MANUFACTURING

additive

3D ADEPT MAG

DOSSIER : HOW DO AM COMPANIES HELP TACKLE CLIMATE CHANGE? - TANGIBLE ACTIONS ON THE GROUND.

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3D ADEPT MEDIA
All about Additive Manufacturing

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Hello & Welcome

« From Promise to Action »

It's that time of year again when all eyes are on Formnext... And to mark the occasion, this edition of 3D ADEPT Mag, which will be distributed during the fair, focuses on 'sustainability'. This may sound redundant when you see how much this word, as well as the words «climate change», are used at every turn, in all industries and in political debates. Only, to date, the hype has been about a lot of promises and yielded little to no action.

At 3D ADEPT Media, we wanted to go beyond these promises for the Additive Manufacturing industry and for all vertical industries that use AM technologies. One of our main challenges for this edition was to find relevant questions that would avoid any form of «greenwashing», questions that allowed contributors to share key ideas, figures and tangible actions that show how they are working to achieve their net zero emission goals.

It seems easy for large companies with resources and big budgets to do this, but let me tell you that smaller companies are not lagging behind. Unlike large companies where decision making often slows down the implementation of actions, smaller companies have the opportunity to think about a business model that takes these concerns into account from the very beginning of their venture.

From a manufacturing point of view, whether before or after an object is actually manufactured, sustainability issues are refocusing the debate on «materials». The dossier, 'post-processing', 'research' and 'applications' segments highlight the importance of rethinking the production of materials and their use through different lenses and companies.

Moreover, the manufacturing perspective reveals that even if they have to act individually, industry players have to consider other stakeholders. Software providers therefore play an important role, as do 3D printing service providers, 3D printer manufacturers and post-processing companies.

So no, this edition of 3D ADEPT Mag is not a set of fine words, it is an edition that shows what has already been done, what is being done and what remains to be done. It is an edition that calls for action and analysis of the type of society we want to build.

Kety SINDZE
Managing Editor at 3D ADEPT Media
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Editorial

The Leader in Additive Manufacturing

LSAM
Large Scale Additive Manufacturing

LSAM Project Manager, Scott Vaal, takes you on an informative tour of the Thermwood LSAM. A complete system that can both print to near net shape and then machine the print to its net shape. LSAM is by far the fastest way to 3D print large tools or parts.

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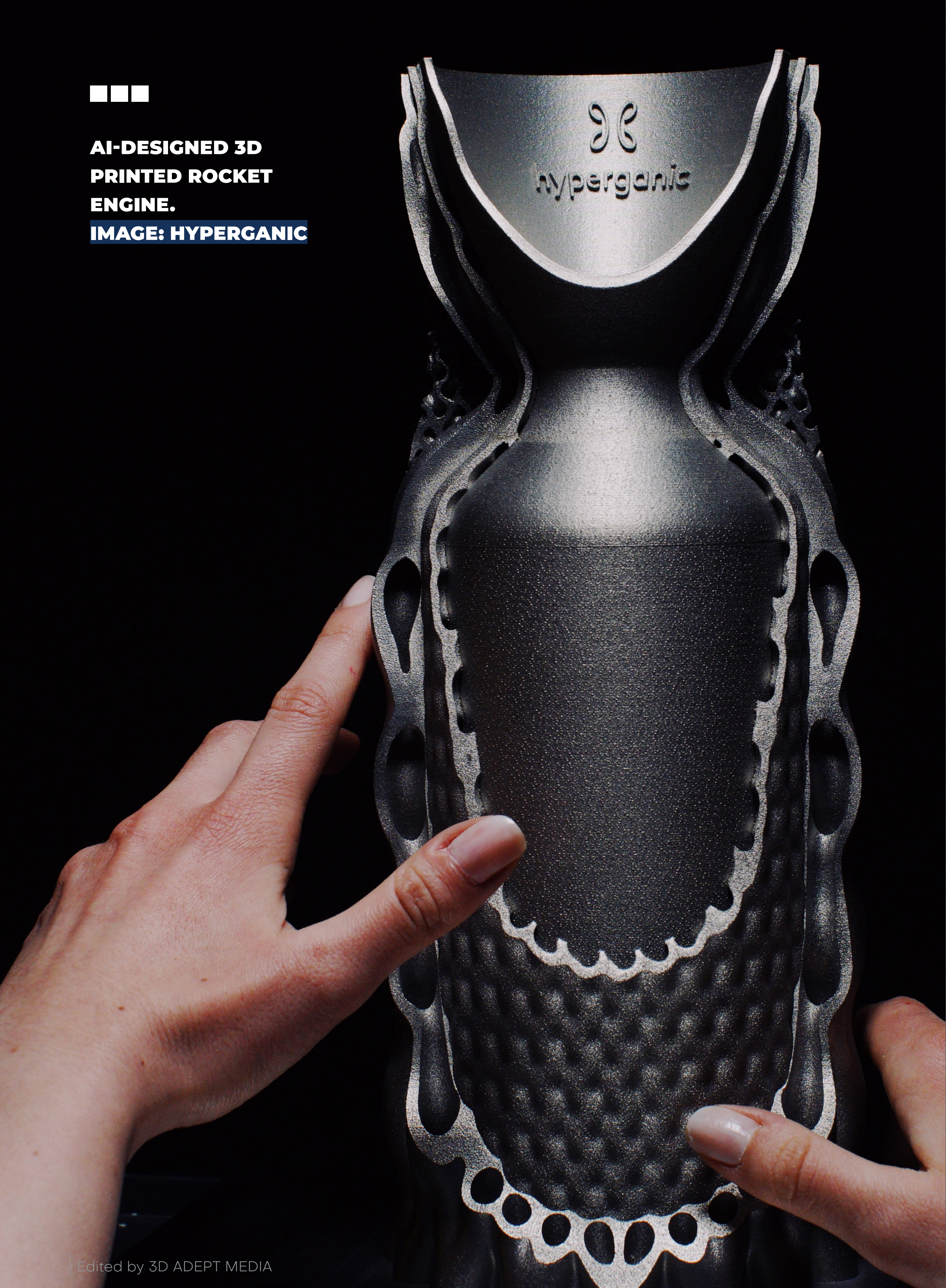


AI-DESIGNED 3D PRINTED ROCKET ENGINE.
IMAGE: HYPERGANIC

HOW DO AM COMPANIES HELP TACKLE CLIMATE CHANGE ? – TANGIBLE ACTIONS ON THE GROUND.

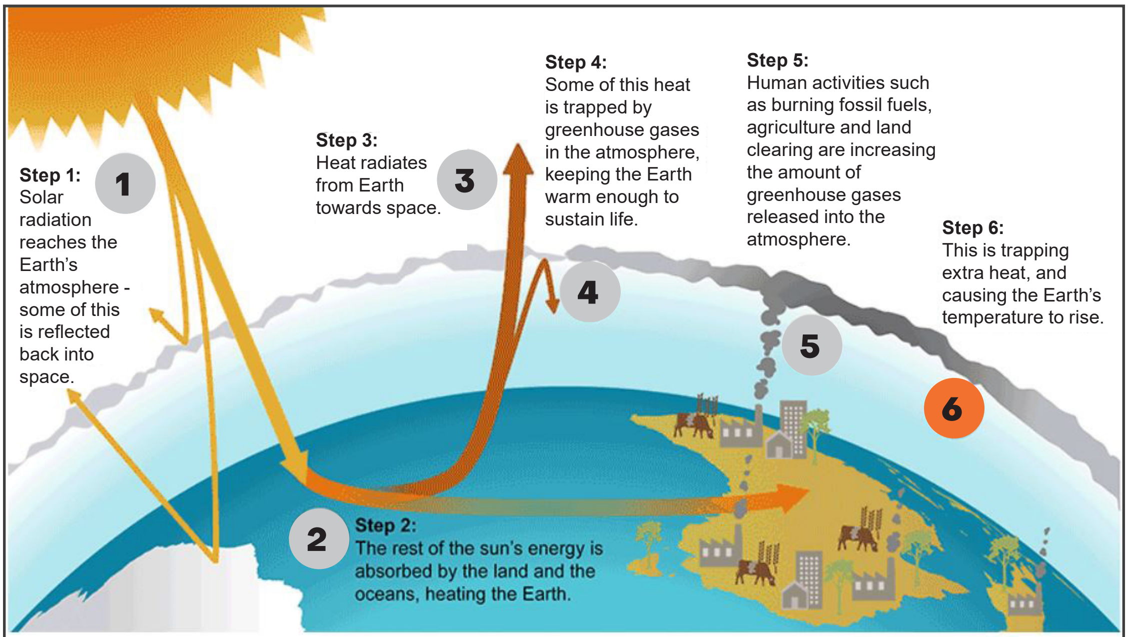
*Climate change is a topic that is on everyone's lips. Governmental authorities have sounded the alarm so loudly that both legal entities and individuals feel they have a mission: play their part in addressing climate change issues. Among the multiple fields this problem can be tackled on, there is **manufacturing**.*

According to the Environmental Protection Agency, the American manufacturing industry accounts for almost a quarter (23%) of direct carbon emissions. The situation is just as dire for the European industry which emits an annual total of 880 million tonnes of carbon dioxide equivalents making it one of the largest emitters of greenhouse gases on the planet. Not to mention that, be it in Europe or in the US, manufacturing remains a field of activity that is deeply linked to other economic sectors such as power and transportation. Beyond these interconnected sectors, one should recognize that the more manufacturing grows, the more new technologies are being developed to help improve operations; new technologies that may be uniquely positioned to beat climate change. And, as you may already know, one of these technologies is **Additive Manufacturing (AM)**.

Here is the thing, AM inevitably involves the contribution of different stakeholders for scaling manufacturing; stakeholders who include a wide range of **software experts, material experts, 3D printer manufacturers**, or **post-processing**** specialists, just to name a few. How can each of them address climate change issues? This is the million-dollar question we are going to discuss in this exclusive feature.

Climate change: the basics

To put this into context, climate change is about observed changes over the 20th century, in the average weather conditions of regions across the world. These changes include the rise in global average air and ocean temperature, increased global sea levels as well as long-term sustained widespread reduction of snow and ice cover. Furthermore, extra heat in the climate system is the cause of these changes, and this extra heat is due to the increase **of greenhouse gases in the atmosphere (or greenhouse gas emissions)**, which are primarily the result of human activities.



Greenhouse effect

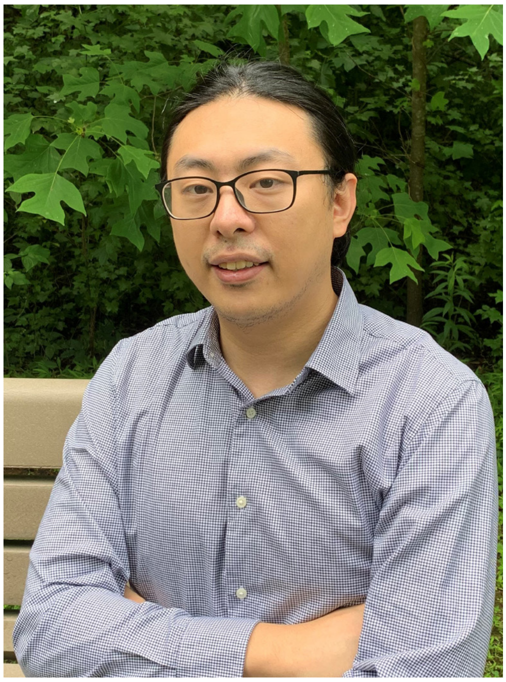
Source: Australia Government | Department of Agriculture, Water and the Environment

Those greenhouse gas emissions are measured in every product's **carbon footprint** – *hence the term carbon dioxide equivalents* - at each stage of the lifecycle product. All of this becomes more complex for companies because, for each product – produced and consumed –, various factors should be taken into account to measure the total carbon footprint, factors that include the **materials** used in fabrication, the **manufacturing** processes or **transportation**.

These factors – which are the most widely mentioned ones when it comes to manufacturing – highlight the need for companies to implement a **sustainability strategy** to address them. That's why ***climate change and sustainability issues are often addressed interchangeably within organizations.***

According to **Dr. Runze Huang**, researcher in sustainability, CEO and Cofounder of ExLattice Inc, *"climate change and/or other environmental impacts might be the most mentioned challenges to be addressed, and that could be possibly addressed now, regarding sustainability. Sustainability consists of economic, social, and environmental aspects, which is a much larger concept than climate change. Among those aspects in sustainability, economics is assumed to be addressed most of the time because it's the traditional fundamental block to business/industry; social aspects are generally complicated, can be extremely difficult to address, and not easily tangible. So, this seems to leave environmental aspects including climate change to be the lower hanging "unaddressed challenge", and often it leads to thinking that sustainability is being addressed when progress is made regarding climate change.*

Secondly or more importantly, it is because addressing climate change and environmental impacts, in many cases, could also benefit the economic and social aspects from a larger perspective. Many measures taken to reduce emissions are related to improving efficiency, reducing waste, and leveraging new technologies, which bring long-term tangible economic gains and job growth at the same time to the factory/business and the whole society."



Dr. Runze Huang, researcher in sustainability, CEO and Cofounder of ExLattice Inc

On the other hand, although AM is said to beat climate change through its various stakeholders, the industry still lacks a measurement model to confirm the validity of this statement. Researchers and sustainability experts like **Dr. Huang** said *the most used tool/model for providing key data is* ***life cycle assessments (LCA) or life cycle inventory analysis****, a method that covers 5 major life cycle stages including material extraction, manufacturing, transportation, use, and end of life.*

"A good LCA model generally contains parameterized sub-models for each life cycle stages to estimate energy use/ GHG emissions from bottom-up with basic design/engineering data. And it also should include sub-models for various AM processes such as FDM or DMLS, and sub-models for traditional manufacturing processes like machining or injection molding for comparing purposes. The use phase sub-model should be customized for the specific application of the AM parts/ products to be analyzed. Such model allows for estimation of the life cycle energy and emission net changes with changing inputs directly from AM users", Dr. Huang notes.

How does this translate into each stakeholder influencing parts production via Additive Manufacturing ?

The software perspective

The use of software in an additive manufacturing production requires various capabilities that can be categorized into five main types of software: Design (CAD), Simulation (CAE); Processing (CAM), Workflow (ERP/ MES), and QA & Security. Depending on which software publisher an engineer relies on, it is possible to find a software that encompasses one or several of these capabilities.

Should every software company therefore apply the LCA model? The answer is much more complex than we think.

Production of a rocket engine. Image: Hyperganic

"We must be clear on the challenge we are up to: Not only do we need to reduce carbon emissions — this is where light weighting could help — but we need to go to zero emissions, and likely less than zero, to stay below critical levels. Under our current engineering and manufacturing models, this change would take generations", **Lin Kayser**, Founder and CEO of **Hyperganic** states from the outset.

According to Kayser, adopting a new engineering and manufacturing paradigm is an *"absolute must"* and while AM – as a manufacturing process - is a critical step under this paradigm, **algorithmic design** is another pivotal one.

"We need to engineer objects through computer code, not through the current manual visual process - instead of an engineer drafting a blueprint in a CAD program, this new way of engineering uses algorithms to craft the most intricate and advanced objects in much shorter amounts of time. Coincidentally, this is exactly how Nature works. Nature builds things additively using blueprints or code contained in the DNA. Under our new paradigm, Nature shows us the way forward", he adds.

Taking example on **Hyperganic Core**, a voxel-based geometry platform for AI-based and algorithmic design developed by his company, **Kayser** explains how interesting it becomes, to create objects by encoding the process one goes through when one designs something into a computer algorithm.

"Instead of creating one object, you create a process that designs objects of that category. Now, you can engineer complex objects ***in minutes instead of weeks*** *and test out different input parameters quickly, which may result in radically different designs. If you think about it, almost all innovation that we witnessed in the last 40 years came from the Information Technology sector, and is driven by Moore's Law.* ***A software paradigm encourages re-use, standardized interfaces and accelerated information exchange.*** *If someone builds a database, I can just use it, I do not need to learn how to build one. If someone builds a better one, I can probably just swap out that component, because it uses a standardized interface. This dramatically speeds up the development of complex software systems. In engineering, on the other hand, people are mostly busy designing the same thing all over again. Any improvement that you make to your objects rely on you, as an engineer, to learn some new tricks and apply new principles. There is little opportunity to share components and use what other people have done. The only way through is buying physical components, and that is a very limited way to re-use ideas"*, he adds.

It's quite paradoxical and interesting to see how **Kayser's** explanation also illustrates

Lin Kayser, Founder and CEO of Hyperganic

two of the "three R's rule" in sustainability **(Reduce, Reuse and Recycle)** – a rule that enables environmental protection and the preservation of resources through a priority approach, the ultimate goal being to get the most practical benefits from products and to generate the minimum amount of waste. In this specific case, Kayser's explanations highlight how an algorithmic design approach helps **reduce time and re-use already built designs in the creation process.**

While this is very interesting, we should recognize that it does not provide tangible data that proves its viability with regards to climate change. This makes us think that one way to measure the positive impact of this approach is through **applications**. How are applications made? And how do we measure improvements these new applications provide as compared to previous made using other manufacturing processes?

"Most people will think of having more lightweight components or functional integration. This is great, as it is important to save material and get away from "heavy metal" carbon-heavy processes. However, the real impact is going to come from radical innovation, enabled by AM. For example, 3D-printed copper spools for electric motors can have complex shapes that reduce eddy currents. This helps the motor get more efficient at high speeds. 3D-printed battery components can help us improve energy density and enable new types of energy storage in general. New types of AM-enabled rocket engines could enable single stage to orbit. These are just a few instances of how 3D printing can move entire industries towards more sustainable innovations" Hyperganic's spokesperson said about the reduction of carbon footprint in vehicles.

The materials' perspective and "the dirty little secret of additive manufacturing".

Before we go further, please note that 'carbon footprint' and 'energy' will be used interchangeably as from now. We will take into account that sometimes, energy and carbon dioxide emissions are considered as separated items when it comes for instance to running the manufacturing tools on solar electricity and, other times, they are so intertwined that it is not just possible to consider them separately. A good example of the latter case, is the extraction of raw materials out of the earth and their processing into well-defined molecules.

That being said, it should be noted that the "inner energy" of materials used for fabricating products is an important – and often less-considered contributor to the total carbon footprint of those products. Furthermore, from a manufacturing standpoint, it's a complex and difficult step to change the integrated energy of materials without changing the way they are produced and their final properties.

Imagine for a second that, this energy refers to everything that goes into the extraction, purification, production, and transportation of raw materials.

In this case, AM becomes a technology production of choice as it helps decrease the materials component of the carbon footprint through energy-efficient geometries that utilize much less material than traditional manufacturing processes.

6K Additive is drawing the industry's attention here to the way materials – especially metals - are produced. According to **Frank Roberts**, Group President 6K Additive, *"it's at the material production stage that manufacturers can make a real change with regards to sustainability. In metal powder production, the industry is woefully behind on the environmental front. In fact, we refer to this as "the dirty little secret of additive manufacturing". Specifically in metal powder production, the incumbent technologies use feedstock that needs to be created specifically for their process (such as wire) which consumes energy to manufacture and requires transport (often from overseas). Their process also creates waste during the manufacturing process that either is sold for scrap value or in the case of titanium will most likely be burned or end in a landfill. Using traditional methods for metal AM powder production, up to 70 percent of the material produced can be waste. A substantial volume of material is produced at unusable sizes and this waste material either goes back into the process – burdening the material with two or three times the energy cost – or is sent to landfill, this process is extremely wasteful."*

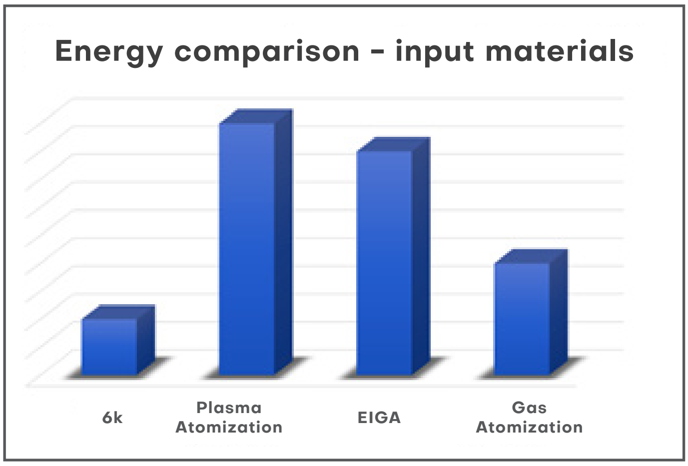

Frank Roberts

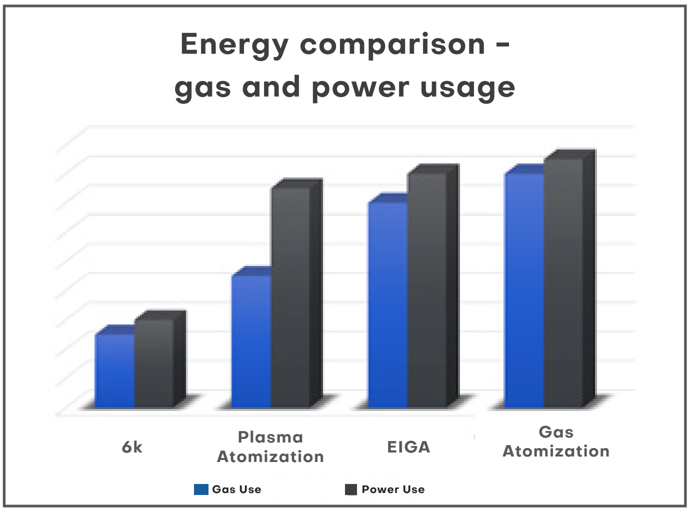
To avoid negatively counterbalancing the sustainability benefits reaped in later stages of additive manufacturing, 6K Additive has been developing a powder manufacturing process - named UniMelt®- that guarantees at 95%+ that most, if not all, of the material is usable powder and not waste from the process.

