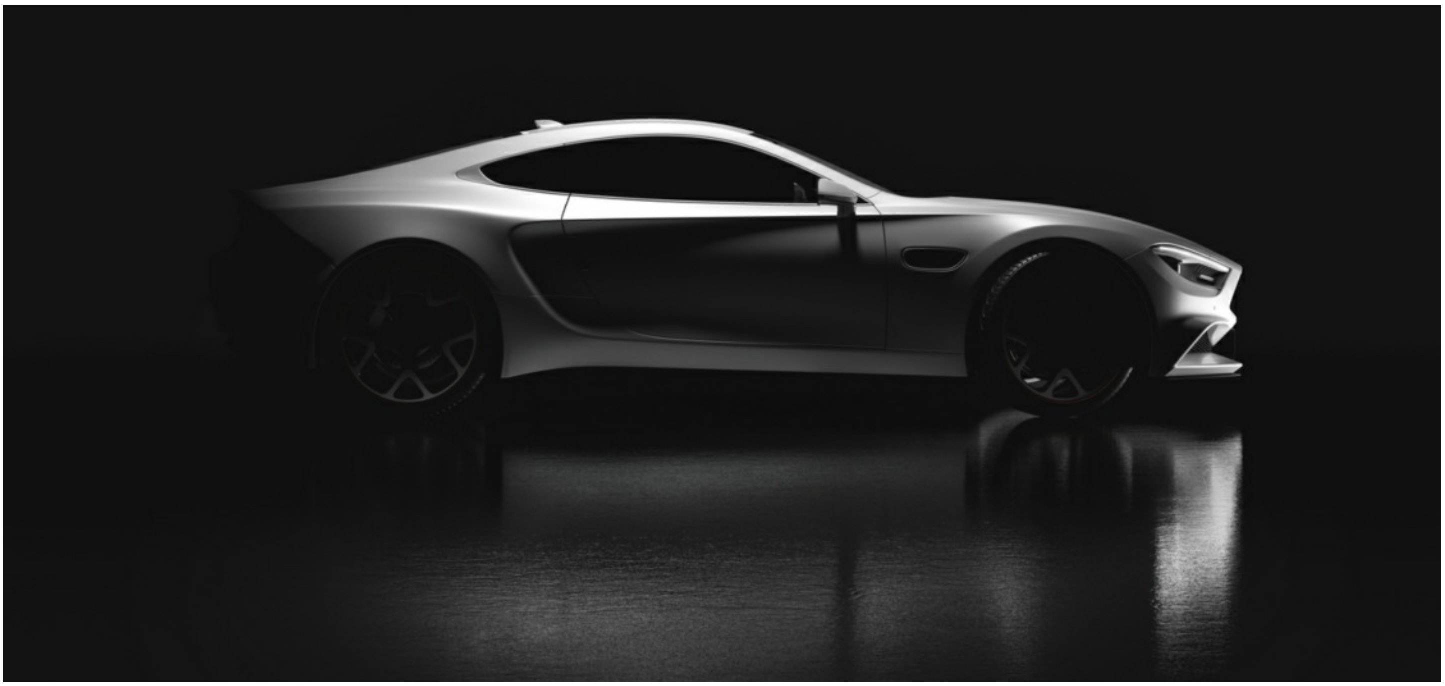
**August 2021**
Author: Dr Phil Marshall

# IT'S SHOW TIME FOR 5G AND INDUSTRY 4.0 IN AUTOMOTIVE MANUFACTURING



*The automotive industry is experiencing tremendous disruption due to accelerated demand for electric vehicles (EV), new platforms and services, and sustainable manufacturing practices. Carmakers are upgrading existing manufacturing facilities and building new factories to support sustainable EV vehicle production combined with maturing internal combustion engine (ICE) vehicles. With these upgrades, carmakers developing new capabilities, such as EV battery and power-train production, are implementing targeted Industry 4.0/smart manufacturing capabilities to enable data management, robotics and automation, and real-time monitoring and control. These capabilities require robust network connectivity. Today fixed connectivity is typically favored as the primary connectivity for non-mobile assets. Wi-Fi is used in some cases for mobile equipment and backup connectivity for non-mobile assets. 5G is gaining some traction in automotive manufacturing facilities, which we expect will accelerate as private 5G networking matures and 5G becomes better aligned with the specific use-cases for automotive manufacturing. Notable examples include:*

