HP EV WHITE PAPER

Polymer Additive Manufacturing in the Electric Vehicle Sector

Introduction

Like many other industries, the automotive market is reeling from the effects of disruption. Shifting consumer preferences have led to a realignment in production.

Picture 1: Tesla car

Introduction

The (traditional) automotive industry is also faced with new competition, which is largely focused on electric and autonomous vehicles.

Due to a semiconductor chip shortage in 2020, 2021 and into 2022, many automakers are even rethinking their sales and delivery models.

Additive manufacturing has the potential to be transformative in the automotive sector. Because it is a digital workflow, there are many efficiencies to be gained, not only in how and where products are manufactured, but also how they are designed, tested and eventually distributed. Using advanced tools and workflows, parts can be developed in CAD and optimized with the help of data validation software and printed when and where they are needed.

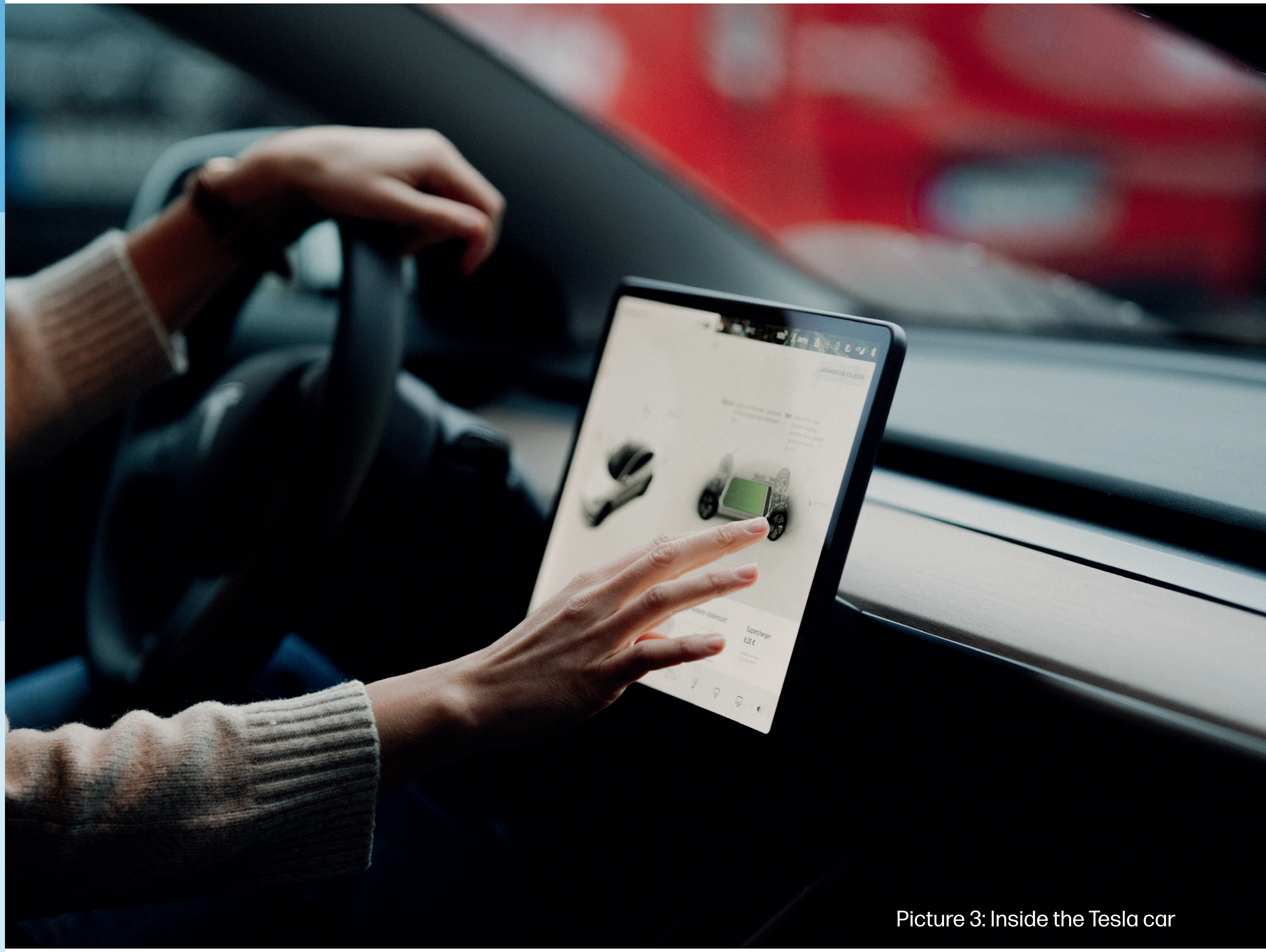
Additive manufacturing can also help automotive companies with light-weighting. Reducing the weight of a vehicle helps improve its energy efficiency. The digital technology inherent in 3D printing, combined with generative design and other software tools, can help engineers reduce the weight of individual parts while also reducing the overall number of parts, and simplifying assembly of larger components.

