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Additive Manufacturing & Injection Molding

Comparing, Contrasting & Considering the Opportunities

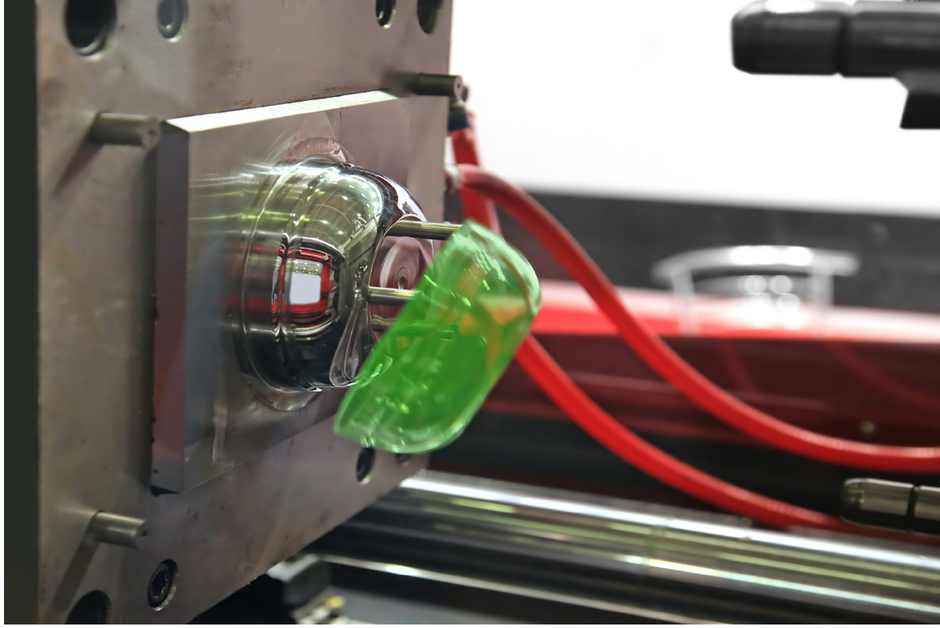
E-Book

3D printing, also referred to as Additive Manufacturing, is often viewed as a manufacturing process competing — or at least trying to compete — with the more well-established injection molding process for the production of plastic parts. There is actually some value in this narrative because for some applications AM can compete well. This is because industrial 3D printing technologies and materials have evolved, and continue to evolve, into production processes that can more efficiently and cost-effectively produce higher volumes of parts. This competition is good — up to a point. Not everything has to be viewed as competitive, however, and with these two manufacturing processes there is actually some complementary cross over. And, let's be real, for very high volumes of plastic parts (100's of thousands) AM is still not even in the same ball park as injection molding.

3D printing has long been accepted as a vital tool in the development phases of product development: it enables speedy design iterations and incisive engineering decisions. However, most manufacturing teams leave the technology right there in the development phase – as a prototyping tool only.

When that happens, a trick is most certainly being missed. 3D printing technologies have advanced in both capability and capacity meaning that for low / medium volume and HMLV applications they can either compete directly with injection molding or they can enable more effective injection molding by producing the moulds.

This paper aims to consider the scope of both processes, their advantages (and disadvantages) for production and where they are actually complementary to each other.