- *Reliable, safe and secure (aka ultra-reliable-low-latency uRLLC) network connectivity for industrial and collaborative robotics.*
- *Scalable and reliable machine connectivity for condition monitoring and predictive maintenance and anomaly detection, and;*
- *Ubiquitous connectivity to support digital twinning, supply chain optimization, and other sustainability initiatives.*

*Given its capabilities, 5G should already have more robust positioning for automotive manufacturing but is hindered by competition from fixed and Wi-Fi . Although Wi-Fi lacks performance and fixed networking lacks flexibility, they are both well understood and tend to be favored. Moreover, 5G has been spearheaded by telecom companies, with a long legacy with consumer broadband services. We believe that this causes the 'chameleon-like' positioning of 5G, which emphasizes its technical prowess, rather than the unique use-cases that it enables for in vertical markets like automotive manufacturers.*

# 5G should already have more robust positioning for automotive manufacturing but is hindered by competition from fixed and Wi-Fi.

## Introduction

Automotive manufacturing is massive. Carmakers, including Volkswagen Group (VW), Toyota, Daimler, Ford, Honda, and General Motors (GM), are amongst the ten largest discrete manufacturers globally. The automotive industry is well established and highly competitive, with unique product development and manufacturing techniques that have been refined over decades. However, the industry is experiencing tremendous disruption, with growing electric vehicle (EV) popularity, efficient vehicle platforms, connected vehicle services and assisted and autonomous driving. The industry disruptions are illustrated by Telsa's market valuation, which surpassed Toyota in July 2020.

dustry disruptions are illustrated by Telsa's market valuation, which surpassed Toyota in July 2020.

The automotive industry has responded to the market disruptions with radical strategies to embrace electric vehicle technology and sustainable manufacturing practices, with software and service-centric vehicle solutions. These strategies leverage Industry 4.0 and smart manufacturing capabilities, which are prioritized for key strategic objectives without creating unnecessary commercial and operational risks.

Industry 4.0 requires reliable network connectivity to digitally enable machines and other infrastructure on the factory floor. Today the lion's share of network connections are fixed to ensure highly reliable connectivity. Wireless technology such as Wi-Fi and 5G provides connectivity for mobile equipment, such as mobile robots, and for secondary backup connections for non-mobile equipment. 5G includes broadband, ultra-reliable-low-latency (uRLLC) and massive machine type (MTC) connectivity, and private networking capabilities to support many of the requirements for manufacturing facilities. This report investigates carmaker Industry 4.0 strategies and digital use-cases that create potential opportunities for 5G.

## Decades of Sustainable Innovation

Over decades, automotive manufacturing has evolved with 'sustainable innovations' to optimize production and address changing customer demands. Carmakers were amongst the earliest companies to adopt robots, and as an industry, are the largest share of robotic technology. The automotive industry is highly competitive. While carmakers are eager to improve operational performance and efficiencies and trial new and innovative solutions, well-established principles typically underpin their technology investments. For example:

- Most product developments are advancements and customizations of existing platforms and leverage customer product familiarity and preferences towards iconic brands. For example, Ford's iconic Mustang was first manufactured in 1964. In 2021, Ford has fifteen Mustang trim variations in its line-up.
- Car-making includes complex and high-precision processes that are deceptively challenging to automate. Even with the latest advancements in machine vision, artificial intelligence (AI), and robotics, many manufacturing tasks still depend on the dexterity and adaptability of production line personnel.
- The stakes are high. Manufacturing production down-time costs typically exceed USD 20,000 per minute. Product quality is crucial, and recalls are tremendously expensive. For example, in 2016, a defective airbag cost General Motors (GM) USD 4.1 billion in vehicle recalls, and;
- Factory safety and security are paramount and must cope with massive and environmental complexity manufacturing facilities. For example, Telsa's Freemont factory covers 5.3 million square feet and has over ten thousand employees.

