AACHEN CENTER
FOR ADDITIVE
MANUFACTURING

Discover3DPrinting @SMM 2022

Basic AM Seminar

Viktoria Krömer | 06.09.2022

SMM formnext

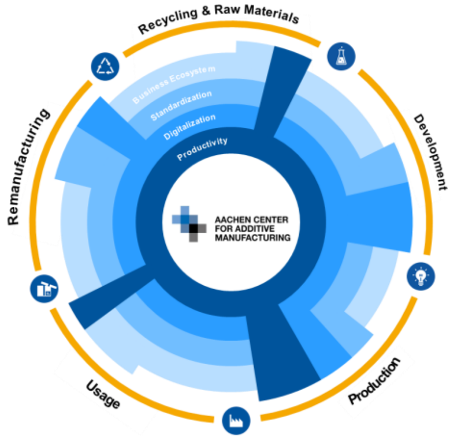
The ACAM Offers Services in the Areas of Consulting, Engineering, Research and Education with a Focus on the Additive Manufacturing Industry

Your Presenter

Viktoria Krömer

- Consultant for ACAM Aachen Center for Additive Manufacturing GmbH
- Research Associate at the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

Perspective and focus



Community

BUSINESS Members

BASIC Members

COOPERATION Members

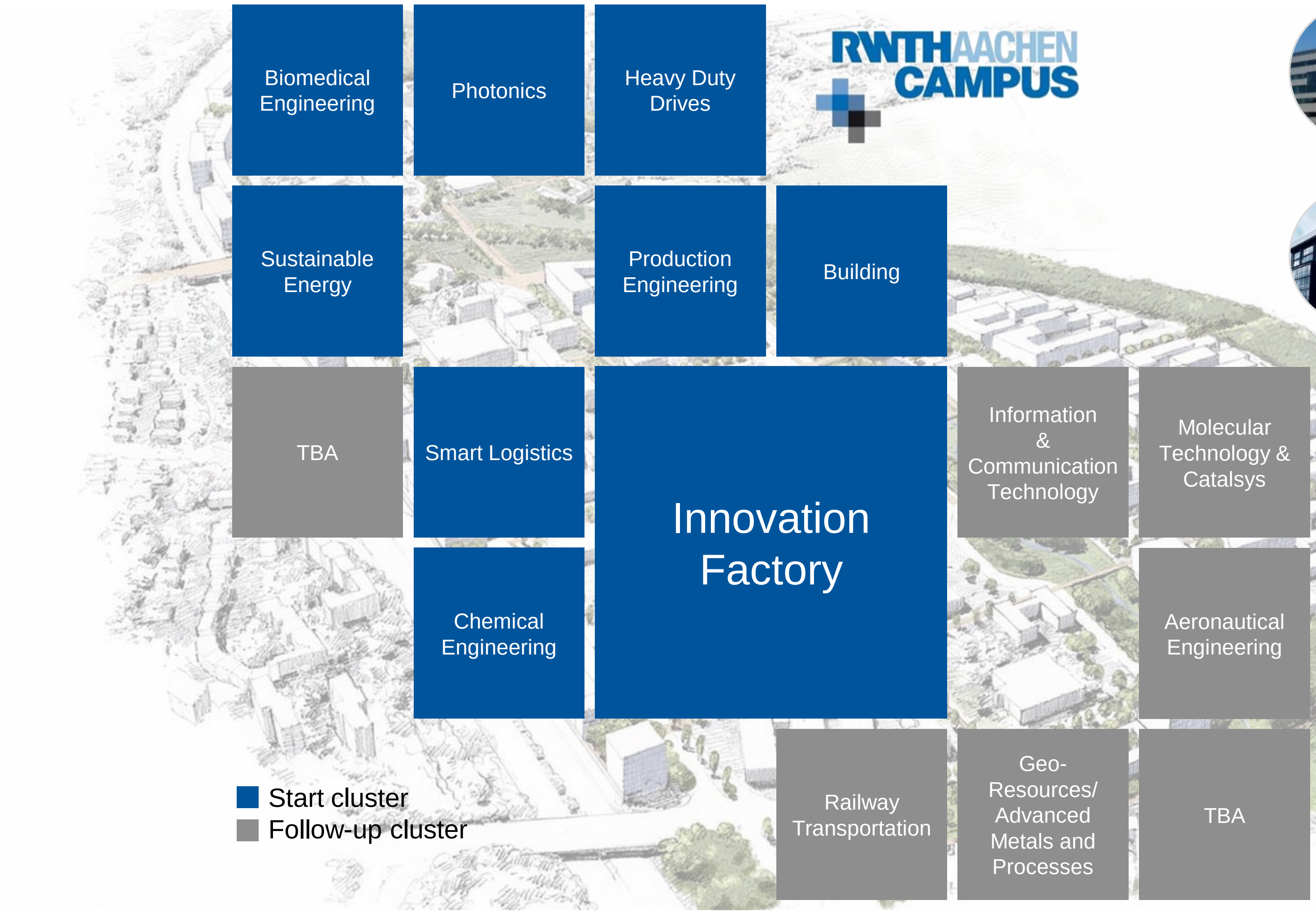
Key figures

- One-stop-shop for additive manufacturing covering the entire process chain
- Pooling of resources of RWTH Aachen Campus and facilitating industry’s access to the Additive Manufacturing expertise of leading scientific and research institutions
- Over 100 researchers engaged in topics around the AM product life cycle and industry structure
- Delivery of approx. 40 industry project in consulting, engineering and research

Heritage
At the Time of Charlemagne, Aachen was the Capital of Europe

Image Source: DAP RWTH Aachen University

RWTH Aachen Campus:
16 Research Clusters Are Developing



Cluster Smart Logistic

Cluster Heavy Duty Drives

Cluster Photonics

Cluster Sustainable Energy

Cluster Production Engineering

Cluster Bio-Medical Engineering

Cluster Chemical Engineering

Heritage
The Cradle of Metal AM

The cradle of metal AM

The world‘s most vivid and multifaceted AM ecosystem

1995

First Hybrid Machine Tool

1997

Basic Patent for SLM

2001

First Tool Insert

2008

First Implant

2015

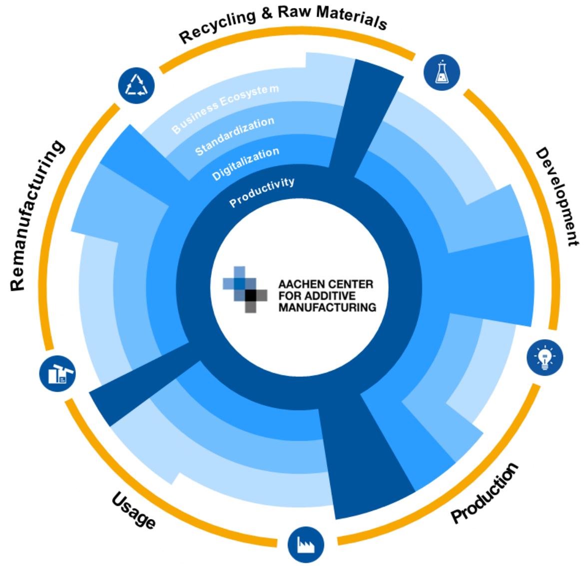
Foundation of ACAM

Image Source: DAP RWTH Aachen University, Fraunhofer ILT, Campus GmbH

The Aachen Center for Additive Manufacturing

Navigating AM complexity

Creating opportunities by leading-edge **R&D**, professional **training and education**, and agile **engineering** and **consulting** services



- Dedicating **3,000 m²** lab space to AM research
- Connecting **100+ researchers** in the field of AM

Leading-Edge Research in Additive Manufacturing

The ACAM is your one stop shop for Additive Manufacturing research, education, engineering and consulting.

Our Member Network

BUSINESS Members

oerlikon | TOYOTA | GMH GRUPPE | ZOLLERN | GRÄNGES | MTDG MANUFACTURING TECHNOLOGY DEPLOYMENT GROUP, INC.

BASIC Members

Materials Magic Hitachi Metals | PROTIQ A Phoenix Contact Company | TÜV SÜD | DAIDO STEEL | SCHAEFFLER | LMT TOOLS | NISSAN

SCHÄFER | toolcraft | AMEXCI | APPLIED MATERIALS | aalberts | DENSO Crafting the Core | kurtz ersa

MESSER | voestalpine ONE STEP AHEAD. | Danfoss | GE Additive | OTTO FUCHS | Linde | THE AVIATION AM CENTRE

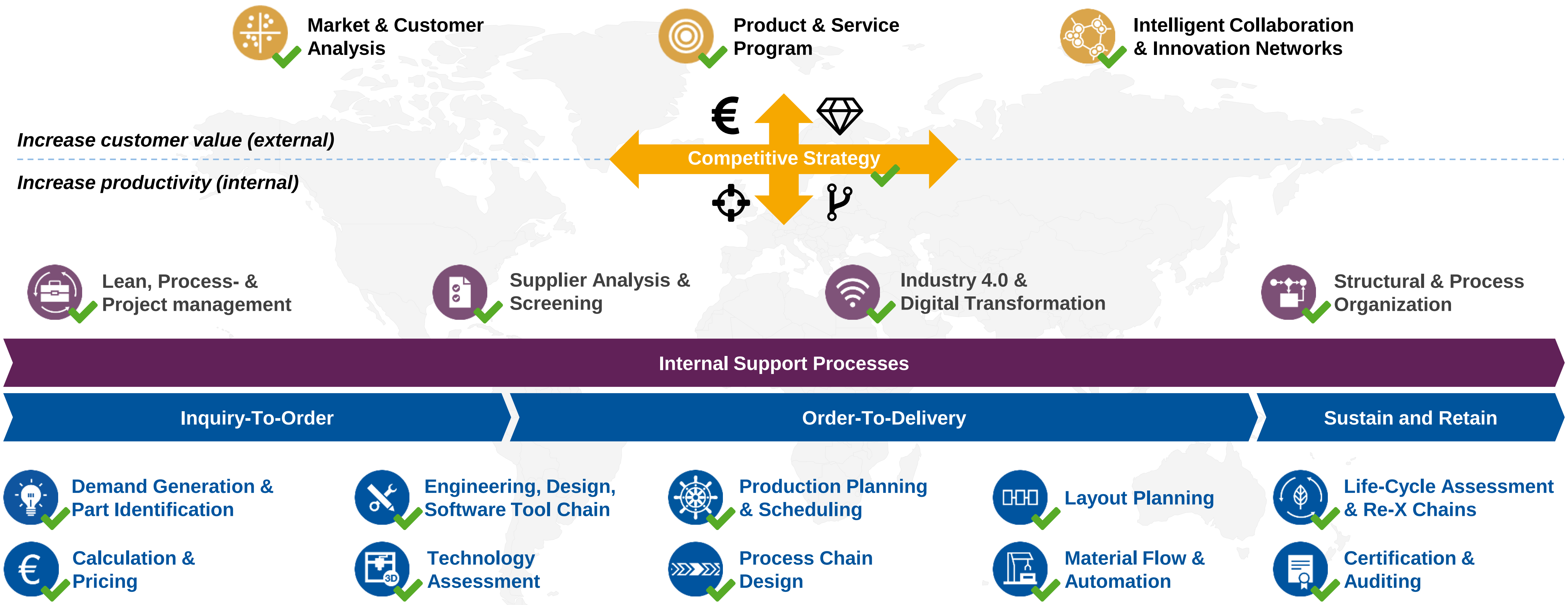
OWL | Hydro | AddUp | VDM Metals | GEA engineering for a better world | AUBERT&DUVAL

COOPERATION Members

Efficient Elements | LUNOVU Integrated Laser Solutions | ACUNITY | stratasys | ENABLE3D

IXUN LASERTECHNIK GMBH | formnext | 3YOURMIND | AMGTA

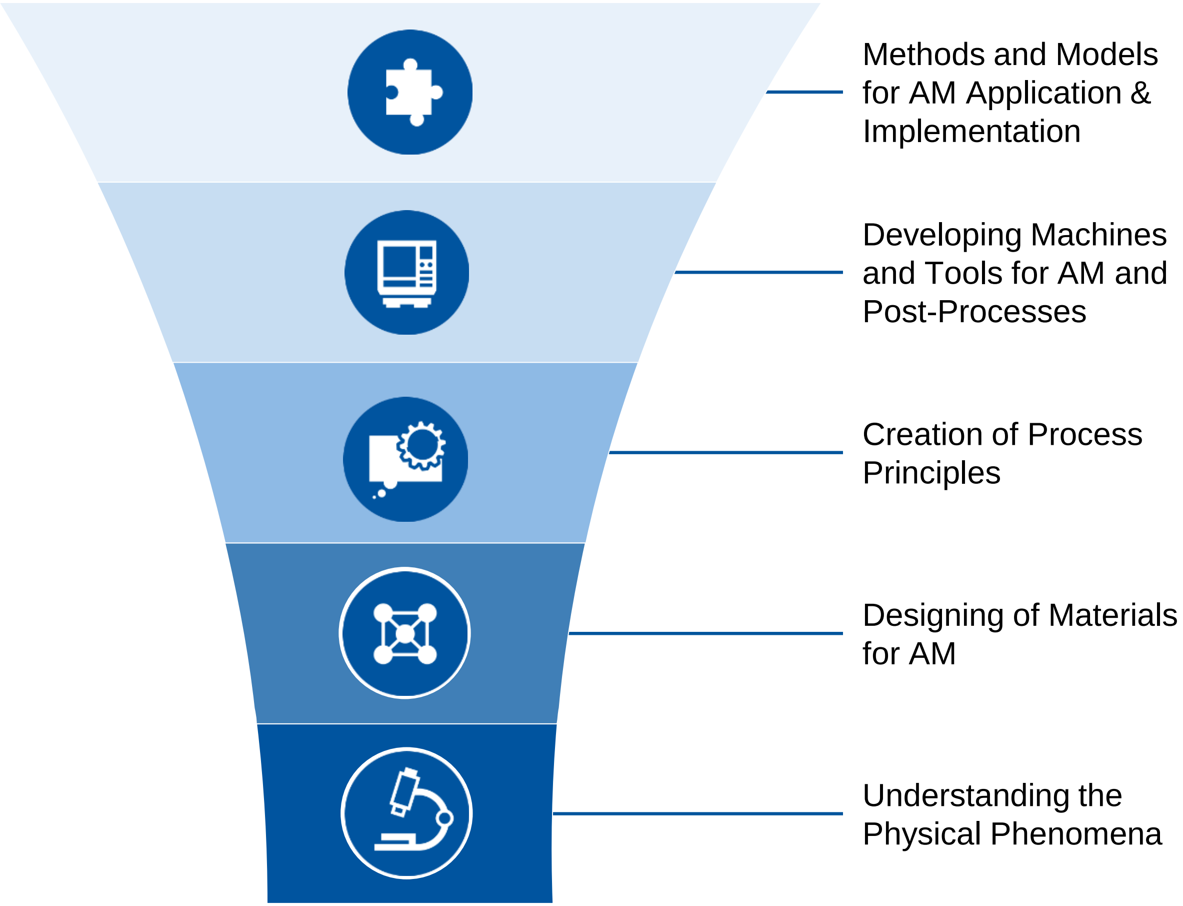
Consulting
Enabling Manufacturing Companies



Market & Customer | Top-Level Business Processes | Support Processes

Research & Development
The Future of Additive Manufacturing

Driving Additive Manufacturing Forward



Connecting Industry and Research

Consortial ACAM Projects

- Annual R&D projects from research partners exclusive for ACAM members
- Quick knowledge boost by collaboration

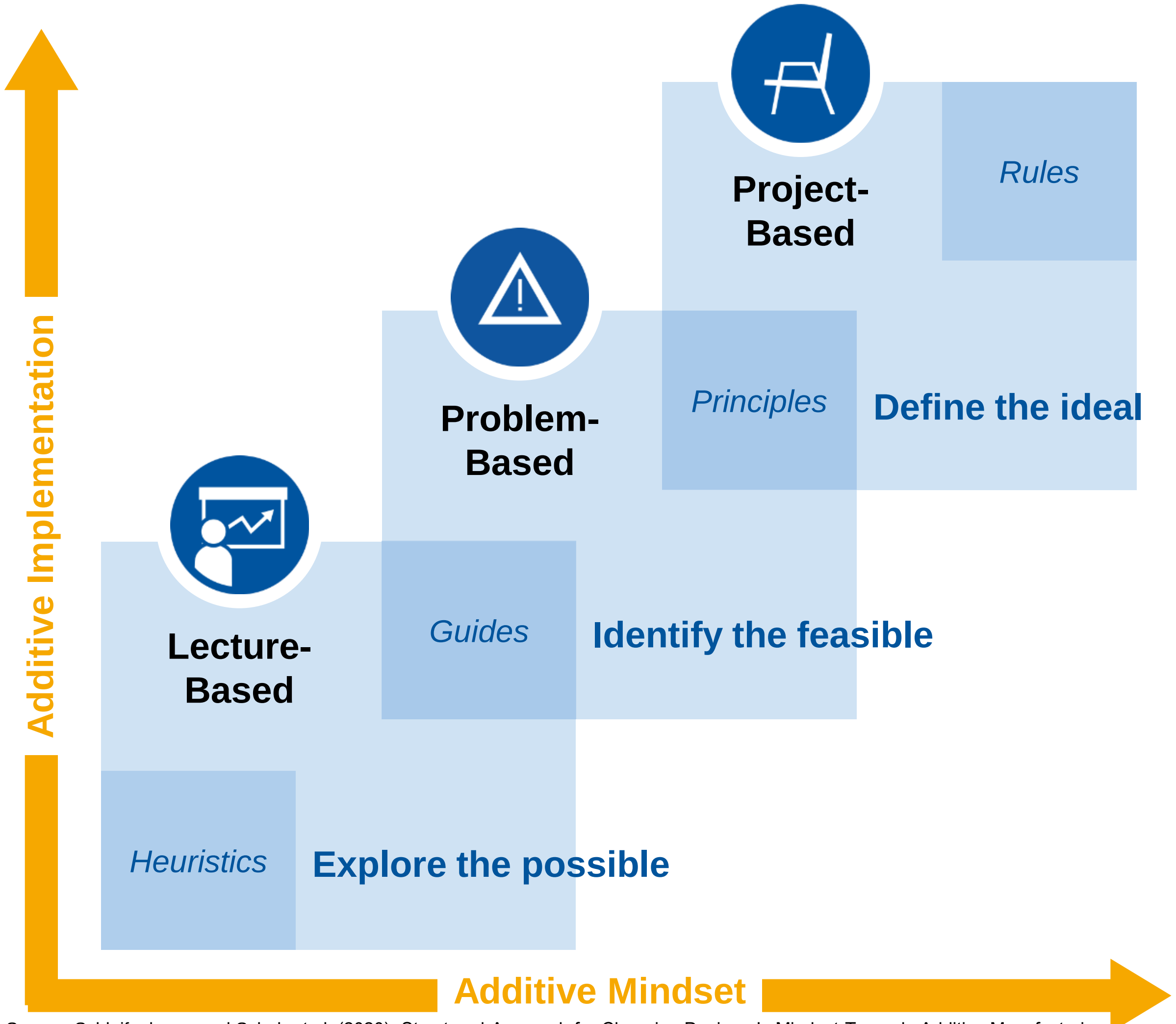
Bilateral R&D Projects

- Address contemporary challenges in R&D projects
- Overcome risks by fast results from leading-edge research

Public-funded R&D Projects

- Take part in shaping the future of Additive Manufacturing
- Benefit from public funding to reach long-term goals

Education
Implementing an Additive Mindset



Targeting Continuous Learning

Project-based Approach

- Starting with predefined goals
- Structuring the design process and integrating existing knowledge
- Focus on discussions about solutions

Problem-based Approach

- Starting with selected examples
- Understanding theoretical fundamentals of design problems
- Focus on the perception of problem indicators