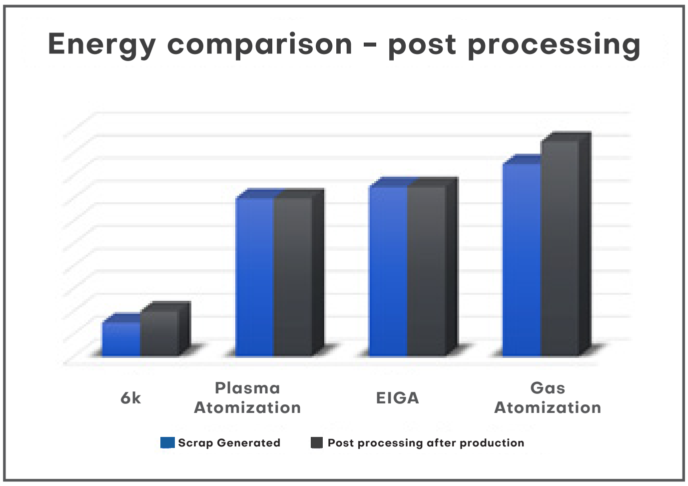
"Additionally, the UniMelt process can use feedstock material sourced from various input streams including machining scrap, used powder, AM supports and failed AM builds. All of these feedstock sources essentially count as near zero carbon footprint, as they are often considered scrap material. 6K Additive recycles and upcycles this "scrap" material into premium powder for AM", the company's expert points out.

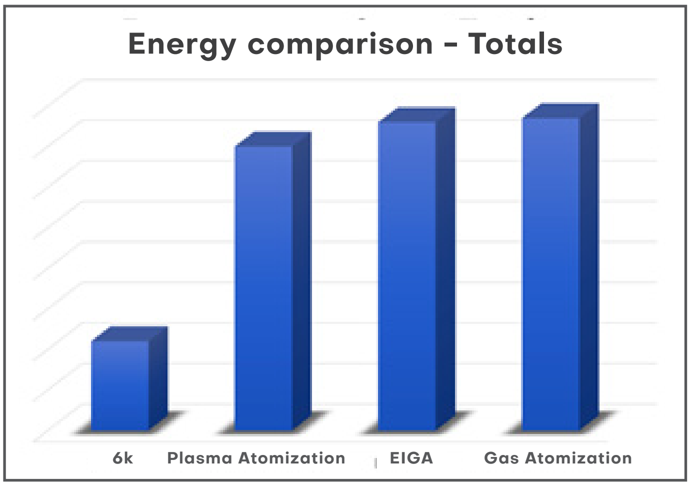
"The UniMelt system is the world's first and only industrial-grade microwave plasma production process that has a yield of near 100 percent, almost eradicating the production of unusable powder, and in addition uses scrap or used material as feedstock. This represents a true circular economy by recycling powders and materials from many different sources to be used in the UniMelt process – certified scrap materials from CNC manufacturing, used AM powders, failed models, even condensate materials from AM equipment. Using the UniMelt system to recycle these materials into premium metal AM powders, without losing any performance credentials in the process, merits a true sustainable alternative.

Additionally, the UniMelt process uses significantly less energy and gas to produce powder. Because the material is pre-sized prior to being put through the process, the UniMelt is only spheroidizing the material using far less gas than atomization. Additionally, because the material coming out of the process is the correct size, the post-processing time and energy after is also far less in the 6K Additive process. Below are four charts that illustrate these points. We currently have contracted with a 3rd party environmental agency to conduct a ***Life Cycle Assessment on the 6K Additive process*** *against the incumbent technologies. This report is expected to be finalized in mid-Q4, 2021. Based on information we've received from industry experts and customers the below charts illustrate the energy comparison against other material manufacturing processes",* **Roberts** told 3D ADEPT Media.









While waiting for this LCA report to be finalized, let's note that the materials company is currently working with space company Relativity to produce quality certified powder from scrap material. The new material would later be used in the additive production of an end-use space part. Despite the confidentiality that surrounds this partnership, preventing 6K Additive to make any comment regarding this development, the company ensures that through other partnerships, with Form3D and Castheonfor instance, they sell powder derived from sustainable sources. Designed for production applications, these powder materials met or exceeded ASTM specifications.

As examples, here are the specifications for 6K Ni718 and Ni625 that are commercially available.

TENSILE PROPERTIES - Ni718

	Powder	YS (MPa)	UTS (MPa)	EL (5%)
XY	6K (HT)	1227	1455	19
	6K (HT & HIP)	1220	1413	23
	ASTM F3055 (HT)	940	1240	12
Z	6K (HT)	1241	1372	22
	6K (HT & HIP)	1282	1413	24
	ASTM F3055 (HT)	940	1240	12

6K Premium Nickel Powders

· Ultra clean
· No satellites
· High sphericity
· Free flowing
· High apparent density
· Low interstitials
· High density powders

First 3D printed High Entropy Alloy part – Image: 6K

TENSILE PROPERTIES - Ni625

	Powder	YS	UTS	EL	RA
XY	6K (HT)	429	897	54%	60%
	ASTM F3056	275	485	30%	30%
Z	6K (HT)	345	886	55%	59%
	ASTM F3056	275	485	30%	30%

What about non-metals?

Bringing producers of non-metals around this table is of paramount importance when we know that most AM users still leverage non-metal AM technologies. For those applications, AM can decrease the material's embodied energy by displacing parts that would have traditionally been made with a high-embodied-energy material. In this case, AM users should keep in mind that every production part should not necessarily be fabricated with metal AM.

Sometimes, polymer or composite 3D printing can perfectly do the job, delivering even a lower embodied energy (and often lighter-weight) solution. From a materials producer standpoint, we've developed a keen interest in **PolySpectra** that ambitions to create high-performance AM materials and processes with overall carbon footprints that are a fraction of today's state-of-the-art materials and processes.

The company has developed **COR Alpha** which stands for **Cyclic Olefin Resin**. The additive manufacturing polymer is described as unique because of its sheer ruggedness and integrates a set of qualities that are comparable to injection moulded plastics.

We mention the material today because the producer strongly believes that *"in order to have a chance of making an impact [in climate change], you first need 3D-printed materials with the performance and durability to displace traditional manufacturing processes."*

To illustrate how COR Alpha does that, the company has shared the dramatic reduction in estimated carbon dioxide equivalents of printing with the COR Alpha material, compared to injection molding with three common engineering plastics.

CO2 Equivalents (Kg) / Polymer (Kg)	Material Production	Part Forming	Total
ABS	3.6	1.3	4.9
Nylon 6	6.7	1.3	8.0
Epoxy Thermoset	8.0	1.3	9.3
PolySpectra COR Alpha	4.0	0.1	4.1

Source: PolySpectra. Estimated carbon footprint comparing 3D printed COR Alpha to three common injection molding polymers.

"With COR Alpha, we can 3D print parts with the strength, toughness, and working temperatures of today's state-of-the-art polymers — with the bonus of a significantly reduced carbon footprint. If we're successful at using polymers like COR Alpha to dramatically lower the energy required to manufacture durable goods, we'll unlock a new paradigm of energy-efficient manufacturing by leveraging chemical bonds to displace the work currently performed by electrons. This could have a huge effect on the energy requirements and carbon footprint of manufacturing — and could be a climate change difference maker", **Raymond Weitekamp**, Founder and CEO of PolySpectra declares.

Part produced with COR Alpha. Image: PolySpectra.

The manufacturing perspective

Not only are there various types of 3D printing technologies, but most of them remain very energy hungry and are about comparable to machining at the production stage. This means that AM will not always win in the "process energy" category.

An example that might actually work in favour of AM is the energy usage of a typical benchtop-sized DLP printer. When compared to a traditional injection moulding tool, it turns out that the difference in the process energy is 100X, which means, as per **Weitekamp's** words that, *"DLP printing processes can use as little as 1% of the energy of an injection moulding tool."*

However, this is just one example that we have been able to identify. The market still presents a lack of resources regarding measurement methods of AM technologies' environmental impact.

And…transportation?

Transportation after manufacturing does not only require to deal with transmission of the product to the end user. It has also required to take into account storage of these products and ultimately some loss if they are not purchased. Thanks to 3D printing production on-demand, decentralized production has become the way to go for manufacturers to reduce stocks and global footprints.

If you have been in this industry for a while, you know that the Covid-19 pandemic has expedited the implementation of **distributed digital manufacturing** across organizations, which means shorter lead times as well as lower transportation energy.

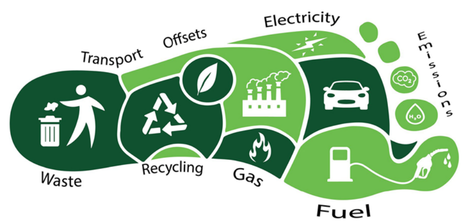


Image: CO2 Living

Even though the system has proven itself, we can't help but question ourselves if it will not have an impact on companies producing traditional systems that are usually located on economies that need to base their production on the use of labour intensive.

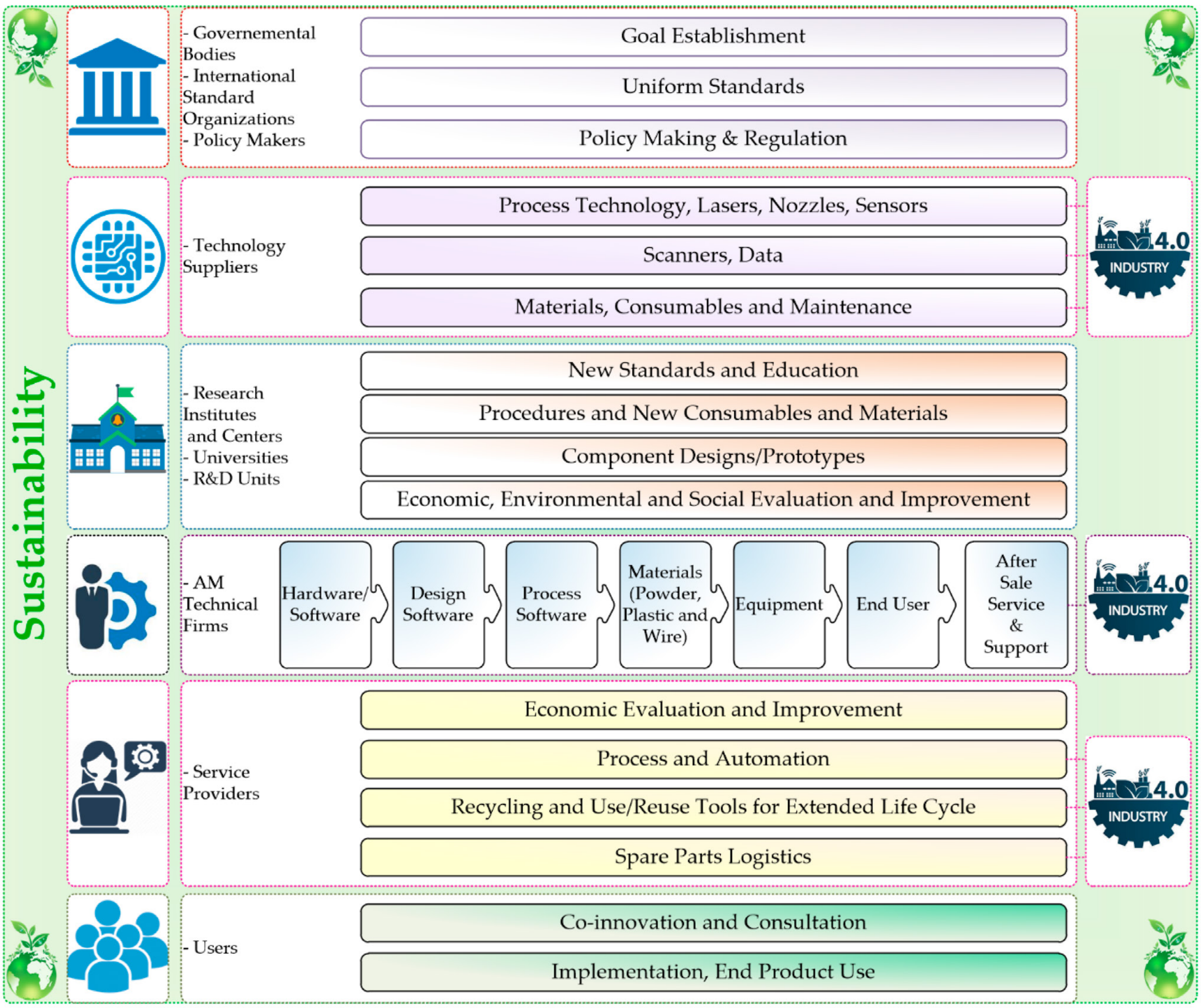
To this, **Dr. Runze Huang** responds that *"the impact would be noticeable just in the short term. Decentralized production is a nice concept but does not bring large enough benefits for a major shift for most of the companies. It was applied more recently due to the impact of COVID-19 and its disruption of the existing supply chains. As that supply chain gets stable, the scale of the economy still works and dominates. And it depends on whether having a decentralized model can lead to a reduction in footprints from a life cycle perspective."* For the expert, *"companies should focus more on the application than the supply chains. The potential benefits and impacts, both environmentally and economically, of the use phase are still greatly larger than the other life cycle stages combined in a lot of cases. The differences can be an order of magnitude. I think it applies to our AM industry, not just companies using distributed models. The best and fittest application wins."*

Concluding notes

As far as manufacturing is concerned, new business models based on AM, will potentially be complementary to the traditional models, and some cases, might even cannibalize the traditional ones. For these new model ones to work or even cannibalize the traditional ones effectively, they should necessarily involve infrastructures that go beyond the simple use of AM technologies, to encompass smart infrastructures related to Industry 4.0.

However, these smart infrastructures make it more complex to measure the environmental impact via the LCA model and might lead to the use of other individual analysis methods to prove the viability of a sustainability strategy. As a matter of fact, this feature highlights the importance of the LCA model, but also recommends at various levels to focus on applications to appreciate the environmental impact of AM on climate change.

One thing is certain, putting sustainability and climate change at the forefront of a business model that implies AM, requires to take into account all key stakeholders – at socio-economic and technological levels – that may have their part to play in this industry 4.0 transition.



Legend: The prosed framework of all key stakeholders contribution of additive manufacturing based on where they are able to act, in light of Industry 4.0 transition. Source: Impact Assessment of Additive Manufacturing on Sustainable Business Models in Industry 4.0 Context.

Notes for the readers

**The post-processing perspective has been addressed in its own segment.

This dossier has been written based on resources and interviews with several organizations of the industry. Main contributors include:

Dr. Runze Huang is an independent researcher in sustainability, LCA, and techno-economic analysis of AM. He received his Ph.D. in mechanical engineering from Northwestern University with a focus on the sustainability of advanced manufacturing. His related published work has been applied/recognized by US DOE, Deloitte, and other organizations. He is also the CEO and Cofounder of **ExLattice Inc**, which is an AI startup providing real-time engineering simulation solutions for AM. His work on "Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components" can be found here.

Hyperganic, a software company that proposes an engineering paradigm, derived from how the Egyptians built the pyramids and the Romans built aqueducts – that is where you, as an engineer, come up with a great idea, draw a blueprint, and then have someone build it. You would always err on the side of overengineering because if that thing doesn't work, you must start all over. Fast forward a few thousand years and that is what engineers do every single day, even with Computer Aided Design. Hyperganic's approach allows you to explore a much broader set of solutions. If something doesn't work immediately, you can redesign it quickly without much effort and the result changes in seconds or minutes. When engineering requires less effort you can become more radical and innovative, you come up with solutions that lie outside the trodden path. **Lin Kayser**, a German serial entrepreneur, co-founder and CEO of the company answered our questions as part of this issue. He also recently shared key insights into why **Algorithms and AI are the missing pieces in the Additive Manufacturing game.**

6K Additive's heritage comes from 20 years of upcycling titanium scrap into grain refining products. Today the alloys group of 6K Additive sells 3 million pounds of titanium compacts, that is used as a grain refinery for the aluminum industry, resulting in 3 billion pounds of aluminum that is used for the automotive, aerospace and medical sectors. In fact, if you own a Ford F150, 6K Additive's Ti material derived from titanium scrap is in your truck. This knowledge and expertise directly translates into the process used for producing feedstock for 6K Additive AM powders and the institutional knowledge of the group helps ensure premium, quality powder for our customers. In addition, a key driver and mission of 6K is supporting clean energy initiatives and addressing climate change. These goals are not only for the additive manufacturing industry, but throughout the 6K business which also operates in the **battery materials sector and future materials**. Each sector of the business supports the other, helping 6K develop more high-performance, advanced materials, sustainably.

PolySpectra is on a mission to develop materials and 3D printing processes that will use less energy, produce fewer emissions, and ultimately help mitigate the progression of climate change. The company uses light-activated catalysts to 3D print advanced functional materials. Their modular platform enables us to deliver materials with a broad spectrum of tailored properties from a single chemical system. They call this process functional lithography.

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THE IMPORTANCE OF CHOOSING A METAL ADDITIVE MANUFACTURING SERVICE PROVIDER

Once you have decided to go down the Metal Additive Manufacturing (AM) route, the next step is at least equally important. While «value for money» is often the most analysed criterion, the truth is, working with a solutions provider must go beyond this important argument. Indeed, not only is the market filled with companies offering AM services, but also confusion can quickly arise when one realizes there is also a wide range of metal AM technologies. What criteria should you use to favour one technology over another? And most importantly, how should/do you envision the future of your production with that Metal AM solution?

Over the last years, Metal AM has gradually seen a shift from prototyping towards mainstream production technology for several industries such as medical, aerospace and automotive.

Widespread industry adoption has however been focussed on relatively small sized components as the production of large sized metal parts wasn't technically possible or economically attractive using powder-based processes.

Size does matter!

