MANUFACTURING

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3D ADEPT MAG

3D PRINTING

CAN ADDITIVE MANUFACTURING PLAY A ROLE IN DRIVING HYDROGEN FUELED GAS TURBINES ?

METAL AM - POST-PROCESSING - SOFTWARE - MATERIALS

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3D ADEPT MEDIA
All about Additive Manufacturing

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Hello & Welcome

Temperatures are on the rise

We are back at this time of the year where our eyes and thoughts are focused on the upcoming Formnext event that will be held in Frankfurt from November 15th to 18th. Nobody will say it aloud, but there is this intense pressure for great performance and strong results, and companies' participation at Formnext is also a way to announce their new vision – if any – and strategy, and its implementation and outcomes are what we witness throughout the following year.

So, the heat might be on right now for companies given the trade shows season, but we also feel a different kind of "heat" with the growing concerns and pressure surrounding the fight against climate change and for sustainability; a fight that is spiralling out of control with the gas and energy problems that result from the war in Ukraine.

If we disregard these consequences for a second and focus on what we, understand "organizations", have the power to control, we will realize that the goal of finding a balance between preserving safety measures and "greenness" is a hard one to strike.

Indeed, it's one and easy thing to say we are "sustainable", it's another one to walk that talk. AM companies tend to forget the triple bottom line (people, planet and profit) that embodies a true sustainable vision to only focus on developing a sustainable product – for which it's often hard to deliver data.

In this edition of 3D ADEPT Mag, we wanted to put things into context. We have presented this «triple bottom line» in different articles and how it can be taken into account in a «sustainability vision» that includes additive manufacturing. Of course, some industries are more likely to integrate this principle, but demonstrating it through tangible data (possibly resulting from life cycle assessments) is the example others are waiting for to get to work. That's the whole point of this new issue of 3D ADEPT Mag.

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Editorial

Can Additive Manufacturing play a role in driving hydrogen fueled gas turbines ?

To avoid climate disaster, billions of dollars are invested in hydrogen, which should meet a quarter of our energy needs by 2050. To enable this transition, industries that produce carbon dioxide (CO2) have the biggest role to play in this fight. With the power generation sector totalling ~46% of global CO2 emissions from fossil fuels, most organizations are exploring a transition to the use of hydrogen as a zero-carbon gas turbine fuel. What does this renewable energy transition with Additive Manufacturing (AM) look like?

I might be working in a technology-focused trade press, but there are topics that have always sounded utopian for me. Hydrogen is one of them. It has always sounded so fictional…like in The Mysterious Island, a novel by French writer **Jules Vernes** (published in 1875), where an engineer explains to a journalist how water could eventually replace coal as an energy source. We are not very far from this reality today, as hydrogen increasingly receives attention as a possible cross-sectoral energy carrier that could allow emission reductions in several fields of activity, including hard-to-abate ones. And I need to admit it: this is not a Sci-Fi novel. This is happening.

Hydrogen is a clean fuel that, when consumed in a fuel cell, produces water. It can be obtained from water using solar- or wind-generated electricity. Since it does not release any CO2 when used as fuel, it would play a crucial role in the decarbonization of thermal power generation. Interestingly, gas turbines are only one amid several types of thermal power generation. To enable this transition to a hydrogen economy, organizations are rethinking the role of gas turbines while taking into consideration a number of variables unique to hydrogen.

The present dossier ambitions to understand the role of gas turbines in this renewable energy transition and the part AM can play to enable it. To address this topic, we will discuss the following items:

I – The role of gas turbines in a sustainable energy system

II – AM strategies one can explore to bring the hydrogen economy closer to an effective implementation across the entire thermal power generation sector or enable green hydrogen fueled gas turbines to start.

I - The role of gas turbines in a sustainable energy system

A gas turbine is a type of combustion engine that can turn natural gas or other fuels into rotational energy. They are currently part of the cleanest fossil-fuel based power generation solutions, can absorb the fluctuations of renewables and enable emission reductions, using low or carbon-neutral fuels like natural gas, biogas, industry waste gas and hydrogen-enriched fuels.

The discussion about hydrogen fueled gas turbines is brought to several countries' agenda as most of them are looking to reduce their dependence on fossil fuels. Hydrogen therefore becomes an interesting alternative when other renewable energy sources are available in limited or fluctuating quantity.

"Gas turbines are effective when it comes to balancing volatile renewable energy generation thanks to their flexibility and short ramp-up times. Future carbon-free power generation requires ramping of hydrogen capability in gas turbines with hydrogen produced from water and surplus renewable electricity. Energy generation using hydrogen fueled gas turbines has another huge advantage : [this well-known energy generation technology if established all around the world would be much faster, technically and economically feasible and facilitate the introduction of green hydrogen generation]." **Eduard Hryha**, Professor, Director of CAM2 centre, department of Industrial and Materials Science, Chalmers University of Technology, states.

Eduard Hryha, Professor, Director of CAM2 centre, department of Industrial and Materials Science, Chalmers University of Technology

For **Vladimir Navrotsky**, AM Chief Technology Officer and Senior Principle Key Expert at Siemens Energy, the interest in hydrogen fueled gas turbines is driven by environmental, political, technological and economic considerations that are worth mentioning. Apart from specific country goals on net zero emissions, organizations will very soon deal with "*stricter regulations on emissions and use of fossil fuels due to the Paris agreement (COP21), [as well as] other initiatives (e.g. European Green Deal, EU Taxonomy*". From an economic standpoint, one notes an "*increasing carbon pricing through CO2 taxes or emissions trading and a customer pressure*": not only companies and utilities have their own requirements to reduce carbon footprint but they also receive requirements from customers, investors and financing institutions (e.g. European Investment Bank (EIB)). From a technological standpoint, Navrotsky notes that e.g. for the chemical industry the "*possibility to utilize hydrogen rich off-gas from refinery and chemical processes*" is a strong incentive for the use of hydrogen fueled gas turbines. For industrial users and utilities, "*potential future blending of hydrogen in existing natural gas networks and pipelines requires that existing gas turbines and existing power plants are enabled to cope with a certain share of the hydrogen content in the fuel*."

Vladimir Navrotsky, AM Chief Technology Officer and Senior Principle Key Expert at Siemens Energy

The picture shows the Siemens SGT-8000H gas turbine.

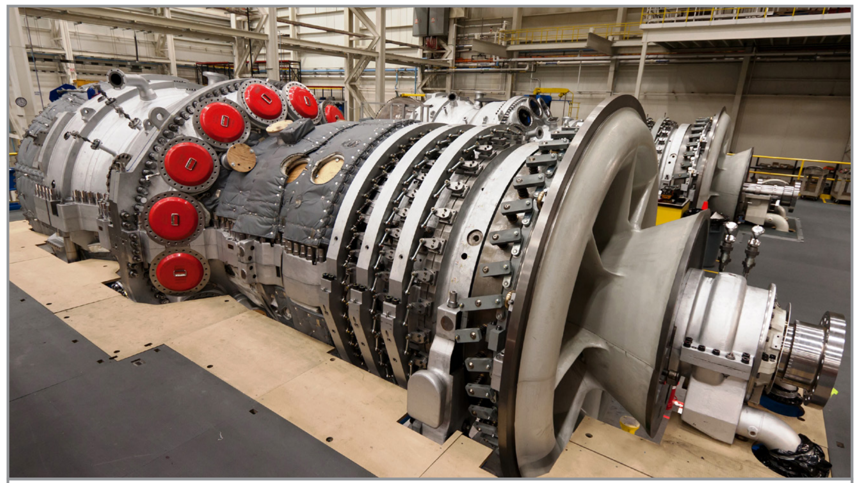
This means that, to envision a *"net zero future"*, a power plant might want to use post-combustion carbon capture – or they might want to leverage green hydrogen in new or upgraded gas turbines in their existing power plant. Hydrogen-ready gas turbines can also operate in combined-cycle power plants. In this case, they would use surplus heat to generate steam that powers a second turbine.

Energy technology company **Siemens Energy** for instance, has been granted a third-party certification (TÜV SÜD) for its **"H2-Ready"** power plant concept. According to the company's representative, it covers the three phases in the life cycle of a plant:

· The Bidding Phase - when the concept of the hydrogen-readiness is established according to the client's H2-roadmap (Concept Certificate - Generic).

· The Project Phase – when the concept is implemented into the design and construction of a H2-Ready power plant (Project Certificate – Project specific).

· And the Transition Phase – when the plant is converted into H2 fired plant, once hydrogen is available (Transition Certificate – Project specific).


Credit: Siemens Energy - The picture shows the Siemens SGT-8000H gas turbine.

"The "H2-Ready" concept certificate provides a roadmap describing how a new power plant needs to be designed to co-fire hydrogen or even burn pure hydrogen", **Navrotsky** completes.

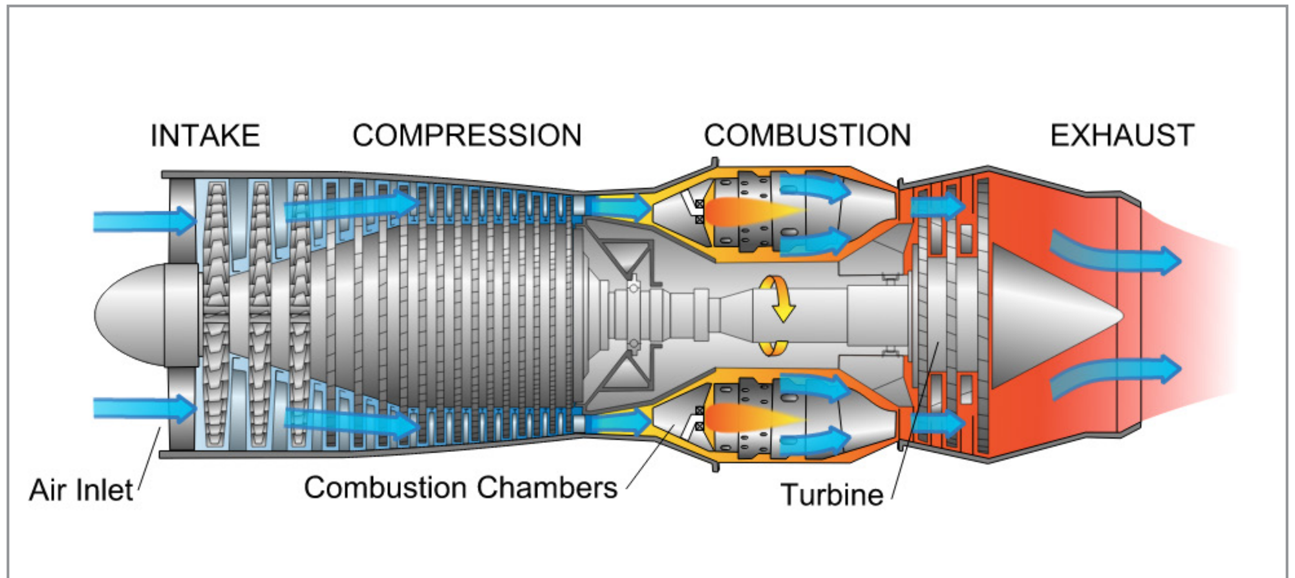
The thing is, despite these benefits, hydrogen is not a perfect chemical element. It currently remains expensive and is not the safest source of energy. *"Hydrogen is a highly reactive fuel, with flame temperatures significantly higher than natural gas flame temperatures. Compared to natural gas, its flame speed is more than three times faster and has an auto-ignition delay time more than three times lower"*, Navrotsky outlines.

Part of this issue can be addressed through the integration of manufacturing processes that enable the adaptation of gas turbine components for hydrogen applications. That's certainly where AM and digitalization come into play.

II – AM strategies one can explore for implementing a hydrogen economy or to enable green hydrogen fueled gas turbines to start.

"AM plays a number of important roles when it comes to both hydrogen generation (e.g. catalysis) as well as utilization of it as a fuel", **Hryha** comments.

Let's make it easy for outsiders and explain how a gas turbine operates to better understand Hryha's comment. A gas turbine has three main components: a **compressor** which takes in air from outside of the turbine and increases its pressure; a **combustor** that burns the fuel and produces high pressure and high velocity gas and a **turbine** that takes out energy from the gas coming from the combustor.



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Two of the most important aspects of the AM value chain where industries focus their strategy are **design** and **materials**.

The design perspective

*"Burning hydrogen gas faces a lot of challenges connected to the high reactivity of the hydrogen gas as well as high temperature flame. Therefore, to facilitate this, novel and significantly **more complex design of fuel burners**, not feasible or possible to produce using conventional metal forming technologies for modern high-temperature materials, is required to assure proper fuel mix and enable efficient hydrogen burning. Hence, almost unlimited design possibilities, provided by AM, open new ways for manufacturing of complex fuel burners, not possible until now"*, Professor **Hryha** lays emphasis on.

Siemens Energy has specifically worked on these applications. With over 50 industrial 3D printers in-house, Siemens Energy has already achieved several applications of AM and is currently looking to further industrialize their processes. During a conversation with 3D ADEPT Media, **Navrotsky** highlights how Additive Manufacturing has been pivotal to ensuring the acceleration of design and prototyping of their **gas turbines H2 burners**:

"In our workshop in Finspong, we did start the extension of H2 capability of medium-size gas turbines with 3rd generation DLE (Dry Low Emission) combustion in 2008. By 2016, we did reach 10% of H2 capability. Implementation of AM for MGT burners design and manufacturing in 2016 significantly speeded up the H2 capability progress. As a result, in 2018, we already achieved 50% H2, and in 2022 75% of H2. In 2023, we are planning to test 100% H2 for certain turbine frames. AM enables design that can manage all mentioned issues related to H2 combustion. Implementation of lattice structure in the burner design does not only enable good mixture of H2 and compressor air, but it also acts as a cooling arrangement - the fuel acts as a coolant. This resulted in the lower metal temperature of the burner during operation. Currently our SGT-600, -700, and -800 gas turbine burners with H2 capability are manufactured with AM technology."

The materials perspective

According to Professor **Hryha**, *"[the need for] high-temperature materials, required for such a high-temperature flame, [is] beyond the current state-of-the-art. Here is another advantage of AM: control over solidification and microstructure formation processes during additive manufacturing of the complex component can be used to synthesize novel high-temperature materials."*

As part of the MAGDA project funded by Sweden's innovation agency Vinnova, Hryha is currently investigating new materials for green hydrogen fueled gas turbines through additive manufacturing. Together with several partners, Hryha will explore critical factors of alloy design, powder characteristics and AM fabrication recipes for successful manufacturing of tailored Ni-based alloys with excellent high-temperature mechanical and corrosion properties. The results of this project will allow Höganäs to introduce new powders on the market for AM, allow Siemens to develop PBF-LB manufacturing of the components for hydrogen fueled gas turbines, and allow to introduce new PBF-LB (EOS) and post-AM (Quintus) processes enabling fabrication of difficult-to-build AM materials.

When asked why the focus is made on Ni-based alloys, Hryha replies that they *"are the most suitable material candidates for high-temperature applications thanks to the combination of high strength and stability at high temperatures."* The fact is, *"high-performance Ni-base superalloy needed for advanced applications, such as components for hydrogen fueled gas turbines, are very difficult to process by AM without encountering significant cracking issues. We implement a comprehensive and holistic approach to mitigate cracking in advanced high-temperature Ni-base superalloys for high-temperature applications combining three main ingredients: tailored alloy design, dedicated PBF-LB process and post-AM process development. A lot of reported data focus on one of the aspects, however for such a complex material and design, material, AM and post-AM process have to be developed in synergy to assure*


3D printed part - ©Siemens Energy

AM Autonomous workshop at Siemens Energy - ©Siemens Energy

robust AM manufacturing. PBF-LB provides high freedom of both, design and process control, meaning that smart combination with post-AM HIP process allows us to not only minimize/avoid defects, but also control microstructure and properties by integration of HIP and heat-treatment in one cycle (also, further minimizing manufacturing costs)", he continues.

While he couldn't expand much on the project for now, he did share that it is important to clearly understand the physical and technical possibilities and limitations during all three steps to assure successful, economically and technologically feasible AM material, process and post-AM processing.

