ORIGINAL RESEARCH
COMMISSIONED BY

AMGTA ADDITIVE MANUFACTURER
GREEN TRADE ASSOCIATION

ADDITIVE SUSTAINABILITY

October 31, 2023

Life Cycle Analysis Report:
Executive Summary

Comparative Analysis: 3D Material Jetting vs Traditional Methods for Designer Luxury Goods

Prepared by

REEVES INSIGHT

Introduction to AMGTA

The Additive Manufacturer Green Trade Association (AMGTA) is the only global organization bringing together companies throughout the manufacturing ecosystem to promote and elevate the conversation around additive practices as an environmentally beneficial strategy for addressing lead times, supply chains, waste streams, energy consumption, technological advancements, and overall environmental and societal impacts. This informed and ongoing collaboration between AM technology developers and practitioners is enabling the AM industry to address the need and demand for more sustainable manufacturing and more resilient and flexible supply chains in a strategically, financially, and environmentally beneficial way. Fundamentally, the AMGTA brings together the manufacturing and sustainability communities to better understand the leverage-potential of additive manufacturing.

AMGTA members represent the entirety of the manufacturing ecosystem—from design and source materials to end products and users. These members demonstrate their industry leadership by working together to address the compelling issues around rapidly evolving manufacturing demands, stakeholder expectations, geopolitical events, climate impacts and a changing ecology. Through member forums, rigorous research, and business use-case analysis the AMGTA works to better understand and communicate the direct impacts and potential of additive manufacturing and the marketplace demand for more sustainable manufacturing to increase acceptance and adoption of additive practices.

The AMGTA works with member organizations to raise the profile of their sustainability efforts and the potential for more sustainable manufacturing through their products, services, and systems. The AMGTA represents its members at additive manufacturing industry forums and conferences to promote the environmental benefits of additive practices. The AMGTA also represents its members within the sustainability community to promote the power and potential of additive practices to deliver on bold environmental goals. We engage member organizations in ground-breaking research projects and business case studies to better understand the potential of AM, inform ongoing industry development, and increase acceptance and adoption of more sustainable manufacturing practices.

The AMGTA is engaging AM technology leaders, the broader manufacturing industry, and the overall sustainability community in an independent and comprehensive way in which no one company, regardless of size or position in the market, can do on its own.

ADDITIVE MANUFACTURER AMGTA GREEN TRADE ASSOCIATION

Message from the Executive Director

We are pleased to issue the third body of research in a series of independently commissioned papers designed to reveal the environmental benefits of additive manufacturing adoption. We are committed to advancing the research and publication required to better understand the sustainable value of AM technologies as part of the manufacturing cycle for broad business cases. This collaborative study with Stratasys and Pattern Group, assessing the impact of a print-to-textile process, is our first research undertaking involving polymer. It delivers important data that supports the value of AM to impact one of the most historically polluting industries in the world.

This study in collaboration with Stratasys is a clear win for manufacturers like Dyloan, a subsidiary of Pattern Group, which are pushing the boundaries to innovate better, more sustainable consumer fashion goods. We applaud Dyloan and their design clients for their industry leadership, their willingness to share their processes and data, and their willingness to share this information with the broader manufacturing community. The urgent need for more sustainable manufacturing will only be met by bold collaboration. Stratasys' and Dyloan's, through this research, have stepped up in a big way.

Sherri Monroe
Executive Director, AMGTA
November 2023

Industry Collaboration

Our dedication to Mindful Manufacturing™ is a commitment to our customers. By embracing sustainable practices and innovative AM technologies, we're working to reduce global carbon footprints – our own and our users. This study showcases how the adoption of our advanced AM offering empowers customers to deliver manufacturing solutions that improve their impact on the environment and at the same time deliver competitive advantage through innovation in production for design.

stratasys

Dr. Yoav Zeif
CEO, Stratasys
November 2023

EXECUTIVE SUMMARY

Comparative Analysis: 3D Material Jetting vs Traditional Methods for Designer Luxury Goods

This study, commissioned by the AMGTA and conducted by Reeves Insight, a UK-based AM consultancy practice, in partnership with Stratasys, a global leader in AM technologies, and Pattern Group, a leading company in the engineering and production of luxury fashion brands, and their subsidiary, Dyloan Bond Factory, analyzed the transition from traditional manufacturing methods to advanced Additive Manufacturing to create a logo applique for luxury designer shoes, printed on fabric, produced by a material jetting process. The results showed a dramatic 24.8% reduction in CO_2-eq emissions and a 48% reduction in stock material across the supply chain when compared to the traditional process.

