

A woman with long brown hair, wearing a black sleeveless top and black pants, is leaning over a silver car at a charging station. She is looking at the car's front end. The background shows a city street with trees and buildings. A green sign with a white plug icon is visible on the left.

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Moving electric vehicle manufacturing into the fast lane

Executive summary

Electrified mobility possesses significant potential to create short-term disruption in the automotive industry. Sales of electric vehicles (EV) are rapidly and steadily increasing, driven by improving battery technology, regulatory pressure, intense investment and an expanding charging infrastructure. As demand increases, established and startup automotive manufacturers need to quickly ramp-up EV production and reduce manufacturing costs to take advantage. EV manufacturing, however, presents unique challenges to automotive companies. By leveraging comprehensive digital twins of the product and production lines, manufacturers can design and validate assembly processes and entire facilities virtually, improving quality and accelerating production ramp.

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Electric vehicles on the rise

Major automotive OEMs and new startups alike are well entrenched in the pursuit of autonomous, connected, electrified and shared mobility. Dozens of companies have established programs for designing and testing autonomous and connected vehicles, either for personal use or as part of a shared mobility system. Progress is being made, but large-scale, real-world applications of these technologies are still years in the making. Electrified mobility, on the other hand, has the potential to create significant short-term disruption in the automotive industry and is already on the way to mainstream adoption.

The recent and rapid growth of electric vehicles (EVs) is driven by several factors (figure 1):

- Key EV technologies, such as batteries, are improving faster than expected
- Greater regulatory pressure at national, regional and city levels is driving early adoption of what is perceived to be a new norm
- Intense investment into EV programs and startup companies from a variety of sources, both traditional automotive companies and new entrants to the market
- A growing network of EV charging stations makes it easier and more convenient to use an EV every day

Electrified powertrains also provide key benefits for automated, connected and shared mobility systems. For example, ridesharing and mobility companies are investing in automated driving technologies to enable vehicles to operate within their system while not in use by the owner. This will increase the usage of personal vehicles significantly, simultaneously making vehicle longevity more critical. EV powertrains naturally support this need due to their relative simplicity. With fewer moving parts, EVs tend to last longer while encountering fewer mechanical issues.

The effect of these driving forces is evident in the growing adoption of EVs by mainstream consumers. EV sales have seen steady growth over the last five years. EVs are projected to match the sales of internal combustion engine (ICE) vehicles by 2030, and to surpass them by 2040. To meet this increased demand and remain competitive in a changing market, automotive manufacturers will need to ramp up their ability to manufacture EVs at volume.

A growing Chinese EV market is the primary source of the rapid expansion of EVs in the automotive industry. China houses a majority of the EV startups. Industry analysts estimate that China is home to 200 or more EV startups, some of which have been the recipients of billions of dollars of funding. In addition to startups, existing Chinese automotive OEMs are aggressively pursuing EV and plug-in hybrid vehicles.

The automotive shakeup, however, is industry-wide. Global automakers are under pressure to reduce costs as they finance the largest automotive industry transformation in decades. Volkswagen, for example, has committed \$49 billion to the development of electric and connected vehicles through 2023 (Rauwald, 2019). This investment includes the complete re-tooling of several manufacturing facilities to produce new electric vehicles (Rauwald, 2019). Other companies, while less aggressive than VW, are following suit.

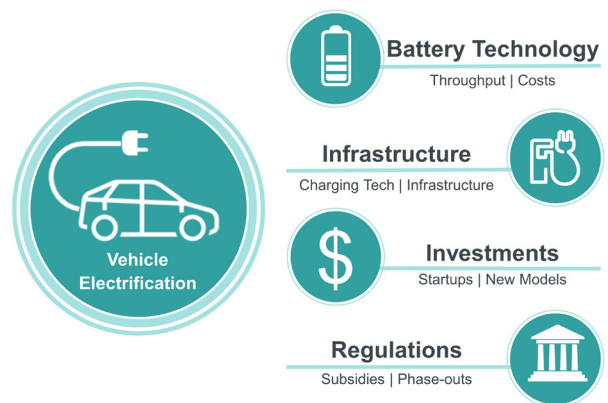


Figure 1: Four factors driving EV growth.

Electric vehicle manufacturing challenges

EVs present new challenges that major automotive brands and startup companies have yet to face. Drive range and vehicle cost continue to be central concerns of consumers. Automotive manufacturers must maximize the drive range of their vehicles while continuing to reduce costs through more efficient production.

