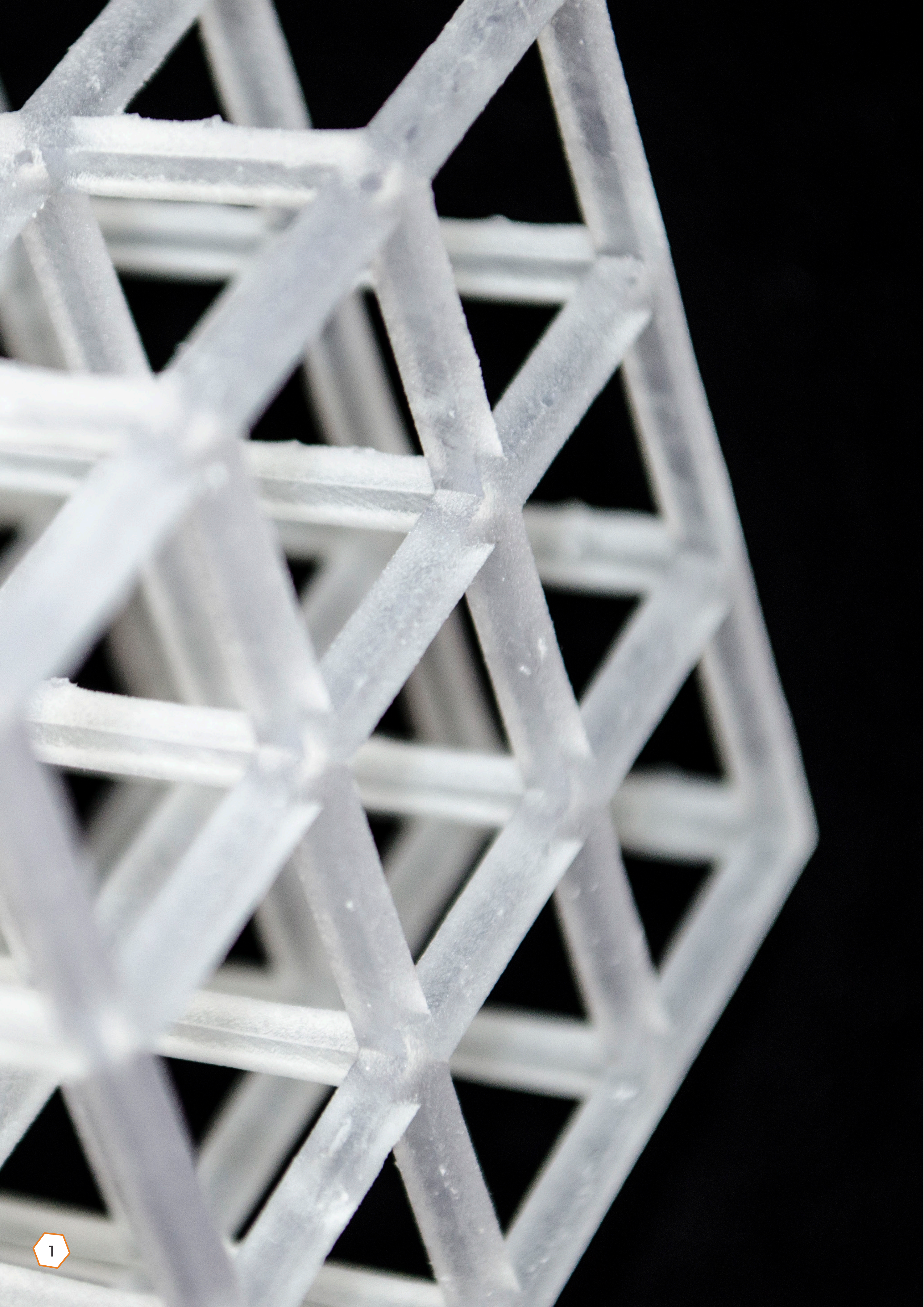
Sustainable AM
Chances and challenges for a green future

Ecological Sustainability

A working group of the Network Mobility goes Additive e.V.



AUTHORS

Dr.-Ing. Dominik Ahlers
Funding Strategy Leader
SLM Solutions

Dr.-Ing. Christian Bay
Strategic Development and Cooperations Additive Manufacturing
Campus Additive.Innovationen CA.I Bayreuth

Hans-Alfred Breuninger
Owner
Breuninger Consulting

Jan Dittmann
Project Engineer
Mobility goes Additive e.V.

Dr. Christoph Kiener
Principal Key Expert Digital Solutions for Materials
SIEMENS AG

Alexander Mahr
Senior Engineer Academic Counsellor (ret.)
Campus Additive.Innovationen CA.I Bayreuth

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung

INTRODUCTION

In an era defined by rapid technological advancements and an increasing awareness of environmental issues, the manufacturing industry stands at a pivotal crossroads. Additive Manufacturing (AM), often referred to as 3D printing, has emerged as a transformative force, offering unprecedented possibilities for innovation and production efficiency. As businesses strive for competitive advantage, there is a growing imperative to integrate ecological sustainability into the very core of additive manufacturing processes.

It is often claimed that AM is a „green“ technology in its entirety. On closer inspection, however, it quickly becomes apparent that one must differentiate more precisely. If the advantages of AM, such as design freedom and material efficiency, are properly exploited, AM can be significantly more sustainable than all traditional manufacturing technologies. However, there are also some challenges regarding ecology that have not yet been solved.

The aim of this management summary is to provide a concise yet comprehensive overview of the critical dimensions surrounding ecological sustainability in additive manufacturing, in order to facilitate a more informed debate and opinion on the topic. After giving an overview of the global AM market, this is done along the phases of the Circular Economy: Theses on sustainability are set out and explained for each phase.

Further sources and images provide approaches for more in-depth research on the topic.

We, the participating authors of MGA's Ecological Sustainability working group, hope you enjoy reading and look forward to lively debates on the topic!

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung

Overview of the global AM Market

First emerging in the 1980s, additive manufacturing has evolved greatly in recent decades, experiencing annual growth of about 20% in the years leading up to Corona. The pandemic has refocused the market to some extent.