This year-long study analyzed the cradle-to-gate of a 3-dimensional graphic component attached to the heel of a luxury athletic shoe. The AMGTA commissioned the study in 2022 to better understand the potential environmental benefits of additive design and manufacture in an industry that may not be top-of-mind when thinking of additive practices – fashion. The study compared the manufacture of the 3D logo component through the traditional and additive methods. The study was limited in scope to this one component and not the entire shoe. The study evaluated both processes for a production run of 16,000 logo components for 8,000 pairs of shoes. This study was peer reviewed by the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University as research partner of ACAM Aachen Center for Additive Manufacturing GmbH.

Key takeaways from the study include:

- **Reduction in Greenhouse Gas Emissions.** The additive manufacturing print-to-textile production process showed a 24.8% reduction in CO_2e emissions, when compared with traditional processes.
- **Reduction in Material Usage:** AM print-to-textile showed a 49.9% reduction of stock material across the supply chain, also reducing and streamlining related transportation needs, and 50.0% less material in the resulting 3D printed logo component.
- **Reduction in Water Usage:** The AM process showed a savings of more than 300,000 liters of water across the 16,000 logo components.
- **Reduction in Power Consumption:** The additive manufacturing process cut electrical energy consumption by 64%.
- **Reduction in Supply Chain Dependencies:** The shift to AM reduced supply chain dependencies from 4 technologies to 1: with a single additive workflow – and transportation and logistics impacts are eliminated for 3 processes.

Of the many potential environmental benefits of additive design and manufacture across nearly every industry, streamlined production processes, reduced material usage and waste, and reduced energy consumption are often suspected but require critical analysis to be quantified and lead to the adoption of more sustainable methods and processes. This study looked at a very specific and quantifiable design element to understand the impacts of these advanced manufacturing technologies.

cont'd.

Comparative Analysis cont'd.

The traditional multiple-step process studied includes 2D Inkjet printing and thermal welding of injection molded parts with sheet polyurethane materials. The streamlined additive process included material jetting using photocurable liquid resins with significantly fewer steps.

The results of the study showed a 24.8% overall reduction in CO_2-eq emissions for the additive process compared to the traditional method. Across the 16,000 logo components studied, the additive process resulted in nearly one metric ton less CO_2-eq emitted.

The studied manufacturing run was shown to require 49% less material by weight when produced additively and the resulting logo component had 51% less material than the traditionally produced component resulting in a marginally lighter-weight final product. The AM process also eliminated the use of up-stream paper-backed materials requiring significant amounts of water in their production – more than 300,000 liters for the 16,000 components studied.

The additive 3D printing process also used 64% less electrical energy compared to the traditional process which included energy-intensive injection molding and thermal bonding. With the traditional process using significantly more electrical energy than the additive process, this would suggest a "greener" energy source would have a greater impact on the traditional process. Additional environmental and operational efficiencies were documented related to reduced supply chain dependencies and reduced steps in the production process.

	GWP of the overall logo design	Water footprint	Recyclable waste	Non-recyclable waste	The material in the final product	Overall material consumption	Power consumed
3D PRINTING	0.36 Kg CO_2e per pair	Zero liters per pair	0 Kg total for 8,000 pairs	145 Kg total for 8,000 pairs	191 Kg total for 8,000 pairs	336 Kg total for 8,000 pairs	2,548 kWh
TRADITIONAL MANUFACTURING	0.48 Kg CO_2e per pair	39 liters per pair	134 Kg total for 8,000 pairs	156 Kg total for 8,000 pairs	382 Kg total for 8,000 pairs	671 Kg total for 8,000 pairs	7,128 kWh
PERCENTAGE BENEFIT OF 3D PRINTING OVER TRADITIONAL MANUFACTURING	**25% Less** CO_2e per pair	Water footprint **eliminated**	Recyclable waste **eliminated**	**7.5%** reduction in non-recyclable waste	**50%** reduction in raw material in the final product	**49.9%** reduction in overall material needed	**64.3%** reduction in electrical energy consumed

Fig. 1 *– Comparison of outputs from the traditional and 3D printing approaches*

Study Overview

This study provides a detailed environmental analysis of two manufacturing methods that produce a 3-dimensional (3D) graphic logo component, as seen in Figure 2 *(overleaf)*. The graphical element adorns the heel-spur location on the designer footwear, as seen in Figure 3 *(overleaf)*.