Vehicle weight is a major determiner of drive range; a 10 percent weight reduction can improve fuel economy up to 8 percent (Shea, 2012). Unfortunately, electric drivetrains and batteries are significantly heavier than ICE powertrains. To counteract the increased weight of electric powertrains, vehicle manufacturers are incorporating advanced lightweight materials into the vehicle body. Replacing conventional materials with lightweight magnesium and aluminum alloys or carbon fiber can reduce the weight of a vehicle body and chassis by up to 50 percent. Vehicle manufacturers must incorporate these materials intelligently and ensure that weight reductions do not compromise vehicle safety.

Drive range is also impacted by the size and chemistry of the vehicle batteries. Many EVs currently on the market are adapted from pre-existing ICE vehicles. Due to differences in the packaging of ICE and electric powertrains, these non-native EVs compromise battery size to fit into the existing architecture (figure 2).



Figure 2: Native EV platforms provide more configuration flexibility and greater drive range by accommodating larger battery packs.

Manufacturers are shifting to modular native EV platforms, both to better accommodate electric powertrains and to support high-volume production. Native EV platforms can accommodate battery packs that are up to 25 percent larger, providing greater drive range, and support flexible powertrain configurations (Chatelain, Erriquez, Moulière, & Schäfer, 2018). Advances in battery chemistry will continue to improve the energy density of these batteries, further improving range.

The cost to manufacture and purchase EVs will decline as production increases, but reaching price parity with ICE vehicles will require additional advancements in battery production methods. Batteries are the primary contributor to the cost of EVs. The production of battery cells is the primary challenge, accounting for 70 percent of the total cost of the battery pack. Improving cell chemistry that increases energy density will help, but battery producers will need additional means of reducing cell production costs to deliver cost-effective vehicle batteries.

Finally, automotive OEM and supplier relationships will become more important and more complex. For automotive OEMs, this transition will present new challenges in managing their supply chains including lead-time, quality assurance and traceability of the product lifecycle across organizations. Suppliers will see a great opportunity for growth and evolution into providers of more complete vehicle sub-systems. With growth, however, comes additional risk. OEMs will set aggressive time-to-market goals for increasingly complex systems. In addition, suppliers will need to ensure robust collaboration and traceability procedures are in place as they work with OEMs and other suppliers.

The digital twin moves electric vehicle manufacturing into the fast lane

Creating a digital twin of the product and the production can solve the challenges of EV manufacturing by blurring the boundaries between design and manufacturing, merging the physical and digital worlds. These digital twins capture physical asset performance data from products and factories in operation. The data from smart connected products in the field and factory equipment is aggregated, analyzed and integrated into product design as actionable information, creating a completely closed-loop decision environment for continuous optimization.

Such a comprehensive digital twin enables manufacturers to plan and implement manufacturing processes for new lightweight designs and modular vehicle platforms while reducing the costs of battery production and coordinating across deep supplier ecosystems. This approach will not be optional, but required for automotive companies as they transition into the dynamic and fast-paced future of their industry. Let's examine how the digital twin helps solve each challenge.

Lightweight Designs

The integration of new materials into vehicle architectures is key to many manufacturers' strategies for reducing the weight of vehicles while maintaining vehicle safety. These new materials, however, introduce new manufacturing constraints. For example, the increasing use of aluminum and carbon fiber to create vehicle bodies has caused an adoption of new joining technologies. Most vehicles will contain a mixture of traditional and new materials. This means that new materials will join with conventional product components.

A digital twin of the production process enables engineers to evaluate multiple methods of joining vehicle components, including joining technology and tool orientation, to identify the most accurate and efficient process. For instance, laser welding requires high accuracy especially when dealing with complex component geometry. A key challenge is achieving a smooth and continuous welding seam, without splitting the seam into multiple segments. Using a digital manufacturing

tool like the Tecnomatix® portfolio to build a simulation of the product components and robotic welding tool, a programmer can quickly define a welding seam on the product geometry that accounts for robot collision constraints and configuration to produce a single welding seam.

New materials are not the only change agent related to lightweight vehicle design and manufacturing. Advanced technologies like additive manufacturing (AM) can also contribute to the reduction of vehicle weight by enabling the production of more sophisticated component geometries. AM allows engineers to reimagine product design to expand their capabilities, improve performance and reduce material usage and weight. AM also empowers companies to re-invent manufacturing by eliminating tooling, castings and molds, and reducing manufacturing components to simplify processes.