The Overall Landscape

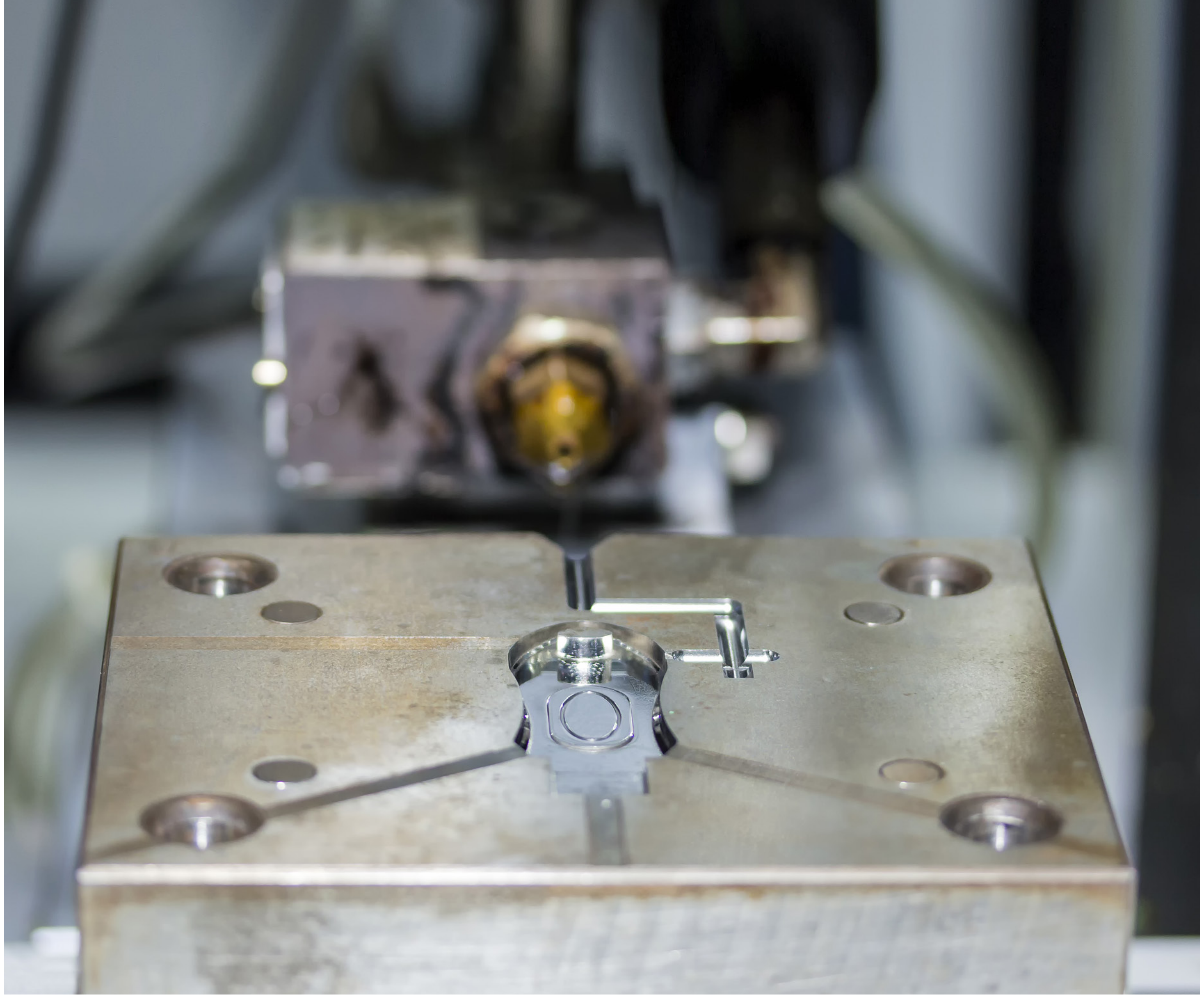
At the outset, it is worth taking a quick look at the landscape for each of these manufacturing processes within the larger context of the global manufacturing sector. For the latter, one source quotes the value of global manufacturing production in 2022 to be US$ 44.5 trillion and predicts it to decline to US$44.3 in 2023 (due to the well documented post-pandemic issues and the effects of the war on Ukraine). It is probably best not to take these numbers as absolute values; however, for illustrative purposes and as a guestimate, it works well enough as the baseline for the specific sub-sectors of injection molding and AM.