The first and more traditional manufacturing method uses a multiple-stage 2D printing, injection molding, and thermal welding process as in Figure 4 *(overleaf)* to produce the component, which is then laminated to a fabric substrate and becomes part of the footwear upper. The second, more recently developed method deposits material directly onto the fabric substrate using a 3D material jetting process, eliminating the need for multiple manufacturing steps. For purposes of this study the Stratasys Polyjet™ J850™ TechStyle™ was used.

This document models the environmental impact of both methods within the Italian fashion specialist Dyloan Bond Factory, a subsidiary of the Pattern Group. Dyloan Bond Factory, established

cont'd.

in 1987 in Abruzzo, is focused on research, engineering, prototyping, customization, and production of semi-finished products, accessories, fabrics, and finished garments. Dyloan works closely with leading fashion houses to enable sustainable materials innovation across the supply chain.

This document models each manufacturing method within the Dyloan Chieti facility. The model is based on manufacturing 16,000 logo components for 8,000 pairs of designer sneakers. The analysis considers the environmental impact of the different manufacturing processes and materials. The primary analysis metrics are air, water, and land emissions, with air emissions expressed as Global Warming Potential (GWP) measured in carbon dioxide equivalent units (CO_2e).

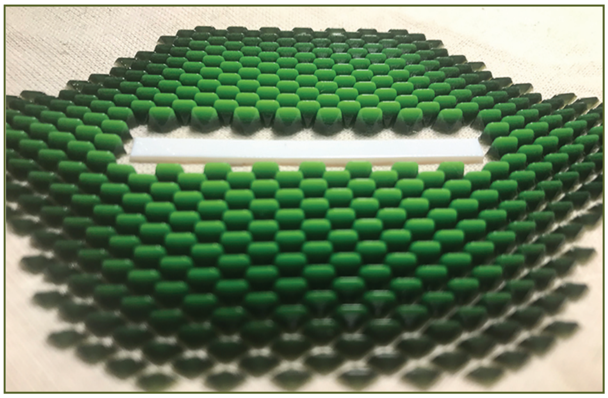


***Fig. 2** – Heel spur logo component 3D-printed directly onto fabric substrate.*

***Fig. 3** – Heel spur graphic location.*

***Fig.4** – Production detail image of full heel spur assembly.*

cont'd.

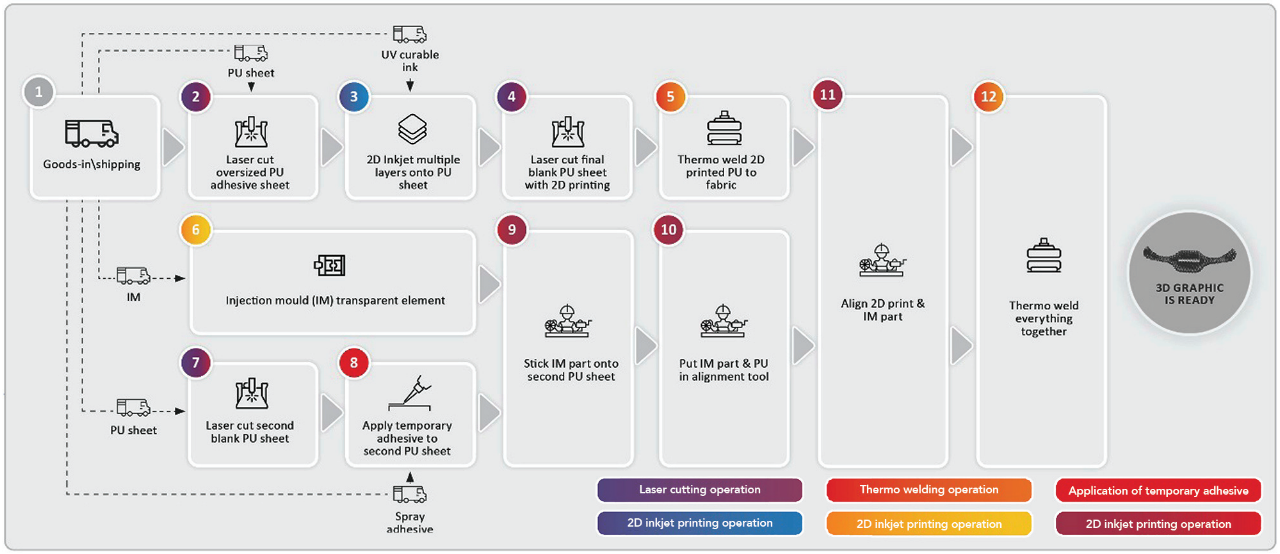
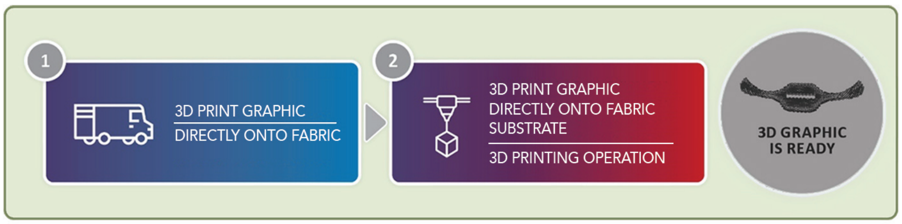