## Electric Vehicles are a bellwether for disruption

While automotive manufacturing will retain many of its hallmark characteristics in the foreseeable future, carmakers are developing new and disruptive manufacturing strategies for the EV market. In recent years EV market demand has accelerated and benefited from Telsa's success and global interest in sustainability initiatives to reduce greenhouse gas emissions. Over the next ten years, the global EV market will have a 20 percent cumulative annual growth rate (CAGR) to equal the Internal Combustion Engine (ICE) vehicle market by 2030.

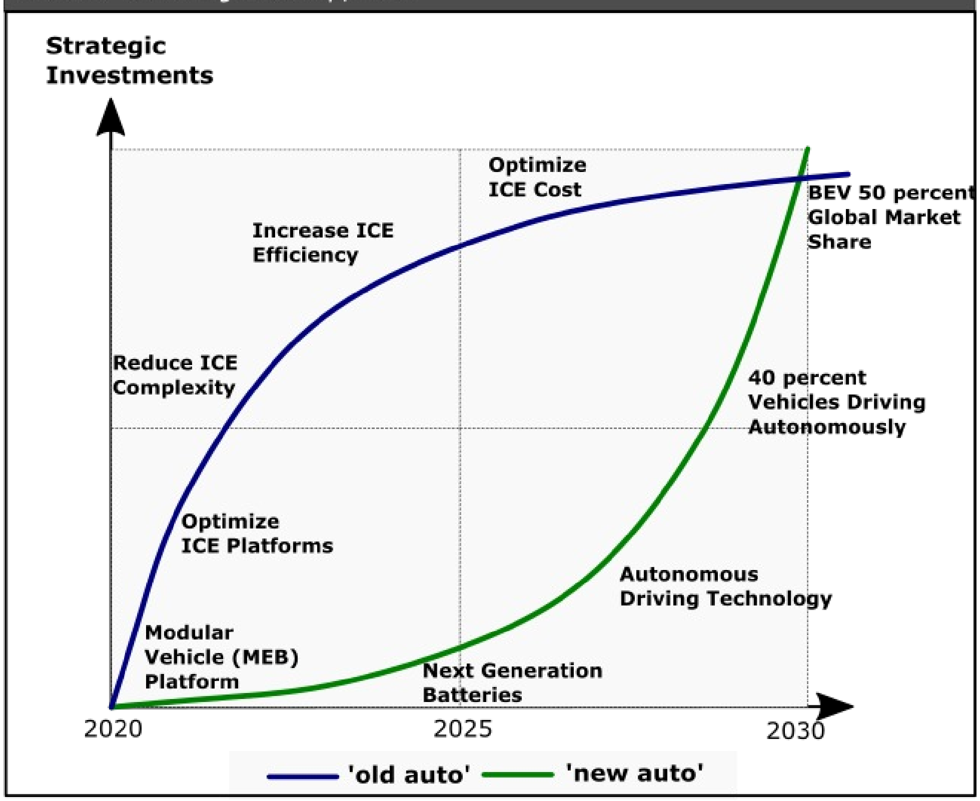
Even though EV popularity is increasing, EVs are still considerably more expensive than internal combustion engine (ICE) equivalents and lack adequate charging infrastructure in most countries. Approximately half of the bill-of-materials (BOM) for a typical EV is for the electric power-train, of which, 30 percent is for battery technology. By comparison, the average ICE power-train costs less than 20 percent of a typical vehicle BOM.

To reduce EV costs and improve driving range, significant research and development, and manufacturing efforts focus on improving the charging rate, longevity, and cost of EV battery technology. Considerable progress has already been made and enabled an 85 percent improvement in EV battery costs since 2010, which according to Bloomberg reached an average of USD 137 per kWh in 2020. Average battery costs must be below USD 100 per kWh for EV and ICE vehicles to have price parity. Carmakers believe this is achievable by 2025. Battery cost savings and performance gains come with improved supply chains and design and manufacturing techniques. Further improvements will come as new technologies, such as solid-state battery designs, are brought into the mainstream.

As EV's become more cost-effective, ICE vehicles will likely become more expensive with stricter emission controls, particularly in markets with clean-energy electricity production.