Key take-aways

- Additive manufacturing is already a reality for final parts production.
- The design freedom afforded by additive manufacturing can help improve the performance of electric vehicles.
- Additive manufacturing is becoming a viable option for production while also supporting product development.

Picture 2: Tesla car steering wheel

But while the auto industry sees the opportunities with additive manufacturing, two big issues have kept it from reaching its full potential. The biggest challenge has been with part quality. In order to fully complement other production methods, parts need more than functionality. They have to look and feel professional, while also being repeatedly accurate.



Picture 3: Inside the Tesla car

Cost at scale has been another big barrier. When comparing additive with injection molding for example, there is typically a breakeven quantity where it becomes less expensive to mass manufacture. Until recently, that number was fairly low for most applications. But historically, over time, digital technologies become better, less expensive, and faster. To receive serious consideration, additive manufacturing needed to follow a similar path, and with the help of recent innovation, the industry has reached an inflection point.

Why Electric Vehicles?

Back in 2015 if you had asked an automotive executive about the threat of disruption, few would have predicted what actually occurred. In its annual survey of automotive executives, KPMG asked the respondents if a major disruption would happen over the next five years. In 2015, over half thought it was unlikely. Just one year later, an overwhelming 82% said a business model disruption was somewhat or extremely likely to happen.[1] What caused them to rethink their position?

In April 2016, Tesla announced the Model 3

Their new electric vehicle (EV) promised good performance and battery life with a starting price of just $35,000 (USD). Within a day of the launch, Tesla booked over 200,000 reservations for the new car. Since then the Model 3 has become the best-selling electric car in history with more than 800,000 units delivered through December of 2020.[2]

Picture 4: Tesla lights

Fast forward to 2021 and Tesla's market capitalization is an estimated $1 trillion (USD). By contrast, Toyota and Volkswagen – the world's two largest automakers – have a market cap of $252 billion and $134 billion respectively. The market caps for U.S. automotive giants GM and Ford are even lower at approximately $91 billion and $85 billion.[3]

In addition, several new players have entered the market. Rivian, which made headlines with an initial public offering (IPO) valued at $86 billion beat Tesla, GM and Ford to market with a fully electric pickup. The company's investors include Ford, which considers Rivian a strategic play, and Amazon which has ordered

Tesla Model 3

Picture 5: Tesla Model 3

100,000 Rivian vehicles to be delivered by 2030.[4]

China has also invested heavily in electric vehicles and has made significant gains over the last few years. By the end of 2019, there were over 2.5 million battery electric vehicles (BEVs) operating in China, compared with less than 1 million each in Europe and the USA.[5]

While China may have taken an early lead, recent data suggests that EV sales are gaining ground elsewhere. Nowhere is this trend more evident than Norway, where 65% of new cars sold in 2021 were electrified. A year earlier the number was 54%, and with the incentives Norway's government has put in place, EVs are expected to account for as much as 80% of sales in 2022.[6]

Is it any wonder then that when KPMG conducted its survey in 2020, battery electric mobility was seen as the most important trend in the automotive industry?[7] Industry investments also reflect those views. Between 2019 and 2025, automakers will invest $37 billion (USD) in their North American plants. According to LMC Automotive, over 77% of that spending will be directed at sport utility vehicle (SUV) and EV projects, and 28% will be spent on projects that encompass both.[8]

