AMPOWER INSIGHTS

Additive Manufacturing **New metal technologies**

Upcoming technology principles:
Potential and outlook

INSIGHTS GAINED:

- Overview of upcoming metal AM technologies
- Potentials, opportunities and availability
- Tool for quick technology assessment

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March 2020

Insights gained

Overview of upcoming metal AM technologies
Potentials, opportunities and availability
Tool for quick technology assessment

Management summary

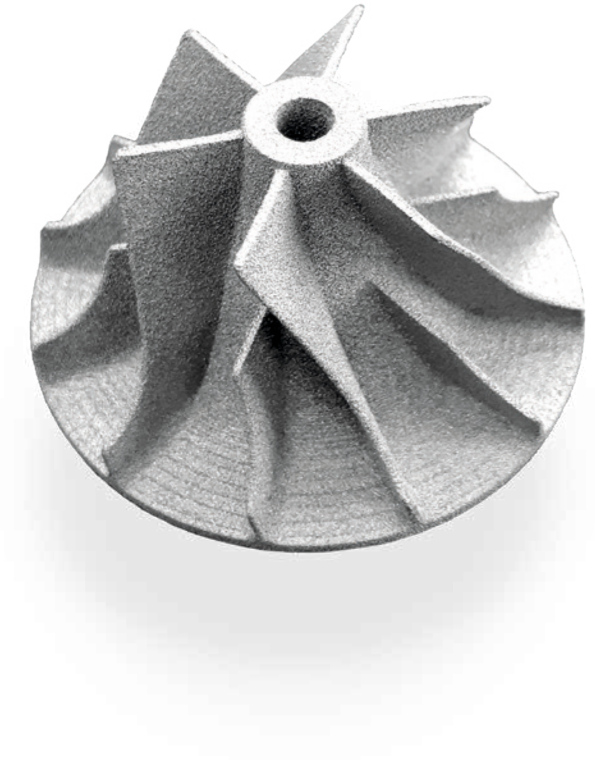
Metal Additive Manufacturing is often associated with Laser or Electron Beam Powder Bed Fusion process. However, there are more than 18 different technology principles identified today. While some of these principles are in an early development stage, many are successfully used in industrial set-ups or it is expected that they will find a viable niche as manufacturing technology.

To be successful in using metal Additive Manufacturing, it is highly important to choose the right established or new manufacturing technology. Therefore, the 6th volume of AMPOWER Insights provides an overview on upcoming technology principles and assesses their potential.

To evaluate the state of the art of a metal Additive Manufacturing principle, AMPOWER introduces a new methodology – the AM Maturity Index. This index provides the user with a tool for quick assessment based on the technology as well as industrialization maturity. While the technology index evaluates the current production process capability and machine concept, the industrialization index reflects the existing knowledge base and availability in the market.
Newly introduced direct metal technologies covered in this issue are Resistance Welding, Friction Deposition and Liquid Metal Printing. Here, the printing process allows direct production of a metallic part without further process steps. Additionally, several new sinter-based technologies are in development and on the verge to be introduced into the market. In contrast to the direct technologies only the green part is created additively, which has to be sintered in an additional step to gain metallic material properties. These technologies include Powder Metallurgy Jetting, Metal Lithography, Metal SLS and Mold Slurry Deposition.

For most of the technologies AMPOWER expects that a state of industrial use requires 5 years or more. Technologies such as Friction Deposition, Resistance Welding or Metal SLS benefit from use of established machinery or traditional 2D counterpart processes and are thus projected to be used in industry within 2 to 5 years.

Download this paper at www.am-power.de/insights



About AMPOWER

AMPOWER is the leading consultancy in the field of industrial Additive Manufacturing. AMPOWER advises their clients on strategic decisions by developing and analyzing market scenarios as well as compiling technology studies. On operational level, AMPOWER supports the introduction of Additive Manufacturing through targeted training program as well as identification and development of components suitable for production. Further services include the setup of quality management and support in qualification of internal and external machine capacity. The company is based in Hamburg, Germany.

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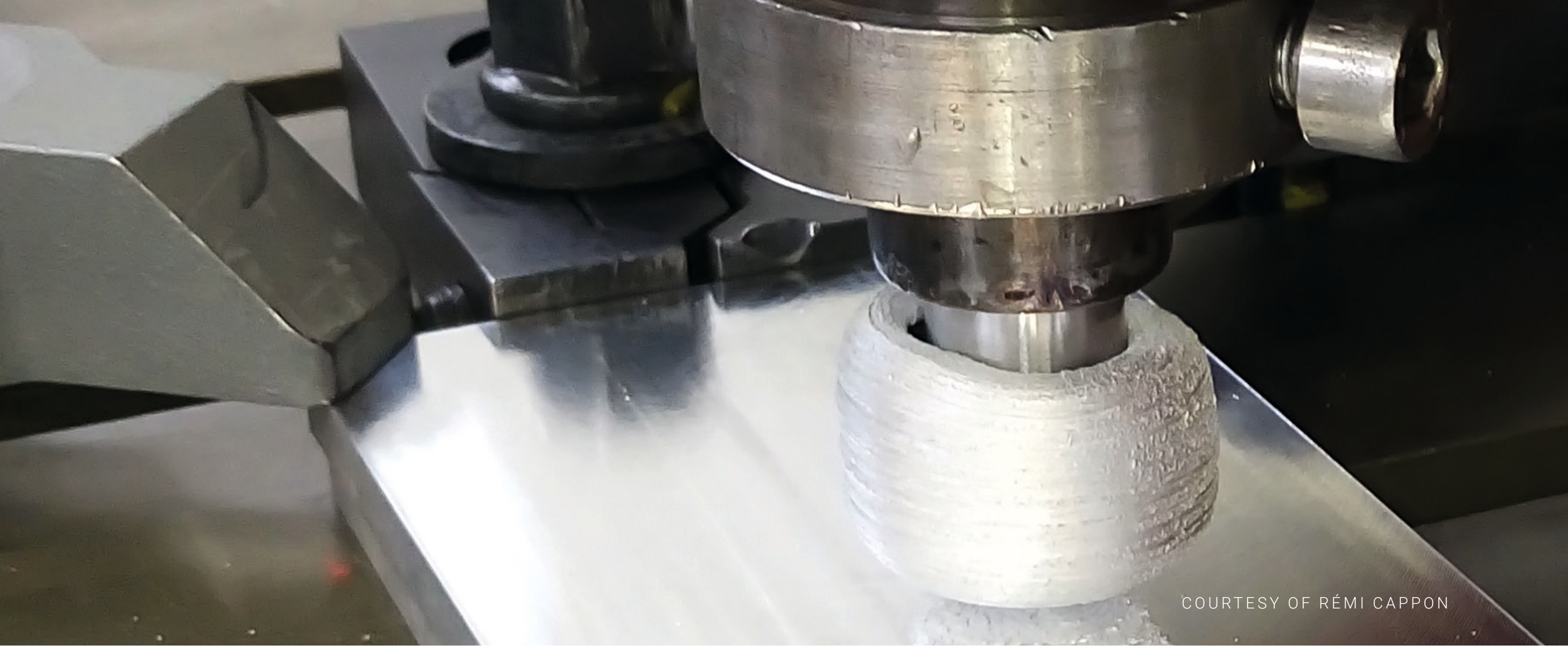
Introduction



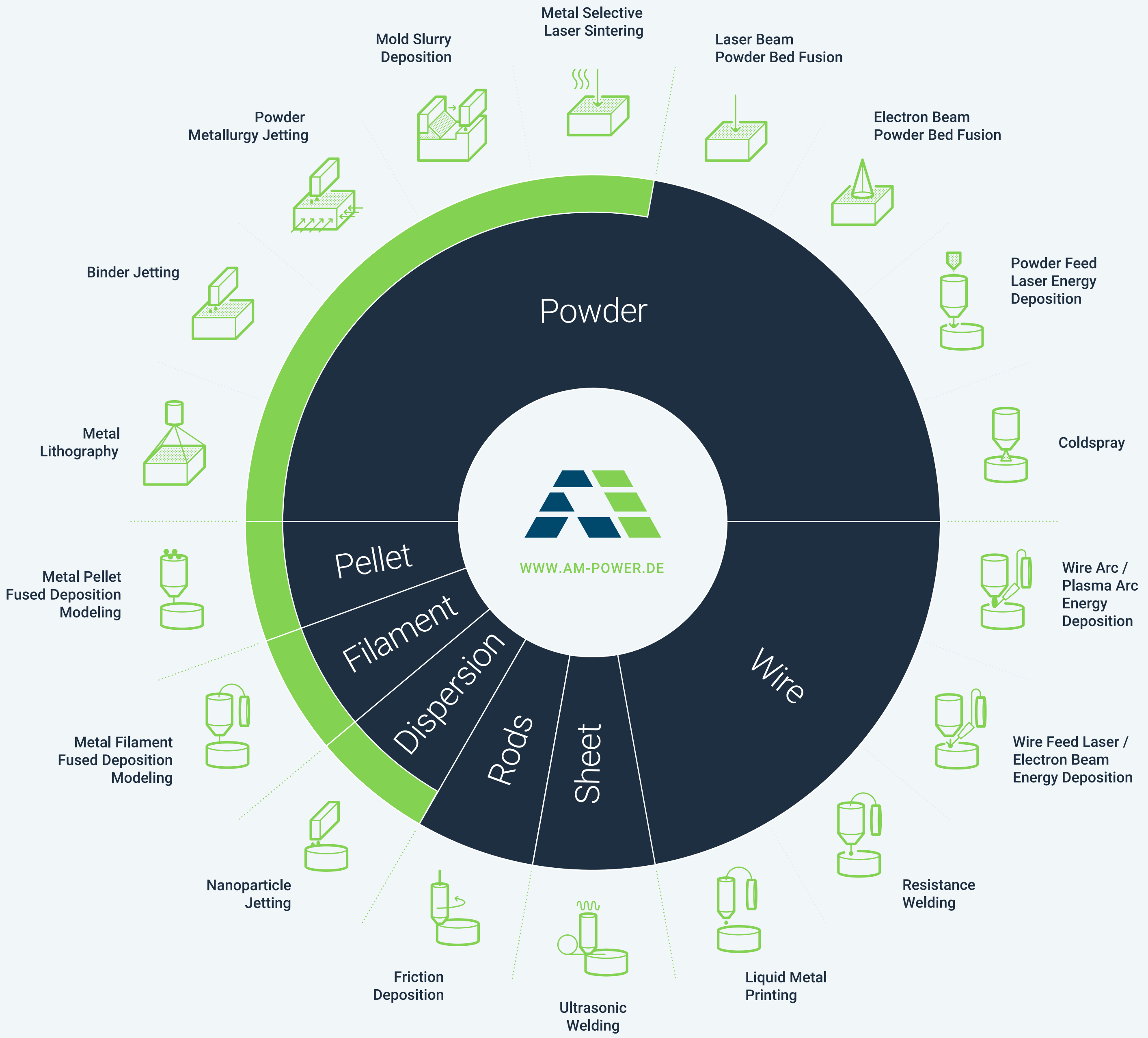
Metal Additive Manufacturing landscape

Metal Additive Manufacturing is often associated with Laser or Electron Beam Powder Bed Fusion. However, there is more than 18 different technology principles identified today.

The different metal AM technologies can be clustered into two groups. Direct technologies on the one side, and sinter-based, indirect technologies on the other. Additive Manufacturing processes from the former group create a part directly by melting metal feedstock, processes from the latter group use at least a two-step manufacturing process. Firstly, a green part is additively created and only in the second sintering step the part is densified to achieve typical metallic properties.

Most of the direct Additive Manufacturing technologies are used in multiple industrial applications today. Furthermore, they are focused on in various R&D projects to establish a wide knowledge base. Due to the increased industrial interest over the last decade, a highly competitive machine supplier landscape has formed. Currently, the most common technology is Laser Beam Powder Bed Fusion.