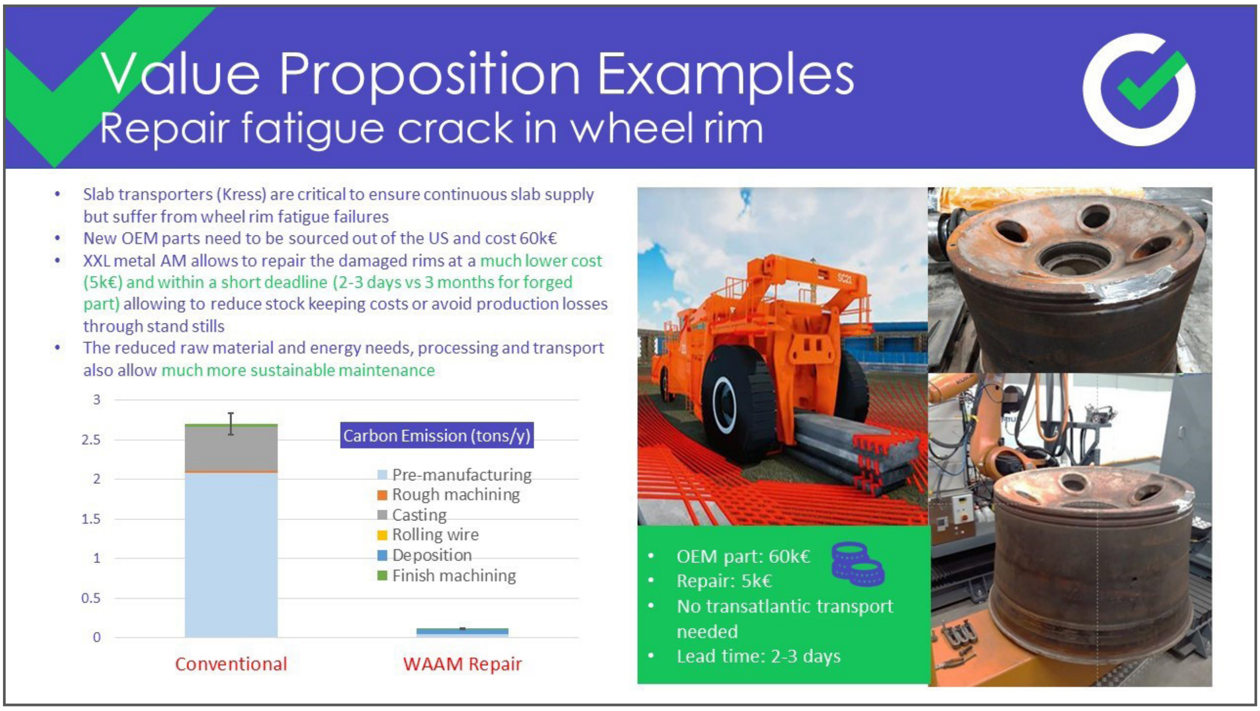
The **intrinsic benefits of AM** (small lot sizes, inventory reduction, obsolescence management, etc.) **are particularly appealing for large sized metal components used in industries** such as oil & gas, maritime, energy, transport, mining, aerospace, or heavy industry. These industries often use castings or forgings which, depending on the environment they are used in, could be made of carbon or stainless steel, nickel-based alloys or even titanium. The fact is, the more complex the geometry becomes, the more the casting or forging process itself results in significant material waste, but also suffers from extended lead times and non-negligible failure rates.

All of these constraints often lead manufacturers to explore manufacturing processes which could best meet these requirements.

"The combination of component size and functional complexity makes a compelling case for the wire based DED-processes (CMT and plasma) offered as a one-stop-shop manufacturing service by Guaranteed as it allows parts up to 10 x 5 x 6 meters and up to 20 tons to be produced near-net-shape within short lead times at a competitive cost. Currently the ***material database is already well populated (steel, stainless, Inconel, titanium, aluminium, bronze ...),*** *but it can easily be expanded at the request of our customers",* ***Joachim Antonissen****, CEO Guaranteed comments.*

From a cost standpoint, it should be noted that there is a wide choice of commercially available welding wires, which come at a considerably lower cost compared to their powder counterparts. Added to this, the fact that quasi 100% dense parts are produced, omitting the need for hipping, makes wire-based processes such as WAAM an interesting choice from an economic point of view.

As Guaranteed's technologies allow a hybrid approach by depositing on top of an existing component (e.g. plate or cylinder) or even to repair an existing part, the business case is further improved even without taking into account logistic savings such as reduced lead times or stock keeping costs. Beside the resulting economic benefits, localized repair or on-demand near net shape production also contributes to sustainability as it significantly reduces the need for raw materials and transport.



Cost is important, quality is the best way to reduce it

Unlike most situations where "premium quality" is synonym of "expensive cost", in this case, cost and quality are not conflicting but rather reinforce each other. Pursuing high quality is ultimately the best way to reduce costs. Indeed, when switching from Conventional Manufacturing (CM) to Additive Manufacturing (AM), the certification requirements imposed by the part's severe operating conditions obviously need to be considered when assessing the business case. Depending on the criticality level of the component, certification might impose a substantial amount of destructive test samples to be produced alongside the actual part. Through its process control software, Guaranteed is able to ensure part performance which significantly reduces the number of expensive trial-and-error loops. Being involved in various collaborative projects aiming at establishing clear certification guidelines for the use of AM in oil & gas, maritime, rail and mining industries, **Guaranteed is driving this further to turn certification into an inherent part of its quality assurance framework**. Process qualification, rather than single part qualification, will broaden the portfolio of AM parts and components, to achieve faster qualification and/or certification than nowadays. In close partnership with leading universities, Guaranteed is developing the next generation of WAAM technology. The latter will allow deposition speeds to be increased even further without compromising on quality while dynamic mechanical properties will be enhanced beyond those of forged material by in-process microstructural manipulation technologies.

"Born from innovation, we use state of the art unique simulation, monitoring and inspection tools to guarantee first time right zero-defect production. Being raised in Industry, we guarantee one-stop-shop industrial reliability", ***Sander Plasschaert****, CTO Guaranteed states.*

Is the best spare part a virtual one?

As installations operate in increasingly challenging environments, there is a larger likelihood of essential parts breaking down, becoming obsolete due to technological changes or changes to standards or going out of production before their end of life. The small series sizes and short life cycles of parts relative to the installations present a challenge in inventory management and further strengthen the case for the deployment of large size metal AM.

Traditional production technologies make it too costly and require too much time to produce parts on demand. The result is a significant amount of inventory of infrequently ordered parts. This inventory ties up capital for products that are unused. They occupy physical space, buildings, and land while requiring rent, utility costs, insurance, and taxes. Meanwhile the products are deteriorating and becoming obsolete. Being able to produce these parts on demand using AM reduces the need for maintaining large inventory and eliminates the associated costs while leading to greater asset longevity.

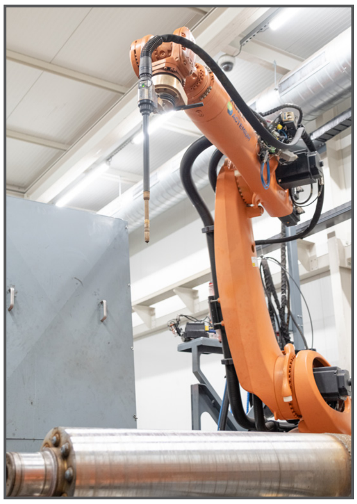
In an automotive assembly line, for example, only 8% of each euro invested is spent in actual assembly. Each individual component is produced separately and has inventories of its own, while all parts also need to be transported. Studies have shown that up to 10% of a manufacturing company's revenue is tied up in inventories. The resources spent producing and storing these parts could be used elsewhere if the need for inventory were reduced.

Today, Guaranteed is already actively participating to digital warehouse eco-systems in sectors such as oil & gas, railways and maritime industry.

"AM supports our operations with shorter lead-time because it creates a shift towards buying parts just-in-time as opposed to just-in-case. The traditional way of buying spare parts at the onset of installing new equipment, may no longer be necessary if we can print the parts with the same or improved quality. Spare parts stored in a warehouse require proper storage and preservation which comes at a cost and does not provide agility when operating conditions change and the original spare parts may no longer be suitable. We believe that printing spare parts just-in-time eventually reduces the costs of sourcing specific parts, especially those that are critical for business operations", A. Goh, Shell points out.

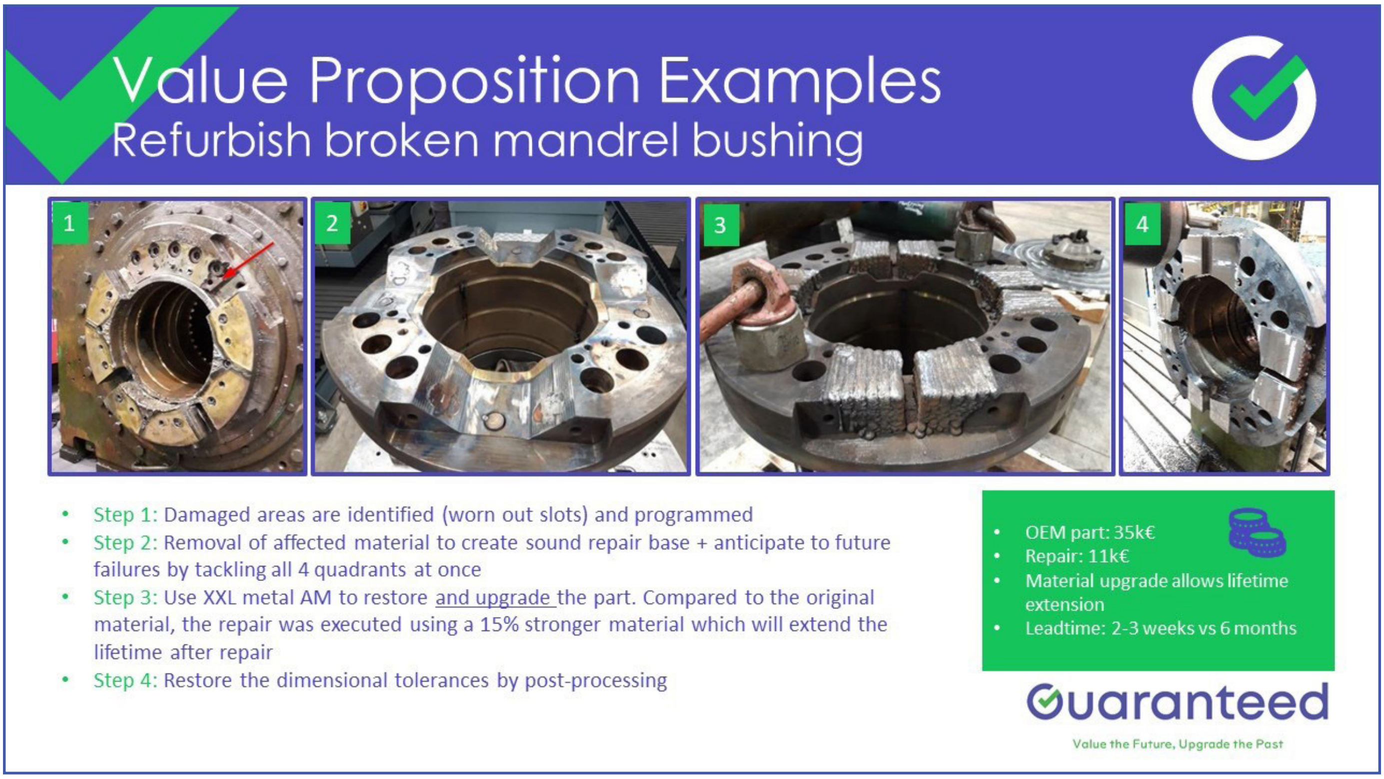
Value the future, upgrade the past

Ageing installations are a common issue in many industries. Assets are increasingly used beyond their original design life, which results in parts becoming high-risk for downtime or failure. This can result in significant non-productive time which could cost upwards of hundreds of thousands of euros annually. Maintaining the integrity of equipment is difficult given that like-for-like replacements of parts are no longer available due to obsolescence of the equipment model or changes in engineering standards.



Guaranteed's on-demand WAAM services allow such parts to be reproduced at an affordable cost, even for lot size one, repaired or refurbished. In the latter case, the original part design or material selection is given an upgrade which allows the refurbished part to have an increased performance or life time as compared to the original OEM part.

For very large parts or failures occurring in remote areas, the costs and logistics involved in dismantling and transporting the damaged part might become prohibitive. To resolve this issue, Guaranteed developed a ***"mobile WAAM additive repair service"*** which allows **on-site or even in-situ repair or remanufacturing to be achieved**.



Less is more

With climate change as the central challenge of the 21st century, resource efficiency and reducing the carbon footprint have become vital challenges for today's manufacturing industry. Localized production to decrease transportation efforts and manufacturing products on demand to directly lower waste and avoid scrapping excess parts will eventually become necessities to avoid taxation or institutional penalties. Additionally, the demand to refurbish machines and products to extend their lifetime will continue to grow.

"AM and digital parts libraries will result in cost savings through smaller inventory volumes and reducing costs and risks of late life and obsolescence. As Equinor moves to zero carbon and increases its renewables presence, reducing the environmental impact of equipment production and the transport of parts through the supply chain will become increasingly important", ***Brede Laerum*** *– Equinor adds.*

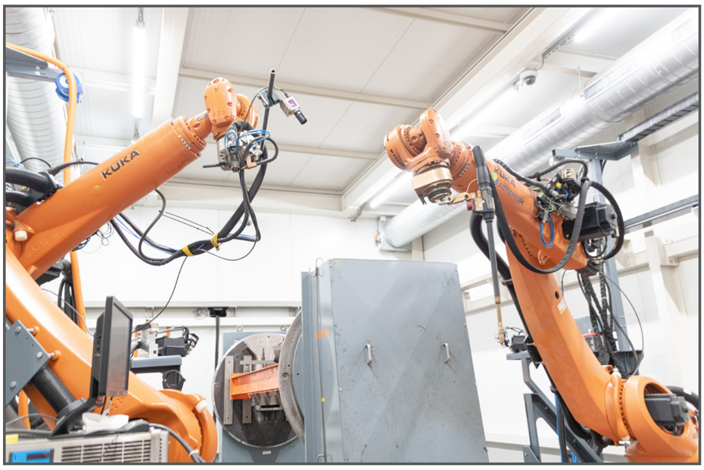
In a recent study which has been performed by Guaranteed in close collaboration with the University of Cranfield and its spin-off company WAAM3D, a comparative life cycle analysis was made for several parts. As compared to conventional manufacturing options such as casting or forging, the results of this study clearly demonstrate the significant savings which can be achieved in terms of carbon emissions and energy consumption for WAAM production and even more so for WAAM repair or refurbishment.

The sustainable character of our technology already provides Guaranteed access to funding from the booster fund of the European Institute of Technology which invests in companies that realize sustainability and reshore work to Europe.

Proof, not promises

As the proof of the pudding is in the eating, Guaranteed works in full transparency and close collaboration with its customers worldwide to analyse, optimise and share the learnings in each business case. **For some of our customers this means that we will recommend considering repair or refurbishment rather than complete remanufacturing while for others the benefits of on demand spare part production will allow reducing warehousing costs and generate a direct impact on profitability** as working capital requirements will be lowered resulting in additional cash flow. Mitigating obsolescence issues either directly in ageing production equipment or indirectly in inventories by just-in-time manufacturing represents yet another way the services provided by Guaranteed can create value.

Last but not least, the resource efficiency and CO_2 emission savings resulting from working with Guaranteed provide a pathway to a more sustainable future by reducing the amount of primary and secondary emissions.



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EQUINOR : AN "ADDITIVE MINDSET" TO ADDRESS CLIMATE CHANGE AND SUSTAINABILITY ISSUES

Credit - Ole Jørgen Bratland
Copyright - Equinor - Fieldmade

There are some industries – like the energy sector – where the struggle to drive climate change is more challenging than others. ***Brede Lærum*** *and* ***Pantea Khanshaghaghi*** *took 50 minutes of their Wednesday shift to discuss this topic with 3D ADEPT Media. Trust me, it's quite complicated to address all the points of this vast topic in just 50 minutes, but they are enough to confirm that a company is on a right track to deliver on its climate ambitions. And* ***Equinor*** *is.*

With over 21,000 employees committed to providing affordable energy for societies worldwide, the Norwegian state-owned multinational energy company is on a journey to net zero emissions through the **optimisation of its oil and gas portfolio** as well as the development of **growth in renewables** and **development of low-carbon value chain** in carbon capture and hydrogen.

With political pressure and the level of regulations that are rising around climate change, the Stavanger-headquartered company – just like fellow organizations in the field – is continuously integrating sustainability concepts to understand the effects of its own actions, but also to measure them in order to achieve its net zero emission goals.

"There are two main areas that energy companies look into, when it comes to climate change and sustainability. The first one is the CO2 emissions from producing oil and gas – and we are working hard to reduce that as much as possible – and the second one is reducing the footprint for the product that is being used around the world. This second challenge makes it crucial to address the 'carbon removal project'. We are actually developing a solution to capture the carbon and send it back into a place where there will be no risk of seeing it again", **Lærum** told 3D ADEPT Media.

For Equinor – and all other organisations that can play a role in climate change, overcoming these challenges requires to take into account multiple fronts including manufacturing and that's exactly why **Brede Lærum** and **Pantea Khanshaghaghi** were the right spokespersons for this topic.

Indeed, **Lærum** is Head of the Additive Manufacturing Centre of Excellence at Equinor, Chairman of the Fieldmade Digital Inventory project and Chairman of the international network «AM Energy». **Khanshaghaghi** on the other hand, is the project leader in Business development, responsible for sustainability through Additive Manufacturing at Equinor.

From an additive manufacturing perspective, *"we are looking into the CO2 emissions related to our procurement process, when we purchase equipment, goods and other products. This third area has a huge potential when it comes to reducing the consumption of raw materials and the corresponding energy consumption and CO2 emissions. Additive Manufacturing is perfectly fitted into a circular economy model"* he adds.

Pantea Khanshaghaghi

"The oil and gas industry has several challenges to address but the whole world has a bigger challenge: the materials we are consuming. Hundreds of billions of tons of materials are consumed worldwide and we are not able to recycle them (We recycle less than 9% of them). This major concern raises several issues including pollution - because at least 1% of pollution comes from manufacturing (Manufacturing is responsible for 31% of global emission –which is the highest among different sectors)– and the security of supplies that the pandemic has highlighted, especially in Europe.

Additive Manufacturing is uniquely

positioned to play a role in these three main challenges. For example, when we say that we are going to achieve less waste and in all different phases of the manufacturing process, we can do so because the technology itself allows for less use of materials. Transitioning from conventional manufacturing processes to AM processes is just a first step in the actions that can be implemented.

Indeed, mining those materials is another problem. This means that, each production usually requires us to manufacture a lot of products in order to be commercially visible. We have to send these products to subsidiaries or partners across the world but also keep some of these products in case we would need them later. All of this requires a lot of materials, transportation, and resources that could be saved for other purposes. That's the reason why, at Equinor especially, we are looking to transit into a digital world where we will not need to produce a lot and transport a lot. We would avoid this "overuse" of materials and send the products just when and where we will need them. By doing so, we are already able to cut CO2 emissions at multiple levels. On top of that, we are saving lots of time and money as a producer and for the end-user", **Khanshaghaghi** outlines, speaking of these three main areas and why AM is a pivotal manufacturing tool for each of them.

As **Khanshaghaghi** explained the importance of these three scopes/areas for an energy company (production of emissions, products used around the world as well as purchase & consumption of goods), she laid emphasis on the importance of the latter for AM professionals. Indeed, one can extend the lifetime of equipment either by using AM to repair, by getting obsolete parts using 3D printing or by avoiding replacing certain components.

"In the latter case, we would not need to take our raw materials, we don't have to consume more energy to produce those parts, and therefore no CO2 emissions will be produced. So, by reducing the consumption of goods, we can actually quite contribute to the reduction of CO2 emissions. But that remains a relatively new area", she said.

Additive Manufacturing, a tool to translate net zero emission goals into practice

First signs of AM activities have been seen at Equinor in 2016. According to the head of AM at the Centre of Excellence, it all started as a research activity where the team ambitioned to discover if they can effectively trust AM and what would be the main benefits for Equinor. At present, the AM unit integrates about 34 polymer 3D printers (FDM & SLS) that serve an education purpose.

"We do not have an ambition to be a parts producer. We want the suppliers to continue producing parts, now using AM. That's the reason why, although we keep a strong focus on metal AM technologies in our various activities, we do not invest in such technologies for our in-house activities. That being said, there are seven different and recognized AM technologies within this industry. Our activities and tangible examples of application explored so far, reveal a great potential for Powder bed fusion, DED aka LMD, and wire-arc AM", the Head of AM emphasizes.

Although AM in its essence, is a sustainable method – since you build from nothing as opposed to starting with a large lump of metal and reduce it gradually; with AM you can optimize the parts through topology optimisation and reduce raw materials –, there are no confirmed data that may help state which metal AM process is more sustainable today.

However, comparative analysis of how certain applications are produced can help appreciate the potential of a given AM technology and trust even better the sustainability strategy of a given company. To illustrate this statement, **Lærum** took the example of the comparative **life cycle assessment (LCA)* of a cooling fan** – produced using AM and via conventional manufacturing (CM) processes.

In this specific case, the carbon footprint of the electric motor – of the cooling fan produced via the two types of manufacturing processes – has been assessed with regards to its Global Warning Potential (GWP)* over 100 years.