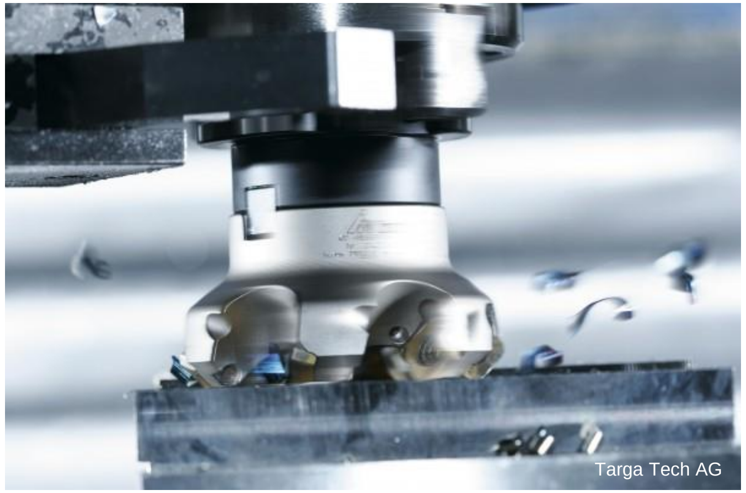
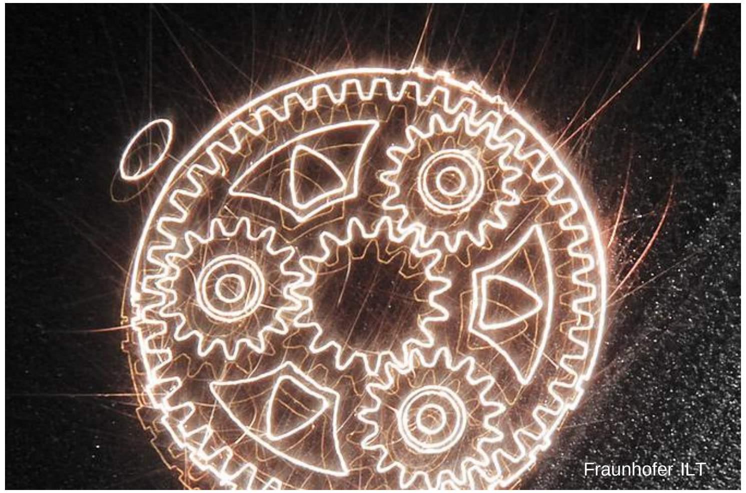
Lecture-based Approach

- Starting with heuristic information
- Summary of experiences and theoretic knowledge
- Structured lectures transporting information
- Focus on existing knowledge of audience

Source: Schleifenbaum and Schuh et al. (2020): Structured Approach for Changing Designer's Mindset Towards Additive Manufacturing

Basic AM Seminar – Content

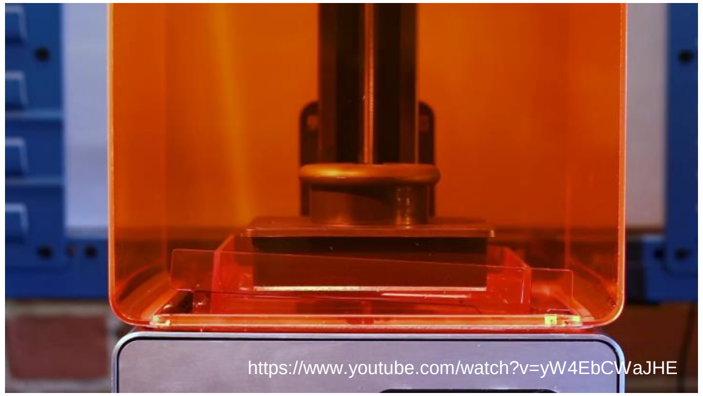
Introduction to AM
Subdivision of Manufacturing Technologies

Subtractive Manufacturing	Formative Manufacturing	Additive Manufacturing
 Targa Tech AG	 Roth & Effinger	 Fraunhofer ILT
Manufacture of geometry by removing of defined areas from workpiece	Forming a given volume into geometry under the condition of constant volume	Stacking of volume elements (usually in layers)
■ Milling ■ Turning ■ …	■ Deep Drawing ■ Molding ■ …	■ Laser Powder Bed Fusion ■ Laser Metal Deposition ■ …

Additive Manufacturing – Definition

Definition (ASTM 52900)

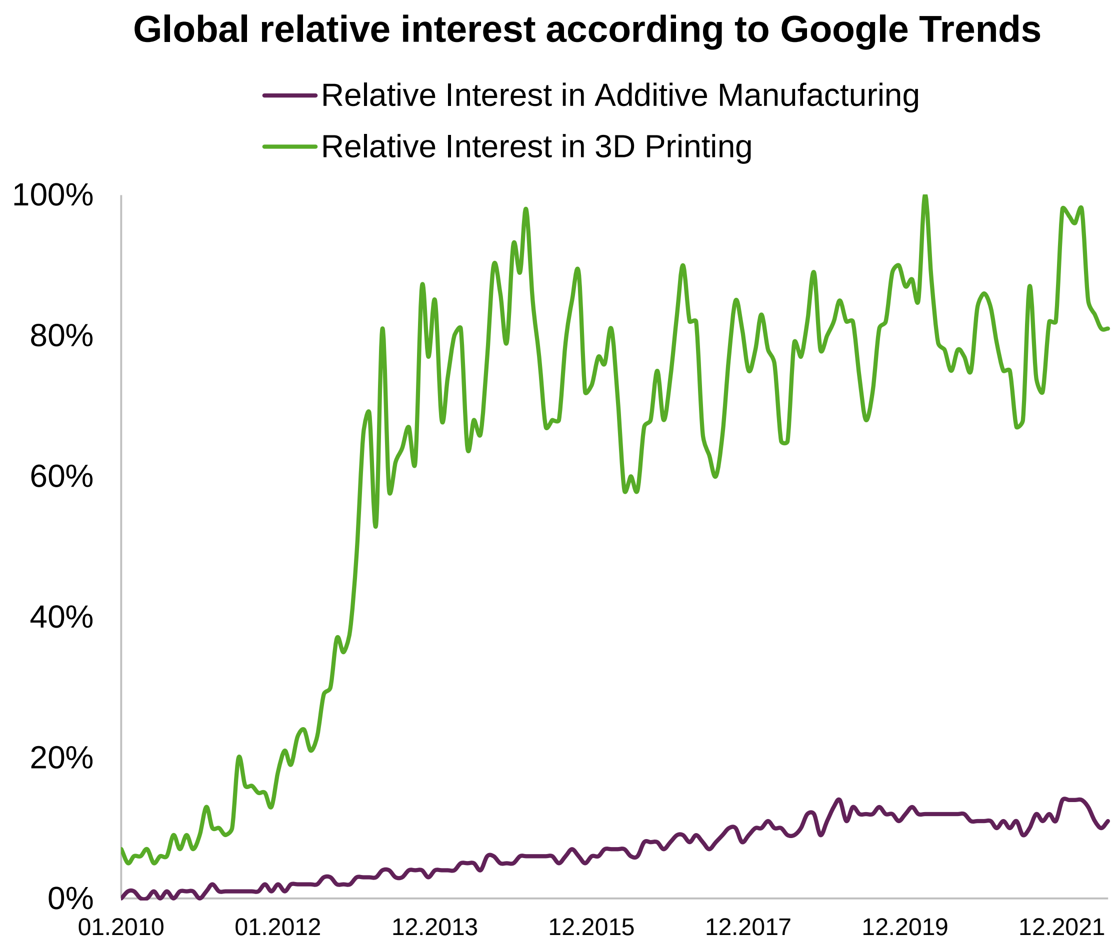
“Additive Manufacturing (AM) is defined as the process that
- ***produces components from 3D model** data*
- *by **joining material usually layer by layer**,*
- *as opposed to subtractive and formative manufacturing methods.”*



Definition (VDI 3405)

*“Manufacturing process in which the **workpiece is built up in successive layers or units**.”*

Introduction to AM
Global Interest on AM According to Google Trends



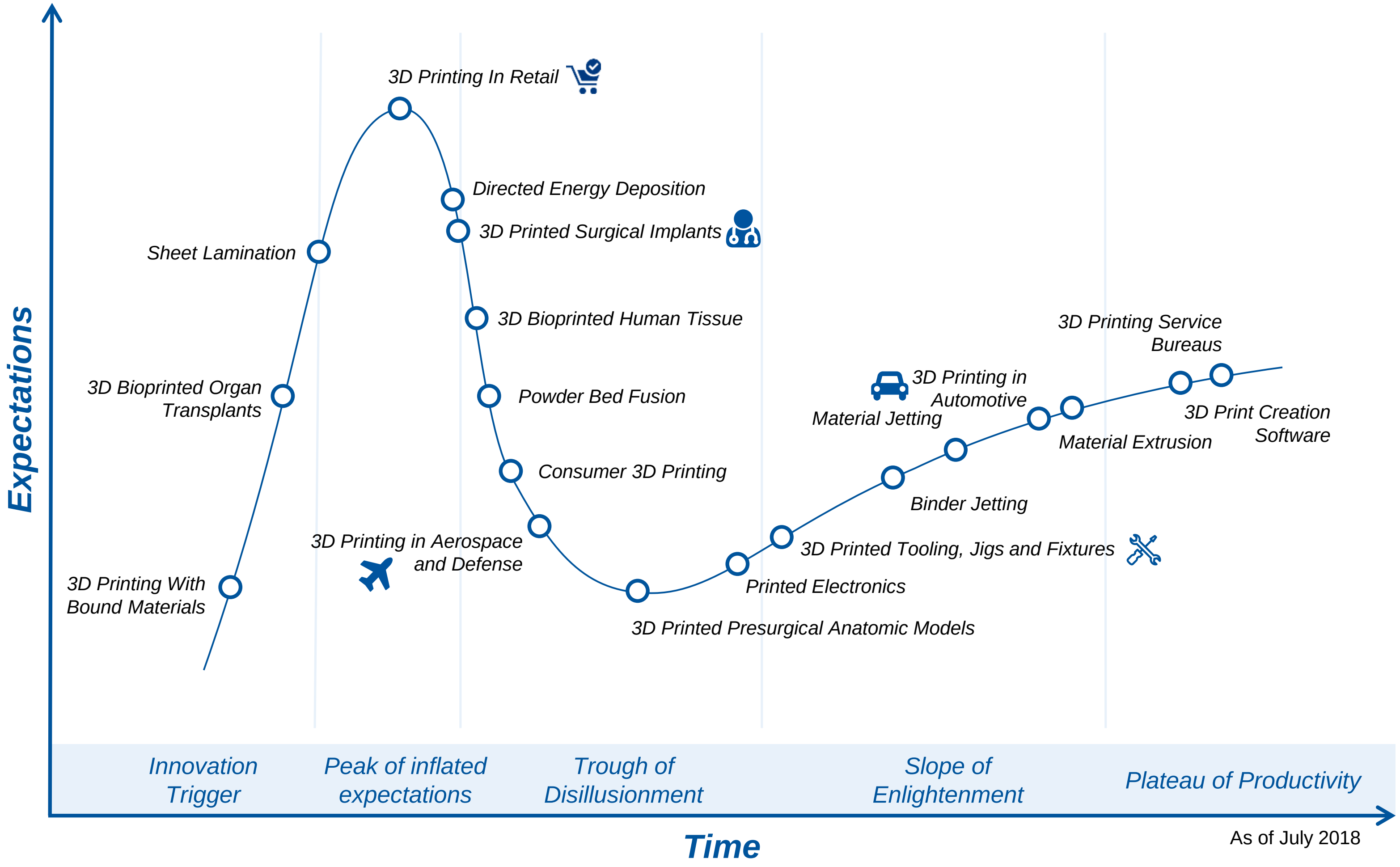
Source: Google Trends

- **Overall positive trend** of relative interest in AM and 3D printing in online search platforms
- **Lower interest in AM compared to 3D printing** because **AM** is the **more scientific term**
- **Strong increase (hype) until 2013/2014** of the search term **3D printing**

"3D Printing has the potential to revolutionize the way we make almost everything"

Barack Obama, State of the Union, Feb 2013

AM – Overrated Hype or Manufacturing Revolution?

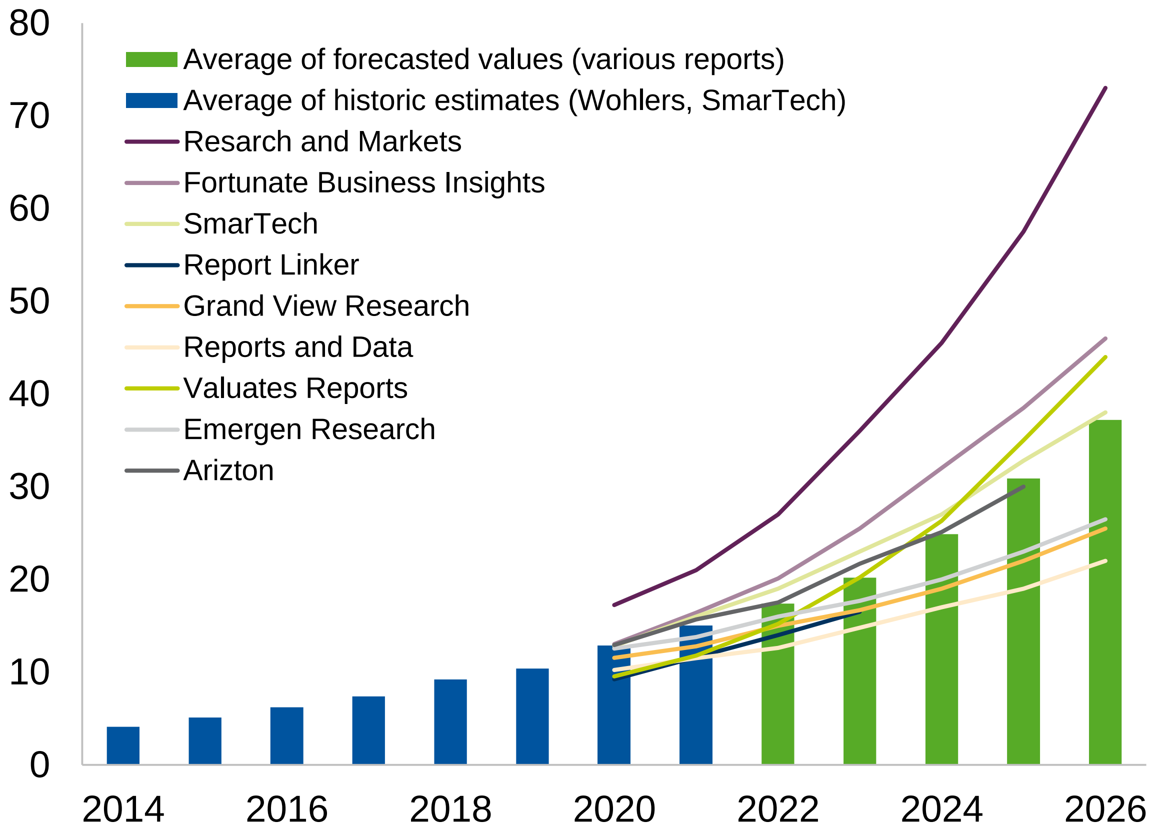


- *2015-2016*: Adoption of metal AM in high-tech industries
- *2016-2018*: Plastic AM for low-volume end-part production
- *Since 2018*: Widespread adoption of low-volume end-part production
- *Since 2021*: Plastic AM established for series production

Source: Gartner Hype Cycle 2018, 3D Printing Trend Report Hubs 2022

Introduction to AM
Positive Historic and Future Development of the AM Market

Total AM market size according to different market reports [$ billion]

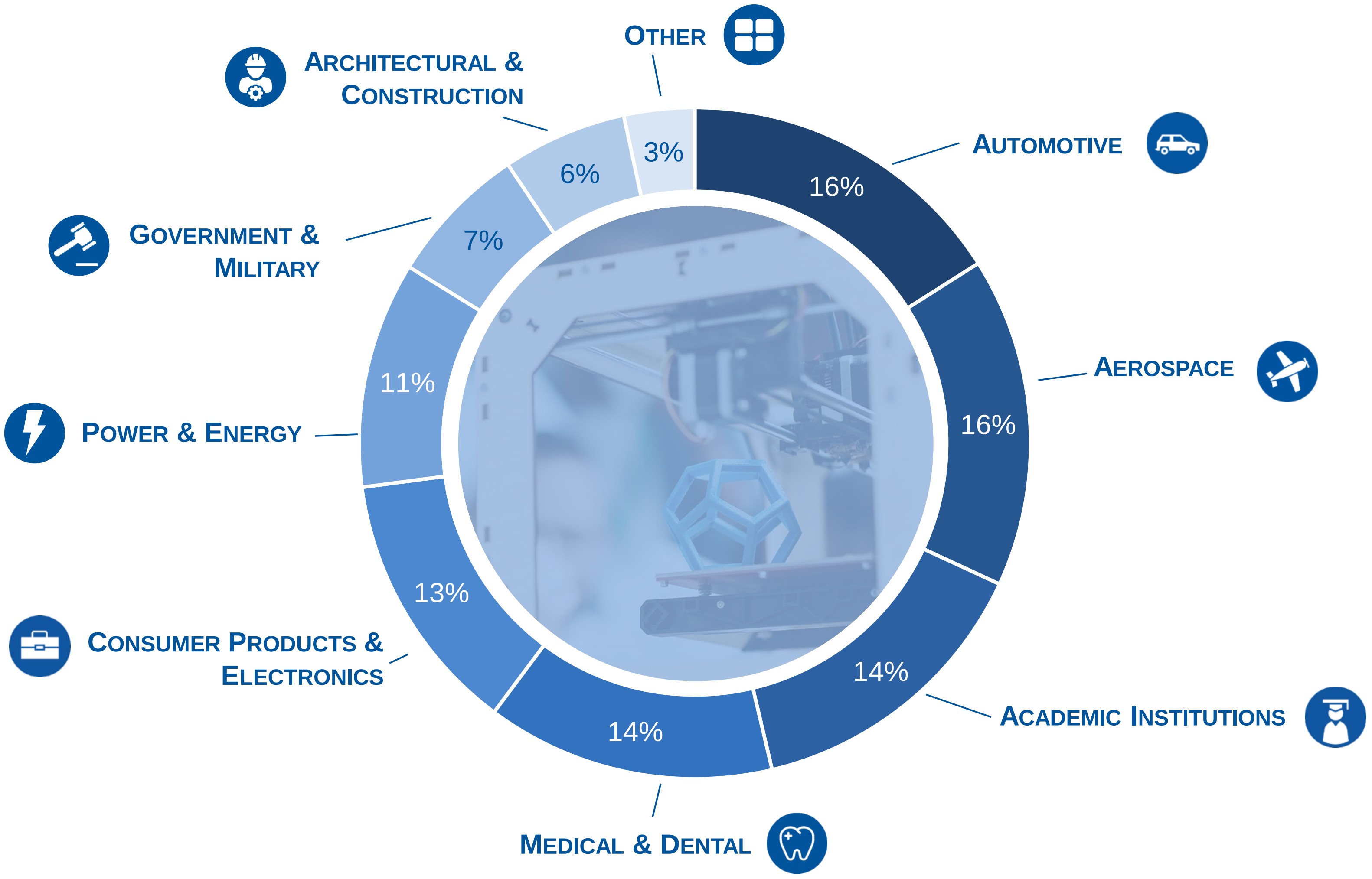


- **Overall positive** forecasted and historic growth rates in all reports
- **Diverging positive forecasts** indicate a **developing** volatile and uncertain market

- **Included revenue (primary market):**
  - AM systems
  - Software
  - Materials
  - Services