Significance of the AM market:
The global AM market was worth approximately €12.8 billion in 2021 in the post-Corona period, according to Wohlers Associates Inc. and grew 7.5% despite Covid. This includes sales of equipment, materials and software, and services. Other sources, such as Hamburg, Germany-based AM Power, a consulting firm specializing in additive manufacturing, see the total market at about €8.3 billion, or more than 35% smaller. If you compare these market volume figures with the VW Group's investment in electromobility for the next five years (2021-2026) at €35 billion, the AM global market is smaller than 1/3 of this investment amount.

Reference to global manufacturing:
If we now put the total AM market in relation to the total global production, the AM market volume is less than 0.1%. According to Wohlers, this value may rise to a maximum of 5% in the further future.

Important fields of application for AM technology:
Especially in the energy, aerospace and medical technology sectors, AM technology has become indispensable and is of existential importance for the user industries. For example, well over 90% of the hearing aids sold worldwide are printed. In the aerospace sector, the proportion of flying components is increasing sharply. AM technology has a key function and pioneering role for the further development of important application fields and thus also for the topic of sustainability.

Despite its small market share, AM technology has an absolute pioneering role - also with an impact on other industries. This also applies to sustainability. Therefore, the present results of the Sustainability Working Group are of important significance for the entire product life cycle of the products concerned beyond the AM sector.

Hans-Alfred Breuninger
Owner
Breuninger Consulting

DESIGN

AM Design freedom enables more sustainable products and processes

One major potential of Additive Manufacturing due to the layer wise building process is the high design freedom in relation to conventional manufacturing technologies. Design freedom does specifically mean the realization of lightweight structures, complex shapes and the integration of several components into one or fewer components (monolithic manufacturing). The often-used term „complexity for free“ suggests that there are no manufacturing restrictions in AM and therefore CAD design can be used without restrictions. Yet, there are specific manufacturing restrictions in AM in relation to its specific technologies. But there are also certain production restrictions in the AM, even if they are significantly smaller in scope and severity. [3]

Bringing the design freedom of AM in context of sustainability, several benefits are imaginable and have already been proved in several use cases: In aviation, the advantage in terms of sustainability is particularly evident in the use phase of the manufactured component. Approx. 2,500 liters of kerosine can be saved with a saving of 1 kg of part weight due to lightweight engineering. [2]

That significant environment impact in aviation is also evident in the production phase. Typical buy-to-fly material ratios of 4:1 (input material to final component) are common using conventional manufacturing technologies (e.g. 5-axis milling processes), with some components having a ratio as high as 20:1. Use cases developed at the Fraunhofer ILT show that the AM technology of powder bed fusion of metals can achieve material savings of approximately 60%, along with time savings of 30%.[1 4]

However, this advantage does not simply lie on the street but has to be worked out with interdisciplinary engineering. This concerns both the design of components and the integration of process and application knowledge as specific requirements in the development process. Only when significant advantages of the design are developed, the sustainability potentials of AM can be (comprehensively) tapped. Otherwise, only minor or negative beneficial effects of AM on sustainability can be expected.

Sources:

[1] Despeisse, Ford: Additive manufacturing and sustainability: an exploratory study of the advantages and challenges (2016). https://www.sciencedirect.com/science/article/pii/S0959652616304395

[2] AMPOWER: Sustainability of Metal Additive Manufacturing (2022). https://ampower.eu/download/10833/

[3] Kumke, M. (2018). Angepasste Konstruktionsmethodik für additive Fertigungsverfahren. In: Methodisches Konstruieren von additiv gefertigten Bauteilen. AutoUni – Schriftenreihe, vol 124. Springer, Wiesbaden. https://doi.org/10.1007/978-3-658-22209-3_5

[4] unpublished use case of aerospace bracket of University of Bayreuth

Dr.-Ing. Christian Bay

Strategic Development and Cooperations Additive manufacturing

Campus Additive.Innovationen CA.I Bayreuth

Freedom of design enable more efficient use of materials and resources

Additive manufacturing has garnered significant attention for its potential to revolutionize manufacturing processes. One crucial aspect that sets it apart from traditional manufacturing methods is the freedom of design it offers. The question at hand is whether this freedom truly enables a more efficient use of materials and resources. In answering this question, it becomes evident that the freedom of design in additive manufacturing leads to a more efficient use of materials.

Unlike subtractive manufacturing, where excess material is removed, 3D printing builds objects layer by layer, ensuring that only the necessary material is used. This precision significantly reduces material wastage, a critical factor in resource optimization. On the other hand material wastage is produced by unprinted powder or wasted prints.[1]

Moreover, the customization possibilities unlocked by freedom of design play a crucial role in resource efficiency. Additive manufacturing allows designers to create products tailored to their intended purpose, eliminating unnecessary material and weight. The ability to optimize designs leads to resource-efficient outcomes across various industries, from aerospace to healthcare, and contributes to a more sustainable approach to production.

Furthermore, the integration of sustainable materials is facilitated by the flexibility of additive manufacturing. Designers can incorporate recycled or eco-friendly alternatives, reducing reliance on virgin resources and supporting the principles of a circular economy.

However, it is essential to recognize the challenges associated with additive manufacturing. Proper material recycling and waste management are crucial to ensuring a responsible and sustainable approach to its usage. A product should be designed from the beginning so that the end process of recycling is integrated into the design process. [2]

In conclusion, freedom of design in additive manufacturing undoubtedly enables a more efficient use of materials and resources. By reducing material waste, optimizing designs, and incorporating sustainable materials, 3D printing paves the way for a greener and more resource-efficient future in manufacturing. Some novel AM approaches are the opposite of recycling-friendly products, for example multi-material prints.

Sources:
1 AMPOWER: Sustainability of Metal Additive Manufacturing (2022). https://ampower.eu/download/10833/
2 Despeisse, Ford: The Role of Additive Manufacturing in Improving Resource Efficiency and Sustainability (2017). https://inria.hal.science/hal-01431086/file/346973_1_En_15_Chapter.pdf

Jan Dittmann
Project Engineer
Mobility goes Additive e.V.