Other considerations to take into account

"Many power producers might believe that replacing burners in gas turbines is enough, but whether you're converting an old plant or building a new one there's far more to H2-readiness than that. High-hydrogen fuels not only pose challenges for the combustion system of the gas turbine, but also to the gas turbine package and plant as well. The package design must be evaluated to ensure all components and systems are capable of safely running with higher hydrogen contents in the fuel. Upstream of the combustion system, hydrogen fuels can require changes to component materials, pipe sizes, as well as sensors and safety systems. Downstream, the exhaust path must be evaluated. Varying exhaust gas properties can impact heat transfer and corrosion rates, possibly impacting the life of components", **Navrotsky** warns us.

As you can see, we have only tackled a tiny part of the problem. Not only is hydrogen still in its infancy, but the use of AM as a technology that can foster its adoption and its effective implementation across the gas turbine industry also requires to take into account the complexity of the technology and its maturity at the current state of the market. As **Navrotsky** implies, there is still a long way to go given the current considerations to take into account at the design, materials, machines and most importantly standards levels. And the latter can only be effective through cooperation with universities on the one hand, and cooperation with machine and powder suppliers on the other hand.

Concluding thoughts

High expectations are currently placed on hydrogen and its advantages for a climate-safe energy future. In the midst of this media hype, it is fair to say that it is green hydrogen, generated from renewable sources, that will probably deliver the most significant environmental benefits as long as industries and governments can prove its profitability – this may only be the beginning of a new era but the tiny little part of Additive Manufacturing should not be neglected.

Markus Tacke on the enterprise strategy at the heart of Oerlikon's path to AM and the 'try everything, fail fast' ethos

December 2016. Switzerland's **Oerlikon Corporation AG** acquired **citim GmbH** – leading producer of metal 3D printing parts – giving this way the first clues to the group's Additive Manufacturing ambitions. That period saw a combination of acquisitions and new facility investments enabling the company to establish itself as a developer of both AM materials and parts, offering its customers the complete process chain, from new alloy development to component post-processing and testing. This is what I knew about Oerlikon when I met the company's representatives for the first time, during their official launch onto the AM scene at Formnext 2017.

Fast forward to 2022. The company's activities in the AM industry are shining over other sectors of activity where it has a deep expertise in, demonstrating how these various businesses can complete each other in a certain way, hence the company's new positioning as **ONE Oerlikon**. To better understand its current positioning within the industry, explore what the future holds for the group and discuss this multifaceted approach in this business of innovation, I sat down with the right advocate: **Markus Tacke**, CEO of Oerlikon Surface Solutions.

ONE Oerlikon

With +/- more than 11 000 employees in thirty-eight countries, Oerlikon is growing at a rapidly increasing rate. Outside of the AM industry, the company is mostly known for its surface coating division and for the construction of systems and plants for the production of manmade fibers. However, the new rebranding sheds more light on its entire portfolio which is made up of 7 brands:

- Oerlikon Additive Manufacturing, its AM division that provides metal powders, prototyping and series production;
- Oerlikon Metco which provides materials and surface solutions;
- Oerlikon Balzers known for its surface technologies;
- Oerlikon Barmag for the development of manmade fiber spinning systems and texturing machines;
- Oerlikon Neugmag for BCF carpet yarn and synthetic staple fibers plants;
- Oerlikon Nonwoven acknowledged for a comprehensive range of solutions for all important nonwoven production processes; and
- Oerlikon HRSflow which develops hot runner systems for the polymer processing industry.

When asked which brand is currently gaining momentum the most, Tacke provides a nuanced response that reflects the

Markus Tacke, CEO of Oerlikon Surface Solutions

difference between "trending on the market" and the brand that has *"the highest growth"*.

"It turns out that Oerlikon has a strong positioning in each of the market it operates on. We do note that materials and surface solutions draw a lot of interest while our AM division has the highest growth. As far as AM is concerned, we focus on metal AM processes and applications", Tacke comments. And the CEO's explanations on their AM business makes me understand how AM is more than just a manufacturing strategy; it's an enterprise strategy.

The enterprise strategy at the heart of Oerlikon's path to AM

For a group like Oerlikon that operates in multiple sectors, implementing AM requires a broad perspective and strategy over the enterprise, a clear understanding of the benefits that might come, as well as the ways different businesses of the enterprise will need to adapt (or might intertwine). AM is often said to be a tool among many others in the production environment, but when you look at the executive perspective, you come to realize that it's a supply chain in a box that calls for out-of-the box thinking in terms of how the company might adapt to deliver its promise.

In the case of Oerlikon for instance, AM has not been integrated entirely from scratch into the group's business. **The company's solid expertise in materials** has been the driving force behind its positioning in the AM industry.

"We approached AM from our materials competences. We have a key experience in developing powders for applications and we combine that

experience with our process capabilities and align them with the requirements of the AM market", the CEO explains.

This is just one of the many understandings we get from the executive perspective. Another one consists in **combining its deep expertise in AM with the one it has in other fields of activity.**

"If you look at AM projects, most of them are about optimizing the processes. At Oerlikon, we are fortunate enough to have all the resources in-house to manufacture the most-demanding of components. Our design expertise lies in our ability to develop some of the most complex materials, our AM expertise today encompasses everything we need to know to operate a 3D printer to visual inspection, and improve efficiency and quality. Added to that our deep knowledge in surface coating expertise, we are pushing the boundaries of AM beyond the manufacturing process itself", he adds.

Furthermore, to position oneself sustainably on this market, it's crucial **to expand one's technology capabilities**. To do so, companies can either acquire other businesses or develop products.

Oerlikon did both. If its early stages have been marked by acquisitions, the company also *"develops some expertise"*. *"Going forward, we will continue to do both. From a technology standpoint, you can have a great technology, but if you don't know how to leverage all its capabilities, you will never be on top of your league. That's the reason why, we invest a lot in our R&D activities"*, Tacke outlines.

As part of their R&D activities, the team focuses on the development of more suitable AM materials – a key area of interest is aluminum as it's a key enabler to achieve lightweight aerospace parts with high efficiency - and optimization of their properties with the AM machines they utilize. Other areas of focus include the visual monitoring of the printing process (in-situ visual inspection and flow panel optimization) as well as the development of other processes to make viable applications.

A quick look at Oerlikon's key milestones over the past five years shows how the three points of this strategy have been implemented:

In 2020 for instance, Oerlikon AM and Hirtenberger Engineered Surfaces joined forces to apply the Hirtisation Process to the prototyping business, which is expected to improve productivity by eliminating extra finishing steps. Last year, the company announced the development of a new high entropy alloy that could replace super duplex stainless steels in the additive production of structural components, such as centrifugal pump impellers. This year, the company shows its willingness to advance R&D activities within the AM industry by cofounding the TUM-Oerlikon Advanced Manufacturing Institute. Over the next five years, up to thirty dissertations focusing on technical research along the entire value chain will be supervised. These include the development of new, tailor-made materials, studies on the printing process and the reciprocal interactions between processes and materials, as well as the entire additive manufacturing procedure.

The 'try everything, fail fast' ethos

With all that is being said, one could easily think that because Oerlikon has the financial resources, thus the means to support its goal, the company is evolving in a "fairy tale" where everything works well. It doesn't (always).

The reason for this is simple: most part manufacturers start their AM journey with faulty expectations as to where the journey might lead, and narrow expectations about where the benefits might be realized. And I believe Oerlikon is no exception. The truth is, this standpoint does not always take into account the different avenues of transformation (e.g. design, production, operations, accounting and image) that AM might affect, nor all possible applications where significant savings can be achieved – yes, because at the end of the day, AM, especially metal AM and related processes remain expensive technologies.

While he didn't expand on their challenges, Tacke did recognize that they have been through the highs and lows everybody goes through:

"The AM world has a start-up spirit. While we recognize the freedom of design that opens up new opportunities, I see a different momentum in this industry compared to classical engineering applications. The technology might be a new solution to a lot of manufacturing problems, but it does not advance at a fast pace as other tech fields – as the IT for instance –. There are several reasons for this, one of them being to find the ideal way to manage this environment. You can fail fast with AM, but if you've found your path, you can grow fast".

At the end of the day, the success of the right AM strategy also comes down to the implementation and understanding of the right processes by the engineer. For Tacke, this part of the job heavily depends on education that should be provided to enable (future) engineers to understand AM capabilities. For the rest, and because AM remains a relatively *"new technology"*, it's crucial to be able to adapt your business. Oerlikon certainly tried a lot, failed but most importantly, bounced back quickly. For any manufacturing business, whether you're an Oerlikon or an SME, failing to adapt can be fatal.

EOS on the cost consideration and where it makes sense to integrate digitization and automation in an AM production environment

*Put two Additive Manufacturing veterans together, with respective expertise on both the commercial and current economic market of the AM industry and the technological side, and you can expect a conversation on insights that matter into the additive manufacturing world. A few weeks ago, during a morning coffee discussion, **Markus Glasser**, Senior Vice President of EMEA at EOS & **Marius Lakomiec**, Team Manager Digital AM Solutions at EOS, sat down with me to discuss digitization and automation. It's fair to say I went through a wide range of emotions on that day – and I am going to tell you why below – but I eventually had to admit that Industrial 3D Printing company EOS makes magic happen when it comes to the integration of digitalization and automation across the most demanding industries that leverage AM technologies.*

If you had told me four years ago to sit down with Glasser and Lakomiec to discuss digitalization and automation within the AM industry, I would have said no. The reason for this is simple: I am very cautious about buzzwords – If not well utilized, they can easily become a solid marketing weapon that companies use to promise a lot and deliver little on the production ground floor. And if we had to make a list of the top five buzzwords used in our industry, digitalization and automation will be on top of it. So, while I was dubious at the beginning of this conversation with EOS representatives, I paid great attention to the team's mindset, strategy, and technology strengths and how they are currently deployed to achieve their objectives.

On another note, it's crucial to take into consideration the current market – which is driven by a lot of economic, political and even sanitary changes (due to the Covid-19 pandemic), and these changes urge industries to recognize the now vital importance of digitalization and automation processes, to foster their adoption for the good of their business.

"We cannot move forward without taking into consideration all of these aspects", Glasser says, talking about the current economic, political and even sanitary changes. *"We now even have to take into consideration the increasing energy costs that the market has to deal with. This means that we have to explore new ways of creating markets and products that save energy. Digitalization and automation play a key role in enabling that. Let's take the example of the automotive industry: while the world needs a dependable alternative to fuel-based transportation – something that electric vehicles may very well help with, automotive OEMs face several challenges regarding procuring components, supply chain and quality concerns – to name a few –, all of which can be addressed through digital transformation, AM and automation. Similar concerns are faced by manufacturers in the consumer goods industry who depend a lot on resources that come from China to manufacture their final products. One thing we learned from the pandemic is that there is an opportunity to explore if we focus on the local market and this can be done safely if digitization and automation help to mitigate these risks"*, he adds.

Before emphasizing Glasser's statements, Lakomiec's first words implied that he had understood those feelings raised by buzzwords: *"The thing with*

Markus Glasser, Senior Vice President of EMEA at EOS

buzzwords is that they do not enable professionals to focus on what matters: the technology that enables real transformation not to mention that they give this impression that [manufacturing processes can be adjusted and improved in the blink of an eye]. Industry 4.0, digitization and digital thread are truly buzzwords and make the whole work on a factory floor takes time. It should be about technology and how it enables transformation." Taking the example of the supply chain within the automotive industry, Lakomiec explains that automotive OEMs have started reconsidering their strategy for the production of components. The reality is, the number of hurdles keeps increasing: the shortage of raw materials, price inflation, not to mention manufacturing issues that could have been prevented, etc. creating a domino effect across the whole value chain.

The automotive industry is just one example among many and the truth is, there are so many items to consider that it can quickly become overwhelming for companies trying to find their path in this journey. While taking into account the current economic, social and political environment, my conversation with EOS' representatives highlights three areas of interest for the current AM market:

- Where it makes sense to integrate digitization and automation right now

- The cost consideration and

- The next area of focus.

Where it makes sense to integrate digitization and automation right now

The topic of digitalization and automation is so broad that it can fill an entire magazine. As a global trade press that focuses on AM, it made sense to discuss it through the prism of vertical industries adopting AM technologies.

"We should explore each component that may affect manufacturing as part of the supply chain. To do so, in our AM division, we apply real digital twins that may simulate everything upfront", **Lakomiec** outlines.

As the drive towards digitalization gains momentum and the value of the digital thread is sung from all corners of the industry, the digital twin has positioned itself as one of the advanced technology concepts that could help manufacturers earn credibility and viability in the new digital manufacturing realm. In **a recent dossier dedicated to digital twin (DT) technology**, 3D ADEPT Media found out that DT might be a potential solution that can be leveraged to overcome many issues in additive manufacturing but the lack of thorough understanding of the DT concept, framework, and development methods constitute key factors that slow down the development and integration of such technology across AM production environments. The DT concept goes beyond what may happen to a physical product, to encompass the prediction of **production** and **performance** within specific environments. This means that industry insiders' understanding of DT may vary from one situation to another, as they can refer to the DT of a product, production or performance.

Marius Lakomiec - Team Manager Digital AM Solutions at EOS

In this specific case, EOS' Team Manager Digital AM Solutions focused **on the importance of DT within a production environment.** This means that their technology can create a virtual copy of a real-world component in the manufacturing process by using inputs from a real-world component to mirror the real part's status, functionality, and/or interaction with other devices.

"By applying DT, we can identify, predict and solve issues upfront. We can know exactly the quantity of parts a production might require, the number of machines required for their production – if we apply medium or large size machines –, if there will be bottlenecks, where these bottlenecks would be if they occur, the number of shifts required and even the number of operators that will be needed during the production", the Team Manager Digital AM Solutions explains.

If you are just like me, and before watching a film, you watch the trailer and read the synopsis (and everything in between) to have the certainty that you will not be disappointed because the film will have a happy ending, then the DT technology is for you. You will not be disappointed at the end of the production because you would have assessed supply chain dynamics, identified issues before they happen and anticipated process success.

Speaking of the vertical industries that will benefit the most from DT, the Senior Vice President of EMEA mentions the *"aerospace, energy and medical industries if we stick to metal 3D printing applications." "Overall, we can ensure that the customer benefits from the entire value chain. We are currently working with various partners such as Siemens Energy to optimize a wide range of solutions. Our long-term objective is to enable the adoption of our DT technology across the entire value chain from product to production and performance"*, he adds.

In the meantime, the team focuses on immediate issues to address and works hand-in-hand with partners who bring different technical expertise to the table. By working on specific projects (such as the "air conditioner" project mentioned in the lines below), the EOS team can develop optimized processes for end-use applications. That being said, Glasser notes that the vertical industry that will certainly benefit the most from the DT technology is the **aerospace industry**. *"It's an industry that is currently leveraging AM [and looking to leverage AM – for OEMs who are not there yet –] for series production."* According to Glasser, with aerospace companies, the discussion is no longer about whether or not they should adopt DT but about **change management** – (a topic we discussed with Oerlikon's CEO Markus Tacke on pages 13 and 14 of this magazine). *"It's about certifying the entire process to achieve viable end production"*, Glasser points out.

So far, in theory, the DT technology is a promising technology that can drastically change any manufacturing business. In practice, we know any advanced solution comes at a price that all companies cannot always afford and that's a reality leading technology providers should not neglect.

The cost consideration

In the current industry, large OEMs and corporations regularly make headlines with announcements related to the inaugurations and creations of *"factory of the future"* technology centers. The latter showcase digital manufacturing and automation solutions, and require large investments to roll out changes to production. Smaller players have a different history. For them, process and technology changes are driven by more concrete, nearer-term ROI which means they cannot always have the resources to integrate digital manufacturing solutions, yet they should also be able to leverage these technologies.

"And they can", Glasser enthuses. *"We have a contract manufacturing process with certified manufacturers that enables SMEs to benefit from advanced digital manufacturing solutions. We are currently working with Oerlikon in that area. And much more can be done: we can also reshape a bit our portfolio, and reduce the CAPEX for smaller entities and we work to integrate innovation centers where SMEs could learn more about technology solutions they could leverage in their business"*.