Sinter-based technologies on the other hand gained wide-spread attention only in the last couple of years. Due to their, in principle, faster printing process, they promise higher through-put compared to direct technologies. An overall cost reduction per part can thus be expected. Emphasizing this potential, machine suppliers try to increase their market share by targeting larger volume applications from traditional production. Overall, the supplier landscape of sinter-based technologies is much less developed and often individual technology principles are proprietary processes of the inventor.



Metal Selective Laser Sintering
Mold Slurry Deposition
Laser Beam Powder Bed Fusion
Powder Metallurgy Jetting
Electron Beam Powder Bed Fusion
Binder Jetting
Powder Feed Laser Energy Deposition
Metal Lithography
Coldspray
Powder
Metal Pellet Fused Deposition Modeling
Wire Arc / Plasma Arc Energy Deposition
Pellet
Filament
Dispersion
Rods
Sheet
Wire
WWW.AM-POWER.DE
Metal Filament Fused Deposition Modeling
Wire Feed Laser / Electron Beam Energy Deposition
Nanoparticle Jetting
Resistance Welding
Friction Deposition
Liquid Metal Printing
Ultrasonic Welding

Assessment of state of the art of metal AM technologies

Only Powder Bed Fusion and certain Direct Energy Deposition technologies have reached common industrial use within the group of all AM technologies. Binder Jetting will reach industrial use within the next two years and possibly surpass LB-PBF as the leading metal AM Technology within this decade.

To evaluate the different AM technologies AMPOWER has developed a model to describe the technology readiness level of an Additive Manufacturing technology based on two indices. The Industrialization Maturity Index and the Technology Maturity Index describe and compare the capabilities and adoption rate of each AM technology in an industrial environment. Both indices are crucial factors for evaluating the current status of a technology.

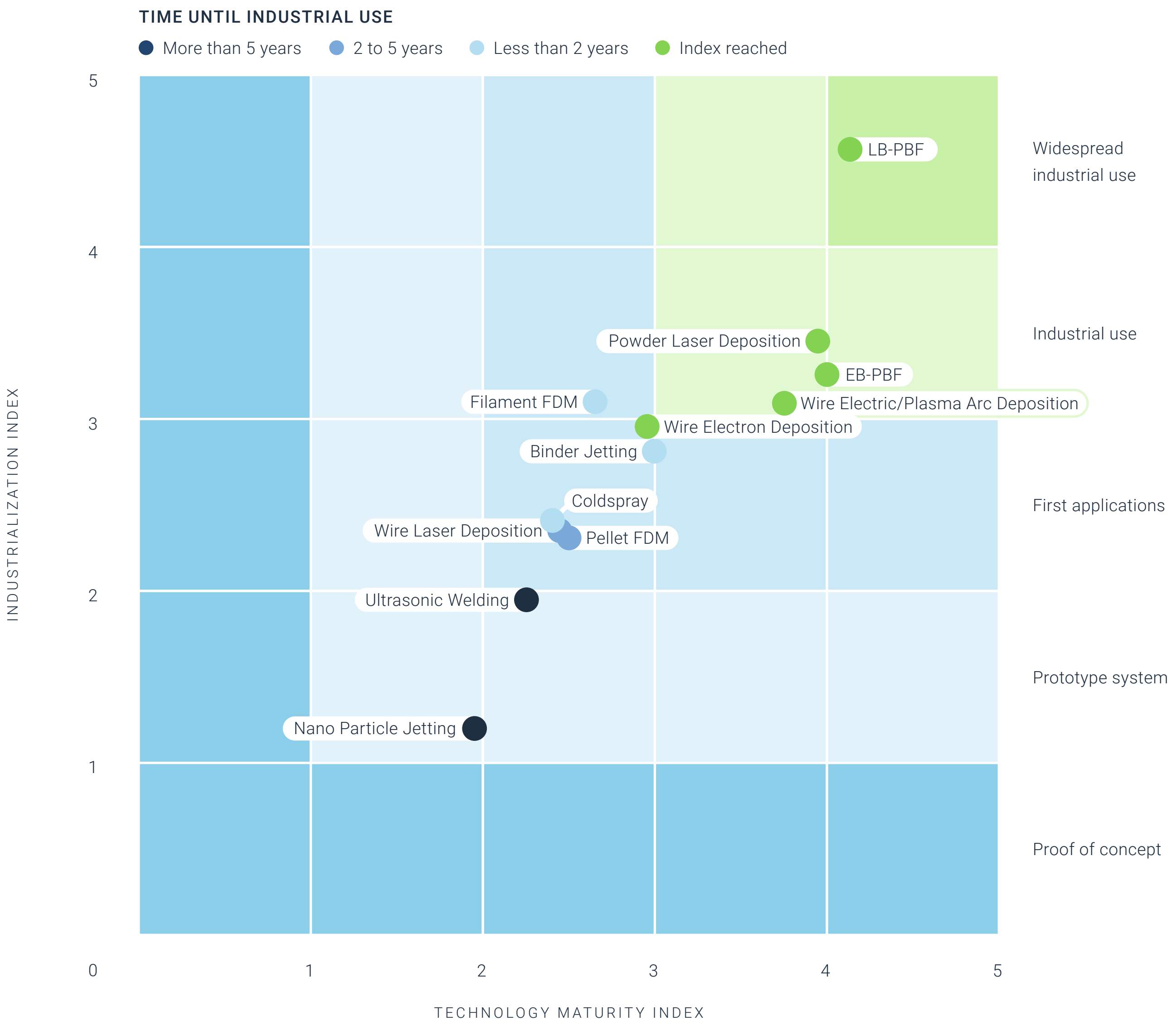
Only Powder Bed Fusion and some DED technologies are commonly used in industry with LB-PBF having the highest penetration rate across industries, materials and applications. Binder Jetting is expected to join PBF technologies within the next two years and possibly surpassing them within this decade. This is especially driven by the high anticipation of the users and large commitment of the system suppliers and their investors to this technology. Other technologies will struggle to differentiate from each other and/or to successfully reach multiple industrial applications. They will find niche applications, but not successfully industrialize on a wide base.

Introduction to the Maturity Index

Typically the technological maturity proceeds the industrial maturity, especially in the early stages of a new AM principle. The technology has to reach a certain performance before it is adapted in first industrial applications and rises therein as well. Especially for proprietary technologies the rise in industrial maturity is often hindered or slowed down additionally by the lack of competition on the supplier site and therefore the restraint to adapt from the user site. This tendency can be seen when comparing the development of LB-PBF and EB-PBF in the last decade. The single-source supplier situation of EB-PBF limited the adoption in industrial applications and a widespread academic research and therefore public knowledge and innovation.

The evaluation of the new AM technologies in this issue will focus on the technological maturity. As described the Industrialization Maturity Index is comparatively low and non conclusive for technologies just introduced into the market or even still in a prototyping stage.

Maturity Index 2020 for Additive Manufacturing



Technology Maturity Index

The Technology Maturity Index assesses the maturity of a technology in four weighted categories. It is rated by a number between 1 (basic research has been done) and 5 (established full-scale production technology).

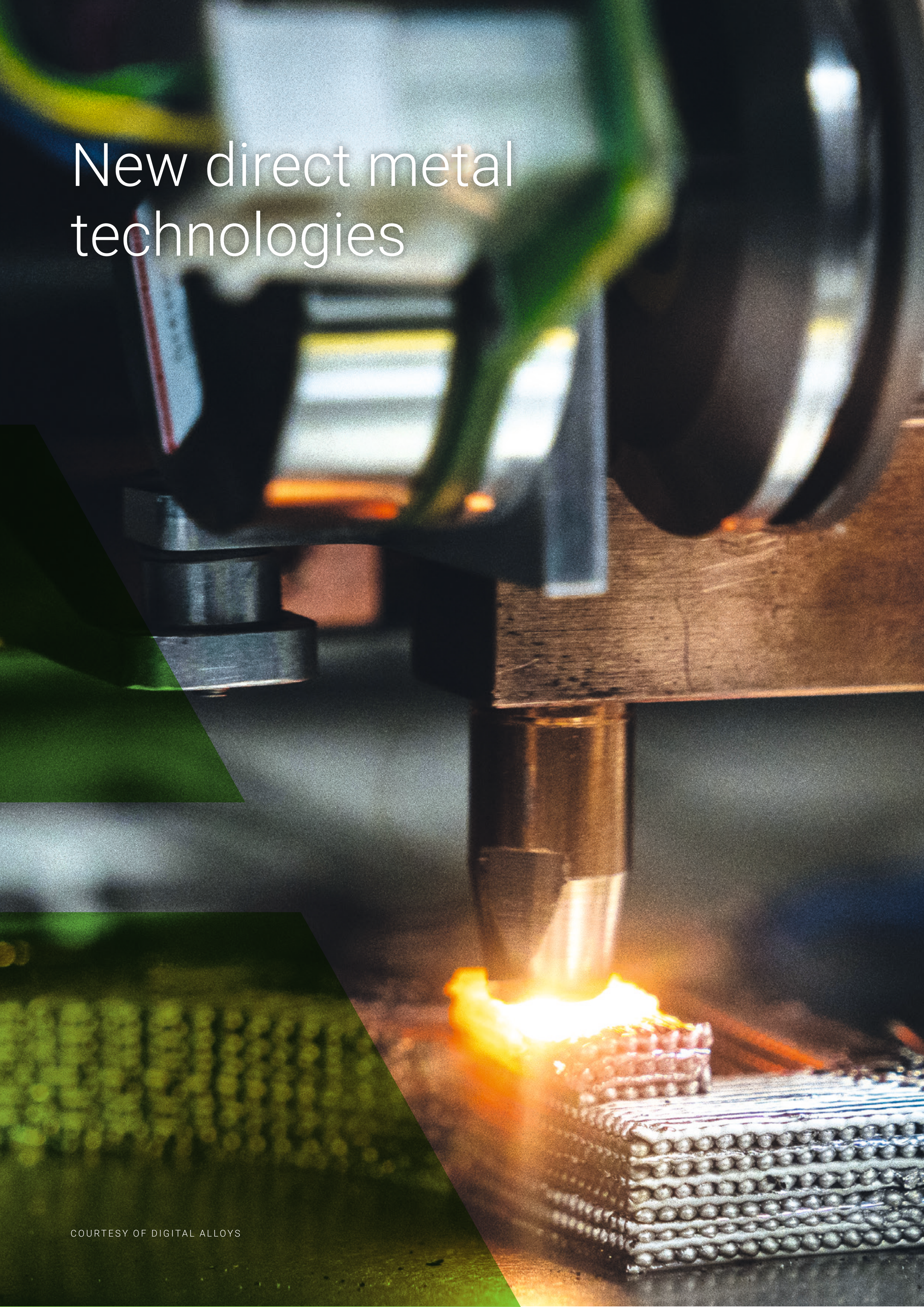
Series production capability:
Basic R&D on manufacturing use to established in full-scale series production with integrated periphery

Process capability:
Basic process R&D to defect free, high repeatability and reproducibility for any parts

Machine concept:
Proof-of-concept and prototypes to off-the shelf series and customizable machines