Both of these manufacturing sub-sectors have wildly varying valuations. GM Insights quotes that the "[i]njection moulded plastics market garnered over USD 300 billion in 2022 …. [and] the industry is set to witness 3.5% CAGR from 2023 to 2032." This is in line with the analysis from Grand View Research which quotes "the global injection molded plastics market size was valued at USD 284.7 billion. It is expected to expand at a compound annual growth rate (CAGR) of 4.2% during the forecast period [to 2030]." A more conservative analysis is presented in a recent report from Research & Markets, which states: "The Global Injection Molding Market was estimated to be valued at $187.7 Billion." At least the later qualifies that it is an estimate!

There are similar variations in the value of the AM sector too, depending on where you look. This time, Research & Markets is not so conservative and says that: "the global market for Additive Manufacturing and Materials [is] estimated at US$ 40.4 Billion [and] is projected to reach a revised size of US$196.6 Billion by 2030, growing at a CAGR of 21.9% over the analysis period. Plastic … is projected to record 22.3% CAGR and reach US$118.2 Billion by the end of the analysis period. A more recent report from Market Watch states that "[t]he Global Additive Manufacturing & Materials Market was valued USD 16.07 billion … and is expected to register a CAGR of 25.7% over the forecast period." While according to SmarTech Analysis, the report they published recently states even more conservatively that the AM industry grew 23% to US$13.5 billion, but projects it will grow to $25 billion by 2025.

The most recent Wohlers Report also points to strong "AM industry growth of 19.5%" and currently values the sector at $18 billion, with strong growth projections.

If we take the median values — $243 billion for injection molding and $26.95 billion for AM — it is immediately obvious that the injection molding sector is almost 10 times the size of the AM sector as of today. If the (surprisingly consistent) predictions for growth rates of each sub-sector remain accurate, however, AM is going to close the gap significantly over the next decade or so. It would seem pertinent to also point out that the injection molding figures focus solely on plastics, while the AM figures include all material types, so the gap is actually bigger than at first glance, within the scope of this paper.



At a Glance
Injection Molding vs. Additive Manufacturing

Injection molding is a leading process for the manufacture of plastic products and components. It is widely used for the mass-production of identical parts with tight tolerances (typically 50 to 100 microns) and superior surface finishes. For high volumes it is a cost-effective, accurate and repeatable process that yields high-quality parts for large series production in a broad range of materials.

Industrial 3D printing technologies increasingly offer viable production alternatives for plastic product manufacturers, with some competing extremely well on surface finish and tolerances (typically 50 to 300 microns). Moreover, 3D printing presents a number of key advantages over injection molding because it is a wholly tool-less process that also provides unprecedented flexibility when it comes to design, both in terms of complex geometries and part consolidation. This flexibility also facilitates low-cost design iterations ahead of full production, during production or for future product generations.

Considerations

As any manufacturing team knows, there are fundamental questions that must be asked — and answered — for any new product development project. Leaving aside the development phase, the following questions pertain to production and process selection. Experienced manufacturing teams will likely have an idea of the route they'll take — maybe even be pre-disposed to an existing process. Or, manufacturing teams could address these questions with a view to challenging the status quo?

The starting point for determining the most suitable manufacturing process for any product or component, as it has ever been, is the application.

1. How straightforward - or complex - is the part?

The answer to this question can directly inform the manufacturing process selection. And yet, you probably already realise that it is not always as obvious as:

- simple parts equal injection molding

- complex parts equal 3D printing.

When is anything ever that simple?

It is true that injection molding is particularly suited to straightforward designs and parts with consistent wall thicknesses. With that said, injection molding does not preclude complexity and can accommodate parts with undercuts and intricate features. This comes at a premium, however, because as the complexity of the part increases, so too does the complexity of the tooling required to injection mould the parts. This adds significant, upfront costs to production. However, once the tool is prepared and ready to go, production can begin at the manufacturing location immediately.

There is, though, a definite complexity gradient for injection molding that has to be taken into account: go too high and the costs can become prohibitive. Go further still and you reach a ceiling and it becomes impossible.