For example, in September 2021, Ford Motor Company announced plans to scale its electric vehicle offering. It will be investing over $11 billion in two massive campuses that will produce the next generation of electric trucks and the batteries needed to power future Ford and Lincoln vehicles. BlueOval City, a $5.6 billion facility which will be located in Tennessee, will have its own battery plant and focus on building electric F-Series pickups. The other facility, which will be called BlueOval SK Battery Park, will be located in Kentucky and consist of twin battery plants that will be utilized in other Ford and Lincoln EVs. The company will invest $5.8 billion in that facility and together the two locations will employ over 11,000 workers, while generating over 129 gigawatt hours per year of U.S. battery production capacity.[9]

General Motors is also ramping up to meet the demand for electric vehicles. In October of 2020 they announced Factory Zero as a cornerstone of their EV strategy. Instead of shuttering their Detroit-Hamtramck facility, GM said it was investing $2.2 billion into the factory so it could be used to build the new GMC Hummer EV truck and other electric vehicles. Factory Zero officially opened in November of 2021, and will also produce the Chevrolet Silverado electric pickup and the Cruise Origin, which GM calls "a purpose-built, electric, self-driving shared vehicle."[10]

Picture 6: Mustang Mach-E

Polymers in Automotive

Cars and trucks are made with many different materials and while they typically only make up 10% of the weight of a vehicle, up to 50% of the volume in modern vehicles are typically plastics. The use of plastics is expected to increase as manufacturers strive to further reduce weight, increasing performance and fuel efficiency.

Right now, three main types make up 66% of the plastic used in manufacturing a car: polypropylene (32%), polyurethane (17%) and polyvinyl chloride (PVC) (16%). While they are used in many different automotive applications, interior furnishings currently account for more than 44% of the plastics used to produce a vehicle. Electrical components and exterior furnishings each account for approximately 15%. Powertrain, under the hood, and chassis applications make up the remainder.[11]

As automakers explore new areas including body and light panels, seat bases and covers, steering wheels, floors, headliners, rear package shelves and fascia systems, the amount of plastics used in vehicles is likely to grow even further. Consumer demand for in-car connectivity and the digitization of modern vehicles are also driving innovation in plastics. As software and powertrains continue to evolve there are new safety concerns and needs for materials that can help improve performance while also providing better heat resistance and electrical properties.

In the automotive industry, injection molding is one of the most common processes used to mold plastic. Because of its broad range of capabilities, injection molding is used to produce door handles, hoses and tubes, console and dashboard trim, entertainment console covers, buttons, panels and more. Blow molding is also widely used with plastics because of its ability to produce complex parts that cannot be made economically with other technologies.

Picture 7: Charging station

3D Printing in Automotive, Then and Now

"In addition to surface quality and dimensional integrity, one of 3D printing's biggest opportunities lies in its ability to bring polypropylene, TPU, and nylon to the automotive market," said automotive industry expert, Michael Whitens. "For 30 years prior in the additive industry, those materials and machines that could run them, were scarcely available. Being able to 3D print the same materials that are used in mass production creates opportunities throughout the automotive product lifecycle."


Picture 8: Mustang Mach-E

When it purchased the third 3D printer ever made over 30 years ago, Ford Motor Company became one of the earliest adopters of additive manufacturing.[12] Since then many companies in the automotive industry have experimented with the technology and achieved varying levels of success. In the early days, machines were expensive and slow, part quality was rudimentary and there were few performance-oriented materials. As a result, 3D printing found its early foothold in modeling and prototyping.

In the last five years though, the 3D printing industry has advanced further than it had in the previous 30.[13] With better machines, materials, software and know-how, automotive companies are pushing their additive manufacturing aspirations beyond prototyping into digital production of final parts.

3D printing has advanced to the point where it now offers several distinct advantages. Because parts are built additively, layer-by-layer, they can be designed in new, more efficient ways. By implementing design for additive manufacturing (DfAM) principles, designers can improve and consolidate their current parts and even simplify components, reducing complex assembly steps.