Source: Hubs Additive manufacturing trend report 2021 and cited sources

Introduction to AM
Market Overview



Source: Wohlers Report 2021

Introduction to AM
General AM Process Chain

	Pre-Processing	In-Processing	Post-Processing	Final Component
Physical Dimension	▪ Material preparation ▪ Production resource preparation ▪ Machine preparation	▪ Physical generation of geometry	▪ Build job removal and cleaning ▪ Part finishing – e.g., support removal, heat treatment, surface treatment, quality assurance	▪ Assembly ▪ Labelling, packaging, shipping
Digital Dimension	▪ Data preparation (CAD & CAM) ▪ Build job preparation ▪ Production planning	▪ Execution of machine code ▪ Printing process monitoring	▪ Acquisition and evaluation of quality assurance data	▪ Evaluation of data for long-term improvement

Key Characteristics of Additive Manufacturing

Additive


form-werkzeug.de

Geometry is generated by adding material instead of removing or forming

Toolless

Component geometry is independent from tool


Fraunhofer ILT


Aniwaa

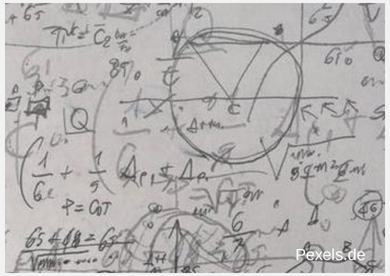
Digital


Pexels.de

Direct manufacturing based on 3D models

Complex

Different technologies require specific expert knowledge


Pexels.de

AM Benefits and Barriers

AM Benefits

- **Design freedom**: Complex features, lightweight, monolithic
- **Flexible design** iterations and engineering changes
- **Integration of functions**
- Economic **small quantities** and **individualization**
- **Short time** and efficiency **idea to product**
- **Short supply chain**
- **Insourcing:** Appealing for staff in industrialized countries & high degree of automation
- **Sustainability** by material reduction or efficiency in performance

AM Barriers

- **Long printing times**
- Almost **no economies of scale**
- **Low surface quality** as-built
- **Large geometrical tolerances** as-built
- **Requires** “Additive Mindset” and **skills**
- **Complex quality assurance** and **certification**
- **Health and security** measures required

AM **benefits and barriers** are **not generic –** consideration of use case, AM technology and process chain mandatory

Source: Unsplash, Pexels

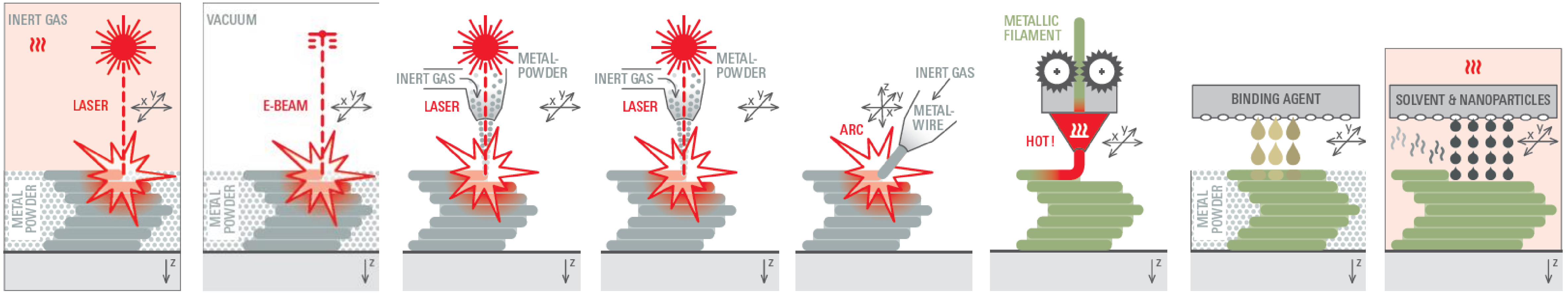
Basic AM Seminar – Content

AM Technology Overview
Segmentation of Established Metal AM Technologies

Additive Manufacturing

Metal

Powder Bed Fusion		*Direct Energy Deposition*			*Material Extrusion*	*Binder Jetting*	*Material Jetting*
Fused with laser	Fused with electron beam	Laser energy absorbed by substrate	Laser energy absorbed by powder feedstock	Fused with electric arc	With filament, green part to be sintered	Joined with bonding agent, to be sintered	Cured with heat, to be sintered
L-PBF Laser Powder Bed Fusion	**EBM** Electron Beam Melting	**LMD** Laser Metal Deposition	**EHLA** Extreme High Speed LMD	**WAAM** Wire Arc Additive Manufacturing	**Metal FDM** Metal Fused Deposition Modeling	**BJ** Binder Jetting	**NPF** Nano Particle Jetting



Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technology Overview
Segmentation of Established Metal AM Technologies

Additive Manufacturing

Metal

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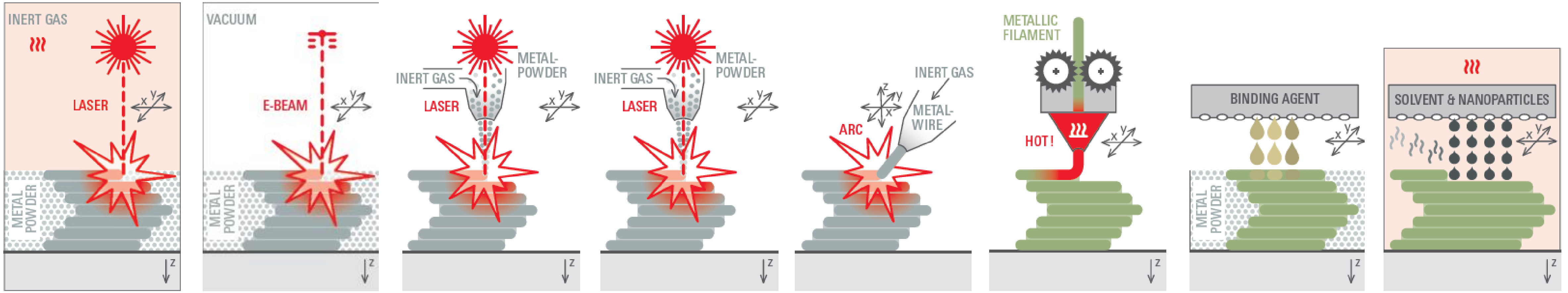
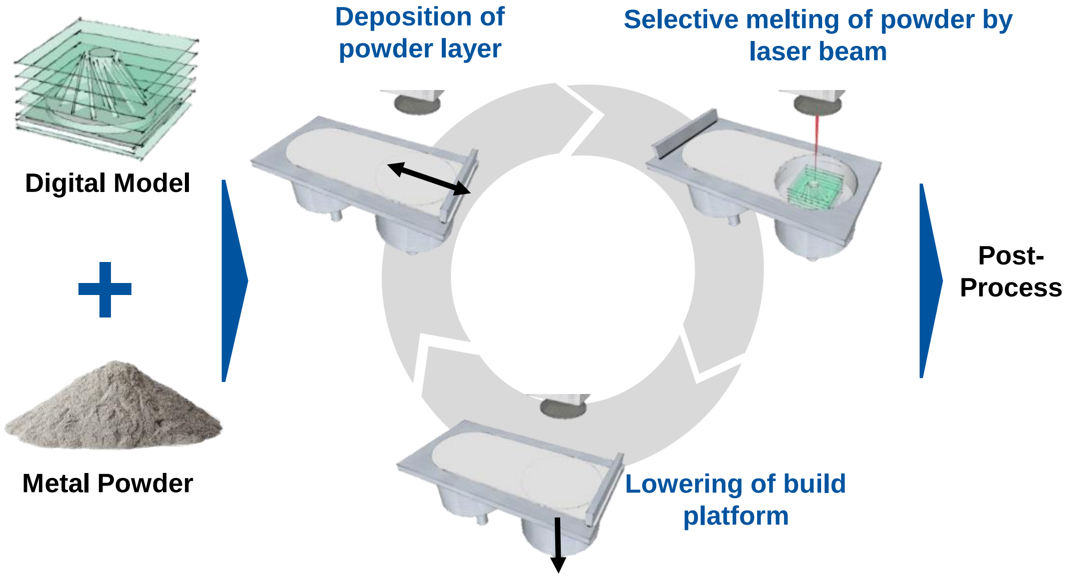
L-PBF Laser Powder Bed Fusion	**EBM** Electron Beam Melting	**LMD** Laser Metal Deposition	**EHLA** Extreme High Speed LMD	**WAAM** Wire Arc Additive Manufacturing	**Metal FDM** Metal Fused Deposition Modeling	**BJ** Binder Jetting	**NPF** Nano Particle Jetting



Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technologies
Laser Powder Bed Fusion of Metal (LPBF)

Process Principle

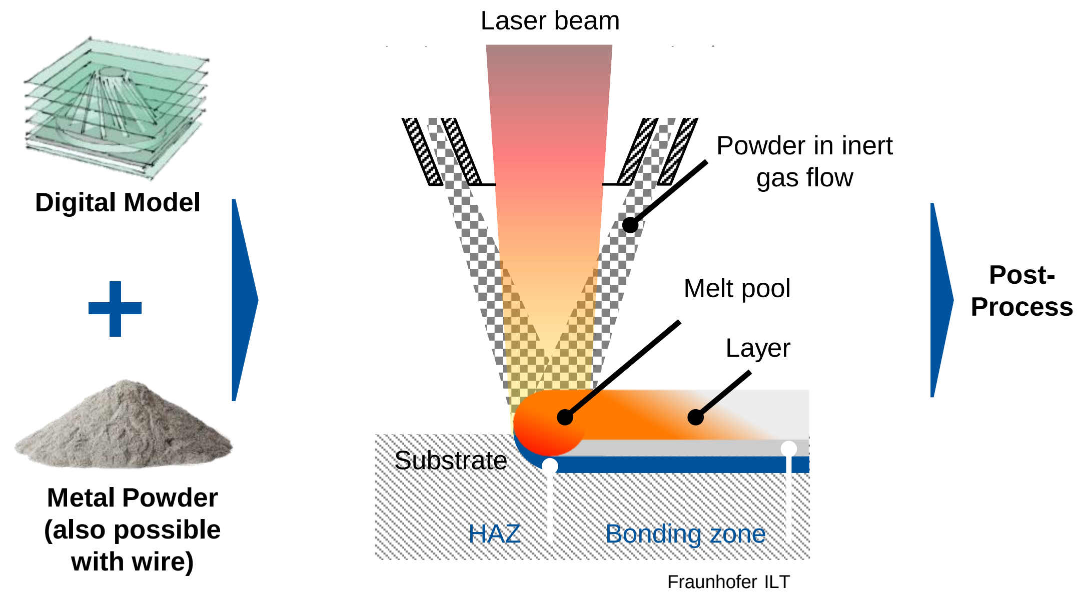


Process in Action

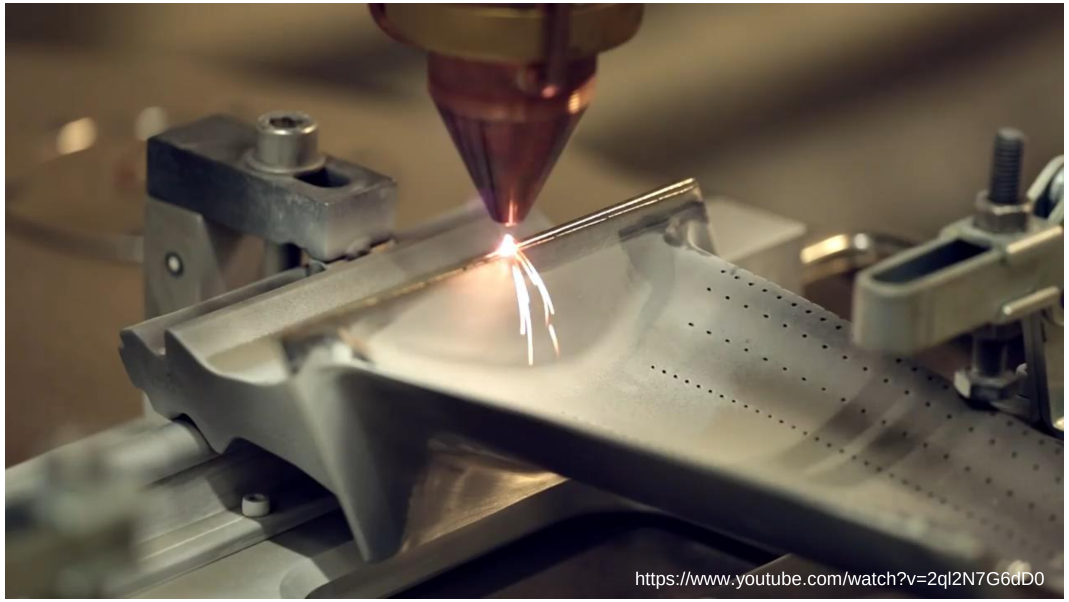
- Selective melting of metal powder layer-by-layer with one or more lasers
- Requires support structures for overhangs
- General suitability for weldable materials, comparably many alloys are qualified (e.g., steels, Ni base alloys, CoCr, copper and alloys, Ti and alloys, Al alloys, refractory metals, Mg alloys, HEA)

AM Technologies
Laser Metal Deposition (LMD)

Process Principle



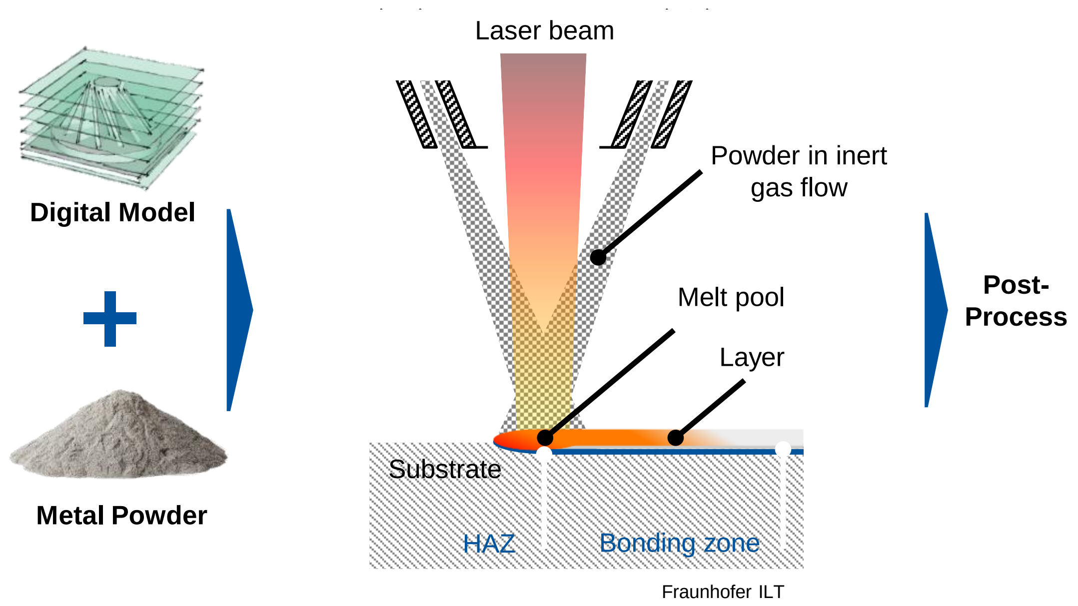
Process in Action



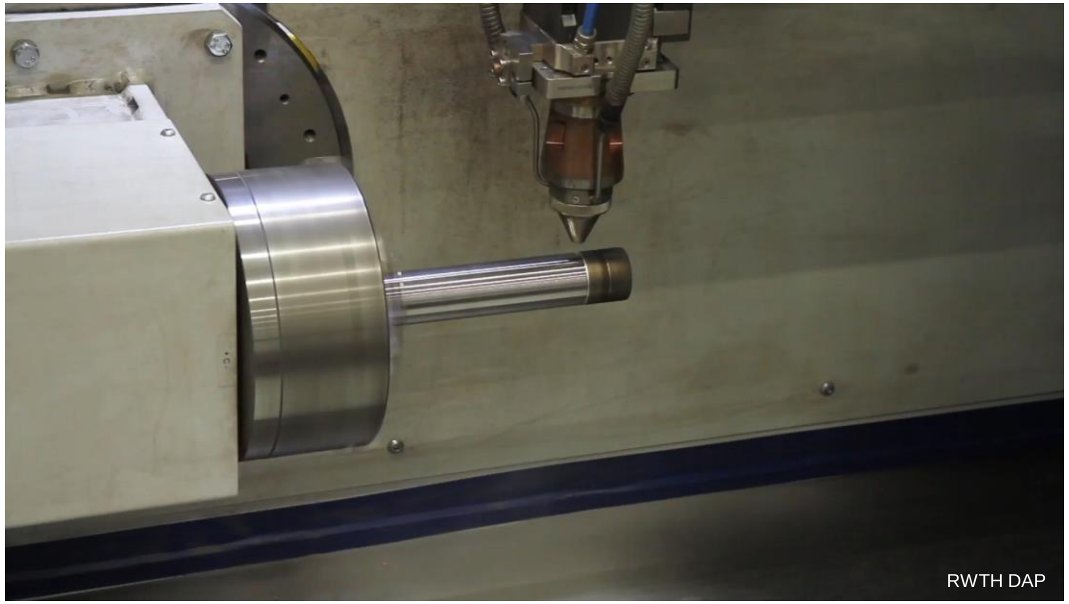
- Used for additive manufacturing, additive coating and repair (deposition on existing geometry)
- Powder is transported by an inert gas flow
- Energy for melting the metal powder is mainly deposited in the substrate, not directly in the powder
- General suitability for weldable materials, different materials qualified (e.g., steels, Ni-base alloys, Al alloys)

AM Technologies
Extreme High Speed Laser Metal Deposition (EHLA)

Process Principle



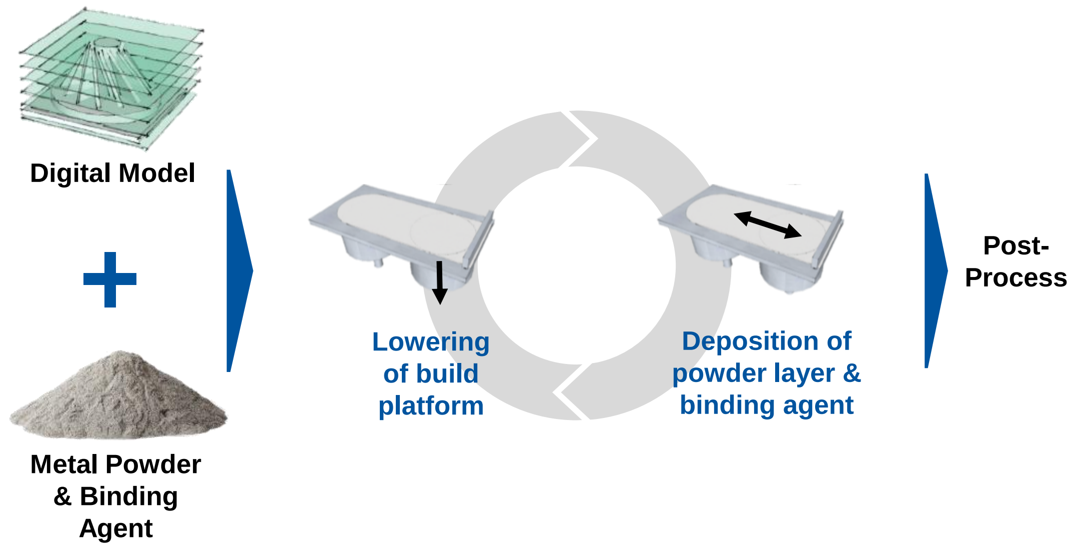
Process in Action



- Application of homogenous coatings on rotationally symmetrical parts with higher process speed than LMD
- Powder is transported by inert gas flow
- Energy is mainly deposited in the metal powder and not the substrate
- EHLA for AM of 3D parts is an emerging technology

AM Technologies
Binder Jetting (BJ)