Fig. 5 (above) – traditional manufacturing process by steps

Fig. 6 (right) – 3D manufacturing process by steps



It should be noted that this document does not provide a full Life-Cycle-Analysis (LCA) of the finished footwear, as defined within ISO 14040:2006. Rather, the document provides a detailed Life-Cycle-Inventory (LCI) analysis for the 3D logo component manufacturing stage leading to eventual footwear production. The LCI analysis documented in this report is a technical process that quantifies all inputs to and outputs from the manufacturing stage within a system boundary. The inputs are energy and raw materials; the outputs are emissions to air, water, and soil; solid waste generation; products; and co-products.

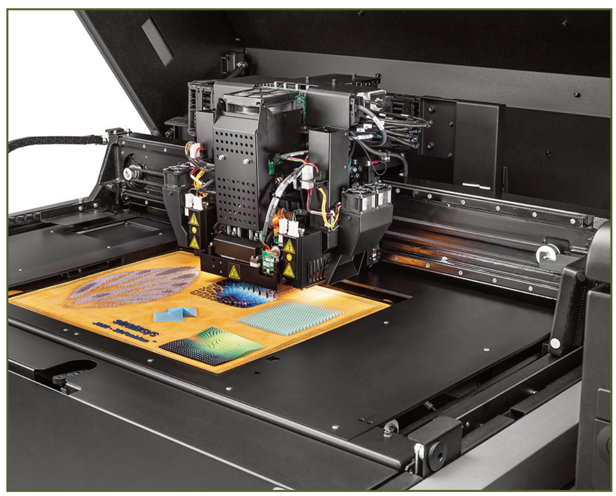


Fig. 7 Stratasys J850™ TechStyle™ 3D Printer

Summary of Findings

In the use case of designer footwear, 3D printing using material jetting produces a logo component with a 24.8% lower CO2e than traditional manufacturing using injection molding and thermo-welding. Across the 16,0000 logo components required, 3D printing would deliver almost one metric ton less CO2e emitted into the atmosphere. Moreover, this reduction in CO2e can be increased further by improving both the efficiency and productivity of the 3D printing hardware used.

cont'd.

Summary of Findings cont'd.

Across the supply chain, the 3D Printing approach requires 49.3% less material by weight than the traditional supply chain, eliminating over one-third of a metric ton of stock material. Moreover, the 3D-printed logo has 50.5% less material than the traditional logo, resulting in a marginally lighter-weight final product.

The traditional manufacturing route requires a paper-backed PU sheet material as the primary bonding agent, with large amounts of water needed to manufacture this paper. For the 16,000 logo components assessed within the study, over 300,000 liters of water were required to enable the traditional approach. This water footprint was mitigated with the 3D printing approach.

The traditional and 3D printing approaches produced similar levels of non-recyclable waste, circa 150 Kg, which can be incinerated for energy recovery. The traditional approach also produced over 131 Kg of recyclable waste, primarily paper. No recyclable waste streams were attributed to the 3D printing approach.

Although four different raw material streams enable the traditional supply chain, it was found to have a slightly lower impact than the 3D printing supply chain regarding transport-related emissions. The higher transportation impact of 3D Printing was largely due to raw material logistics and the distances associated with moving specialist 3D printing resins. By contrast, the traditional manufacturing method uses an established network of local supply chain partners.