It is no secret that 3D printing can produce parts that are too expensive or impossible with injection molding — it's one of the many well-documented benefits of additive technology. It's also the go-to argument for making 3D printing a "competitive" manufacturing technology. The argument is not without merit — it is not hard to find examples of the complex geometries such as lattices, internal channels, overhangs, thick/reinforced walls and hollowed out sections that industrial 3D printing systems can produce that injection molding struggles with.

This capability offers myriad opportunities for designers to reduce weight, build in ergonomic features and add logos and part identification, to name a few advantages.

The size of a part is also a fundamental question in determining how it will be produced. Curiously, both injection molding and 3D printing operate optimally in the small – medium part size range. For 3D printing, build volumes are the limitation. However, large parts can be built in smaller sections and assembled post-build. For injection molding, again, machine size can constrain part size but moulds can be made in multiple pieces to produce parts that can be later assembled. Thus, both processes can accommodate larger product sizes but this comes with trade-offs in terms of additional downstream assembly and considerable time and cost penalties.

2. How many parts are required in total?

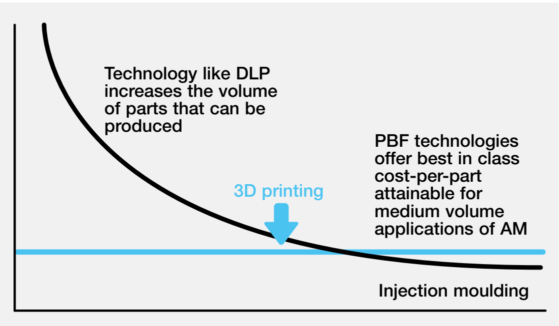
This is where is gets interesting.
Injection molding is proven, over many years, to be highly cost effective for high and very high volumes of products.
It is also a fact that 3D printing cannot even begin to compete at this level.
But, what, precisely is "this level"?
From experience, it is easy to get lost down the rabbit hole when trying to put specific numbers on low volumes, medium volumes and high volumes of product. There are wild variations depending on how you try to contextualise it and between different research sources (industry sector, applications within that sector, manufacturing process etc; even between service providers offering a number of different manufacturing processes).

Using a number of sources and a little common sense, a rough but sensible set of general boundaries is suggested as follows:

Low volume: <1000 parts.

Medium volume: 1000-100,000 parts.

High volume: >100,000 parts



The chart above is a generalized cost curve of 3D printing versus injection molding. The x-axis depicts the number of parts and the y-axis the cost per part. At the intersection and onwards along the x axis, injection molding is the more cost effective. The reason this chart does not have numbers on it is because the numbers at that intersection have changed a great deal over the last decade, and they continue to change with the intersection getting lower down the curve. To reiterate – it always depends on the application — but the process capabilities and capacity of 3D printing keep improving. Production runs in the tens of thousands for small application of plastic products with 3D printing are not uncommon today. Examples can be found across the dental, medical, general manufacturing (enclosures and fixtures etc) sectors.

This leads to some supplementary considerations for volume requirements that can have a big impact on costs, logistics and, yes, sustainability:

2a. Are parts required all in one go or over a number of months / years?

Let's use a generic example of a small part, with medium complexity. If this part is required in high volume (> 100,000), in a single production run, we've established that 3D printing will not compete well with injection molding. However, if a more agile approach to production is required with medium volumes of a similar product but over a longer period of time, 3D printing can again become a viable option to supply production-on-demand and greatly reduce stock piling and inventory.

If, say, 60,000 of these parts are required over a 12-month period, they can be produced in one run with injection molding, or they could be produced in a series of 5,000 parts per month (or as required) with 3D printing.

Which leads to:

2b. When and where do you need your parts?

Again, this question refers to agility in production both in terms of where the parts are produced and how they are distributed. Rather than producing 60,000 parts in one location (which injection molding dictates) and distributing globally, 3D printing is a digital process, allowing parts to be produced in the numbers required at the location they are needed. This has cost implications as it can reduce shipping costs significantly, while simultaneously having a positive environmental impact. One final point on this, localising production in this way and moving it closer to markets and customers also goes some way to mitigating supply chain risks.