The combination of 3D printing and DfAM also allows engineers to create lighter-weight parts, which are critical in certain industries, including automotive. When weight is reduced, vehicles operate more efficiently and expend less energy. For example, reducing the weight of a gas powered vehicle by 10% can help improve its fuel economy by as much as 8%.[14]

3D printing is Ideal for EVs

Perhaps nowhere is light-weighting more valuable than with electric vehicles. As mentioned above, under the same conditions, a lighter vehicle consumes less energy than a heavier one. Lightening the weight of EVs has a circular effect. Less overall weight means a smaller, more efficient battery can be employed, which of course further reduces weight.

Beyond light-weighting, 3D printing empowers electric vehicle manufacturers with many other benefits. Because parts are made digitally, they can be economically manufactured in small batches enabling just-in-time and on-demand production. A digital workflow also means that parts can easily be customized or personalized and be produced in hours instead of days or weeks, offering a speed-to-market advantage that can have a dramatic impact on overall production time.


Picture 9: Electric charger

EV Applications for 3D Printing

"There are scenarios where it makes sense for companies to use additive for early validation and then switch to injected molded parts later down the road," said Aaron DeLong, HP's 3D Printing Applications Development specialist for automotive. "In those circumstances, they should consider running both types of parts through their entire validation plan. Currently, injection molding will likely be less expensive at 100K parts, but if both technologies have been tested, when volumes diminish to the point where additive is cost effective, they can make the switch as the additive part has already passed the validation process."

Prototyping and Verification

While advanced software can simulate performance, physical testing is still needed. 3D printing is ideal for small part volumes, and the quality and material properties of some 3D printing technologies allow engineers to produce parts that can be tested in real-world conditions. These advanced prototypes are very different from those produced by earlier 3D printing technologies. They're capable of holding liquids and gasses, making them ideal for bottles, hoses and other automotive components. The cost per part is also low, allowing designers to make full use of generative design, printing and testing prototypes until the part is completely optimized for final production.

Picture 10: Electric charger

At Extol, a Michigan-based company that specializes in plastics assembly technology, custom automation, and engineering services, for example, teams build functional prototypes of fluid reservoirs using polypropylene (PP) parts made from injection molding. They can complete the final assembly in one day, but the customer supplies their own injection molded parts and Extol must often wait for up to 7 weeks for them to arrive. Even though Extol has no control over when the parts will show up, the delays in functional testing and validation caused the customer to push for faster design cycles and improved efficiency.[15]

Picture 11: Tesla electric charger

In an effort to save time and better control the manufacturing process, Extol leveraged 3D printing technology to additively manufacture fluid reservoir prototypes with polypropylene. They then used hot-plate welding and other typical plastic assembly processes to build final components. The combined parts were non-porous and were capable of fluid tightness, allowing the new functional prototype assemblies to be burst- and leak-tested using the same methods that were utilized with the previously injection-molded parts. The combination of advanced 3D printing technology and a specially-formulated polypropylene material allowed Extol to reduce the overall time for prototyping and validating this critical automotive component from 7 weeks down to just 6 days.

As global automakers race to build new EV platforms, having the ability to shave weeks off the development cycle for any part is helpful, but when applied throughout the vehicle, 3D printing technology has the potential to help automakers save months or even years of development time.

Final Parts Production

In 2020, electric vehicles set sales records in the U.S., and reached an all-time high market share of 1.8%. In the month of December alone, EVs earned 2.5% of market share and are estimated to achieve 3.5% of total market share by the end of 2021. More than 100 new EV models are expected to launch over the next four years and by 2025 this is forecast to help propel total EV market share beyond 10%.[16]

Statistics like these help underscore the urgency vehicle manufacturers face regarding electric vehicle development. But, while the growth is impressive, real-world numbers are still relatively small. So far in 2021, Tesla has sold almost 80,000 of its Model Y crossover, and over 50,000 Model 3s.[17] But others such as the Nissan Leaf and the Porsche Taycan have sold only 7,229 units and 5,367 units respectively. By contrast, the three top-selling gas powered vehicles in the U.S. (pickup trucks from Ford, Ram and Chevrolet) have sold nearly a million units in the same timeframe.

