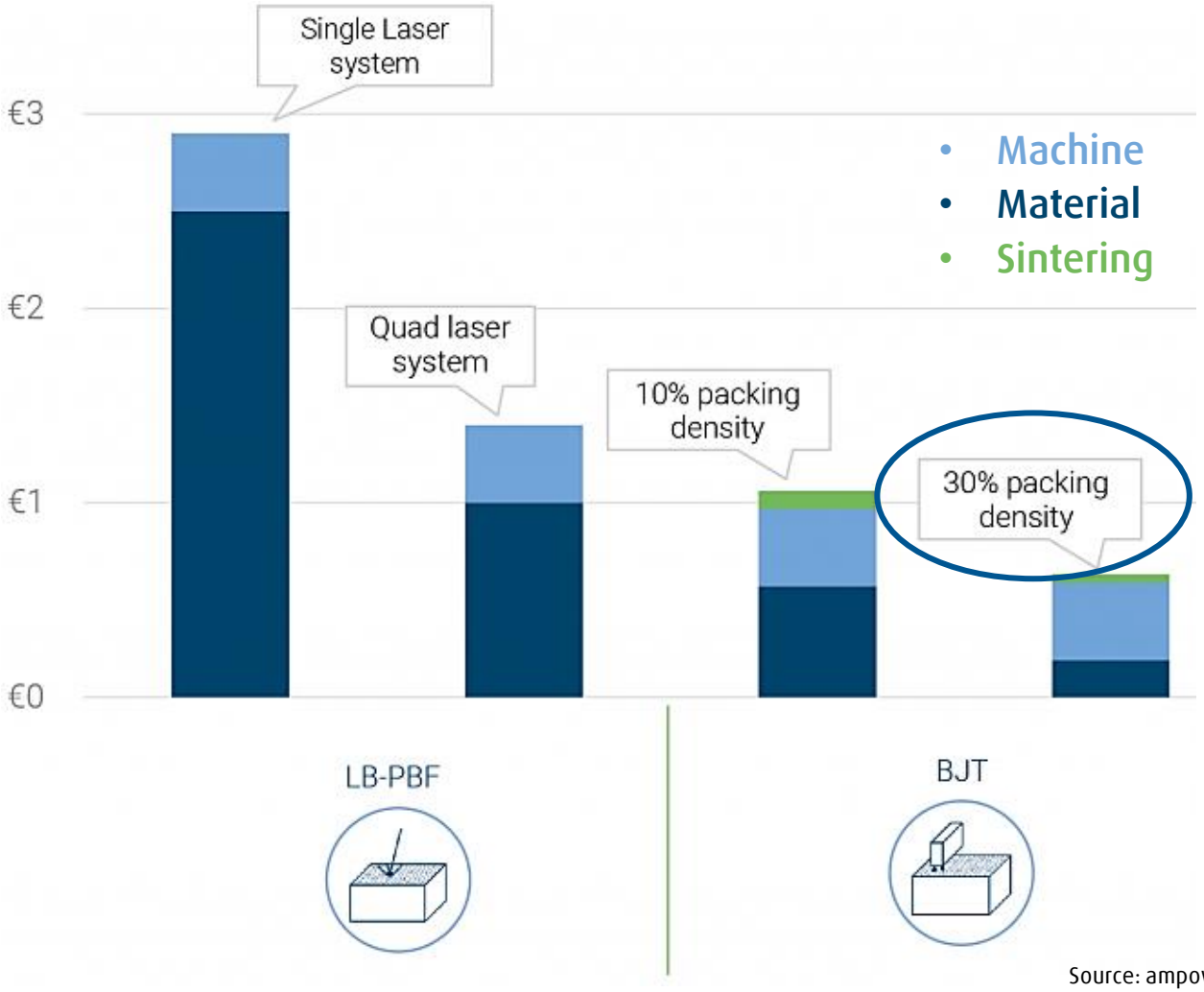
*depends on material & print parameters

Binder Jetting – Productivity



- No supports needed → powder sufficient support
- Full utilization of build volume
- Print speed only influenced by build height