Lærum explained that the supplier told them to replace the whole electric motor (weighing 1 and half tons) because the (obsolete) fan was broken. They calculated CO2 emissions related to the replacement of a new part. The CO2 emissions for producing this fan locally were 3.8kg but replacing the whole pump – as initially indicated – would have caused them to produce 4 500 kg of CO2 emissions.

Brede Lærum

Discussion

Transportation

- **AM fan is about 1/5th of CM**
- **AM has fewer transportation «steps»**
- **AM has lower weight**

- **Volume not considered**

Source: Equinor.
Unit [Kg/CO2e]

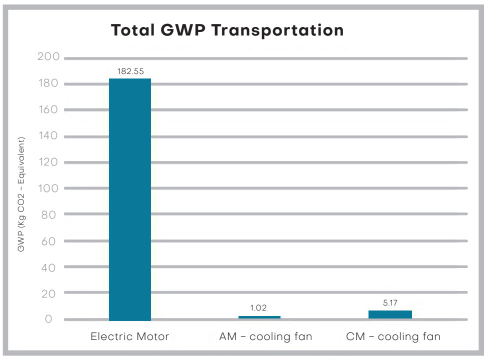

Figure: Total GWP Impact due to transportation

	Cradle to grave	Cradle to cradle	GWP from transportation
Electro motor	4509,456	2071,218	182,55
AM cooling fan	3,773	1.702	1.02
CM cooling fan	15,436	8,353	5,17

In addition, the expert points out that the use of recycling of raw material reduces the GWP from 45% to 54% in the three respective scenarios.

	Cradle to grave	Cradle to cradle	GWP reduction circular approach
Electro motor	4509,456	2071,218	54,07%
AM cooling fan	3,773	1,702	54,89%
CM cooling fan	15,436	8,353	45,89%
GWP reduction AM vs CM	75,56%	79,62%	Source: Equinor
GWP reduction AM vs new motor	99,92%	99,92%	

"It's a completely new scale. By extending the lifetime of that motor, we avoided 4 500 kg of CO2 emissions related to the production of a new pump. If you add that to all the different equipment we are considering to replace, this will add to a rather large sum of CO2 every year. It's a really new era to look into when it comes to CO2 emissions. The whole industry should look into this "scope n°3" of emissions", **Lærum** adds.

As the expert explains, taking the example of the broken fan, looking at this "scope n°3" requires to look at the country where the components are being produced and where the raw components are being taken out.

Furthermore, this production using AM refocuses the debate on the importance of circular economy and its ultimate purpose which goes beyond recycling. *"The main purpose of circular economy is to design the waste out and that's exactly what AM does. First of all, we are using less materials, and thereafter, when we design the new part, we do so in a way that it will be recycled – or at least have a longer lifetime"*, **Khanshaghaghi** notes.

"By changing our behaviour and our way of dealing with all the equipment, we can of course contribute to reduce CO2 emissions", the Head of AM completes.

Credit – Ole Jørgen Bratland – Copyright – Tjeldbergodden

A fight that requires other partners

It's one thing to know the process and identify the steps that one should take in this fight for climate change, it's another one to have the right partners to do so.

The latest partnership where the company is involved alongside independent technology research institute **SINTEF**, and gas company **Gassco** , is a project from **Kongsberg Ferrotech**, a Norwegian robotics company, that designs and manufactures subsea robots for the oil and gas industry. Together, the three companies will develop 3D printing technologies for subsea equipment repair and maintenance.

Inspection, maintenance, and repair **(IMR)** robots are pivotal to the success of this project as they can achieve repairs and modifications in a dry environment while being completely submerged. So far, the teams have already completed deepwater testing on the composite repair in the Trondheim Fjord in Norway.

According to the sustainability expert, the concept of circular economy will once more play a key role here since AM will be used to repair instead of replacing. *"That's kind of designing the waste out again"*, she reminds us. *"From a manufacturing standpoint for instance, they will look at the way they can recycle all the metals they have. Amid the companies that will help us in this process, there is f3nice that recycles metal scraps into atomized powder."*

While AM is another great tool that illustrates the circular economy process in production, **Khanshaghaghi** highlights the importance for organizations to think about a **better energy mix** for that. *"For instance, it is not interesting to use fossil fuels heavily in a country that is already planning to use renewable energies"*, she notes.

In the same vein, Equinor's collaborators also note the enriching experience they have through collaborations with startups. In addition to f3nice mentioned above, **Lærum** mentioned **Fieldmade**, a tech startup that ambitions to change the linear supply chain into a network-based approach. The startup has partnered with **Siemens Energy, TotalEnergies** and **Equinor** to develop an on-demand 3D printing ecosystem for parts supply.

"Together, we are demonstrating that AM is contributing to sustainability throughout the whole circle of circular economy. In this specific case, the technology serves as a catalyst for the new digital ecosystem that we are building with Fieldmade and Siemens Energy. In the long-run, this platform will be a commercial product - promoted by Fieldmade – with two main functions: connect all operators and all suppliers in a huge digital network for spare parts. Secondly, all these suppliers could promote their own digital parts into the network so that the digital inventory will be driven by the ecosystem – not purchased by the operator-. Although AM is an important enabler for the digital inventory the main point is on-demand production of parts, using AM, CNC machining or any other fast, reliable and repeatable manufacturing method. The plan is to gradually reduce the physical inventory while building the content of the digital inventory", **Lærum** explains.

And now…?

Most energy companies that are challenged on carbon topics used to reflect on how they should grow in renewables, develop carbon capture and storage solutions or even produce less oil and gas over time. All of this is totally understandable when we look at how the society wants them to address this issue.

From a practical standpoint, this conversation with Equinor reveals that organizations should no longer only look at AM as the beautiful technology that will produce complex parts. It is possible to get tangible results regarding sustainability if we explore the use of Additive Manufacturing when developing digital solutions across the whole value chain, such as maintenance, production optimization and supply chain management. Now, imagine how far they can go if they add to 3D printing, data science and artificial intelligence.

With the goal of scaling digital solutions across its global portfolio faster than expected, and thus contributing to increased production as well as reducing maintenance, drilling and facility cost, Equinor recently increased its 2025 improvement ambition by 50%, from 2 to 3 billion USD. Added to that the aforementioned examples and the partners by its side? Their efforts to become a net-zero energy company will definitely pay off by 2050.

Notes for the readers:

For those who are not familiar with certain terms, please note that:

A Life Cycle assessment or LCA (also known as life cycle analysis) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).


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POWDER RECOVERY IN AN AM PRODUCTION: WHAT? WHY? HOW?

At the very beginning, when manufacturers started using Additive Manufacturing (AM), the market was severely lacking in materials specifically designed for the technology. Contract manufacturers therefore worked with leftovers and scrap with general specifications, which restrained the success of part quality.

Today, material producers have developed metal powders with AM production in mind. However, their high cost has increased the demand for recycling of unmelted powder – especially in powder-bed AM processes. For manufacturers who are willing to explore reuse or recycling strategies, meeting this demand also means enabling sustainability performance – or at least enabling an environmental framework to sustainability. Most importantly, meeting this demand requires to leverage interdisciplinary resources that go beyond the simple expertise of material experts.

The present feature ambitions to discuss some of the powder recovery/reuse technologies and strategies that could be used to save metal powder while taking into account these interdisciplinary resources. It might serve as a complementary resource to the dossier "***Issues raised by metal powder removal***", as it will also focus on the importance of the recovered powder with regards to sustainability and viability of materials.

Powder recovery: the "Why"

Let's establish some key facts: although one advantage of AM is that metal powder can be recycled for the next production, it should be noted that recyclability depends on the type of material that is utilized.

From a **manufacturing** standpoint, most productions reveal that only a small amount of the powder that flows into the build chamber is melted into a component which means an important quantity of powder can be reused or scrapped.

From a cost perspective, it can bring a wide range of benefits including profitability to recover and reuse the unmelted powder. Indeed, an operator who does not reuse the powder, will throw it away and will add this loss to the overall cost of the part that has been produced (and this will remain one of the reasons why metal 3D printed parts are said to be very expensive). This means that recycling the powder helps manage powder stock, and decrease the global cost per part.

From a **sustainability** point of view, using the same feedstock enables to maximize its output and avoid unnecessary scrap that can also be very costly to dispose of.

Andreas Hartmann, cofounder and CTO at Solukon Maschinenbau GmbH highlights each of these perspectives by laying emphasis on **where powder recovery** should take place:

*"Firstly, taking into account the **printing process** itself. Only a small amount of the total amount of powder is actually fused into a component. The rest of the powder either remains in the chamber or is trapped in cavities or internal channels of the printed part – potentially reusable powder in both cases. Not recovering this powder would mean to dispose of a huge amount of powder which hasn't been used for printing at all.*

This way, powder recovery follows the fundamental idea of sustainability, i.e., the avoidance of the depletion of natural resources.

*Secondly, **resources are finite,** this also applies to metal powder. It therefore is crucial to recover and recycle the metal powders in order to guarantee sustainability in additive manufacturing as far as possible.*

*The level of **sustainability** regarding powder recovery is heavily dependent on the industry and the application. There are industries where powder recycling is not possible (due to certifications). For these industries in particular, comprehensive concepts for proper disposal or downcycling of powder should be developed. Regarding down cycling, perhaps it is possible to use the powder for components that do not need to be certified (training components, prototypes, etc.)."*

What we understand from Hartmann's statement regarding sustainability is that not only may it raise several questions throughout the lifecycle of specific products, but it also requires to understand metal powder production lifecycle. The latter might include extraction to form a pure or alloyed metal product, some specific additional processing steps for appropriate powder production and analysis of powder specificity during production or even validation for customised metal 3D printing equipment producers.

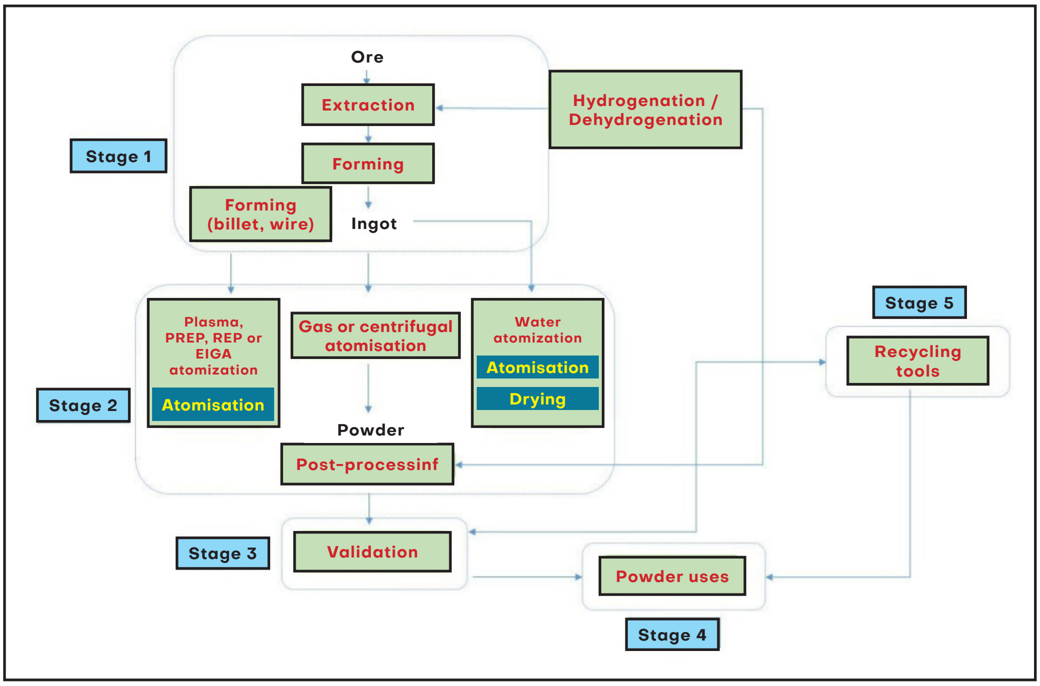


Figure: This figure features a powder production lifecycle steps flow chart (adapted from Dawes et al.], where PREPplasma rotating electrode process, REP-rotating electrode process, EIGA-electrode induction melting gas atomisation) have been leveraged.

In other terms, this means taking into account water atomisation, gas atomisation, plasma atomisation, the plasma rotating electrode process, and centrifugal atomisation or hydride– dehydride process.

Depending on your situation, each of these steps will not necessarily be the most important to focus on. Indeed, as seen in our interview with F3nice (page 49), if you are a materials producer that uses scrap to produce powder, you will mostly focus on **atomisation** – not to mention that, sometimes, material producers have their proprietary technology which lays emphasis on other aspects of production. However, if you are a parts manufacturer, your most important step should probably be to focus on **post-processing**.

Powder recovery: the "How" & the "What"

How do we effectively recover powder? What impact can the recovery process & recovered powder have on other stages of manufacturing?

At this level, the considerations (the "What") that need to be taken into account should justify the choice of powder recovery process leveraged to recycle materials.

First and foremost, one thing manufacturers should always keep in mind is that **every material ages differently** therefore **their characteristics are likely to change during manufacturing, recovery and reuse**. Also, it becomes pivotal to trace the evolution of powder characteristics at various stages of recycling to produce parts with consistent properties.

According to **Solukon's CEO**, to minimize the risks of having a material whose characteristics will be different from the raw material, operators should focus on aspects that may influence these characteristics during the powder recovery process:

"For trouble-free reuse the powder must inevitably be free of any contamination to minimize obstacles in subsequent printing processes. A clean environment for powder recovery therefore is mandatory. To improve the quality of the recovered powder a safety gas atmosphere is beneficial. Flowability of the powder is increased while humidity decreases – both mandatory for subsequent printing processes with reused powder.

In addition, when using reactive materials an inert atmosphere is mandatory to avoid the risk of explosions.

*Another effect to be prevented is the so called **«aging of powder»**. Due to interaction with the surrounding atmosphere, the un-melted metal powder ages gradually which means the quality of the powder is reduced due to oxygen absorption. Correspondingly, the surface morphology and chemistry, the shape and size distribution as well as the flowability of the particles are modified. The aged powders may affect the final properties of the printed component negatively, making the number of times that metal powder can be cycled limited".*

Andreas Hartmann, cofounder and CTO at Solukon Maschinenbau GmbH

All of these aspects provide a holistic approach to AM production, where process steps merge directly into one another. For **Solukon**, these steps consist in applying a secured unpacking stage, a depowdering stage as well as a post-processing stage.

For the company, the powder recycling process should be designed as follows:

" – ***Depowdering:*** *After unpacking the parts in the 3D printer, the depowdering station removes critical powder residues from the parts in a protected atmosphere and collects them contamination-free in the chamber bottom.*

– ***Sifting:*** *The powder residue can then be fed to the powder-recycling unit. There it is sieved and refreshed with fresh powder.*

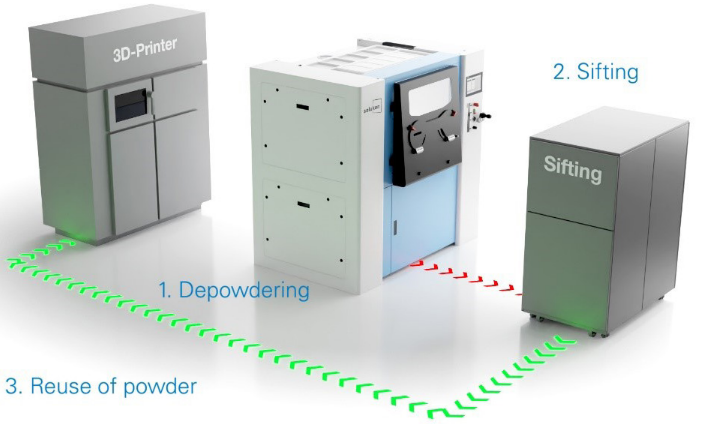
– ***Reuse of powder:*** *the powder is now ready for further printing processes."*

While an automated powder recycling process suggests that the reused powder after reconditioning (sieving process) may have similar characteristics than the raw metal powder, it should be noted that these characteristics may vary from **one specific metal AM process to another.** In this vein, an operator who uses metal AM machines with a vacuum cleaner for instance, might obtain a material with different properties.

Moreover, AM machines such as the one from **Renishaw** that integrate an internal sieve have dedicated reuse methods.

Furthermore, in order to know if reusing the unfused powder or if the recovery process is worthy for a specific project, operators should also take into account production and purchase considerations.

Evonik raises our attention on the fact that the number of times one can reuse a powder "*depends on the parts and the build job. Ideally [operators] should be able to work with a fix old/new ratio without any scrap.*" The fact is, once the criteria that the parts need to meet have been defined, some operators often find if more affordable to purchase powders close to the production specifications. In this case, the number of reuse cycles will also be limited as the powder can degrade only so much before it is



out of use. Not to mention that, the property requirements of the component to be printed will determine how much the operator will monitor the powder or how many times it can be reused.

As for the **viability of the powder**, sometimes, recovery and reuse might result in a refined particle size distribution, but with marginal change in powder morphology. Other times, "*viscosity has to be measured*" – as is the case with polymer powders. "*Depending on the result the old/new ratio has to be adjusted*", Evonik told us.

The sustainability perspective

"*How sustainable is powder recovery process in AM?*" Reality shows that powder recovery has a proven record in terms of overall costs of production parts, and reuse of powders. Unlike ten years ago, the current AM market is filled with automated post-processing solutions that can facilitate this process. "*Solukon depowdering systems for instance, usually recollect up to 100 % of the powder, contamination free and in a protected atmosphere*", the company notes. But is it enough? As Hartmann continues, it "*is the door-opener for a reasonable approach to sustainability in the first place.*"

We couldn't agree more with him but there should be more as the industry is continuously seeking for key data that may help them understand the lifecycle sustainability in Metal AM processes, post-processing processes and materials production processes, key data that are based on demonstrative methods of lifecycle assessment (LCA), and databased inventories.

We have to admit that at the moment, very few resources are available to sustain these. "*With rising serial production, the need for sustainability will grow not only for ethical recycling reasons but also with regard to costly disposal of the powder*", the CEO ensures.

In the meantime, what should we do?

Notes for the readers

Solukon is an expert in industrial depowdering in additive manufacturing. The company's systems ensure a safe, reliable and repeatable automated depowdering of metal and polymer components. With parts that are becoming more complex and tough to handle, the demand for quality assurance and qualification of the processes is on the rise. Therefore, they believe that a holistic approach of the AM process chain is key to a proper powder lifecycle and sustainability. "*We see depowdering as a part of the build job itself and a door-opener for proper and powder-free post-processing (heat treatment, support removal etc.)*", the company notes.

It would have been hard to discuss this topic without any comments from a materials producer. For that, we called upon **Evonik**, a chemical company that boosts the chemistry of high-performance polymers and additives into ready-to-use materials for infinite 3D applications. Evonik does not supply metal-based material for AM to date but they do provide a wide range of materials for several AM technologies.

Other external resources leveraged include Renishaw's, as well as a research led on Metal Additive Manufacturing Recycling.

DOES NATURE HOLD THE ANSWER TO SUSTAINABILITY ? A LOOK AT BIOMIMICRY AND ITS PRACTICAL USE WITHIN THE 3D PRINTING SPHERE.

If everything we use comes from natural resources and that natural ecosystems are often described as models of sustainability, does that mean that every 3D printed product inspired by nature is de facto a sustainable product ?

It makes perfect sense to explore how nature can inspire 3D printing companies. As a matter of fact, 3D printing companies that have already gone down this route, have embraced the concept of biomimicry and yes, applications shared so far, revealed some real cool designs inspired by nature. But that's not enough, not today when we are looking for tangible examples that can support the 'sustainability' argument, for examples that show what is possible in industrial production.

So, we caught up with **Flavia Libonati**, researcher and Associate Professor, at Università degli Studi di Genova – an Italian University – and whose work is at the intersection of nature, materials, 3D printing and engineering. Her research focuses on toughening and failure mechanisms of biological structural materials, such as bone and nacre, from molecular to engineering scale and on the design of novel composites. She uses a material-by-design approach, combining Nature and engineering principles including 3D printing to improve the mechanical properties of materials, thus combining them successfully in an optimal way.


