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Hype Cycle for Automotive Technologies, 2020

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Most automotive design innovations are underpinned by electronics. This document includes the technologies and innovations that will enable future automotive capabilities. This Hype Cycle interpretation offers a holistic view to aid strategic planning.

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This document was revised on 28 July 2020. The document you are viewing is the corrected version. For more information, see the Corrections page on gartner.com.

What You Need to Know

Innovation in the field of automotive technologies has been focused on making vehicles more automated, more fuel-efficient and more connected. CIOs at technology providers serving the automotive industry can use this research to understand the factors influencing the adoption of these technologies and their potential business impacts.

We highlight the key technologies that will improve user experience, enhance motor vehicle safety, and reduce fuel consumption and environmental pollution — mainly from the hardware viewpoint. Gartner forecasts that, from 2020, vehicles with the hardware to support Level 3 autonomous driving capability will be widely produced, even though most will still be authorized as Level 2 autonomous vehicles legally. Hardware capability will keep preceding the software capability, regulations and standardization in this field.

The Hype Cycle

The Hype Cycle for Automotive Technologies highlights technologies in fields such as autonomous driving, electric powertrain and connectivity. The majority of technologies profiled in this Hype Cycle are supporting those objectives. We evaluate the stage of each technology from the viewpoint of the maturity and the expectations in the market, then position each technology on the slope of the technology life cycle (which consists of five stages).

For example, sensor technologies such as light detection and ranging (lidar) are used primarily to enable autonomous driving — and they have already mostly surpassed the Peak of Inflated Expectations. We expect them to reach the Plateau of Productivity within the next five years because they are indispensable technologies for autonomous driving. Vehicles with Level 3 autonomous driving hardware capability (both computing and sensing) will be widely produced from 2020. However, it will take five to 10 years for Level 3 autonomous vehicles to enter the mainstream, as software must be improved. Autonomous driving Level 4 and Level 5 will be realized with far more powerful computing capability and robust software. The technology advancements, which will enable Level 4 and Level 5 autonomous vehicles, will accelerate the growth of robotaxi and car-sharing services — changing car buyers' behavior — but it will take more than 10 years for these changes to materialize.

In the electric powertrain fields, two hybrid electric vehicle (HEV)-related technologies, 48V mild HEV and plug-in HEV, reached the Plateau of Productivity in 2020. Regulations force automakers to reduce vehicle emissions with these technologies. It will take a long time for automakers to produce electric vehicles that meet car buyers' real demands, such as long driving distances and a short charging time. Activity is increasing in battery technology development; silicon anode technology has yet to make any significant debut, but venture investment continues as the silicon-dominant anode batteries technology slides toward the Trough of Disillusionment. Meanwhile, the solid-state lithium-ion batteries technology is at the pre-Peak of Inflated Expectations. However, most automakers either have strategic partnerships with battery providers or develop internally with a view to launch an EV in the next two to five years — which could eclipse the opportunity window for silicon-dominant anode batteries.