Binder Jetting – Low costs

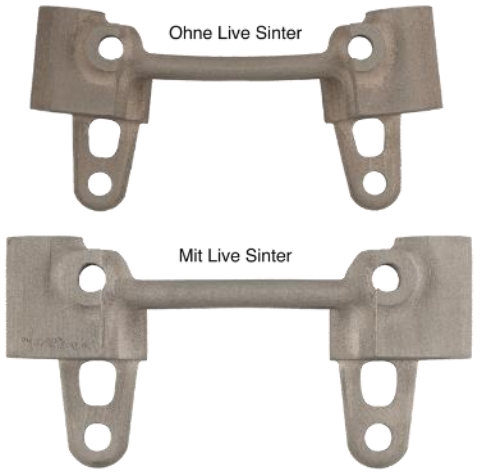


Source: ampower.eu

Binder Jetting – Challenges & Limitations

Design

- Dimensional control due to shrinkage → design, process control, simulation
- Sintering supports necessary for large overhangs
- Depowdering of small features
- Very fine cooling channels not possible



Source: Desktop Metal

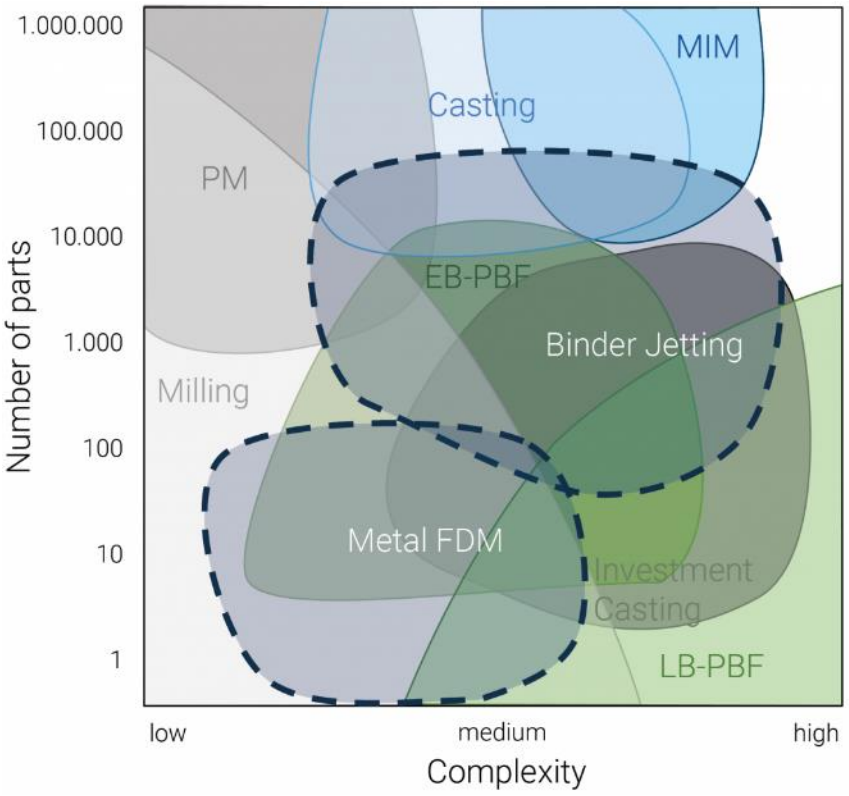
Sintering

- Densities from 90-99 %
- Shrinkage not uniform
- Risk of C or N_2 contamination from binders
- Mechanical properties comparable to Metal Injection Molding (established process)
- Porosity of up to 1 % → bad fatigue properties (cyclical loads)