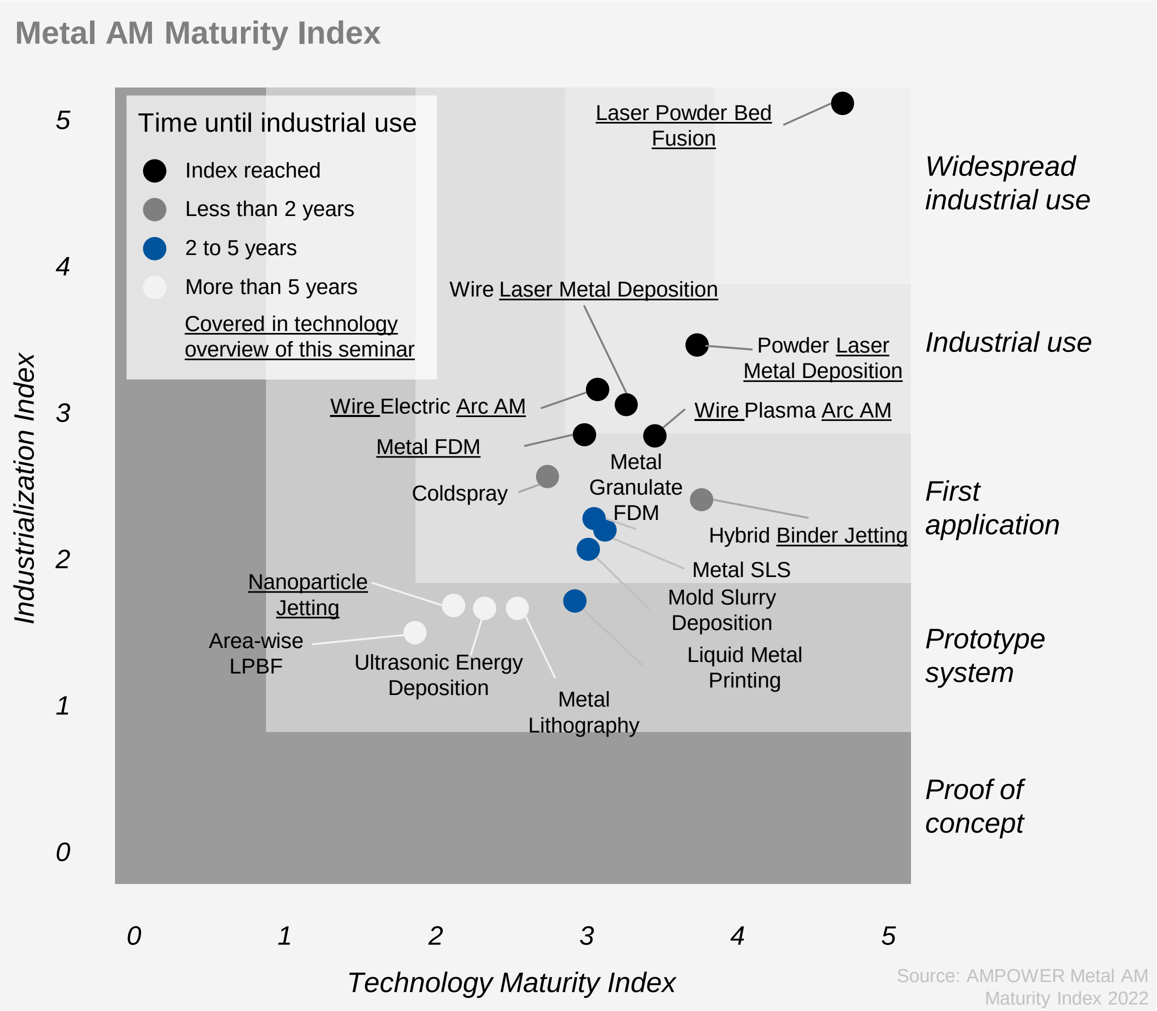
Process Principle



Process in Action

- Production of complex geometries by selective deposition of binder agent on metal powder layer by layer
- As-built part is in green state and requires further processing steps for functionality (e.g., curing, depowdering, sintering)
- Compared to LPBF lower technological maturity and less materials qualified, but potential of higher productivity

AM Technology Overview
Technology Readiness – Metal AM Maturity Index



- Twenty different work principles
- Over 194 OEMs supplying machines
- LPBF only technology widespread established in industrial use
- 7 technologies with index reached
- Many technologies as first application and prototype system

AM Technology Overview
Available Metal Materials

Precious Materials
- Mainly gold and silver material for jewelry applications

Nickel-Based
- Corrosion-resistant
- High mechanical strength
- Hardening possible

Copper Alloys
- High heat conductivity
- Low absorption of laser radiation

Cobalt-Based
- High strength & hardness
- Temperature-resistant
- Corrosion-resistant

Stainless Steel
- High ductility
- Corrosion-resistant
- Easy to post-process

Titanium Alloys
- Lightweight, high strength per density
- Corrosion-resistant

Tool Steel
- High ductility
- Corrosion-resistant
- Easy to post-process

Aluminum Alloys
- Lightweight
- Low material density
- Suitable for casting

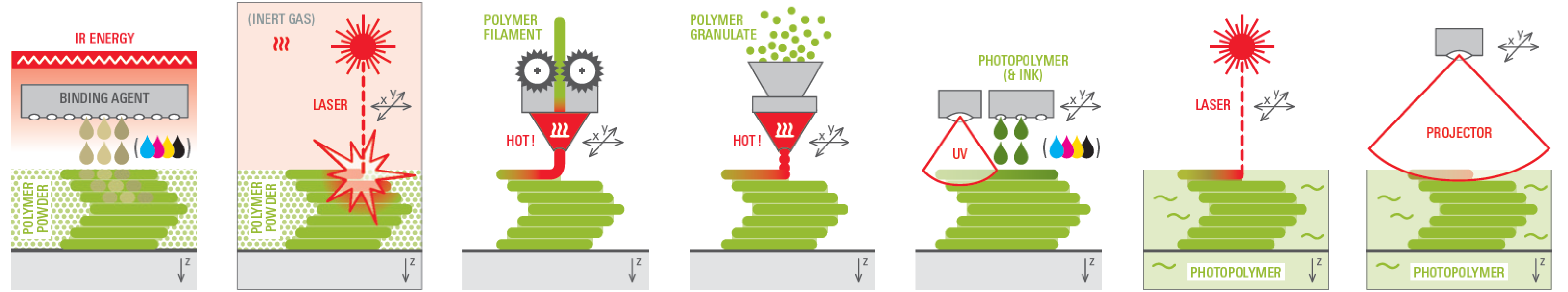
Source: BCG (2019)

AM Technology Overview
Segmentation of Established Polymer AM Technologies

Additive Manufacturing

Polymer

Powder Bed Fusion		*Material Extrusion*		*Material Jetting*	*Photopolymerization of Resins*	
Fused with agent + energy	Fused with laser	With filament	With granulate	Cured with UV light	Cured with laser	Cured with projector
MJF Multi Jet Fusion	**SLS** Selective Laser Sintering	**FDM** Fused Deposition Modeling	**Granulate FDM**	**MJ** Material Jetting	**SLA** Stereo Lithography	**DLP** Digital Light Processing



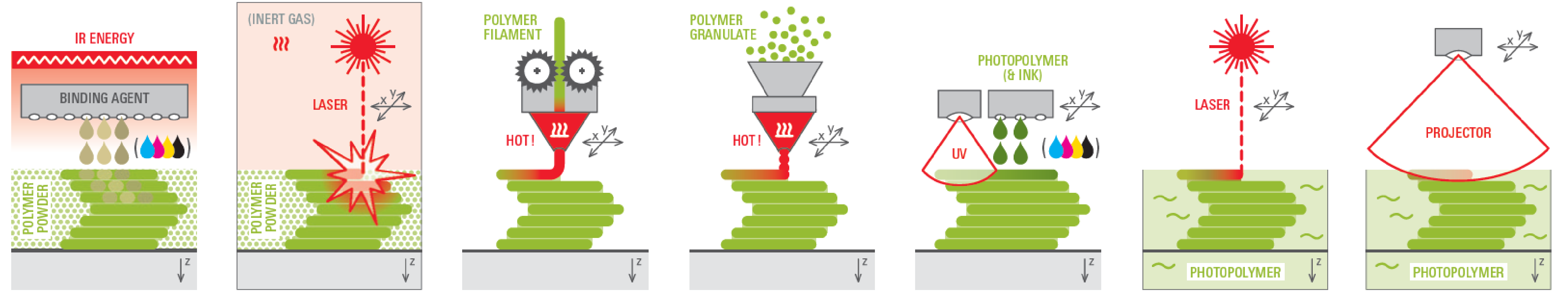
Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

AM Technology Overview
Segmentation of Established Polymer AM Technologies

Additive Manufacturing

Polymer

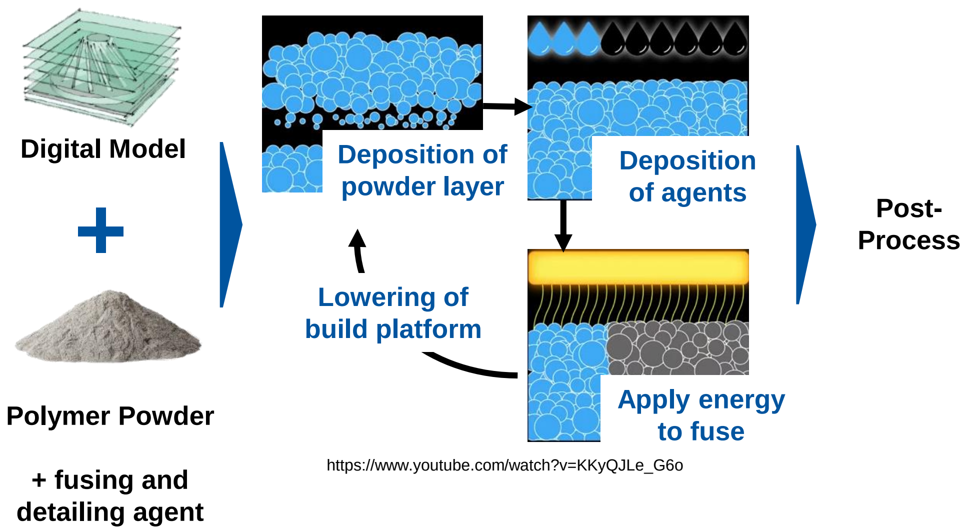
- ***Powder Bed Fusion***
  - Fused with agent + energy → **MJF** Multi Jet Fusion
  - Fused with laser → **SLS** Selective Laser Sintering
- ***Material Extrusion***
  - With filament → **FDM** Fused Deposition Modeling
  - With granulate → **Granulate FDM**
- ***Material Jetting***
  - Cured with UV light → **MJ** Material Jetting
- ***Photopolymerization of Resins***
  - Cured with laser → **SLA** Stereo Lithography
  - Cured with projector → **DLP** Digital Light Processing



Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

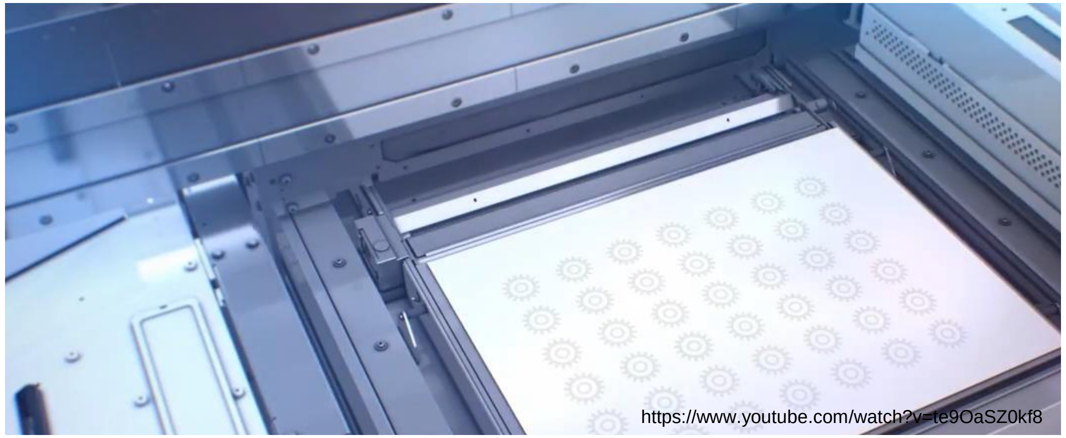
AM Technologies
Multi Jet Fusion (MJF)

Process Principle



https://www.youtube.com/watch?v=KKyQJLe_G6o

Process in Action

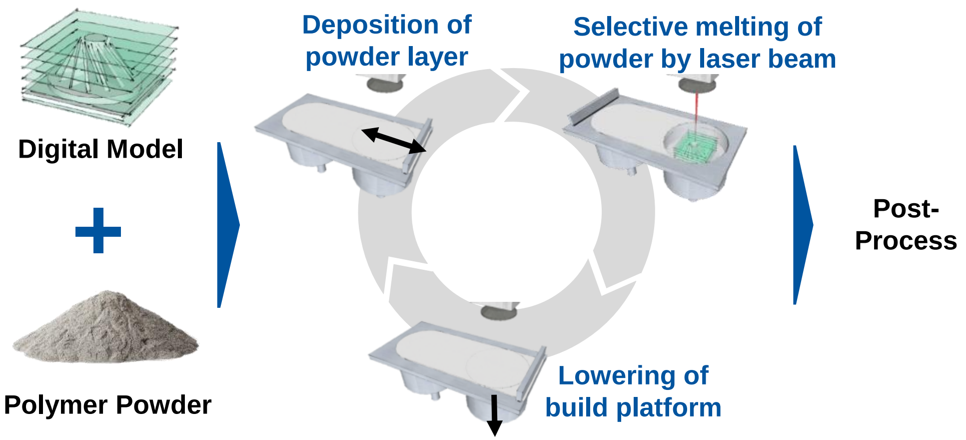


https://www.youtube.com/watch?v=te9OaSZ0kf8

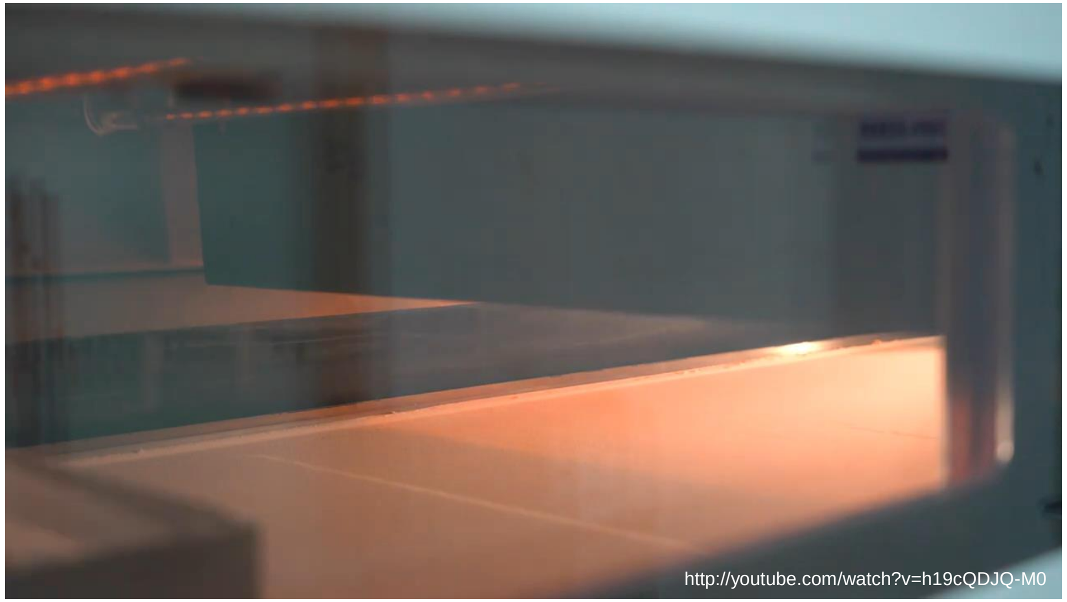
- Layer-by-layer application of material applied to powder in build chamber
- Introduction of liquid binder by inkjet print heads to bond powder particles together
- Energy input (curing) through UV lamps

AM Technologies
Selective Laser Sintering (SLS)

Process Principle



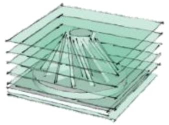
Process in Action



- Production of complex geometries by selective melting of polymer powder with one or more lasers
- As-built parts are usually white (polymer color)
- Many different materials available (e.g., PA11, PA12, TPU, PEEK, TPE, PP)

AM Technologies
Fused Deposition Modeling (FDM)

Process Principle



Digital Model

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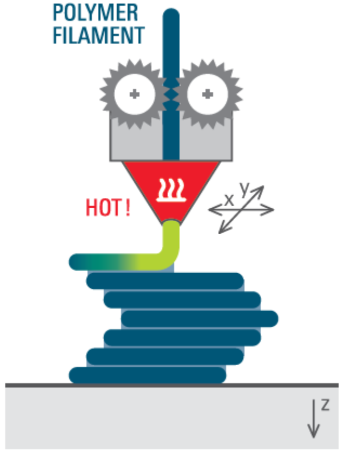
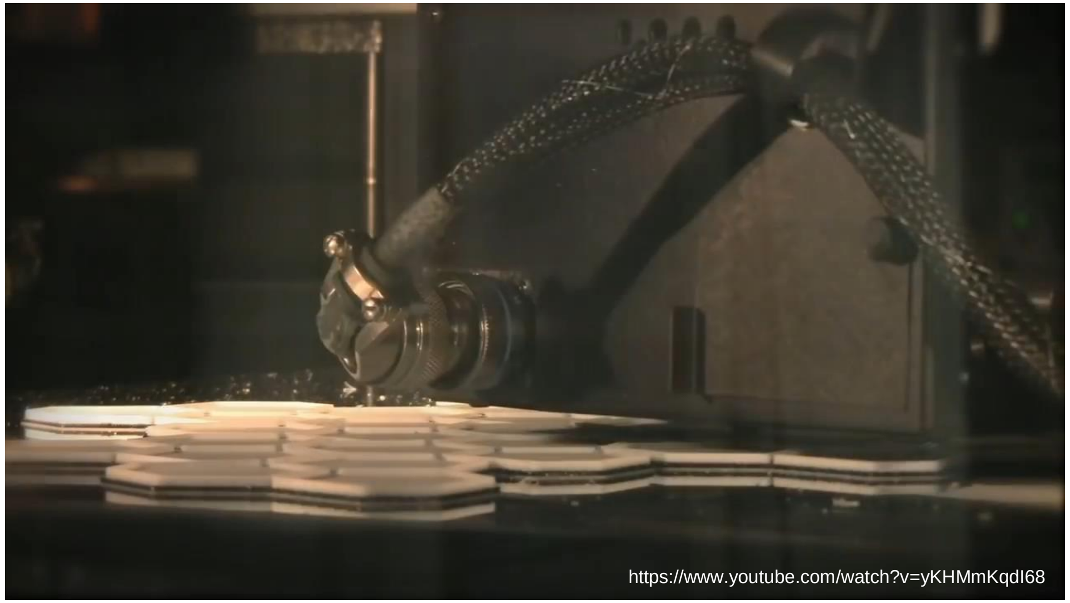
Thermoplastic filament



Post-Process

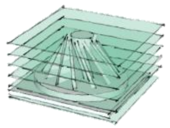
Process in Action



- Thermoplastic filament is molten and extruded through a hot nozzle
- Support structures are required for overhangs
- Use in industry, but also huge open source and DIY community
- Many materials available (e.g, PLA, ABS, PP, PA, PC, TPE, TPC, TPU, PEEK, PEKK, PPSU, PEI)

AM Technologies
Stereolithography (SLA)