Increased EV market demand is particularly disruptive to manufacturing, requiring new factories and upgrades to existing facilities. As manufacturers embrace EVs, they must also pursue parallel strategies to refine and optimize ICE-based products, which will be the 'cash-cows' for carmakers during the next decade. During its July 2021 Strategy Day, VW summarized its product strategies with two parallel paths: the so-called 'old-auto' and the 'new-auto'. VW is responding to expectations that battery EVs (BEV) will represent 50 percent of the global market by 2030. Like most other carmakers, VW is gearing up for EV growth. VW also plans to target software and service opportunities that capitalize on critical capabilities, such as vehicle connectivity, assisted and autonomous vehicle control, and digital twinning.

**Volkswagen Group, Long Term Strategic Vision**
*Source: Volkswagen Group, 2021*



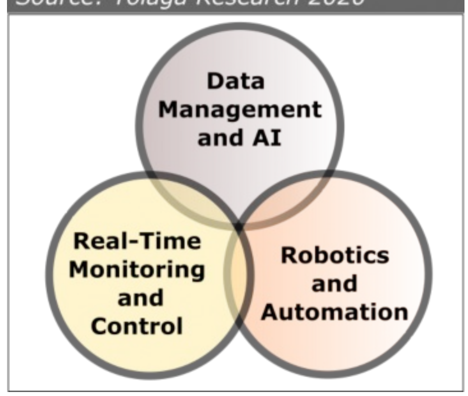
## Getting under the hood of Industry 4.0

Industry 4.0 was coined in Germany over a decade ago to describe the digital transformation of manufacturing. It incorporates the notion of smart-manufacturing and strives for factory convergence with product lifecycle and supply chain activities. Industry 4.0 capitalizes on factory instrumentation with the Internet-of-Things, AI, data analytics, and connectivity as core enabling technologies. Increasingly, 5G is positioned as a complementary technology for Industry 4.0 because of its ability to ease connectivity challenges with increased agility and flexibility. A variety of Industry 4.0 initiatives for automotive that use 5G have been trialed and implemented. Several recent examples include the following:

- June 2021, BMW explains OPC-UA and edge computing to support its Industry 4.0 data exchange requirements.
- July 2021, KUKA deploys a Nokia 5G Private Network in its Augsburg development center to develop 5G enabled industrial robots and automation systems.
- May 2021, Bosch launches its 'universal AI solution for manufacturing,' which depends on 5G data exchange capabilities.
- April 2021, Nokia provides 5G private wireless networking to KATCH Network to support Japan's automotive and high technology manufacturing.
- February 2021 Ford engine production to benefit from Ericsson connectivity in pilot EU initiative.
- November 2020, Mercedes-Benz opens its new Factory 56 in Sindelfingen vehicle assembly plant, which incorporates WLAN and 5G technology to support state-of-the-art Industry 4.0 capabilities.
- June 2020, Toyota plans to deploy a private 5G network in its engineering manufacturing facility in Fukuoka, Japan.
- February 2020 Audi and Ericsson run pilot project with 5G connected collaborative robots in Audi's Production Labs.
- February 2020 Volkswagen and BMW confirm massive Industry 4.0 investments

Industry 4.0 initiatives include diverse use-cases that can be described in three overlapping categories: Data Management and Artificial Intelligence (AI), Real-time Monitoring and Control, and Robotics and Automation.

**Industry 4.0: Use-case Categories**
*Source: Tolaga Research 2020*



Data management and AI are pervasive and capitalize on machine data, industrial IoT instrumentation and management tools, and extensive connectivity to harvest, manage, monitor, and act upon data collected from manufacturing environments. However, machine data and protocols are typically proprietary and have siloed operating environments that impede Industry 4.0 efforts. As a result, carmakers have a variety of programs to eliminate data silos in their manufacturing environments. For example, BMW plans to use OPC-UA to integrate machine data in its factories and VW's announced factory upgrades include extensive data standardization efforts.