Recyclability

- High reactivity of fine powders → decreasing processability over time

Application of Binder Jetting



Source: ampower.eu

- **Benefits of Additive Manufacturing**

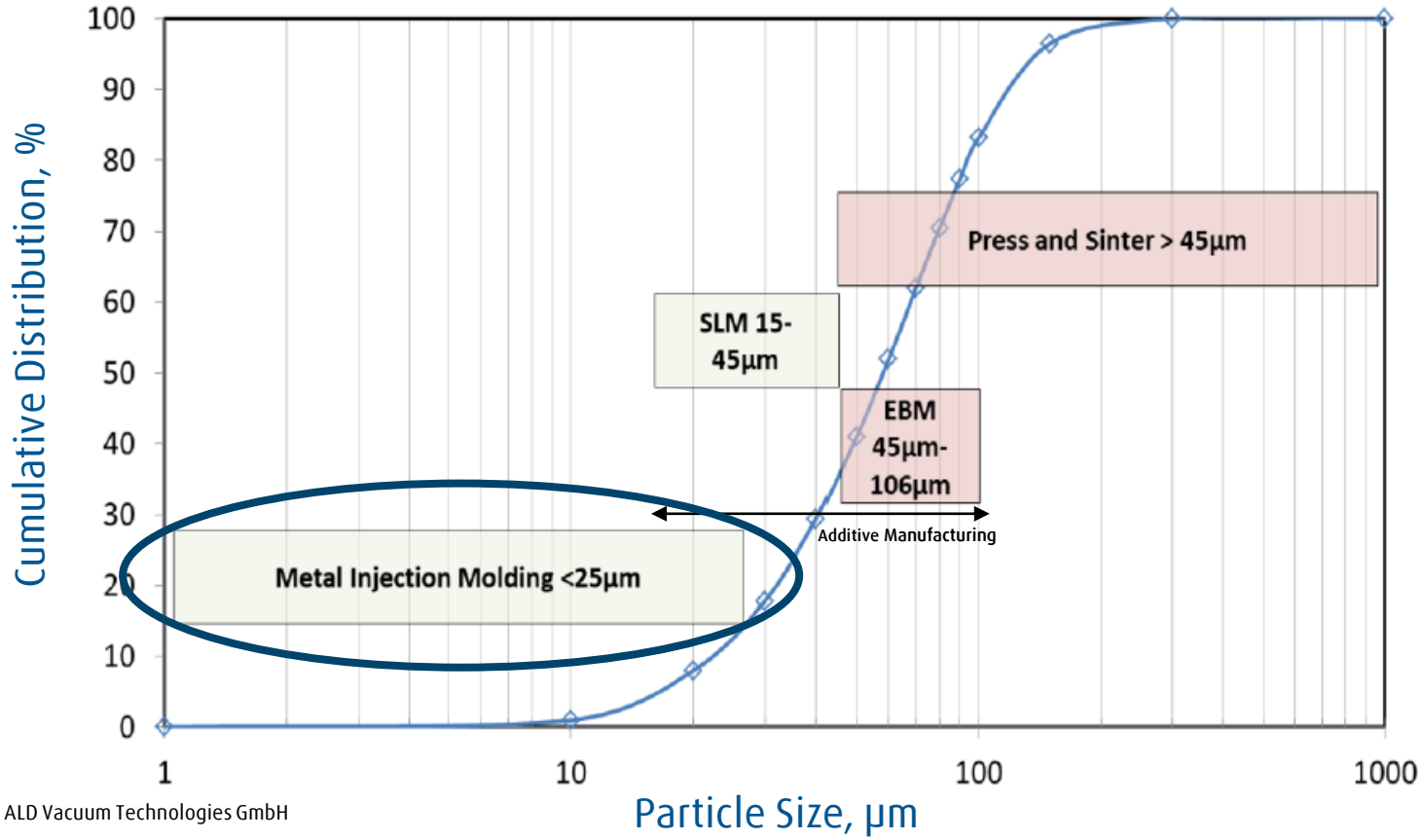
- **But now with**
  - High productivity
  - Cheaper than other metal AM technologies