Picture 12: 3D-printed coolant manifold

For automakers the move towards electrification causes a big dilemma. Until the demand is high enough, they need to build their new electric vehicles in smaller volumes competitively while also managing profitability. For established brands this is difficult enough, but for smaller brands and startups it's even more challenging.

In some scenarios, 3D printing offers a competitive advantage for shorter runs. For example, EDAG is a leading global engineering service provider for the automotive industry with headquarters in Wiesbaden, Germany. In the process of developing systems for a client's electric vehicle, they identified a coolant manifold that was ideal for additive manufacturing.[18]

Using an integrated solution from HP and Siemens, they were able to 3D print production quality parts, at the quantities they needed, faster, cheaper and more sustainably than they could have with traditional processes.

Cadillac Blackwing

"As EV markets expand, volumes will continue to increase and that will need to be addressed," said HP's DeLong. "3D printing and technologies like injection molding are complementary. As production speeds get faster, additive manufacturing can absorb more short-run work."

While manual transmissions are still the choice for many enthusiasts, sales have declined over the last decade. For example, only 23% of all 2019 Chevrolet Corvettes were sold with a manual transmission. As a result, with the launch of the new C8 model – and for the first time in 67 years – the brand decided to forgo offering a manual transmission.[19]

Cadillac recently announced the specifications for its 2022 V-Series Blackwing cars. Not only are they the most powerful Cadillac models ever introduced, they are also available with a stick shift. Unlike the rest of the industry, Cadillac's Blackwing customers buck the trend, ordering a manual 62% of the time.[20]

The Blackwing series also represents a breakthrough for GM as they are its first models to utilize 3D-printed production parts.[21] Manual versions of the car feature several parts that were designed for additive manufacturing. Two of the parts are air ducts made with HP Multi Jet Fusion technology and unique PA-12 nylon material. Not only are they functional, helping create space for the manual gearbox, they're also cost-effective. Doing so helped GM prove that additive manufacturing technology was the most cost-effective manufacturing solution.

Picture 13: 3D printed HVAC ducts and metal bracket for 2022 Cadillac Blackwing vehicles

Coatings and Finishings

Parts in modern vehicles don't just need to be functional, they also need to meet aesthetic standards. With interior trim pieces, this might mean using colors like gloss black and mimicking textures such as wood grain and brushed aluminum. Electrical components such as wiring harnesses, electrical connections and battery covers typically use colors like orange and yellow to communicate high voltage and other potential safety issues.

In addition to painting, research has been done by companies like Cerakote and BASF with regards to coatings that will easily apply and adhere to polymer-based 3D printed parts. Cerakoting offers many unique performance properties including improved hardness and impact strength, in addition to increased abrasion, wear, corrosion and chemical resistance. Forerunner 3D, a leading 3D printing service bureau based in Michigan, is an innovator in the space and has successfully cerakoted parts made from several 3D printable materials, including nylon and TPU.[22]

Jigs and Fixtures

"With conventional manufacturing, you will get a batch of fixtures in a period of weeks or months," said Mark Wynn from Yazaki North America Inc. "With 3D printing you get your parts in a number of hours, you have a low cost per part, and you get the benefit of strong, durable materials."

Even when end-use parts don't make sense for 3D printing, it can still play an important role.

Jigs and fixtures for example, are complex manufacturing aids that improve accuracy and repeatability by helping robotic and human operators hold, guide, and align specific parts and components throughout production and assembly. These tools are highly customized and until recently most were Computer Numerical Control (CNC) machined.

But over the past few years that has changed. Now more and more companies are 3D printing their jigs and fixtures. In part this is speed and cost-driven. Jigs and fixtures are typically needed quickly and produced in low quantities, making them ideal candidates. But the design freedom offered by additive manufacturing increases value by allowing companies to simplify their parts, reduce weight and even manufacture entire assemblies as one piece. Ultimately they save time and cost throughout the production process.

It can cost as much as $10,000 to manufacture an electric vehicle battery.[23]

The cells themselves account for 60-80% of the total costs but batteries have many other parts including electronics, connectors and packaging that enable their safe and efficient use. The assembly process is complex and labor-intensive, making jigs and fixtures a necessity.