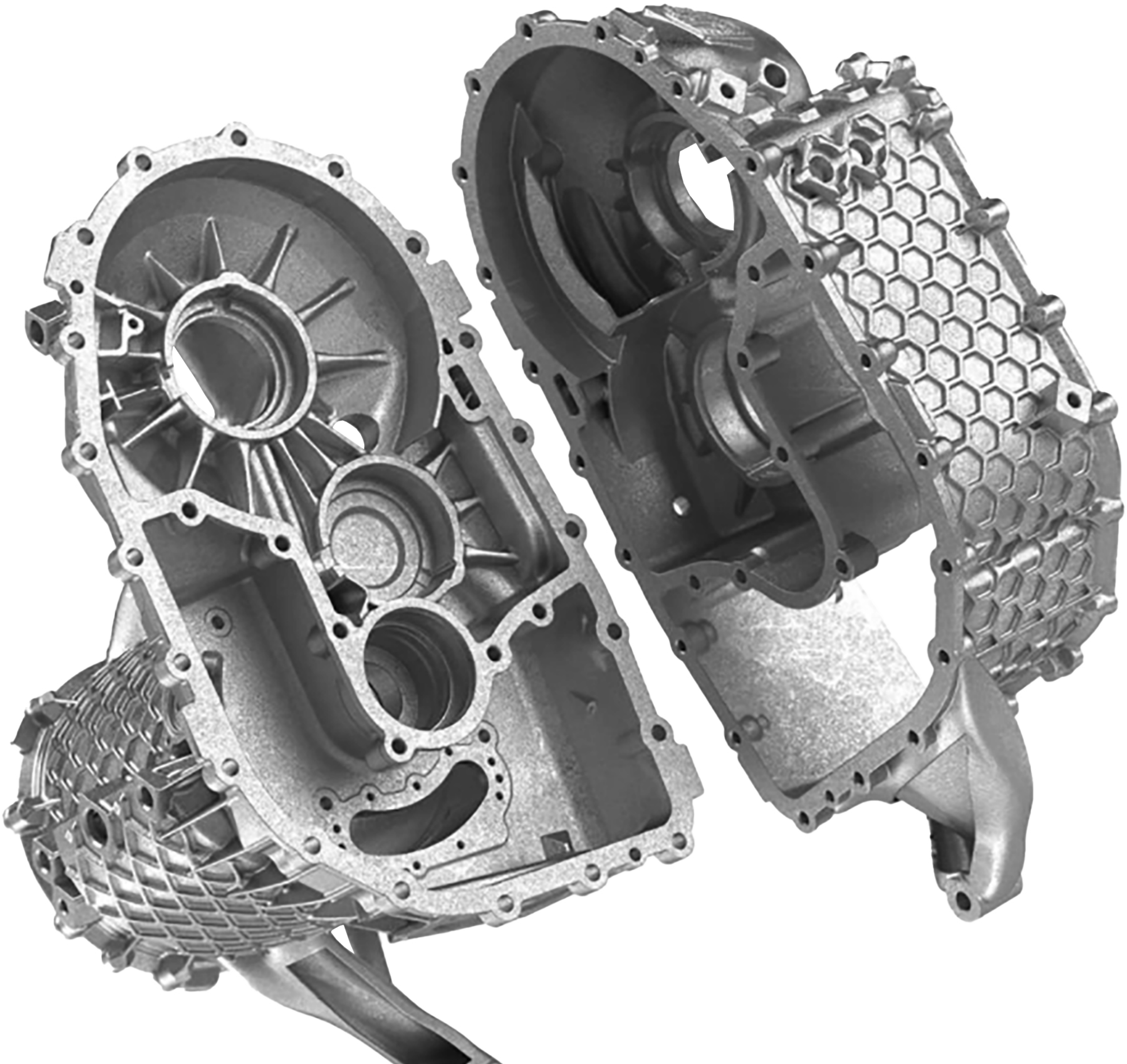
Lightweight structures made with AM help to save energy

Through 3D Printing the possibility is given to design structures with less restrictions than for conventional productions methods like casting or machining. This enables completely new approaches for lightweight components like free form design and even bionic inspired geometries. Saving weight is of enormous importance in most industries. “Every single kilo saved in all Lufthansa aircraft saves over 31,000 liters of jet fuel per year”.[1] The efficient use of materials and the resulting very good buy-to-fly ratio naturally also reduce the CO2 emissions of the manufactured component during the product‘s life cycle. And for this reason, the effort made is important to support the sustainability goals in the world.

One example, where many advantages of additive manufacturing have been implemented, is the e-drive housing from Porsche: From Topology optimization with lattice structures in order to reduce the weight, to functional integration of cooling channels. Furthermore, higher stiffness and reduced assembly time by the integration of parts and improvements in part quality are achieved.
A Pump Impeller produced with additive manufacturing L-PBF technology lead to a weight reduction of 70%, while lead time was reduced from 20 weeks to 4 weeks, thereby lowering inventory capital and costs.
In summary, AM has the potential to provide sustainability on many levels, be it less weight, better properties, or even less stockpiling of products and tools and therefore will help to save energy.

Sources:
[1] Braun: Wie kann die Luftfahrt umweltfreundlicher werden? (2018). https://www.airliners.de/wie-luftfahrt-antworten-cockpit-12/36398

Dr.-Ing. Dominik Ahlers
Funding Strategy Leader
SLM Solutions



PRODUCTION

AM enables toolless production for a sustainable impact

One major potential of Additive Manufacturing is the manufacturing without any tools due to the digital process chain. In contrast to conventional manufacturing technologies like injection molding, that parts can be directly manufactured layer wise without any tools for bringing the material in shape using AM. That benefit in economical and ecological perspective is particulary relevant for small to medium part quantities and lots.
AM makes production on demand possible: Needed parts especially at the beginning (prototyping) or the end (spare part production) of the typical product life cycle can be manufacturing without any tools in the specifically temporally needed lot size. That means in obsolescence management that serial parts have not to be manufactured with over production capabilities and for stock. Especially so-called slow movers where the need of small lot sized spare parts are hard to predict can be manufactured in small lots where and when they are needed: "just-in-time". With that production on demand, it is therefore possible to reduce both revision times and the storage capacities previously required, as well as the associated logistics costs for obsolescence management. [1]