In-process quality control:
No features to in-process control and simulation

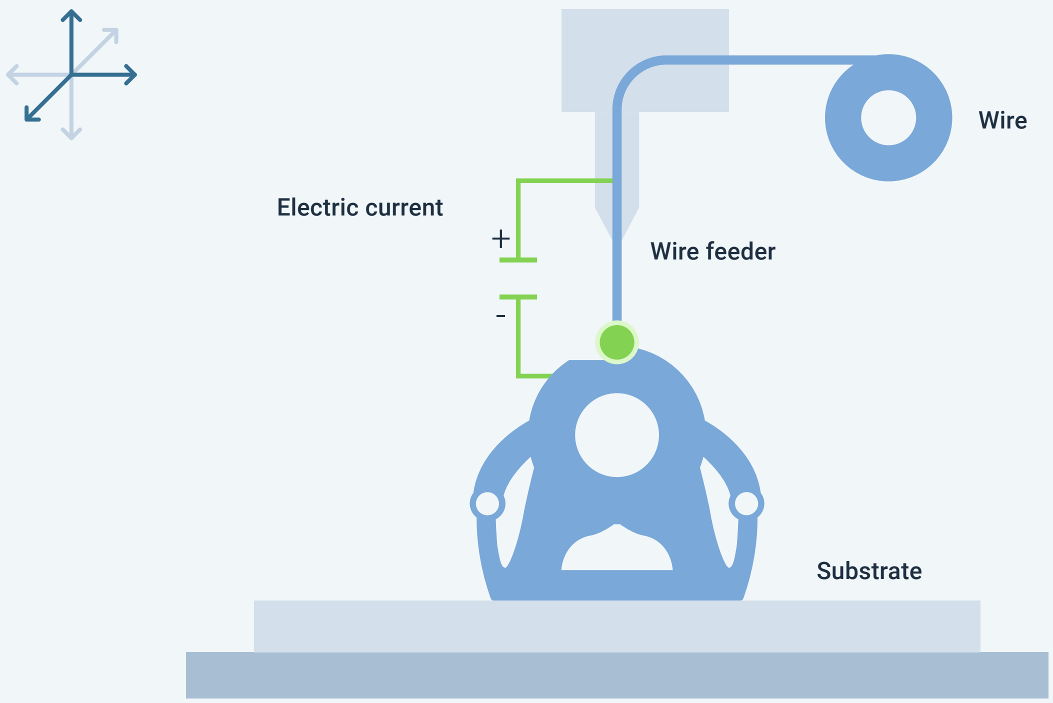
New direct metal technologies



COURTESY OF DIGITAL ALLOYS

Resistance Welding

Resistance Welding, or Joule Printing™ how the inventor DIGITAL ALLOYS branded this process, is a technology commonly used in two-dimensional static welding applications such as spot welding for automotive body parts.



The technology is based on a thermo-electric process. Heat is generated at the interface of the parts to be joined by passing an electrical current through the parts for a precisely controlled time. The parts have to be in direct contact and a certain pressure has to be applied to join the material. DIGITAL ALLOYS transferred this technology principle to a 3D printing process.

A metal wire is pushed through a nozzle onto the base material. An electric current runs through the wire and base material, creating a high temperature at the point of contact. The bond between the previous layer and the wire is realized by a mixture of melting and diffusion of the material at the interface.

Potential

High speed and isotropic material properties possible

- **Low cost and high speed**
  Wire material and simple system setup have potential for low cost and high speed.

- **Homogenous microstructure**
  Due to the non-welding process, the microstructure is non-directed, which results in isotropic material properties.

- **Closed loop control**
  By directly measuring major process parameters, the technology has a high potential for a real closed loop process control.

Technology Maturity Index

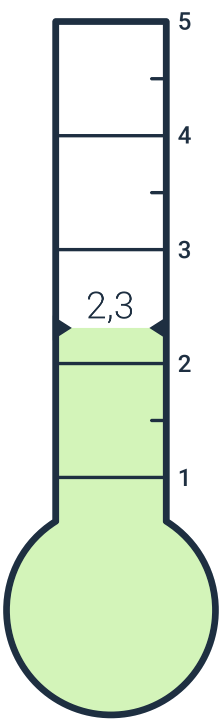
Challenger for established DED technologies

2 **Series production capability:**
Resistance welding is currently in R&D development state. First application testing.

3 **Process capability:**
The process leads to constantly good and reproducible material properties.

2 **Machine concept:**
No serial machines available. Current systems in alpha/beta stadium.

2 **In-process quality control:**
High potential for closed loop process control, however, not yet industrialized.



Interview with DIGITAL ALLOYS

What was the initial idea to look into the technology?

The inspiration for Joule Printing™ came from the observation that powder-based printing processes were too slow, expensive, and complex. Wire was chosen as a feedstock because it is low cost, safe and widely available. With wire as a starting point, the most efficient way to melt it is with resistive (aka joule) heating.

When and what was the situation where you realized this is something we can go to market with?

Once an early prototype was built to demonstrate Joule Printing™ and it was producing small but high-quality metal parts, DIGITAL ALLOYS was officially formed and funded.

Can you summarize the unique selling point of your technology?

The fastest, lowest-cost, and highest-quality metal AM solution for near-net-shape parts.

What other AM or traditional manufacturing technologies do you see as competition to your technology?

We view traditional manufacturing processes as the only true competition. Joule Printing™ is being evaluated for improving the production of parts that are currently machined from billet, castings and forgings.

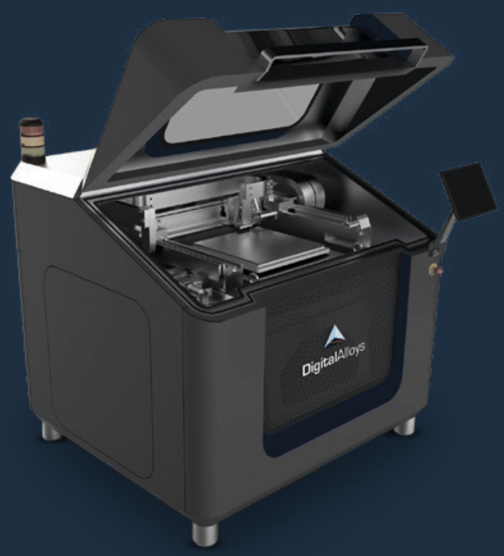
Where do you see boundaries or limitations?

The only fundamental limitation is development and commercialization time. The first Joule Printing ™ system can build parts ranging in size from a golf ball to a beach ball. Future, larger printers will address much larger parts.

Duncan McCallum

CEO at DIGITAL ALLOYS

Co-founded and sold CILK ARTS, VELOBIT
Previously venture capitalist at BESSEMER VENTURE PARTNERS and FLAGSHIP VENTURES
Two degrees from MIT, MBA Harvard Business School



Fast facts on DIGITAL ALLOYS

Founding of company: January 2017
Investors: BOEING, LINCOLN ELECTRIC, KHOSLA VENTURES, G20 VENTURES, among others
First alloy: H13 Tool Steel
First industry: Automotive
First application: Tooling
Commercial availability: Parts in 2020, printers in 2022

RENDERING OF DIGITAL ALLOYS PRODUCTION MACHINE
COURTESY OF DIGITAL ALLOYS

What has been the most challenging hurdle to overcome, the most challenging development?

The core printing process is sensitive and requires sophisticated control strategies. The timeline for developing these was initially underestimated.

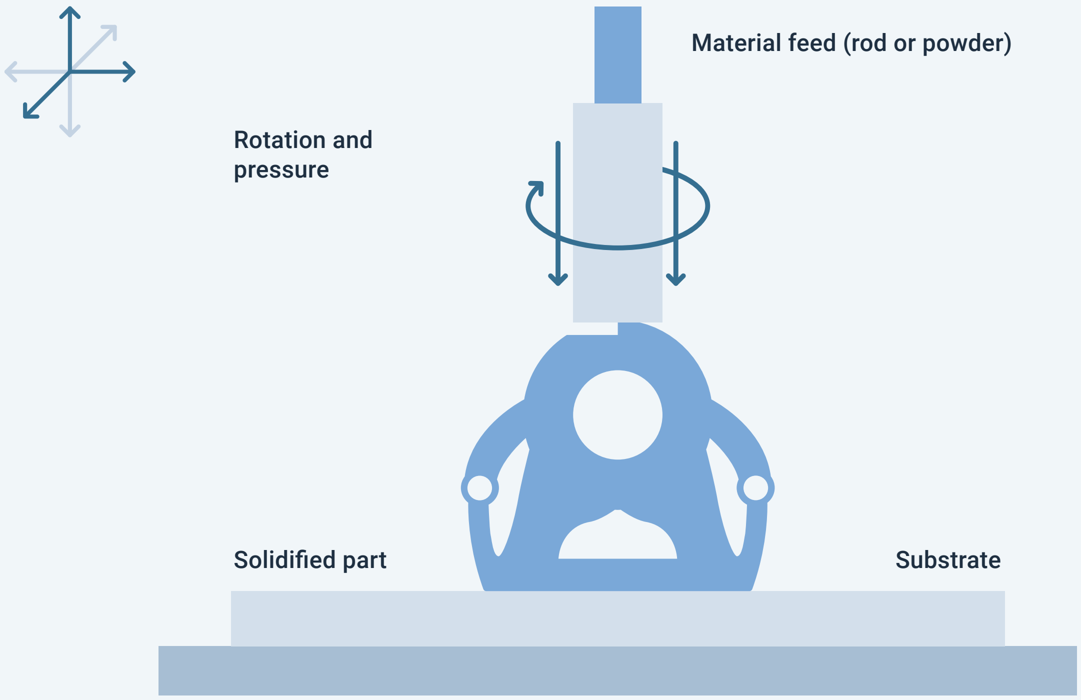
In 5 years, what is your vision regarding this technology?

In 5 years, Joule Printing™ will be a widely adopted manufacturing process for saving time and money. Before someone orders billet, forgings, or castings from a hard-to-process metal like titanium or tool steel, they will ask "should I use Joule Printing™"?

TEST COUPON TI-6AL-4V
FROM DIGITAL ALLOYS PROCESS

Friction Deposition

In Friction Deposition a metal rod or alternatively powder material is depositioned on the substrate by friction created thru downward force and rotation.



Friction welding is a technology based on patents that date back to the 1950s. This solid-state welding process generates heat through mechanical friction between workpieces in relative motion to one another, with the addition of a lateral force to plastically displace and fuse the materials. It is mainly used to join cylindrical objects like pipes and drills.

Friction Deposition is based on the same technological principal. A combination of high downward forces and rotation of the metal rod creates enough heat thru friction that the material flows freely. The layer is formed due to plastic deformation of the material. The design freedom of this technology is strongly restricted. However, uniform material properties and high throughput make the technology interesting for production of blanks, especially from alloys which are inherently difficult to weld. This in particularly is interesting for alloys that are not available in the desired dimensions as stock material. Also repair applications are a potential use case for this technology.

Potential

High speed and wide material range

- **High throughput**
  Low cost feedstock, high throughput and low system investment lead to low part cost.

- **Standard materials**
  Nearly every metal material can be processed by Friction Deposition.
  However, alloys with low melting temperature are best suited.

- **Knowledge transfer**
  Long history in friction welding offers potential for transfer of knowledge.

Technology Maturity Index

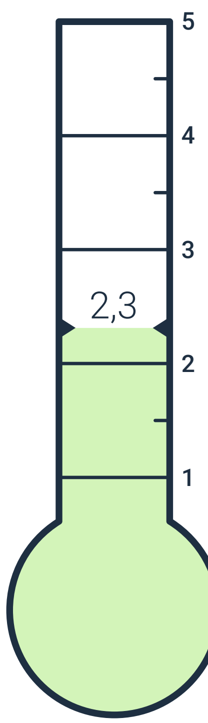
Technology with repeatable material properties

2 **Series production capability:**
First production setups in testing.

3 **Process capability:**
The process leads to constantly good and reproducible material properties.

3 **Machine concept:**
First industrial machine concepts are available.

2 **In-process quality control:**
Sensors tracking system parameters.



Interview with HELMHOLTZ-ZENTRUM GEESTHACHT

What was the initial idea to look into the technology?

The technology of Friction Surfacing Layer Deposition (FSLD), as it is labelled in the scientific community, has its origin in the 1940s as two-dimensional process to join, coat and repair components. Today, there are mainly research activities such as the programmes running in our department. A few industrial players are currently looking to commercialize the technology.

Can you summarize the advantages of the technology?