Integrating AM into vehicle production will create some challenges. AM requires specialized equipment and methods that must interact with conventional manufacturing processes and tools. A major challenge for manufacturers is achieving this integration while scaling AM processes to meet the high-volume production typical in the automotive industry.

A comprehensive digital twin facilitates the industrialization of additive manufacturing by unifying product design, manufacturing design and actual production. With advanced product design and simulation tools, engineers can prepare parts for AM from the outset. Generative design and topology optimization optimize component geometry for weight, material usage and strength. The component can then be validated using advanced materials simulations and prepared for the printing process. This preparation includes printing orientation and support structures, as well as slicing, hatching and printing simulations. These solutions can even perform post-processing and inspection on the virtual component to verify the component design and manufacturing process.

Such an end-to-end system can produce astounding results. AM has become a major piece of Ford's manufacturing eco-system. One of their AM applications, according to Ford, has the potential to save the company more than \$2 million (Goehrke, 2018). Other major automotive manufacturers are investing in AM as well. BMW recently announced a project to further integrate AM into its vehicle production. The company expects its new AM lines to reduce manual processes from 35 percent to 5 percent, cutting the cost of metal components in half (Jackson, 2019).

In another example, the EDAG Group leveraged a fully integrated AM process to minimize the weight, development time and cost of their scalable battery housing, SCALEbat (figure 3). AM was used to manufacture a geometrically complex coolant distributor with active valve control. This component regulates the volume-flow of coolant in each of the battery housing's three cooling circuits individually. EDAG was able to reduce pressure drop by 22 percent due to the geometric freedom provided by AM.

EV Platforms

As manufacturers shift towards native EV platforms, their assembly processes will need to shift towards a more modular build environment. This strategy applies to EV initiatives at established OEMs and at start-up EV companies with a mid-term to long-term vision. In addition, strategic alliances between global automakers will be important methods of gaining access to foreign markets, diluting the cost of platform development and accelerating supply chain optimization through scale. Ford and VW have announced such an alliance in which Ford will purchase 600,000 units of VW's modular electric vehicle platform (Volkswagen, 2019).

Assembly methodologies, processes and tooling will evolve to support these modular build scenarios that can quickly adapt to market conditions. As a result, manufacturing planning must be digitalized to become more agile and integrated. Leveraging a digital twin of the product, engineers can evaluate manufacturing methods virtually, analyzing multiple tools, assembly

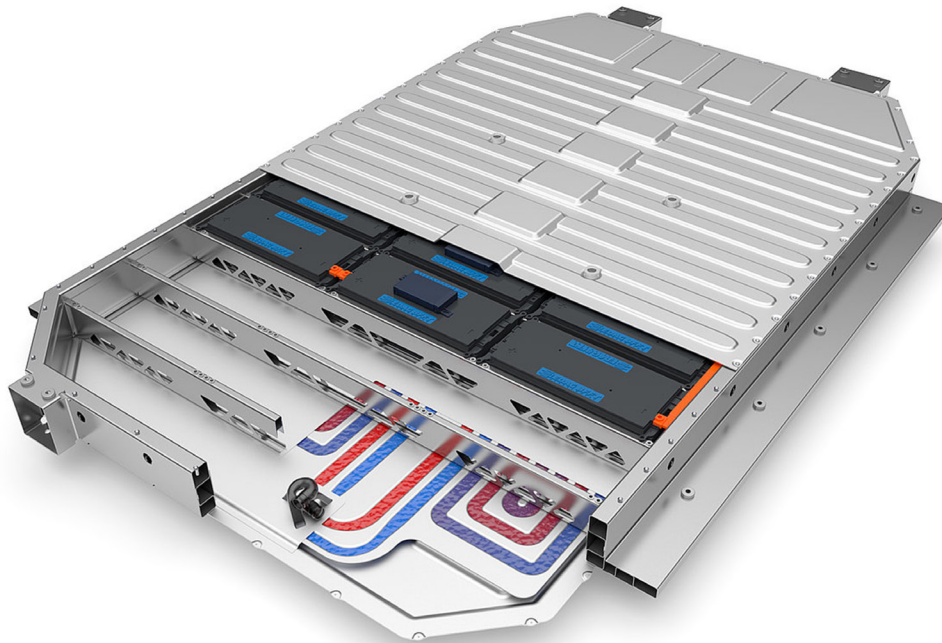


Figure 3: The EDAG Group's SCALEbat modular battery housing features an additively manufactured coolant distributor.

sequences and production line configurations while identifying and resolving issues (figure 4).