AM technologies are not per se simpler or easier to handle with. But there are technologies that can be used to lower technological and business model-related barriers due to tool-less and digital manufacturing, i.e., material extrusion with polymers. This means integrating consumers directly into the product development and manufacturing process, speeding it up and ensuring that a newly developed product delivers the intended customer benefits before it is mass-produced, creating significant capital lockup and environmental impacts. [2]

Sources:
[1] Anderhofstadt, Disselkamp: Disruptiver 3D-Druck. Neue Geschäftsmodelle und Wertschöpfungsketten. Carl-Hanser-Verlag München, ISBN 978-3-446-47020-0
[2] Bay, Baum: Innovative Geschäftsmodelle durch additive Fertigung und ihre Potentiale für den Vertrieb. In: L. Binckebanck et al. (Hrsg.), Digitalisierung im Vertrieb, Edition Sales Excellence, DOI 978-3-658-38433-3_23

Dr.-Ing. Christian Bay
Strategic Development and Cooperations Additive manufacturing
Campus Additive.Innovationen CA.I Bayreuth

Material efficiency in AM: AM processes only use the material which becomes the part

In the production of complex components by means of machining, machining rates of up to 95 % are common.[1] As a result, only a small amount of the base material is used in the product to be manufactured. In contrast, AM processes have a high potential to produce complex components with high material efficiency because material is only added where it is actually needed. Nevertheless, AM processes typically result in material losses due to process and handling-related reasons.

One reason that lowers material efficiency in AM is the need for support structures. These can be caused either mechanically (in AM processes without a self-supporting function of the geometry, such as material extrusion) or thermally (in AM processes with high temperature gradients, such as powder bed fusion of metals).

In addition, powder bed-based AM processes require significantly more base material compared to the mass of the component to be manufactured, since the entire build volume has to be covered with powder.

The powder, which is not used for the manufactured product, can be affected by the thermal load during the manufacturing process. Typically, most of the powder can be recycled and reused several times if the powder requirements are respected. Nevertheless, losses in the handling of the powder lead to a reduced material efficiency. E.g., powder contained in cavities of the manufactured component or between support structures after the manufacturing process is often removed during post-processing of the component and is not reintroduced into the powder cycle. Furthermore, material efficiency can be reduced by entraining powder into filters through the gas flow. Figure Y shows an example of the average material efficiency in the multiple production of a gear wheel by powder bed fusion of metals. The gear wheel was produced by different employees, different materials and on different machines in order to minimize their influence.

Sources:

[1] Volkwein: Konzept zur effizienten Bereitstellung von Steuerungsfunktionalität für die NC-Simulation. Herbert Utz Verlag München (2007). ISBN 978-3-8316-0668-9

Further Sources:

Lutter-Günther, Hofmann, Hauck, Seidel, Reinhart: Quantifying Powder Losses and Analyzing Powder Conditions in order to Determine Material Efficiency in Laser Beam Melting (2016). https://www.scientific.net/AMM.856.231

Alexander Mahr

Senior Engineer Academic Counsellor (ret.)

Campus Additive.Innovationen CA.I Bayreuth

DISTRIBUTION

AM allows for localized production and optimized supply chains

Today, highly complex, global supply chains are the norm even for simple products. These cost-driven chains not only cause high emissions due to many transport routes, but are also more fragile the more complex they become. In an age of global crises such as pandemics, climate change, and constantly evolving conflicts, problems with supply chains have become commonplace. Even small disruptions can have a big impact and bring entire production lines to a standstill.

Additive manufacturing can bring an answer to these problems: With AM machines located at the point of use, it is possible to produce decentralised and locally.
The result is that you save on building land and real estate, and don‘t have dead capital stored in warehouses for years. Because the components are available as a digital data model, they can be sent around the world in seconds and with minimal emissions. This also enables significantly faster iteration cycles in product development.

Further Sources:

Verboeket et al.: Additive Manufacturing for Localized Medical Parts Production: A Case Study (2021). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8545237/

Calignano, Mercurio: An overview of the impact of additive manufacturing on supply chain, reshoring, and sustainability (2023). https://www.sciencedirect.com/science/article/pii/S2772390923000124

AMFG.ai: Why Should Companies Embrace Distributed Additive Manufacturing? (2021).

https://amfg.ai/2021/03/15/why-should-companies-embrace-distributed-additive-manufacturing/

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung

USE

AM can extend the lifetime of existing products

In particular, high-investment assets such as large machines, vehicles, and aircraft often have a long service life. With increasing age, the availability of critical spare parts becomes more and more difficult, as contracts with component suppliers gradually expire and purchased parts are discontinued piece by piece by the supplier. Especially for drawing parts that are not regularly available on the market, availability quickly becomes difficult due to part consumptions that are difficult to plan. Maintenance managers are constantly confronted with the conflicting goals of high spare parts availability and low inventory costs. Overstocking of spare parts often results in valuable resources being scrapped at the end of the product life cycle. It is not uncommon for functional assets to be taken out of service and scrapped because difficult, conventional spare parts procurement makes continued operation uneconomical.

Additive manufacturing can ensure that special spare parts in particular, which in maintenance context are only required in small quantities and cannot be procured conventionally, can be procured again economically. This ensures that the maintenance of long-lived assets can be operated economically for longer, which ensures longer use of the tied-up resources and delays a new acquisition. Thus, not only can resource consumption be reduced, but significant cost savings can also be achieved.

Further Sources:
Despeisse, Ford: Additive manufacturing and sustainability: an exploratory study of the advantages and challenges (2016).
https://www.sciencedirect.com/science/article/pii/S0959652616304395
Despeisse, Ford: Extending product life through additive manufacturing: The sustainability implications (2015).
https://www.researchgate.net/publication/282075975_Extending_product_life_through_additive_manufacturing_The_sustainability_implication

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung


ICE
NEUERO
25t

Limone
Lemon - Citron
ICE TEA

Decentralized recycling enables lower carbon footprints in AM

The vision of resource-efficient manufacturing at batch size one is often claimed as an outstanding property of AM. Fused Filament Fabrication, as one of the most used AM technologies, satisfies this statement only in a restricted sense, through simple handling for non-experts and low-cost materials and machines. Next to performance-driven and process-influencing attributes, the question of a general ecological improvement through thermo-mechanical recycling rises.