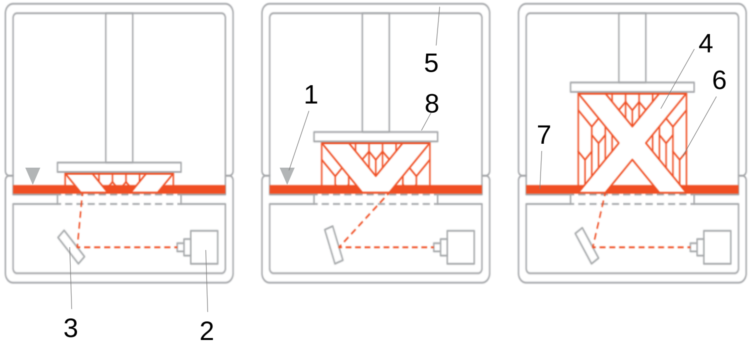
Process Principle



Digital Model

+

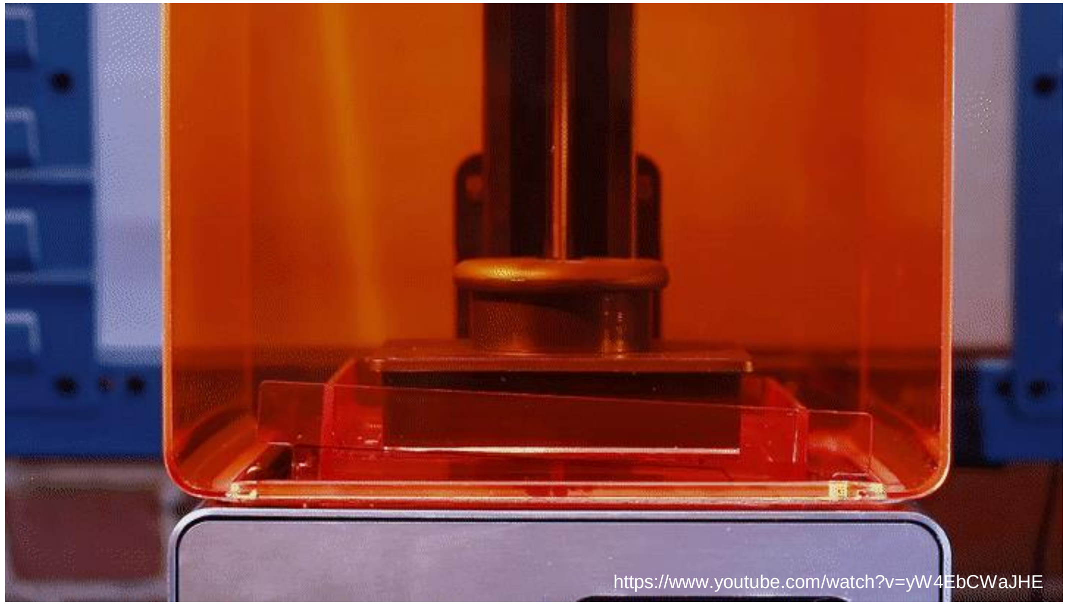
Photo-reactive resin



1. Surface of polymer bath
2. Laser
3. X-Y-scanner
4. Generated part
5. Housing
6. Support structure
7. Polymer batch
8. Build platform

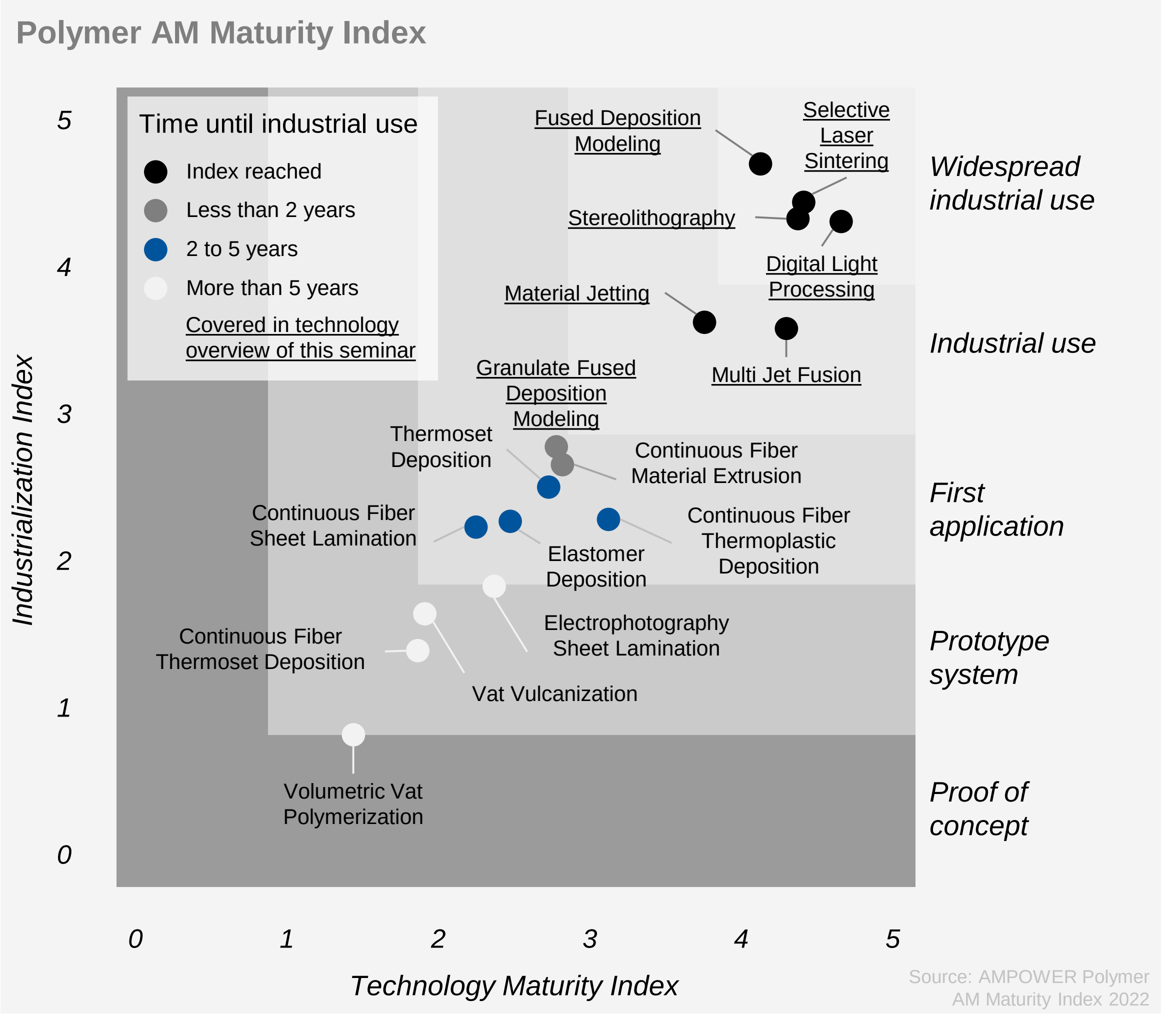
Post-Process

Process in Action



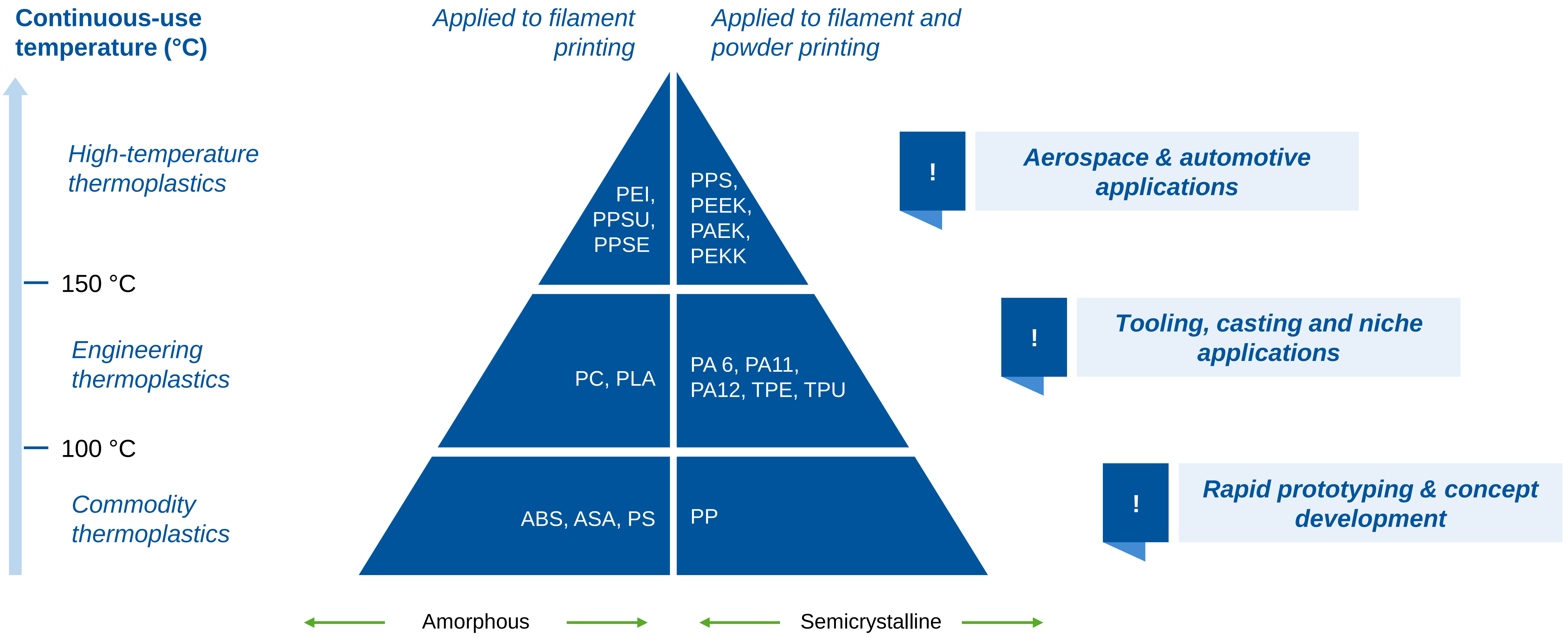
- Polymerization of photo-reactive resin by selective scanning with a UV laser beam (usually through transparent container from below)
- Requires support structures for overhangs
- Wide range of photo-reactive resins with different optical, thermal and mechanical properties

AM Technology Overview
Technology Readiness – Polymer AM Maturity Index



- Sixteen different work principles
- Over 240 vendors supplying industrial machines
- SLS, FDM, SLA and DLP with widespread industrial use
- 6 technologies with index reached
- Many technologies as first application and prototype system

AM Technology Overview
Available Polymer Materials

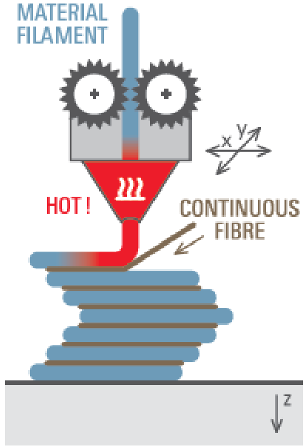


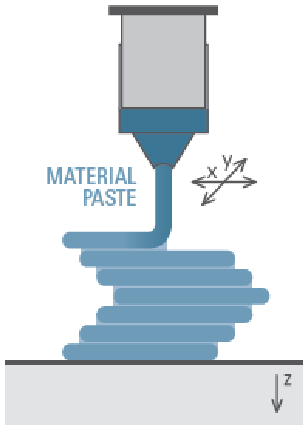
Source: 3DMaker Engineering, RapidMade, EOS, BigRep

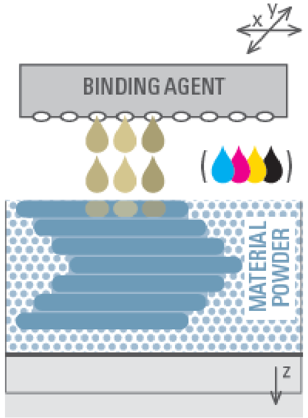
AM Technology Overview
Segmentation of Other AM Technologies

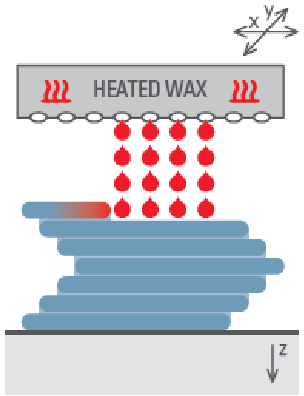
Additive Manufacturing

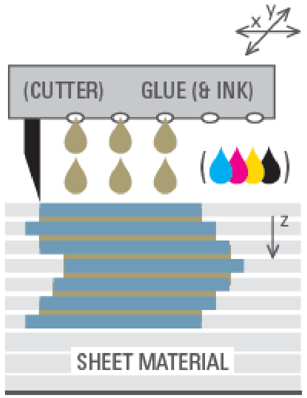
Reinforced polymer fibers	Any material paste	Sand or gypsum	Wax	Composite or paper
Material Extrusion		***Binder Jetting***	***Material Jetting***	***Sheet Lamination***
Material extrusion of **composite**	Paste extrusion of **any material**	Joined **sand or gypsum** with bonding agent,	Selective application of **wax** droplets	Cured with projector
CFF Continuous Filament Fabrication	**PEM** Paste Extrusion Modeling	**BJ** Binder Jetting	**DOD** Drop on Demand	**SDL / LOM** Selective Deposition Lamination / Laminated Object Manufacturing







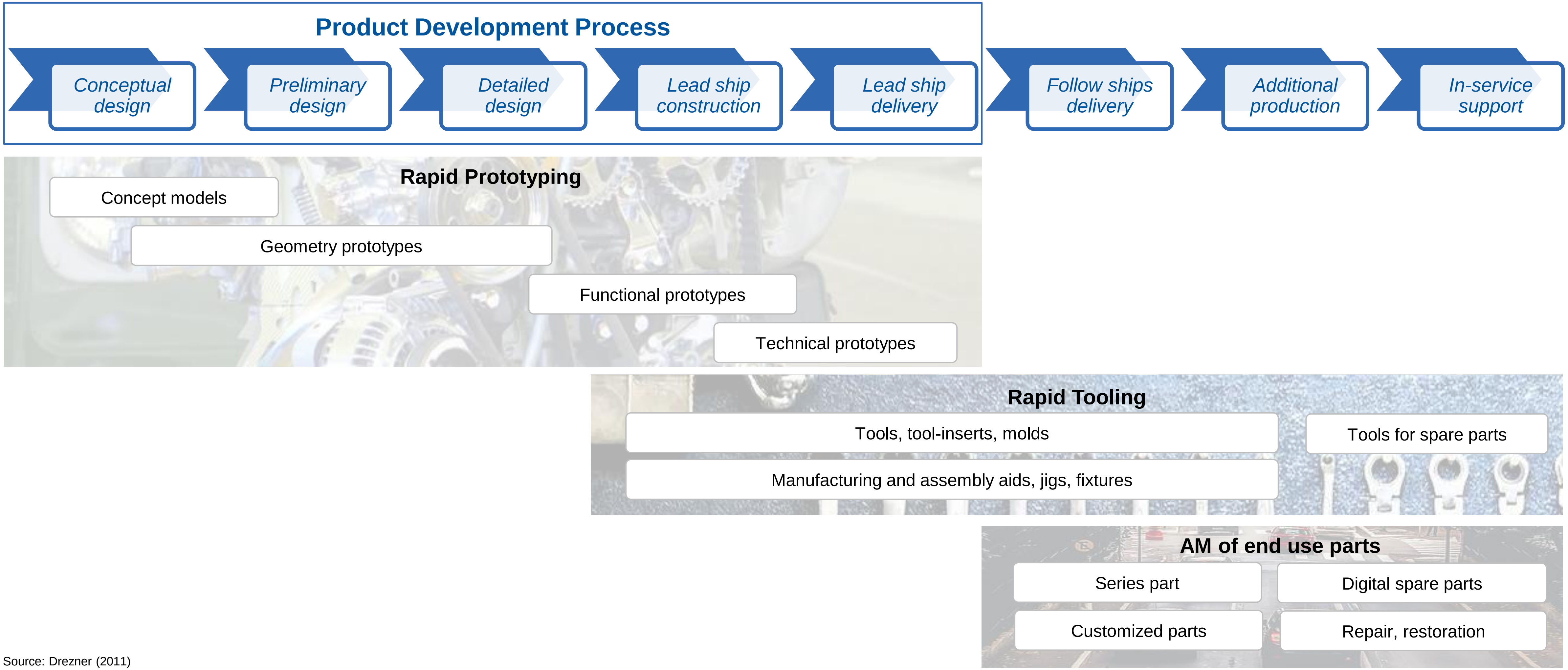




Source: Derived from Fomrnnext AM Field Guide Compact and DIN EN ISO/ASTM Terminology

Basic AM Seminar – Content

AM Application Examples
Fields of Application Along the Ship Development Process

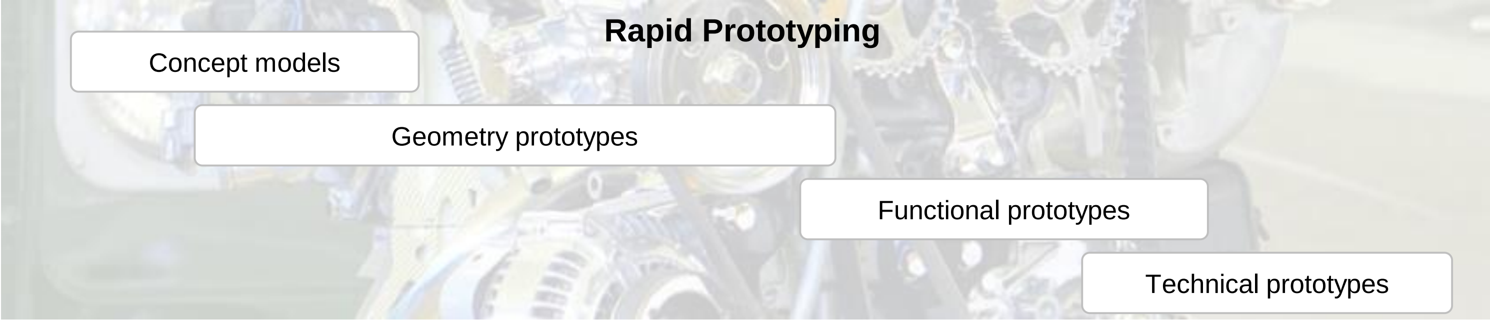


Source: Drezner (2011)

AM Application Examples
Fields of Application Along the Ship Development Process

Product Development Process

Conceptual design → Preliminary design → Detailed design → Lead ship construction → Lead ship delivery → Follow ships delivery → Additional production → In-service support



Source: Drezner (2011)

AM Application Examples
Geometry Prototype – Aiming at a Real-Size Replica

Characteristics

- Usage of AM technologies in prototyping processes of traditional sailing yacht designs
- Mechanical and design improvement with updated prototypes
- Goal: Continuous scaling until a real 1:1 prototype can be manufactured
- AM technology: Material extrusion

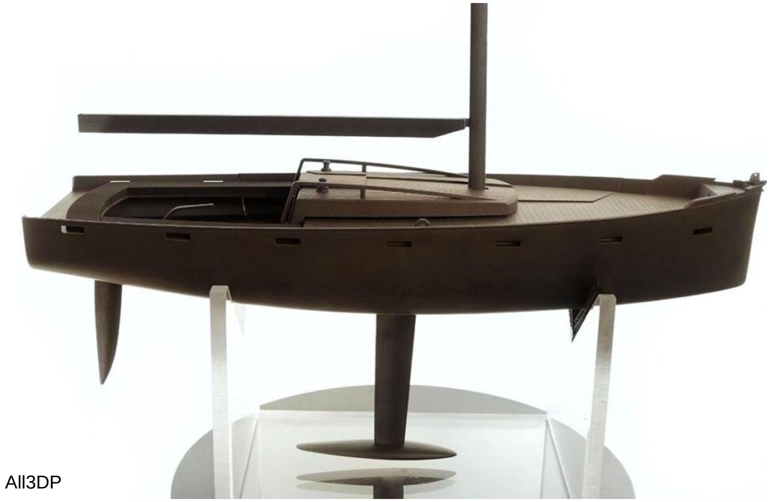
Utilized AM Benefits

- Flexible design iterations and engineering changes
- Short time and efficiency from improvement to product
- Economic small quantities compared to real scale prototypes