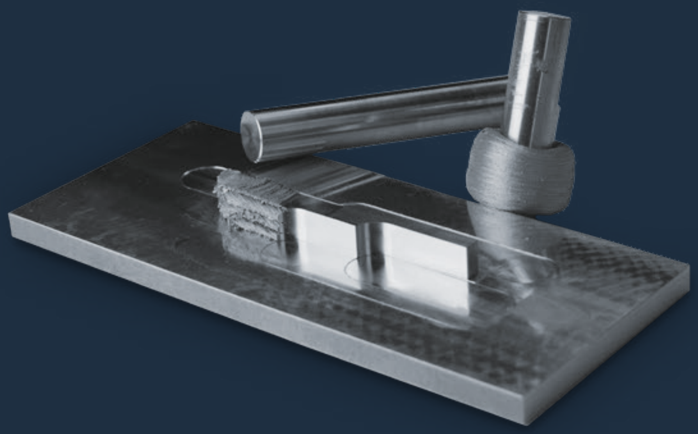
The major advantage is processing of metallic materials in the solid phase. The severe plastic deformation results in a fine-grained microstructure that exhibits good ductility, strength and toughness comparable to its wrought counterparts. We see in general no anisotropy of the mechanical characteristics and no internal defects.
Another potential advantage comes into play when considering joining of dissimilar metals. Certain metallic materials as e.g. Fe and Al cannot be combined well using fusion-based welding processes due to the formation of brittle intermetallic phases. With this solid-state process technology, however, dissimilar metals such as nickel based alloys with steel as well as aluminium with titanium or aluminium with steel, respectively, can be joined.

What other AM or traditional manufacturing technologies do you see as competition to your technology?

The technology of Friction Surfacing Layer Deposition does not directly compete against other Additive Manufacturing solutions. The production speed is similar to other DED technologies such as Wire Arc Additive Manufacturing.
The use of the FSLD technology in its current state will remain a niche application for prototyping, building high strength thick walled structural parts, local modification and repair of e.g. deep draw dies. An example of an application is shown at the lower aircraft fuselage structure demonstrator in our department. Here, we study the use of the process for selective strengthening of aerospace components, by adding a local reinforcement at locations of stress peaks, i.e. near the window frame, so that we are able to increase the components load capacity and avoid failure.

Prof. Dr.-Ing. habil Benjamin Klusemann
Head of department

Institute of materials research
Department solid state joining processes
at Helmholtz-Zentrum Geesthacht, Germany



Fast facts on HELMHOLTZ-ZENTRUM GEESTHACHT

First alloy: Aluminum
First industry: Aerospace
First application: High strength simple geometry structural part

DEMONSTRATOR WITH SPENT AND NEW STUD
COURTESY OF RASMUS LEISSNER

Where do you see boundaries or limitations?

Limitations are certainly the machinery due to the need for high stiffness, to cope with the high process forces and moments. Also, thin-walled structures are currently difficult to manufacture due to the high process forces during the e.g. plastification. Moreover, today's machines are mainly used in R&D environments with manual CNC programming. The technology therefore lacks tools and algorithms for automation and integration into industrial CAD and CAM software solutions. Nevertheless, due to the process being purely mechanical, this is a challenge that can be easily overcome.

What has been the most challenging hurdle to overcome, the most challenging development?

Finding a robust process parameter window is required to achieve uniform quality of all applied layers. However, once a suitable set is established the process is rather stable and achieves very good repeatability and good quality deposits.

In 5 years, what is your vision regarding this technology?

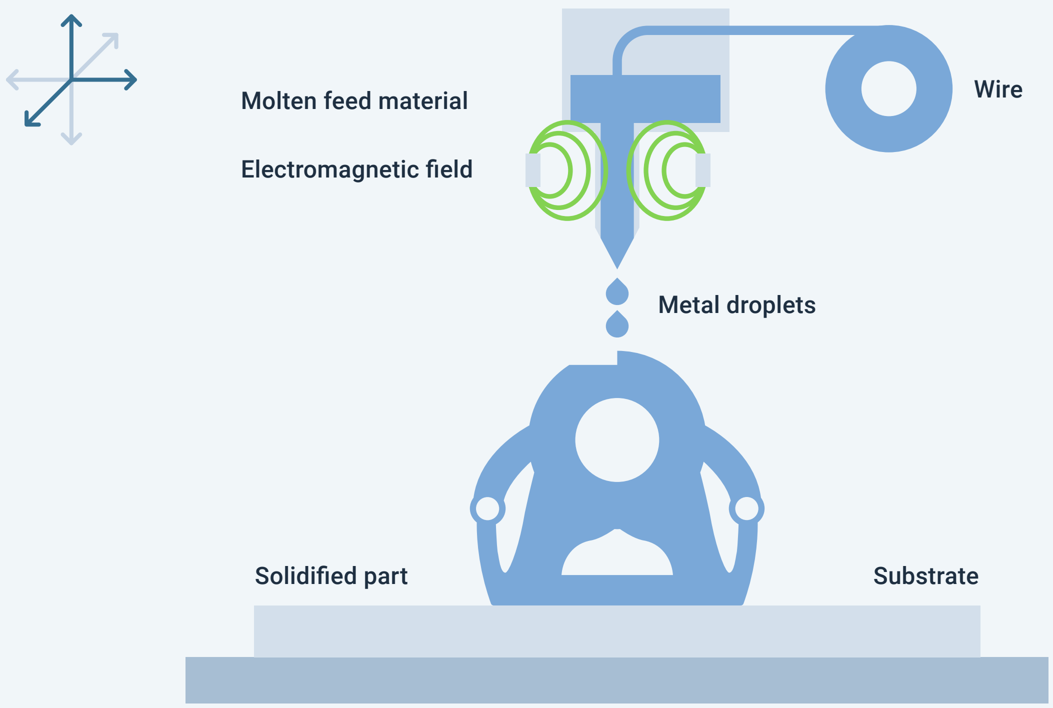
Besides prototyping, that we already see today, in 5 years this technology will be on the road to enable first industrial products. Robotic applications of the technology will be a reality by then. Applications in the aircraft and space structures will have to undergo qualification procedures, which can be lengthy in some cases.

Dr. Arne Roos
Group Leader

Institute of materials research
Department solid state joining processes
at Helmholtz-Zentrum Geesthacht, Germany

Liquid Metal Printing

Liquid Metal Printing was first introduced by VADER SYSTEMS before the company was acquired by XEROX. The technology uses droplets of molten metal that are deposited on a base plate to directly create the part.



Liquid Metal Printing is a technology initially developed by the family startup VADER SYSTEMS that got acquired by XEROX in 2019.

The process uses common welding wire which is fed into an inductively heated melting pot. At the bottom of the melting pot, the molten material is running through a small nozzle which is surrounded by an electromagnetic field. By triggering pulses of the field, single droplets are formed. The droplets fall freely on the substrate plate and solidify at once. Droplet forming, size and frequency are controlled by the electromagnetic field and the nozzle diameter.

Currently, the inventor of the technology focuses on process development for aluminum alloys. With 6061 and 7075 alloys, the technology is capable of processing high strength materials, which are currently not feasible with many other metal Additive Manufacturing technologies.

Potential

Low cost and high strength alloys

- **Low cost**
  Usage of low-cost wire feedstock, high potential throughput for serial system.

- **High value materials**
  High strength aluminum alloys are opening new business cases based on the casting industry for automotive and aviation.

Technology Maturity Index

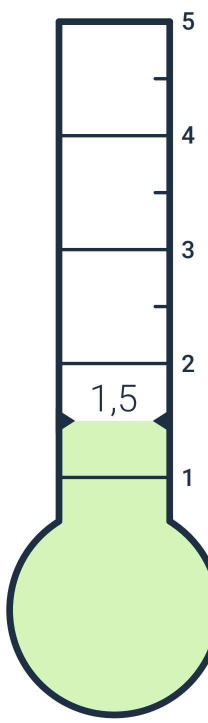
Technology at the beginning of its development

1 **Series production capability:**
R&D on manufacturing use and application development.

2 **Process capability:**
The process yields solid parts. Independent analysis of properties missing.

2 **Machine concept:**
Alpha/beta machines running.

2 **In-process quality control:**
Sensors tracking system parameters.



Liquid Metal Printing

Interview with XEROX

What was the initial idea to look into the technology?

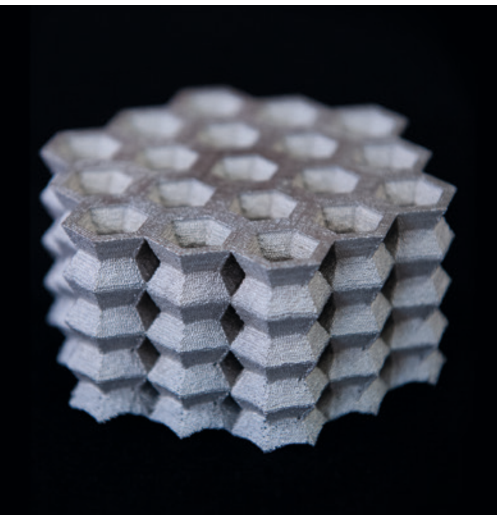
XEROX has been in the additive manufacturing (AM) market for more than 20 years, and today our inkjet printheads are used by leading 3D print equipment manufacturers in their systems. We always knew we were going to enter the 3D print industry with our own product, and when we acquired the liquid metal technology from VADER SYSTEMS in January of 2019, it gave us a differentiated offering to bring to the market. We have spent the last year using XEROX's experience in equipment design, software, and materials to commercialize the technology, and we are excited to bring our first product to market later this year.

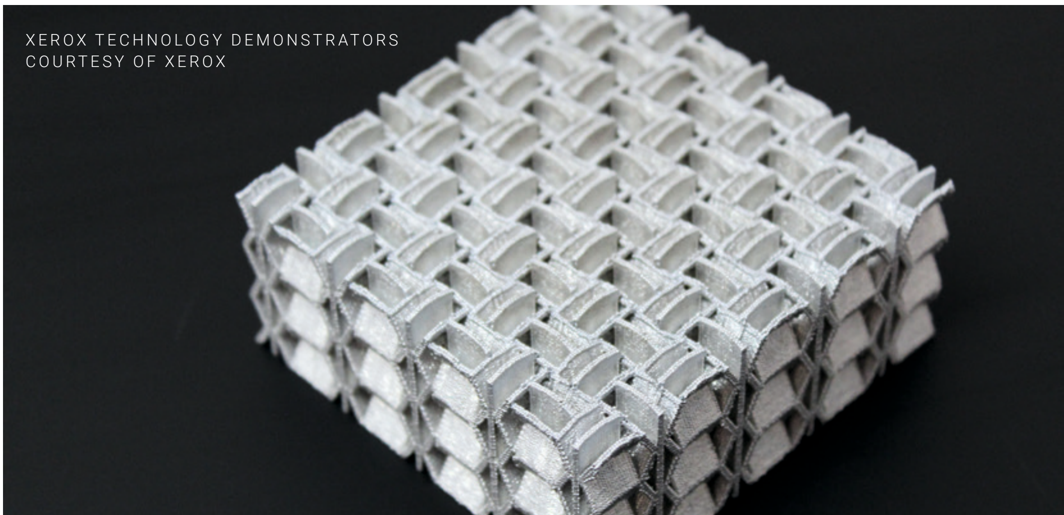
Can you summarize the unique selling point of your technology?

Our liquid metal technology uses off-the-shelf alloys, which means parts are denser, faster to make, and cheaper compared to those made with metal powders. Our AI-based 3D software improves the digital manufacturing process — from part design and costing to production and performance analysis — while achieving consistent and predictable part quality. Pairing these two technologies will allow manufacturers to design and fabricate parts that meet their structural and cost requirements on the first try.