Real-time monitoring and control and robotics and automation applications require ultra-reliable and low latency connectivity. Commonly fixed connections are used to reliably connect non-mobile equipment, in some cases with wireless (Wi-Fi or 5G) backup. However, fixed connections lack scalability and agility and cannot connect mobile equipment, such as autonomous mobile robots (AMR). 5G aims to address these challenges with high bandwidth, ultra-reliable and low latency, and massive machine-type connectivity capabilities. However, some manufacturers are using Wi-Fi instead because it's familiarity and simplicity.

In April 2020, VW announced its upgrade plans for 15 of its manufacturing facilities, with standardized data and analytics with integrated cloud solutions. 5G was notably absent from VW's April 2020 factory upgrade announcement. VW stated that it can achieve the necessary upgrades with fixed and Wi-Fi connectivity. VW has committed to using 5G in its factories and acquired 5G radio spectrum in 2019. We believe that VW's April 2020 decision illustrates 5G's lack of ecosystem maturity and inadequate positioning for factory floor use-cases. We expect VW to use 5G in its factories once the technology matures, and particularly when its Industry 4.0 initiatives require massive machine type (MTC) connectivity.

Non-real-time data analytics can be supported with latency insensitive connections and typically require integration with manufacturing execution systems (MES) and enterprise resource planning (ERP) systems. These systems are provided by companies like ABB, AVEVA, Dassault, GE, Parsec, and Siemens. While ERP and MES systems are relatively mature, they become considerably more expansive and strategically important as carmakers pursue their Industry 4.0 efforts.

Automotive manufacturers use robotics and automation for targeted applications, such spot-welding, internal supply chains, painting, large component assembly, and scheduled pelletizer reconfigurations. However, even with advancements in robots and automation, automotive manufacturing cannot be fully automated and will continue to depend on production line personnel for the foreseeable future.

Traditionally, robots operate in an isolated and secure environment, mainly for health and safety reasons. However, with advancements in sensors, data analytics, AI, and edge computing, industrial robots (typically with smaller form-factors) can now operate close and, in some cases, in collaboration with factory workers.

**Machine data and protocols are typically proprietary and have siloed operating environments that impede Industry 4.0 efforts.**

Automatic guided vehicles (AGV), which are commonly used to transport vehicle components, are being upgraded and complemented with autonomous mobile robots (AMR), which leverage fleet management solutions to provide greater operational flexibility. AMR technology use advancements in assisted and autonomous driving technologies and are provided by a variety of companies including, ASTI (acquisition announcement by ABB in July 2021), Boston Dynamics (acquired by Hyundai Group in June 2021), Continental, Desmasa (for collaborative mobile robots), InVia, KUKA, and Omron.

Ultra-reliable connectivity is crucial for industrial and collaborative robots to operate safely. Commonly fixed connectivity is used for non-mobile robots. However, wireless can provide redundant connectivity, remote user interfaces, and greater operational flexibility. Typically, Wi-Fi-type wireless connectivity is sufficient for non-critical user interfaces but inadequate for emerging multifunctional use-cases that require operational flexibility and high bandwidth and latency-sensitive connectivity. This is creating opportunities for 5G-enabled robots. For example:

- KUKA's partnership with Nokia, (described above). KUKA is interested in the flexible and secure connectivity that 5G offers and the potential to use 5G in conjunction with other key technologies such as edge computing to provide agile multifunctional operations.
- In December 2020, Omron signed a strategic partnership with Nokia to accelerate the development of 5G for manufacturing businesses with Industry 4.0. Omron is responding to Industry 4.0 opportunities to enable greater automation and operational flexibility for high-mix low-volume production environments and to address skilled labor shortages, and;
- In July 2021, InVia raised funds from Microsoft, Hitachi, and Qualcomm, to develop 5G- enabled robots and drones.

While the potential use-cases for robotics and automation are extensive, automotive manufacturers typically target scalable solutions that don't disrupt established operations. In addition, the unique characteristics of automotive manufacturing are challenging. For example, Telsa struggled to automate its more complex vehicle assembly activities, even with the most advanced computer vision and AI capabilities. Telsa found that proficient assembly workers could be significantly more efficient and reliable than the most advanced robots.

