

Whitepaper



By

Syed Nameer, EOS Senior AM Consultant

Michael Wohlfart, EOS Senior AM Consultant

Arve Kallum, KSHP Chairman

Lars Kallum, KSHP Chief Engineer

Adam Hiller, SIEMENS Digital Industries Software AM Consultant

Benedikt Altmann, SIEMENS Digital Industries Software PreSales Solution Consultant

Heat Exchangers Reimagined

A Seamless Digital AM Journey towards Efficiency and Sustainability

This Whitepaper gives answers to:

Why AM enables production of more efficient applications

What are the steps to unlock the full AM potential

How digital solutions enable reduced production costs in AM

Content

Introduction	3
Introduction to Contributing Companies	5
Part Screening & Selection	7
Initial Design with CPP (Cost per Part)	10
Redesign with Siemens NX and Process Optimization Using Smart Fusion	11
Production Optimization	19
Cost per part (CPP) Overview	23
Outlook	25
Summary	28

List of Figures

Figure 1	Additive Minds Journey	5
Figure 2	Part screening framework for the KSHP Part describing all technical and economic criteria	8
Figure 3	Eco-Tech matrix for KSHP heat exchanger	9
Figure 4	AM cost distribution of first heat exchanger design	10
Figure 5	Analysis and cleaning of the design with Siemens NX	12
Figure 6	Comparison of surface quality before and after adding true faces	12
Figure 7	Working principle of Smart Fusion	13
Figure 8	Heat exchanger with standard support strategy	14
Figure 9	Heat exchanger with low angle support strategy that is enabled by Smart Fusion	15
Figure 10	EOSPRINT integration in Siemens NX	15
Figure 11	EOS M 290 production setup. Tecnomatix simulation for one system	22
Figure 12	EOS M 300-4 production setup. Tecnomatix simulation for one system	22
Figure 13	Four scenarios for Tecnomatix simulations	23
Figure 14	Overall cost comparison between different scenarios	23
Figure 15	Detailed cost structure of different scenarios	24
Figure 16	Carbon emissions (CO ₂ e) with respect to the baseline i.e., valued at 100%	26
Figure 17	Advanced heat exchanger design with light-weighting approach	27
Figure 18	Advanced heat exchanger design with internal TPMS structures	27

List of Tables

Table 1	Different optimization scenarios for the heat exchanger simulated on the EOS M 300-4	18
Table 2	Tecnomatix output for baseline and scenario 3	21

Introduction

Laser powder bed fusion (LPBF) is an additive manufacturing (AM) technology used to create three-dimensional objects by fusing layers of powdered material using a laser. The process begins with a bed of metal powder, which is spread evenly over a build platform. A high-powered laser then scans the surface of the powder, selectively melting and fusing it together in a precise pattern. This process is repeated layer by layer, with each new layer being added on top of the previous one, until the final object is complete.

LPBF offers several advantages over traditional manufacturing methods. It allows for the creation of complex geometries with higher efficiency that would be difficult or impossible to produce with traditional machining methods. It also enables the production of small batches or even one-off parts without the need for expensive tooling. Heat exchangers are a perfect example for applications that can leverage the mentioned advantages through AM.

This whitepaper presents a comprehensive view of the entire AM customer journey, spanning from part identification and application development to production optimization, all with the overarch-

ing goals of cost reduction and enhanced manufacturability. The focal point of this exploration is a heat exchanger integral to a heat pump developed by Kallum Sustainable Heat and Power (KSHP). Design and production optimization for the heat exchanger has been carried by a seamless digital workflow, powered by Siemens Digital Industries Software solutions. Smart Fusion, a technology to reduce the need for support structures and the experience of EOS Additive Minds consultants supported the customer in tailoring the LPBF process parameters to fit the application requirements, eliminating unnecessary process inefficiencies. The whitepaper also signifies and highlights the importance of process parameters that can substantially allow cost reduction even with limited or no design changes.

By adhering to these specific stages of an AM development cycle, you'll discover how the integration of digital tools not only enhances the manufacturability of complex applications but also substantially lowers the cost per part, establishing a feasible foundation for serial production.

Redefining Efficiency of Heat Pumps

Conventional heat pump technology is based on boiling and condensation of a working fluid. This concept is, however, limited by the critical temperature of potential working fluids. Above the critical temperature the working fluid will not condense. Therefore, the maximum achievable temperature is typically lower than the required temperature for industrial process heat.

Several companies and research institutions have explored various heat pump technologies which can deliver sufficiently high temperature to facilitate re-use of some of the large waste heat resources. So far this has been met with limited commercial success. This is partly due to the high cost of machines that have had relevant technical performance.

The KSHP heat pump uses a Stirling process with air as working fluid. This process uses a cyclical compression and expansion of the working fluid. There are heat exchangers for uptake of low temperature heat and rejection of high temperature heat from the working fluid. To achieve an efficient process, the heat exchangers need to create a minimal friction loss during operation. At the same time the coefficient of heat transfer needs to be high in the hot and cold heat exchangers. The heat exchangers should also have limited volume, since the heat exchanger volume is a dead space which reduces the compression ratio of the process.

Several production methods were considered for the heat exchangers. To keep the cost of the heat pump system at a competitive level it was decided to use

diesel engine parts and 3D printed heat exchangers. As the heat exchangers would need to be carefully optimized with regards to internal volume, flow resistance, heat transfer and strength we assumed that more than one design iteration could be necessary. This further strengthened our conclusion about AM being the right technology for the heat exchanger production.

The production of the heat exchangers was initially contracted to a Norwegian company. The company did several attempts to produce the heat exchanger, however they had to give up due to the high complexity of the heat exchangers. Fortunately, they had previously cooperated with EOS and could establish the contact. The heat exchanger design was subsequently optimized for printing in cooperation with the EOS Additive Minds team and a first prototype was successfully printed.

Heat treatment and machining of the first prototypes has been done in Norway. The heat exchangers were then installed on the heat pump. First trials demonstrated that high temperature is achievable and that the production methods are suitable. However, further iterations are required to comply with the results of the CFD analysis. Starting with the results of the first prototype the whitepaper leads through different iterations of the application.

Introduction to Contributing Companies

KSHP

Norwegian company Kallum Sustainable Heat and Power (KSHP) was established in 2019. The purpose of the company is to develop a high temperature heat pump for recycling of industrial waste heat. Presently the European industry loses 292 TWh annually. This represents a direct value of about 29 billion USD. A substantial part of this heat can be re used as process heat, provided that a cost-efficient heat pump can be provided.

EOS

EOS provides responsible manufacturing solutions via industrial 3D printing technology to manufacturers around the world. Connecting high quality production efficiency with its pioneering innovation and sustainable practices, the independent company formed in 1989 will shape the future of manufacturing.

Powered by its platform-driven digital value network of machines and a holistic portfolio of services, materials and processes, EOS is deeply committed to fulfilling its customers' needs and acting responsibly for our planet.

Along with products around systems and materials, EOS also supports its customers through its consulting arm, Additive Minds. Additive Minds advice customers along their AM journey to ensure successful implementation of the technology. Through training and collaborative projects, Additive Minds enables customers to leverage the full potential of AM.

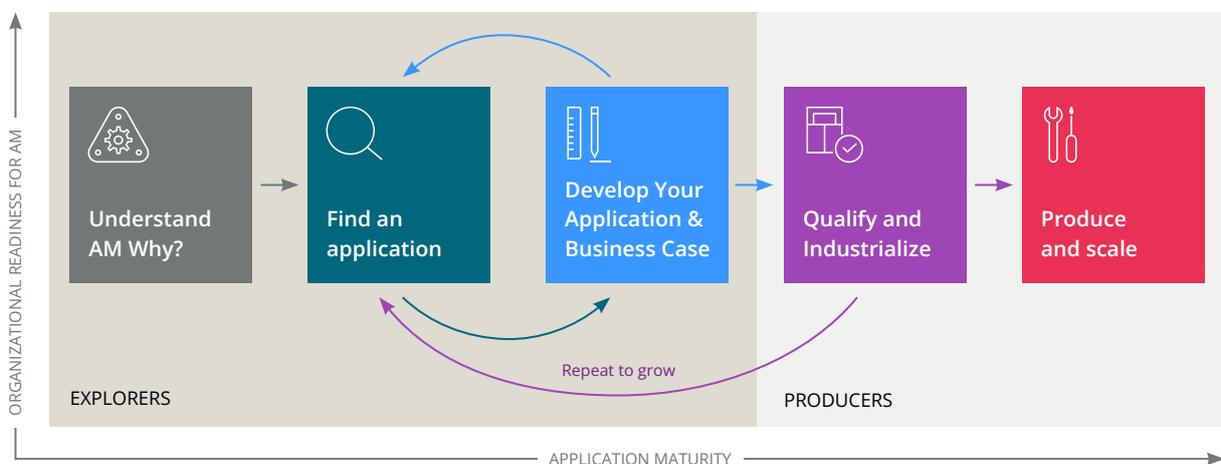


Figure 1. Additive Minds Journey

Siemens

Siemens Digital Industries Software was founded in 2007 as Siemens PLM Software, a business unit of Siemens AG and became a separate legal entity in 2019.