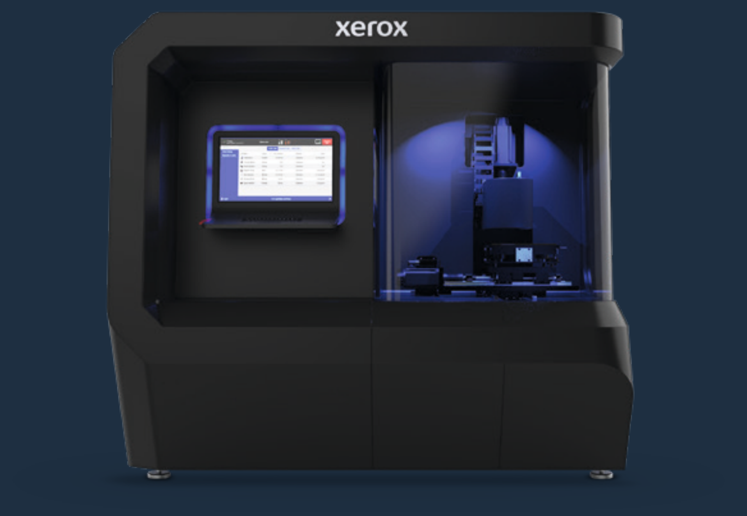
What other AM or traditional manufacturing technologies do you see as competition to your technology?

The main competition in the AM field are processes that use metal powders. However, unlike metal powders, the metals used in liquid metal are the real alloys, so manufacturers can design parts using materials they are used to working with. Liquid metal eliminates many of the post-processing steps associated with metal powders, such as depowdering, debinding, and sintering, which are timely and costly steps. It's also much safer than processes which use metal powders, so manufacturers do not need to make any significant facility changes.





XEROX TECHNOLOGY DEMONSTRATORS
COURTESY OF XEROX



Fast facts on XEROX

First alloy: Aluminum 4008 and 6061
First industry: Automotive/Transportation/Aerospace
First application: Parts/tooling
Commercial availability: 2020

XEROX PRODUCTION MACHINE
COURTESY OF XEROX

Where do you see boundaries or limitations?

The largest boundary is one that the entire industry is facing: full-scale buy-in of the technology from manufacturers. While some have been quick to see the advantages of 3D, others are taking a more cautioned approach. In order for 3D to take hold in true manufacturing, the industry needs to focus on the nuts and bolts, like design for additive, better integration into manufacturing workflows, standards, and other areas beyond the print technology.

What has been the most challenging hurdle to overcome, the most challenging development?

The biggest challenge has been taking what started as a small operation focused on a technology and moving it towards being a revenue generating business. Thankfully, we have a lot of experience doing this at XEROX. We have relied on our expertise in jetting, print process, software, and materials to advance the technology, while also developing a business plan to bring a commercial product to market by the end of 2020.

In 5 years, what is your vision regarding this technology?

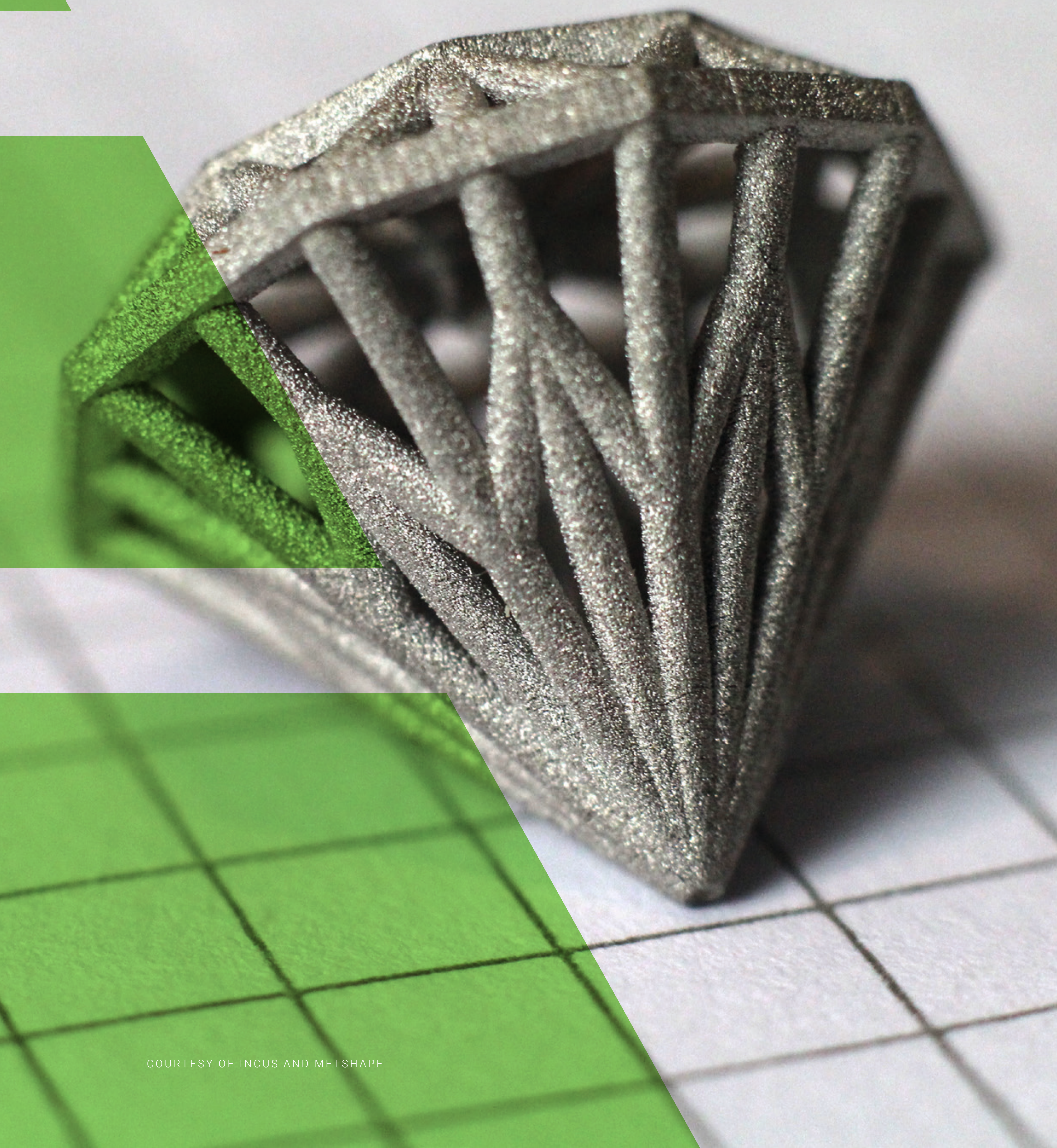
There are many different options for where our liquid metal technology can go in the future. While we are focused right now on bringing our first commercial product to market, we could look at faster print speeds, materials beyond aluminum alloys, larger build volume, multiple materials, and printed electronics applications.

Kevin Lewis

Business Lead for Additive Manufacturing at XEROX

During his almost 28 years at XEROX, he has held leadership roles in engineering, business unit operations, voice of the customer and product planning, competitive intelligence, and strategy.

New sinter-based technologies

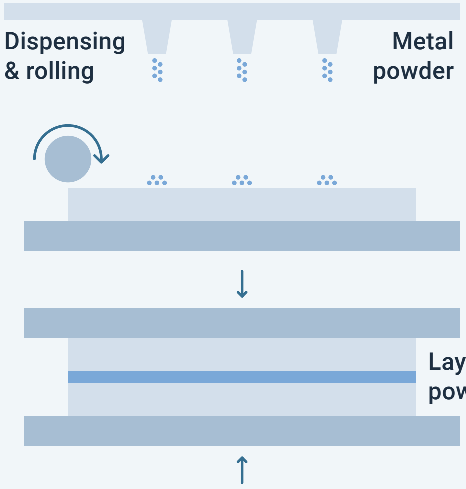


COURTESY OF INCUS AND METSHAPE

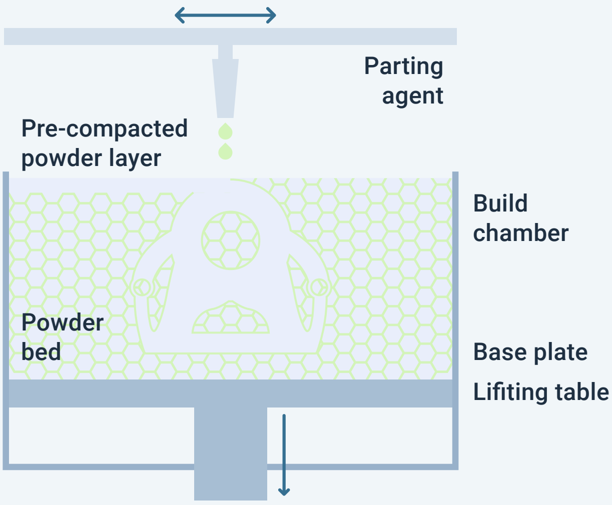
Powder Metallurgy Jetting

Since a few years STRATASYS is developing a technology named “Layered Powder Metallurgy”. Unlike other AM processes, the technology is working in several sequences.

1 Powder layer compaction



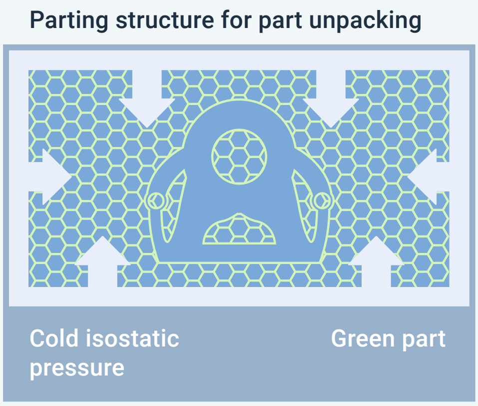
2 Contour jetting



In a first sequence, non-uniform powder is spread out in a layer followed by applying mechanical force to is press and compact the powder layer. This “sheet” of metal powder is moved and stacked in a printing chamber. On each layer, a wax-based material (parting agent) is applied onto the metal powder at the outer contours of the part. Additionally, the parting agent is used to divide larger areas where no part is present (“supports”).

After adding the last layer, the complete build job stack then undergoes a cold isostatic pressing process, which densifies the powder up to 96 %. After this densification, the parting agent wax and the support material surrounding the part are removed. The final part properties are achieved in a sintering process that increases the density further. The high compaction during the cold isostatic pressing allows for a sintering process of aluminum alloys, which consequently is the focus material at the moment.

3 Green part densification



First STRATASYS machines are currently installed at alpha customers for testing and evaluation. Public presentation of the process and the machines are expected at the end of 2020 with commercial release of the technology early 2021.

Potential

Leveraging powder metallurgy know-how

- **Low Cost**
  The use of low cost MIM powder and existing press sintering technology has potential for a low-cost AM process.

- **Wide material range**
  Since the printing process is mostly independent from the alloy, it is expected to be suitable for existing range of powder metallurgy materials.

- **Leveraging of PM industry experience**
  The process has similarities with powder metallurgy technology. Low-cost powder can be processed in high speed.

Technology Maturity Index

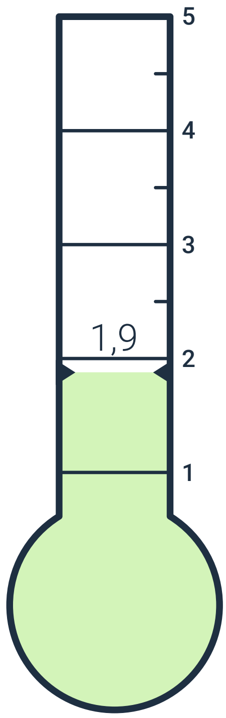
Multi step process with many interfaces

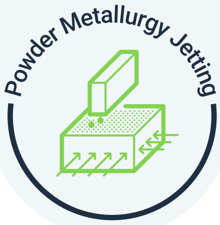
2 **Series production capability:**
First production setups in testing.

2 **Process capability:**
The process yields solid parts. Independent analysis of properties missing.

2 **Machine concept:**
First systems at beta customers running.

1 **In-process quality control:**
Many uncertainties for process control due to multi sequence process.





Interview with STRATASYS

What was the initial idea to look into the technology?