"We have also seen SMEs get directly involved through projects funded by the EU or regions. Such projects provide companies with standards and regulations they can utilize in their activity. The POLYLINE project is a great example as it gathers experts from science, research and industry around the development of automation solutions for the use of AM in the automotive industry. Other solutions for SMEs could be to explore platforms created by software companies that aim to enable (local) production across several countries", Lakomiec comments.

Antenna bracket for RUAG's sentinel satellite (source: EOS)

The next area of focus

With everything that has been said in the lines above, with the increasing cost pressure on the one hand and the main challenge of AM which is to ensure repeatability, on the other hand, areas of focus right now vary from one company to another.

Lakomiec outlines that quality assurance, digitization and automation are items that will always be discussed at multiple levels and different degrees but the cost conversation, and the ability to secure and control the value chain are items that will affect decision-making processes, therefore they should be the next focus.

For Glasser, on the other hand, the next area of focus should be applications. Like many industry insiders, Glasser believes that working on the right applications helps to advance and optimize manufacturing processes. One of the recent partnerships shows that EOS is currently walking the talk as together with Hyperganic, they will build a residential air conditioner that uses 10 times less energy using AM.

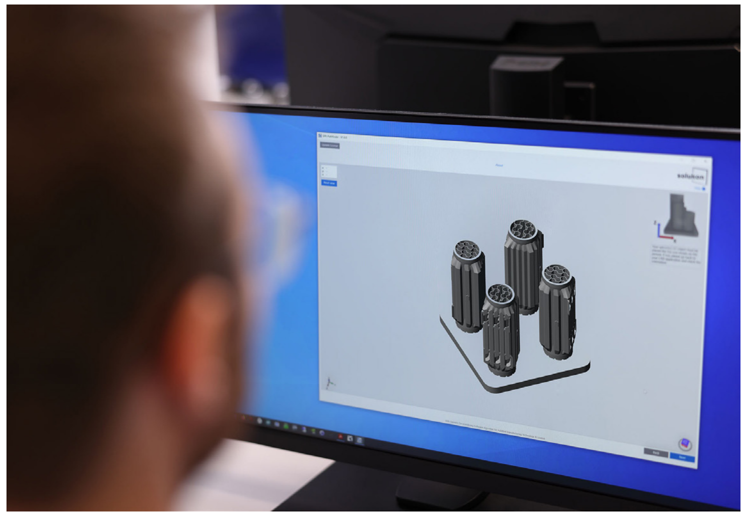
Moving forward I understand each of their different visions: having complete control over costs, QA and value chain is somehow having the certainty that your application will be viable, and meet industry standards but enabling applications through these processes is the tangible example that demonstrates they perfectly work together. It's a virtuous circle.

This double interview was undertaken on the lead up to AMTC, Europe's C-level conference dedicated to Additive Manufacturing - and where EOS took an influential role.

SOLUKON'S SPR-PATHFINDER® SOFTWARE TO BRING DEPOWDERING OF 3D PRINTED PARTS TO THE NEXT LEVEL

The development and improvement of depowdering solutions is not solely based on machines. A key part of their functionality and their ability to achieve an automated and repeatable work is based on the software capabilities they leverage. That's in any case one thing we learn from machine manufacturer Solukon.

At the beginning – in 2018 –, we only talked about the company's depowdering machines with the intelligent software solution developed in collaboration with Siemens as key capability. Since then the SFM-AT800-S was then the very first and only machine to benefit from this solution.



Named **SiDAM**, the software was the brainchild of **Dr. Christoph Kiener**, Principal Key Expert on Functional Design for Manufacturing at Siemens Technology. *"Vibration-excited powder behaves almost like a fluid when it flows out. That's how we quickly realized that we could find success by using path identification as well as particle and flow simulation in the software,"* says Kiener.

What we didn't know is that the software prototype was only made available to a select number of Siemens' and Solukon's development partners. Today, Solukon is the **exclusive licensee**. It has developed it into a corporate Solukon product, and is now bringing it to the AM market under the new name, **SPR-Pathfinder®**, allowing its customers to purchase licenses for the first time.

"It's a logical step for us to license the depowdering software exclusively to Solukon, thereby enabling the pioneer in industrial depowdering to offer the market an even more effective product," says **Dr. Georg Bodammer**, Senior Venture Director at **Siemens Technology** Accelerator. *"This way, customers can get everything from a single source: the market-leading depowdering system and the exclusive, intelligent software."*

A perfect timing and a meaningful name

The timing is perfect for the Solukon team as the company embarked on a journey to improve its digital solutions. Remember, last year saw the development of digital tools on Quality Assurance, by integrating automation and new IoT Solutions for depowdering.

This year, the company goes one step further as the SPR-Pathfinder® software makes the digital twin of a part usable in post-processing for the first time. I love the capabilities of digital twin technologies.

"In contrast to conventional manufacturing processes, 3D printing uses the part's digital twin. To date, however, this was only utilized during the printing itself. With SPR-Pathfinder®, the part's digital twin can now also be used during depowdering. This is how we ensure that the potential of the digital twin can be used to the fullest in post-processing as well," **Andreas Hartmann**, CEO/CTO of Solukon, recalls.

I am aware of the challenges to implement the digital twin technology in (additive) manufacturing environments, so seeing such solution pushed forward sounds like good music to my ears.

What's even more interesting is that, in this specific case, the name **SPR-Pathfinder®** has not been given randomly. Solukon deliberately drew on the established depowdering technology Smart Powder Recuperation, also known as SPR®. The latter generally involves automated rotation on two axes as well as adjustable vibration in a safety-controlled atmosphere. The algorithm-based SPR-Pathfinder® calculates the ideal motion sequence for the most complex geometries, finding the best path to allow the powder to flow out completely, a press release reads.

However, a **new name does not necessarily mean new procedure**. As a matter of fact, the main steps to leverage the intelligent depowdering solution remain the same: upload the file to SPR-Pathfinder® - set the calculation parameters - specify the file storage location - start the calculation - transfer the cleaning program to the Solukon system.

More on the process operation

To remove excess powder from complex internal structures, SPR-Pathfinder® uses the build job's CAD file to calculate the ideal motion sequence in the Solukon system. The SPR-Pathfinder® calculations are based on a flow simulation that analyzes the part's digital twin. The individually calculated motion sequence is then read by the Solukon system, which in turn runs the programmed paths. This ensures that even the most complex parts are cleaned—in record time and without any human programming effort, the company explains.


Andreas Hartmann, CEO/CTO of Solukon

Another important thing to keep in mind is that SPR-Pathfinder® runs as on-premises software — this means that users can only leverage it on the company's own devices (PC or notebook), not in the cloud. Each license is bound to a device and is always valid for the current version at the time of purchase.

Visitors at Formnext 2022 will have the opportunity to discover how SPR-Pathfinder® software depowders even the most complex geometries in an SFM-AT800-S, at **Solukon's booth in Hall 12.0, B21**. In addition to the software, all four metal systems will also be on display. We're certain the impressive parts in the depowdering systems will once again attract a great deal of attention. For the first time ever, Solukon will also address the unpacking and depowdering of polymer parts at its booth. Diagrams and videos will explain the design of the SFP770, the company announces.

In case you miss Formnext, note that Solukon customers can also test SPR-Pathfinder® free of charge and without obligation. To do so, they would need to register for a 30-day trial version on Solukon's website.

How to post-process resin 3D printed parts ?

Like in almost any Additive Manufacturing process, post-processing is an essential stage that should be conducted to obtain the final 3D printed part with the desired properties in resin 3D printing technologies. Whether we deal with stereolithography (SLA), digital light processing (DLP) or LCD 3D printing, leveraging the right post-processing tools to deliver the final part is sometimes what is needed to remove this misconception whereby resin 3D printing is only meant for the production of prototypes while FDM 3D printing can be best suited for production parts.

The article below aims to discuss the various methods/tools that can be leveraged to give a resin 3D printed part a great finish. It is part of two series of insights: a series that ambitions to provide a thorough understanding of each post-processing task, and another one that ambitions to understand the secrets of resin 3D printing. This latter series already made us delve into the various considerations that need to be taken into account to choose a resin 3D printer, and the different forms of toxicity and solutions explored to reduce it in such processes. These are all crucial information you should be aware of before utilizing a resin 3D printing technology.

That being said, it should be noted that resin 3D printing technologies can produce prints with fine details and very small features (as small as 03 mm). The bad press these technologies often suffer from is that, most prints often need to be oriented at an angle, requiring therefore support structures to be attached to the model. These supports eventually leave marks on the surface and create uneven surfaces hence the absolute need of at least one post-processing step.

We have already identified **three commonly used post-processing steps** that can be leveraged in a resin 3D printing workflow. Other post-processing steps can be performed depending on the manufacturing goal to achieve.

"The process can be daunting for any organization simply because of the number of steps required to finish a part. It includes multiple steps that are traditionally done manually by a technician and require both time and skill. This can become even more of an undertaking when companies scale their process into full production. Performing all these steps manually may be fine for a few desktop printers, but with multiple large format printers or a farm of dozens of smaller format machines, manual labor, and management of the excess resin can become problematic quickly. Many post-processing steps need to be performed in a resin workflow, including removing parts from the platform, removing uncured resin, traditionally with caustic solvents in tanks, and manually removing support structures. Additional steps can include UV and/or thermal curing", an expert from PostProcess technologies told 3D ADEPT Media.

Before addressing the very first post-process step, let's remind that this stage of the manufacturing process should be conducted with the required safety precautions: gloves (nitrile or neoprene gloves), glasses, protective clothing or a paper towel to catch any drips. Until the last step of the post-processing stage (curing in a UV curing box / chamber), the resin remains highly sensitive to UV light, so it's recommended to avoid exposing it to UV light before post-curing; this way, it will not polymerize.

1- Cleaning the 3D printed part

Once the printing process is completed, the component (called green part) needs to be removed from the build plate. The operator (already protected with gloves) can do so by using a blade or a sharp tool. It is recommended to not use water or any cleaner to remove resin from the build platform. However, they can apply **isopropyl alcohol (IPA), tripropylene glycol monomethyl ether (TPM), dipropylene glycol monomethyl ether (DPM** – ideal for industrial applications –) **or (Bio) Ethanol** on the paper towel they will use to clean the build plate.

Image via PostProcess Technologies

Although all these solutions can be used to wash the 3D printed parts, one notes a slight preference for IPA when it comes to washing the SLA prints. This step should be done before removing the support structures. The 3D printed part should be moved around in the solvent as well as soaked for optimal cleaning. Depending on the complexity of the part (whether or not it has narrow channels), or the resin used during the fabrication, the operator might need to use a syringe to clean the internal resin and stop resin from curing and blocking channels.

If you are dealing with large batches of production or if you need to do this step regularly, you might want to consider **washing stations** or **ultrasonic bath**. Washing stations can come as an additional option in your 3D printer package and sometimes, they can be designed for both *washing and curing*. An ultrasonic bath is used in professional environments. Once the bath is filled with one of the aforementioned fluids, the 3D print needs to sit for a couple of minutes so that the fine layer of uncured resin stuck can be removed.

In such cases, complete automation to the integral resin 3D print operation would be worth exploring. *"Our resin removal solution automates the excess resin removal step in the resin workflow. Once the build plate is removed from the printer, the entire plate (for most printers) can be placed directly into a PostProcess DEMI series solution, where both the parts and the plate are cleaned of uncured resin. Our solutions are automated thanks to a combination of proprietary software, advanced hardware, and sustainable chemistry"*, PostProcess Technologies says, speaking of their solution. Due to the saturation limits of their proprietary detergent compared to that of IPA, the company's solution creates less waste during the resin removal process when compared to traditional solvents. *"It is also a safer option than traditional solvents, as it has a significantly higher flashpoint than IPA. The PostProcess comprehensive system of software, hardware, and chemistry is proven to reduce post-processing steps by 50% or greater. The proprietary process reliably removes resin materials from even intricate or delicate 3D printed parts while increasing productivity and reducing cycle time, consistently cleaning full trays in under 10 minutes"*, PostProcess Technologies says.

2- Removing the support structures

Credit: Ameralabs

This step can be done before or after curing. In general, it is recommended to remove the structures before the curing process because the process is easier. Operators that remove them after curing, take the risk of damaging the part or taking off small divots of material.

In any case, the cleaning step should have left very little to no stickiness on the surface. The operator would therefore need a model cutter or flush cutter to remove the supports – if they do not want to do it by hand.

3- Curing or post-curing the 3D printed part (depending on the 3D printer used)

The 3D printer resin left on your print's surface can be harmful and cover the part's fine details by forming a thick layer of uncured resin; not to mention that, sometimes, the resin 3D printer does not adequately cure some areas of the print – leaving the part unable to use by the end-user. A UV-curing station comes into play to cure the model and make it ready for the end-application.

In more technical words, one notes that the polymerization reaction is not necessarily completed after the printing process. This means parts cannot deliver their final material properties hence their exposure to light and heat. This process is called post-curing and helps to solidify the material properties.

SLA, DLP or LCD 3D printed parts may require to cure in a high-power UV curing box / chamber for 15 minutes at 65 degrees Celsius. The preferred wavelength of the curing unit should be between 300 – 420 nanometres (nm).

This step can also be a great fit for parts with a wide range of thicknesses and unsupported overhangs that suffer from warpage due to irreversible deformation during thermal cure. As seen in Carbon Digital Light Synthesis™ (Carbon DLS™) 3D printing process, this *"baked-induced inaccuracy typically originates from differential shrinkage between thinner and thicker walls of parts, and parts softening at elevated temperatures. UV post-cure can potentially address these issues by reducing mass loss during baking and increasing green strength."*

"There are different workflows for different resins. This can require a very specific workflow to create the desired end product. For example, most prints will require a UV curing step, but the UV exposure can vary between each resin to achieve the mechanical properties advertised by the resin manufacturer. Removing excess resin from parts is done using solvents, but we cannot use one solvent for every resin. Differing resin properties may call for different solvents", PostProcess Technologies warns us.