Today, Siemens Digital Industries Software has over 24,000 employees worldwide. The headquarter is in Plano, Texas, USA, and offices and facilities are operated in over 40 countries, serving customers in more than 140 countries.

Siemens Digital Industries Software serves a wide range of industries, including aerospace and defense, automotive, electronics, energy and utilities, and medical devices.

Siemens Digital Industries Software helps customers to unlock the full potential of additive manufacturing and realize the benefits of this emerging technology.



Part Screening & Selection

KSHP was introduced to EOS via a Norwegian company and Innovation Norway. Innovation Norway has been helping Norwegian based customers understand AM and take their first steps in the technology. The case at discussion corresponds to a heat pump that was discussed during the application identification phase of the program (see vertical 2 in figure 1).

Additive Minds has developed a part screening and selection methodology that uses a combination of technical and economic criteria to assess the suitability of applications. The technical criteria of the methodology focus on size, material, and quality. The screening is done to ensure whether the size of the application is feasible to print, thereby acting as a first screening indicator. This is followed by evaluating if AM materials are available that fulfill the application requirements. Lastly, linked to material selection are the quality requirements. Quality requirements can include surface roughness, mechanical properties, and dimensional accuracy but also other properties like chemical resistivity. The

KSHP heat exchanger fits EOS's portfolio machines, and the material properties of 316L fulfill all mechanical, thermal, and chemical requirements. However, room for improvement was highlighted in the screening process with points such as the depowdering strategy and support structure strategy.

Under the economic dimension, the methodology looks at cost per part, complexity, and value add. Complexity can refer to both manufacturing complexity and geometric complexity. The heat exchanger case from KSHP had an apparent geometric complexity as the design proposed was unsuitable to be manufactured conventionally. The cost-per-part targets for KSHP were slightly exceeded, but that is where redesign and process optimization come into play. The value adds can be multifold such as lead time to market, digital inventory, distributed manufacturing, customization, or sustainability. For KSHP, the value add was clear, and it was a quicker R&D cycle considering the stage they were in as a company and in the product's lifecycle.

Part



Technical Fit

Size	Material	Quality
175x289x154mm	Conv Mat: SS316L	Hot Air/Exhaust Gas flow > Around cooling water/liquid
V: 1231.2cm ³	AM Mat: AlSi10Mg/ SS316L	Corrosion Resistant
Suited for EOS M 400-4 but can be attempted at M290		Temp. Requirements: ~300 degrees below 400 °C
		Min Diameter: ~1mm
		Depowdering difficult
		Hardness and Mechanical Requirements ~ Not too Important
		Tolerances: ~ AM can go upto 0.04mm - 0.06mm

Economic Fit

Complexity	Cost	AM Value Add
AM part > To be printed in AM	Target Costs ~ None at the moment	Surface Roughness > Good for AM > Higher conductivity
2 parts for prototype > Once Benchmark approves > Redesigned	AM Cost: AlSi10Mg ~ 4500 Eur	Redesign
	AM Cost. SS316L ~6800 Eur	Optimizing the part > To bring costs down
		Tool Free Method > But no tool free for Post processing
		Quicker R&D cycle

Evaluation

T	E
2	2

Figure 2. Part screening framework for the KSHP Part describing all technical and economic criteria.

Based on a discussion with the customer, a scoring was given on each dimension, both technical and economic. For KSHP the rating was at two each which placed the application under the redesign phase. The rating is given on a scale of one to three, where three represents a perfectly suitable fit, two represents a medium fit with aspects of improvement, and one represents a non-suitability of the criteria for AM.

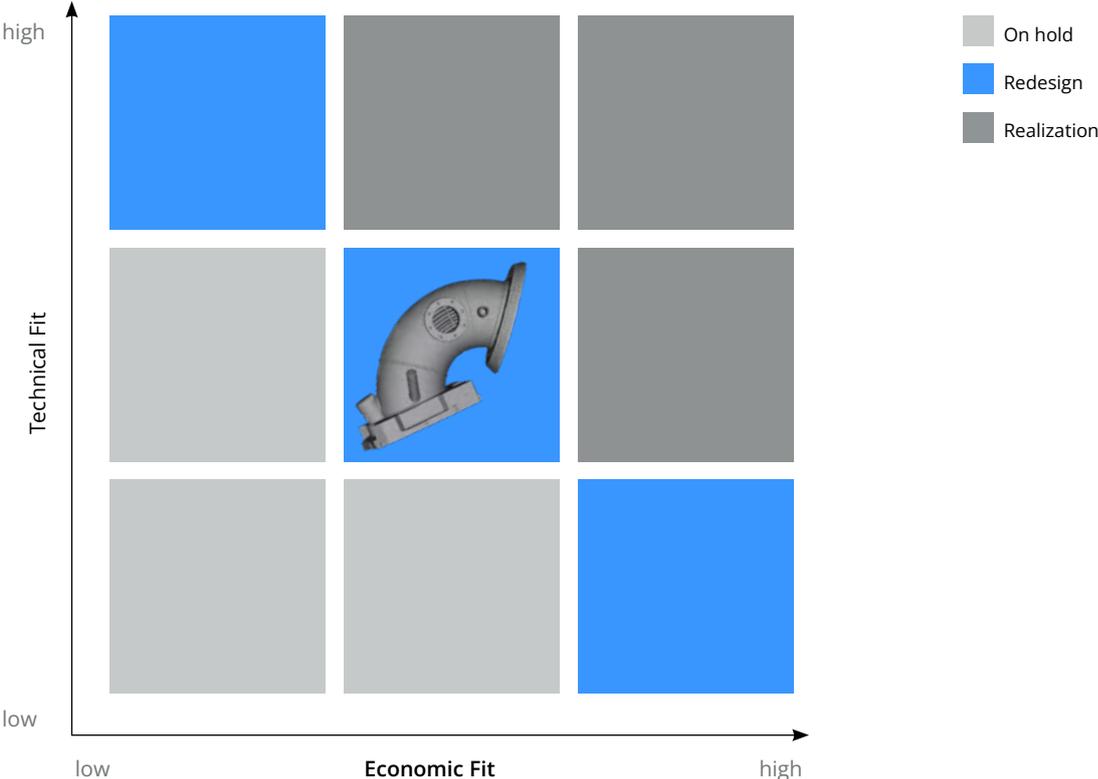


Figure 3. Eco-Tech matrix for KSHP heat exchanger.

Initial Design with CPP (Cost per Part)

The initial part was tested and without undergoing any redesign a conservative support structure strategy was chosen to print the part. No specific software was used for optimization at this stage apart from enablement through the EOS Additive Minds team. The focus for the first prototype was not to optimize cost but rather to ensure buildability on the first attempt with a conservative approach.

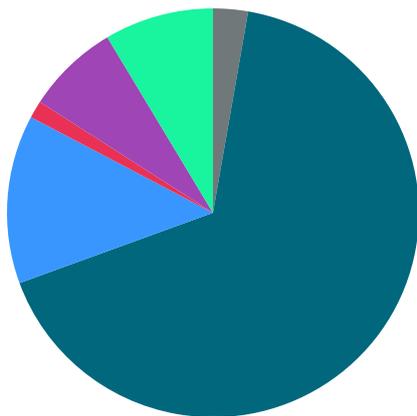


Figure 4. AM cost distribution of first heat exchanger design.