Despite the advantages of metal AM, high costs and low throughput prevent metal AM from being considered viable for low-mid volume applications (1,000's-10,000's of parts per year).
In addition, Metal AM today is focused on high end alloys like titanium and nickel, whereas the majority (75 %+) of the consumption in the global metal market is in mainstream alloys such as iron, steel and aluminum.
Therefore, we have decided to develop a new technology named LPM (Layered Powder Metallurgy). LPM is the first of kind metal AM tech designed for low-mid volume production apps, using standard low-cost PM powders at unrivaled throughput and optimized to process mainstream alloys.

When and what was the situation where you realized this is something we can go to market with?

In the last 2 years we were impressed by the quality of the parts produced with LPM while demonstrating the above-mentioned principles. At that point, we decided to make our first public announcement regarding the development of this technology.

Can you summarize the unique selling point of your technology?

With LPM, we can offer the freedom of design AM can offer, but at the same time at 10x+ lower cost, 10x+ higher throughput and utilizing a process which is best suited for mainstream alloys.
Given the above, we believe LPM is the world's first AM technology that can really be compared on a cost level to traditional metal manufacturing technologies in low-mid volume production applications.

Ronen Lebi

VP of Corporate Development at STRATASYS

New key growth initiatives, investments, joint ventures and establishment of new technology platforms such as LPM at STRATASYS
Prior to STRATSYS strategic management consulting and investment banking services
Bachelor's degree in Agricultural Economics, Hebrew University, Isreal and MBA, Interdisciplinary Center, Israel & Wharton School, University of Pennsylvania, USA

Fast facts on STRATASYS

First alloy: Al 2014
First industry: Automotive
First application: Housings/Covers and brackets for automotive
Commercial availability: Not publicly disclosed yet

DEMONSTRATOR PARTS STRATASYS TECHNOLOGY
COURTESY OF STRATASYS

What other AM or traditional manufacturing technologies do you see as competition to your technology?

In the metal AM space, we don't have a direct competitor as we address different applications. However, we are frequently compared to Binder Jetting given the compelling economics and high throughput both are aiming to offer. We believe LPM has advantages in the type of materials we can print (starting with Aluminum) and the larger size of the parts we can make, in a process which is fundamentally different from Binder Jetting and which involves compaction, enabling us to guarantee high density and dimensional stability from the green part to the final sintered part.
In the traditional space, some of the applications we target can be done with investment or die casting or metal injection molding.

Where do you see boundaries or limitations?

Our technology is less suited for very small applications that require very tight tolerances or ultra-fine features. In addition, our technology may be less appealing for processing parts made from expensive materials like titanium.

What has been the most challenging hurdle to overcome, the most challenging development?

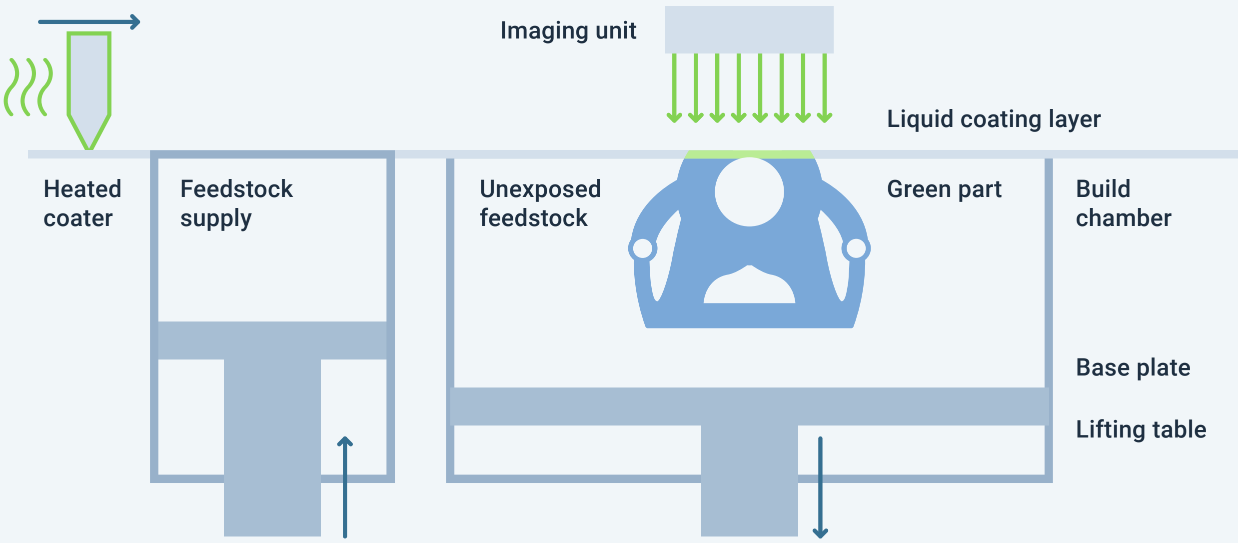
As this is new Additive technology, we had to build from ground up the process parameters across the entire process to achieve optimal and stable part quality and properties. Obtaining such parameters requires establishing a very diverse set of expertise beyond printing, including chemistry, software (advanced simulation), metallurgy and industrial hardware (compaction and sintering).

In 5 years, what is your vision regarding this technology?

In 5 years, we envision this technology to become widely adopted for serial production of select applications and perceived by the market as a fundamental metal AM technology.

Metal Lithography

The Metal Lithography technology is developed by companies such as INCUS and their partner METSHAPE. It is based on the well-established Stereolithography technology.



Stereolithography was the first publicly announced Additive Manufacturing technology. The technology is based on a photochemical process by which light causes chemical monomers and oligomers to cross-link together to form polymers.

Metal Lithography is utilizing this technology principle. However, the photosensitive polymer binder is mixed with metal powder creating a new kind of feedstock. Like in Stereolithography, the material is spread out in a thin layer and afterwards a UV-light projector selectively cures the polymer binder.

The result is a polymer component that contains a high fraction of metal powder particles. This green part has to go through a debinding and sintering process like all other sinter-based technologies.

Many of the advantages of Stereolithography like high accuracy and low cost, can be transferred to Metal Lithography.

First machines have been installed at a service bureau and parts can be ordered on demand.

Potential

Productive manufacturing of high-resolution parts

- **High accuracy**
  Fluid components and Stereolithography curing technology enable fine details.
- **Low cost**
  Potentially low cost and high productivity by stacking.
- **High surface quality**
  High surface quality possible through fine resolution.

Technology Maturity Index

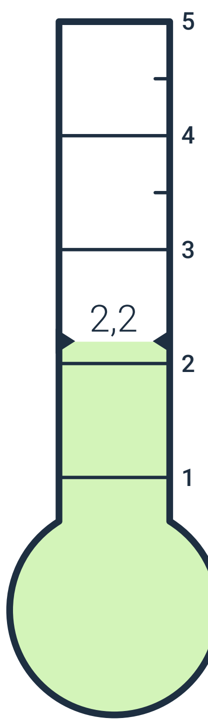
Multi source is pushing maturity

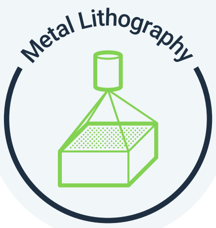
2 **Series production capability:**
Currently in between R&D and pre-production testing.

3 **Process capability:**
The process yields solid parts. Independent analysis of properties missing.

2 **Machine concept:**
No serial systems. Currently alpha/beta systems in use.

1 **In-process quality control:**
No process monitoring available yet.





Interview with INCUS and METSHAPE

What was the initial idea to look into the technology?

The lithography-based 3D printing approach is already applied to high-performance ceramics and plastics. We want to use the benefit of high surface aesthetics combined with MIM-like material properties, since we see that this combination is often missing in metal AM.

When and what was the situation where you realized this is something we can go to market with?

After seeing the first sintered part and confirming the proper material properties.

Can you summarize the unique selling point of your technology?

Surface aesthetics combined with similar material range and resulting material properties compared to metal injection molding

What other AM or traditional manufacturing technologies do you see as competition to your technology?

Other 2 stage or indirect processes, such as Binder Jetting

DEMONSTRATOR PART: CHAIN
COURTESY OF INCUS AND METSHAPE

Dr. Gerald Mitteramskogler
CEO at INCUS

Since September 2019 CEO of INCUS
Heading metal division at LITHOZ, Austria
Master's degree in mechanical engineering and dissertation at Vienne University of Technology, Austria

Fast Facts on INCUS and METSHAPE

Founding of INCUS: September 2019
Founding of METSHAPE: April 2019
Investors INCUS: AMV
First alloy: Stainless steel 316L
First industry: Jewelry
First application: Ring
Commercial availability: 2020

DEMONSTRATOR PART: GEAR WHEEL
COURTESY OF INCUS AND METSHAPE

Where do you see boundaries or limitations?

Similar limitations compared to MIM.

What has been the most challenging hurdle to overcome, the most challenging development?

Development of a debinding cycle for more demanding materials, such as Titanium.

In 5 years, what is your vision regarding this technology?

That LMM is standard for a ramp-up production of complex parts prior to MIM or even as a substitute for mid-level quantities.

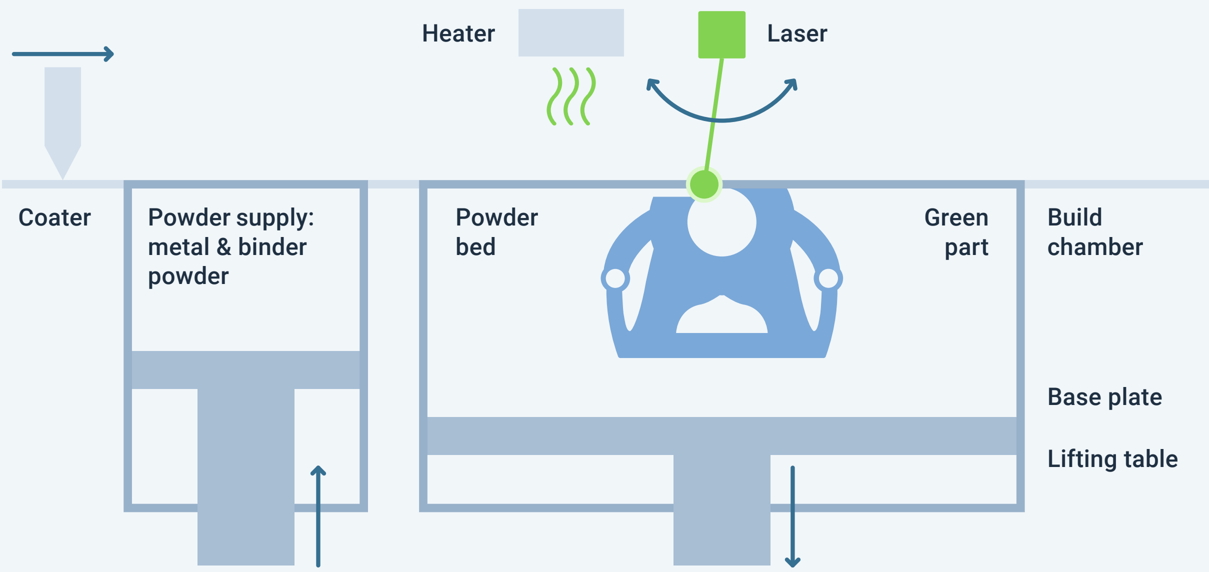
Dr. Andreas Baum

CEO at METSHAPE

CEO of METHSAPE, service supplier of Metal Lithography
Dissertation TU Dresden, Germany
Dipl.-Ing. in mechanical engineering at HS Pforzheim, Germany

Metal SLS

The Metal SLS technology was invented by the startup HEADMADE MATERIALS from Germany. The technology is based on the well-established Selective Laser Sintering technology, which is primarily used to produce polyamide components.



Selective Laser Sintering is one of the oldest and most mature AM technologies with a high industrial penetration level. Many end use parts such as spectacle frames are manufactured in large quantities. In prototyping of industrial polymer parts, SLS is the most common technology due to superior surface quality and material properties.