Regarding direct emissions to the atmosphere during production, there were no measurable emissions from the Stratasys J850™ TechStyle™ 3D printer. Hence, no Scope 1 emissions are related to

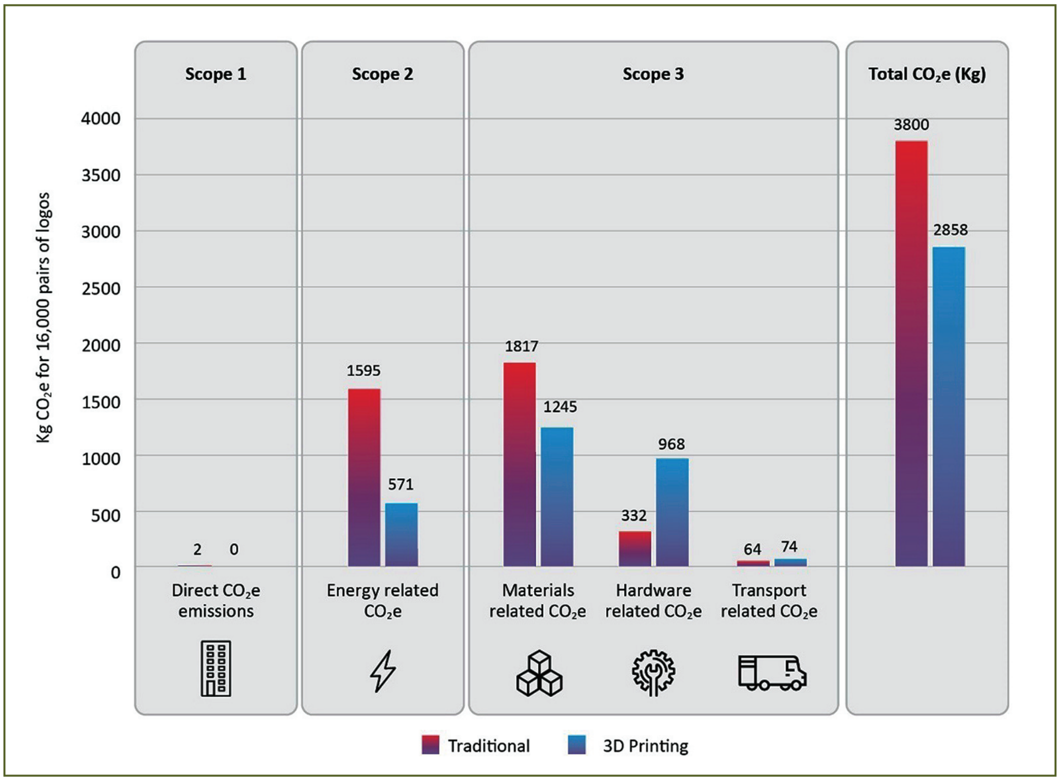


***Fig. 8** – GWP by scope for traditional manufacturing and 3D printing Of 16,000 logo components.*

cont'd.

the 3D printing approach. There are, however, minimal Scope 1 emissions from the traditional approach, where direct emissions result from multiple laser-cutting operations. However, these emissions represent less than 0.04% of the total CO_2e of the traditional process.

The traditional manufacturing approach using injection molding and thermal bonding requires 7,122 kWh of electrical energy. The 3D printing approach requires only 2,548 kWh of electrical energy. The 3D Printing approach, therefore, uses 64% less electricity than the traditional approach. It was found that 42% of the CO_2e associated with the traditional approach can be attributed to Scope 2 energy-related emissions. In contrast, only 20% of the 3D Printing approach was related to Scope 2 activities. This disparity in Scope 2 emissions would suggest that the physical location of the 3D Printer and the local energy mix will have less impact than the location of the traditional approach. In short, the traditional approach should not be adopted in locations with a poor energy mix.

Almost 80% of the CO_2e of the 3D printing approach was related to Scope 3 activities, largely the photocurable resins used in the 3D printing process and the materials from which the printer was made. It was suggested that the material-related impact could be reduced by adopting new 'green chemistry' formulations. Moreover, the hardware impact could be reduced through increased system productivity or more sustainable materials within the machine design.

Figure 8 (previous page) shows the distribution of CO_2e by scope for both manufacturing approaches when used to make 16,000 logo components.

Scope one direct emissions and scope three transport-related emissions represent only a small percentage of the overall GWP. The primary causes of CO_2e are the energy used within the manufacturing processes, the raw materials consumed during manufacturing, and the manufacture of the machinery needed to enable production.

In summary, using material jetting with a Stratasys J850™ TechStyle™ 3D printer, there is a clear environmental benefit when producing the use case of 16,000 logo components on a fabric substrate.

3D printing results in substantially less waste, CO_2e emissions, and global warming potential. Adopting 3D printing also reduces water consumption and the creation of recyclable waste.

Background

3D printing, also known as Additive Manufacturing, has been heralded by many as the catalyst for a new industrial revolution in the digital age[1].