During our cost per part (CPP) analysis of the first design, we discovered a common phenomenon: The CAPEX-related cost, which includes both system and peripheral costs, constitutes the largest portion of the cost per part. This situation is mainly caused by a long build time but it is advantageous, because it opens up opportunities for optimization. When CAPEX dominates the CPP, there's always room for improvement.

System costs are closely tied to how efficiently the machine is used. So, the more the build process is optimized to increase utilization, the lower the part costs will be. This optimization is key to reducing expenses.

The second significant factor in CPP is material costs. Here, we have identified a potential for improvement regarding material consumption. Light weighting of the application and reduction of support material leads to lower mass and less material that is used during the LPBF process. This feedback was given to the design team for implementation.



Redesign with Siemens NX and Process Optimization Using Smart Fusion

As noted above, there is room for improvement for cost per part and therefore we went through a structured process with Siemens NX and considered Smart Fusion for the printing process. Smart Fusion is a tool to locally control the energy input during the LPBF process, thereby avoiding overheating and enabling significant reduction of support structures.

Initial Design

A majority of parts that are introduced to the market that are additively manufactured have not been optimized for additive manufacturing, which also means that there is untapped potential in improving quality and cost per part. This causes several potential issues to arise during the AM process. Analyzing the first prototype of the heat exchanger, three key issues have been identified: distortions, surface quality, and overheating areas. The part was designed inside of an external CAD system, which was then forced to be exported as an STL or similar file format. Since most additive machines and software take STL files,

this universal option was chosen. The problem with an STL file is that quality can suffer due to exporting of tetrahedral meshes rather than true CAD geometry. Typically, you will see these areas arise on rounded surfaces, holes, and other curved geometry. Since most of the geometry falls under these checks, this causes the file to need some repairs and modifications to ensure a high quality print. In addition, there were some support geometries already applied to the part that were there for the purpose of ensuring adhesion to the build plate and a mounting zone for post machining processes.

Part Modification and Improvements

Because the part was challenging due to printability and the STL export, geometry clean-up and modifications needed to be made. The first issue was that degenerated facets and folded facets existed in the model. We initially tried to use JT (file format) conversion, but the system used to design the part had errors upon exporting, resulting in even worse results.

We began to automatically clean up and repair the geometry using Siemens NX. Then some manual clean ups were performed in some areas of concern, to have more flexibility on the results achieved and further improve the part quality.

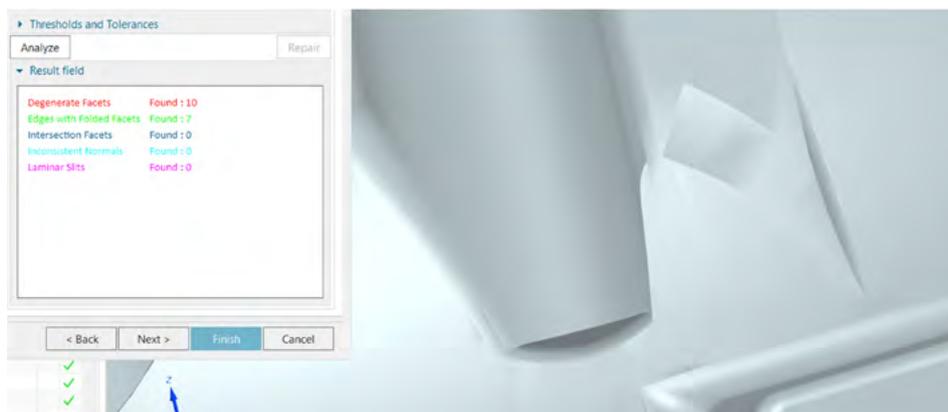


Figure 5. Analysis and cleaning of the design with Siemens NX.

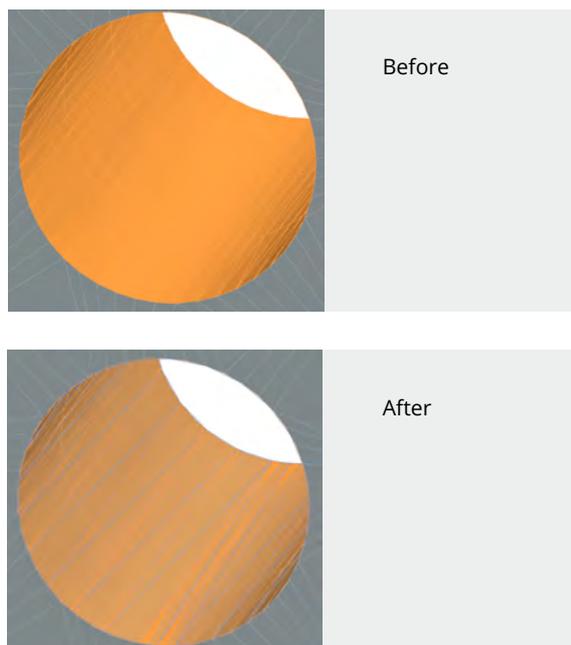


Figure 6. Comparison of surface quality before and after adding true faces.

The surface quality was poor in detected areas. Some repaired automatically and some needed further attention. This was done with NX Convergent Modelling™ to smooth and repair these areas of concern.

We also noted the part had no true faces, resulting in geometry that was more difficult to directly CAD model too. After adding true faces, we were able to assemble and put true CAD geometry where required and avoid export issues with certain hole features.

The surface quality before the operation seems to be tessellated and linear. Surface quality after repair is smoother and of better quality.

Other modifications included changes to volume supports that were added to the part to ensure a better print angle and smoothing additional geometry sections as needed. Once these were completed, these functions were also added to NX Additive Manufacturing validation tools to ensure further printability such as void detections, surface roughness, wall thickness issues, and print times.

Smart Fusion

Support structures are an integral part of the metal laser powder bed fusion process, serving three main purposes: counteracting internal stress caused by the laser powder bed fusion process, enhancing heat transfer in overhanging regions, and connecting the part to the build platform. However, the objective should be to minimize their use due to the drawbacks they bring. Support structures not only cause longer build times but also lead to unnecessary material consumption and added post-processing efforts to remove them after printing. EOS has developed Smart Fusion, an advanced software tool that regulates energy input into the part using a feedback

loop integrated with the EOSTATE ExposureOT monitoring system. ExposureOT detects light emissions from the melting process that correlate to overheating. By comparing this signal to a target grey value, Smart Fusion communicates with the 3D printer's laser control system to optimize energy input for subsequent layers. This dynamic adjustment of the energy input enhances heat distribution, significantly reducing the need for support structures without affecting build time. The reduced material consumption even leads to a shorter build time compared to conventional support strategies thus reducing costs.

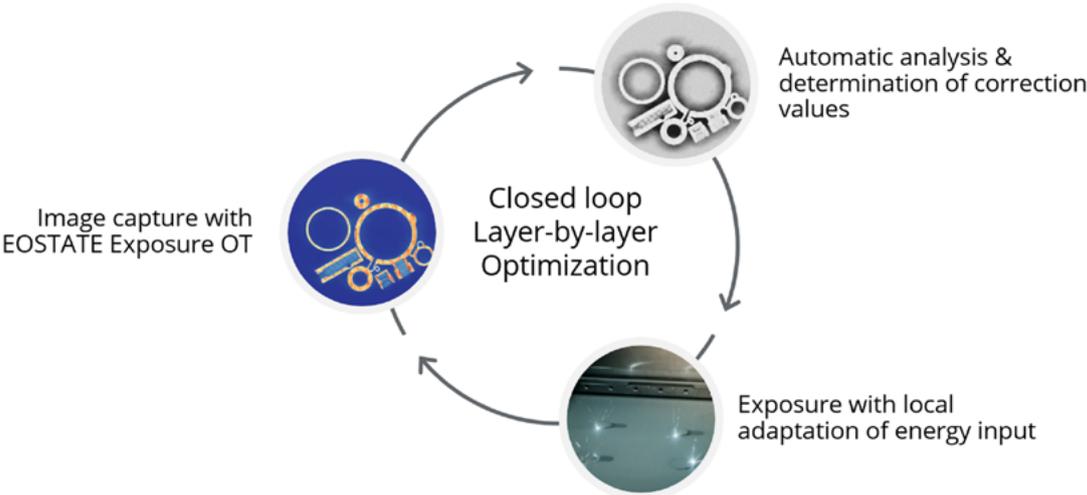


Figure 7. Working principle of Smart Fusion.