Libonati Flavia

From the outset, **Libonati** said that *"we are dealing with a two-way process. 3D printing can transform biomimicry and vice-versa. On the one hand, 3D printing has revolutionized everything, including the biomimicry design approach. The technology and its principles have opened the design space, broken down several manufacturing barriers and now enable designers to 3D print components with very complex shapes. On the other hand, biomimicry transforms 3D printing to the extent that it opens new perspectives and changes at a functional level. It helps for instance to explore new material possibilities, new material functions as nature does. 4D printing for instance, enables to get new functions within the printed component by adding a new dimension, so it goes beyond the simple manufacture of the part."*

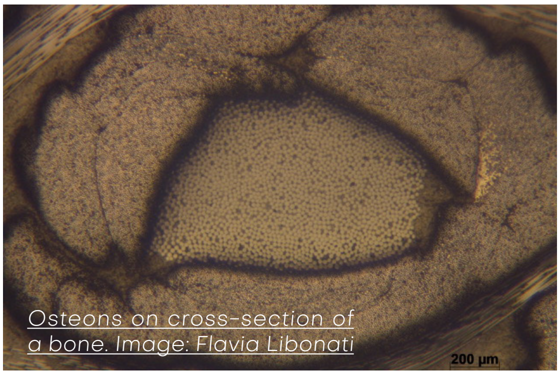
The professor goes even further to explain the principles of nature that are leveraged by engineers:

"Nature uses a few building blocks, such as proteins and minerals; and–through complex hierarchical structures¬¬–it creates a variety of materials, which are multi-functional, efficient, and sustainable. If you think about the basic materials seen in nature –nacre, bamboo, bone, etc. They have a very complex structure and diversify a lot, and this diversity of structures and functions can also be seen within the same material. Bone for instance, is a material that features many sub-structures, which are made of minerals and proteins, to name a few composition items. These structures are mixed together at different length scales – from the nanoscale to the macroscale –to yield different complex macrostructures able to perform different functions in the body. Seven levels of hierarchy are actually recognized for this material. Even within our body, the bone tissue differentiates a lot so, a compact tissue will definitely not have the same properties as the spongy one, but both are made from the same building blocks. We can do the same with 3D printing. We start with these building blocks and then we look at nature and how a specific local shape can affect and enhance the performance of a whole part. Thereafter, we try to combine these building blocks and diversify the various substructures to bring out for instance, composites with different properties".

By understanding how materials function in the nature for instance, by emulating the natural world, engineers can easily find solutions to some of their design challenges. The example of the way materials work in nature is just one that stands out from the crowd as Libonati notes that every trade of the 3D printing value chain can see their work affected by a biomimicry approach. This includes the designer, the materials expert, or even the parts producer.

"In the designer's work, the biomimicry approach will affect the creative part and help provide optimal solutions inspired by nature. It's easy for designers to take inspiration from solutions found in Nature, not only because they are optimized, but they are not covered by intellectual property. A materials expert on the other hand, will need to understand how these solutions work and how to translate it into synthetic materials, bearing in mind that the latter are not living materials like biological materials."

However, **“the evolution of 3D printing is very related to the evolution of materials”**, she said, hence this focus on materials as part of this feature. *“The more we open the palette of materials we can print, the more we can develop a diverse range of structures for materials, and therefore, a wide range of material' formulations and their printability”*, she adds.



Osteons on cross-section of a bone. Image: Flavia Libonati

The example of 3D printed architected* materials developed thanks to nature and engineering principles

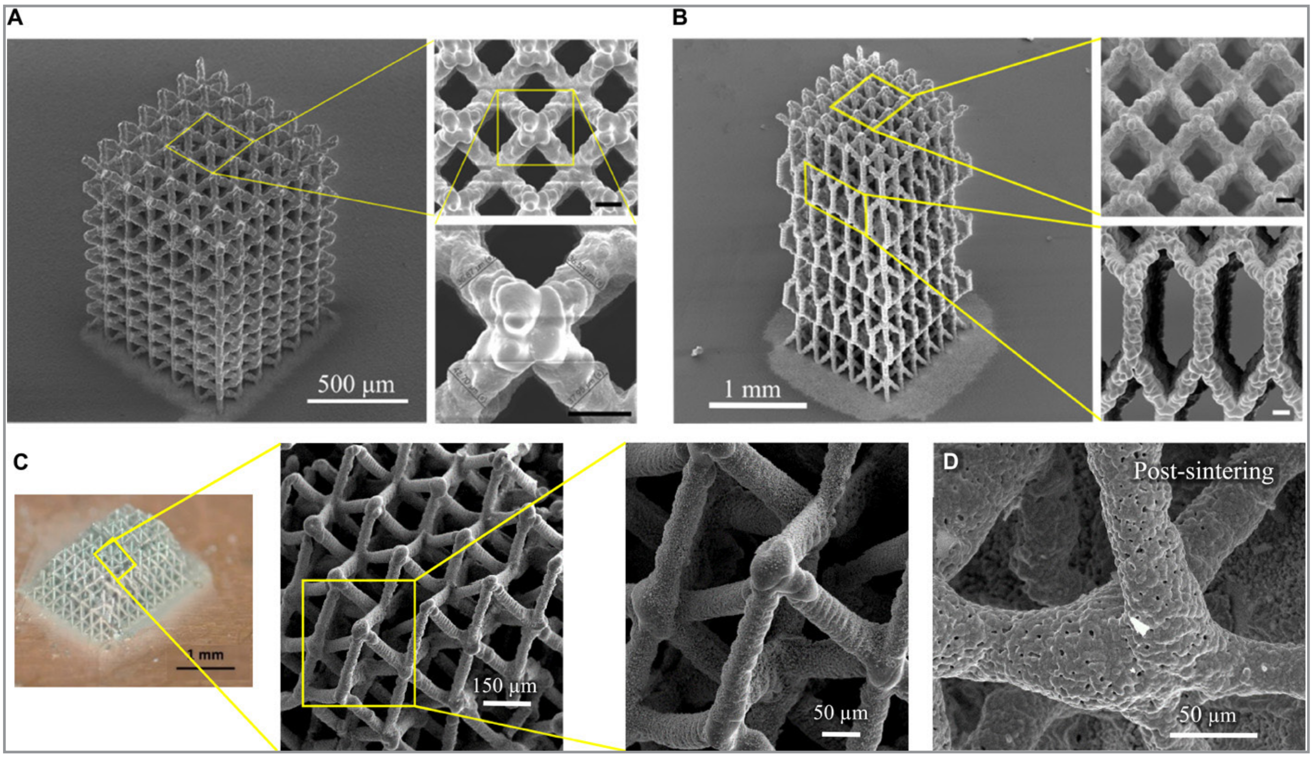


Image: Three-dimensional microarchitected materials and devices using nanoparticle assembly by pointwise spatial printing. Pointwise-printed 3D microarchitectures with different network topologies. Credit: Science Advances.

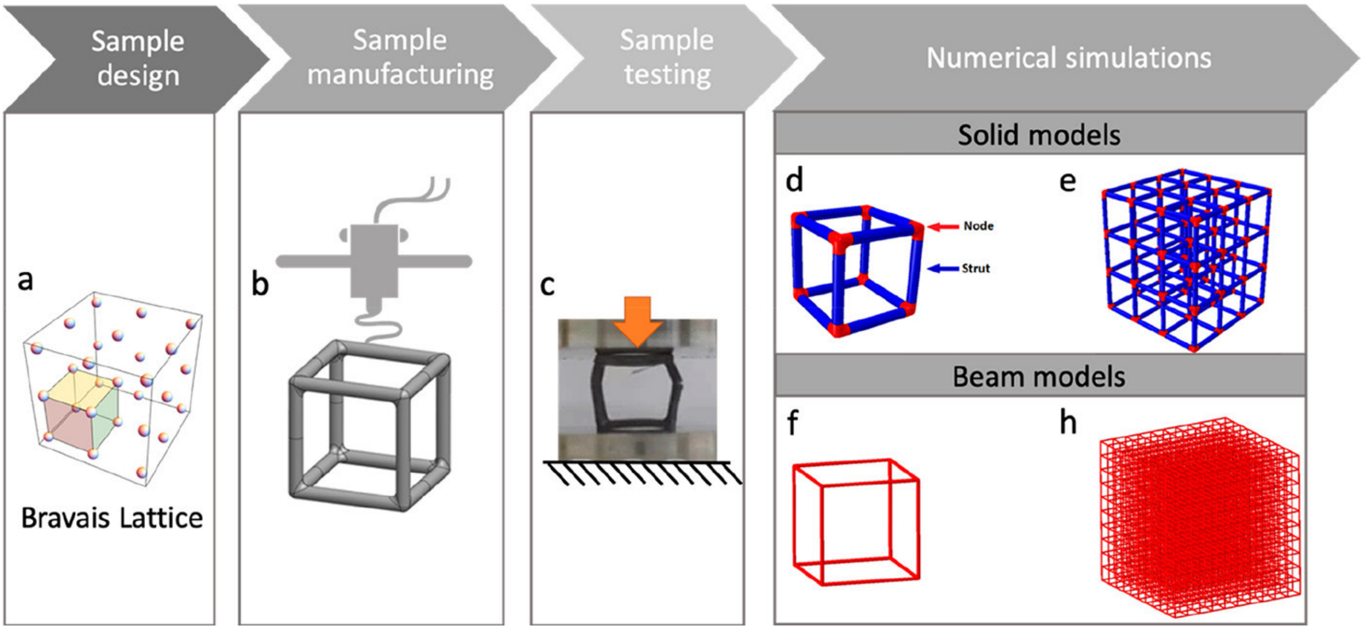
(A) An open octahedral microarchitecture with truss elements having a diameter of about 35 µm. Scale bars, 50 µm. (B) Pointwise-fabricated microarchitecture with a combination of octahedral and hexagonal structures. Scale bars, 50 µm. (C) Top surface of an octahedral scaffold structure at different magnifications and (D) truss elements of the 3D-printed scaffold after binder escape and nanoparticle sintering and possible grain growth

As part of a research project, the Associate Professor, together with a team of researchers, has provided a deeper understanding of the structure-property relationship of crystal-lattice-inspired materials. While the study starts with single unit cells inspired by the cubic Bravais crystal lattices, the research team utilized what they learned from Nature on the one hand, and on the other hand, a set of methods which include 3D printing and mechanical testing, to investigate the influence of different printing parameters, and numerical modelling to design lightweight architected materials.

While Nature provides solutions for porous structures, from shock-absorbing hedgehog's spines to trabecular bone, it should be noted that the shock-absorbing hedgehog, which helps to prevent injuries, is very similar to a foam that fills the central part of a spine, supports the thin outer wall, contrasting local instability and allowing the whole system to bend further without breaking. The trabecular bone on the other hand, is another example of cellular structure at the microscale with energy-absorbing properties. With an open-cell porous arrangement, apparently random, it is *“carefully designed by Nature to bear specific local loadings and to fulfil different functional needs while keeping a low weight”*, the research reads.

“Numerical models, validated based on experimental testing carried out on single unit cells and embedding manufacturing-induced defects, are used to derive the scaling laws for each studied topology, thus providing guidelines for materials selection and design, and the basis for future homogenization and optimization studies. We observe no clear effect of the layer thickness on the mechanical properties of both bulk material and lattice structures. Instead, the printing direction effect, negligible in solid samples, becomes relevant in

lattice structures, yielding different stiffnesses of struts and nodes. This phenomenon is accounted for in the proposed simulation framework. The numerical models of large arrays used to define the scaling laws suggest that the chosen topologies have a mainly stretching-dominated behaviour, a hallmark of structurally efficient structures where the modulus scales linearly with the relative density. By looking ahead, mimicking the characteristic microscale structure of crystalline materials will allow replicating the typical behaviour of crystals at a larger scale, combining the hardening traits of metallurgy with the characteristic behaviour of polymers and the advantage of lightweight architected structures, leading to novel materials with multiple functions." the report says.



Legend: Framework of the study: (a) inspiration from the Bravais cubic lattice; (b) cell design and 3D printing; (c) mechanical testing; (d,e) 3D solid FE models of (d) unit cell and (e) array; (f, h) 3D beam FE models of the (f) unit cell and (h) array. Image (a) generated by the authors using Wolfram Demonstration Project, © 2021 Wolfram.

What we will keep from **Libonati's** explanations is that *"nature does everything from the nanoscale on, with a hierarchical organization, and we need to find a way to translate the process into manufacturing, while maintaining a multiscale precision. This way, we will find better ways to develop new high-performance materials."*

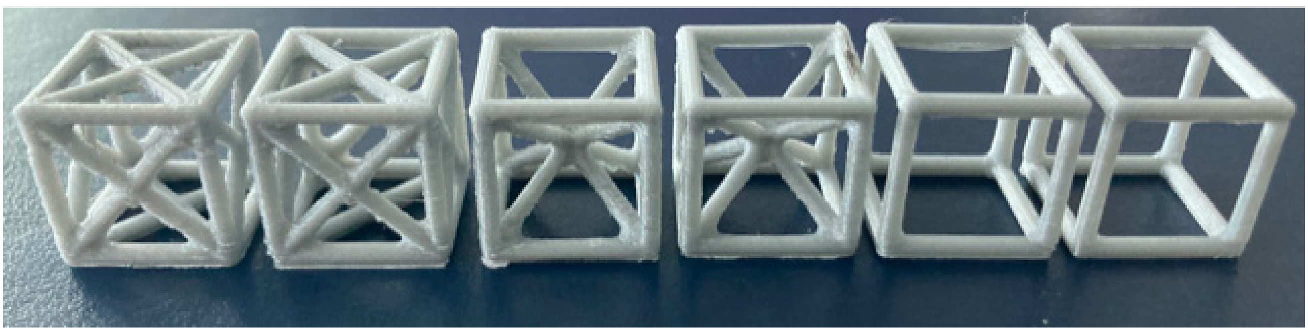
In addition to 3D printed architected materials, other examples of a biomimicry approach within the 3D printing sphere highlight the use of honeycomb structures in 3D printed parts. The honeycomb pattern results from the cross-section study of a real honeycomb. In a 3D printed object, this pattern can deliver greater strength while using less material.

Since the biomimicry-design approach somehow leads to the fabrication of 3D printed objects with less materials, it's fair to say this approach may enable the development of more "green products" in the long run. However, without any quantifiable data regarding the complete value chain, it will be hard to confirm how "sustainable" it is for manufacturers.

Reality is, the commercial market for bio-based products or materials is almost non-existent, even though in the meantime a lot is being done at the research level. Therefore, one should recognize the efforts of researchers like Libonati who are leveraging the full capabilities of biomimicry to extend the palette of 3D printing materials, or to advance new manufacturing processes like 4D Printing.

Notes for the readers

Architected materials are a class of materials that are treated like a structure.



Kenan Boz - Technical Manager at EPMA.

THE SUPREME PROJECT REVEALS THE PERFORMANCE AND SUSTAINABILITY ADVANTAGES OF AM COMPONENT PRODUCTION

GUEST COLUMN

In the May-June 2021 of 3D ADEPT Mag, we presented some of the work carried out in the EU-funded SAM project, where EPMA is a partner. In this issue, we go through some of the results of another project that EPMA contributed to, namely the SUPREME project. That will lead us to discuss sustainability of Additive Manufacturing (AM) in general.

The SUPREME project consortium

Named *"Sustainable and flexible powder metallurgy processes optimization by a holistic reduction of raw material resources and energy consumption"*, this project received a budget of about 10M€ funded by the Horizon 2020 – SPIRE programme (grant agreement n°768612). It started in 2017 and in December 2020.

The work was a cross-sectorial integration and optimisation between several PM processes, such as gas and water atomisation as well as mechanical alloying for metal powder production, Additive Manufacturing, and other near-net shape technologies for end-parts fabrication (namely Metal Injection Moulding and Hot Isostatic Pressing).

The consortium aligned many industrial partners from the whole supply chain for the various technologies and a strong group of RTD organisations, and was led by the coordinator CEA-LITEN, Grenoble (France).

EPMA was involved as a dissemination and communication partner, and contributed by managing the website where periodic newsletters have been made available, by promoting the project in various events (including the yearly EuroPM congresses), and by organizing specific training sessions in its Summer School (at the University of Trento, 2019), in the PM Life AM module (at Fraunhofer IFAM Dresden, 2019) and a one-day SUPREME Experts Training Workshop on 26th November 2020 where key Consortium partners gave insights into the activity and the results obtained.

In addition to that, the consortium published several technical papers in peer-reviewed journals and conferences (again, including the EuroPM series).

The SUPREME concept

As the project title suggests, the idea was not just to improve the technical performance of the different processes included: the ultimate goal was to achieve at the same time environmental advantages, focusing on some of the impact factors. Thus, many Key Performance Indicators (KPIs), including, the ones for the environmental side, the CO2 Equivalent, the Minerals Depletion and the Energy Depletion (but also water, gases, and other specific KPIs for each process), were used to quantify the improvements.

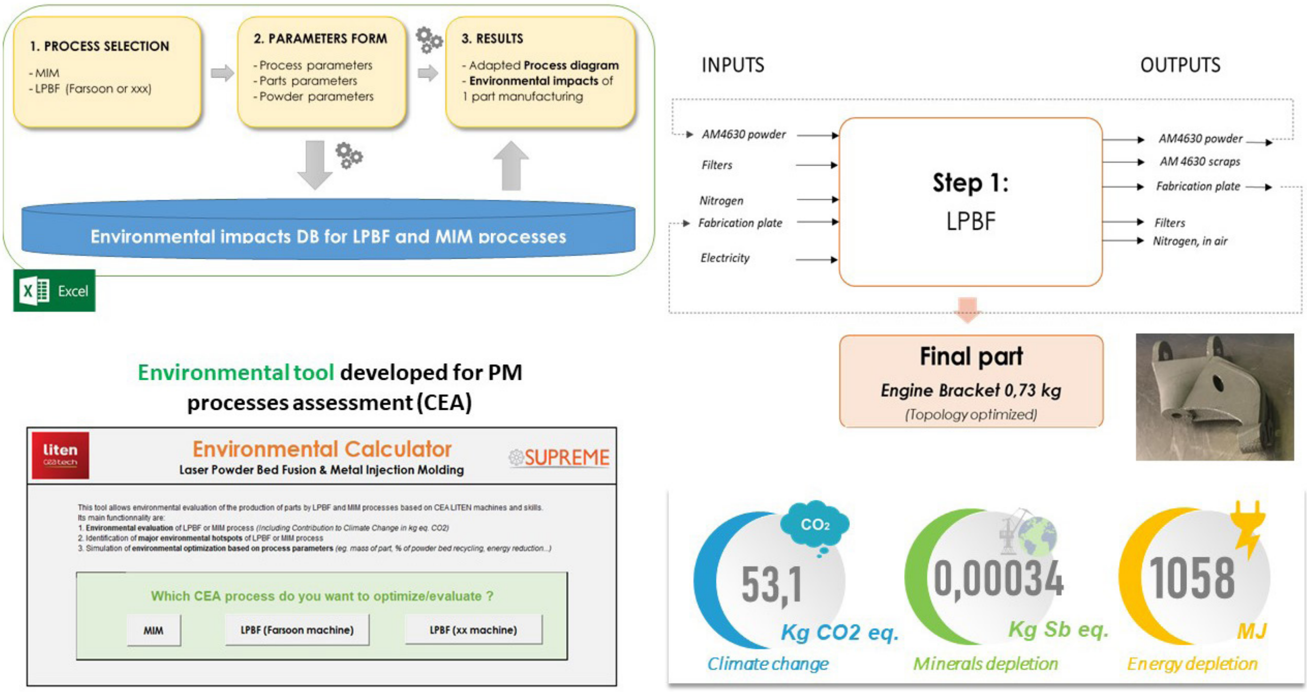


Figure – Environmental tool developed in SUPREME to evaluate Powder Metallurgy Processes (L-PBF and MIM) in terms of environmental impacts. In this case, on the production of a topology optimised Engine Bracket.

Optimisation was boosted using specific process monitoring equipment that was delivered and installed on the different production lines (Figure 3), allowing full tracking of process capabilities, consumptions, etc.

10 use-cases representing 20 production routes were studied in SUPREME: a gang saw blade tool for cutting stones (Metal Injection Moulding); a motor bracket for aeronautics (Laser Powder Bed Fusion); 2 medical implants and 2 medical tools (L-PBF, MIM and Metal Fused Filament Fabrication); 2 automotive engine brackets (L-PBF and Plasma Metal Deposition); and mould inserts for injection moulds (L-PBF). As shown, many of the cases were related to AM processes.