All3DP


Winform

All3DP


All3DP

Source: https://all3dp.com/3d-printing-will-change-way-sail/, Sener (2019)

AM Application Examples
Functional Prototype – Hybrid Manufacturing of Large-Scale Parts

Characteristics

- Triple-blade “WAAMpeller” (1,350 mm diameter propeller)
- Goal: Spare-part supply
- AM technology: WAAM, material: Nickel Aluminum Bronze (NAB)
- Application type: Prototype

Utilized AM Benefits

- Facilitation of extensive material testing and analysis to match material properties with specific application
- Optimization of part design according to application
- Speeding up of product development process and optimization of process parameters


Vogel

Valkwending


3DPrint

3DNatives

Source: https://www.bairdmaritime.com/work-boat-world/prototype-3d-printed-propeller-unveiled-in-rotterdam/, Sener (2019)

AM Application Examples
Fields of Application Along the Ship Development Process

Product Development Process

Conceptual design → *Preliminary design* → *Detailed design* → *Lead ship construction* → *Lead ship delivery* → *Follow ships delivery* → *Additional production* → *In-service support*

Rapid Tooling

- Tools, tool-inserts, molds
- Manufacturing and assembly aids, jigs, fixtures
- Tools for spare parts

Source: Drezner (2011)

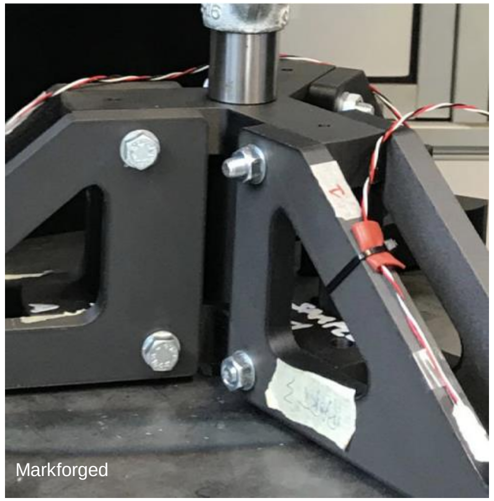
AM Application Examples
Manufacturing and Assembly Aids – Lifting Tool

Characteristics

- 3D printed device to carry the assembly of a cylinder liner with piston and connecting rod
- Steel tools expensive, time-intensive to manufacture and heavy to use and transport
- AM technology: Fused Filament Fabrication (continuous carbon fiber reinforcement)
- Application type: Tool

Utilized AM Benefits

- Economic small quantities
- Reduction of production time
- Demand-driven manufacturing
- Weight reduction by 75% while maintaining load capacity



Source: Markforged, Ziolkowski and Dyl (2020)

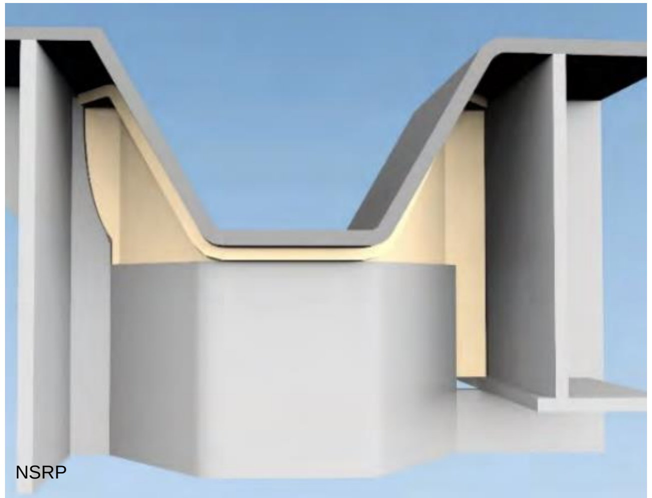
AM Application Examples
Rapid Tooling – Jig for Joint Connection

Characteristics

- T-AO Expansion Joint Connection is pivotal to the ship's operation and difficult to envision how it ties into surrounding structure
- 3D printed part used to help with its installation
- AM technology: Stereolithography
- Application type: Jig

Utilized AM Benefits

- Shorter installation time
- Shortening of product development process
- Economic small quantities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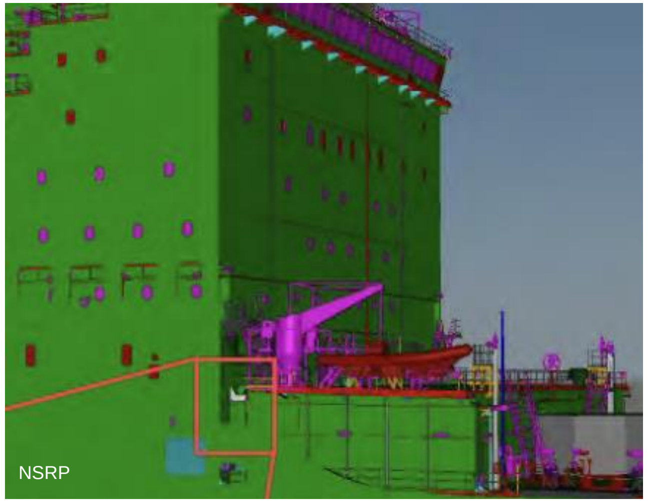
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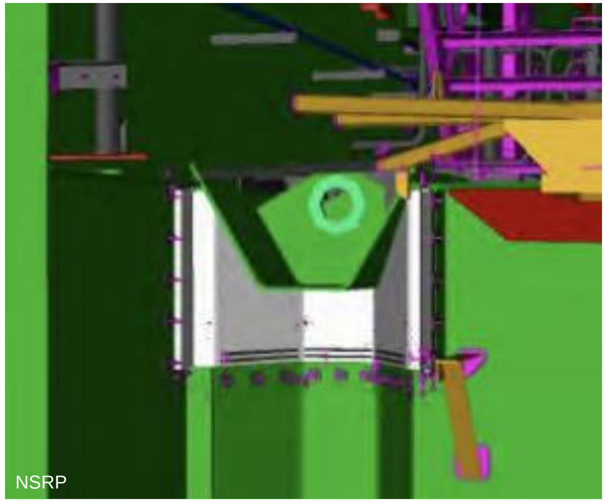

NSRP


NSRP

Source: NSRP

AM Application Examples
Fields of Application Along the Ship Development Process

Product Development Process

Conceptual design → *Preliminary design* → *Detailed design* → *Lead ship construction* → *Lead ship delivery* → *Follow ships delivery* → *Additional production* → *In-service support*

AM of end use parts

Series part	Digital spare parts
Customized parts	Repair, restoration

Source: Drezner (2011)

AM Application Examples
(On-Board) Spare Parts Manufacturing

Characteristics

- Spare parts are manufactured on-board, stored nearby or transported to the ship when requested
- Metal and polymer AM according to required part
- Example parts e.g., scupper plugs used to close drainage holes to prevent oil or contaminant spills

Utilized AM Benefits

- Cost reduction due to elimination of shipping
- Reduction of inventory – demand-oriented supply
- Reduction of down times (short duration between identification of part and physical replacement)

3DPrintingIndustry

US Navy

OICPrecision

Source: http://rwappleton.com/3Dprinting.pdf

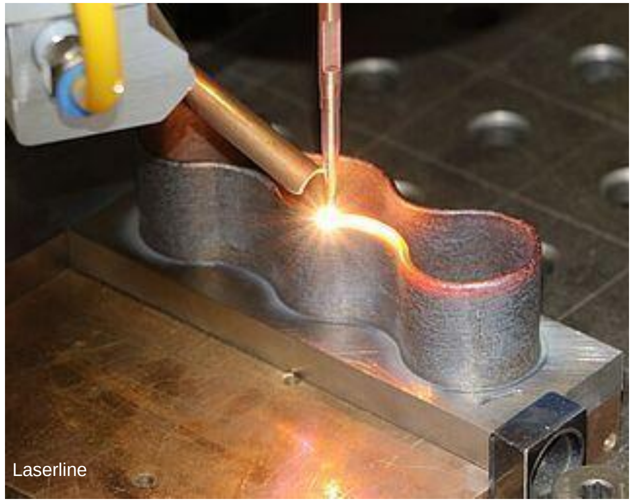
AM Application Examples
On-Site Repair

Characteristics

- Ships usually last much longer than planes or cars
- Obsolescence of parts and retiring of their ways of manufacturing increases the costs for repair
- AM enables on-site repairs
- AM technology: Metal cladding or cold spray (rebuild of worn or damaged surfaces)

Utilized AM Benefits

- Safety improvement through faster replacement of damaged parts
- All levels of complexity and increasing size parameters
- Reduction of downtime
- Cost decrease due to part repair instead of part change



Laserline

Creaform3D

Source: Greenship, Ziolkowski and Dyl (2020)

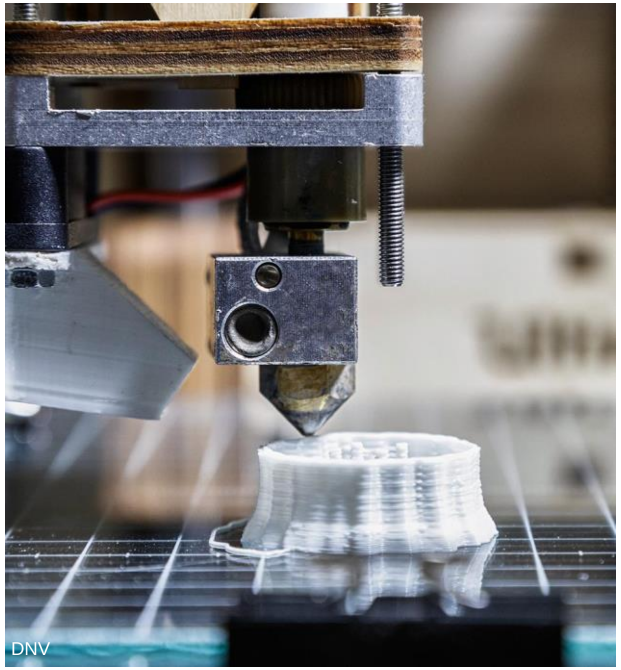
AM Application Examples
Customization of Interior Components

Characteristics

- Customization of interior design adapted to individual customers' needs
- AM to enable economic manufacturing of small quantities
- AM technologies: Multiple technologies
- Application type: Customized part

Utilized AM Benefits

- Economic small quantities
- Realization of complex geometries and function integration
- Facilitates responsiveness to customer needs
- Decrease of production cost of exclusive products


DNV


Yc.com


Superyachtstories

Source: https://greenship.org/wp-content/uploads/2017/01/The-maritime-opportunity-space-of-3D-print.pdf

Basic AM Seminar – Content

Successful Adaption of AM
Benefits Through an “Additive Mindset“

Comparing Apples with Oranges…

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

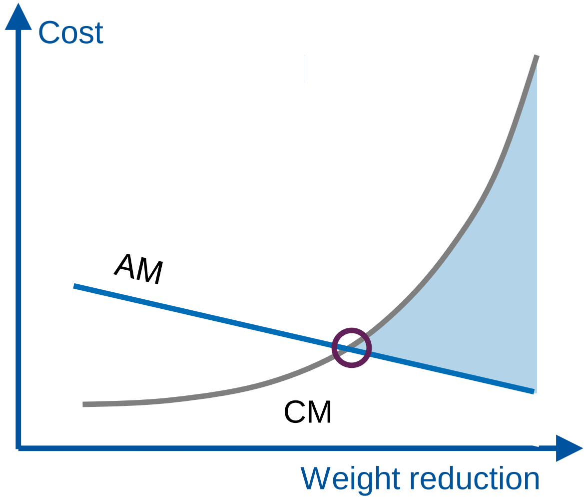
…Additive Manufacturing is different

- **Different cost structure:** High upfront investment costs and high material prices, but not driven by economies of scale
- **Financial return** and **technological feasibility** must be considered in **identification of parts with positive business case**
- Enables **new business models** such as mass customization or digital warehousing
- **Products and required expertise** along the product life cycle are different (e.g. Design for Additive Manufacturing)
- Some AM technologies require complex **health & security measures**

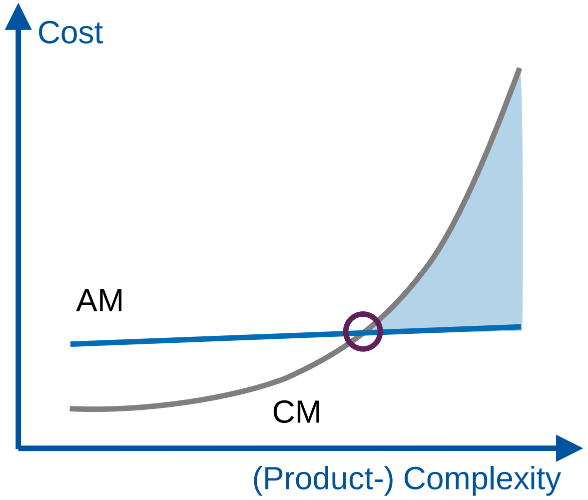
Source: Effectory, TCT

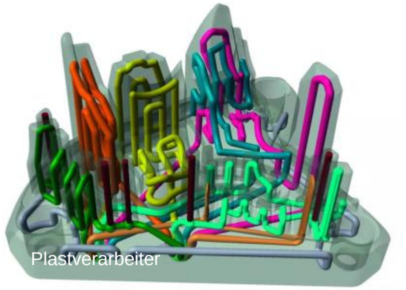
Successful Adaption of AM
Different Cost Structure of Conventional Manufacturing (CM) and AM

Weight reduction means cost reduction

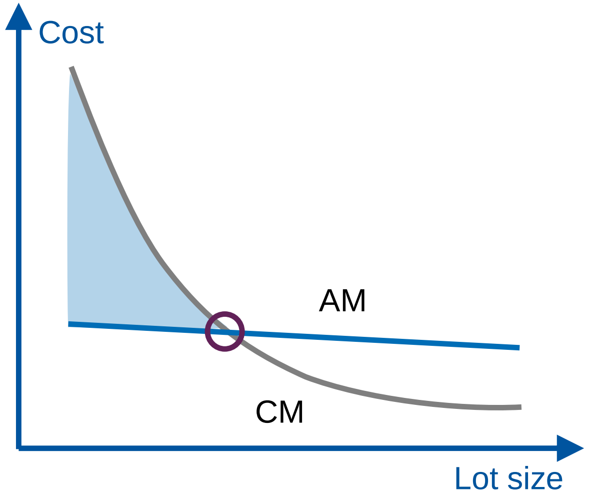


Complexity (almost) for free





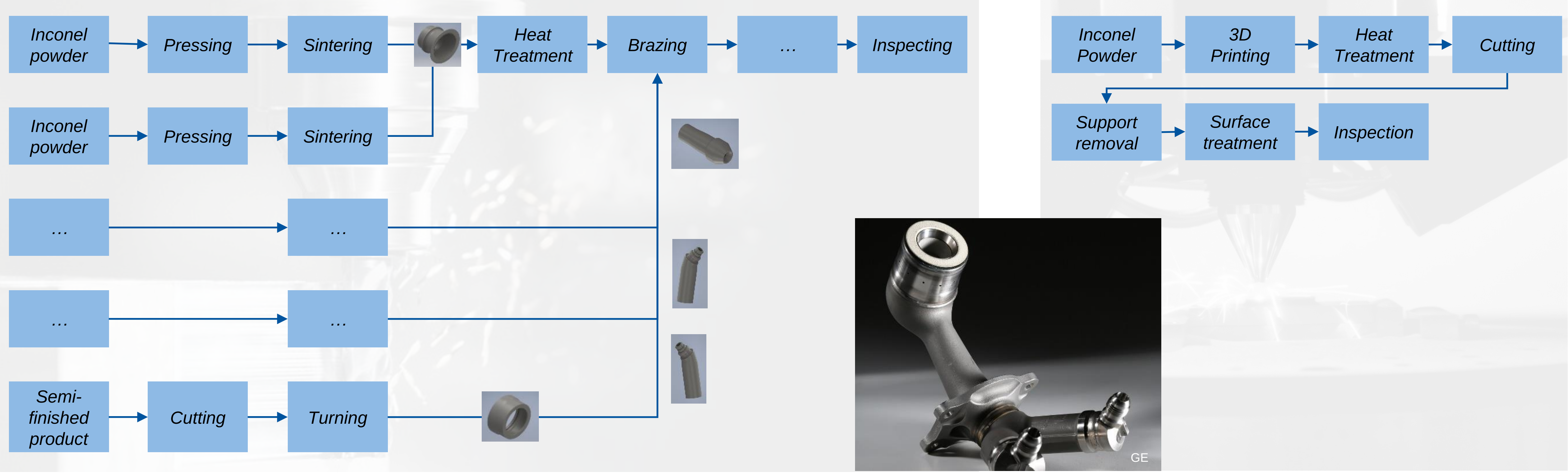
Individualization (almost) for free



Successful Adaption of AM
Different Process Chains Result in Different Manufacturing Cost Structure

Conventional process chain

Additive process chain



Additive Manufacturing allows to transfer process chain complexity to part design (e.g. through part consolidation)

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Source: Effectory, TCT

Successful Adaption of AM
Benefits Through an "Additive Mindset"

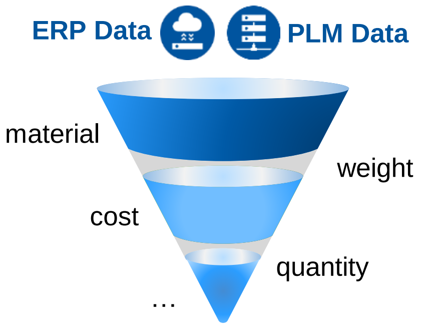
Part identification process

- *Preliminary Selection*
- *Financial Assessment*
- *Technological Assessment*
- *Implementation*

Preliminary selection with search- and culture-based approach

Search-based (top-down)

*Uses **PLM database** with defined **filter criteria to identify** potential parts in a **semi-automated manner.***



AM candidates

Quick wins considering a **huge data base** to **increase stakeholder support**

Stronger engagement on the long term with **better integration of DfAM**

***Training** of employees for **wider** identification of opportunities with AM and for an **additive mindset**.*

Culture-based (bottom-up)

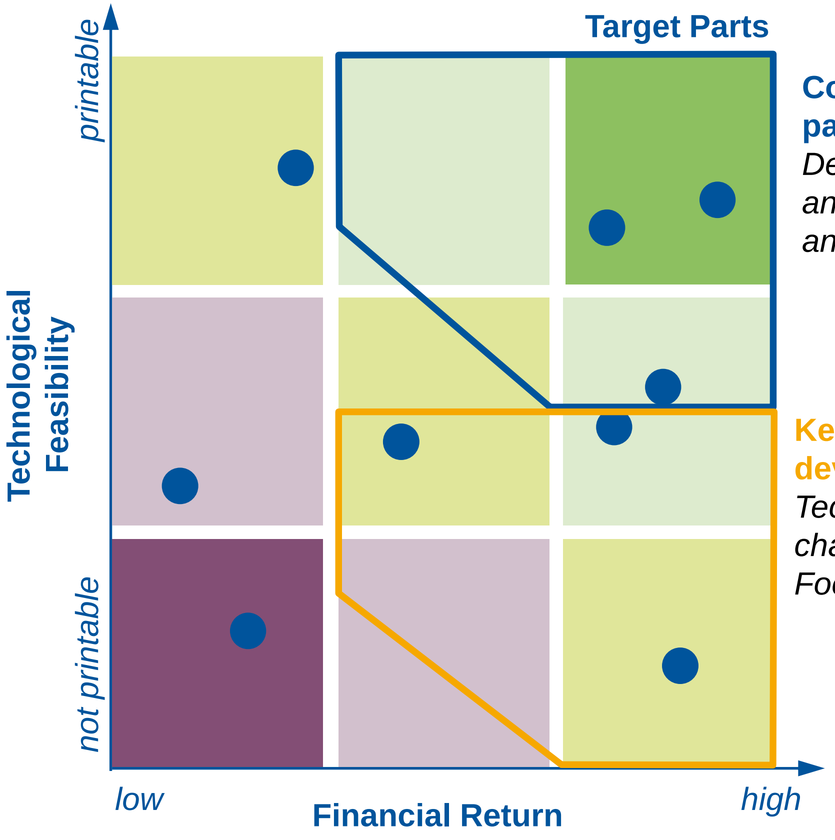
Source: ACAM Webinar "Software or Expert? Part Identification for Additive" with RWTH DAP