Siemens Consolidation Choices

There is a certain level of AM design that was highlighted in this whitepaper. However, in this domain our focus was on quick wins hence we looked into support structure optimization to improve buildability. One of the main issues when originally printing this part was overheating that had a negative impact on buildability and also on surface quality of the internal fluid channels. Both can depend on a lot of factors such as material type, process parameters, overhang location and wall thickness of the features. Typically, these can be relieved with support structures or by morphing geometry to not have any areas that aren't supported. In a typical scenario, engineers will go to lattice types supports (see block / lattice supports below) which will allow for easy support removal and quality assurance. An option is to add perforations to these supports to lower the amount of waste

and decrease the print time needed. By doing this, it may cause more warping and surface quality issues than intended. One thing that Siemens has noted when it comes to these parts is that it is better to over support in some cases where surface quality is a must, rather than lowering supports and causing a lower quality print to be made. In AM, since a lot of these issues are related to thermal problems, adding supports that act as heat sinks will alleviate the problems. In NX, we can design these supports while also adding lattice support types with solid support types (see solid supports below). We are also able to design any support imaginable due to it being a CAD core background using an automatic design support. We then ran this to the 35-degree overhang angle, which is a typical number when thinking metal powder bed additive manufacturing.

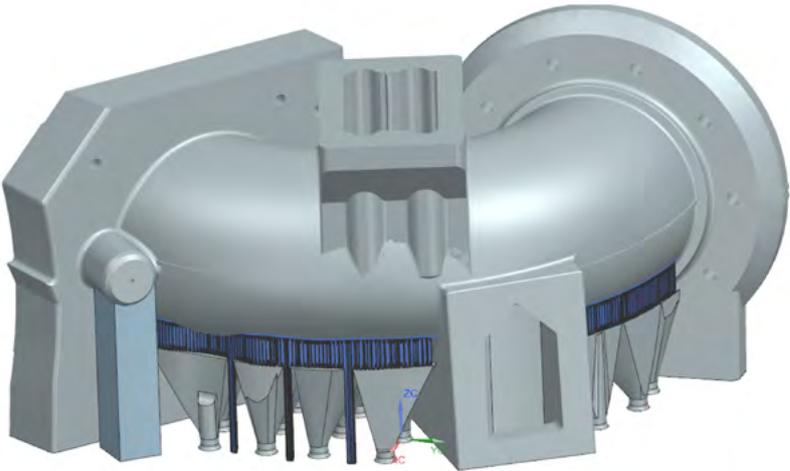


Figure 8. Heat exchanger with standard support strategy.

By taking advantage of Smart Fusion during the printing process, significantly lower angles are still printable. Considering the round heat exchanger geometry, a solid support strategy that only covers overhangs below 10 degrees has been chosen. Even though this is still STL geometry, we are able to create faces directly on the geometry and modify our own solid supports. We could use industry standard volume supports, but they did not have proper teeth placement and would be more difficult to machine.

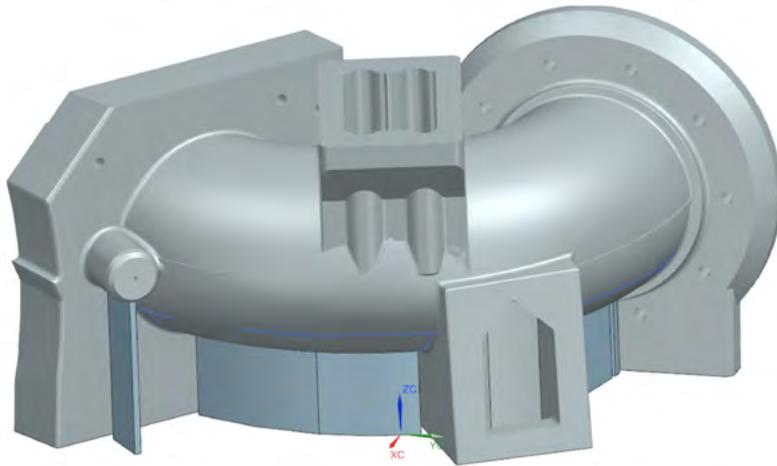


Figure 9. Heat exchanger with low angle support strategy that is enabled by Smart Fusion.

EOSPRINT Integration into SIEMENS NX

SIEMENS and EOS have been solution partners in the additive manufacturing domain since 2018. In this partnership, this allows a user to perform their entire additive workflow inside of NX without needing to export the part into a separate print preparation software like EOSPRINT2. This saves the user time and allows for easier, more repeatable, and more scalable printing operations. Once the part was completed inside the NX environment, it was directly linked to the EOS machine and an openjz file, the native EOS print file format, was created for the printer and could be directly delivered to the printer if on the same network.

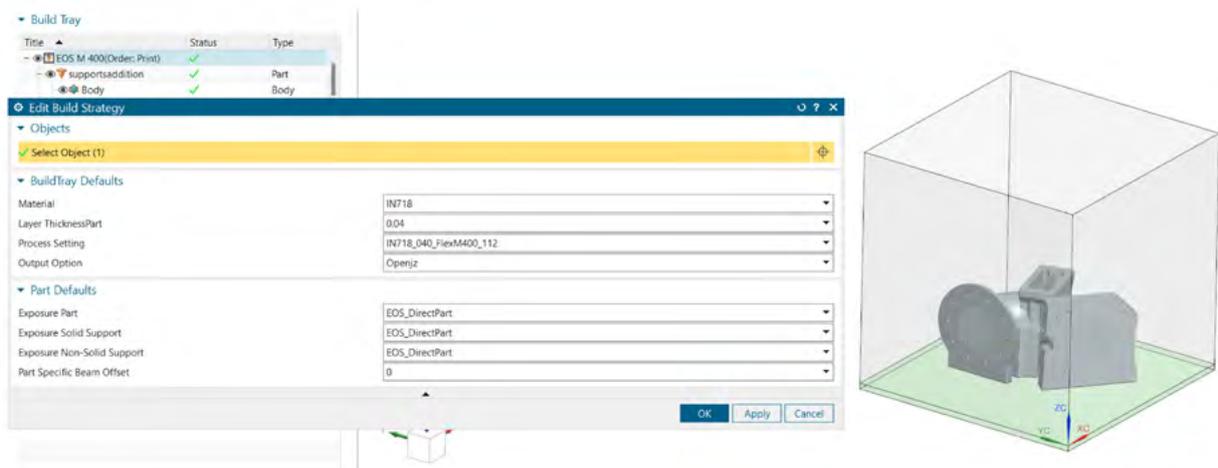


Figure 10. EOSPRINT integration in Siemens NX.

Parameter Optimization

EOS standard processes have undergone thorough process parameter development and rigorous testing across different Technology Readiness Levels (TRL). However, these parameters are a balanced compromise by design, accommodating diverse customer specifications and industry standards. Considering the specific requirements of an application, like the KSHP heat exchanger, these standard process parameters can serve as a robust foundation for further optimization to increase productivity while still fulfilling the part requirements.

Given the heat exchanger's unique characteristics, there are multiple areas where process parameter optimization can be applied to achieve the desired outcomes, increase efficiency, and fulfill part requirements.

Solid Supports

Solid supports serve as temporary and sacrificial components. Unlike most applications, solid supports do not require the same strict material and surface roughness criteria. Even at a 95% density, they maintain sufficient mechanical strength to fulfill their intended role during the printing process, which is providing heat transfer and counteracting internal stresses. Disabling contour and UpSkin exposure while modifying parameters like layer thickness, scan speed, and hatch distance can yield notable improvements in productivity without compromising the intended support function. Additionally, transitioning from Stripes to NoPattern exposure can not only reduce build time due to fewer jumps but also enhance buildability of this support type.

Block / Lattice Supports

When using a block support type strategy, similar to that of the conventional 35-degree design, optimizing the exposure order of the support vectors can be achieved through an algorithm, effectively reducing jump delays. Additionally, typical adjustments to decrease the build time for supports include implementing a skip layer approach. The layer thickness of the support exposure is set to double the layer thickness compared to the one used to print the part. Moreover, the scan speed can be increased to a certain extent, provided that buildability and strength requirements allow for a slightly less stable printing process.