Four demonstrators (Figure 3) were monitored in detail: (i) iron ore grinding, (ii) gas atomization, (iii) 3D metal printing of automotive bracket with 3 different L-PBF machines and (iv) one PMD machine.

3 L-PBF machines monitored thanks to PATBox systems

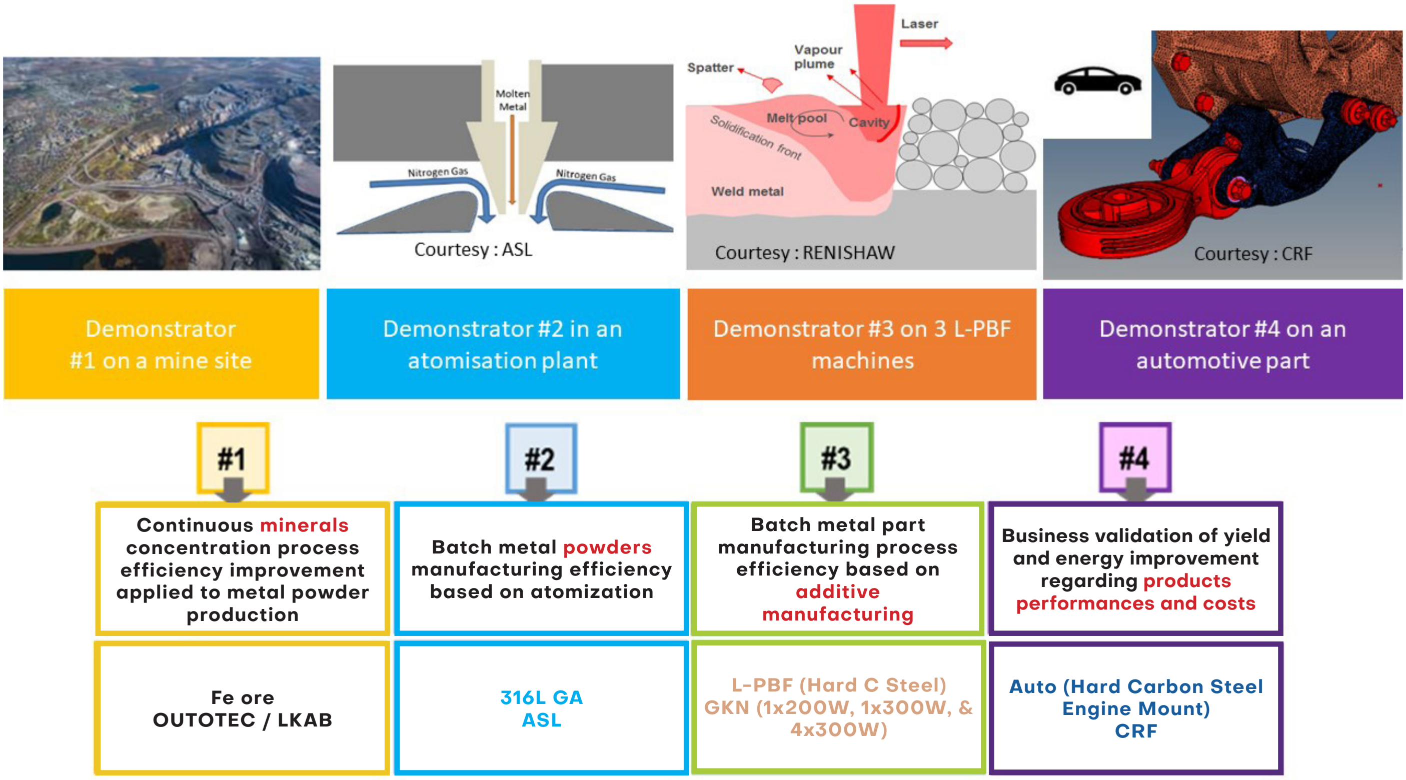


Figure - SUPREME demonstrators, selected along the PM value chain. Demonstrators #3 and #4 are directly, and also #2 partially, AM-related.

AM results in SUPREME

Looking at the AM-related results, that are spread over the whole supply chain (including even or refining, that was included in demonstrator #1), some results were obtained already in powder production. The partners involved worked both on Gas Atomisation (GA) and on Water Atomisation (WA) (Figure 4).

The improvement of the GA process for AM grade powders with a new atomiser led to reduction in **energy consumption by 33.8%, gas consumption by 35.7%, simultaneously improving powder yield by 66.1% and production rate by 90.5% compared to the previous process.** WA resulted in a further energy consumption reduction of 78.5%.

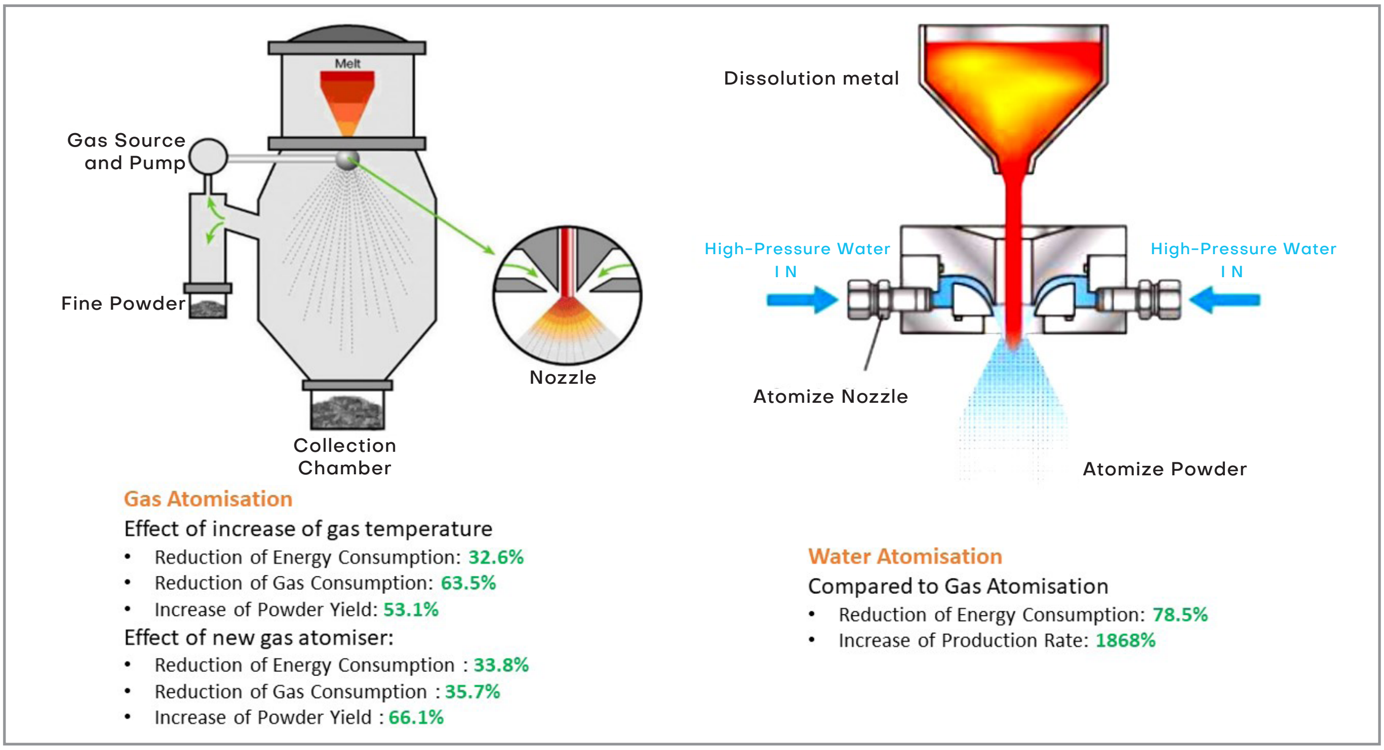


Figure - Improvements for Key Process Indicators of the AM-related powder production processes studied in SUPREME

Further downstream in the supply chain, KPIs were quantified (Figure 6) for several AM processes: L-PBF, PMD and Laser Metal Deposition (LMD).

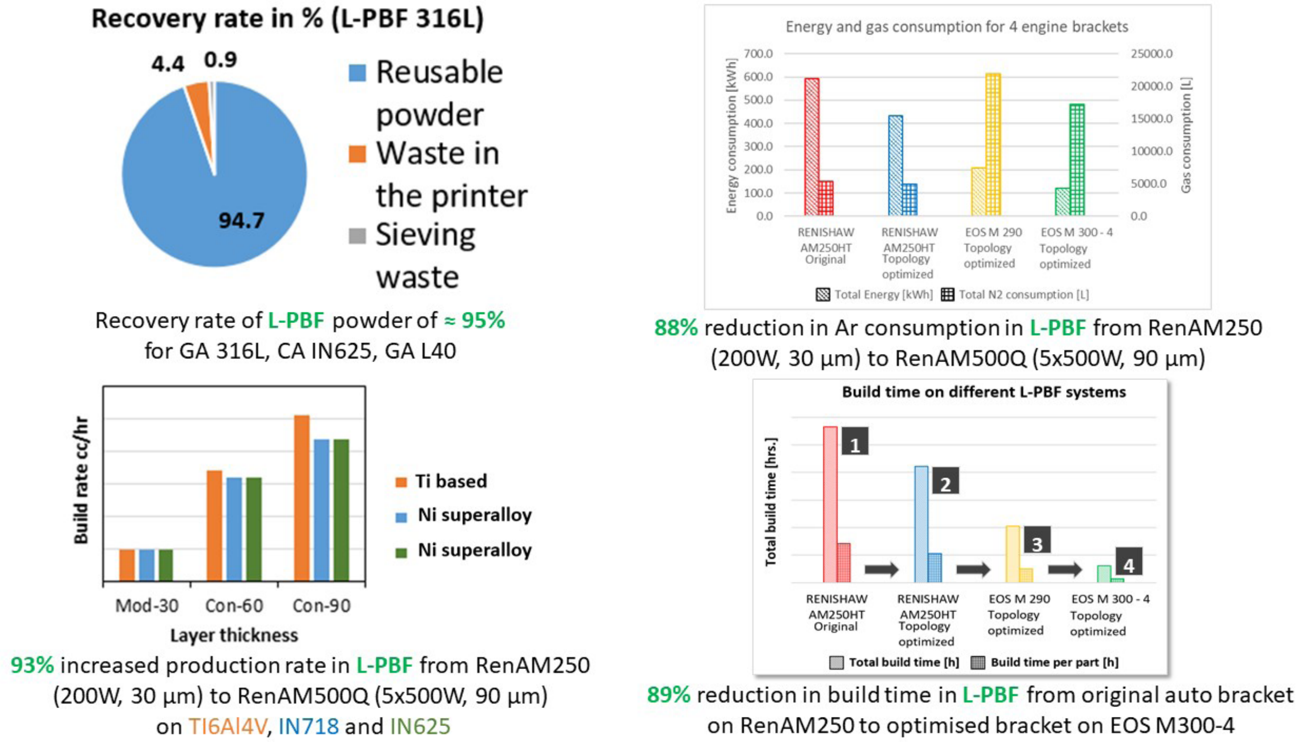


Figure – Main results obtained in SUPREME on the Laser Powder Bed Fusion process

Compared to the baseline (the process presently used to produce the same part industrially), the build time of an automotive L-PBF engine bracket was reduced by 51 % and the production rate increased by an outstanding 1050 %, whilst nitrogen consumption was also reduced by 21.6%. Lightweight L-PBF topologically optimized >99% dense Hard Carbon Steels parts with detailed datasheets have been developed and are available now on the market from a consortium partner.

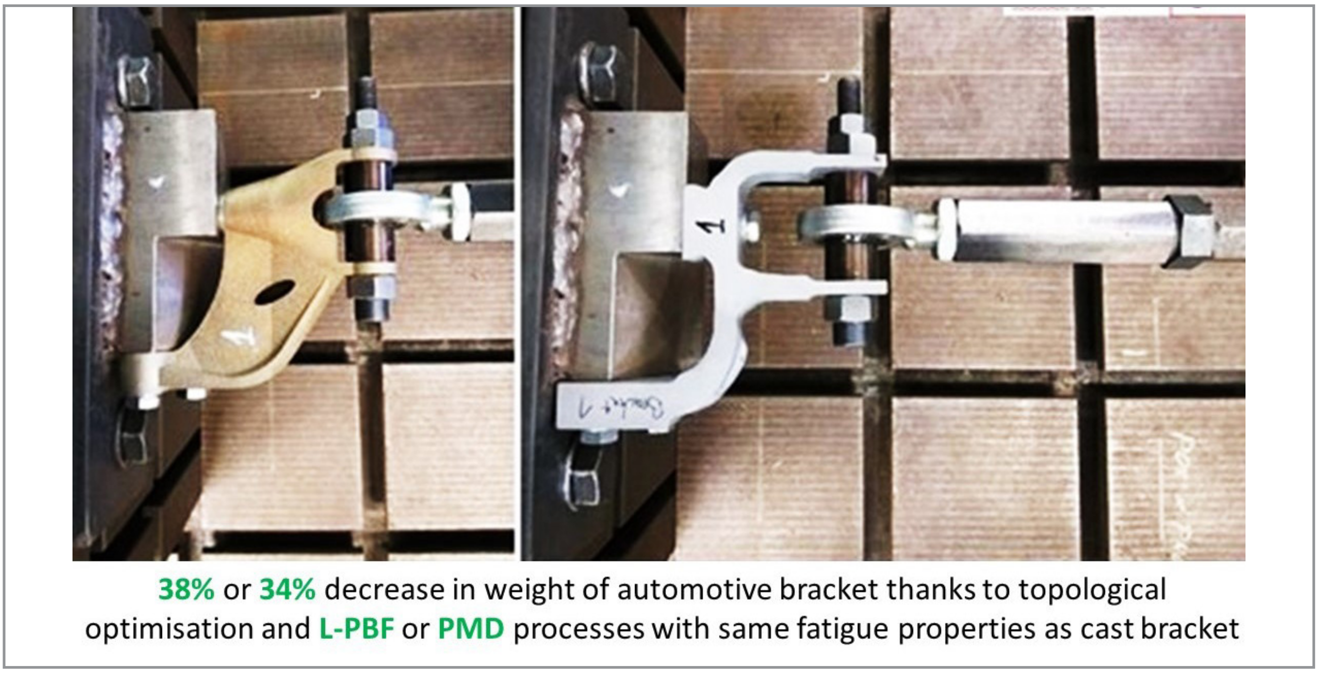


Figure – Automotive brackets developed in the SUPREME project during their test on a fatigue bench.

The LMD process optimization with a HC22 superalloy resulted in a 500% improvement of productivity and an 83% reduction in argon consumption.

PMD process optimizations with a WA 17-4PH steel led to a 16% increase in the deposition rate with same mechanical performances.

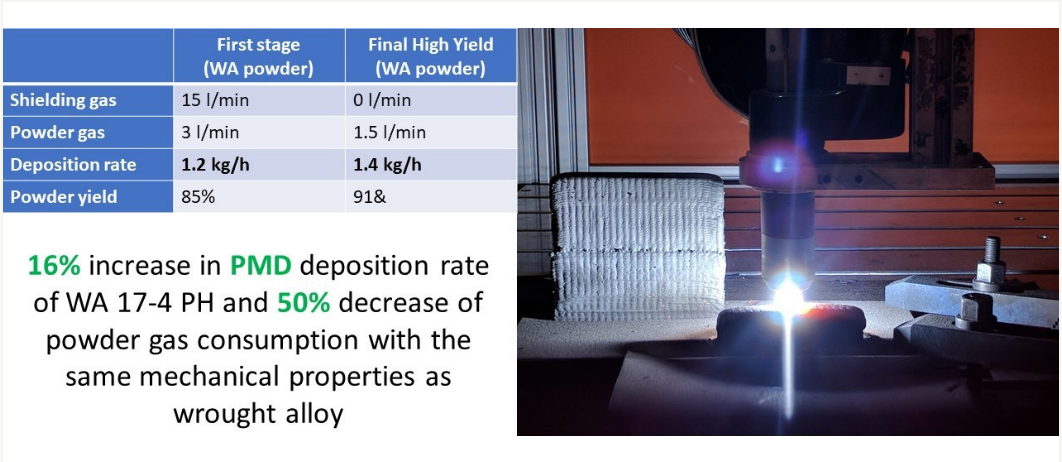


Figure – Main results obtained in SUPREME on the Powder Metal Deposition process

Even when the new process did not improve carbon footprint for part production, the LCA calculations showed a chance for AM: regarding the aeronautics topologically optimized bracket, after slightly more than one year of flight, the impact cost in terms of CO2 emissions due to the L-PBF process will be compensated by CO2 savings in flight compared to the initial baseline part.

L40 steel moulding tools for plastics achieved a 31% reduction in material yield losses, a 5% improvement in energy efficiency, a >230% increase in production rate and a >30% reduction in CO2 emissions after 6000 parts injected.

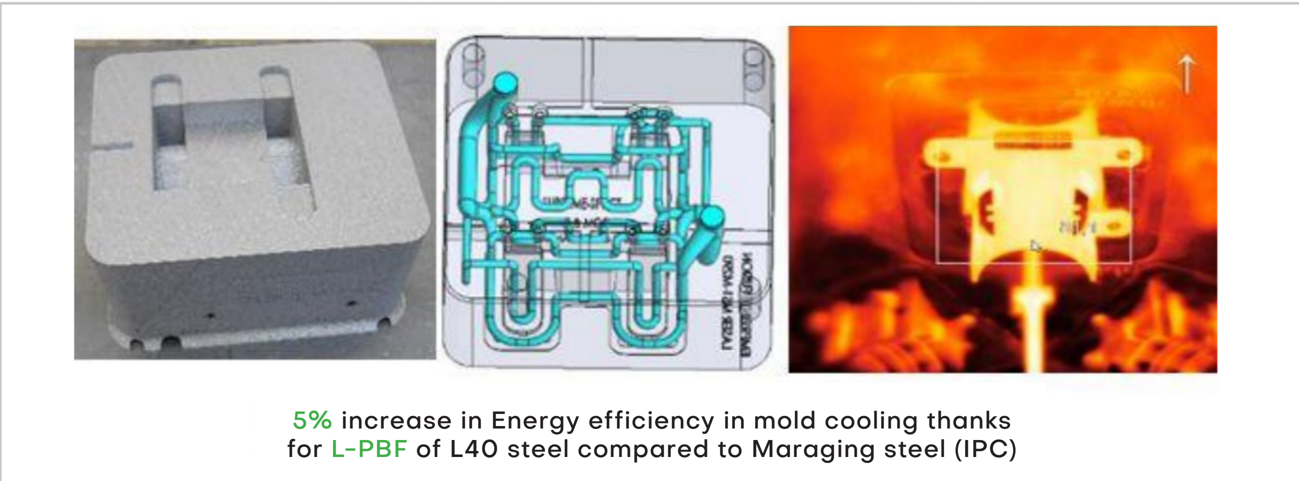


Figure – L40 steel mould developed in SUPREME by L-PBF. Right: during injection tests.

Another important result came from a study on reuse of metal powders in L-PBF, that showed that even with a recovery rate of 95% the mechanical properties of the AM test bars were not significantly impacted.

AM and sustainability: opportunities and challenges

The SUPREME project confirmed that AM can be an excellent way to reduce the environmental footprint of a part. But clearly, not all cases might give equivalent improvements, and sometimes the result might be unsatisfactory, especially compared to the baseline.

Although AM can promise a general reduction of the material used in the part for the same function, the extreme being the topological optimisation used for instance for larger structures like antenna supports or other aerospace applications, its potential in terms of resources and energy usage reduction and global environmental footprint sometimes results hindered by inefficiencies in the process itself, that are characteristic of the AM process chosen. In some cases, especially when comparing to very well established and optimised present processes (stamping, casting, or even machining), this could lead to an increase in impact despite the near net shape capability. As explained, this might be further compensated by other advantages, for instance the weight reduction attained by topology optimisation reduces the contribution to environmental impact during the downstream use (and in the recycling or disposal at end-of-life).