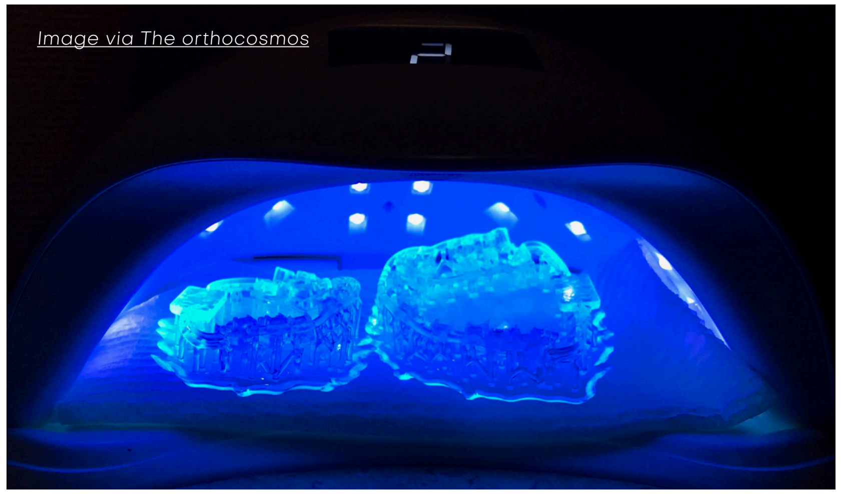
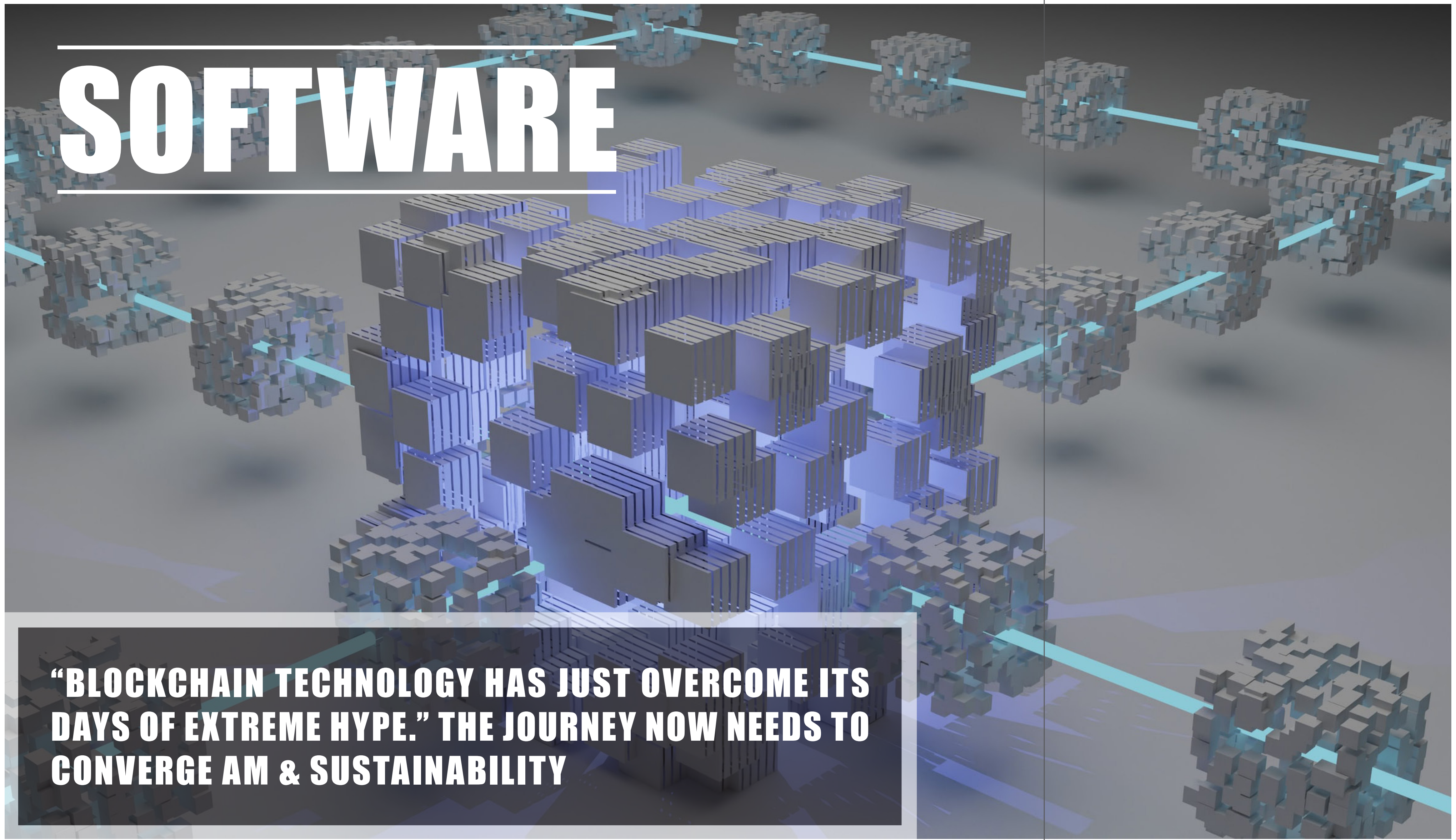


Image via The orthocosmos

Some resin 3D printer manufacturers tend to release dedicated post-processing machines alongside their resin printers to give the user an end-to-end resin 3D printing setup. Others partner with post-processing experts to provide a complete 3D printing setup to their customers. A similar partnership has been seen with Carbon and Post-process Technologies for resin removal solutions. Those who cannot afford to pay a curing station can use a nail polish lamp and let the model sit overnight or build their own curing chamber. If you have a limited batch of parts and if you are not limited by stringent production time, an environmental-friendly option would be to use solar power.

Other post-processing solutions for resin 3D printed parts

In general, these three main steps constitute the main ones that can be explored to deliver resin 3D printed parts with the desired properties. Other solutions can be explored depending on specific manufacturing requirements – to deliver detailed finish, smoother surface and colorful parts. They include for instance sand blasting, grinding, painting, coating or electroplating.



SOFTWARE

"BLOCKCHAIN TECHNOLOGY HAS JUST OVERCOME ITS DAYS OF EXTREME HYPE." THE JOURNEY NOW NEEDS TO CONVERGE AM & SUSTAINABILITY

Just fourteen years ago, blockchain appeared onto the scene of the financial market as the power behind cryptocurrencies. Over time, the technology found its place within supply chains, but was limited to pilot projects until distributed manufacturing came into play. As applications are continuously being explored to advance this technology, one thing became certain: making blockchain and additive manufacturing converge is a great way to enable distributed manufacturing to thrive, but the transition to a circular economy can make this road a difficult one to scale. The article below aims to contribute to the Industry 4.0 literature by discussing the impact blockchain may have on additive manufacturing through the lens of circular economy.

Simply put, blockchain is a protocol for sharing and updating information by linking ledgers or databases in a decentralised, peer-to-peer, open-access network. This distributed ledger technology (DLT), which first emerged as a way of facilitating cryptocurrencies, can lead to a powerhouse marriage when combined with other technologies. At the beginning, the whole idea of keeping manufacturing centralized has been based on the willingness to save costs and keep control but do you really keep control when supply chains are continually stretched to the point that trust is degraded?

Let's take the example of a military aircraft: on the one hand, servicemen on the ground are frustrated because of delays and hurdles of the conventional aerospace supply chain, on the other hand, suppliers sometimes spend way too much time to get the digital rights-managed (DRM) part files of a crucial part – let alone the manufacturing time. This implies that without the digital rights-managed (DRM) part files, there is a risk that the file may be corrupted or tampered with upfront or that designers simply don't know how many times a design might be printed once it is sold, or even that intellectual property can be stolen. This initial goal to save costs can therefore be aborted or can likely result in extra costs if the wrong files are purchased.

With all these issues popping up, part manufacturers, OEMs and stakeholders in vertical industries started exploring the use of blockchain as a miracle solution. Interestingly, the use of AM requires to explore that solution at multiple levels:

*"Additive manufacturing is an ideal solution for rapid prototyping, producing spare parts, and to reduce transportation costs by decentralized manufacturing. **The core problem is the prevention of illegal copies,** because once you've obtained the printing file you can make as many copies as you want. This is where blockchain technology can offer a solution, so most of the technology's use cases in the industry are therefore based on the prevention of illegal copies. This can be achieved in many ways. One is **transparency.** Serial numbers can be created on blockchain and integrated into the 3D model. Serial numbers on blockchain are unique by design, so any re-use can be excluded. If this measure alone is not sufficient, it can be propped up with "Track & Trace" on blockchain to follow the path of each printed part.*

*Another use-case involves the **modification of the printer hardware or software (ideally both)**, so that it requires a "Token" of the design file for every printout.*

*Blockchain Technology also comes into play when the **actual printing file is stored on a decentralized file system such as IPFS, and access rights are administrated by smart contracts.** This can be a token or just some digital rights management based on cryptographic proofs.*

*Apart from prevention of illegal copies, **blockchain can help to ensure the quality of a product.** This is achieved by transparency too. Deriving a cryptographic fingerprint of data, a so-called "file hash" is key to ensure that a file is not tampered with. When you print a model, you want to make sure that no one has modified it, e.g. reduced or increased wall-thickness or support structures or has changed labels, logos, or other elements. Especially in the area of 3D printing in biotech and medical applications, this security is essential. Blockchain is the perfect tamper proof database, because it doesn't allow any backwards-modification of data. Those are the most relevant use-cases to-date with an obvious economic benefit ",* **Johannes Schweifer**, CEO and Co-Founder of blockchain infrastructure company **CoreLedger** told 3D ADEPT Media. While the current focus is made on the use of blockchain in an AM production environment, CoreLedger's blockchain platform can be used across various industries.

The company's **Token Economy Operating System** (TEOS) provides all functionalities to build viable end-to-end use-cases, starting from documentation on blockchain, tokenization and accounting, to governance and trading. One of the most significant achievements of the company in this field is its partnership with Swiss company AMBITORIO AG with which it develops a solution for using blockchain to tokenize 3D print model files and thereby limit the number of copies that can be made.

While 3D printing equipment would need to be retrofitted to integrate blockchain, CoreLedger and Ambitorio can already integrate this solution.

The documentation features inherent to distributed ledger technology (DLT) can be used to ensure the authenticity of a file, while tokenization and accounting create a supply of file tokens and enable distribution on the built-in decentralized market, where those tokens can be traded.

If we dig a little bit further, Schweifer's point of view underlines the fact that four distinct characteristics enable an effective integration of a blockchain technology:

- a distributed nature that enables stored data to be "distributed" (pun intended);

- a specific consensus mechanism that ensures the validity of transactions and new entries and removes the need for a central trust-building authority;

- the use of cryptographic measures and digital signatures to compel each stakeholder to prove their identity before a transaction is validated by the network;

- further security elements to enable traceability and verification.

Furthermore, we need to recognize that the digital nature of AM makes it a promising opportunity to integrate blockchain within a distributed Additive Manufacturing environment. Needless to say that real-life implementation differs from one use case to another, whether we deal with Data & IP protection, traceability, authentication and certification, smart contracts, and process automation.

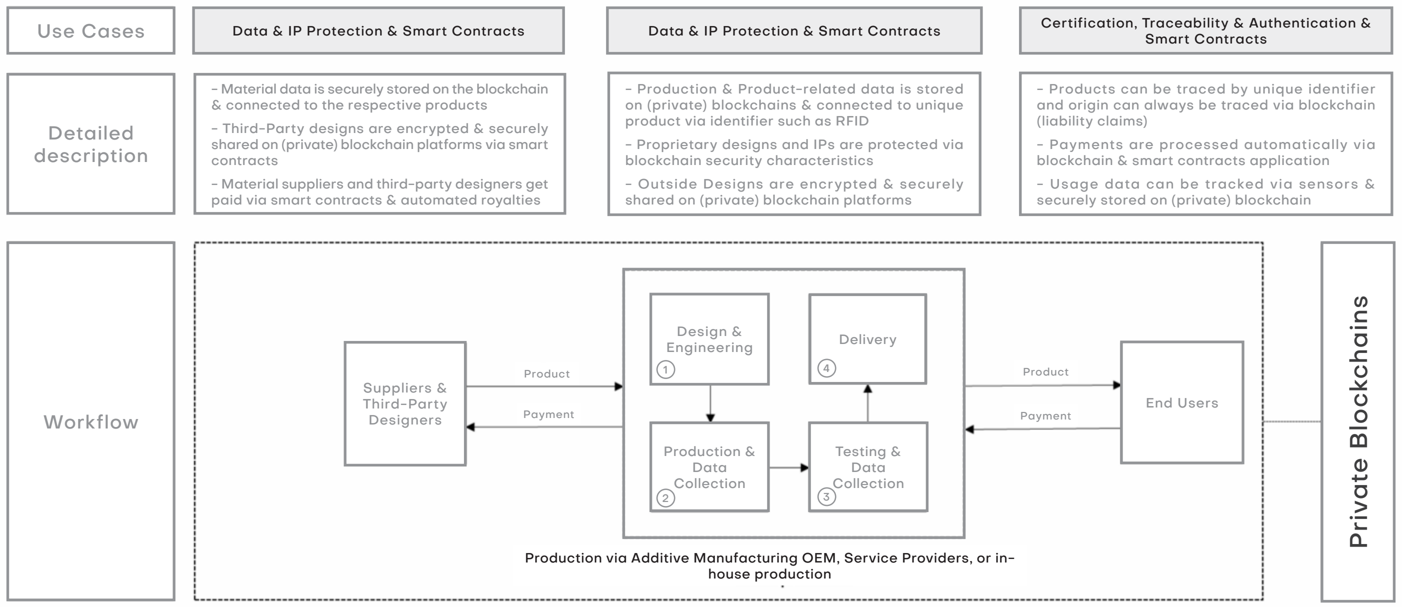


Figure : Blockchain-enabled additive manufacturing framework
Source: Trouton, Vitale, Killmeyer (2016), Blechschmidt, Stöcker (2016), and own illustration.

Moreover, the combination of challenges raised by each of these use cases also hinders the scalability of the technology within an AM environment – not to mention their cost implications. Emphasizing on some of the challenges and solutions on this road, Schweifer notes:

"First, there is the technical hurdle. Effective copy-protection requires a hardware and software modification. The model itself is just bits and bytes, and there are plenty of ways to steal it without any blockchain authorization. End-to-end encryption plays an important role here. The second hurdle is the transparency itself. Not every industry is ready for total openness when it comes to providing information about the whereabouts of the 3D printed products. Geolocations, a person's identity, and even company names could be sensitive. This is especially true in medical and biotech applications. Cryptography can be used to obfuscate the data, but this would reduce transparency. The underlying blockchain is also a challenge. Many proposed solutions are based on Ethereum technology, but they were written when transactions on the Ethereum blockchain were cheap.

[Ethereum is a large blockchain ecosystem.]

"When the gas limit became a problem, transactions became quite pricey. It wouldn't be economical to pay 30 or 40 USD just to create a serial number on Ethereum. Apart from Ethereum, there are many other choices, but that's exactly the problem. How can you avoid running into the same cost-problem (…) And which blockchain to choose? In the absence of an industry standard, there is no easy "blockchain of choice" either, and that's before we get to the question of whether it should be a public or private chain. These questions have to be addressed on a case-by-case and company-by-company basis, depending on their specific requirements. Then there are some ***practical hurdles. If we assume that the number of copies are limited by the number of tokens, then each token represents the right to print exactly one copy. But 3D printers don't have a 100% success rate, especially not with complex geometries.*** *Token-based approaches therefore require an automated quality check, which can grant a refund"*, he continues.

Johannes Schweifer – CEO and Co-Founder of CoreLedger

This number of questions makes it difficult to envision a blockchain-enabled business model in AM – let alone one that complies with sustainability.

Can a blockchain-enabled business model comply with sustainability?

CoreLedger's representative raises a number of questions that are worth exploring for companies that are looking to integrate blockchain into their production environment. From a manufacturing and IP protection standpoint, I guess there isn't much to say anymore. The CEO made it clear that the right process lies in the trust the user has in the token and not in the buyer.

From a profitability standpoint, the integration of blockchain can be appealing to local manufacturing businesses. While a consortium of companies affirms they have been able to integrate blockchain within [a cross-continent distributed Additive Manufacturing environment](), I remain very cautious about such deployment given the fact that we still lack viable benchmarks.

In addition, local manufacturing can also bring to the table the benefits of sustainability we probably all know already: local production = less transportation, therefore less CO2 emissions and on-demand production. To this argument, Schweifer adds:

"It must be possible to recycle 3D printed parts into raw material. Thermoplastics are the most viable material for this purpose, which excludes already some additive techniques. Blockchain Technology comes into play when Track & Trace mechanisms can be used to reward the returning of broken or retired parts into the product cycle. Products can, for example, be labelled with serial numbers and when they are recycled, the serial number is invalidated and some reward tokens are paid, which in turn are used at the beginning of the product cycle, to e.g. pay for printing runs (new serial numbers) or raw materials".

This argument may be valid but here again, I remain cautious because of another counter-argument: **the goal of finding a balance between preserving safety measures and "greenness" is a hard one to strike**, thus the technology has earned a bit of a bad reputation for implementing a consensus mechanism that's energy-intensive.

We should recognize the fact that, there are a few different varieties of these consensus algorithms to choose from, some of which are better than others. Those consensus mechanisms include Proof of Work (PoW), Proof of Stake (PoS) and Proof of Authority (PoA). It's up to the user to have a clear understanding of each of them in order to determine what they have to compromise on.

"The current market of blockchain and AM is still in its infancy, with many ideas and projects. Blockchain technology has just overcome its days of extreme hype. NFTs and Tokens overshadowed every alternative use-case for the technology during the past years, drying up funding for non-financial projects. Blockchains kept emerging as well, making earlier implementations on costlier or slower blockchains obsolete. This naturally hampers progress.