Assessments from academia and research show a tendency of the environmental potential of recycling in consideration of extrusion-based production applications regarding human health, ecosystems and resources. This potential can mainly be exploited if the recycling process is executed at industrial scale.

The industrial recycling demonstrated the sensitivity in energy and waste aspects for the investigated pre- and post-processes. Otherwise, sorting and collecting as well as transportation and distribution process of the virgin material are considered sensitive.

Moreover, the rather low inhibition threshold of decentralized recycling regarding costs, technologies and qualification leads to an easy access and wider distribution of shredding, granulating and re-extrusion of filament for material extrusion technologies.
This makes it financially and ecologically affordable for industrial and home users as well to have decentralized and on-site management of failure and damaged parts as well as components that are no longer in use.

Further Sources:
Bay, Nagengast, Neuber, Döpper, Schmidt: Environmental assessment of recycled petroleum and bio based additively manufactured parts via LCA (2022): in Lecture Notes in Mechanical Engineering, ISBN 978-3-031-28838-8

Dr.-Ing. Christian Bay
Strategic Development and Cooperations Additive manufacturing
Campus Additive.Innovationen CA.I Bayreuth

RECYCLING

AM can be key enabler for circular economy (Cradle to cradle)

As the world grapples with escalating environmental concerns and dwindling resources, the concept of the circular economy has gained significant traction. A circular economy aims to minimize waste, reduce resource consumption, and promote sustainability by keeping products, materials, and resources in use for as long as possible. In this context, additive manufacturing has emerged as a transformative technology that holds the potential to revolutionize how we approach production and consumption. By enabling localized, on-demand manufacturing and promoting resource efficiency, additive manufacturing is poised to play a pivotal role in advancing the circular economy.

The linear economic model, characterized by a „take, make, dispose“ approach, has long been associated with negative environmental consequences, including excessive waste generation and resource depletion.

The circular economy seeks to break this cycle by prioritizing the following principles:

1. Design for Durability and Reusability:
Products are designed with longevity in mind, using high-quality materials and components that can be easily repaired, upgraded, or disassembled for reuse.

2. Reduce, Recycle, and Recover:
Resources are conserved through recycling and recovering materials from used products, reducing the need for virgin resources and minimizing waste.

3. Local Production and Consumption:
Goods are produced closer to the point of consumption, reducing transportation-related emissions and minimizing the environmental impact of global supply chains.

Unlike traditional manufacturing methods, which often involve subtractive processes that generate significant waste, AM is inherently more efficient and environmentally friendly.
Here‘s how additive manufacturing aligns with the principles of the circular economy:

Optimization for Sustainability in the Design phase:
AM enables intricate and complex designs that were previously impossible using traditional manufacturing techniques. This allows engineers and designers to create products with improved performance, durability, and resource efficiency. Furthermore, AM uses only the material required to create a product, minimizing waste. Traditional manufacturing often generates excess material during the production process, which can result in substantial resource wastage.

On-Demand Production and Customization:
AM allows for localized, on-demand production. This means that products can be manufactured when and where they are needed, reducing the need for large-scale production, warehousing, and long-distance transportation. Customization becomes more feasible, enabling consumers to obtain products tailored to their specific needs.

Repair and Upcycling:
AM can facilitate easy repairs by producing replacement parts with precision. This extends the lifespan of products and reduces the need for complete replacements. Moreover, discarded products can be upcycled by breaking them down into their constituent parts and using those materials to create new items.

Material Recycling:
Some AM processes allow for the use of recycled or biodegradable materials, further reducing the environmental impact of production. This aligns with the circular economy‘s emphasis on resource recovery and recycling.

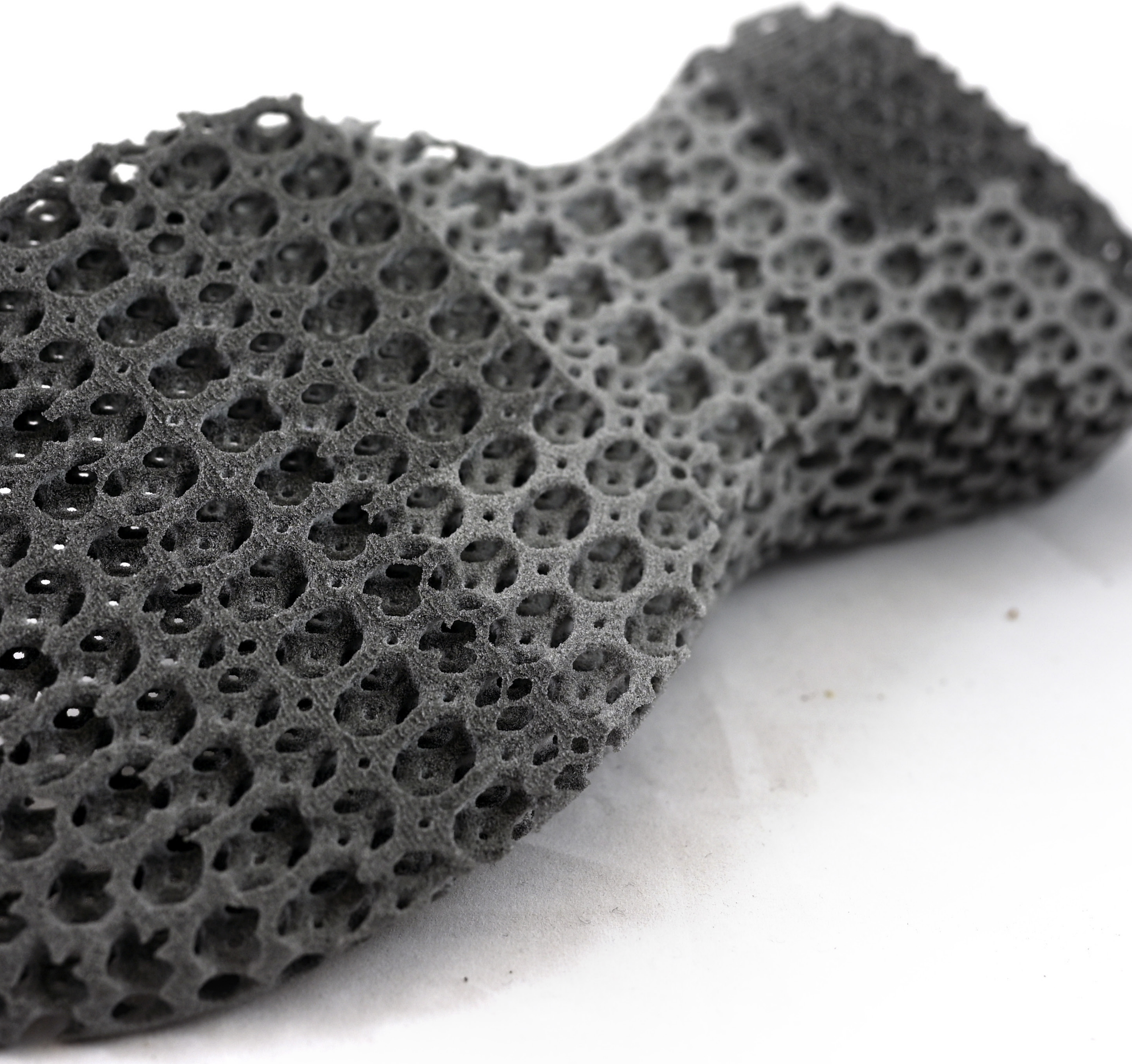
Further Sources:
Tavares, Ganga, Filho, Rodrigues: The benefits and barriers of additive manufacturing for circular economy: A framework proposal (2023).
https://www.sciencedirect.com/science/article/abs/pii/S2352550923000507