The factors impacting sustainability in AM can be grouped in three main categories: **environmental, economic** and **social.**

Environmental Factors

Environmental factors mainly cover the **efficient use of material and energy consumption.** In addition to that; emissions, amount of waste, transportation and even biodiversity are factors that will have an impact on sustainability of AM. In most cases, the amount of material used in AM is much lower than in subtractive manufacturing methods. On the other hand, recycling by melting and atomisation of used powder is not as easy as recycling of chips and scraps from a conventional manufacturing method. Metal powder is preferably re-used in the AM process directly in the workshop only after a simple sieving or sent back to a reconditioning process. It can be used in a different industry as well. The production process of the powder itself, being rather complex, makes powder recovery a very important step for ensuring process sustainability along the entire life cycle of the product. Since any impurities in the used powder will show up as defects in the final part, the recovered powder needs to be of the highest quality possible, targeting an extended product life. This is important to consider when the powder manufacturers do not take back the used powder for reconditioning.

Economic Factors

Economic factors are to be measured through **economic viability, market presence, and indirect economic impacts**. The minimization of cost and the drive to improve the value of products has a direct impact on the economic performance. Some government policies may lead to an incentive scheme or reward system for the implementation and development of more economically sustainable ventures. Current state of the art makes AM feasible for low quantity production of highly complex shapes. In addition, the possible re-use of powder mentioned before also has a big impact on sustainability of AM. An entire repetition of the melting and atomisation process for metal powder disrupts the feasibility of AM not only for sustainability, but also as an alternative manufacturing process in general.

Social Factors

In particular, four categories of social impacts can be considered as relevant.

1) **Health and social well-being**: Perceived and mental health, subjective well-being, feelings of stress, anxiety, apathy, depression, expectations about what will come (more jobs, more economic growth, etc.)

2) **Institutional, legal, political, and equity**: implementation of projects with great commercial interest can create pressure on the institutions and governments, patents and copyrights can change significantly

3) **Quality of the living environment (liveability):** Working conditions regarding dust, noise, risk, dour, vibration, blasting, artificial light and safety, life expectancy and quality of life, waste management, crime and violence changes.

4) **Economic and material well-being:** workload, access to goods and services, economic prosperity and resilience, Loss of employment resulting from new technology, disappearance of local economic systems and structures, labour intensity, employment schemes, types of work, working hours, working places, changes in knowledge and skills.

As it can be predicted, not all social factors might have a positive impact on sustainability of AM. As an example, the loss of employment in one sector resulting from a new technology might be a threat for the community.

Conclusions

Additive Manufacturing must demonstrate its sustainability to present and potential customers in order to find growing application. The pressure towards a greener industry can be a formidable driving force for the technologies that can prove to give advantages. As some of the features of AM processes can be dangerous for sustainability, the processes need to be improved and tuned, via quantitative monitoring and analyses. Projects like SUPREME are trying to implement solutions along the supply chain that go in that direction.

EPMA will be ready to support further projects for the evaluation and improvement of sustainability of Additive Manufacturing. The full Publishable Report on SUPREME is available on the Cordis website and a more user-friendly version is also freely downloadable on the SUPREME project website.

Acknowledgments

We would like to thank Dr Thierry Baffie of CEA-LITEN Grenoble, coordinator of the SUPREME project, for the assistance in the writing of this article.

Applications | Materials

What 3D printing materials are an interesting choice for fashion and what is this sector's approach to sustainability?

Words of Andreina Martinez Tancredi

With a market size of 1.5 trillion U.S. dollars, Fashion is one of the biggest industries in the world. However, the sector is currently facing hard times due to the COVID-19 crisis, as we all are. The pandemic has raised attention to underlying issues that were not previously considered before. Those issues include but are not limited to the delicate and intricate supply chains, the increment of brands' digital presence, as well as the experimentation with new technologies such as 3D Printing and materials - mainly bioplastics or recycled materials. The article below will discuss the use of 3D printable materials in the fashion industry and this sector's approach to sustainability concerns.

Enabling wearability and comfort with appropriate materials

Fashion is about the **joy of self-expression**; something that 3D printing users easily understand as the technology enables the **freedom of design**. By integrating 3D printing into their creative process, fashion designers can create products that enable them to express their mood, interests, and beliefs. To do so, they rely on Computer-Aided Design (CAD) to develop intricate designs that can translate beautifully into a piece that is unique and customizable.

However, one of the biggest concerns raised by 3D Printed Fashion is **wearability and comfort**. One simply cannot find joy in fashion if an apparel is uncomfortable for the wearer. There are, at least, three paths to 3D Printed Fashion I can identify related to comfort:

- Rigidity and structure: The use of materials such as Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), and Polyethylene terephthalate (PET) used in Fused Deposition Modeling (FDM) Printing, do not deliver comfort to the wearer, but one can still use them to create interesting wearable pieces. We only need to turn our heads to Cosplay, in which fans usually use these materials to recreate garments from their favourite characters from video games, anime, comics, and more. Another possibility is to use these rigid materials to create, precisely, structure in a garment like a corset. Nevertheless, those rigid materials are not always very comfortable to wear. Another idea is to create other accessories like buttons, embellishments, and trimmings. The following image highlights a corset made by **Raquel Banegil** mixing bioplastics with PLA boning, as part of her research in the field.

A dress that combines 3D printed parts and microcontrollers (Source: Anouk Wipprecht)

- Concerning flexibility and fluidity. Thermoplastic Polyurethanes (TPU) can play a key role here. Recreus' FilaFlex, an example of such materials, is a filament used by Danit Peleg in her 3D Printed Fashion collection. This material is easy to work with, can look like fabric and can be breathable for the skin if you control the infill in each piece. Nevertheless, it can feel like plastic to the skin; that is why designers generally use organic fiber textiles like cotton, silk among others, to create linings. A large number of fashion designers and entrepreneurs, including myself, are used to experimenting with this material in the design and manufacture of garments, as seen in the picture.

- Concerning the mix of materials with fabric: This path consists in depositing material directly to a fabric, like tulle, cotton, or even woven fabrics, to take advantage of both worlds. Fashion designer Julie Daviy's approach is quite interesting here as she prints in fabrics which, when shrunk allow for incredible volumes in a garment.

People and designers are using these three methods to create garments. As materials and technology evolve, there will surely emerge various paths to 3D Printed Fashion.

New materials for new needs

3D printing materials are continuously developing, but none of them are specifically designed for the fashion industry, as suggested in the aforementioned three paths that should be taken into account to enable wearability and comfort in 3D Printed Fashion.

As **Susana Marques**, fashion designer and researcher in 3D printed textiles, said to an interview for Women in 3D Printing in 2020: *"we do not have technology aimed at our industry, materials, printers, software … nothing is developed taking into account the specific needs of fashion, but it is already possible to find very functional solutions".*

When it comes to fashion design using 3D printing, designers have to use their creativity and knowledge to translate materials, software, and printers that are specifically conceived for industries as different as automotive, aeronautics or others, to create solutions that are sustainable, relevant yet fashionable.

An **interesting branch of fashion is the use of technology and textile to enhance physical capabilities or diminishing them**. Now imagine mixing that branch with Additive Manufacturing. An example of that is the work that **Marques** is doing on the research of 3D printed textile surfaces for unsighted individuals, in which she is experimenting with tactile and olfactive materials for clothing to reduce the gap between people with disabilities and fashion brands.

Biopolymers are another material taking over the fashion industry. Experiments in this area start to question how we consume and produce objects and how we close the loop in the circular economy. These materials made with alginate, sodium chloride, or gelatine, are under research for many purposes like packaging for example, but in fashion, a great example is Charlotte McCurdy, who created a water-resistant jacket from plastic made of algae.

In Spain, **Mariel Díaz**, CEO of Triditive and Women in 3D Printing's Ambassador for Asturias, is investigating the use of apple waste in the cider manufacturing process for the creation of 3D printing materials.

According to Mariel in an interview for the newspaper La Nueva España this year: *«We have to analyse what type of pieces can be printed with this technique, but it is feasible and we understand that it can be a solution for all this material that is discarded and with which the cider makers may not know very well what to do»*, with the advantage that those biopolymers are biodegradable synthetic substances.

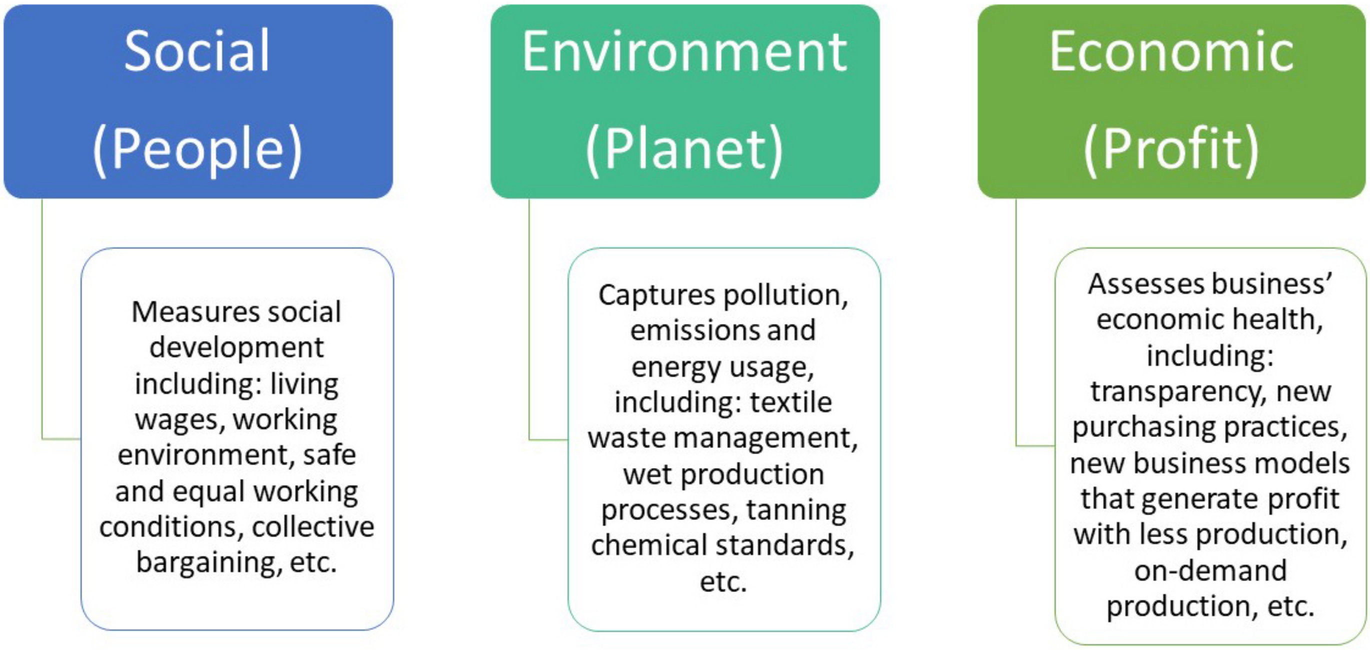
In the same vein, there are already filaments that are compostable, meaning that with the action of certain agents like water, oxygen, microbes, a piece can disintegrate in a short time.

As for the combination of bioplastics and Additive Manufacturing, there is still work to be done and research to be made, but a new way of doing Fashion is emerging and surely, we can benefit from a solution that is sustainable and waste-free.

Fashion and Sustainability

One of the biggest problems in the Fashion Industry is the pollution created by overconsumption and overproduction. According to McKinsey and Global Fashion Agenda in their report: "The fashion industry accounts for around 4% of emissions globally, equivalent to the combined annual Green House Gases (GHG) emissions of France, Germany, and the United Kingdom. (…) Under its current trajectory, the fashion industry will miss the 1.5-degree pathway by 50%". We have created a monster that is devouring our planet.

Sustainability is surely permeating brands as we as consumers gain awareness of the problem we are generating. Sustainability is now a need more than a trend and more and more brands are taking into consideration the three big pillars in sustainability: people, the planet and profit.



In 2020, Julia Daviy won the gold prize of the Edison Awards with the Organic Skirt Project, defined as "*A digitally created and deeply customizable in more than 1,000 variants 3D-printable skirt is the first project uniting different worlds – digital and physical, non-organic and organic, additive manufacturing, and traditional craftsmanship.*" Using a large-format industrial 3D printer, Julia created impressive collections that are similar to traditionally made clothes and with sustainability in mind : a zero-waste approach in the design and printing, an intensive and ongoing research on new materials and processes.

Nowadays, in the fashion industry, a brand must be sustainable and all efforts should be made to enhance the way clothing is produced, from the materials we source, to the people that work in our brand. And us as clients, reduce the quantity of clothing we discard.

And…now?

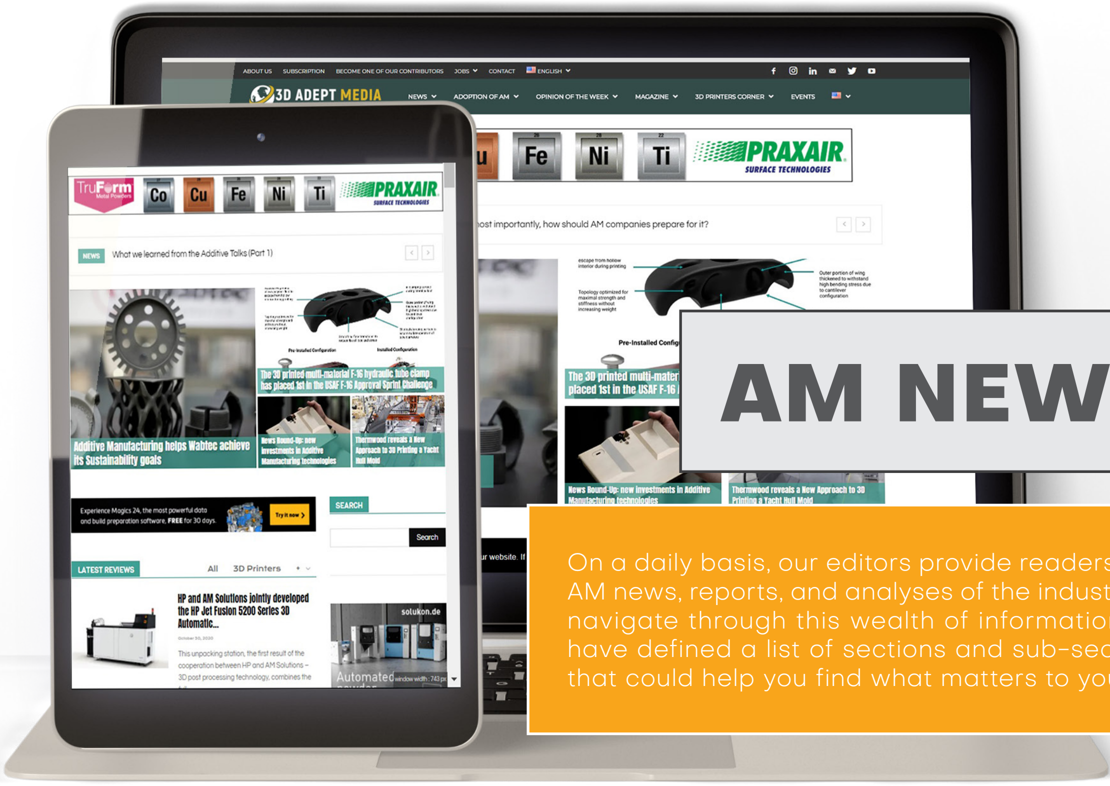
The fashion industry is experiencing structural changes to transform the production processes, the materials sourcing, and the important role workers play in the production of a garment. It is not a mystery that we wear the same clothes as we did centuries ago. Have a look at what you are wearing right now, you can see that little has changed over the years, yet we are still putting the Earth in danger as well as endangering ourselves in the (not-so-)long run.

Technology is here to help us create new paths to change and improve the way we do what we do, and the fashion industry is a major player in our lives, for better or worse.

New materials and new technologies such as AM in the fashion industry could and must be the answer to climate change and sustainability concerns. They should lead to a new set of values revolving around the beauty and joy of self-expression.

Now that we've gone through the state of 3D printed fashion, let your mind wander about the possibilities of merging Additive Manufacturing and fashion.

Andreina Martinez Tancredi is Women in 3D Printing's Ambassador for Valladolid, Spain, and a Master Degree candidate in Innovation and Technology in Fashion Design by the Polytechnic University of Madrid, Spain. She has a Degree in Aeronautical Engineering with a focus on Project Management, with more than 6 years of experience in different areas in the civil aviation and automotive industries, such as Risk, Operations, Quality, and Project Management. Currently, she is interested in the mix between Fashion and Technology and their possible contribution to the Aerospace Industry, as well as how Additive Manufacturing can help tackle major issues in the fashion industry.



AM NEWS

On a daily basis, our editors provide readers with AM news, reports, and analyses of the industry. To navigate through this wealth of information, we have defined a list of sections and sub-sections that could help you find what matters to you.

Do you have any current information related to 3D printing or a press release that needs to be published ?

Send an email to contact@3dadept.com

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HOW RECYCLABLE AND 3D PRINTABLE ARE METALS? F3NICE TOLD US.

We will remember spring 2020 as a period of confinements that led to the shutdown of several activities around the world. For Luisa Elena Mondora and Matteo Vanazzi, in addition to the pandemic that hit their beloved country - Italy - even more than most countries, spring 2020 also comes with the memory of the creation of F3nice. Both cofounders actually came up with the idea of F3nice in 2019, on the heels of an analysis in the Oil & Gas industries. With the decommissioning of offshore assets for the oldest oil fields in the North Sea, and the digital inventory for on-demand and "just in time" production of spare parts, they investigated the possibilities to use the high value scrap metal from offshore decom to power a circular economy project. The two entrepreneurs ambitioned then to produce sustainable AM feedstock that could empower the metal AM industry and in particular, the digital inventory initiative.

As you may have seen in our interview with Equinor in this edition of 3D ADEPT Mag (page 23), the project of F3nice has gained traction over time and has even raised the interest of Equinor Ventures that has signed a Letter of Intent with the Italian start-up. F3nice ambitions to live up to its name – whose pronunciation is similar to the Italian word for Phoenix, "Fenice" (the bird that obtains new life by arising from the ashes of its predecessor) – by sourcing metal scrap and disused parts and transforming them into metal 3D printable powder.

In this Q&A series, we have asked Mondora 7 questions to help us understand how recyclable and 3D printable are metals.

Luisa Elena Mondora (right) and Matteo Vanazzi

3D ADEPT Media (3DA): What services does the company provide?

Mondora: *F3nice sells high quality, sustainable metal AM feedstock, with a process that saves over 90% emissions compared to the standard process. To some end-users, F3nice offers the chance to recycle their own dead inventory, scrap metal, and acquire the metal feedstock made with it, in alignment with their sustainability mandate towards circular economy and lowering CO2 emissions.*

3DA: According to you, what are the key steps of powder production lifecycle?

Mondora: *I would say that the choice of the atomization technology is not taken enough into account when choosing the feedstock for an AM process. Let's talk about standard materials, such as Stainless steels, Inconel alloys and others. Today on the market we see powder made with water atomization and IGA (inert gas atomization) marketed towards highly complex printing processes such as powder bed fusion. Given that the cost of the feedstock account only for a very limited fraction of the AM process cost, why settling for a lower quality powder (in morphology, rheology, and other characteristics) that may lead to lower properties on the printed artifact, when VIGA (vacuum inert gas atomization) feedstock yields such a superior quality? This is the reason why we chose VIGA as atomization technology for F3nice plant for those materials.*

3DA: Are these steps necessarily the same when you use waste to produce powders?

Mondora: *Sorting and preparation of the scrap metal is key to guarantee the high standard quality of the powder and the repeatability of the process! Given that the atomization technology choice is one of the most important choices we had to make when we designed our production plant.*

3DA: Can we recycle all types of metal AM powders/waste/scrap?

Mondora: *With VIGA technology, we can work with all materials with exception of those that require a higher melting temperature, such as Titanium. For Ti Alloys (and other high value alloys, that require smaller batches) we are considering a second atomizer that allows plasma melting of the input metal.*

3DA: Does the recycled powder have the same characteristics and properties than the original one?

Mondora: *Yes! We did a test print for tensile and elongation specimens using F3nice powder on an EOS M290 Printer, using standard 316 printing parameters, and then we printed the same specimens with EOS own brand feedstock. University of Stavanger performed mechanical testing on both set of specimens and the results where aligned; the differences in the mechanical properties where within the error range of the testing machine!*

3DA: Let's take the example of the widely-used AM process: LPBF. Can we recover F3nice4S 3D printable powders in a given production and reuse it? (If possible, how many times?)