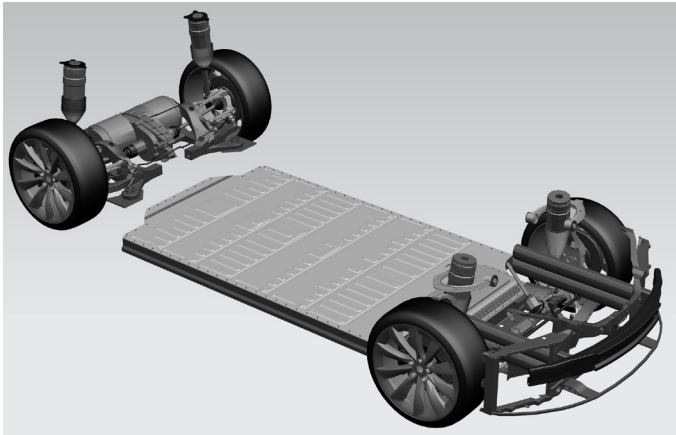


Figure 4: Engineers can use the digital twins of these sub-assemblies to plan and evaluate manufacturing processes.

Vehicles contain hundreds of parts that need to be assembled. A planning team defines assembly processes that identify the tools and equipment needed to assemble each product, and the sequence in which this assembly should occur. Advanced process planning solutions help planners allocate vehicle parts to new assembly processes and can identify parts that have yet to be processed. Furthermore, these solutions can access libraries of processes to reuse proven process knowledge such as assembly standards, time estimates, quality checks and more. This reduces the time required to create high-quality assembly process plans, enabling rapid response to product or production changes.

Next, each planned assembly process can be distributed within the context of the manufacturing facility constraints, enabling planners to define and validate the assembly sequence. Planners can select tooling based on the product requirements from tool libraries, driving standardization. They can also assign checks for tool reach and access or ergonomic feasibility to align the process with manufacturing standards.

An integrated process simulation environment enables a manufacturing engineer to load the digital twin of an assembly sequence to perform static and dynamic checks for tool collision and other manufacturability constraints. The results of the simulation can be captured and attached to a manufacturability check, which can then be updated to a product lifecycle management (PLM) solution. The PLM solution can then use the manufacturability checks to publish a dashboard

showing the adherence of processes to manufacturing standards at the station, line, or factory level to provide an estimation of process maturity. As these processes are developed, it will become crucial for manufacturers to capture as much data and knowledge from each implementation to assist production ramp-up in other facilities.

The benefits of digitalization extend to the factory level. With digital production planning and simulation tools, planners can evaluate production line configurations, and entire factory layouts to optimize manufacturing operations. Industrial engineers create a virtual model of the manufacturing facility to define and optimize factory-specific operations. To begin, the engineers can access defined assembly processes directly from the PLM solution, such as Teamcenter® Manufacturing software, to insert into the factory floor plan. These assembly processes form the “building blocks” with which the engineers will define a production line or factory layout.

Next, the engineers plan and evaluate each production line. Each of these lines may produce several vehicle models and variants. The engineers can examine and validate the variation in work content in any given workstation for each vehicle model or variant. Furthermore, the engineers can perform line-balancing analysis to ensure that workstations and operators are neither under or over-worked. The engineer can then quickly reconfigure the allocation of operations to work stations to resolve issues or improve performance.

Finally, engineers can leverage the virtual factory and production line models to plan and optimize factory logistics and material delivery. With consideration of the rate of production, planners can identify material delivery locations and review delivery routes and corridors. Automated guided vehicles (AGVs) can be simulated in the context of the factory layout to ensure proper functionality. Engineers can even virtually commission control logic for automated systems based on the simulations. This enables the engineers to ensure that material is delivered where it is needed, and when it is needed to prevent production delays.

Battery Production

Reducing the cost of battery production is a critical step to the success of EVs. Integrated digital solutions can help battery producers achieve cost-effective batteries by connecting battery design with manufacturing and establishing a digital thread throughout the flow.