Hedrixson: Additive Manufacturing Will Aid and Accelerate the Circular Economy (2023).
https://www.additivemanufacturing.media/additive-manufacturing-will-aid-and-accelerate-the-circular-economy/

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung

RECYCLING

Multi-functional mono-material: AM and software-defined digital commands create functionality with less eco-footprint



In a bionic approach, engineers get inspired by such concepts and do the same – using digital commands and spatially adjusted treatment of a basic material to generate multiple 3D-resolved functionality: digitalization generates multi-functionality from mono-material. Multi-functionality addresses sustainability, resource and climate protection threefold:

1. recycling capability:
„multi-function with mono-material“ – each monolithic component contains one type of pure material – preferred for recycling in closed material flow loops.

2. more environmentally friendly materials:
Function arises primarily from geometric structure, while the material chemistry becomes secondary: Chemical elements with high eco-footprint can be avoided.

3. efficiency and performance in application:
reduction of energy and CO_2 emissions in operation through improved energy efficiency during operations.

AM enables local multi-functionalities in polymer part properties like density, hardness or young’s modules via functional gradation. Starting from a material, it can be implemented in part manufacturing by means of its process-side structuring (structural gradient). The porosity can be adjusted locally or the material properties can be changed by means of a targeted energy input. Based on at least two different materials, the adjustment can be made by a smooth material gradient or by varying the different materials in relation to each other (ratio gradient). In this way, the internal structure of the part can be optimized to meet specific requirements, irrespective of its external structure or basic shape. The AM technology “High Speed Sintering (HSS)” offers particularly great potential for the production of functionally graded components from a mono material through the targeted variation of process parameters.[1]
In metals parts, for instance in PBF-LB/M, the simultaneous control of the mechanic and laser-based machine parameter at the 3D-printer (e. g. metal powder layer thickness, laser speed / position / power / wobbling / pulsation, flollow-up of molen areas) are a mighty tool: Metal solidification and, hence, crystallite structures can be influenced, leading to increased yield strength or smoother surface properties. Additionally, defined pore network structures can be generated at specific locations. This enables applications as efficient cooling, clean combustion, acoustic absorbance or particle filtering. Often, for instance in cooling, the improved functionality allows to use less heat resistant materials, which often have a severe eco-footprint in ore mining and metal refining. So, intelligent design with multi-hierarchic enables better functionality with resource protection in manufacturing and operations.

Sources:
[1] Kemnitzer, Tarasova, Pezold, Daniel: Fertigung funktional gradierter Bauteile im High Speed Sintering. In: Maschinenbau. 1 (2021). ISSN 2730-9843

Dr. Christoph Kiener
Principal Key Expert Digital Solutions for Materials
SIEMENS AG

Dr.-Ing. Christian Bay
Strategic Development and Cooperations Additive manufacturing
Campus Additive.Innovationen CA.I Bayreuth

RECYCLING

Use of AM can extend product lifetimes by repair and remanufacturing

AM can be applied in different stages of the product life cycle. After the End of Life (EoL), AM offers in the after sales service the ability to distribute especially sporadic spare parts with high complexity. Sporadic spare parts have to be manufactured conventionally with great effort for holding and using production facilities and technologies duntil End of Delivery Obligation (EoDO).

That radical shift from serial overproduction and physical ware housing to digital warehousing leads to lower costs for storing and logistic and higher resource efficiency. That shift can be extended by outsourcing the obsolescence management and after sales services to specialized companies, which use AM for demand-driven spare part production.

Using AM for rapid manufacturing of spare parts also leads to new possibilities regarding refurbishment and industrial remanufacturing. Instead of replacing a complete assembly due to one single damaged part, the assembly can be remanufactured using AM for spare part production of that single demanded part. That leads to longer lifetime of the assembly and more remanufactured same-as-new parts.

Moreover, shuttered, worn and demanded components of assemblies, products and product areas can be repaired layer-by-layer using AM technologies. That extends the lifetime of the assembly or product and reduces resource consumption.