3. Cost per Part

This is the big one. Possibly the most important one. But it still needs to be considered within the context of the previous points.

One of the huge advantages of 3D printing processes is that they are tool-less processes. The production of the tool mould for injection molding is costly and time-consuming and it all happens up front. And here is the critical point – injection molding requires large up-front capital investment for production to take place. As outlined above, 3D printing for production allows for a pay-as-you-go business model, especially if working with a contract manufacturer, but even if production is in-house.

This is where the volumes come in to play, because for the highest volumes the ROI on injection molding in terms of cost-per-part can be dramatic — the cost of the mould tool is static and so the higher the volumes of parts produced from the mould, the lower the cost per part. With 3D printing the costs will be uniform from part 1 to part 20,000+ (the chart above, in the volume section, illustrates this point as well).

The chart below also gives an overview of price comparisons for some specific parts and when and how 3D printing, with SAF technology, can compete successfully.

Parts cost comparison - Injection Molding vs. SAF

	Part Name	Dimension [mm]	External Inj. Molding Cost per part $	SAF H350 Cost per part $	Saving	Break-even total production volume	Max Parts Per Build
	Cable clip guide	15x17×49	$ 2.35 5,000 parts/yr	$ 2.19	7%	19,900 parts	1020
	Bracket	60×55×55	$9.40 500 parts/yr	$4.10	56%	6,536 parts	171
	Electronic connector	80×80×52	$ 119.48 50 parts/yr	$30.61	74%	820 parts	30

There are many factors to consider in the cost-per-part equation: there is the obvious production activities themselves (machines, energy, material costs, labour, post processing etc). But also, the additional considerations of distribution, shipping, storage and warehousing.

4. Iterations

Another consideration that is worth pointing to: will there be product iterations and therefore design changes? This is another area where 3D printing technologies offer a significant advantage for ongoing production, and where injection molding can be restrictive. Manufacturing with 3D printing technologies allows an ongoing, iterative approach. Changes can be made at any time with little to no cost implications. Once a mould tool has been commissioned for a specific product or part, it is pretty much set in stone, or, at least, steel. Modifying it is nigh on impossible, if not very expensive.