Successful Adaption of AM
Benefits Through an "Additive Mindset"

Part identification process

- *Preliminary Selection*
- *Financial Assessment*
- *Technological Assessment*
- *Implementation*

Mapping of possible candidates to find target parts for implementation



Collaboration with technology partners:
Development of prototype components and processes to validate assumptions and prove AM feasibility

Keeping in backlog for future developments:
Technology and market evolution can change the feasibility status of parts. Focus on parts with high potential ROI

Source: ACAM Webinar "Software or Expert? Part Identification for Additive" with RWTH DAP

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Source: Effectory, TCT

Successful Adaption of AM
Business Models Based on AM

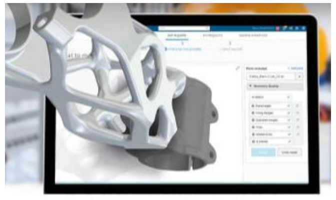
AM Benefits

- **Design freedom**: Complex features, lightweight, monolithic
- **Flexible design** iterations and engineering changes
- **Integration of functions**
- Economic **small quantities** and **individualization**
- **Short time** and efficiency **idea to product**
- **Short supply chain**
- **Insourcing:** Appealing for staff in industrialized countries & high degree of automation
- **Sustainability** by material reduction or efficiency in performance

Enabled business models for AM users (not a conclusive)

Digital spare part warehouse

Service provider



Online marketplace

Mass customization

Co-Production

…

Successful Adaption of AM
Digital Spare Part Warehouse

FIT ADDITIVE MANUFACTURING GROUP

Specialized manufacturer – FIT AG

- Expertise in additive manufacturing, rapid prototyping & tooling and spare parts manufacturing
- Introduction of **demand-driven production of "critical" spare parts**
- **Examination of the usefulness** of additive manufacturing in terms of cost & quality

Spare parts on demand

- Production costs and delivery times can be planned (-**30% total costs | -75% response time in case of need**)
- **Minimization** of failure risks
- **Elimination** of warehousing
- **Digitization** of additively manufacturable spare parts & backup in virtual warehouse Production "on demand"
- Also used for discontinuous series components

Source: FIT AG

Successful Adaption of AM
Service Provider

oerlikon am

Specialized service provider – oerlikon am

- Service provider for metal series parts in a variety of industries (e.g., automotive, aerospace, medical or energy)
- Design, development and **series manufacturing partner** of manufacturing companies

High-quality 3D-printed parts

- Covering **entire metal AM value chain** lowering the market entrance barrier for manufacturing companies
- Certified according to ISO 9001 and AS/EN 9100 in Europe and the United States
- **Facilitates reliable, risk-reduced** acquisition of **certified series metal parts** for manufacturing companies
- **Seizing of AM benefits** without having to establish own AM production

Source: oerlikon am

Successful Adaption of AM
Online Marketplace with Instant Quoting

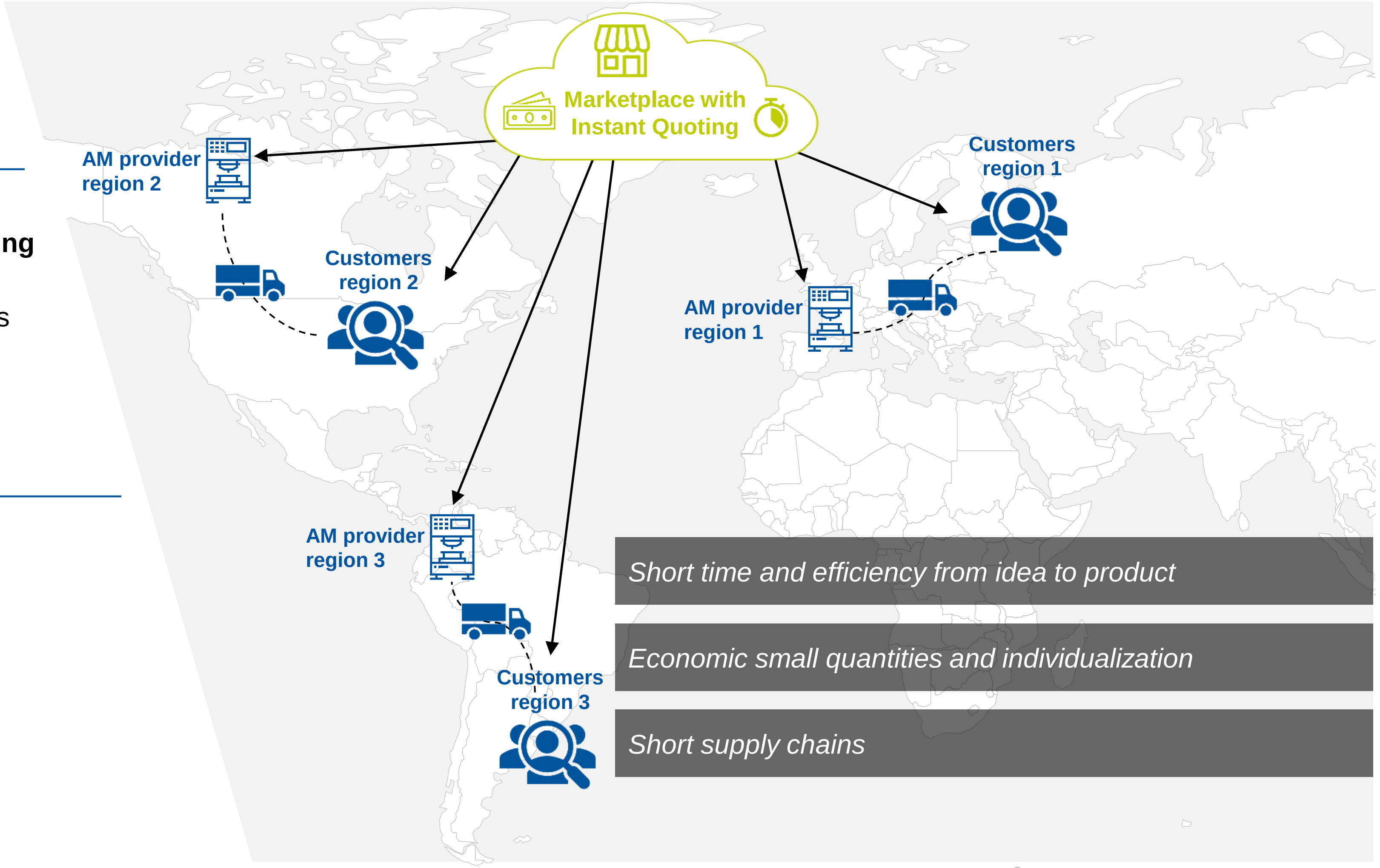
PROTIQ Xometry HUBS A PROTOLABS COMPANY

Online marketplace for AM

- Integration of manufacturing providers
- Platform for customers to **compare manufacturing services** of of different providers
- **Instant quoting tool** with cost and delivery dates based on CAD upload by customer
- Automated design check of uploaded models

Exemplary AM marketplaces

- Protiq
- Xometry
- Hubs
- Jellypipe
- HP Digital Manufacturing Network



Short time and efficiency from idea to product

Economic small quantities and individualization

Short supply chains

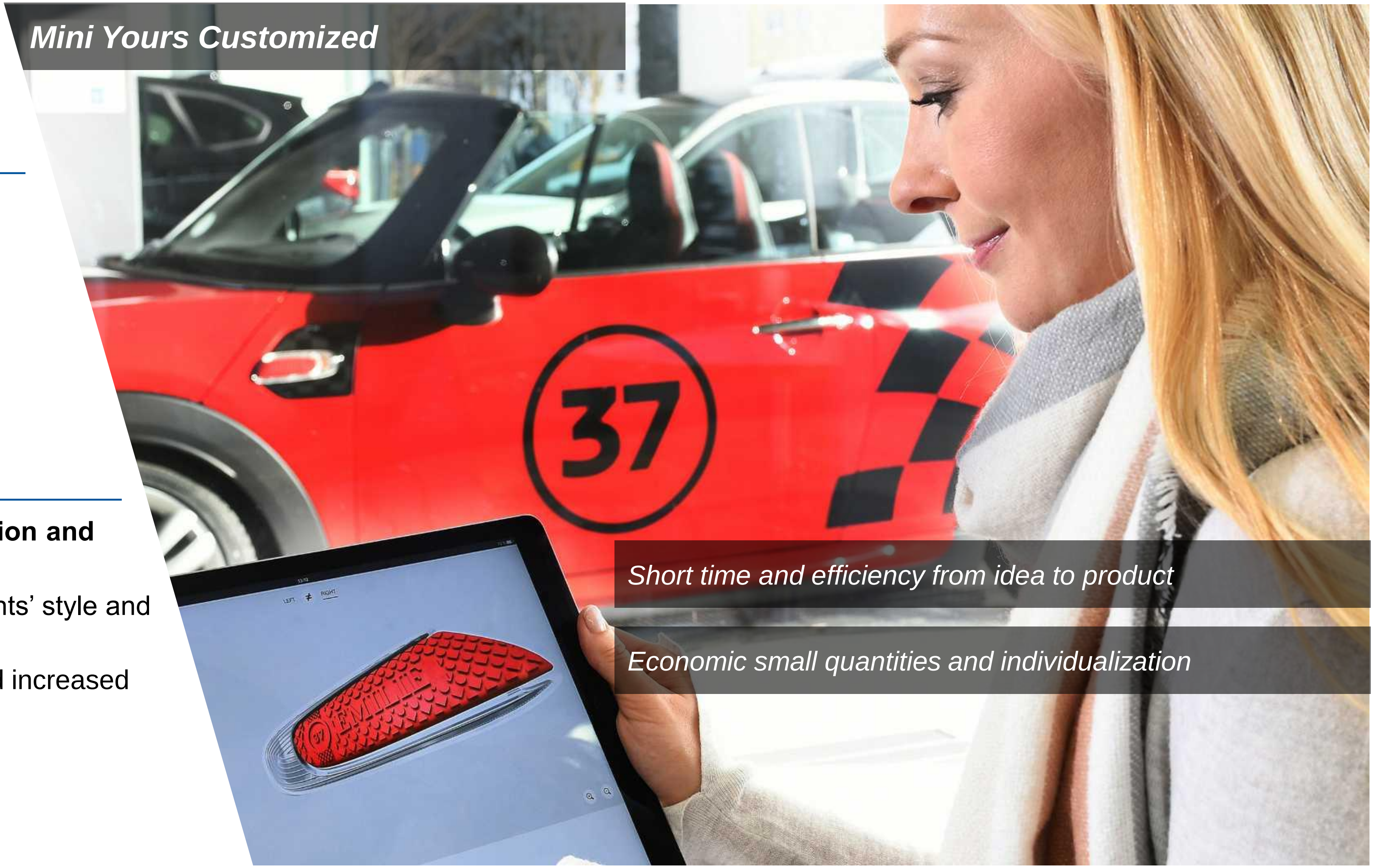
Successful Adaption of AM
Mass Customization

3D printing customization service

- Set-up of online shop for customers to indicate **customized changes to implement** in their BMW Mini
- Customizable parts: door sills, door projectors, interior trims and side scuttles
- Polymer AM technologies used

Adaptability to multi-level customers

- Addressing **customers' need for individualization and customization**
- Customized parts are designed according to clients' style and additively manufactured
- **Economic realization of customized parts** and increased customer satisfaction



Source: BMW, Sculpteo

Successful Adaption of AM
Co-Production

Product design service

- Development and marketing for AM brands
- Aiming at companies striving towards digitization
- Design aimed to facilitate physical manufacturing **by end users**
- Monomaterial part design for circular economy

Print@home applications

- **Inclusion of customers into value creation process** for better and more individualized products
- Shared value creation (**print@home application**)
- Reduced transport and waste through demand-oriented product supply
- Facilitated circular economy through monomaterial design
- Economic supply of small-series products

Enable3D & Wiesemann 1893

Shortened product supply times and supply chain

Economic production of individualized products

Higher sustainability through facilitating circular economy

Source: Enable3D, Wiesemann 1893

Successful Adaption of AM
Benefits Through an “Additive Mindset“

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Source: Effectory, TCT

Successful Adaption of AM
Algorithmic Design for Additive Manufacturing – Generative Design

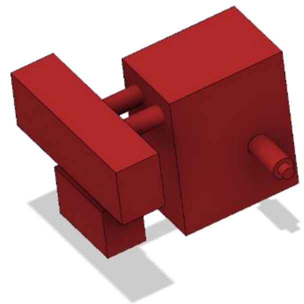
How?

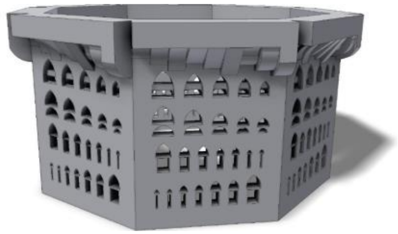
Conventional design | *Additive design*

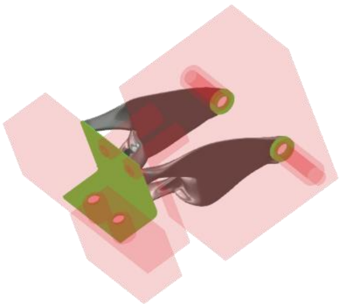
Source: RWTH DAP, e.GO

Algorithmic Design for Additive Manufacturing – Generative Design

Definition of design space → *Definition of manufacturing constraints* → *Definition of loading and boundary conditions* → *Algorithmic shape optimization* → *Evaluation and adaption of generated options by engineer*







Design and process know how engineer

Algorithmic optimization

Decision by engineer

Source: RWTH DAP, e.GO

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Source: Effectory, TCT

Successful Adaption of AM
Health & Safety Risks and Measures for Prevention

Risks of Metal Powder


GHS05: Corrosive


GHS01: Explosive


GHS02: Flammable


GHS03: Oxidizing


GHS06: Toxic


GHS07: Harmful


GHS08: Health hazards


GHS09: Environmental hazards

Health & Safety Measures

Standard PPE

- Protective gloves
- Work protective clothing
- Respirator mask
- Tight-closing safety goggles
- Anti-static work shoes

Extended PPE

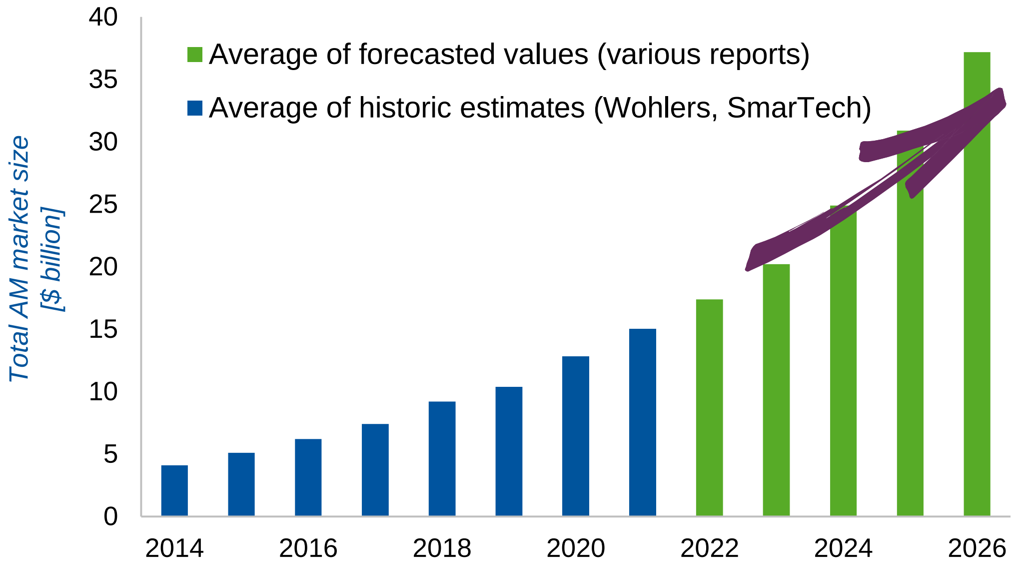
- Heat-protective gloves
- Flameproof clothing
- Full respiratory mask
- Protective shield
- ESD wristband

Prevention of health hazards requires implementation of specific safety measures

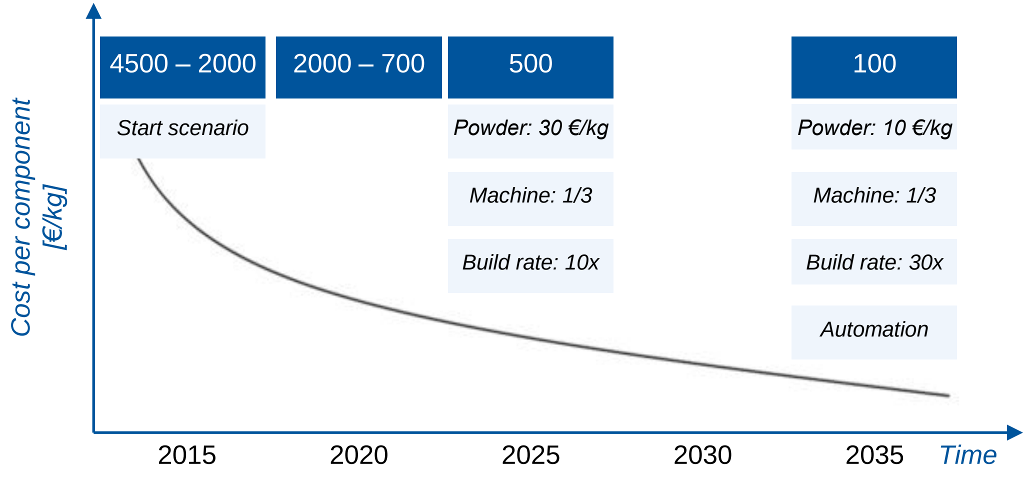
Basic AM Seminar – Content

Future Perspective of AM
What Does the Future Hold for Additive Manufacturing?

Expected market development



Prognosis of cost development[1]



- *Increase of machine productivity*
- *Higher technology readiness level*
- *Higher degree of automation*

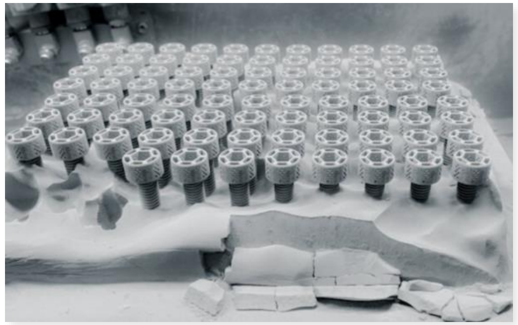
The AM market is predicted continuous strong growth and costs for AM parts are expected to decrease.
Current barriers of AM are addressed in industry and ongoing research and development.