The Metal SLS technology is enabling this machine technology to print metal green parts. Instead of polymer feedstock, a powder compound is used made of polymer and metal powder. This powder is loaded into the standard SLS machine and the chamber is heated close to the glass temperature of the polymer. The laser system melts the polymer component creating metal green parts. The following debinding and sinter process are very similar to other sinter-based technologies, such as Metal FDM or BJT.

Potential

Utilization of existing SLS installed base

- **Fast availability**
  Nearly every SLS system can process the material, thus turning polymer systems into metal systems.

- **Low threshold**
  SLS systems are well known and have a high degree of maturity.

Technology Maturity Index

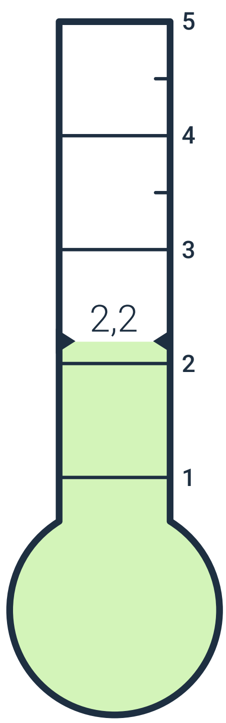
High maturity due to well-proven system technology

2 **Series production capability:**
The SLS technology has high production rates, however, this is yet to be shown for the metal SLS feedstock.

2 **Process capability:**
The process leads to dense sintered parts but still shows variance in material properties.

3 **Machine concept:**
The systems are available as off-the shelf series machines. However metal process has to be established.

3 **In-process quality control:**
SLS technology offers a high degree of process control.



Interview with HEADMADE MATERIALS

What was the initial idea to look into the technology?

During the time at the research institute SKZ, which has a lot of experience with processing highly filled polymers in Additive Manufacturing, my colleague Christian Fischer and I became aware of the great potential of sinter-based technologies. Motivated to shape the future Additive Manufacturing landscape we started five years ago to develop our Cold Metal Fusion technology ('Metal SLS').

When and what was the situation where you realized this is something we can go to market with?

Having our first prototype in hand with a density of 96 %, we realized that we really made a big step and had superior properties compared to other technologies at that time. Just being at the beginning of our development we recognized the great potential to serve an enormous market need with our idea.

Can you summarize the unique selling point of your technology?

Our materials are processable on standard machines enabling a lot of customers to produce metal parts cost efficient on an existing, mature and scalable machinery. No other AM technology offers easier adoption possibilities.

Our customers also appreciate our very high green part strength which allows not only a process-reliable serial production but also the possibility to rework green parts (grinding, milling, joining) before the sintering step.

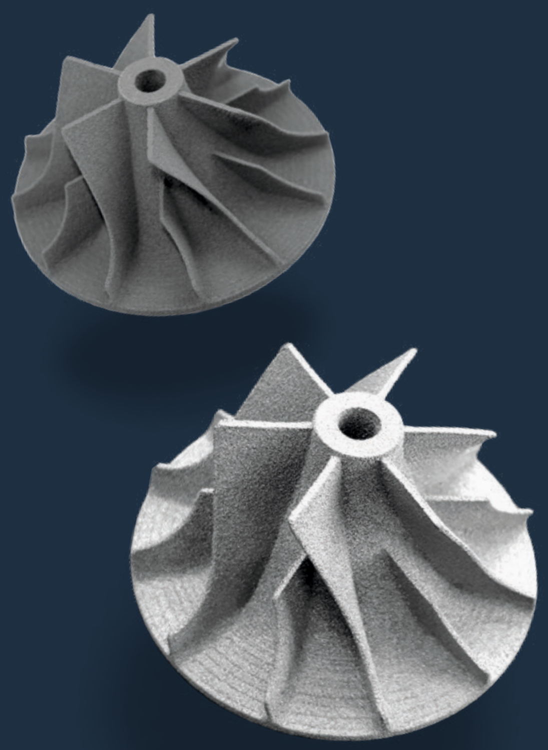
What other AM or traditional manufacturing technologies do you see as competition to your technology?

Our Cold Metal Fusion technology bridges the gap between metal LB-PBF and conventional powder metallurgical processes and is complementary to these processes. Other developing sinter-based technologies like BinderJetting are also tackling that emerging part of the metal market.

Christian Staudigel

Managing Director of the HEADMADE MATERIALS

6 years research and industry projects at SKZ
4 years in automotive industry at SAMVARDHANA MOTHERSON PEGUFORM
Master's degree material science, Friedrich-Alexander-University Erlangen-Nuremberg, Germany and Master's degree in business administration, Julius-Maximilians-University Wuerzburg, Germany



Fast facts on HEADMADE MATERIALS

Founding of company: April 2019
Investors: not disclosed
First alloy: Stainless steel 316L
First industry: Medical industry
First application: Housing
Commercial availability: Machines are already on the market, materials for a broad bases at the end of 2020

IMPELLER – GREEN PART (TOP) AND SINTERED (BOTTOM)
COURTESY OF HEADMADE MATERIALS

Where do you see boundaries or limitations?

Like all sinter-based technologies the most significant limitation is the part size. Due to the sintering process problems like distortion and fracture increase with part size.
Our 3D-printing process allows you a lot of freedom for design and part size. The limitation is definitely set by the sintering process to avoid distortion and fracture. But compared to classical sinter-based approaches like Metal Injection Moulding, we increase the possibilities for the sintering step, also for larger part designs.

What has been the most challenging hurdle to overcome, the most challenging development?

Like all developing companies we face a lot of challenges like technical issues, finding skilled employees, choosing the right partners, assess the market and customer development in the right direction and so forth. I think for me the most challenging step was mentally to follow in the footsteps of an entrepreneur with all its different tasks and duties.

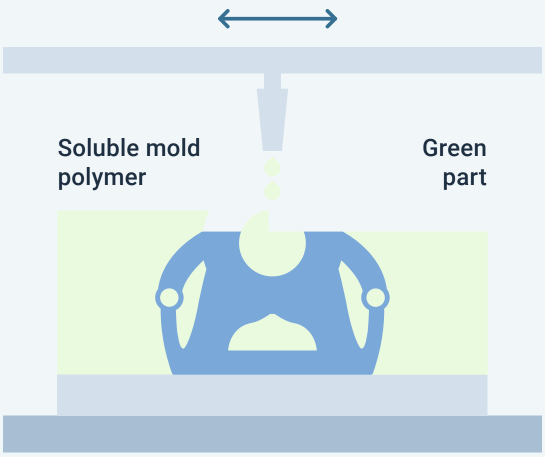
In 5 years, what is your vision regarding this technology?

To be one of the leading technologies in 3D-printing and to unlock the tremendous potential by enabling our customers to produce better products in a more cost-efficient way. Or in a few words: Printing a better world!

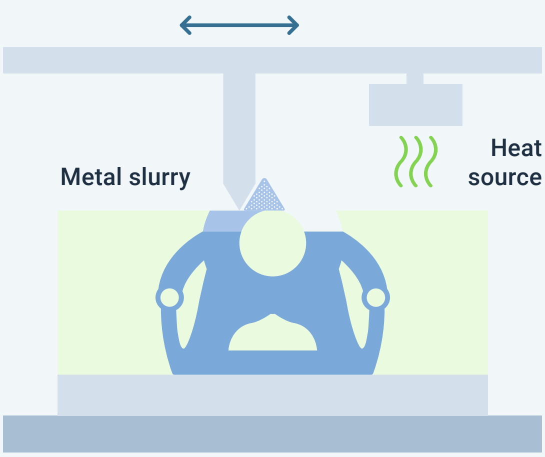
Mold Slurry Deposition

The Slurry Deposition process is known for processing ceramic materials. Isreal based start-up TRITONE stealthily developed a new process method for metal materials and went public with their solution MoldJet™ at Formnext 2019.

1 Mold jetting



2 Slurry deposition



The centerpiece of TRITONE’s machine prototype is a horizontally rotating carousel, that delivers the working platform to stations with different functions. At the first station, a soft polymer or wax is printed to form a mold, which is filled with a layer of slurry at the following station. The proprietary slurry is made up from metal powder and a binder component. The slurry is dried before the process continuous with the next layer. TRITONE’s prototype machine already incorporates a quality control and feedback loop by analyzing each layer and eventually “scrapping” and re-printing single layers, if quality issues occur. The final part out of the printing process is in green state. It needs to be removed from the mold material, debinded and sintered to achieve final metal material characteristics A wide range of materials are already available, such as steels, titanium alloys as well as copper- and nickel-based materials.

Potential

High cost-saving potential through use of MIM powders

- **Well-known alloys**
  The slurry is based on readily available and low-cost MIM powder. However, feedstock at this point is proprietary.

- **Medium batch size**
  With a rather high deposition rate the technology has the potential to cover medium batch sizes of several hundred to thousands parts.

Technology Maturity Index

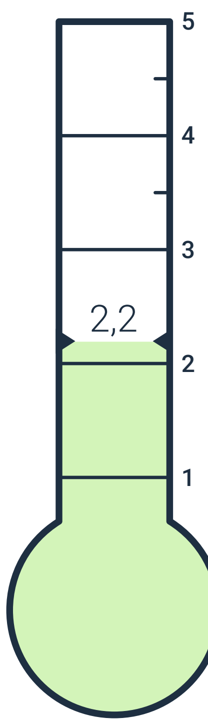
Prototype machine with high output capabilities

2 **Series production capability:**
Currently in between R&D and pre-production testing.

3 **Process capability:**
Capable process for specific parts.

1 **Machine concept:**
Prototype machine running.

4 **In-process quality control:**
In-process quality control implemented.



Interview with TRITONE

What was the initial idea to look into the technology?

We see the metal 3D printing as a natural development of the 2D Digital printing. The revolution that the digital printing brought to the printing world, should now be copied and executed in the metal manufacturing world.

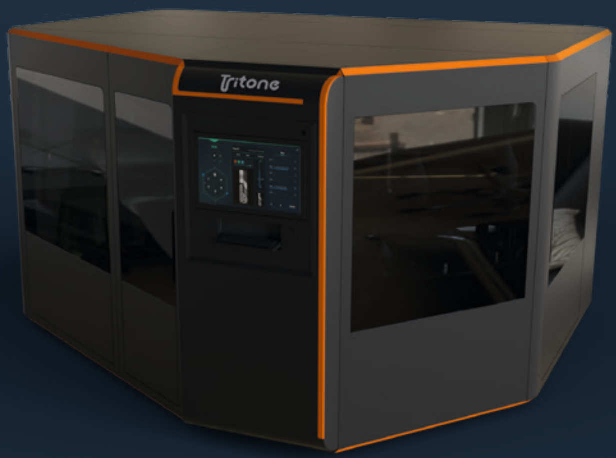
Can you summarize the unique selling point of your technology?

We believe our MoldJet™ technology has a few unique advantages which differentiate us from other technologies in the market. First, we keep a safe and clean industrial environment by utilising a powder-free process using metal or ceramic paste in sealed cartridges. Second, we offer a wide range of materials (we can use any standard MIM powder as a basis for our paste) that can be easily changed between jobs in an industrial manufacturing throughput of 1600cc/hr. Our MoldJet™ technology enables an accurate print of big and small parts with fine detail and high surface quality. In addition our "green parts" are very dense and easy to handle which leads to up to 99% density of the sintered part.

What other AM or traditional manufacturing technologies do you see as competition to your technology?

Basing our technology on powder metallurgy, we see our technology a complementary solution for MIM, PM press and CNC. For MIM, we can be the solution when small-medium quantity or big parts production is required and for CNC we can print the parts efficiently and accurately and only when extra accuracy is required to complete with CNC and by that saving a lot of time, materials and of-course producing geometries that cannot be done by any of the traditional technologies.

DEMONSTRATOR PARTS TRITONE TECHNOLOGY
COURTESY OF TRITONE



Fast facts on TRITONE

Founding of company: 2017
Investors: FORTISSIMO CAPITAL
First alloy: Stainless steel 316L
First industry: Tooling
First application: Complex drill made from H13 tool steel
Commercial availability: 2021

RENDER OF TRITONE DOMINANT PRINTING MACHINE
COURTESY OF TRITONE

Where do you see boundaries or limitations?