5. Materials

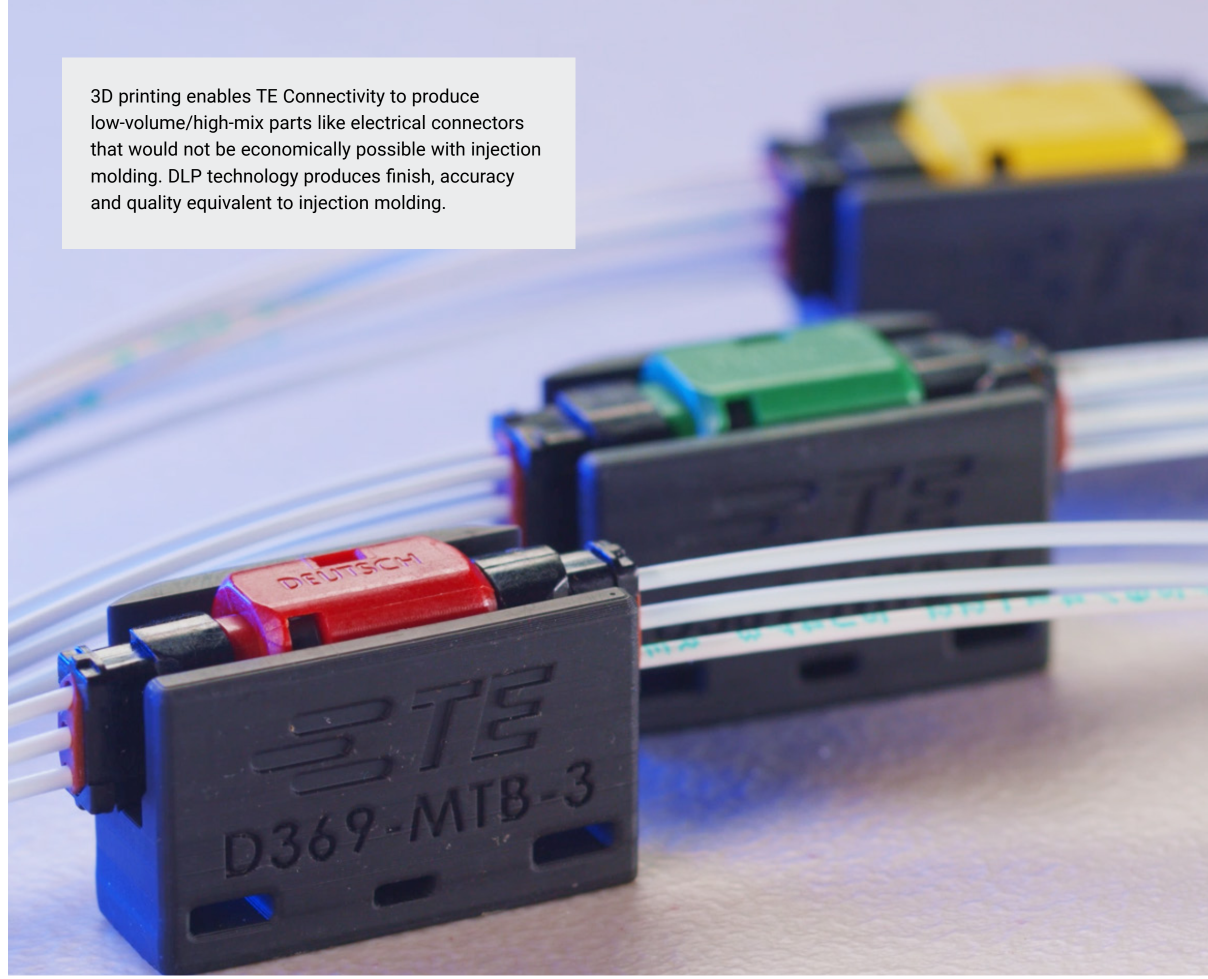
Industrial production technologies require the availability of polymer materials that provide the right properties for the selected application. The most widely used polymer materials are also available for 3D printing processes — think thermoplastics such as PA 11, PA12 and glass-filled & carbon-filled Nylon as well as photopolymers or thermosets.

However, despite significant developments in production-grade specialty materials for 3D printing, the palette of material options is still smaller for 3D printing compared with the thousands of options available for injection molding.

As manufacturers continue to discover the benefits of 3D printing for manufacturing applications, material companies continue to invest heavily in developing more "functional" materials, both photopolymer thermosets as well as powder and filament thermoplastics. While many high-performance materials are focused on improved mechanical properties, we are now starting to see additional functionalities being added; such as weatherability, ESD (electro static discharge), FR (flame retardancy), FST (flame, smoke, toxicity), low loss dielectric, food contact and medical grade. These next generation AM materials are clearly aimed at addressing end-use parts that need specific functionality for specific applications.

This evolutionary journey of such AM thermoplastic and photopolymer materials parallels the evolution of IM thermoplastics, which were at one time in a similar state, offering a basic materials palette that grew through specialization, one application at a time, to the vast range of options available today.

This air duct part of an automotive HVAC system, printed with SAF™ technology. Traditionally, a part like this might be molded as two halves and assembled. With SAF technology, the halves can be produced as a single part, reducing post process assembly and points of failure.