Advanced battery design and simulation solutions enable engineers to optimize cell design and performance at early stages of development. Cell geometry can be defined and optimized in the context of the battery modules and final package. Then, battery cells, modules and packs can be evaluated in a virtual production process, enabling engineers to optimize the design for improved assembly and disassembly. This prevents the occurrence of tedious or time-consuming assembly tasks that can create bottlenecks in production.

Manufacturing engineering for the battery pack can mimic that of a body shop. The structural engineering and joining method (fastening, laser welding, arc welding, etc.) is defined in product engineering. Once simulation of the battery pack is completed, data for the battery module, cell, or pack, as well as relevant manufacturing features is released to the manufacturing engineering department to build the production stations. The manufacturing engineers can use the actual battery pack design data to build production stations with an appropriate mix of automation, robotics and human operators. Design inputs can also serve as production requirements. Manufacturing processes must not surpass the speed, acceleration, vibrations, temperature, or humidity that the battery pack will experience in an operational vehicle.

For example, once battery modules are fixed to the battery pack housing, operators need to connect the battery modules together using cables. The design of the battery modules and connectors need to account for operator posture and anthropometrics, as well as clearance with other structures on the battery module. Later in the product lifecycle, the cables may need to be disconnected to allow battery repair. Therefore, the connectors must also be detachable.

Modern CAD solutions, such as Tecnomatix Process Simulate, feature integrated manufacturing interfaces that enable a user to select the target anthropometry and posture for the operation (figure 5). The engineer can then examine whether there is enough space on the connector for operators to grip, whether enough clearance to other structures on the battery module is reserved, and whether the relevant ergonomics standards are met.

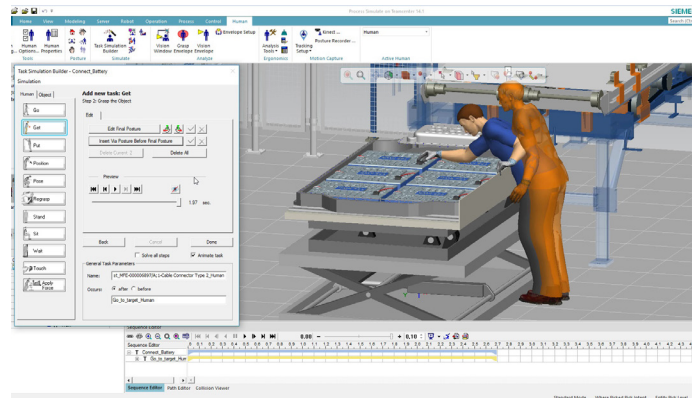


Figure 5: Engineers can virtually examine operator ergonomics to ensure comfortable working conditions.

These capabilities can also be used to validate operator ergonomics and refine the layout of the production line. The battery assembly sequence can be defined and evaluated to ensure optimal cycle times. Such simulations may also uncover problems. The battery package may be too large for the defined assembly when lying flat. Smaller operators will have difficulty reaching across the package while taller operators will need to adopt an unsafe posture. Engineers can modify the layout by inserting a tilted workbench, allowing operators to perform the assembly easily. A corresponding ergonomics report can also be generated to ensure compliance. The process simulation tool can then validate the new process cycle time and generate work instructions from the first-person view of the operator.

Supplier Evolution

Leveraging a comprehensive digital twin will enable OEMs and suppliers to collaborate effectively and efficiently under tight delivery timelines. Such a digital twin facilitates model-based definition and engineering that can help improve designs for manufacturing processes. Assembly variation analysis and automated feature-based CMM programming ensures first-pass manufacturing quality and can identify root causes of product defects. The digital twin can also be used to plan quality inspections and tie these to change management processes. With these capabilities, OEMs and suppliers can achieve faster quality ramp-up with root-cause analysis that feed back into product design change processes.

Suppliers will also need to remain flexible to short lead times and accelerated evolution of assembly methods to meet variable demands. Digital twins of the production facilities will allow these companies to make the best use of existing capabilities while quickly identifying and designing new production lines or assembly processes (figure 6). If additional production lines or new assembly processes are necessary, manufacturing engineers can use NX™ Line Designer software to design these additions in the context of the current factory, verifying floor space and layout. Digital twins of the production also facilitate the inclusion of factory design into product engineering. Together, these capabilities reduce late changes and help accelerate production

launch with optimized processes. Production throughput will also be improved due to the early integration of product and production engineering.