- **Sweet spot:**
  - Max. dimension of 50 mm
  - Lot sizes from 100-100.000

- **Similar to Metal Injection Molding (MIM)**

- **Applications:** Oil & gas, Automotive, Tooling

Binder Jetting – Metal powders



Source: ALD Vacuum Technologies GmbH

- Fine powders (<25 µm) for high sintering activity and powder bed packing density
- Metal Injection Molding powders suitable, **but binder development complex**

Commercially available materials (April 2022)

Material type	Desktop Metal*	Digital Metal*	ExOne*
Stainless steels	316 L, 17-4 PH, 420, DM HH	316 L, 17-4 PH	316 L, 17-4 PH, 304 L
Low alloy steels	4140	4140	
Tool Steels	D2, S7	D2	M2, H13
Nickel (Ni)	IN625	DM 625 (IN625), DM 247 (MAR-M 247)	IN718
Titanium (Ti)	-	Ti6Al4V	-
Aluminium (Al)	-	-	Al 6061
Copper (Cu)	Pure Cu	Pure Cu	-
Silver (Ag)	Pure Ag	-	-
Gold (Au)	Pure Au	-	-

A lot of R&D or customer qualified materials → Process development for each material a challenge!

* Taken from each OEMs homepage (April 2022)

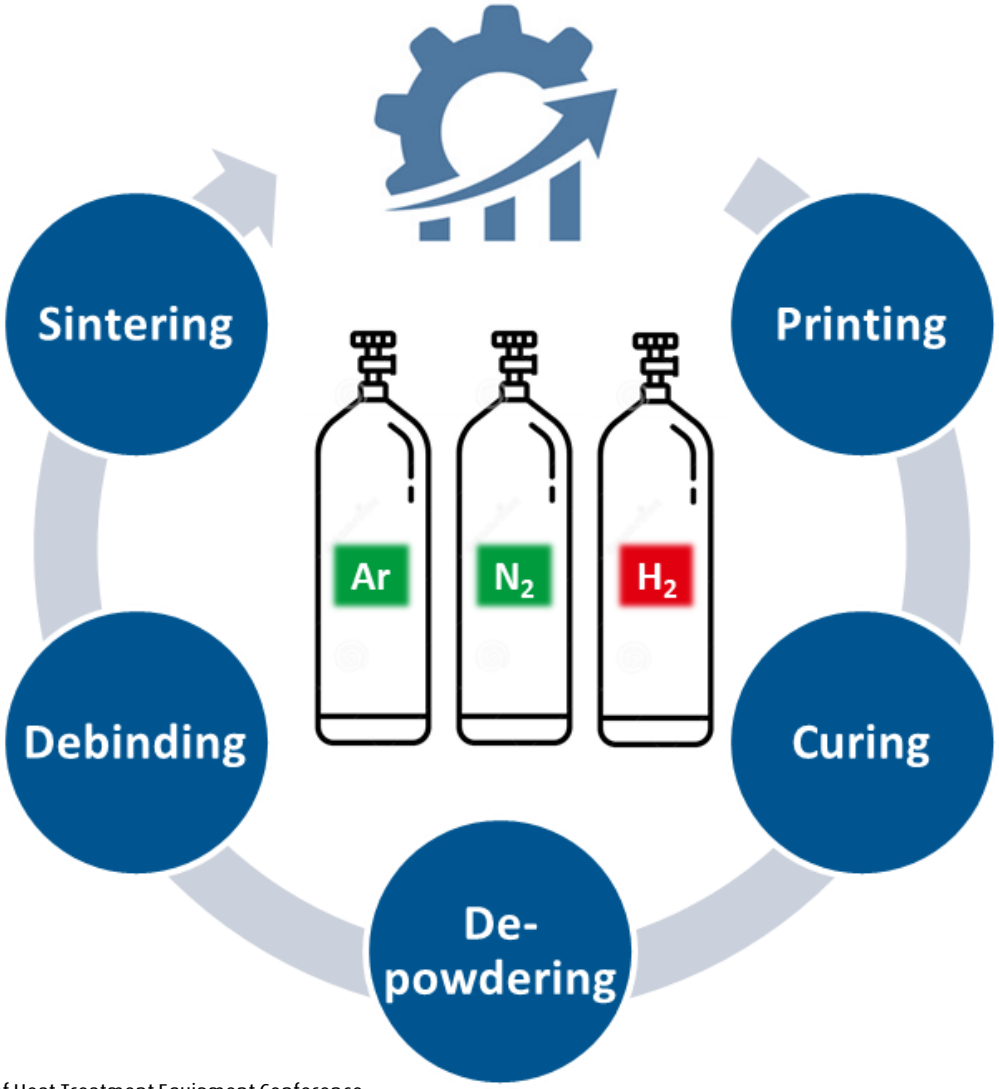
Agenda