As mentioned earlier, with Blue Oval City, Ford is demonstrating its focus on renewable energy, advanced batteries, and innovative new vehicles. The Blue Oval SK battery plant that Ford is building as part of the project is designed to manufacture vehicle batteries, including the supply of raw materials and components and recycling of key materials. Ford has a history of using 3D printing to build hand tools, jigs and fixtures[24] and it is likely they'll utilize the technology further to support the shift to battery manufacturing.

Picture 14: Tesla car

Other Manufacturing Aids

Robots already play an important role in automotive manufacturing, and with electric vehicles the usage of robotics is likely to increase. Manufacturing the batteries themselves is complex, requiring both strength and precision. EV batteries also operate at high voltages and contain hazardous materials, making them ideal for robotic assembly.

But automation isn't perfect. At least a dozen battery fires happened with the Chevrolet Bolt, forcing a recall. The batteries were manufactured by LG and the issue was traced back to machines that were damaging components as they were being installed, allowing short-circuits that led to the fires. So far the recall has cost an estimated $1.8 billion with LG reimbursing GM for the costs.[25]
As automotive companies continue to expand their electric vehicle efforts, they will need to develop specialized end-of-arm tooling (EOAT) to support their use of robotics. The isotropic properties of new additive manufacturing technologies allows engineers to create EOAT tooling with high precision parts for light and heavy duty applications.

Extol, for example, has developed many different types of EOAT with 3D printing.[26] In one example for Continental Tire, they were able to quickly design new tooling and 3D print it in less than 24 hours. But 3D printing wasn't just faster and less expensive, it also allowed for an improved part that weighed 87% less than the previous CNC-machined version. Lightening the weight of EOAT can not only help the robot be more precise, it can also help manufacturers operate more efficiently by using smaller, less powerful robots.

Extol is further advancing EOAT design with the help of new materials. Utilizing a 3D printable TPU, they are now able to design custom vacuum cups, which allow engineers to place and orient vacuum to get the desired grip. Extol is also working with other soft touch materials to create custom fingers and grippers that offer multiple stiffness and rigidity options at a lower cost than CNC.

Picture 15: Mustang Mach-E

Conclusion

Electric vehicles are no longer just a megatrend, they are quickly becoming a "pillar of the future." As the demand for EVs continues to escalate, automotive companies must adapt.

To support their EV efforts, car makers need advanced flexible technologies that can help them design, develop and manufacture new models. There are opportunities for additive manufacturing throughout the EV product lifecycle, from prototyping and part verification to final parts production. 3D printing can also support mass manufacturing with jigs, fixtures and tooling that improve speed, quality and safety.

At present, EVs are selling in lower volumes, and that aligns with additive manufacturing's current value structure. As 3D printing technology continues to benefit from improvements in speed, capabilities and new materials, it will be positioned to address higher-volume production.

Automotive companies that haven't already embraced additive manufacturing should now consider doing so. As with any other emerging technology, competency involves many facets including people, processes and workflows. The faster companies can reduce those to practice, the better positioned they will be to leverage additive manufacturing, now and in the future.

Picture 16: Tesla car wheel

Footnotes

1. For more, please visit the 2015 and 2016 KPMG surveys of automotive executives here https://home.kpmg/content/dam/kpmg/pdf/2015/04/global-automotive-executive-survey-2015.pdf and here https://assets.kpmg/content/dam/kpmg/pdf/2016/01/gaes-2016.pdf

2. The Model 3 sold a total of 439,760 units in 2020, and is now the best selling EV of all time with more than 800,000 units sold overall. For more information please visit https://www.forbes.com/sites/jamesmorris/2021/05/29/tesla-model-3-is-now-16th-bestselling-car-in-the-world/?sh=1e75807145d1

3. Market capitalization is determined for public companies by multiplying the number of shares times the price per share. Market caps quoted are accurate as of December 2021

4. Prices reflect Rivian's IPO on November 10, 2021. For more, please visit https://www.cnbc.com/2021/11/10/amazon-backed-ev-start-up-rivian-set-to-go-public-.html

5. According to the International Energy Agency, by 2019, there were already 2.58 million battery electric vehicles (BEVs) in China, compared to just 0.97 million in Europe, and 0.88 million in the USA, For more information, please visit https://www.iea.org/reports/global-ev-outlook-2020