3D printing makes tangible products layer-by-layer using highly automated machines. 3DP machines are used extensively to produce prototypes, tools, jigs, fixtures, models, and, more recently, end-use consumer products and parts. 3DP adoption is widespread across companies in almost all manufacturing sectors, from medical device manufacture and aerospace to automotive manufacture, electronics, communications, and space.

cont'd.

3D printing enables highly complex products to be made when and where needed. This digital shift can disrupt traditional industrial supply chains, enabling localized, just-in-time manufacturing, minimizing stock holding, and maximizing flexibility.

Initially, high-volume end-use 3D printed part manufacture was constrained mostly to patient-specific medical devices such as hearing aids, orthotic insoles, and dental. However, as 3DP processes have matured, increased productivity, and become more cost-effective, other end-use applications and markets have emerged. One such market is the fashion sector, where 3DP is used to make decorative elements of luxury goods such as garments, apparel, luggage, and footwear.
The growth in the use of 3DP within the fashion sector has led to the development of dedicated 3DP systems capable of printing directly onto fabric substrates. For this study, the Stratasys Polyjet™ J850™ TechStyle™ technology was used to deposit photocurable resin directly onto a fabric substrate.

The Stratasys TechStyle™ process can produce multicolor 3D Prints using multiple inkjet print heads in rigid, flexible, transparent, and translucent materials.

The TechStyle™ technology allows users like Dyloan to adorn fabric with vivid 3D structures. These structures cannot be achieved using traditional screen-printing techniques or 2-dimensional (2D) digital fabric printing technologies. Traditionally, the only way to create a 3D graphic structure on fabric was through a multistage manufacturing process using a combination of 2D image printing, injection molding, and thermal welding, which can be time-consuming and energy-intensive.

The advent of 3D printing on textiles has led fashion houses and brands to question whether this approach could now be more environmentally sustainable than established production methods.

The entire fashion industry is under enormous pressure to improve its environmental sustainability, no more so than the luxury fashion houses, specifically those engaged in footwear.

The fashion sector has long suffered from overproduction, excess stockholding and end-of-life waste streams, and a high reliance on water-intensive manufacturing processes. Digital manufacturing has the potential to address many of these issues through shorter supply chains, more efficient production, and less waste.

In 2012, researchers at MIT estimated that the carbon footprint of a typical pair of running shoes made from synthetic materials was between 11.3 and 16.7 Kg CO_2e. Most of this impact was due to the processing of the raw materials and the manufacturing methods used in shoe assembly. Over the last decade, there has been some effort to reduce the environmental impact of footwear. In 2022, Adidas collaborated with sustainable footwear company Allbirds to launch the Adizero, a running shoe with a reported impact of only 2.94 kg of CO_2e per pair. However, many footwear and fashion companies are still searching for sustainable production methods to reduce the environmental impact of their products.

3D printing could, in part, present a more sustainable solution. As a digital manufacturing process, 3D printing can produce small batches of products as the consumer requires, minimizing stock

cont'd.

holding and overproduction. 3D printing can also replace multiple manufacturing stages within a supply chain, potentially mitigating the need for assets such as tooling and reducing transportation between supply chain partners. Moreover, many 3D printing processes may be more efficient regarding material consumption, energy utilization, and waste, making them a sustainable alternative to traditional manufacturing processes.

However, little evidence supports these claims within the fashion sector or when considering using material jetting 3D printing technology. To this end, the Additive Manufacturer Green Trade Association (AMGTA), working in partnership with Dyloan and Stratasys, set out to undertake a detailed sustainability analysis within the footwear supply chain focused on a specific use case.

The use case chosen was a 3D logo component used to adorn the heal-spur area of design sneakers for a leading fashion brand.

To provide a comparative analysis, specialist consultancy Reeves Insight Ltd was commissioned to model and simulate the production of 16,000 logo components to manufacture 8,000 pairs of sneakers using 3D printing and a more traditional manufacturing approach. .

The 3D printing approach uses a Stratasys J850™ TechStyle™ hardware platform processing photocurable liquid resins. The traditional approach combines 2D inkjet printing and thermal welding of injection molded parts with sheet polyurethane materials.

It should be noted that the simulation and subsequent analysis within this report only consider replacing the graphic manufacturing stage with 3D printing. It does not consider 3D printing the entire sneaker or the life cycle of the final sneakers. As such, this document should not be considered a full LCA for 3D-printed footwear, only an LCI analysis for the 3DP logo component.