Binder Jetting – How does it work?

Why Binder Jetting? (Advantages & Limitations)

Role of gases for the process

Binder Jetting – Role of process gases



Printing – Role of gases

Safe print environment

→Cheaper material choice

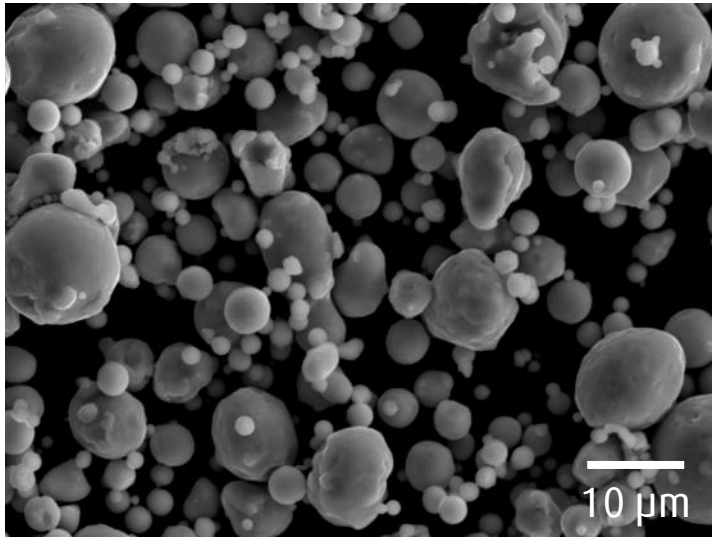
Reactive materials are sensitive to O_2 (oxidation)

→Increase reusability & part quality

Controlled humidity

→Flowability/Spreadability

→Binder interaction



Curing – Role of gases

- Batch furnace process at 150-250 °C
- Purpose:
  - **Evaporation** of moisture and organics
  - **Crosslinking** of polymer chains
    → strength of green part
- Inert environment benefits:
  - **Safe** environment
  - **No** powder **oxidation** (especially fo reactive powders)
    - Protects **reusability**
    - Protects **sinterability**

Debinding & Sintering – Role of gases

Debinding (~ 450 °C)

– Oxidation protection

– Reduction of oxides

– Transport of evaporating binder

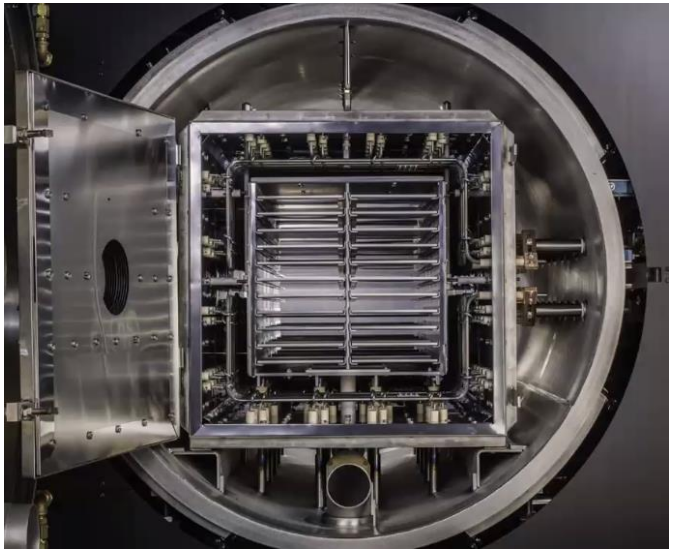
Sintering (near melting temperature)