Even today, when approaching to design a new part, the developer has to take into account the production technology which will be the most suitable for this. The first challenge which we have identified is to take into account in advance that additive manufacturing is one of the solutions that is in the production "tool box" – this challenge is shared for all the AM providers and mainly related to market education. The second challenge is to understand the sintering process and how to design the part according to the guidelines (which are similar to MIM).

What has been the most challenging hurdle to overcome, the most challenging development?

In a complex multidisciplinary development like we do, the most challenging part is to make sure that the SW, HW, mechanics and chemistry are all working together in a perfect sync. On top of that, we aim for manufacturing and hence must be compliant with the demanding manufacturing requirements such as: safety (mainly via powder-free environment), throughput, accuracy & repeatability, part quality, variety of materials, etc.

In 5 years, what is your vision regarding this technology?

Our vision is that our MoldJet™ technology will be a standard when it comes to metal parts production and will be used side by side and complete the existing traditional technologies .

Omer Sagi

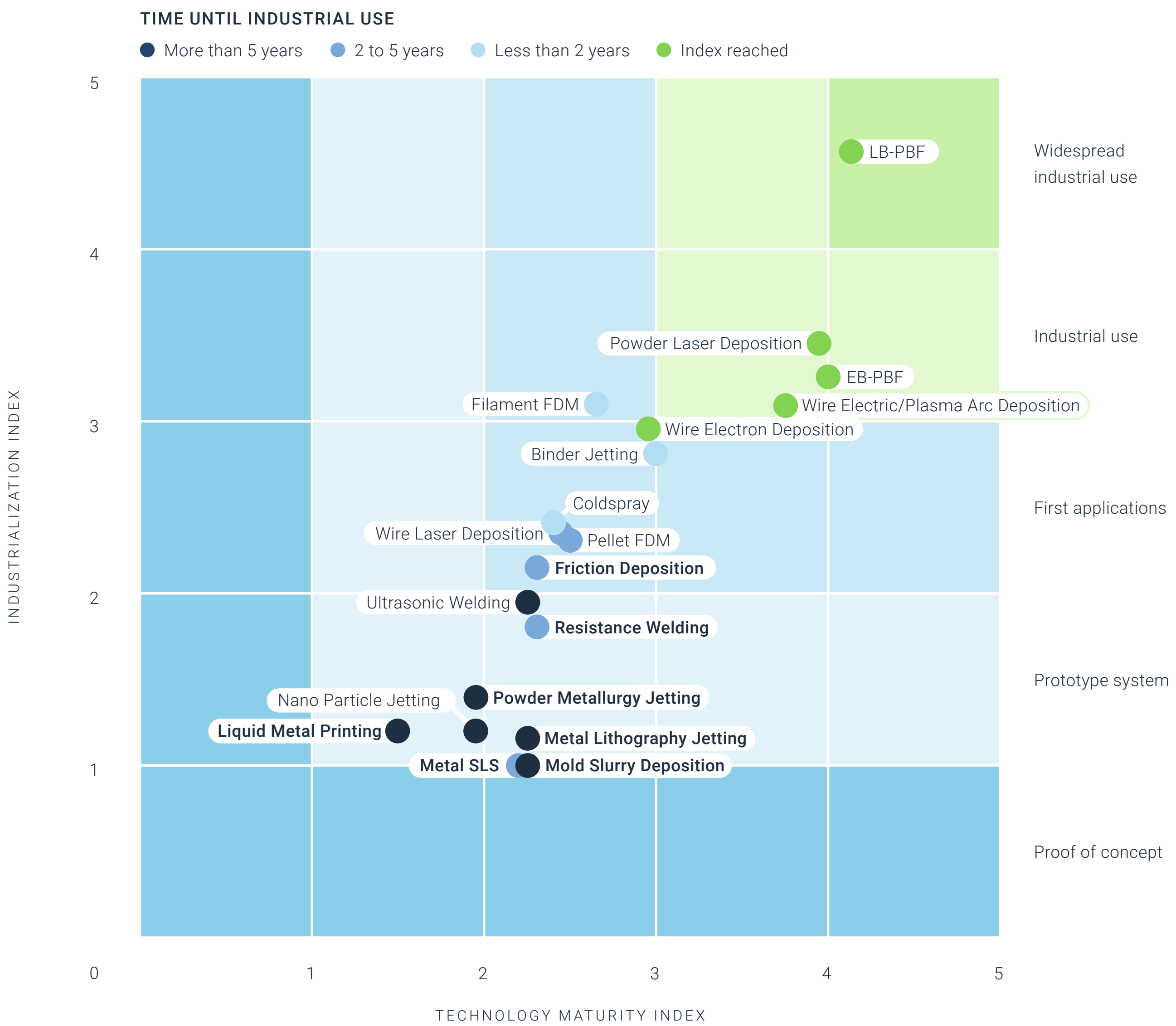
VP of Products and Business Development at TRITONE

Heading multi-million Euro business of Smart Access & IOT solutions for ASSA ABLOY, London. Prior director of products for CONNECTED IOT. Sales, business development and R&D roles at SIEMENS, STRATASYS and APPLIED MATERIALS.
B.Sc. in biotechnology engineering, Ben-Gurion University, Israel, M.B.A. Interdisciplinary Centre Herzliya, Israel, Executive Leadership Management Program IMD business school Lausanne, Switzerland

Evaluation of new technologies

The new metal Additive Manufacturing technologies offer great potential, but will require, in general, several years to achieve industrial relevant maturity. The use of existing AM infrastructure (Metal SLS), unique materials (Friction Deposition) or appealing production speeds (Resistance Welding) promise a faster adoption rate. On the other hand, many sinter-based technologies will struggle to differentiate from each other and will probably only be used in niche applications.

Maturity index of new AM technologies



Future AM mega trends

Industrialization

The Additive Manufacturing suppliers will have to fulfill the increasing requirements from industry that call for higher productivity at lower cost. Key aspects will be the use of low-cost feedstock, automation of the printing process as well as scaling of the machines and processes while maintaining robust production.

Moreover, on the road to larger batch sizes and wide industrial acceptance, AMPOWER expects following general milestones have to be achieved as game changers:

Use of low-cost wire and MIM powder feedstock

System prices below 300,000 €

Material build-up rates beyond 100 cm³/h

New principles and materials

Several new principles are on the verge to be introduced on an industrial level. While for years the only mature technology was powder-bed based, more and more technology principles become industrially feasible and have to be considered when users choose the right technology for their applications. With ongoing developments a wider range of alloys or even multi material approaches will be available that allow for new part functionalities and material properties.

Sustainability

A major theme of our time is the consideration of finite natural resources that call for efficient processes. Metal Additive Manufacturing can play a major role in improving the environmental footprint of a production process by reduction of waste, but also in improving the energy balance over the complete part life-time by providing high-performance and light-weight parts to perform their task.

About the authors

Dr.-Ing. Maximilian Munsch

Maximilian is a professional user of Additive Manufacturing since 2007. In his first affiliations he acquired extensive knowledge in Laser and Electron Beam Powder Bed Fusion for medical applications. He was responsible for the installation and qualification of AM production lines, today turning out over EUR 10 million in revenues, and supported multiple implant manufacturers, among others, setting up a qualified LB and EB-PBF production for regulated applications.

Matthias Schmidt-Lehr

Matthias successfully led multiple projects in Additive Manufacturing with focus on business case and strategic development for AM users as well as system and material supplier. With a history in management consulting he has a wide experience in business development, strategy development and communication. At AMPOWER he led multiple projects concerning DED, BJT and Metal FDM as well as a wide range of polymer AM technologies.

Dr.-Ing. Eric Wycisk

Since 2008 Eric successfully supports OEMs from aerospace, medical and automotive to identify Additive Manufacturing applications and implement production capacities in their regulated environments. With a background in topology optimization, titanium alloys and fatigue he is focused on achieving the maximum part performance with the right AM technology.

Missed out on our previous issues?

Vol. 1: Additive Manufacturing – Make or Buy
Additive Manufacturing became a game changer in many industries. Especially for SMEs, however, high part costs are still the main restriction for further wide-spread adoption of this production technology. AMPOWER Insights Vol. 1 gives a detailed calculation of production costs and introduces the ratio of cost per unit of volume for an easy comparison of technologies and materials.

Vol. 2: Additive Manufacturing of Automotive Components
Medical and Aerospace companies count among the early adaptors of metal Additive Manufacturing. The usually highly innovative automotive industry, however, so far struggles with the high manufacturing cost of Additive Manufacturing. An exception are high performance cars with low production volumes and demand for customization. In the second issue AMPOWER Insights provides a deep dive into the manufacturing route of high performance automotive components.

Vol. 3: Metal Additive Manufacturing with sinter-based technologies
In this study, AMPOWER presents an objective and independent view on the current capabilities of sinter-based AM technologies compared with LB-PBF and metal injection molding (MIM). By analyzing over 50 specimens from 9 different system suppliers, AMPOWER is revealing the characteristics of the different technologies.

Vol. 4: Quality in Additive Manufacturing
Additive Manufacturing is entering industrial serial production. Especially in regulated industries such as aviation and medical, the need for internationally accepted standards and proven practices for machine qualification is continuously growing. To meet this demand, AMPOWER Insights Vol. 4 presents a comprehensive approach and best practices to establish a qualified production environment and gives an overview on standardization efforts and published standards.

Vol. 5: Additive Manufacturing Business Strategy
The metal Additive Manufacturing market is a niche compared to the global market of metal products. However, the potential future market volumes are promising, and many companies are currently in the phase of market entry evaluation. AMPOWER Insight Vol. 5 presents an overview on the current status of the metal Additive Manufacturing industry and analyzes on how to derive a successful business strategy for suppliers as well as users of the technology.

Download **AMPOWER Insights Vol. 1-6**
at www.am-power.de/insights

COURTESY OF RÉMI CAPPON

Special thanks

We would like to thank our interview partners for their time, for providing media and, most of all, for providing invaluable insights into their respective technologies:

DIGITAL ALLOYS, HEADMADE MATERIALS, HELMHOLTZ-ZENTRUM GEESTHACHT, INCUS, METSHAPE, STRATASYS, TRITONE, XEROX

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Find market numbers and technology insights in the new AMPOWER Report

The AMPOWER Report provides the most detailed and comprehensive analysis of the state of the metal AM industry and its projected growth. Additionally, the report provides a deep dive into metal Additive Manufacturing technology. This first edition captures the state of the metal AM industry of the year 2018 and additionally provides a 5-year outlook based on the expectations of suppliers as well as users in this highly dynamic market environment.

Insights Gained

The **AMPOWER Report 2019** is the new reference for the metal Additive Manufacturing industry. It provides a detailed view on the AM market and state of the art AM technologies and generates a forecast of the developments expected in the next 5 years.

Market

- Market size 2018-2023
- Market by region 2018-2023
- Market by technology 2018-2023
- Market by industry 2018-2023
- Material market 2018-2023
- Degree of industrialization
- Investments
- Global system supplier database
- Global service supplier database
- Industrial application overview
- Industrial application database
- Methodology

Technology

- Process chain
- Design for Additive Manufacturing
- Materials
- Cost
- Laser Beam Powder Bed Fusion
- Electron Beam Powder Bed Fusion
- Powder Feed Laser Energy Deposition
- Wire Arc Additive Manufacturing
- Binder Jetting
- Metal FDM
- Coldspray
- Future Technologies

Features & Benefits

- Over 40 figures and graphs of AM market data
- Application database with over 50 industrial applications
- System supplier data based on personal interviews representing 80% of the globally installed base
- Online report with all data and figures directly accessible
- Global system and service supplier database with more than 120 entries each
- PDF report available

AMPOWER

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report@am-power.de

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Read the full report today:
additive-manufacturing-report.com

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