Part Exposure for Heat Exchanger

The 40 μm 316L process is considered a balanced option between quality and productivity but EOS recently introduced a high productivity 80 μm process. This process offers comparable mechanical properties but comes with increased downskin surface roughness, due to the stronger stepping effect caused by the increased layer height. Due to the heat exchanger's mechanical requirements, it is feasible to switch to the high productivity process. To address potential increased surface roughness in the internal channels and its impact on fluid pressure drop and the heat exchanger's efficiency, downskin and surface parameters were adjusted to mitigate this effect. Further potential to reduce build time involves disabling UpSkin exposure, as it is not essential for the heat exchanger's functionality. While UpSkin exposure has mainly cosmetic effects, it increases build time without significant benefits for the heat exchanger.

Process Parameter Optimization of the Heat Exchanger Build

Below is a comparison table showcasing the significant improvement in build time achieved by optimizing the process parameters. All scenarios were simulated on the EOS M 300-4. In the standard scenario, the default EOS 40 μm process for 316L was used for the part and supports, resulting in a build time of nearly 67 hours. This configuration served as a reference for comparison.

In the subsequent simulation, solely parameters applied to solid supports were optimized. This approach represents a conservative method of process optimization, whereby the main part itself remains unaltered. For the support optimization scenario, the support parameter was modified to 80 μm , the exposure pattern was adjusted from Stripes to NoPattern / Time Optimized and the hatch distance was increased. The results show a notable improvement, with the build time reduced to 61.5 hours, representing an 8.2% increase in productivity compared to the baseline.

The most substantial productivity gain was attained in the final scenario, where also the process parameters for printing the heat exchanger itself have been optimized. As a starting point, the high productivity 80 μm parameters developed by EOS were employed, and further adaptations were made to meet all part requirements while achieving significantly increased build rates. One factor contributing to the enhanced productivity was the reduction of recoating time by half, resulting in a saving of more than two hours. To address the potential challenge of increased surface roughness in the internal channels due to a stronger stepping effect caused by the higher layer thickness, adjustments were made to the downskin parameters. Furthermore, UpSkin exposure was disabled. These optimized parameter settings led to a build time of just over 30 hours, representing a 55.0% increase in productivity compared to the baseline configuration.

Scenario	Process Strategy	Part Parameter	Support Parameter	Build Time
1	Standard	40 µm default	40 µm default	66:58
2	Support optimized	40 µm default	80 µm optimized	61:29
3	Fully optimized	80 µm optimized	80 µm optimized	30:07

Table 1: Different optimization scenarios for the heat exchanger simulated on the EOS M 300-4.

These results highlight the substantial potential for reducing build time and, consequently, overall costs by adapting process parameters to specific application requirements. The fine-tuning of process parameters not only facilitates

cost reduction but also aids in achieving desired quality targets that may not be attainable with standard process settings. This serves as a perfect transition to move into the production discussions and optimize the production set up.

Industrialize & Qualify



The application in focus did not belong to a highly regulated industry hence we did not work in this direction. We, however, support customers to certify and qualify their applications as part of the AM step process. For more information, please read [this article](#) or get in touch with Additive Minds. Qualification varies from industry to industry and is a complicated topic hence the link to the article to understand the basics on how we can support.



Production Optimization

What is Tecnomatix?

Tecnomatix is a comprehensive software solution developed by Siemens Digital Industries Software for digital manufacturing planning and production simulation. It offers a wide range of functionalities that enables users to optimize their production processes and improve efficiency.

By creating virtual models of their production lines, Tecnomatix allows its users to simulate and optimize various production scenarios. The digital twin approach helps to identify potential bottlenecks, minimize downtime, and enhance overall productivity.

The software covers a wide spectrum of manufacturing processes, including process planning, simulation, robotics and automation, production line optimization, and quality management. It

assists to design flexible and adaptive manufacturing systems, which are crucial in today's dynamic production environment.

Additionally, Tecnomatix supports advanced data analytics, which enables the users to gather and analyze real-time production data. This capability helps to make data-driven decisions, predict potential issues, and continuously improve manufacturing processes.

Tecnomatix, through its powerful features and user-friendly interface, is a valuable tool for industries such as automotive, aerospace and defense, electronics, and many others, as it facilitates seamless integration of manufacturing processes, streamlines production, and enhances overall operational efficiency.

What Value Does Tecnomatix Generate?

Through simulation-aided production and manufacturing planning companies relying on Tecnomatix optimize their business and increase efficiency. Some key values to mention are:

1. Improved efficiency: Tecnomatix optimizes manufacturing processes, leading to increased productivity, and reduced operational costs
2. Enhanced quality: By simulating production processes, the software helps to identify potential issues in the manufacturing process early, leading to better quality control and fewer defects in the final products.
3. Faster Time-to-Market: Tecnomatix streamlines production planning and execution, enabling faster product development cycles and quicker launches in the market.
4. Resource optimization: The software helps in better resource allocation, leading to reduced waste and increased utilization of machinery, equipment, and labor.
5. Collaboration and Communication: Tecnomatix facilitates seamless collaboration and communication among different teams involved in the manufacturing processes, leading to better decision-making and coordination.
6. Flexibility and adaptability: the software allows customers to respond quickly to changes in demand or production requirements, ensuring their manufacturing processes remain agile and adaptable.
7. Cost reduction: by identifying inefficiencies and improving production workflows, Tecnomatix helps to reduce overall manufacturing costs.

In summary, Tecnomatix empowers customers to optimize their operations, make data-driven decisions, and stay competitive in volatile and rapidly evolving markets.

Here we compare the manual EOS M 290 scenario (baseline) to the fully automated EOS M 300-4 (Scenario 3). In the case of the fully automated EOS M 300-4, the operator involvement is reduced to manual calibration and maintenance tasks hence we see a difference between Scenario 3 1-shift and 24x7 for "Idle time".

	Baseline (EOS M 290)	Baseline (EOS M 290)	Scenario 3 (EOS M 300-4)	Scenario 3 (EOS M 300-4)
Shift Model	1 Shift	24x7	1 Shift	24x7
Jobs / Year	36	37	249	261
Parts / Year	36	37	249	261
Working Time	7803 h	8092 h	7501 h	7882 h
Setup Time	37 h	38 h	19 h	20 h
Idle Time	293 h	2 h	444 h	53 h
Flooding Time	18 h	19 h	187 h	196 h
Scheduled maintenance	171 h	171 h	171 h	171 h
5% safety margin	438 h	438 h	438 h	438 h

Table 2. Tecnomatix output for baseline and scenario 3.

A comparison of the two extreme cases, considering different shift models is done. The table illustrates the outcome of the Tecnomatix simulation conducted by EOS's digital (AMPO) team in collaboration with Siemens Digital Industries Software. The data in the table compares baseline (EOS M 290, a manual single laser system) with the optimal production set-up, denoted as Scenario 3 (EOS M 300-4, a highly automated quad laser system). We typically add 5% safety margins to account for unforeseen production interruptions. Similarly, the scheduled maintenance time has been kept as per recommended practice throughout the year and is same across the table.

The analysis reveals three interesting aspects:

- The throughput increases by 625% from the baseline scenario on a single laser system with standard process parameters, compared to a fully optimized design and process together with a highly automated quad-laser system. (Baseline vs Scenario 3)
- Interestingly, there is not a big difference between a one shift model and a 24/7 operation in both scenarios, 3% productivity gains for baseline case and 10% for scenario 3. In the baseline scenario, this is caused by the very long build time of nearly nine days, which does not lead to many job changes that are outside of working hours. In the fully optimized scenario, it is explainable with the high degree of automation.
- Due to the production process efficiency, we can have time allocated for 'idle time' highlighting the fact that there is possibility and room for improvement.

Opting for a round-the-clock shift model for a mere 10 % uptick in productivity does not present a compelling proposition. Evidently, the part aligns well with a single shift model in the automated scenario, yielding cost savings across labor, operations, and utilizing one the many advantages of AM where machines can run overnight without supervision.