Further Sources:

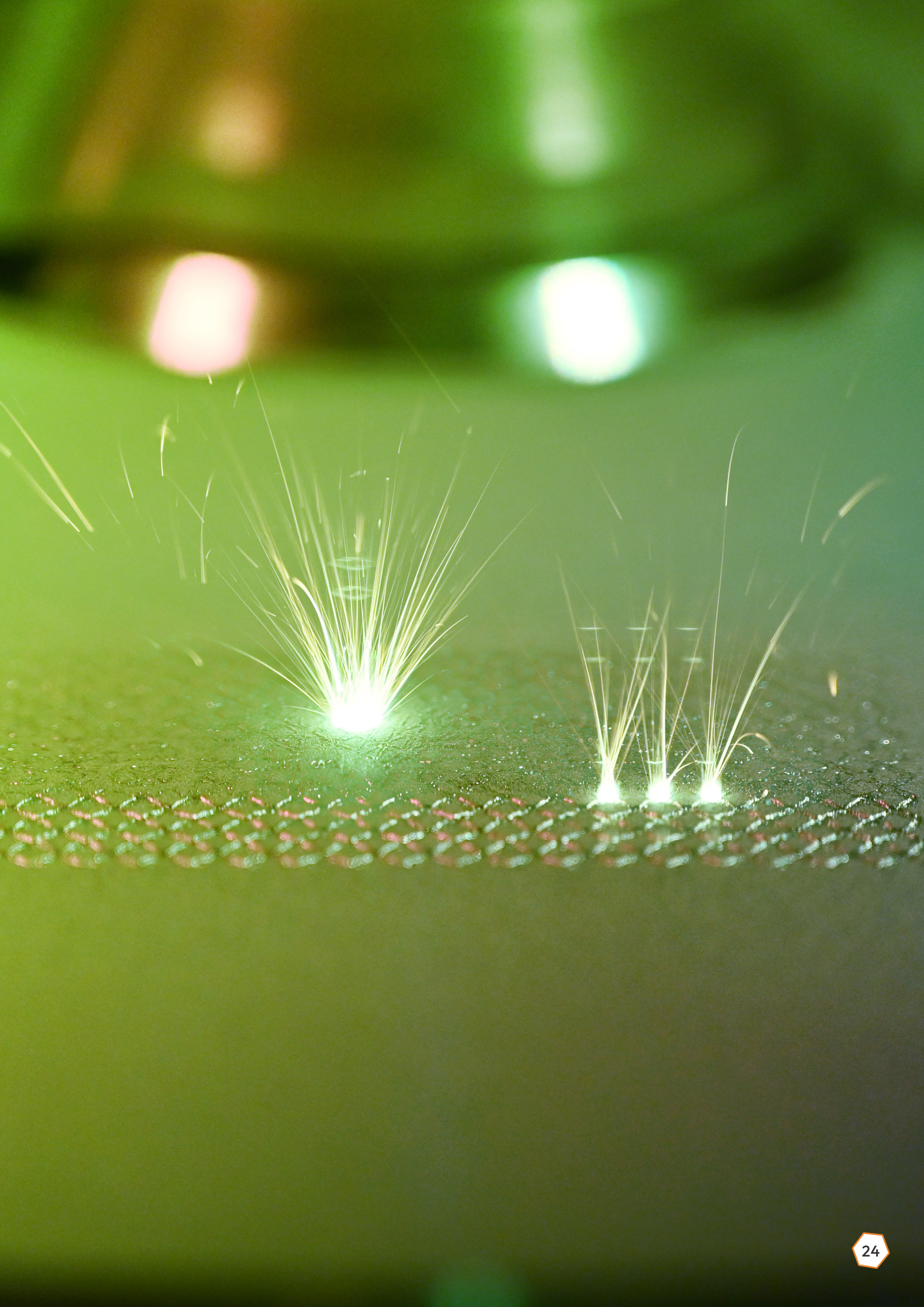
Bay, Baum: Innovative Geschäftsmodelle durch additive Fertigung und ihre Potenziale für den Vertrieb (2023). ISBN 978-3-658-38432-6

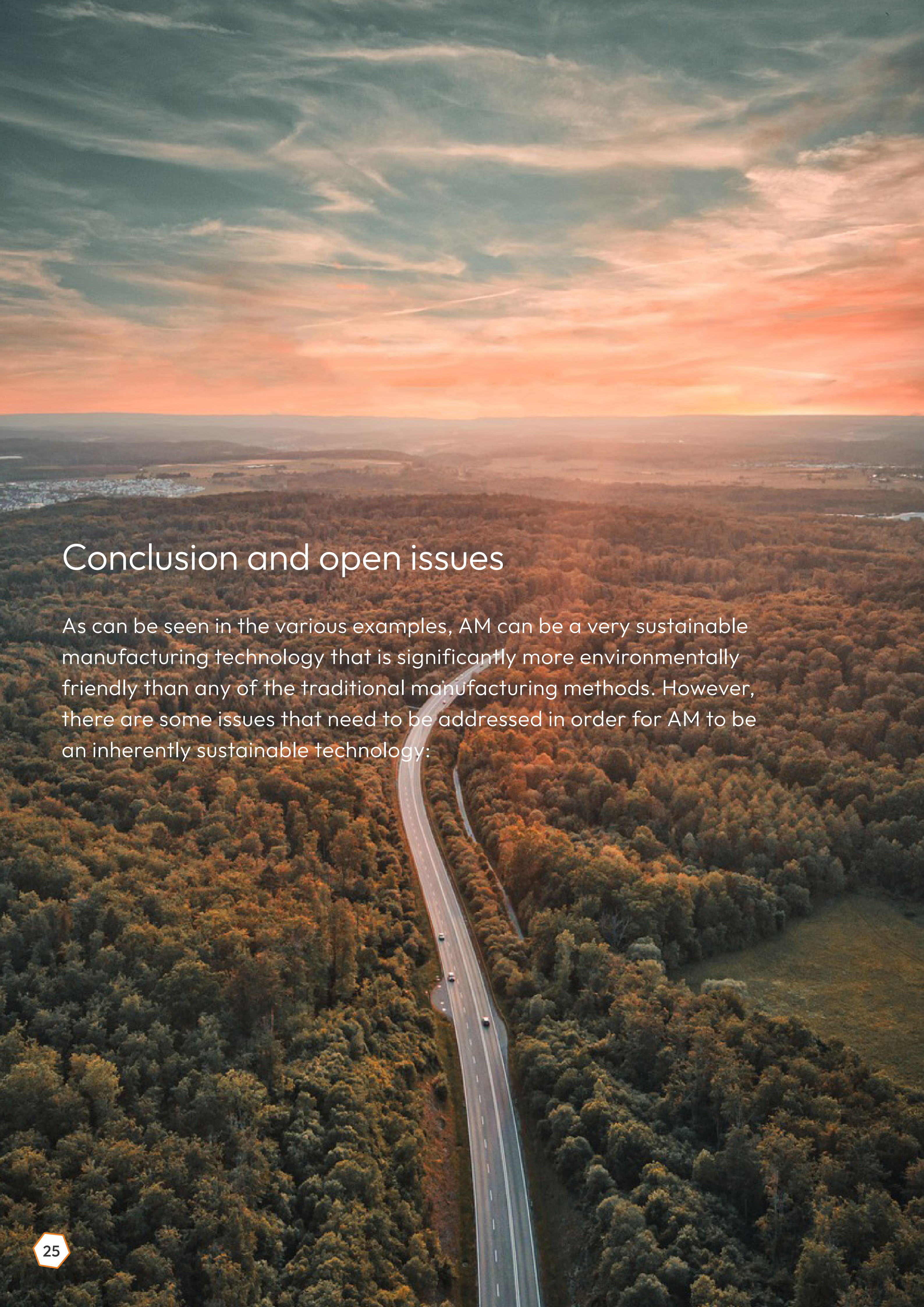
Bluhm: Replique und Miele starten Partnerschaft für exklusiv 3D-gedruckte Zubehörteile (2021). https://replique.io/de/2021/06/21/replique-und-miele-starten-partnerschaft-fur-exklusiv-3d-gedruckte-zubehorteile/;