– Oxidation protection

– Reduction of oxides

– Carburization of steels

– Gas quenching



Source: Desktop Metal

Source: ExOne

Further role of gases

Depowdering

Source: 3dprintingcenter.net

Source: Desktop Metal

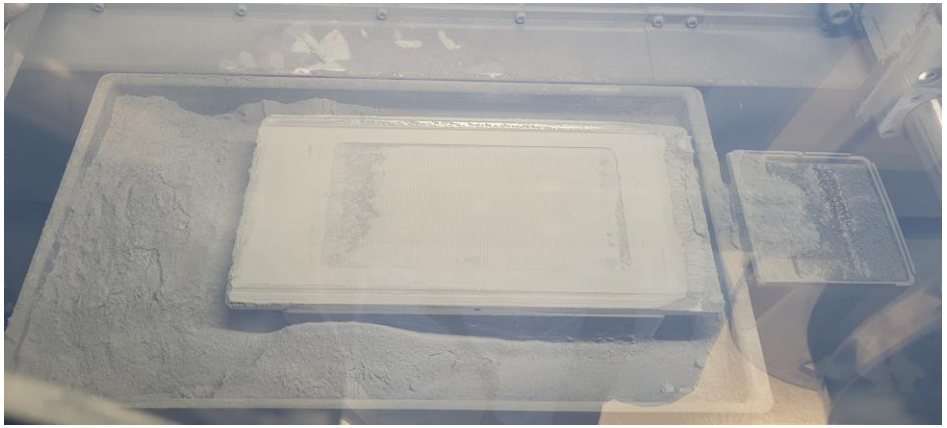
Sieving

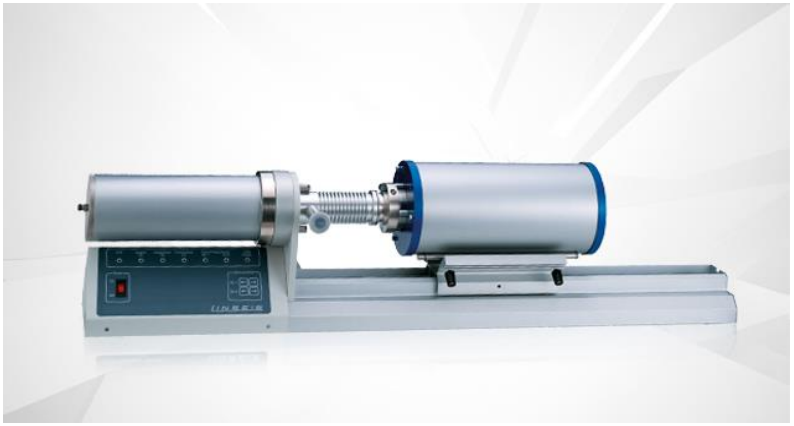
Source: Farleygreene

Storage

Linde ADDvance powder cabinet

R&D projects





Source: Linseis

Reusability of 17-4 PH stainless steel powder in Binder Jetting

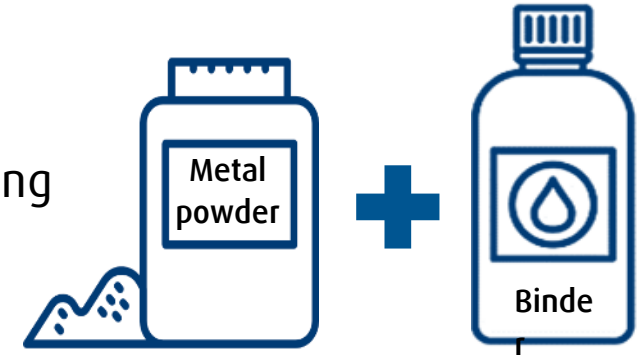
- Raw material (powder) as main cost factor → reusability important
- Change in powder characteristics along the process chain
- Influence of gas along the process chain on powder reusability