As production lines and facilities are designed, implemented and enter operation, detailed information is captured automatically and available for sharing among multiple facilities. This information helps accelerate production ramp-up in new facilities and ensures consistency across a supplier’s production or the OEM’s supply chain. Work instructions, detailed process documentation and even live equipment dashboards can be made available to enable knowledge and information sharing across an organization.

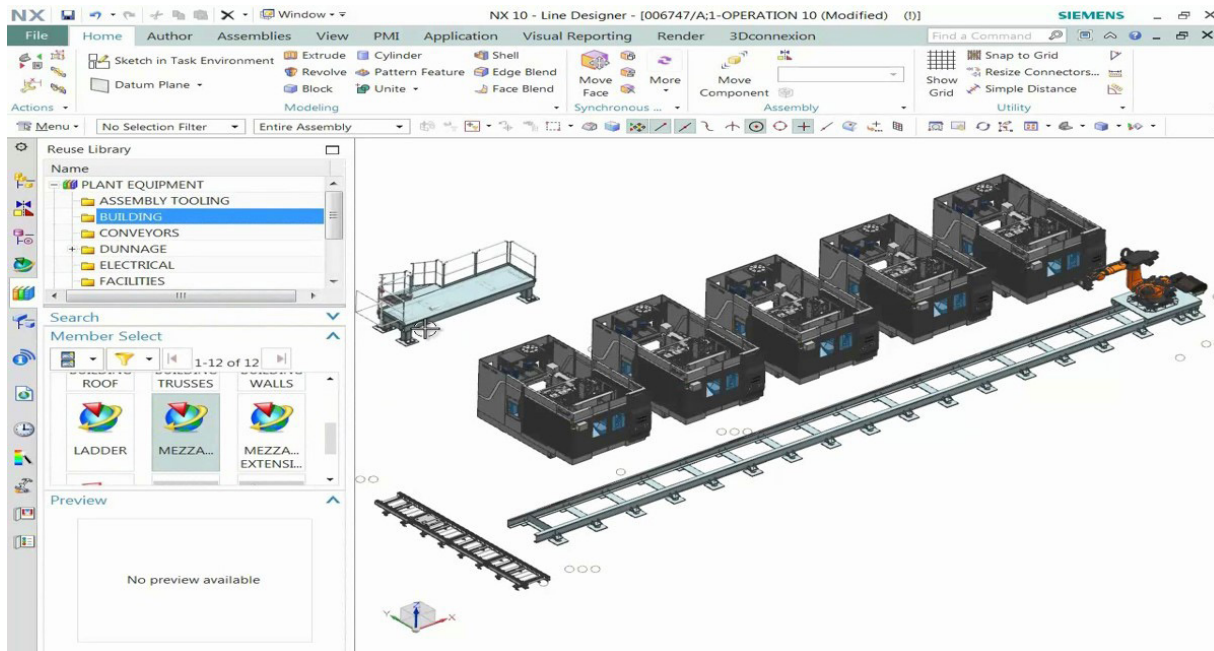


Figure 6: Production digital twins help manufacturers and suppliers develop new production capabilities quickly to maximize each facility and line.

Conclusion

EV manufacturing presents new and novel challenges to automotive OEMs and startups seeking to become major electric mobility players. These companies will need to adopt advanced manufacturing technologies, such as additive manufacturing, and develop modular production facilities to produce the lightweight and flexible platforms needed for next generation EVs. Cost reduction and coordination across the manufacturer and supplier ecosystem will also be critical to fostering the growth of EVs in the market.

Integrated and digitalized manufacturing planning and simulation solutions can help these companies adapt and overcome these challenges by uniting manufacturing with design, and the real world with its digital counterpart. Such solutions will enable vehicle manufacturers to accelerate their production planning and ramp-up by virtually designing and validating production processes for cycle time, product quality and operator

ergonomics. Integrations with product design solutions allow engineers to optimize product designs for manufacturing and leverage the product digital twin during manufacturing planning and simulations. Finally, robust PLM solutions ensure that an unbroken digital thread is maintained among OEMs and suppliers throughout the product lifecycle.

Consumer preference is already shifting towards e-mobility, bolstered by government regulations and increasing accessibility as costs plummet. As the competition ramps up, companies that embrace digitalization from product definition through manufacturing and into production will be able to deliver higher quality products to market in less time, and respond to changes with greater agility and intelligence. In the future, such capability will be necessary to succeed and thrive in the age of electrified mobility.

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