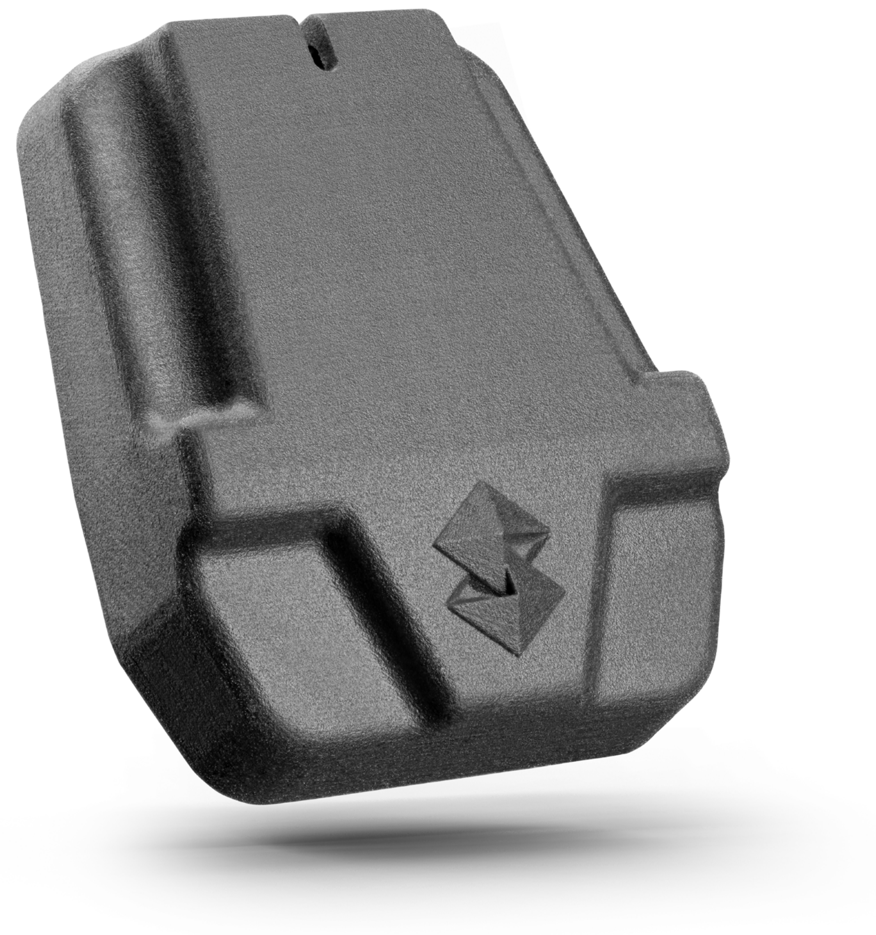
3D printing enables TE Connectivity to produce low-volume/high-mix parts like electrical connectors that would not be economically possible with injection molding. DLP technology produces finish, accuracy and quality equivalent to injection molding.

Not Necessarily Either / Or

So, here's the thing: while 3D printing can provide a viable, efficient and cost-effective alternative to injection molding for some applications; it can also act in a supporting role for injection molding. There are ways that these two technologies intersect in a really useful way that can significantly reduce time and costs.

At the outset, we established that 3D printing remains a vital tool for prototyping. It can also play a vital role in the end-to-end injection molding process in a number of other key ways. The prototypes are a given, to develop the parts in terms of form and function as well as manufacturability. Beyond prototyping though, 3D printing can also fulfil a bridge tooling function for injection molding, whereby an intermediary tool (produced quickly and inexpensively with AM) can be used to adapt, optimize and test the process before committing to the final (much more expensive) tool. Moreover, the capabilities of metal AM systems mean that 3D printing can also be used to produce the mould tools themselves, particularly if complex, multi-cavity tools are required. Tool steel materials and even some more advanced metal materials have now been qualified for use with a number of additive systems.

This typical automotive rain sensor cover was printed by the H350™ 3D printer and created with SAF™ technology. This part has a low cost per part, based on 1,000 parts, compared with injection molding



To Round Up

3D printing technologies, both in terms of capabilities and capacity, have proven that they have made the transition from prototyping to manufacturing processes. This is a vital shift for manufacturing applications where 3D printing can be more efficient and cost-effective. However, it is just as important to state that 3D printing remains a really useful process for prototyping and tooling applications.

Manufacturers are constantly looking to manage costs as they face increasing pressures and competition. The purpose of this paper is to provide some insight into how that can be achieved by considering a variety of options.

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