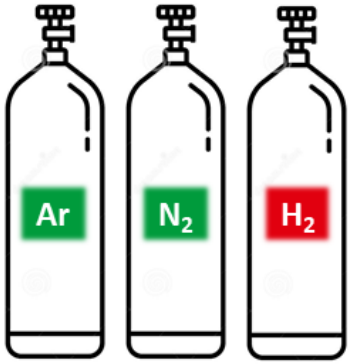
Future:

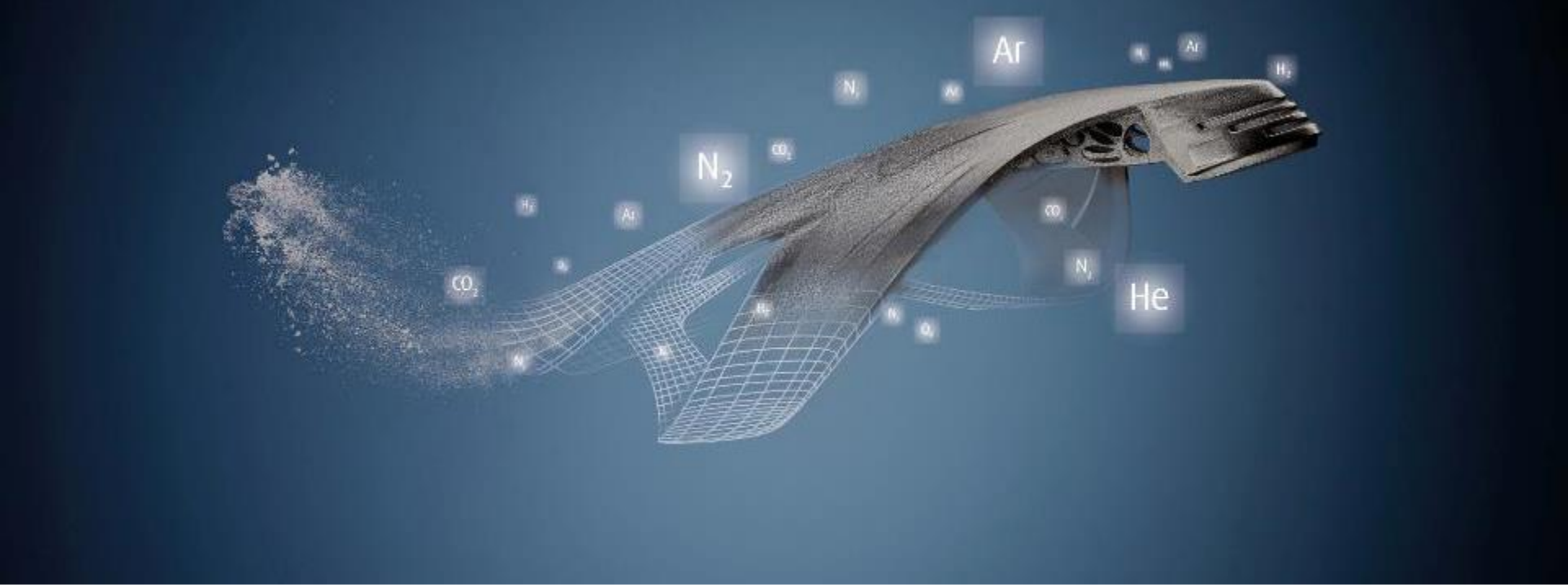
- Development of tailored gas compositions for debinding & sintering of advanced alloys
- Design study on opportunities and limitations of Binder Jetting (small features, sintering)

Summary

- **Raw material:** metal powder + binder
- **Multi-step process:** printing, curing, debinding, sintering
- **Key benefits:** Productivity & costs
- **Challenges:**
  - Sintering shrinkage
  - Material & process development
- **Benefits of gas along the process chain**
- **Increasing interest & material portfolio**







Thank you for your attention

Questions?

Kai.Zissel@linde.com

Making our world more productive