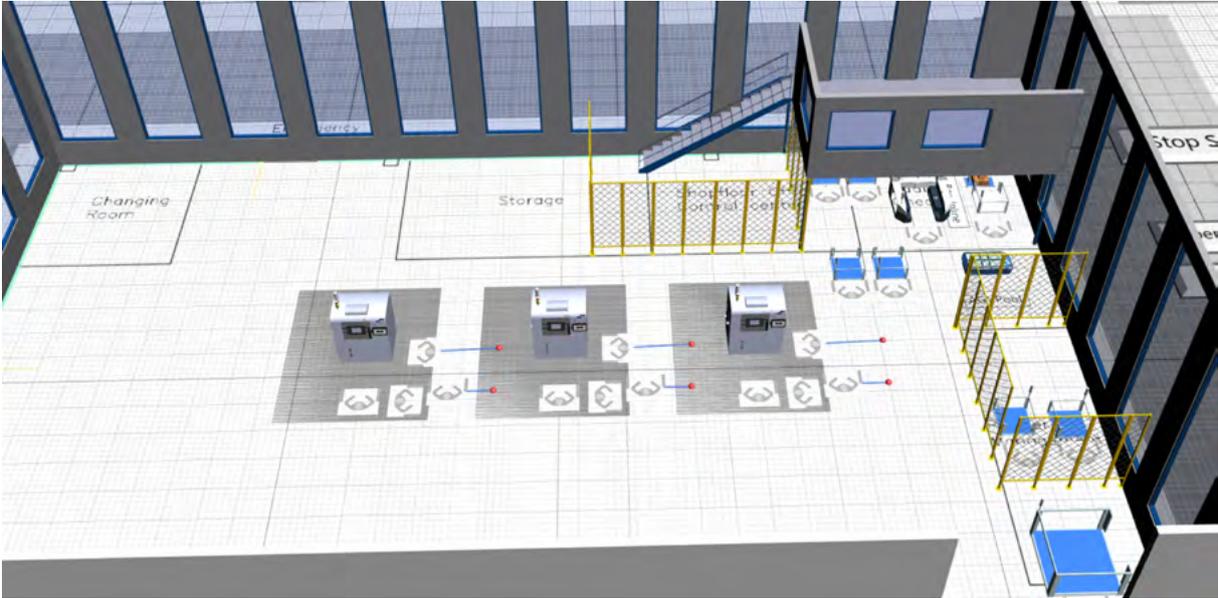


Figure 11. EOS M 290 production setup. Tecnomatix simulation for one system.



Figure 12. EOS M 300-4 production setup. Tecnomatix simulation for one system.

Cost per part (CPP) Overview

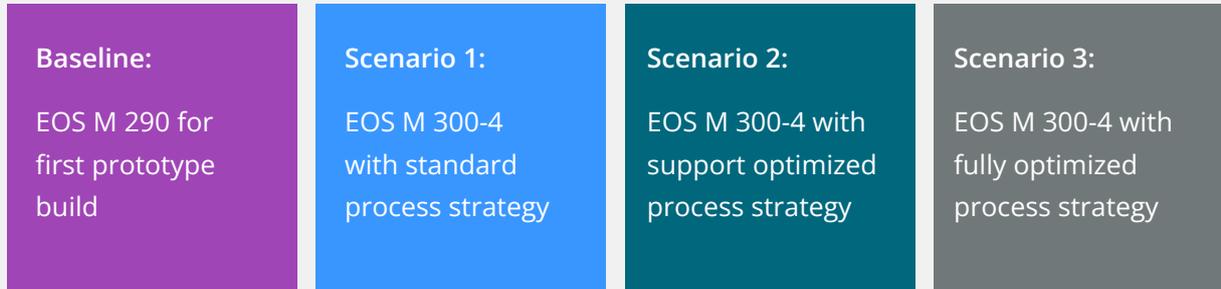


Figure 13. Four scenarios for Tecnomatix simulations.

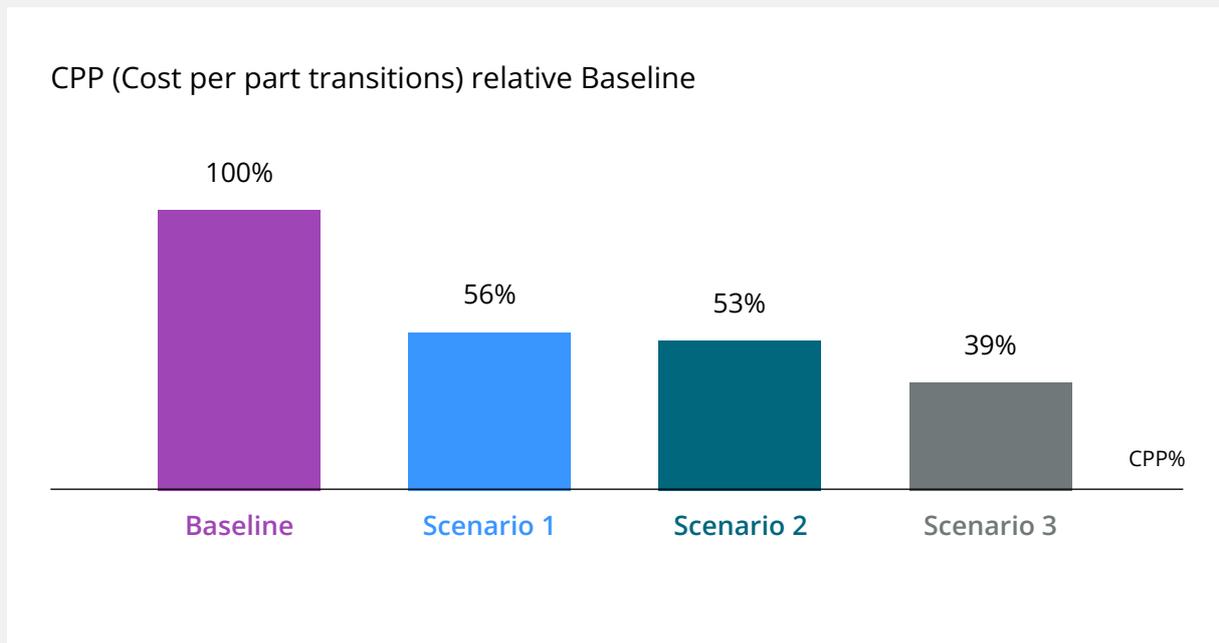


Figure 14. Overall cost comparison between different scenarios.

The baseline case involved the use of EOS M 290 without an optimized design, which was the first prototype build. In contrast, Scenario 1 represents the updated first design iteration using EOS M 300-4, showcasing a substantial 44% reduction in Cost per Part (CPP). This highlights the significance of selecting the right machine for the application. It should be noted that the EOS M 290 may not always lead to more expensive parts than the EOS M 300-4; however, in cases of serial production, the EOS M 300-4 appears to be a much more suitable choice. Moreover, further cost reductions emphasize the expertise of AM specialists from Siemens and Additive Minds, who can fine-tune process and design that lead to cost per part reductions. Scenario 2, which incorporates an optimized support structure strategy, brings the cost

per part down by an additional 9% compared to Scenario 1, resulting in an overall reduction of 47% from the baseline. The final optimization of the part with higher layer thickness and process adjustments in Scenario 3 leads to a significant reduction of 26% in cost per part compared to Scenario 2 and an impressive overall reduction of 61% from the baseline. Such a remarkable transition in the AM world is common with optimized designs and process strategies. Therefore, the key message to take away is,

"Do not be discouraged by the initial cost per part estimate; there is always room for improvement through optimized designs, process parameters and production optimization."