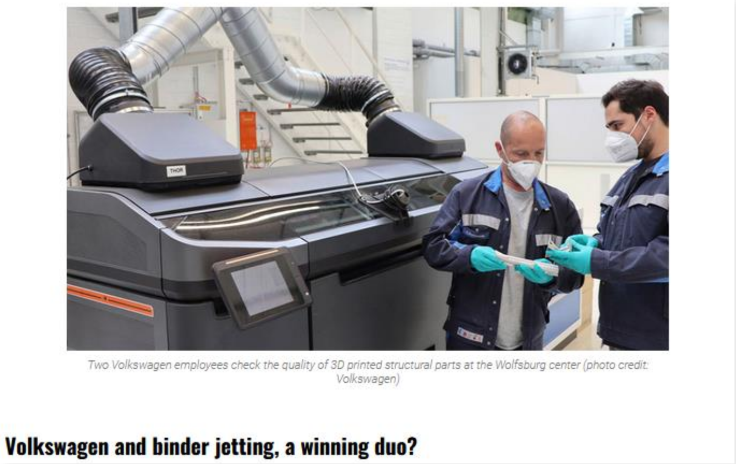
Source: Audi AG, Hubs, [1]LPBF-specific, high uncertainty and unpredictability of certain events

Future Perspective of AM
Emerging AM Technologies – Metal Binder Jetting for Mass Production

Expectations in productivity

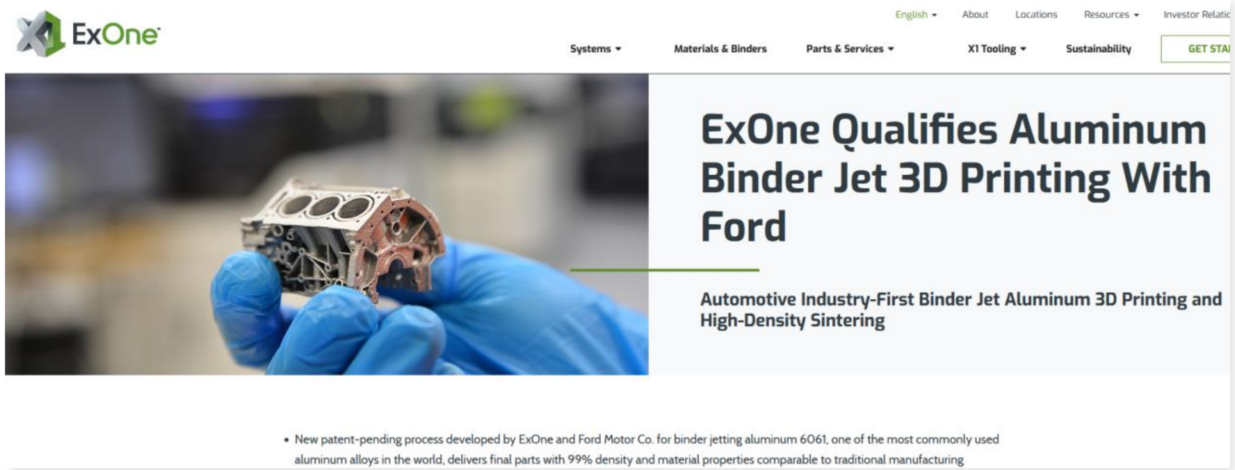
- More parts per build job due to 3D nesting compared to 2D nesting with LPBF
- Faster printing speed especially with high filling degree





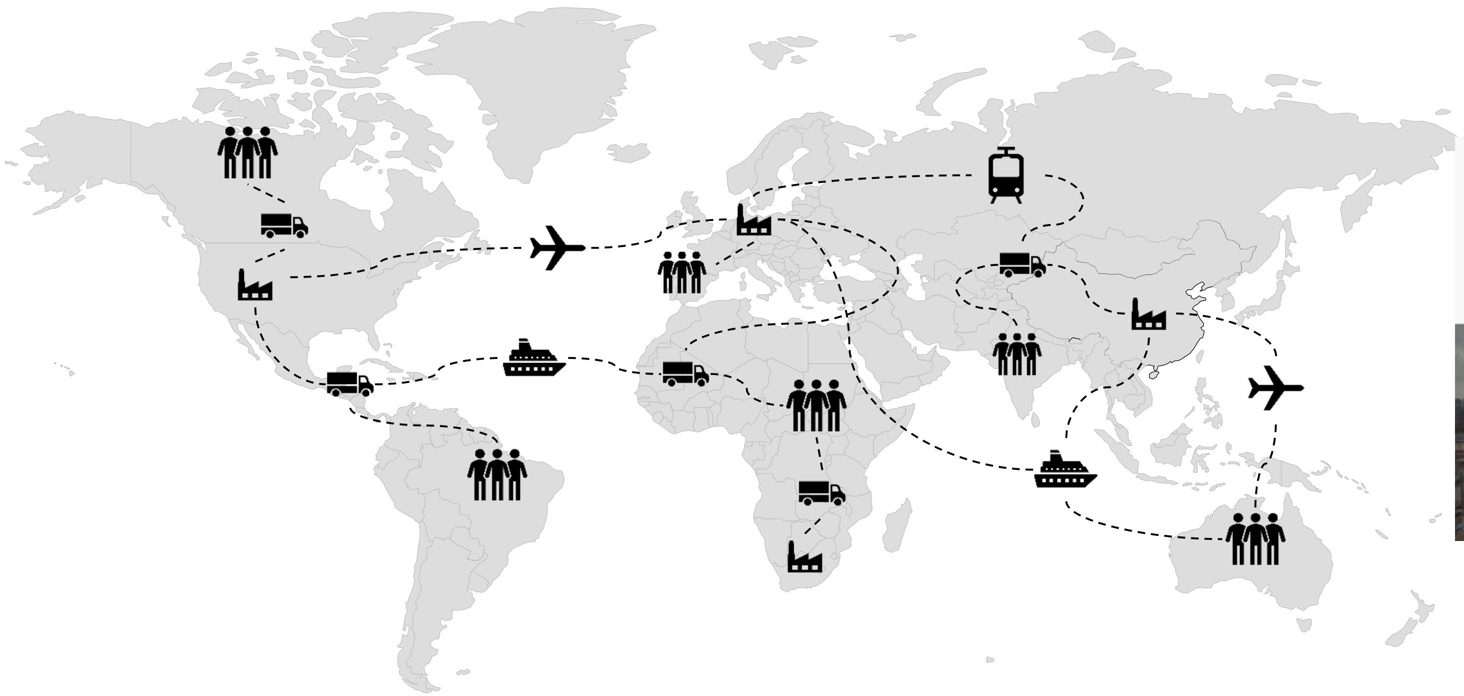
Barriers for realization

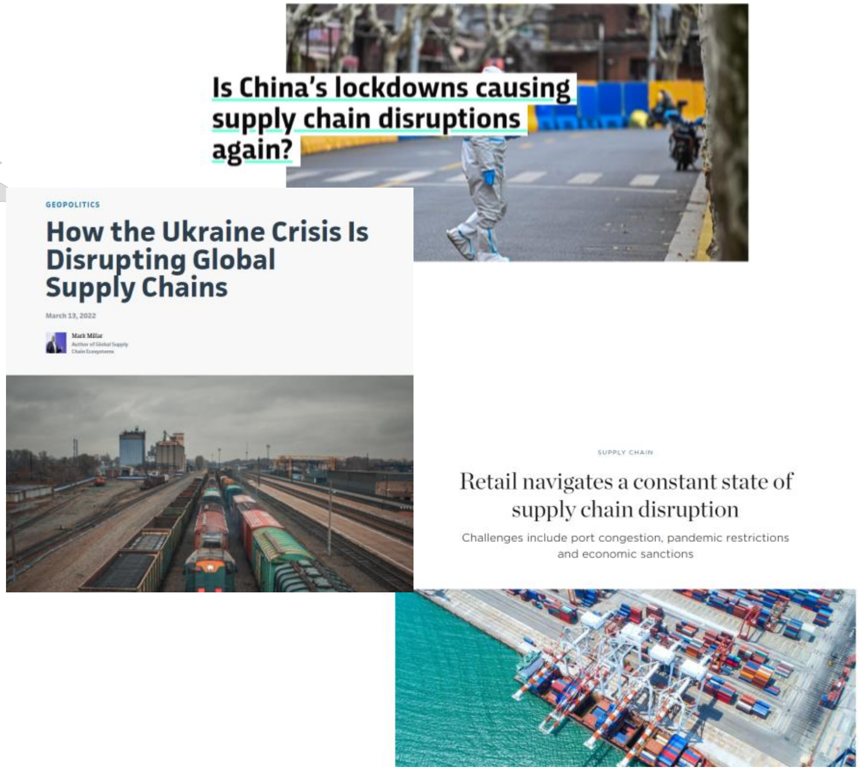
- Additional process steps: Debinding & Sintering
- Automation, e.g., removal of green parts from powder cake
- Comparably low technology maturity compared to LPBF



Source: ExOne, 3Dnatives, AFMG

Future Perspective of AM
Data Security in Digital Supply Chains - Research Project ProCloud 3D





Recent crises have shown the vulnerability of global of supply chains. **Establishing resilient supply chains** is a **key element to competitiveness.**

Source: RWTH DAP, WIBU, BMBF

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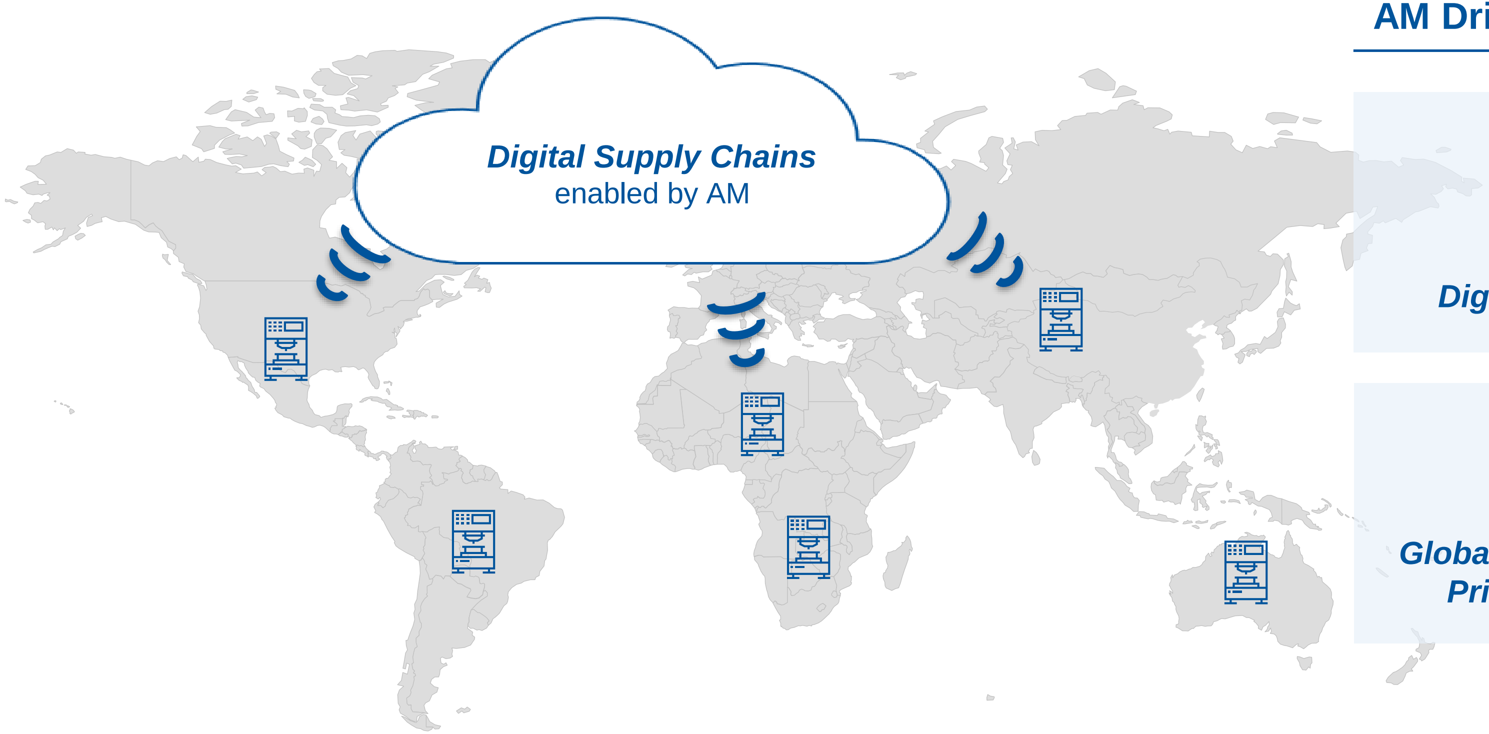

AM Drivers for Resilience in Supply Chains

- *Digital Inventory*
- *Decentral Production*
- *Global Network of 3D Printing Shops*
- *On-Demand Manufacturing*

Digital supply chains enabled by AM have the potential to substitute physical supply chains to large extent. But data transfer, processing and security must be ensured – that is where ProCloud 3D comes into play.

Source: RWTH DAP, WIBU, BMBF

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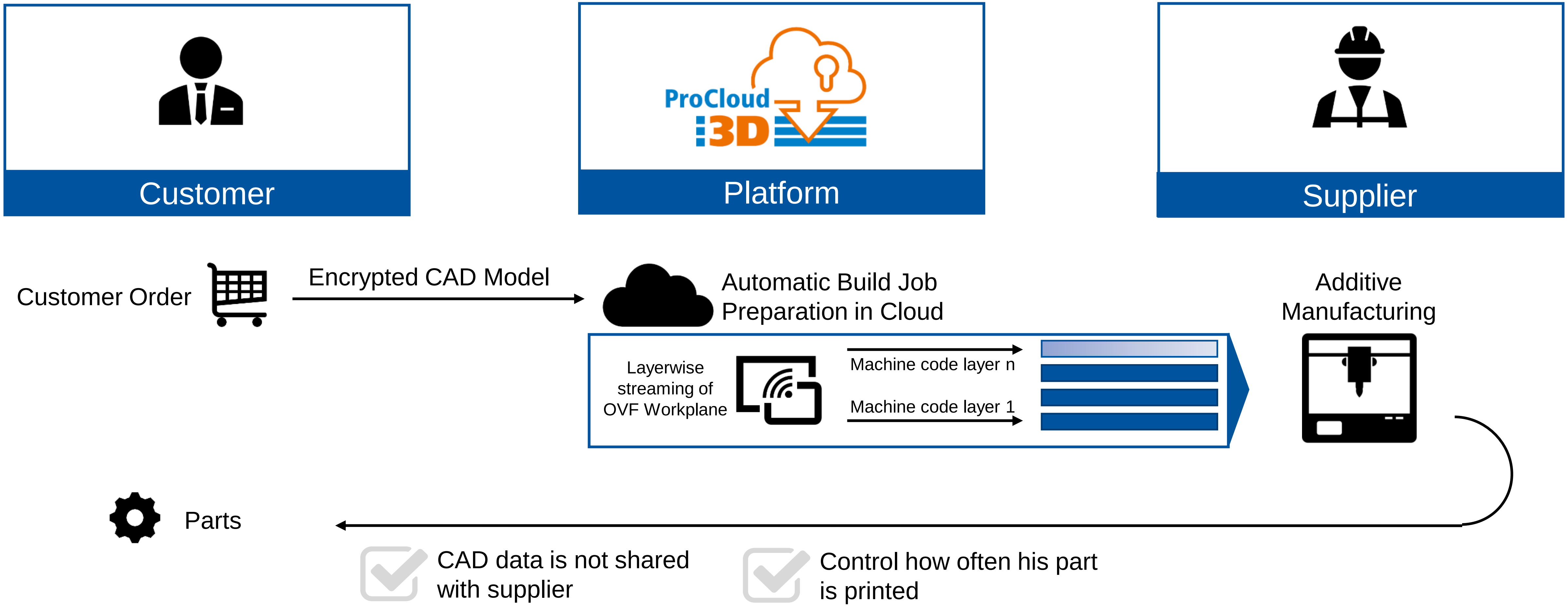


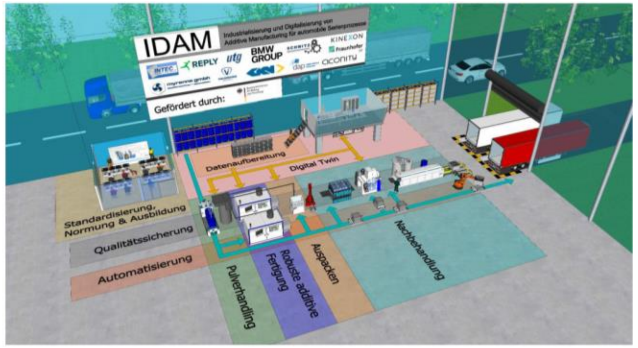
Source: RWTH DAP, WIBU, BMBF

Future Perspective of AM
Industrialization – Joint Research Project IDAM

Initial Situation

- High costs
- Low productivity
- High material prices
- Inadequate connection of enterprise IT systems
- High manual labor efforts
- Lack of consistent end-to-end quality assurance

Digital. Additiv. Vernetzt.



- *Material systems: Aluminum and steel*
- *Production volumes: > 10,000 components/year (@GKN)*
- *Production volumes: > 50,000 components/year (@BMW)*

Results

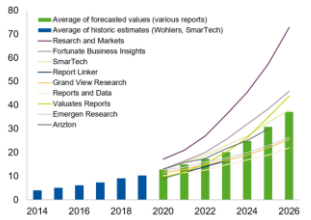
- Line integration of LPBF 3D printing
- Digital connection of all systems
- Reduction of manual work from 35% to 5%
- Continuous end-to-end digital quality assurance

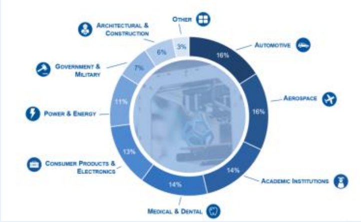
Source: RWTH DAP, Photonikforschung

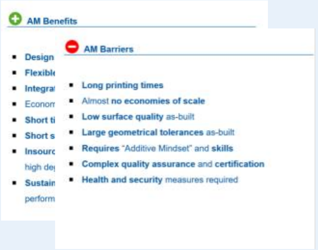
Basic AM Seminar – Content

Basic AM Seminar
Summary

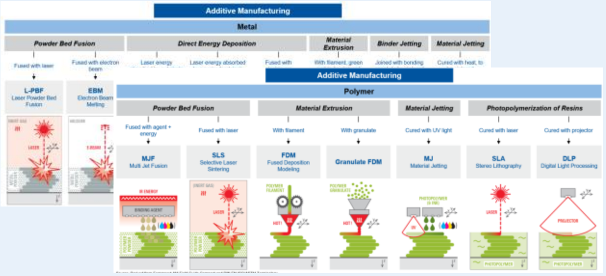
Introduction to Additive Manufacturing







Overview of AM Technologies



- High variety of established and emerging AM technologies
- Varying technology readiness
- Technology-specific characteristics, advantages and disadvantages
- Material choice according to application

AM Application Examples

- Various applications along the product lifecycle
- Differentiation in rapid prototyping, rapid tooling and AM of end use parts
- Taking advantage of different AM benefits according to application

Successful Adaption of AM

***Successful AM adaption** requires **consideration of AM differences**. Without change of expectations, AM turns out as a poor substitute for established processes.*

Future Perspective

- Expected continuous market growth
- Cost decrease due to increased technology readiness level, productivity and industrialization
- Technological and economical challenges are addressed through industry and R&D

Outlook

From…

Via…

Education

Additive mindset

Product analysis

Use case development

To…

Cost savings

Differentiation

Resilient supply chains

Customer satisfaction

Sustainability

Product innovation

The strong market growth of AM continues holding immense potential for most industries.
Successful implementation requires understanding of AM characteristics and strategic business model development.

Thank You For Your Attention!

Viktoria Krömer
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Get in touch with our experts and become a part of Europe‘s most vivid AM and engineering ecosystem!