Operational downtime can be tremendously costly (i.e., USD 22,000 per minute), and many manufacturing facilities operate 24/7. The benefits of robots and automation can rapidly evaporate when outages occur. Solutions that seem compelling in technology trials might not be viable at scale, particularly if they directly impact operational continuity, and:

- Cannot guarantee sufficient reliability and redundancy. Typically, in live operating environments, a minimum of six-nines reliability is commonly needed. Industry 4.0 solutions that support predictive maintenance, condition monitoring, and anomaly detection might be more important for these cases.
- Adequate 24/7 technical support.

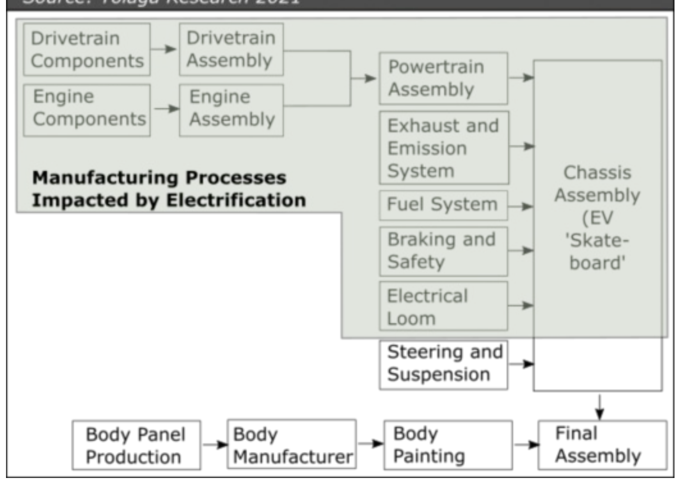
- Cannot meet stringent security and safety standards, particularly for robots operating in close to personnel, and when network connectivity creates new security vulnerabilities, and;
- Cannot be seamlessly integrated into established operational processes. Seamless integration is typically more challenging in brown-field environments where retrofitting is necessary. Green-field implementations can incorporate advanced robotics and automation in factory design processes.

## Real-Time Monitoring and Control

Both brown-field and green-field automotive manufacturing facilities are being equipped with EV production capabilities. Carmakers are also pursuing innovations to drive operational sustainability, fortify and optimize supply chains, improve operational efficiencies, and upgrade products with software-centric design principles. The pace and prioritization of factory innovations vary amongst manufacturers and depend on various factors, including existing products and markets, product differentiation strategies, and overall market scale. For example, Volvo has upgraded its existing manufacturing facilities and has capitalized on the agility of its mixed-model assembly lines to enable EV production. In contrast, other manufacturers like VW are constructing dedicated EV manufacturing facilities for battery technologies, EV power-trains with modular 'EV-skateboards', and EV vehicle assembly.

Volkswagen and Bosch are manufacturing standardized 'EV skateboards' with integrated chassis assemblies modules for third parties to use. These skateboard modules will most likely be used by niche manufacturers or specialized vehicles, lacking the scale and resources for dedicated power-train solutions. Most carmakers plan to develop their own vertically integrated solutions and differentiate their offerings with proprietary battery, power management, and motor designs. These players might shift to standardized EV skateboards if power-train technology becomes commoditized once the market matures.

**Impact of EV Production for Traditional Manufacturing**
*Source: Tolaga Research 2021*




EV assembly plants must incorporate changes in power-train and chassis assembly processes. Body panel production and manufacturing, body painting, and final assembly activities essentially remain unchanged. When mixed-model assembly environments combine EV and ICE manufacturing, pelletized assembly lines require additional sub-flows (e.g., high-voltage functionality). Volvo estimates that a 5 to 10 percent increase in infrastructure capital expenditures will be needed to support EV assembly parallel to its established ICE assembly lines. In addition, scheduling for mixed-model assembly lines can be challenging, particularly when there are significant variations in product volumes and configurations. These inefficiencies increase the need for effective agile manufacturing capabilities to adapt and optimize process flows.

## Car Makers Bring EV Batteries into the Fold

Advancements in battery technology, production capabilities, and secure supply chains are crucial for competitive EV vehicle prices and battery production volumes to keep pace with EV market demand. Furthermore, since 70 percent of EV battery production is in Asia, factory expansions in North America and Europe are crucial.