Nonetheless, there is now growing interest from the industry. Blockchain technology can ultimately help to save money or to prevent loss, e.g. from illegal copies. That's certainly not negligible in terms of economic value. The value for blockchain in Additive Manufacturing is clear: To solve the problem of copy-protection (some form of digital rights management, essentially). Blockchain technology is the perfect tool to prevent copies and counterfeits, therefore it is a natural fit for the task. Once designers of 3D models feel safe to publish their files on a blockchain-based digital-rights platform without reluctance, because they know their intellectual property is protected from illegal use, then we'd have achieved a major milestone", **Schweifer** concludes.


credit: Progold

MATERIALS

Precious Metals AM in Jewelry: the ideal business case in regard to circular economy, but a sector that struggles to scale up. Why?

One of the very first additive manufacturing applications in the jewelry industry dates back to 2008: a ring 3D printed in gold, one of the most preferred precious metals for fine jewelry. Over time, innovation in the field has opened up opportunities for jewelry makers and service bureaus to tap into the opportunities offered by AM. The thing is, just like with any manufacturing business, there is a need to scale up, and to do so responsibly – and that's something the jewelry industry struggles to achieve with Precious Metals AM.

Described as rare metals with a high economic value, precious metals are chemically inert and less reactive than other elements. Unlike in the past where they were mainly used as currency, today, they are regarded as investment and industrial raw materials that can be leveraged across specific industries.

For this niche market, the discussion pops up at a time when consumers have high expectations for what they buy. Ethical sourcing and sustainability issues are now too big to be ignored, even by the most luxurious brands that have built their empire under an unsaid "*don't ask, don't tell*" policy that would retain the mystique of their amazing works — or perhaps make them more attractive to the eyes of the buyer.

The current presumption is that since AM is by nature a "sustainable fabrication process", it would be much easier to demonstrate the sustainability approach of luxurious jewel brands producing products with precious metals. **How far or how close are we from this presumption?** That's the one billion dollar question we would like to address in this exclusive feature.

To discuss this topic, we will explore:

I – Types and main characteristics of precious metals

II – Types of AM technologies that can process precious metals

III – The business case with circular economy and the reason why is it difficult to scale up Precious Metal AM in the jewelry industry

While the focus will be made on jewelry applications, it should be noted that precious metals can also be used in other vertical industries. These industries could be cited when and where required.

I- Types and main characteristics of precious metals

"Precious metals present unique characteristics compared to other metals. They do not oxidize to high temperatures, withstand high corrosion, and do not chemically interact with the environment. Characterized by a long lifetime, they are usually ductile and more lustrous in appearance. While the standards will introduce other material candidates as precious metals, there are currently four primary precious metals on the market: gold, platinum, silver, and palladium", **Damiano Zito**, CEO of AM service bureau **Progold S.p.A**. told 3D ADEPT Media from the outset.

As far as AM is concerned, the technology is suitable for industrial applications when it processes fine spherical precious metal powders made of gold, silver, platinum and palladium alloys. Once refined for AM, they integrate a very fine-grained microstructure, can easily be handled, and deliver high purity and excellent flowability.

"While gold and platinum remain the most widely used precious metals in AM, silver remains the cheapest one compared to other metals. That's why, we easily see more applications with silver", **David Fletcher** completes. The latter is a precious metals 3D printing expert and ex-Head of Business Development AM at **Cooksongold**, UK's largest one-stop shop for jewelry makers.

Available in different forms, the forms **granules or sponge / powder** are most appropriate for industrial use.

Gold – one of the most widely known in jewelry - is unique for its durability, malleability, and ability to conduct both heat and electricity.

Used in jewelry and in other industrial applications, silver is known for its conductive, anti-bacterial and malleable properties.

Platinum on the other hand, receives a great demand from the automotive industry, where it is used to reduce the harmfulness of emissions. When transformed into an alloy, it enables to achieve key applications in jewelry and dentistry. *"Platinum is much more mature when we look at metal 3D printing applications that can be achieved with precious metals; not to mention that it is compliant with the industry standards"*, the representative of **Progold** notes. Unlike other precious metals, it is easy to 3D print platinum thanks to its low reflectivity and low thermal conductivity. For instance, an application that may be produced in three hours using platinum might take up to ten hours with silver.

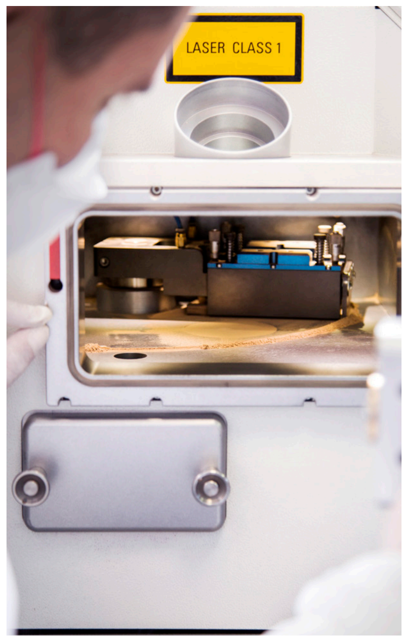
It might not be known as much as gold, silver and platinum, but palladium is a noble metal that is a great fit for jewelry and watch making applications. Resistant to erosion of air and acids, the material is valued for its biocompatibility and resistance to thermal wear. It is also one of the most challenging materials in regard to processing and refining, and incurs high costs in capital.

II – Types of AM technologies that can process precious metals

According to **Fletcher**, the difficulties in 3D printing precious metals lie in the ability of the operator to understand the interdependences between the machine, the powder and the whole process. Taking the example of Cooksongold, he explained that the company can 3D print in 18k yellow gold, 18k red gold, 18k white gold, 925 silver and 950 platinum due to parameters it qualified for their use on EOS machines.

That being said, it should be noted that additive manufacturing technologies that can process precious metals are divided into two groups: ***indirect 3D printing methods*** and ***direct 3D printing methods***. For those who do not know, indirect manufacturing refers to the use of AM to produce tools like dies and molds for traditional processes, while direct 3D printing/manufacturing refers to the creation of parts straight from the design.

In indirect 3D printing, the operator 3D prints a wax pattern that will be used in investment casting to produce the final product. In such operations, resin 3D printing technologies such as SLA are used to create the patterns from castable, wax-like resins. Once the pattern is fabricated, it is covered in a heat-resistant material such as plaster and placed into an oven where the wax is melted. The molten precious metal is then poured into the mold, filling the space left by the wax.



As far as direct manufacturing is concerned, **Progold's CEO** explains that **Powder-Bed Fusion** (also known as Selective Laser Melting) is the most widely used AM process with precious metals. Other technologies that can also be worth exploring are **Binder Jetting** and **Material Jetting**.

"In general, any technology that can process metals, can also process precious metals. However, the appropriate use of powders is of paramount importance to make the most of the manufacturing process and deliver a product with good price-quality ratio", Zito outlines.

A similar argument has been highlighted by **Fletcher**. The truth is, given the high value of precious metals, sometimes, the powder that is used for the additive production is worth more than the machine itself. In fact, sometimes, the price of the precious metal can outpace the price of the 3D printer used to process it. That's the reason why, **a lost is an additive production of non-precious metals is less costly than a lost in an additive production of precious metals.**

"On the other hand, there is an interest in the use of Binder Jetting technology for manufacturing silver. [Remember this qualification of Sterling Silver for Desktop Metal's binder jetting technology]. One of the key challenges though, is the fact that silver is an ideal precious metal for mass production, but the resolution of binder jetting does not meet the requirements of mass production yet. From a sustainability standpoint, the technology has the same carbon footprint that traditional technologies. However, SLM currently remains a top-tier technology for precious metals because the small size of the build volume makes it a great deal to save material on the one hand; on the other hand, the technology can enable to save 3 or 4 times the carbon footprint that you usually generate with the traditional technology", **Zito** explains.

On another note, **Material Jetting** might be the least highlighted but it is typically used with highly conductive silver or gold inks to 3D print electronic devices such as antennas, PCB prototypes, circuitry and sensors.

That being said, indirect 3D printing may be the most popular and less costly option when working with precious metals but the use of direct 3D printing processes is currently fostered by the need for more customization and faster time-to-market. **But can jewelry brands scale up this process while remaining sustainable?**

III – The business case with circular economy and the reason why it is difficult to scale up Precious Metal AM in the jewelry industry.

All three experts invited to this article agree with this truth: **"there is no linear economy in Precious Metals Additive Manufacturing (PMAM)". The industry of precious metals itself relies on a circular economy approach.**

The basic idea behind a circular economy is to create closed loops where both waste and new inputs are minimized and existing items/materials get re-purposed, repaired or recycled. In a linear economy, raw materials are extracted, transformed into products (often producing waste in the process), and eventually discarded.

Here is the thing, in fine jewelry, most of the components that go into making it are entirely recyclable. Precious metals such as gold, silver and platinum can be recycled over and over again with no loss of quality.

So, where does the problem lie? Probably in **the correlation that should exist between sustainability and scalability**. By definition, sustainability is the *"idea that goods and services should be produced in ways that do not use resources that cannot be replaced and that do not damage the environment."* It is also *"the ability to continue at a particular level for a period of time"*.

As organizations are currently exploring new ways to move forward in their sustainability journey, **Michela Ferraro-Cuda**, Course Director, MA Luxury Jewellery Management, and a Lecturer in Luxury Jewellery and Ethical Branding, at Birmingham City University, UK, draws attention to the fact that sustainability currently concerns three main aspects: **Profit, People** and **Planet.**

"First, not only should we agree with the type of sustainability we refer to, but we should also keep in mind that an organization can truly say it is sustainable when it is responsible vis-à-vis these three aspects: it should be profitable, and responsible vis-à-vis its people and the planet" **Ferraro-Cuda** highlights – (the Triple Bottom Line). Based on our conversation with Ferraro-Cuda, there are two groups of people in this sustainability journey; each of them employing or may employ a different path to sustainability:

	People	Planet	Profit
Artisans	Small group of people.	Produce and distribute locally which is good for the environment. However, they use "mercury" in their processes because it is cheap, but it is very damaging for the environment as it releases harmful gases.	Do not make too much profit.
Big corporations	The traditional jewelry industry is often pointed at as an industry that exploits people and that does not have ideal working conditions (minimum wage, environment, etc.) but this can change with AM. Less people involved in the manufacturing value chain due to appropriate technologies.	With AM in particular, they can leverage the exact amount of powder needed for manufacturing – and depending on the technology leveraged, they might save time and energy. Can apply the concept of "distributed manufacturing" to produce locally with AM.	Can easily make profit thanks to marketing resources.

On paper, leading jewelry brands hold all the cards (financial resources included) to be successful in using AM for precious metals. In reality, only a very short number of organizations are exploring the AM route. For Ferraro, there is only one reason that can explain this: ***"the lack of data to support their decisions."*** Is it not the very one thing we request from AM companies and AM users? Releasing data that demonstrates how sustainable a use case is, is the only way to back up words with actions.

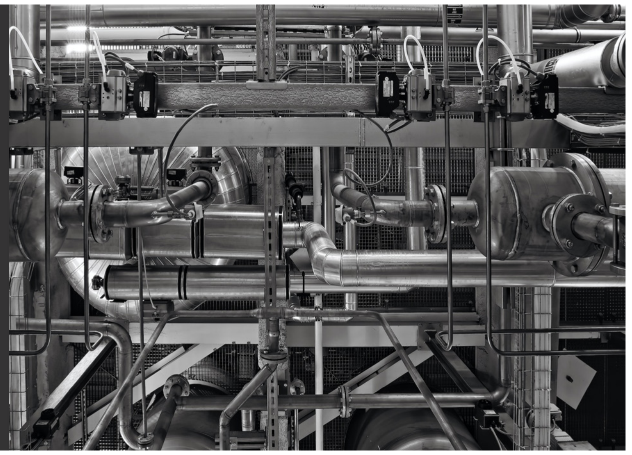
At the end of the day, the price of precious metals remains very expensive – let alone the big price of AM technologies. Big corporations won't take the risk to produce with AM what they can produce at cheaper costs with CNC or casting.

To this, **Damiano Zeto** replies that big corporations should realize that the end customer likes to change and increasingly wants customized products and that's something that AM alone can enable while allowing to control all the manufacturing-related costs. For the CEO, it's ***"a matter of time and a problem of culture"***. As he reflects on his company's journey, he realized that they have been on this market for a decade now, and it's been a few years that other companies have penetrated this market. *"This means that there is a demand that is increasing over time, and that's positive for the AM industry"*, he concludes.

Conclusion

As a report from consultancy firm SmarTech outlines, the penetration of AM into low-batch, high-end, high-performance parts production is the most natural evolution for the use of AM in global manufacturing. The greater accessibility and cost amortization of powder bed fusion systems capable of processing precious metal alloys is expected to drive an increasingly high use of precious metals especially in the jewelry and aerospace segments. Coupled with wider adoption of 3D printing (or multiplanar 2D printing) in electronics, these trends are expected to increase the interest and revenue opportunity around precious metal material for additive manufacturing and the use of AM for precious metal parts.

AM Shapers



The virtuous circle: the triple bottom line and the confluence of forces changing the manufacturing landscape of (3D printed) valves

Given the present economic situation, it's hard to have a decent conversation about oil and gas without having to complain about current price fluctuation. Yet, if we look at the bigger picture – and leave the governments to handle the war in Ukraine and its consequences –, we might realize that one way for oil and gas companies to lower costs and increase margins would be to focus on sustainability. As it has been mentioned multiple times in this edition of 3D ADEPT Mag, "an organization can truly say it is sustainable when it is responsible vis-à-vis these three aspects: ***profit, people*** *and* ***planet*** *" –* ***the triple bottom line****. What's crazy about this idea, is that the more you think about it, the more you realize that additive manufacturing can play a key role in meeting the guidelines related to each of these aspects. It's a virtuous circle.*

The challenges of the oil and gas industry with regards to sustainability have already been discussed in a previous edition of 3D ADEPT Mag. Over time we came to realize that, while regulations dictated by governing bodies continue to establish strict guidelines to follow, there has been a strong shift towards the customers themselves setting tight demands on **valves in industrial processes**.

In case you are an outsider to this industry, please note that valves are a pivotal component of any piping system, hence their importance for the oil and gas industry. They can be used to control flow rates, isolate, protect equipment, and operate in the refining process of oil, gas, hydrogen and other such media. This makes them essential to a wide range of functions and applications.

The thing is, companies that manufacture valves have to respond to a confluence of forces that are changing their manufacturing landscape – automation, agility and digitalization, to name a few – no matter what they are, they have to be perfectly in sync with that triple bottom line.

The triple bottom line

People

For any organization in the oil and gas industry, one of the worst situations that may happen is to have somebody hurt in their facility. To mitigate some of these risks, a lot of companies are investing in artificial intelligence (AI) and robotics to perform high-pressure testing of their valves. Others use control valve diagnostics to monitor valve performance, recondition older valves or simply replace them. Interestingly, in any of the two latter solutions (reconditioning and replacement), you may be able to make profit while complying with environmental guidelines.

Profit and Planet

Those who choose to recondition older valves often do so through the route of a qualified valve repair center which reconditions them back to factory specifications, aka "like new" condition. Through this route, they can save 40-60% compared to buying new valves. Sometimes, it also reduces waste and recycling costs.

On another note, when valves are replaced, they're often thrown in a landfill or sent for recycling. This might require a certain amount of energy to recycle metal, but with the right manufacturing process and powders, it's possible to achieve better ROI. That's something we discovered with materials producer **f3nice** and oil and gas company **Valland**.

The confluence of forces changing the manufacturing landscape of valves

If you are a regular reader of 3D ADEPT Media, you may already have heard about F3nice. Everything about this materials producer is interesting: the history of their creation, their vision, the way they work…but what you should keep in mind here is that they source metal scrap and disused parts and transform them into metal 3D printable powder.