Mondora: *F3nice powder is identical to any other high-quality powder produced with VIGA technology and can be re-used during the printing process just as many times (the number depends on the specific alloy). The added value is that, once the powder is deemed 'exhausted', the OEM can contact F3nice and ask for it to be recycled instead of having the hassle of disposing it (at high cost) as hazardous waste. F3nice can provide this service not only for its products but also for any powder.*

3DA: We know F3nice believes in a more sustainable world and is striving to play its part in this critical mission, but how sustainable are your products/processes?

Mondora: *Thanks to the use of 100% metal scrap as input material, a very positive energy mix (we are based in Norway where, according to electricitymap.org, over 95% of energy comes from renewable sources) and an efficient patented process for the scrap processing, we are able to achieve over 50% of energy saved and over 90% CO2 saved compared to the same product made in the rest of Europe (for example Germany) with a standard process.*

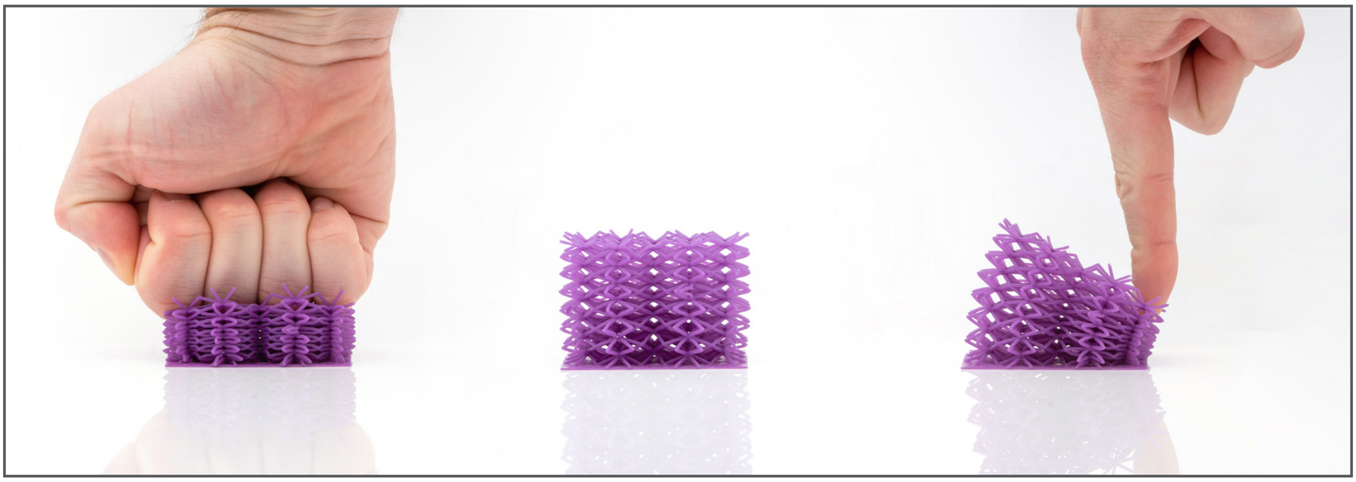
3DA: Is there anything else you would like to share?

Mondora: *We have just signed a 1-year contract with Equinor for the processing of their scrap, and the feedstock made with it will be used to print parts for the commissioning of Johan Castberg field, near Hammerfest, by Fieldmade – in a true Circular Economy Ecosystem!*

FORMNEXT PREVIEW

With nearly 450 exhibiting companies registered, Formnext is making a strong comeback in the world of additive manufacturing events. Below you will find an overview of some of the solutions that will be showcased by companies and that are worth a visit.

Evonik's material campaign continues with new photopolymers for industrial 3D printing



Evonik has had a tremendous year, revealing one after another various forms of materials that can be leveraged by various industries leveraging AM. As a reminder, those materials include a PEEK filament for industrial 3D printing applications - ideal as a metal replacement in certain applications -, a polymer powder INFINAM® PA 6005 P (polyamide 613) – developed in collaboration with Farsoon Technologies, and a 3D printable PEEK biomaterial for medical applications which is not to be confused with the company's **implant-grade filament for medical applications released last year**.

The chemical company showcases two new material developments at Formnext. Named INFINAM® RG 3101 L and INFINAM® FL 6300 L, they complement the company's photopolymers' portfolio and are suitable for use in common photopolymer 3D printing processes such as SLA or DLP.

«We are relentlessly putting our global innovation strength into the development of new photopolymers that enable infinite applications. In this way, we are resolutely driving large-scale industrial 3D printing forward. The Formnext trade show is one of the most important international industry venues for 3D printing. We are therefore very pleased to present our latest ready-to-use high-performance materials here for the first time,» says **Dr. Rainer Hahn**, Head of the Market Segment Photopolymers in the Additive Manufacturing Innovation Growth Field at Evonik.

Specifications of each material

INFINAM® RG 3101 L would deliver excellent impact resistance with high temperature resistance while exhibiting long-lasting thermomechanical performance. 3D printing applications that could be achieved using this material include parts for drones, buckles, or automotive parts. They can be processed by machine and remain fracture-resistant even when subjected to strong forces.

On the other hand, the material company has worked in collaboration with Austrian 3D printer manufacturer **Cubicure** to develop **INFINAM® FL 6300 L**. Cubicure develops a hot lithography printing process. Both companies are commercializing an innovation project jointly launched in 2019.

The **INFINAM® FL 6300 L** the first fruit of this collaboration. According to Evonik, this elastomer from the photopolymer class enables the production of highly flexible 3D objects that excel in material properties essential for elastomers. In addition to outstanding low-temperature elasticity, its strengths include dynamic load cycles of up to one million load cycles.

«INFINAM® FL 6300 L enables completely new manufacturing possibilities in the field of elastic components. Thanks to the high precision with which the elastomer is processed in our hot lithography systems, it is possible for the first time to produce the most complex structures from a rubber-like material. The sports industry is showing great interest in using the material for cushioning elements in shoes, grips or backpacks,» says **Dr. Robert Gmeiner**, CEO of Cubicure.

Evonik bundles its expertise in 3D printing in the Additive Manufacturing Innovation Growth Field. The strategic focus is on the development and production of new high-performance materials for all major polymer-based 3D printing technologies. Within this framework, Evonik has organized its product range of ready-to-use materials under the new INFINAM® brand.

Visitors at Formnext can find Evonik's innovations from November 16 to 19 in Frankfurt am Main, Germany, in **Hall 12.1 at Booth C69.**

CHIRON Group showcases AM Cube: its intelligent additive manufacturing solution

CHIRON Group is a new comer that officially launched its AM activities last year at Formnext connect. With extensive experience in the CNC industry, the company has developed an AM Cube solution that it will showcase for the first time at an in-person event.

With a patented technology for laser deposition welding, the 3D metal printer has been designed using a Cartesian coordinate system, just like a conventional machining center. Thanks to the AM Cube's effortless switching from four to five-axis machining, the laser deposition welding technology is especially well-suited to small quantities and large components with long procurement times and high material prices. In addition, the comprehensive safety and protective equipment enables unmanned operation.

It could enable applications across mechanical engineering, tool manufacturing, energy production and the aerospace industries – from coating components to making repairs to near-net-shape production of semi-finished products.

The CHIRON Group has succeeded in offering two processes – laser deposition welding with both wire and powder – from just one comprehensive system. A real advantage and unique feature of the AM Cube is that the deposition head is changed fully automatically during the process, with the system offering up to three deposition heads.

Process monitoring with DataLine AM and VisioLine AM

In order to analyze and optimize the process of laser deposition welding in a targeted way, two new digital systems are available for the AM Cube. Firstly,

DataLine AM means that all relevant process data can be displayed, recorded and documented continuously in real time. This allows product and process quality to be assessed with certainty. Secondly, VisioLine AM visualizes and saves video files recorded by multiple camera systems (e.g. the melt pool camera, thermal camera, workpiece camera, working area camera), thereby enabling systematic process monitoring.

Moreover, at Formnext, the team from the Additive Manufacturing department will be demonstrating the perfect interaction of additive manufacturing and machining in an exciting use case. They will also be presenting a preview of a second innovation project, AM Coating. This is a system designed for applying particularly hard coatings on brake disks and rotationally symmetrical components. **Hall 12.0, stand A41**.

Solukon adds new feature to its entry-level automated depowdering system for medical 3D printed parts

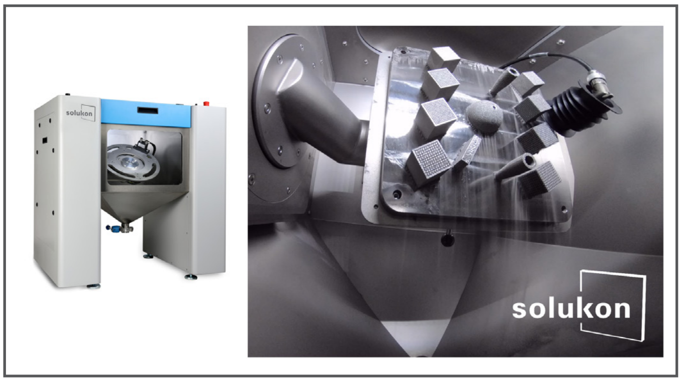
One of the most widely known automated depowdering systems developed by Solukon is the SFM-AT800S solution but let us not forget that the company has also an entry level machine that it has been improving since day one. This solution, the SFM-AT200 system is the one we saw at many industry events or even in a webinar.

Today, the company announces it has further improved the user experience with this machine, by integrating a **new frequency excitation**.

As a reminder, this depowdering solution is based on the company's ***Smart Powder Recuperation Technology*** (SPR®) and enables the removal of powder by part rotation and controlled vibration in a safe & controlled atmosphere. With a small footprint, the machine fits perfectly the removal of powder for small and medium-sized metal parts. Furthermore, Solukon explains that since the process chamber can be inerted within minutes, it makes the machine a great fit for medical parts with lattice structures.

Despite these advanced features, some complex medical parts with narrow internal channels or porous structures may still retain powder residues, hence the importance of a new ultrasonic excitation.

The company explains in a press communication that electric frequency excitation in the ultrasonic range makes the powder "*flowable*". As a result, it only



takes a few seconds for the powder to flow out of these small channels. Add to that the rapid inertisation of the machine, the operator can obtain clean and reproducible parts with no efforts.

Results after first testing of the new frequency excitation

One of the medical companies that has been using AM technologies since its creation, including the **SFM-AT200** from Solukon is the Swiss m4m Center. The Switzerland-based center is a technology transfer center that has dedicated its core business to medical 3D printing. Whenever it is possible, the company does not miss a chance to provide key insights into the way it uses AM technologies and the way these technologies impact the healthcare industry.

For the testing of this new feature in Solukon's entry-kevel machine, the technology center has supplied some medical parts. In compliance with the American standard ASTMF33F, these parts feature extremely fine internal channels and cavities, making them ideal for testing frequency excitation under real conditions.

According to **Nicolas Bouduban**, CEO of Swiss m4m Center, *"frequency excitation further shortens the already short process time of the SFM-AT200 when cleaning medical components. Now, powder flows out of lattice structures, too. Automatic depowdering with the SFM-AT200 is a real door-opener for validated postprocessing."*

Commenting on this frequency excitation, **Andreas Hartmann**, CEO and CTO of Solukon, states, *"Solukon is keen to support MedTech with depowdering solutions. Solukon systems depowder in a standardizable and reproducible way and pave the way for holistic process chains in MedTech." "With the new frequency excitation, we are taking another important step and can now also completely depowder particularly small openings and porous structures of medical components,"* he adds.

Solukon Maschinenbau GmbH will showcase in Hall 12.0 – Booth A139.

ULT AG to demonstrate how extraction and filtration systems can support SLM processes as well as post-processing tasks

Over the past years, **ULT AG** has raised the industry's attention on the importance of air treatment in a production environment. It is in fact, one of the first companies to bring filter technology as well as gas cleaning systems to the AM industry.

During the Formnext show, the company will showcase **a newly developed, unique extraction and filtration system**. The German enterprise describes it as a modular concept with well-proven standard features that can be individually adapted to new or specific applications.

Introduced as a solution that increases the performance range of ventilation systems, this solution completes a portfolio of solutions that already includes solutions for process air drying. The latter portfolio including modular systems of the ULT Dry-Tec® series which ensure ideal air humidity conditions, among others for powder handling or the entire process.

"Due to our 20 years of experience in the additive manufacturing market, we are able to quickly and easily offer solutions that go far beyond standard systems for inert gas cleaning or fume filtration in post processing", explains **Boris Frühauf**, Key Account Manager additive manufacturing and laser technologies with ULT. *"In addition to networking opportunities and a general presence, our goal at formnext is to receive and collect news and innovations that we then refine as part of our intensive research work."*

ULT AG will be present at formnext: **hall 11.0, stand D42.**

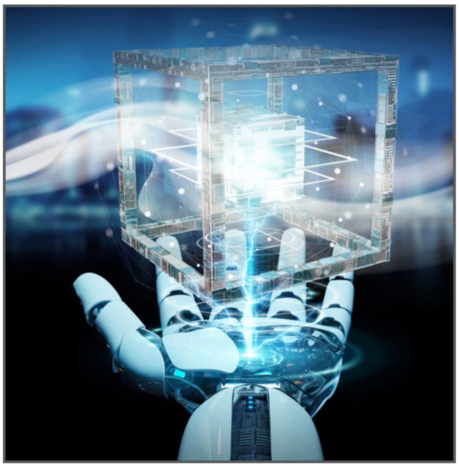


Image: ULT AG – Provider of high efficiency fume extraction technology and process air drying solutions ULT will demonstrate how extraction and filtration systems can support SLM processes (selective laser melting) as well as post-processing tasks.

3 Key Solutions will mark Prima Additive's presence at Formnext

3D printer manufacturer Prima Additive will showcase various solutions at Formnext and will make a key focus on the **Print Genius 150 Double Wavelength, the Print Genius 250** as well as the Laserdyne 811 DED.

The Print Genius 150 Double Wavelength is the new product of Prima Additive's 150 series with Powder Bed Fusion technology. What makes this machine unique is the innovative configuration of the laser sources: a 300 W infrared laser and a 200 W green laser, which can work alternately on the same work area. In this way it is possible to select the best wavelength for optimizing the material absorption of the laser radiation. For instance, you can choose IR radiation for steel alloys, titanium, nickel, chromium-cobalt, or green radiation for pure copper, aluminum or other highly reflective materials. The Print Genius 150 Double Wavelength features a build volume with a diameter of 150 mm and a height of 160 mm.

Another solution on display at the Prima Additive stand is the Print Genius 250, the ideal solution for high productivity metal printing applications, able to reduce production times thanks to its 500 W single-mode dual laser, combined with an intelligent software for a quick orientation of the

pieces and for the definition of the machine parameters. The build volume of 258x258x350 mm makes the machine suitable for the production of medium sized components.

The latest Prima Additive development for Direct Energy Deposition additive manufacturing processes, the Laserdyne 811 DED, will be also on show in Frankfurt. The Laserdyne 811 is an extremely flexible solution: additive, welding, drilling, and cutting 3D and 2D components are supported by a single machine. With the BeamDirector® and quick-change nozzles, in a matter of seconds the machine can be made suitable for the application at hand. The machine features a working volume of 1100 x 800 x 600 mm. The machine can be equipped with a REAL_DED (REal-time Adaptive Laser beam for Direct Energy Deposition) laser deposition head, developed and patented by Prima Additive to increase the performance and the efficiency of the deposition process and let the end-user adapt the laser beam spot dimensions in real-time during the process.

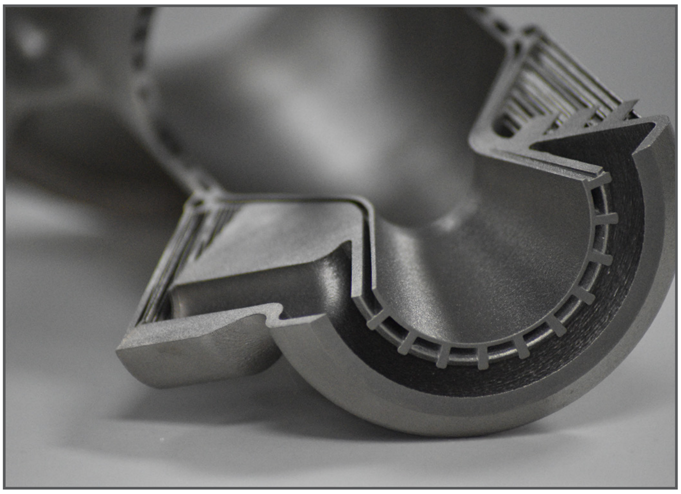
Alloyed shows how to Optimise The Production Of Metal Parts Through Digital Manufacturing

Alloyed is pleased to announce that it will be exhibiting on booth B98 in Hall 12 at Formnext, which is taking place in Frankfurt, Germany 16-19 November. Following the disruptions and travel restrictions caused by the COVID pandemic, this exhibition represents the first large scale event that Alloyed has attended since its formation from the merger of OxMet Technologies and Betatype.

Alloyed offers a unique and complementary stack of technologies for the manufacture of advanced metal components by additive and traditional means. The company has developed and uses a proprietary computational platform and advanced materials modelling to search for the right alloy composition for any application and process. Alloyed's technologies in additive manufacturing deliver better functioning parts faster and more cost-effectively for a wide range of applications. The company's turnkey solution provides technology at every scale from alloy composition, material engineering and part design through to scale for mass production.

Alloyed's novel ABD® rapid alloy design and optimisation platform applies data and advanced physical models to simulate the performance of millions of different potential alloys across a large space simultaneously. This allows optimisation across the full range of performance, manufacturing, and economic parameters relevant to any application. It can be used to choose the right alloy for an application, to optimise an existing alloy, or to design new customised alloy solutions. In simple terms it means better alloys, faster.

The **Betatype** suite of additive technologies includes Engine, a processing platform which uses voxel-by-voxel control of the laser to increase machine productivity and enhance microstructural control, and Architect, an application design platform which takes full advantage of the wealth of data that this level of



laser control involves.

Alloyed also applies world-class expertise in multi-scale simulation to model a full range of thermal and mechanical phenomena, including fatigue and other complex phenomena, as well as microstructural evolution during processing and post-processing. This allows it to optimise both alloy and component design in the light of a manufacturing process and manufacturing process parameters for a given material and performance requirement.

To complete the digital metal manufacturing process, Alloyed can also harness the full potential of AM through the production of physical metal parts. The company has a team with more than 50 years' collective experience of advanced and high-volume manufacturing, design, process development and materials engineering. ADM offers dedicated state-of-the art metal AM facilities that are set up to run an extensive range of metal materials including titanium, aluminium, steel, and nickel alloys. ADM can support application development and deliver production parts at increased scales.

Arburg to showcase a wide range of 3D printed implants made from medically approved PEEK.

AM company **Arburg** is preparing a wide range of innovations at formnext including four Freeformer exhibits and a portfolio from its sister company **InnovatiQ** – which develops a Liquid Additive Manufacturing (LAM) process for additive liquid silicone rubber (LSR) components.

However, visitors might be particularly interested in the ability of the Freeform to convert medically approved Evonik PEEK originals into implants.

"With PEEK, we have significantly expanded our range of materials. It is formed of medically approved original plastic granules, which means it is highly sought after in the AM industry. This material can also be used for technical parts," explains **Martin Neff**, Head of Plastic Freeforming at Arburg. Lukas Pawelczyk, Arburg's Head of Freeformer Sales, adds: *"Converting PEEK is by no means the extent of what's on display, however – trade fair visitors can expect to see four Freeformers and innovative practical examples that demonstrate the huge potential of Arburg Plastic Freeforming (APF)."*

A broader material spectrum: PEEK for medical technology

PEEK (polyether ether ketone) is of particular interest for medical technology applications. At formnext, a Freeformer 300-3X designed for high-temperature applications will convert our partner Evonik's original "Vestakeep® i2 G" plastic granules into customised skull implants for the first time. The original material, which is approved for permanently implantable medical devices, broadens the application spectrum across which Arburg Plastic Freeforming (APF) can

be used. The APF process is also of particular interest when it comes to practical use in medical technology, as it allows for process quality to be reliably documented and for each component to be carefully traced.

Another application for medical technology will be on show as part of a joint project with the University Hospital of Basel, which already uses a Freeformer 200-3X. The exhibit in Frankfurt will show the process of manufacturing resorbable Resomer LR 706 implants, which are a composite of poly L-lactide-co-D, L-lactide and ß-TCP. This Evonik polymer composite contains 30 per cent ceramic additives. This makes the component stronger and also releases calcium to promote bone regeneration.

Arburg will be present in D131, Hall 12.1.

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