All EV carmakers have partnerships with battery technology companies including, BYD, CATL, LG Chem, Samsung, and SKI. However, to ensure adequate supply and capitalize on potential battery technology differentiation, carmakers are extending their supplier partnerships and expanding their battery packaging and production capabilities. For example, Tesla responded to supply challenges with Panasonic by extending its partnerships to include LG-Chem and CATL. Telsa also plans to build additional factories (e.g., Berlin, Germany) and develop its battery-cell technology in-house. In March 2021, Volkswagen Group announced plans to construct six 40GWh battery manufacturing facilities by 2030. Toyota is building battery manufacturing facilities in partnership with Panasonic and aggressively pursuing solid-state technology developments. In April 2021, General Motors (GM) and LG Chem announced plans to invest USD 2.3 billion in a battery manufacturing facility in Tennessee.  In May 2021, Ford announced a partnership with SK Innovation to manufacture battery cells and arrays. In the same month, BMW also announced plans to manufacture battery cells.

Battery manufacturing accounts for 40 percent of overall battery costs and has important implications for battery performance. Current manufacturing processes lack the automation needed for battery production scale to meet growing market demands. In addition, production processes underestimate battery performance profile variations, which depend on battery cell chemistry and cell array constructions. Today carmakers typically source battery cells and complete battery products from partner suppliers. However, carmakers like VW, Toyota, Ford and GM are advancing their battery cell and package manufacturing capabilities to improve their supply chains and create differentiated products.

We believe that carmakers and battery manufacturers will seek various digital transformation technologies to develop and expand their manufacturing capabilities to achieve product differentiation. For example, sensors with real-time feedback to the manufacturing process of battery cathodes can reduce production costs by up to 8 percent. Effective predictive maintenance can reduce the cost of EV battery cell production by 7-10 percent, with the highest impact in the coating and drying processes, followed by formation, compound generation, and aging. Smart assembly and finishing of battery cells can reduce cell production costs by up to 10 percent. In addition, agile cell assembly solutions that account for battery cell chemistry can improve battery performance by more than 15 percent.

Digital twins can track battery cells and arrays through the manufacturing and assembly processes and ongoing operations. Recent academic research projects (e.g. at Imperial College London, University of Warwick, and Beihang University, China), have demonstrated that digital twinning support in smart battery management can enable longer battery life and faster-charging capabilities. These solutions require wide-area network connectivity, remote monitoring and control, advanced data management, and AI capabilities to support EV battery lifecycles proactively.

# Sustainability

Automotive manufacturing is energy-intensive and consumes significant quantities of raw materials. Carmakers are continually improving their processes and procedures to reduce their consumption costs and improve their sustainability profiles. For example, according to the United Kingdom's Society of Motor Manufacturers and Traders, the average energy used to manufacturer a vehicle decreased by 43.3 percent over the last 20 years. There are numerous sustainability-led initiatives that carmakers are pursuing that will drive 5G and Industry 4.0 opportunities. Two notable areas include EV battery production and energy management in vehicle assembly plants.

## Sustainable EV Battery Production

According to an April 2021 ABB research study, there will be a six-fold increase in EV battery demand between 2020 and 2030, which cannot be supported by current and planning manufacturing capacity. This capacity shortfall is exacerbated by complex supply chains for raw materials and over 70 percent of battery production in Asia Pacific.

By building battery factories closer to vehicle assembly plants in Europe and North America, carmakers will have more sustainable EV battery manufacturing capabilities. But carmakers are eager to further their sustainability efforts by using renewables, smart supply chains, and smart product lifecycle management to minimize carbon footprints for battery production, optimize battery performance, and facilitate efficient battery recycling. We believe that these capabilities will require a range of Industry 4.0 innovations, including real-time monitoring and control, data analytics and AI, digital twinning, and wide-area mobile network coverage.

## Sustainable Vehicle Assembly

Vehicle assembly plants have many processes with vastly different energy and raw material demands. Research conducted at the Universities of Durham and New Castle in the United Kingdom investigated typical automotive manufacturing facilities' energy consumption and carbon footprint. The researchers observed that 36 percent of the total energy consumption in a conventional manufacturing plant is associated with vehicle painting processes. The research identifies a variety of thermal energy management solutions to minimize energy consumption. Real-time monitoring and control and data analytics, and AI capabilities could significantly improve the performance of the proposed thermal energy management solutions.