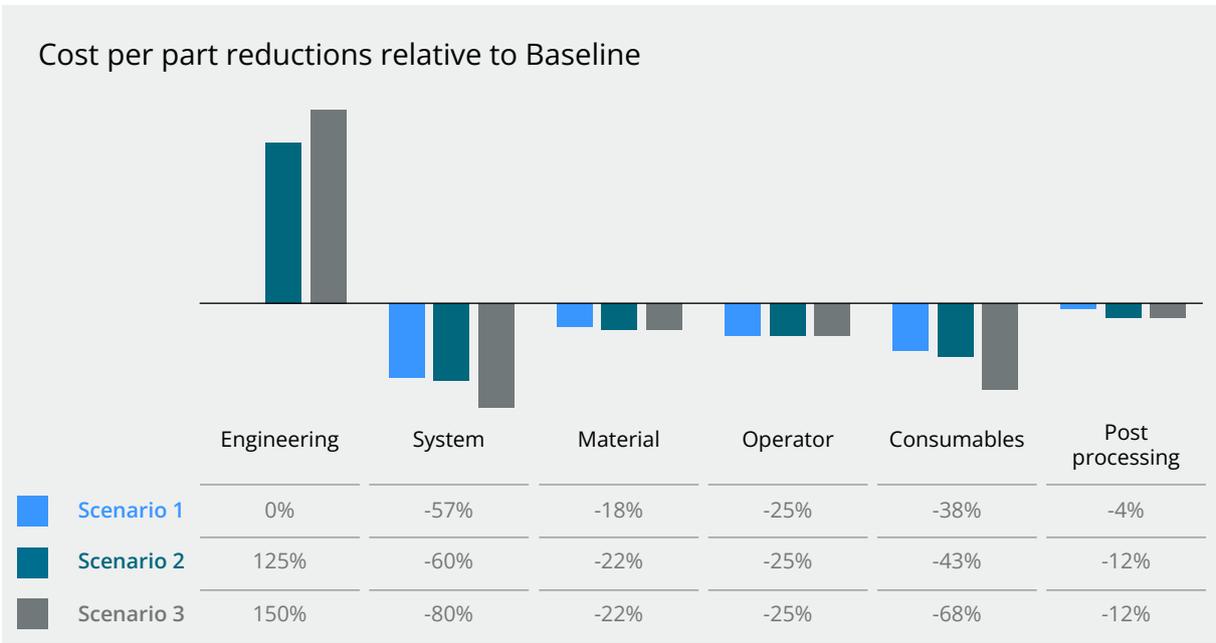


Figure 15. Detailed cost structure of different scenarios.

Overall, we observe a trend of improvements across the costing value chain since transitioning from our baseline method. However, it is worth noting that there has been an increase in costs on the engineering side due to the additional time invested in establishing the appropriate processes and building strategies.

Outlook

The central objective of this whitepaper has been to show the customer journey across diverse stages of the AM application development cycle. While a full AM redesign was not in the scope of this paper, we would like to provide an outlook into further optimization potential.

Another intriguing aspect we're exploring is a comparison of carbon footprints across different production scenarios. This not only highlights how applications like the KSHP heat exchanger can contribute to a more sustainable industry but also underscores the potential for optimizing the manufacturing process in terms of carbon footprint.

Carbon Footprint Calculation

Additive Minds EOS has launched a carbon calculator that allows users to calculate the carbon footprint of an application that is printed on an EOS machine. With EOS's focus on responsible manufacturing, the carbon calculator allows customers to take their own measured values into account to allow for a more precise calculation than other tools on the market, and help customers act more responsibly. EOS also works in collaboration on different customer projects with Siemens Teamcenter to provide value from a sustainability angle to the AM community.

While the quantification of carbon emissions was not initially within the project's

scope, our inquisitiveness impelled us to deploy our recently devised carbon calculator. The outcomes unveiled a substantial reduction of up to 27% in carbon emissions when comparing the baseline design against the configuration realized in scenario 3.

This reduction in carbon emissions primarily corresponds to two facets: firstly, a substantial decrease in energy consumption attributed to enhanced build time efficiency, and secondly, a notable reduction in powder consumption facilitated by an optimized support structure strategy—a testament to Smart Fusion.

An overview of the overall footprint reduction on the part is shown in the graph below, to use and follow the carbon calculator [please click here](#).

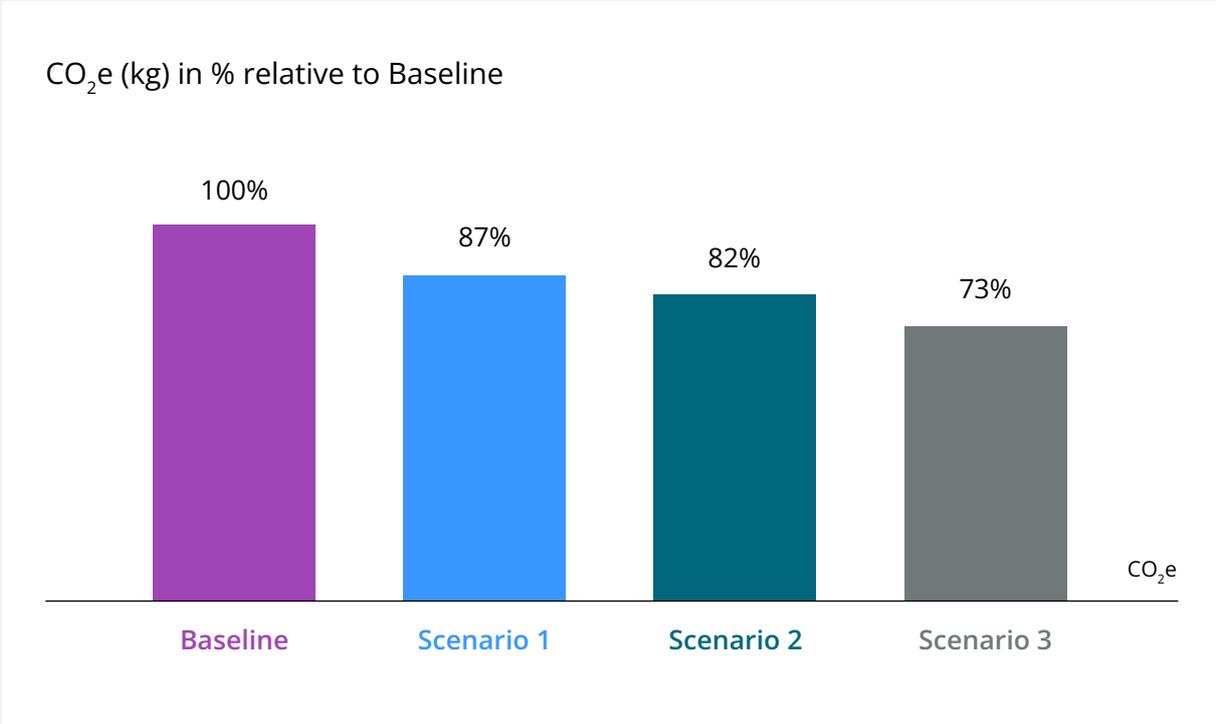


Figure 16. Carbon emissions (CO₂e) with respect to the baseline i.e., valued at 100%

Future Print Optimizations

There is always room for improvement, and we have noticed also the case for our HX in focus here. Some additional ways to improve would be Siemens Topology Optimization, Additive Optimization tools, and Star CCM+ for fluid optimization. This would allow the part to remain to spec, have gyroid or similar TPMS structures created to maintain norms while keeping it printable, and become more lightweight in the process. This combined with the required areas where support structures must be made will ensure more printability in the future.

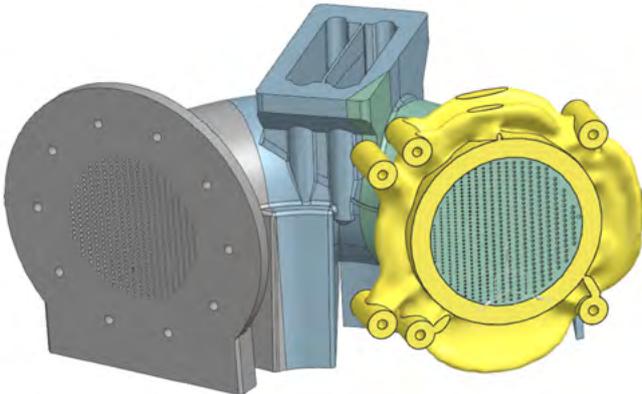


Figure 17. Advanced heat exchanger design with light-weighting approach.

Through light-weighting of a heavy geometry, roughly 25% of weight can be saved while still achieving the same mechanical properties. Although weight reduction might not be relevant for the stationary heat pump, but it substantially reduces production costs.