6. Norway, with a population of 5.4 million, has the world's highest proportion of electric vehicles. In 2021 EVs accounted for 65% of all new car sales. For more, please visit https://uk.investing.com/news/stock-market-news/electric-cars-hit-65-of-norway-sales-as-tesla-grabs-overall-pole-2555880

7. To view the KPMG 2020 survey of automotive executives, please visit https://automotive-institute.kpmg.de/GAES2020/downloads/global_automotive_executive_survey_2020.pdf

8. For more detail, please see LMC Automotive's investment forecast here https://lmc-auto.com/wp-content/uploads/2021/08/LMCA_Follow-the-money-Investing-in-North-American-production_Aug-21.pdf

9. For more on Ford's Blue Oval City announcement, please visit https://media.ford.com/content/fordmedia/fna/us/en/news/2021/09/27/ford-to-lead-americas-shift-to-electric-vehicles.html

10. To learn more about GM's Factory Zero initiative, please visit https://www.gm.com/stories/factory-zero-first-dedicated-ev-plant

11. For more information about the use of plastics in automotive, please visit https://thisisplastics.com/environment/plastics-cars-sustainable/ and https://www.grandviewresearch.com/industry-analysis/automotive-plastics-market

12. Ford purchased the third 3D printer ever made over 30 years ago. For more information, please visit https://amfg.ai/2019/05/28/7-exciting-examples-of-3d-printing-in-the-automotive-industry/

13. Prior to 2017, 3D printing was a multi-billion dollar industry and grew at 24.7% annually. In 2018 the industry reached $10 billion and by 2023 is expected to reach $30 billion. For more information, visit https://amfg.ai/2020/01/14/40-3d-printing-industry-stats-you-should-know-2020-redirect/

14. Reducing a vehicle's weight by 10% can improve fuel economy by 6-8%. For more visit - https://www.energy.gov/articles/545-mpg-and-beyond-materials-lighten-load-fuel-economy

15. To learn more about Extol and their innovative use case for additive manufacturing, please visit https://h20195.www2.hp.com/V2/getpdf.aspx/4AA7-7607ENW.pdf

16. For more on U.S. EV market share and forecasts, please visit https://insideevs.com/news/489525/us-electric-car-market-share-record-2020/

17. Tesla sales figures as of October 2021. For more please visit https://www.caranddriver.com/features/g36278968/best-selling-evs-of-2021/

18. EDAG produces larger quantities of a coolant manifold faster, more cost-effectively and more sustainably compared to traditional manufacturing processes. For more, please visit https://3dprint.com/259719/hp-announces-new-3d-printing-services-partnerships-milestones-ahead-of-formnext/

19. GM forgoes manual transmission in new C8 Corvette https://www.motor1.com/news/407219/gm-dealer-explains-no-manual-corvette/

20. 62 Percent of CT5-V Blackwing Buyers Opted for the Manual https://www.roadandtrack.com/news/a37292337/cadillac-ct5-v-blackwing-manual-take-rate/

21. Cadillac Blackwing Models Are First GM Cars Using Additive Manufacturing for Full-Scale Production https://www.additivemanufacturing.media/articles/cadillac-blackwing-models-are-first-gm-cars-using-additive-manufacturing-for-full-scale-production

22. For more on Forerunner 3D research with cerakoting 3D printed parts, please visit https://forerunner3d.com/hp-mjf-cerakote-paint/

23. EV battery packs use expensive raw materials, higher power components and more electronics, making them cost as much as $10,000 each to manufacture. For more, please visit https://mpoweruk.com/pack_construction.htm

24. Ford uses additive manufacturing for prototyping and making tools, jigs and fixtures https://www.fabbaloo.com/2020/03/ford-vs-ferrari-using-3d-printing

25. GM And LG Are Working Around The Clock On Bolt EV Battery Recall https://insideevs.com/news/532661/gm-lg-bolt-battery-recall/

26. Extol saves Cost and Weight with 3D Printed End of Arm Tooling https://info.extolinc.com/mjf-eoat-webinar

4AA8-1164ENW, February 2022