## Differentiating with Sustainability

Sustainability considerations are essential for carmakers as they continue to expand their EV initiatives and scale back ICE vehicle production in line with market and regulatory expectations. Even though EVs have low operational carbon footprints, consumers, regulators, and industry watchdogs are becoming increasingly aware of the carbon footprint and environmental impact of EV production. As a result, we expect consumers to increasingly favor EVs manufactured with lower environmental impact -albeit while still sporting the advanced features, conveniences, and creature comforts that consumers value. Since this will accelerate sustainability-led initiatives, we believe that it is essential that industry players fortify the positioning of 5G and Industry 4.0 for sustainability.

## Conclusion

Automotive manufacturing is disrupted as it responds to growing EV demands to replace traditional ICE vehicles, new modular and software-centric vehicle platforms, and global sustainability demands. New manufacturing facilities are being built and existing facilities upgraded. Vehicle electrification is disrupting existing supply chains and production lines for existing power-train equipment and creating tremendous demands for EV battery production.

Carmakers are pursuing digital transformation strategies with Industry 4.0 innovations to improve their manufacturing capabilities and respond to industry disruptions. However, their digital transformation efforts are punctuated by the tremendous cost of getting it wrong. Large scale operational outages typically cost USD 22,000 per minute, and vehicle quality problems can result in vehicle recalls costs that run into the USD-billions. Therefore, carmakers are appropriately cautious with their Industry 4.0 efforts, which are typically easier to implement in greenfield than brown-field manufacturing environments and easier for new product categories, such as EV batteries. Several Industry 4.0 use-cases that carmakers are pursuing include:

- **Predictive maintenance, condition monitoring, and anomaly detection**. Since these capabilities can be challenging to implement in heterogeneous production environments carmakers have large-scale data standardization projects. Although predictive maintenance condition monitoring and anomaly detection have broad applicability, efforts must focus on areas of significant importance, for example, battery cell and array assembly and industrial and collaborative robot safety.
- **Standardized data exchange** between factory machines, which enables standardized reporting and collaborative operations.
- **Industrial, collaborative, and autonomous mobile robots.** These robots require robust and secure connectivity and use sophisticated human-machine interfaces (e.g. video and AR/VR), and multifunctional agility for key operational functions.
- **Supply chain optimization solutions** that leverage data analytics and AI capabilities to minimize supply chain friction and autonomous robots to enable agile internal supply chains.
- **Digital twinning** for EV batteries with smart supply chain and product lifecycle management capabilities to minimize carbon footprints and optimize battery performance and recycling.

Fixed network connections are commonplace in factory environments, particularly for non-mobile equipment with ultra-reliable performance requirements. Mobile solutions, such as mobile robots, are either supported by Wi-Fi or 5G connectivity. Many carmakers are trialing 5G technology and, in some cases deploying private 5G networks. With massive factory upgrades and new factory builds planned, we believe that 5G should already have a stronger foothold in automotive manufacturing. Although Wi-Fi lacks performance and fixed networking lacks flexibility, they are well-understood technologies and formidable competitors for 5G. We believe that continued efforts to reduce 5G operational complexity and virtualize core and radio functionality are crucial to address this competition. In addition, 5G's positioning needs to change with more attention towards the unique use-cases it enables, rather than its technical prowess.

## About Tolaga Research

Tolaga is a leading consulting and advisory firm for the mobile industry and the Internet of Things. We are experts in networks, security, critical communications and complex system modeling.

**Our Clients:** Service Providers, Technology Vendors, Enterprise End Users and Private and Institutional Investors

We capitalize on many decades of industry knowledge, implementation experience, advanced modeling and analytics platforms to deliver differentiated services to our clients.

**Our Solutions:** Research Advisory Services, Custom Consulting and Modeling Platforms

## Contact Us

admin@tolaga.com | www.tolaga.com | @TolagaResearch
Tolaga Research Newton MA, 02109, USA