Valland on the other hand, has been operating in the oil and gas industry since 2006. Founded by experts who have been working for more than three decades in the valves business, the company focuses on engineering valves. Their main market is oil & gas exploration and production sectors, including subsea and transmission, and other special service industrial application. In 2016, they started experiencing additive manufacturing (AM) and how the technology could benefit their target industries. The year 2019 marked a period of commitment to developing an AM-related business with the installation of 2 FDM 3D printers. This business continuously expands and 2021 saw the development of an AM-dedicated business unit, named **Valland3D**, with a 3D printing lab capable of handling a wide range of materials spanning polymers, resins and metals.

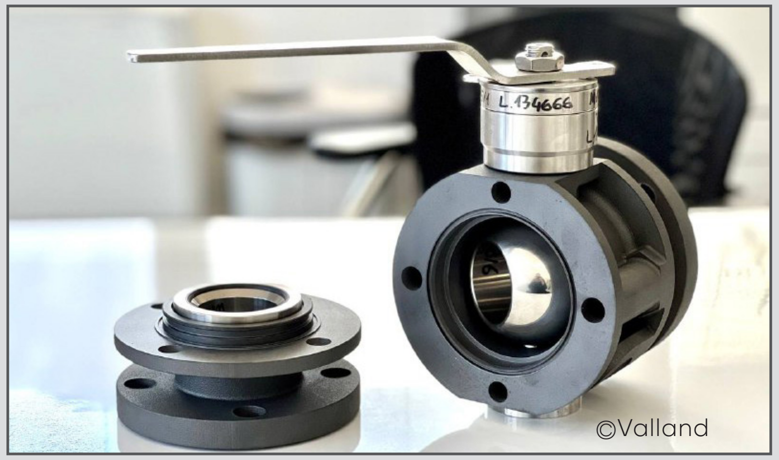
3D printed valve component - ©Valland

"Valland3D currently make uses of AM technologies to develop innovative solutions and produce components for Valland's core and related products which consist of high quality and tailor-made valves for the oil & gas and energy sectors. Building on this, the company aims at spreading through the AM industry an innovative approach based on the concept of working in synergy with the client (eg: end users or EPCs) assisting it along the entire AM value chain. To confirm this, in addition to the pure 3D printing-related services, we offer components' design or re-design applying advanced topology optimization tools and additive process simulation services. Moreover, Valland3D's action is also geared toward supporting partners during the components' usage life cycle through the possibility of adopting spare parts digital inventory solutions significantly contributing in squeezing the spare parts lead time and allowing so for the full realization of an on-demand maintenance approach", **Alex Giorgini**, R&D Engineer told 3D ADEPT Media. In addition to their in-house AM capabilities that include FDM, SLA, LB-PBF technologies and a metal powder atomization R&D hybrid platform capable of combining alternative AM feedstock production technologies, Valland3D can also handle post-processing activities such as components heat treatment and optimization of surface finishing degree through shot peening and sandblasting processes.

Valland3D is one of those companies that believes that AM can positively influence the shift towards a triple bottom line paradigm. As a matter of fact, it has become a regular practice for the team to support AM projects through Life Cycle Assessment (LCA) studies. Last year, it took part in a Joint Industrial Project promoted by Wilhelmsen and thyssenkrupp related to the **redesign for AM and subsequent 3D printing of critical valve components.** *"In the context of the described project, roughly 50% of GHG emissions savings have been assessed by comparing the AM scenario to the conventional manufacturing one through the development of a simulation model based on LCA methodologies"*, **Giorgini** comments.

However, what raises our interest further is the LCA of an additively manufactured part conducted in collaboration with f3nice. The latter aimed to provide a qualitative evaluation of the environmental savings related to the redesign and printing of the body and closure parts of a valve.

LCA of 3D printed valve components



©Valland

As part of this project, f3nice brought its expertise in the development of metal 3D printable powder through the sourcing of metal scrap and disused parts while Valland brought its experience in the design and manufacture of valve components in the oil and gas industry.

According to a report issued on this topic, five main contributions in respect to both the conventional as well as the Additive Manufacturing (AM) routes have been considered:

- **The embodied energy in the steel material**, which is the energetic cost associated with the mining of new material to produce the steel and/or the recycling of pre-existing metal scrap.
- **The creation of the raw product**. This term accounts for the manufacturing of the metal bar which is later used to fabricate the valve components from traditional machining. On the other hand, in the AM value chain, the energy required to produce the steel powder is considered.
- **The manufacturing of the finished components**, requires the use of CNC machining for the conventional parts, while AM and finishing have been considered for others.
- **The utilization**, a contribution based on the weight reduction of the printed parts installed on the FPSO vessel.
- **The transportation and logistics**, due to the different supply chain models adopted in the conventional and AM approaches.

The project team studied **three scenarios** for this last consideration (transport and logistics).

In Scenario 1 dedicated to a conventional manufacturing process, they took into account the fact that the production of the steel billets occurs in major countries located in the South East Asia area, such as India or China while the CNC machining process was performed in Singapore.

Two other scenarios have been explored for AM: one (Scenario 2) where the powder is atomized in Germany from the recycling of metal scrap from Europe – and later used in Singapore for the AM production of the part and another one (Scenario 3) where the powder is atomized closed to Singapore (again, in Indonesia or Malaysia) from local scrap, and 3D printed in Singapore.

Calculations have been carried out taking reference data for each specific process (i.e., energy consumption values in MJ/kg). When possible, real data have been used instead, starting from the atomization of powder carried out by f3nice in 2021, one reads. The final results have been shared through various tables:

Energy Consumption (MJ/unit)			
	Scenario 1 Conventional manufacturing	**Scenario 2** AM from Europe	**Scenario 3** AM in Singapore
Embodied energy	874	95	95
Raw product	266	80	80
Manufacturing	93	867	867
Utilization	0	-116	-116
Logistics	15	18	2
TOTAL	**1248**	**945**	**928**

The project team could achieve these results thanks to the 100% recycled content in the f3nice powder. The energy savings are in the order of 24% – 26% compared to the conventional supply chain. Despite the significant contribution coming from the manufacturing phase (i.e., printing) in the AM scenarios, the use of scrap material guarantees a better LCA. At the same time, the reduction of the total weight of the parts by AM also decreases the raw product costs (less metal to be treated). Finally, the reduction of weight contributes beneficially also in the utilization phase, since the present analysis relates to components that will be transported all along their lifetime, the team noted.

The results of the energy consumption in each scenario have also helped to estimate each of their carbon footprint. With the goal of making calculations easier, the standard energy mixes of the aforementioned countries have been considered as input parameters here.

Carbon emissions [kgCO2eq/unit]			
	Scenario 1 Conventional manufacturing	**Scenario 2** AM from Europe	**Scenario 3** AM in Singapore
Embodied energy	64,6	3,4	4,9
Raw product	19,6	2,8	4,1
Manufacturing	4,8	44,8	44,8
Utilization	0	-8,2	-8,2
Logistics	1,1	1,3	0,1
TOTAL	**90,1**	**44,1**	**45,7**

Results for the carbon emissions are even more positive than what was previously observed for the energy consumptions. The total carbon emissions per unit are nearly half of what was calculated for the conventional supply chain. AM savings range between 51% and 49% for the powder produced in Europe or locally in Singapore, respectively. The increment in savings depends on the carbon intensity (i.e., the energy mix) of the countries considered in the calculations. As for the creation of the raw product in the conventional supply chain, the carbon intensity of India or China dramatically worsens the total carbon footprint of Scenario 1. On the other hand, the average carbon intensities of Europe (e.g., Germany or Italy) and Singapore offer a beneficial contribution to carbon emissions calculations, further increasing the gap between the conventional and the AM supply chains, the report details.

At the end of the day, despite their encouraging outcome, these scenarios are not (really yet) applied in real life – at least the part regarding the use of AM and recycled metal to produce valve components. One of the very first steps that will encourage organizations to follow the AM scenarios and benefit from the triple bottom line's advantages might be to foster the adoption of sustainable feedstocks produced from waste material or end-of-life components. For Valland's E&D Engineer, another area of interest would be the *"energy and consumables consumption efficiency of AM technologies"*. By focusing on this area, the environmental impact related to the components building process would be significantly reduced.

Furthermore, while AM technology providers would need to continually work on the optimization of their processes, exploring the replacement of valve components using AM and 3D printable recycled metal powder could be a win-win for both the end-user and materials producer' business. The role of *"AM feedstocks suppliers (…) will become increasingly relevant considering the issues of critical raw material availability which the world economy will progressively have to face"*, **Giorgini** explains.

Agility and Change


©Valland

While the growing sustainability considerations affect valve design and manufacturing, it's important to keep in mind that not every sustainability action needs to be complicated and huge. Sometimes, lifesaving solutions may come down to the use of agile manufacturing which involved automation and digitalization tools, AM, and recycled 3D printable metallic powder. It's too soon to say where this niche industry is headed, but the timing is right to tell organizations they should plan for change in their manufacturing process in order to stay competitive. That's in any case what companies like Valland do by helping target industries to navigate this new era of manufacturing valves with sustainability in mind.

ENTERING A NEW AGE OF REAL LOW-COST TITANIUM FOR ADDITIVE MANUFACTURING WITH IPERIONX.

Used for everything from cars, medical implants, jewelry to heat exchangers and more, titanium is appealing for its lightweight, strong, stable properties and ability to withstand corrosion. Its low density and high strength make it the ideal material for a wide range of demanding applications, but these characteristics are also the ones that make it difficult to process via conventional manufacturing routes such as casting, hence the increasing interest for additive manufacturing users in exploring it. Here is the thing, titanium often suffers from a bad reputation due to its "rarity". While manufacturers do not explicitly say it is "rare", they do recognize it is rarer than other metals, which results in a higher selling price.

This manufacturing and economic context has drawn the attention of **Anastasios "Taso" Arima**, Founder and CEO of IperionX, who has made it a key business goal **to revitalize a low cost, low carbon U.S. titanium industry**.

Anastasios "Taso" Arima, Founder and CEO of IperionX

"Titanium has the potential to be a key critical material that can be substituted for more widely used higher-carbon metals, particularly stainless steel and aluminum. It is a superior metal to stainless steel and aluminum due to its properties such as high strength-to-weight ratio and excellent corrosion resistance and is critical to the global aerospace, medical, space and defense sectors. Not to mention, titanium was listed in the top 50 minerals deemed essential to the economic and national security by U.S. Department of the Interior", Taso told 3D ADEPT Media.

Founded in 2020, IperionX turned stealth mode off this year by planting its flag to be the first name in American titanium, from raw materials to manufacturing. The company's bold ambition to develop US-based sustainable critical mineral and critical material supply chains, to facilitate the global transition towards a closed-loop, low-to-zero carbon, resource efficient and socially inclusive green economy is backed by the founder's strong experience in the exploration, implementation, financing and permitting of projects.

"I successfully developed one of the leading lithium projects in North America, Piedmont Lithium. Once that project was well advanced and with a strong management team in place, I began to look at other supply chains in the United States that are vulnerable and need to be re-shored; titanium was a standout. We identified very quickly that both titanium mineral and metal supply chains need to be rebuilt in the U.S., we have secured a very large mineral deposit in Tennessee, and we have combined it with an advanced, highly sustainable titanium metal production technology", Taso points out.

In just one year (since it turned stealth mode off), IperionX has achieved milestones that others couldn't achieve in several years of activity. A few of them include a partnership with ORNL to develop low-cost titanium alloys for additive manufacturing, the production of low-carbon spherical titanium from Tennessee minerals, a listing on Nasdaq and even a partnership with luxury watchmaker Panerai to additively manufacture titanium watches.

Each of these milestones has been propelled by a range of proprietary production technologies capable of producing the low-carbon spherical titanium metal using *"100% recycled titanium scrap metal as a feedstock"*.

How does the production process work?

In order to understand the capabilities of these production processes, it's crucial to shed light on the various grades of titanium for outsiders to this sphere. Indeed, determining that titanium is the correct metal for a production is one thing, choosing the right grade of this material is another one – and certainly one of the most crucial steps as the right grade is essential to ensure a successful completion of a production.

Four commercial pure titanium grades (grades 1, 2, 3 and 4) have been identified on the manufacturing market. As far as titanium alloys are concerned, some of the widely-known grades include Grade 5 (Ti 6Al-4V) Titanium, grades 7, 12 and 23 (Ti 6AL-4V ELI).

While all grades are corrosive resistant, strong and lightweight, there are still some important differences that could impact the final results. Choosing a titanium grade requires to consider how the metal will be used, what conditions the titanium will be in, and the size of the titanium parts.

Taking the example of the recently developed spherical titanium powder alloy Ti64, Taso explained how their team has been able to meet the important Grade 5 quality specifications. The grade 5 is said to be the "workhorse" of the titanium alloys – and of the aerospace industry. It accounts for 50% of total titanium usage the world over.

From a manufacturing standpoint, it can be heat treated to increase its strength, used in welded construction at service temperatures of up to 600° F, and it delivers high strength at a light weight, useful formability and high corrosion resistance.

Such material is a great fit for the production of aircraft turbines and structural parts; it is also used in high-performance engine parts, sports equipment biomedical implants, to name a few applications.

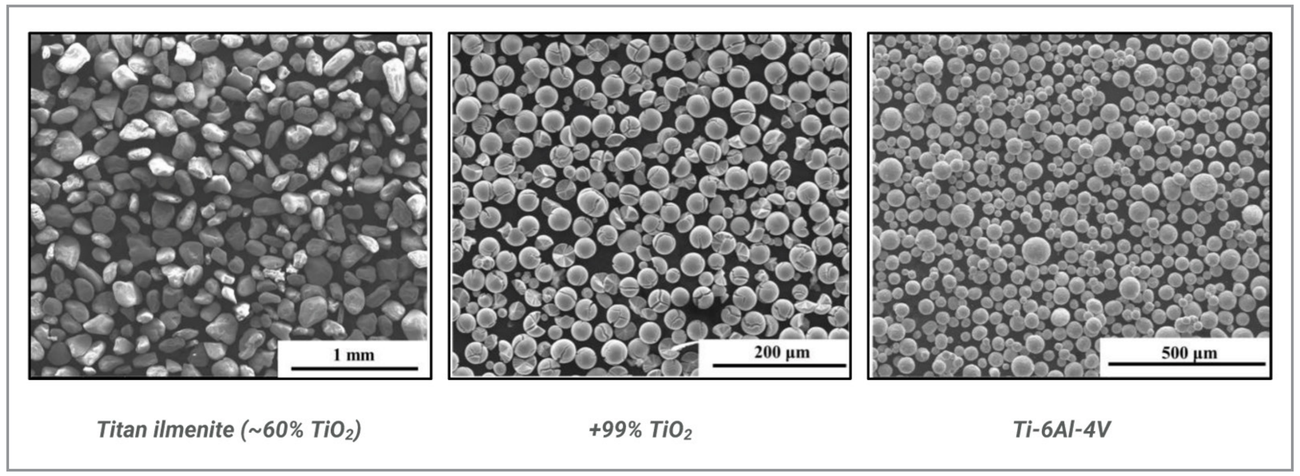
Interestingly, to produce such a high-quality spherical titanium alloy powder and make it compatible with AM, the IperionX team relies on a three-step patented production process: they sourced medium grade titanium minerals (ilmenite) that they upgraded to a +99% titanium dioxide feedstock using the proprietary **Synthetic Rutile and Alkaline Roasting** and **Hydrolysis ("ARH")** process technologies. They blended the high-grade titanium feedstock with oxides of the alloying elements and reduced it using the patented **Hydrogen Assisted Metallothermic Reduction ("HAMR") technology** to obtain low-carbon angular titanium powders. The last step consists in utilizing the patented **Granulation Sintering Deoxygenation** ("GSD") technology to produce the high-quality spherical titanium powder alloy Ti64.

"We can process this scrap metal to create angular and spherical titanium powder as commercially pure titanium, or as various titanium alloys to be used in applications including additive manufacturing and powder metallurgy", Taso explains.

While the conventional **Kroll process** continues to be the dominant technology for the production of titanium metal, the founder of IperionX outlines that avoiding this process has enabled the team to bypass a series of energy intensive titanium melt processes, ingot manufacturing, wire production and gas atomization, which in the end take time, increase the final cost of the material and are not necessarily environmental-friendly.

How sustainable IperionX' proprietary titanium metal processing technologies are?