Dr.-Ing. Christian Bay

Strategic Development and Cooperations Additive manufacturing

Campus Additive.Innovationen CA.I Bayreuth





Conclusion and open issues

As can be seen in the various examples, AM can be a very sustainable manufacturing technology that is significantly more environmentally friendly than any of the traditional manufacturing methods. However, there are some issues that need to be addressed in order for AM to be an inherently sustainable technology:

1. Recycling: unfortunately, many AM materials cannot be recycled. This is especially true of thermosets and duromers, such as photopolymers for SLA. These cannot be re-liquefied after curing, leaving only thermal recycling or landfill as options at the end of life. The often-hyped multi-material prints are also difficult to separate, making recycling challenging to impossible. But even if materials can be recycled and even recycled materials are available as AM materials, in practice they are almost never used because there is a higher trust in virgin materials and no financial incentive to use recycled materials. Furthermore, there are also requirement profiles that presuppose a high level of safety. Today, recycled materials do not yet offer this safety, or the effort required to produce them relativizes the cost-benefit factor.

2. Refresh rate: a frequent requirement of customers, standards and also from material manufacturers is to use the potentially reusable material in powder bed processes only for a limited number of cycles. Some polymer powders must be disposed of after each cycle (100% reresh rate). Similarly, some industries require that their components be manufactured only with 100% virgin powder. This leads to large amounts of waste and has a very negative impact on the sustainability of the manufacturing processes.

3. EHS issues: Many AM materials pose numerous EHS risks. The metal powders used in L-PBF and other processes are often so fine that they are respirable, so they should only be processed under heavy occupational health and safety equipment. If ignored, there is a risk of serious damage to health, including cancer. Many photopolymers are toxic, so protective equipment is also essential here. Direct skin contact can lead to severe skin irritation, and long-term disregard for occupational safety can result in serious illness.

4. Energy content: The production of many AM materials, above all metal powders, requires a high energy input. Typically, metal powders must be melted several times (alloy production, powder atomization, building process) to obtain the final component. This results in a high carbon footprint, of the final component, which is often higher than the footprint of cast components. However, material savings via topology optimization or lattice structures can make the CO2 footprint of metal AM components competitive. In addition, a large part of the energy content is electrical energy, so renewable energy with a low carbon footprint can be used for this purpose. However, this is still rarely used in practice.

5. Build volume utilization: for many AM processes, the installation space utilization of the machine is a critical factor for the sustainability balance of the components. The higher the degree of build volume, the lower the CO2 footprint per component. However, for various reasons, e.g. time pressure, the installation space of AM machines is not optimally utilized.

6. Small overall market size: As shown in the market overview at the beginning of this report, additive manufacturing is only a small share of total global production. It is also not expected that additive manufacturing will replace large parts of traditional manufacturing methods in the future, as these are significantly more economical in mass production. The impact in sustainability that can be achieved by additive manufacturing is also correspondingly limited.
The AM industry can still improve on many of these points if it becomes aware of them and appropriate incentives are in place. However, also in the spirit of honest debate, everyone needs to be aware that AM, like all other manufacturing processes, has its strengths and weaknesses and AM is not a miracle cure for all sustainability problems. Nevertheless, AM has the potential to leave a significant impact if the technology is used to it's full potential.

Helge Schneevogt
Technology Manager AM & Application Engineer Additive Manufacturing
DB Fahrzeuginstandhaltung

Sustainable AM
Chances and challenges for a green future

Photo credits

Cover	Dr.-Ing. Christian Bay
Page 1	Dr.-Ing. Christian Bay
Page 8	SLM Solutions
Page 9	Freepik
Page 12	Dr.-Ing. Christian Bay
Page 13	Deutsche Bahn
Page 16	Deutsche Bahn
Page 17	Pixabay
Page 21	Dr.-Ing. Christian Bay
Page 24	Dr.-Ing. Christian Bay
Page 25	Pixabay

Ecological Sustainability

A working group of the Network Mobility goes Additive e.V.

Imprint:
Mobility goes Additive e.V. | Im Marienpark 22 | Berlin, Germany
info@mga-net.com | +49 (0)30 757 66 111