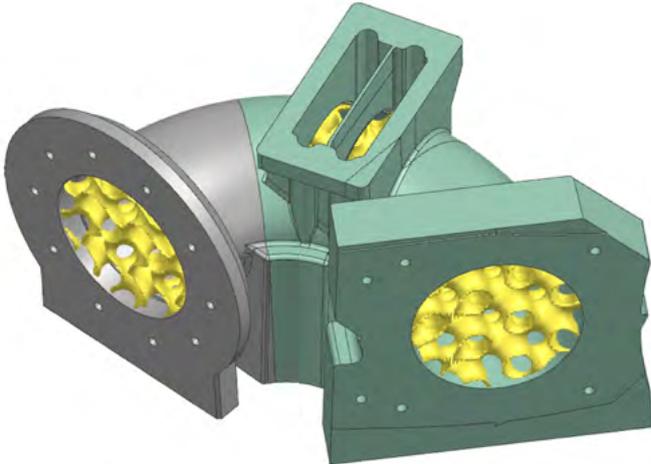


Figure 18. Advanced heat exchanger design with internal TPMS structures.

Changing the internal geometry to TPMS might allow increasing the surface area for heat transfer with similar pressure drop and mechanical properties.

Summary

Additive manufacturing is an innovative production technology allowing cost-effective manufacturing of complex geometries. The whitepaper highlights that by harnessing the design freedom of AM, it becomes possible to create applications that are not only more efficient and sustainable, but also emphasizes that realizing the complete potential of AM necessitates aligning manufacturing particulars with application requirements. This principle holds true for all manufacturing technologies; optimal outcomes are achieved when one comprehends the process and factors in the technology's specific characteristics.

EOS, Siemens, and KSHP worked collaboratively on this whitepaper showcasing their journey through the AM application development process for a heat exchanger. This involved selecting the right application, refining the design, optimizing the manufacturing process, and planning production. Siemens' integrated software solutions demonstrated a practical and effective approach to enhancing the feasibility and cost-effectiveness of producing intricate heat exchanger designs.

The whitepaper lead through following stages of the AM customer journey:

→ **Understand why AM**

AM enables cost-effective production of complex geometries, functional integration and flexible production scenarios.

→ **Identify Applications**

Tools such as the Eco-Tech procedure not only assist customers in identifying AM-appropriate applications but also provide insight into whether additional efforts, such as redesign or part consolidation, are necessary to create a viable case for AM.

→ **Business Case Analysis**

Ensure that a technically viable product aligns with a favorable business case when produced using additive manufacturing. Conducting an initial analysis will unveil the most significant factors for optimizing the business case.

→ **Design Optimization**

Every manufacturing technology has its unique characteristics and design principles. Although AM offers substantial design freedom, its complete potential can only be realized by adhering to Design for Additive Manufacturing (DfAM) principles. Siemens' seamlessly integrated digital solutions enhance the consistency, traceability, and reliability of the application development process — spanning from design and production optimization to direct transfer of print files to the EOS AM system.

→ **Process Optimization**

By customizing the LPBF process parameters to match the specific application requirements, it becomes possible to optimize productivity, buildability, and even enhance quality aspects such as surface roughness.

→ **Production Planning**

A decrease in build time might not necessarily result in increased production capacity unless job changes are synchronized with the shift model. Through simulations using Tecnomatix, various production scenarios are visualized, aiding customers in selecting the appropriate production setup. This encompasses factors like the machine type, the shift model, or the necessary number of machines to fulfill capacity needs.



Are you seeking to minimize support structures and reduce the cost per part for your application? With the utilization of Smart Fusion, we can effectively manage overheating during the printing process, resulting in a significant reduction of required support structures without compromising on build rate. This leads to substantial cost savings and a reduced carbon footprint due to shorter build times, decreased material consumption, and minimized post-processing efforts.

Our Additive Minds team is ready to support you in assessing the benefits of Smart Fusion for your specific applications by analyzing technical feasibility, cost per part and carbon footprint. Contact us today for a tailored assessment.



KSHP sustainable Heat and Power has great plans for the future, with a product that is well aligned with the increasing concern over CO2 emissions and global warming. At the present stage, we are looking for further external investment to accelerate commercialization. Interested investors are invited to contact Monica Hall at monica@kshe.no or +47 911 05 369 for more information.



For Additive Manufacturing to become a reliable industrial manufacturing solution, the right tools and technology need to seamlessly connect design and development to the shop floor. The challenges of doing more with additive manufacturing are designing optimized parts that print first-time-right and repeatedly producing those parts at volume with quality. Siemens NX CAD/CAM/CAE and PLM solutions provide all of the necessary capabilities to industrialize Additive Manufacturing so that companies can not only prototype, but also design and produce ground-breaking products at scale. For more information, please contact Adam Hiller or Benedikt Altmann.

Authors



Syed Nameer

EOS Senior AM Consultant

Nameer is currently working at Additive Minds as a strategy & innovation consultant. He gained a bachelor's degree in mechanical engineering and a master's degree in management at ESMT Berlin, which led to his interest in new technologies. He has consulted numerous customers over the past four years in developing their journey towards adopting additive manufacturing. His expertise lies in determining business cases and financial feasibility for customers planning to enter additive manufacturing. Syed brings a wide diversity of experience along with him together with a passion for data driven decision making when consulting clients.

Contact:

syed.nameer@eos.info



Michael Wohlfart

EOS Senior AM Consultant

Michael has a passion for sustainable energy, the chemical industry, and aerospace. He holds an M.Sc. in chemical engineering from FAU Erlangen-Nuremberg. With many years' experience in the additive manufacturing industry, Michael knows both sides of the business, first as a user of the technology starting in 2013, and since 2017 as a member of the Additive Minds consulting team at EOS, where he supports strategic customers on their way towards serial production. Since 2022, Michael is Senior Additive Manufacturing Consultant at EOS North America advising customers and supporting the establishment of EOS' West Coast Innovation Center.

Contact:

michael.wohlfart@eos-na.com



Arve Kallum

KSHP Chairman

Arve has a Master of Science degree in mechanical engineering and comprehensive experience in the offshore oil and gas industry. He is the main initiator of Kallum Sustainable Heat and Power and chairman of the company. As chairman of a small startup company, contact with possible customers, investors and governmental agencies which support the green transition, are his tasks. In addition to that, Arve also handles system design, installation, assembly work and testing.

Contact:

a-kallum@online.no



Lars Kallum

KSHP Chief Engineer

Lars is a mechanical engineer with a Master of Engineering degree from University of Wollongong, Australia. He has worked with structural and thermal design and analysis in the Norwegian industry for over 20 years. Lars has extensive experience from numerous projects related to oil & gas, fish farming and the wind industry. In KSHP, Lars' main responsibility is the design, 3D modeling and numerical analyses of the heat exchangers.

Contact:

lars.kallum@edrmedeso.com



Adam Hiller

AM Consultant

Siemens Digital Industries Software

Adam Hiller is a recognized additive manufacturing engineer within the industry currently employed at Siemens Digital Industries Software. He has been focused on improving and applying his knowledge to the industry since he graduated from Purdue University with a bachelor's degree in the Engineering field. Currently, Adam has focused his last 6 years in industry toward helping over 100+ companies to achieve their digitalization journey with the Xcelerator portfolio from Siemens and providing his knowledge on Additive manufacturing towards the various use cases he has been given.

Contact:

adam.hiller@siemens.com



Benedikt Altmann

PreSales Solution Consultant

Siemens Digital Industries Software

Benedikt is currently working at Siemens Digital Industries as a Global PreSales for Additive Manufacturing. He started his career in Additive Manufacturing by writing his Master's Thesis about Design for Additive Manufacturing at Fraunhofer IGCV in Augsburg, Germany, followed by working for 3 years as an engineer in design, simulation and application for L-PBF at a service bureau. This is when he worked with the software solutions from Siemens for the first time. In 2022 he decided to join Siemens to drive the software business by combining his experience with the latest software capabilities.

Contact:

benedikt.altmann@siemens.com

Many Thanks for your contribution to:

Fabian Tieck, Digital Manufacturing Consultant

EOS GmbH

Electro Optical Systems
Corporate Headquarters
Robert-Stirling-Ring 1
82152 Krailling/Munich, Germany

Phone +49 89 893 36-0

info@eos.info

www.eos.info

in EOS   EOS3DPrinting

#responsiblemanufacturing

#futureisadditive

Status of 09/2023. EOS is certified in accordance to ISO 9001.
EOS®, EOSTATE and Additive Minds® are registered trademarks
of EOS GmbH Electro Optical Systems in some countries. For
more information visit www.eos.info/trademarks