Legend: IperionX metal powder production process



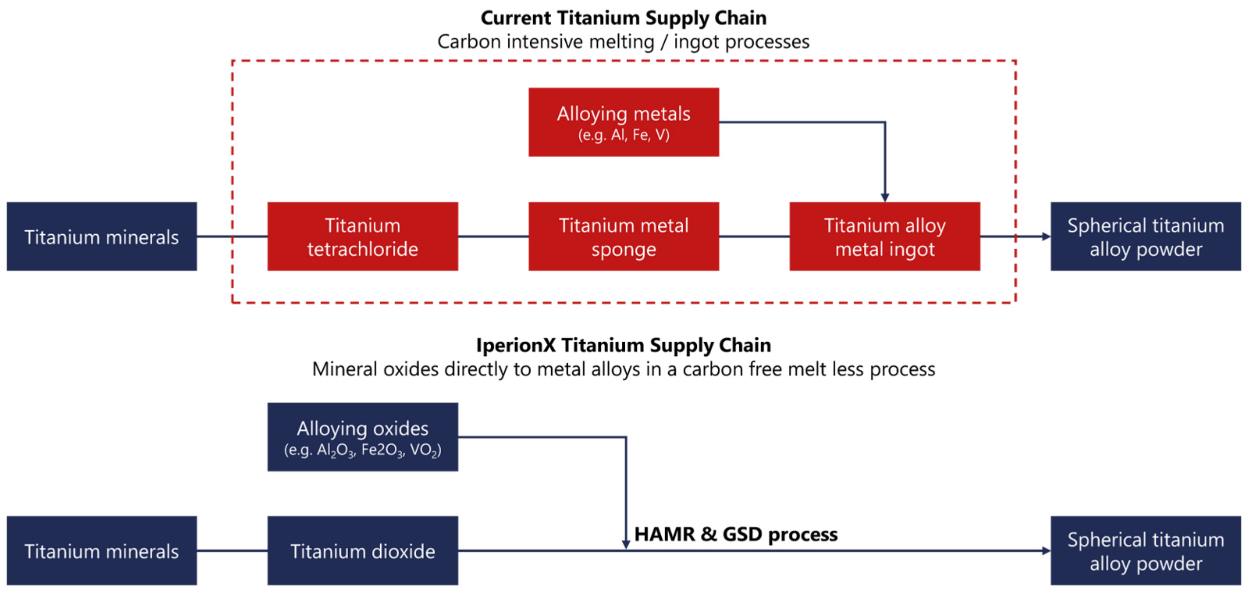
Legend: Scanning Electron Microscope ("SEM") images of IperionX metal powder production process

As discussed with Michela Ferraro-Cuda in the article dedicated to precious metals AM (*page 27 in this edition of 3D ADEPT Mag*), *"an organization can truly say it is sustainable when it is responsible vis-à-vis these three aspects: it should be* ***profitable****, and responsible vis-à-vis its* ***people*** *and the* ***planet***."

Despite the current burden that weighs on most material producers, it turns out that IperionX is in a position to legitimately say it is a sustainable-focused organization. Indeed, producing high-quality materials is great, being able to do so while meeting eco-friendly production requirements is even better. By doing both, IperionX has currently nothing to envy to other metallic powder producers.

"In our current economy, we often take materials from the Earth, make products from them, and eventually throw them away as waste – the process is linear. Companies in the minerals industry tend to produce a lot of waste with their processes and then products aren't recycled. Right now, a significant amount of titanium scrap ends up in the landfill and is too hard to recycle because of its high oxygen levels, but with our technology, that is all going to change. Our HAMR technology enables us to significantly lower the oxygen content in titanium produced from scrap metal, and enables a fully recycled, high quality, integrated and low-cost supply chain of titanium", the company's representative highlights.

To demonstrate how their technologies do not involve the numerous carbon intensive melting processes seen in the Kroll process, the IperionX team compares the various steps they follow to produce titanium alloys with the ones most manufacturers follow by using the Kroll process:



Legend: Existing titanium supply chain and titanium supply chain utilizing IperionX's technologies –Credit: IperionX

Taso underlines: *"Our technologies can produce titanium from either 100% scrap titanium or from conventional titanium minerals. Whilst this image shows the production of titanium metal from titanium minerals, which we have the potential to sustainably source from our Titan Project in Tennessee, we can also do exactly the same thing but with titanium scrap"*.

Furthermore, researchers from the University of Utah recently performed a techno-economic analysis and a full process simulation in ExtendSim (a well-known chemical processing simulation software) to estimate the energy consumption, emissions, and cost at mass production; the ultimate goal was **to assess the commercial viability of the HAMR process.**

With a key focus on the feed materials, reaction conditions (temperature and pressure), and side processes (pretreatment of the feed materials and post-treatment of the products), the findings reveal that the HAMR process is 50% less energy intensive and generates 30% less emissions than the Kroll process, even after accounting for an additional purification step of the TiO2 feed prior to the HAMR process.

The bulk of the energy and emissions savings comes through eliminating the need to chlorinate TiO2 to make TiCl4, and vacuum distillation after the reduction of TiCl4. For the GSD process, the improved yields from this new pathway allows for production to occur at more than 50% lower cost, dramatically lowering the potential price point of high quality Ti powder while keeping energy usage and emissions comparable to the state of practice, a report reads.

In the long-run, from a cost standpoint and thanks to partnerships with organizations such as ORNL, Taso said their *"process will potentially be able to lower manufacturing costs by over 75%"* – taking into account the fact that current spherical powder pricing is typically in the $150/kg to $250/kg range.

The next step one can expect from IperionX

Although its current focus is to deliver added value for the additive manufacturing market, it should be noted that IperionX can produce both spherical and angular powders. To re-shore the titanium supply chain, the company focuses its operations on the U.S. for now. For Taso, *"the US needs to reduce its dependency on Russian and Chinese titanium. Making these processes more sustainable and low-cost is key to ensuring a better future for generations to come"*.

"As we grow and continue to scale, we believe we have the potential to produce at a very competitive price point with the potential to capture market share from the aluminum and stainless-steel markets. [For now, we need to focus on the] re-emergence of domestic titanium supply chains – but created sustainably and at low cost", Taso concludes.

Guest Column

Where is big data in AM ?

The Additive Manufacturing industry is small in comparison with established manufacturing technologies and it needs to evolve to a higher level of output to become more competitive than existing technologies. Big data plays a key role in this path. Collecting big data in Additive Manufacturing is still in its infancy. In this column, AM Flow's Patricia van der Voort shares the company's vision on what big data entails for the AM industry. This is by no means a fully comprehensive article on the subject, as big data definition and big data in AM are continuously evolving.

Let's start with the obvious: Additive Manufacturing is a digital manufacturing technology. Digital implies data. In Additive Manufacturing, almost all steps in an AM-factory can generate useful data. First, the customer: all 'data points' making up their digital N=1 designs, then the printing process itself, manufacturing processes in general, 'quality' of prints, etc. All this data can be the input for a quality-control feedback system, generating a set of optimized process inputs, and will lead to better end-products, higher efficiencies in production, a more sustainable manufacturing industry, more resources and cost reductions.

Before we kick off, we would like to highlight what makes Big Data in AM complex: you can print any object, anytime, anywhere. As the market is currently moving towards mass customization or what we call 'an infinity of geometries', Big Data in AM will be based on a continuous flow of highly variable data.

Types of data

· Print data

· Material data

· Post-processing

· Production data

· ...and more.

Print Data

Print data relates to all data generated during the printing process. But I would also like to add a couple of other data points around printing:

· Digital geometrical data (e.g., in STL, STEP, EPS, DWG or other formats)

· Build nesting data (i.e., where are geometries/prints located and orientated)

· Meta-data (customer info or specific quality constraints)

· ...

Printer OEMs are already generating and gathering data on the actual printing process to identify anomalies during the process itself and automatically pass on the need for the reprint of a specific print (which speeds up the lead time for a print). This data can then be combined with the actual design or nesting data. Factors that influence the outcome of the printer include, among many others:

· **Printer settings**

o Pre-heat temperature

o Laser temperature

o Resolution settings

o Layer height

· **Prints (+ in build)**

o Design and geometry

o Build density

o Print orientations

o Print location

o Vicinity of other prints

· **Cleaning**

· **Cooling**

o Temperature gradient (form outside-in

o Speed of cooling (deformations, warping

o Temperature delta (total amount of cooling or local variations outside the more global temperature gradient)

· **Unpacking**

o Initial temperature

o Auto vs. manual unpacking

o Unpacking

· ...

Material Data

It goes without saying that the quality of each individual batch of material will impact and determine the quality of the print itself. The repeatability of the printing process is influenced by the consistency of material quality. Aspects that can be included in the analysis of the print quality are for instance:

· Production characteristics of a powder batch

· Powder granularity

· Recycle ratio

· ...

Post-Processing data

Nearly all polymer printed prints undergo some level of post-processing. We distinguish the following sub-set of post-process technologies:

· **Substrate removal**

· **Sanding**

· **Polishing**

· **Blasting**

· **Vapor deposition**

· **Dyeing**

· **Painting**

· **Assembly**

· ...

Even if a part has been printed in the highest quality possible, in this specific area of 3D printing, various aspects influence the quality of Additive Manufacturing later in its processing. Several of these aspects per activity include:

· **Polishing**

o Type of stones/medium

o Duration

o Amount of water

o Chemicals added or not

· **Sanding**

o Granularity

o Duration

o Speed

· **Blasting**

o Type of medium

o Duration

o Pressure

· **Cleaning**

o Substrate removal

o Unpacking technology

· **Vapor fusion**

o Materials used

o Deposition

o Duration

o Temperature and pressure

· **Dyeing**

o Type of dye

o Duration

o Speed

o Temperature

· ...

...and many, many more (sub)parameters that could have an impact on the future quality of prints can be identified (we might not notice/see, but what about AI?).

Workflow automation

The AM world today is so much more than just 3D printing prototypes. It's increasingly becoming a full and mature manufacturing technology.

The number of manual operations after printing is growing and with it the number of errors due to incorrect sorting and/or editing, as well as the time required for Quality Assessments.

Therefore, competing with today's traditional manufacturing world requires to take into account workflow automation and digital quality on the one hand, on the other hand, to automate post-processing steps, to deliver error-free and high-quality orders to customers within the shortest possible lead time.

AM-Flow has developed AM-VISION and AM-SORT for workflow automation.

It allows 3D printed geometries (or prints) to be recognized based on shape, color, and size and then sorted for the next machining step; this step can be part of post-processing or quality assessment or shipping. This automation will build a lot on the various data inputs (i.e., parameters) described above. Workflow automation will also require customer-related information such as customer number, order number, shipping address, etc.

All this data is needed to be able to recognize, allocate and sort a print throughout the entire order process based on its unique values. Although some workflow data is available, there are still some loopholes that need to be addressed, such as data flow to and for the MES.

Track & Trace

One of these areas for which data is not available is full Track & Trace on the work floor. AM-Flow is working on developing a Track & Trace system. The basis for this system remains the recognition and sorting of parts, based on available data. However, this data is supplemented with all information about the movement of the prints through the factory. This allows prints to be tracked throughout the entire process, both physically and digitally.

In addition to location, it is also possible to add the time factor to the data; how long is a part staying somewhere, is it on hold or what operations has it undergone? From a purely lean manufacturing perspective, the mindset must be that every 3D printed part should find its way to the exit in the shortest possible time. This requires secure planning if a customer has ordered several items, each to be produced with different print technologies, thus each with different run times impacting the lead time of each individual part.

With all this collected data, you create insight into the total production process. Existing processes and workflows can be analyzed and then optimized. Bottlenecks can be identified; then smart solutions can be developed.

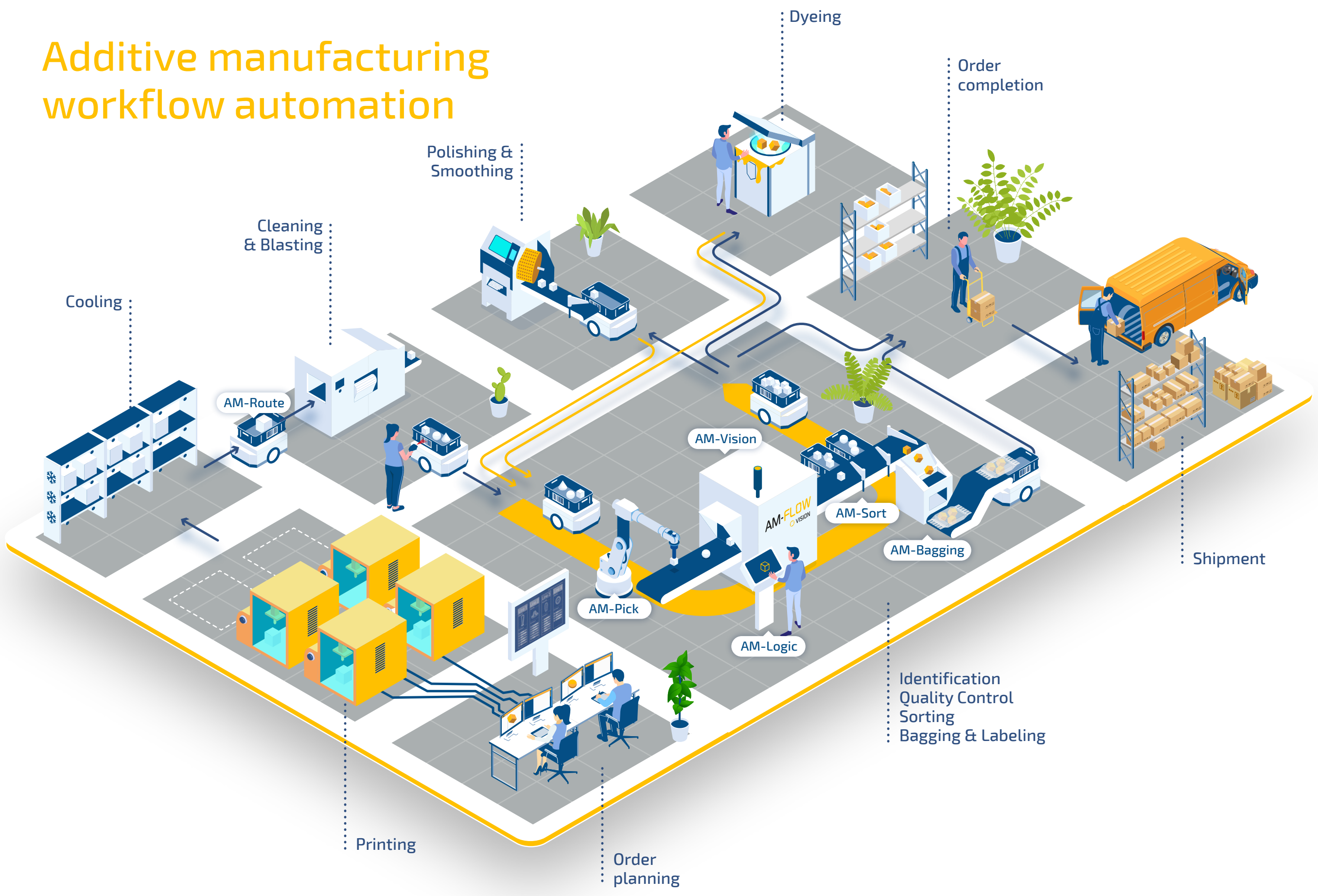
Employees can also be supported in making choices:

- Which order should be ready first?

- Which activities must be carried out first in that end?

This information can then be given as constraining inputs to the AI as well. AM-Flow is convinced that with workflow automation including Track & Trace, a big catch-up can be made compared to the current production world, a world where real-time data is much less available.

Additive manufacturing workflow automation



Quality Assessment

In addition, there is the quality aspect.

The quality of prints has been a topic of debate in the 3D Printing world. At this point in time, we think in all honesty that constant, repeatable quality cannot yet be guaranteed.

Even if you were to print the same batch every day, the quality of the products can still vary - the warping of prints, the creation of sinkholes, differences in size ….

Measuring and checking each print separately is almost impossible when hundreds, if not thousands of geometries are printed per day. And even if it could be done manually with the help of currently available devices, some deviations are difficult or impossible to detect with naked eyes.

Furthermore, quality assessment usually takes place as a final step. If a product has not been 3D printed properly or a processing step has not gone well, this will only be discovered at the end of the process and the product must be reprinted and processed. This currently takes a lot of time. However, checking after more production steps is just too labor-intensive.

A fully automated quality assessment after each processing step, based on the 3D model and finish, is therefore highly desirable and not just automation on its own. The desired solution will have to allow for the processing of hundreds of prints in a limited timeframe – this is the essence of industrializing Additive Manufacturing through for instance, the building of AM factories.

AM-Flow is taking the first step in this direction with the development of an in-line AM-QUALITY module. This solution allows for a fully automated quality assessment to be carried out after each processing step, a first step generating quality parameters as feedback to enable AI-driven quality control automation.

With the AM-QUALITY solution, we would not only be able to identify a defect more accurately and quickly, and give an automatic reprint signal, we would also be able to collect data that enable to errors on geometries. Such information is useful to predict issues that enable to improve the process and prevent errors that may occur in the next production batch. Information about the type of defects in certain material types, the printer used, the machining steps performed, etc. could provide AI-learned insights that anyone in the AM world would learn from.

Conclusion

We believe that the Additive Manufacturing market is growing to a size in which data will increasingly become a driving force of 3D printed output. The diagnostic instrumentation is still to be built; the experience of data analysis and interpretation needs to grow, and finally, deploying all this data is key. We will need to be on a steep learning curve to be able to generate relevant and actionable data. AM-Flow looks forward to the growth and evolution of big data in Additive Manufacturing and aims to actively contribute to the development of this field and meet the increasing demand for industrial quality assessment and control.

During Formnext 2022 in November at Frankfurt or at our demo location in Eindhoven, we would like to discuss your view on workflow automation, quality control and the need for big data in the AM world.

ABOUT PATRICIA VAN DER VOORT

After her education in Civil Engineering, she started her career as project leader in (eco)hydrological projects.

Now she is currently working as a process expert at AM-Flow and is an advisor in business processes and workflow optimization.

The additive manufacturing industry uses more digital information than any other manufacturing industry. She loves how this changes the way she incorporates her knowledge into the AM Industry!

Formnext Preview

Exhibitors' innovations around every corner

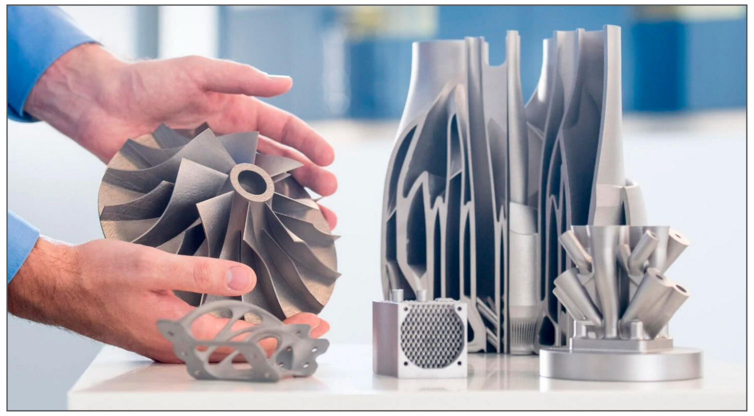
With over 730 exhibitors and more than 50,000 m² of gross floorspace booked by September, Formnext has already surpassed last year's figures, paving the way for an exceptional 2022. The world's leading exhibition for additive manufacturing and modern industrial production will also be setting new standards in content. The supporting program of events is set to be more extensive than ever before, showcasing the latest topics and developments in additive manufacturing from such diverse sectors as the construction industry, aerospace, ceramic applications, and investments. Also playing an important role in the event will be this year's partner country, **France**.

The importance of Formnext for the industry is reflected in the exceptionally high number of innovations already announced by exhibitors. These range from new technologies and systems to innovations throughout the process chain, from materials to post-processing. The announcements below provide a short overview of what you may expect.

TRUMPF (HALL 12.0, BOOTH D 81)

Trumpf to highlight AM with pure copper

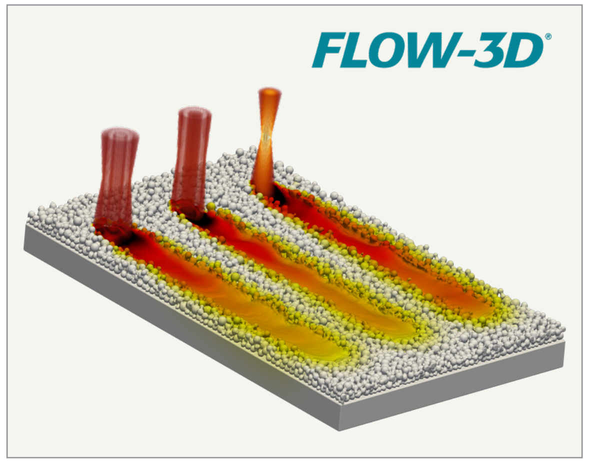
Industrial 3D printer manufacturer Trumpf will highlight large components that can also be printed with pure copper, opening up a new way to manufacture induction coils or components for demanding cooling applications, e.g. for power and optoelectronics. These applications will be showcased alongside the TruPrint 1000, the company's next generation of industrial 3D printers. Built with the highest build rates and capable to deliver outstanding part and surface quality, at low part costs, the TruPrint 1000 also scores with ergonomic, contact-free powder handling and extended monitoring. Its new design is optimized to fit through a standard door and fit in any lab; whether in the dental industry or in a university. The machine will be featured alongside highly productive, semi-automated TruPrint 5000 3D printing system that gets any industrial ready for series production. Visitors at Formnext can learn more about Trumpf's wide range of solutions in **Hall 12, Booth D 81**.



FLOW-3D AM (Hall 12.0, BOOTH B75)

Flow Science to demonstrate the capabilities of its software simulation solutions

Software provider Flow Science develops a wide range of solutions for various industries. In the AM industry, the company is known for FLOW-3D, a software solution for computational fluid dynamics, also known as CFD, a branch of fluids mechanics that focuses on numerical analysis of complex fluid flows. CFD is one of the key tools to create digital twins of physical systems. The company releases a new version of FLOW-3D twice a year, where it introduces new and enhances the existing, physical models, as well as improves the graphical user interface based on the feedback it receives. In **Hall 12.0, B75**, visitors at Formnext will discover the latest upgrades of this software as well as examples of simulations that can be performed with this software. The company will also discuss the capabilities of other solutions such as FLOW-3D POST and FLOW-3D (x), and discuss the licensing options customers can benefit from.



EVONIK (Hall 12.1, BOOTH C59)

Evonik develops new 3D Printing materials with reduced carbon footprint

With a holistic approach based on four cornerstones – carbon footprint, saving fossil resources, reusability rate and recycling –, specialty chemicals company Evonik has announced the release of new 3D printing materials in its INFINAM® portfolio. The introduction of a new grade of PA12 powders with significantly reduced CO2 emissions is the first tangible and publicly announced step Evonik is taking to back words with action. These ready-to-use high-performance materials will replace the previous INFINAM® polyamide 12 materials for all common powder-based 3D technologies such as SLS, HSS or MJF, the company states.

Produced using renewable energies at the Marl Chemical Park, the release of the new sustainable INFINAM® PA12 powders comes along with a certification granted by TÜV Rheinland which conducted life cycle assessments that attest to an improvement in the company's own carbon footprint of almost 50 percent. In the overall life cycle assessment, the new sustainable material grade reveals positive results compared to the castor oil-based polyamides of Evonik's own Terra range. "*Alongside factors such as production efficiency or the reusability of materials, our sustainability approach includes the total life cycle assessments of our materials and their consistent improvement*", says **Dr. Dominic Störkle**, Head of the Additive Manufacturing Innovation Growth Field at Evonik. "Using green energy and renewable or recycled feedstocks for production, we are able to significantly improve the overall eco-balance of our materials. And we work on end-of-life opportunities for our polymers." This might be the first tangible action we see from Evonik but it's definitely not the last one. Moving forward, we might expect the producer to develop a line of INFINAM® eCO products. Visitors at formnext can discover the new powder in **Hall 12.1, C59**.

ECKART (Hall 12.0, BOOTH A101)

ECKART GmbH to showcase the A205 alloy and its various applications in the AM space

Materials producer ECKART GmbH will be present in **Hall 12.0, A101** during this 2022 edition of formnext. AM is a perfect fit to ECKART's core competences in atomizing & classification of Aluminum – and copper based metal powders. To strengthen its footprint in special alloy powders, ECKART has acquired TLS, a market leading niche player in the field of atomization and customization of special alloys of Titanium, Aluminum and Copper. The company will showcase the patent-protected A205 alloy and its wide range applications for foundries and other demanding industries. Designed for metal 3D printing processes, the powder stands out from the crowd due to its ability to atomize in temperature ranges of up to 2500 °C. ECKART TLS aluminium powders are suitable for the following additive 3D printing processes, Powder Bed Fusion (PBF), Electron Beam Melting (EBM) and Metal Injection Molding (MIM).

FARSOON (HALL 11.1, BOOTH D29)

Farsoon announces multi-laser systems that aim to maximize productivity

OEM Farsoon Europe GmbH introduced 4 new models of industrial-scale metal and plastic 3D printing systems to the European market in May 2022. With these new developments, the machine manufacturer ambitions to enable industrials from a wide range of sectors to reach higher productivity while reducing production costs. The new 3D printers feature a truly open platform that enables the user to have full access to a wide range of key parameters. These open systems allow for fine tuning process parameters with a large variety of third-party materials that best suits the needs for specific application and end-use part properties. With these innovations, Farsoon is significantly boosting the competitiveness of additive manufacturing: Parts can be manufactured cheaper with larger and faster machines equipped with multiple lasers. These new Farsoon machines have numerous elements designed to facilitate operation and achieve a higher level of automation. The quality of the parts is also better as documented by monitoring the build process. Farsoon Europe GmbH will present the 3D printing machines and applications at the Formnext 2022 in **booth 11.1-D29**.

Lithoz (Hall 11.1, Booth D39)

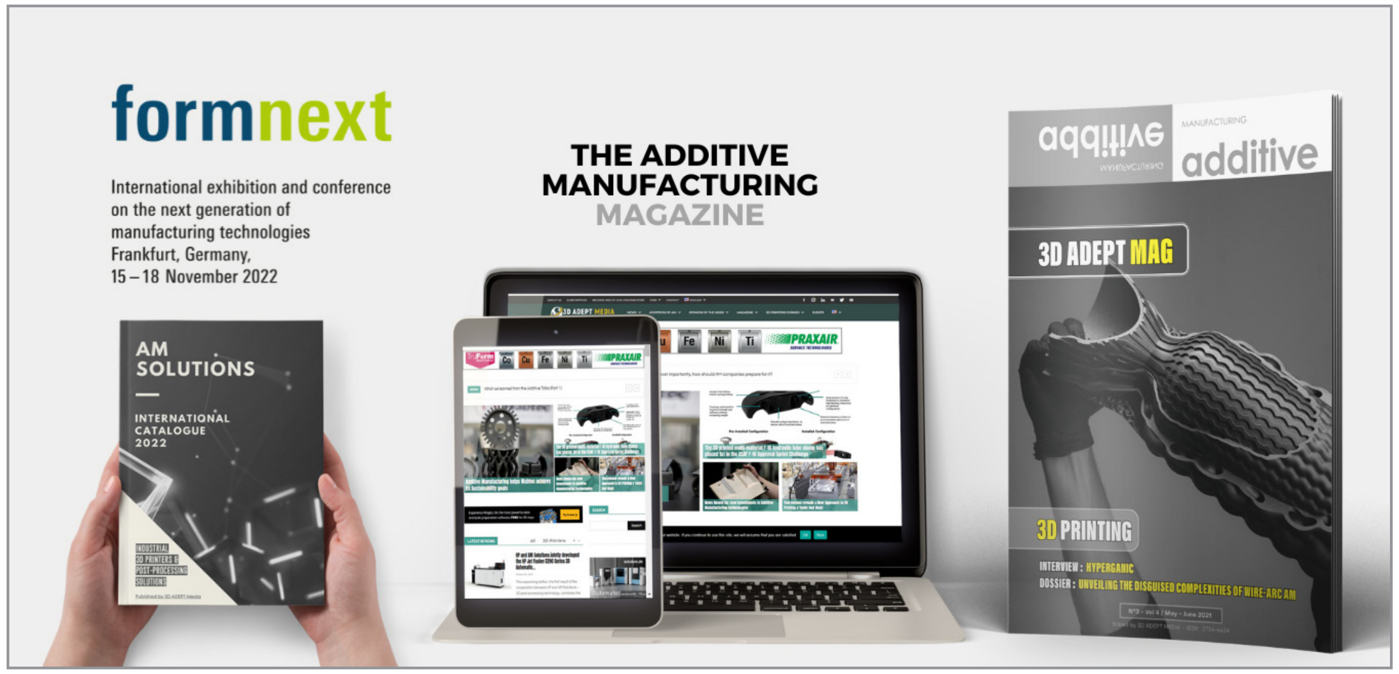
Lithoz turns a vision into ceramic reality: mass production via ceramic 3D printing at Formnext

At Formnext 2022 – in **Hall 11.1 / Booth D39**, Lithoz will present the answer to disrupting the ceramic industry by levelling up profitable mass production in 3D printing. The plug-and-play scalability of their CeraFab S65 ceramic 3D printer has opened the door to a new industrial dimension of complex high-performance ceramics via additive manufacturing. Their compact entry-level model, the CeraFab Lab L30, has enabled easier access to the field than ever before and will be on show in a live demonstration. The Formnext premiere of the CeraMax Vario V900 printer with LIS (Laser-Induced Slipcasting) technology will provide an opportunity to «touch and feel» fully dense ceramic parts with thick walls, while the world premiere of the new LithaBone HA 480 medical material will showcase revolutionary, patient-specific bone implants made from bioresorbable ceramic.

2023 EVENTS

STAY UP-TO-DATE WITH THE LATEST ADDITIVE MANUFACTURING INDUSTRY EVENTS, CONFERENCES, EXHIBITIONS AND SEMINARS.

GERMANY	USA
AM MEDICAL DAYS, DATES TBC	7TH ANNUAL MILITARY ADDITIVE MANUFACTURING SUMMIT, 1–2 FEBRUARY, 2023
EBAM CONFERENCE, 22-24 MARCH, 2023	ADDITIVE MANUFACTURING STRATEGIES 2023, 7-9 FEBRUARY, 2023
HANNOVER MESSE, 17-21 APRIL, 2023	RAPID + TCT, 2-4 MAY, 2023
RAPID.TECH 3D, 9-11 MAY, 2023	**UK**
MEDTECLIVE 2023, 23-25 MAY, 2023	AM FOR AEROSPACE & SPACE, 21-23 FEBRUARY, 2023
AM FORUM BERLIN, 4-5 JULY, 2023	TCT 3SIXTY, 7-8 JUNE, 2023
EMO HANNOVER, 18-23 SEPTEMBER, 2023	THE ADVANCED MATERIALS SHOW, 28-29 JUNE, 2023
AMTC, DATES TBC	VEHICLE ELECTRIFICATION EXPO, 28-29 JUNE, 2023
K 2022 -- THE WORLD'S NO. 1 TRADE FAIR FOR PLASTICS AND RUBBER, DATES TBC	**THE NETHERLANDS**
FORMNEXT 2023, DATES TBC	3D DELTA WEEK, 27-31 MARCH, 2023
SPAIN	**FRANCE**
ADDIT3D - 6-8 JUNE, 2023	GLOBAL INDUSTRIE, 7-10 MARCH, 2023
METAL MADRID, 15-16 NOVEMBER, 2023	PARIS AIR SHOW, 19-25 JUNE, 2023
PORTUGAL	**DENMARK**
EURO PM2023, 1- 4 OCTOBER, 2023	AM SUMMIT, DATES TBC

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