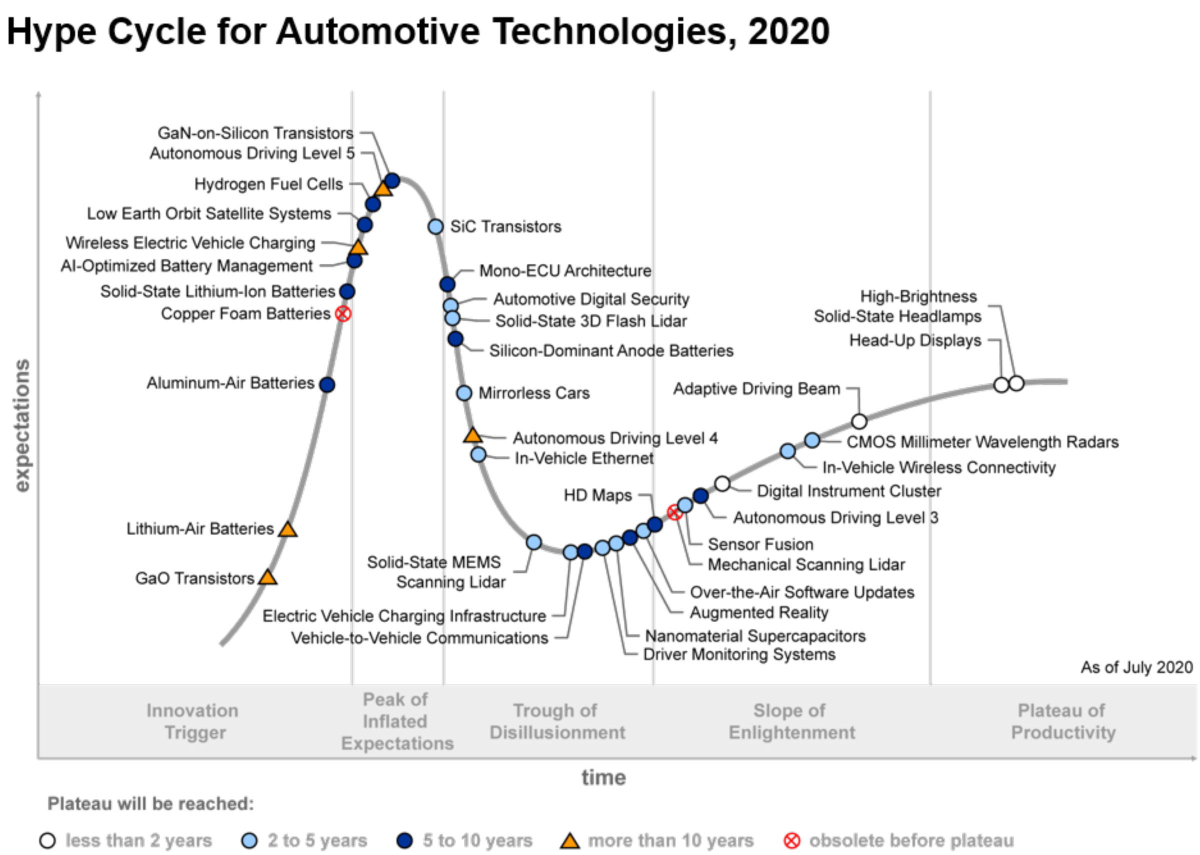
New connectivity technologies will change vehicles. Automotive digital security is considered a must-have feature to protect vehicles from the risk of cyberattack. Automotive digital security is moving to the Trough of Disillusionment, and we forecast that this technology will reach the Plateau of Productivity within five years. Vehicle-to-vehicle communications is also moving through the Trough of Disillusionment, while over-the-air software updates is moving through the Slope of Enlightenment, partly because effective digital security technology has not yet become available.

New Technologies

The following technology has been added in this update of the Hype Cycle:

- AI-optimized battery management

Figure 1. Hype Cycle for Automotive Technologies, 2020



Source: Gartner
ID: 441717

The Priority Matrix

The Priority Matrix highlights the benefits of key technologies and when they will become mainstream.

Autonomous driving Level 3 is an enhanced technology of the current Level 1 and Level 2 autonomy, but we consider **autonomous driving Level 4** and **autonomous driving Level 5** will bring a transformational benefit to various vertical industries and individuals. These two will enable fleet operators to provide their services at far lower costs, enabling more people (including mobility-impaired people) to use transportation services. Limited commercial robotaxi services began at the end of 2018, but it will take more than 10 years for robotaxi and safety driverless fleet services to become a widely available service.

Benefits from **aluminum-air batteries** and **lithium-air batteries** are also considered transformational, with the promise of five times to 10 times the cell energy density for extending EV cruising distance. These technologies will make electric powertrains mainstream, but this will take five to 10 years or more, and they face challenges around charging infrastructure (for example, an aluminum-air battery requires electrolyte top-ups). The benefit of **hydrogen fuel cells** is also transformational, although adoption is slow within light goods vehicles. The technology does scale better than battery alternatives, and for this reason, there is increased interest in the use for trucks and public transport. However, huge investments in the total supply chain is needed for this new energy source. We have kept its years to mainstream adoption at more than 10 years for more than a decade.

Automotive digital security will become widely feasible in two to five years. This technology itself will not change the user experience, but we consider the benefit of this technology as transformational. This is because to realize over-the-air software updates and vehicle-to-vehicle communications, cars must be secured against the risks from cyberattacks. The benefit of **vehicle-to-vehicle communications** is also considered transformational, because this technology will enable cars to try to avoid accidents by superseding the driver's reaction and recognition times. This will be widely used within 10 years.

Figure 2. Priority Matrix for Automotive Technologies, 2020

Priority Matrix for Automotive Technologies, 2020

benefit	years to mainstream adoption			
	less than two years	two to five years	five to 10 years	more than 10 years
transformational		**Automotive Digital Security**	**Aluminum-Air Batteries** **Hydrogen Fuel Cells** **Low Earth Orbit Satellite Systems** **Vehicle-to-Vehicle Communications**	Autonomous Driving Level 4 Autonomous Driving Level 5 Lithium-Air Batteries
high		**In-Vehicle Ethernet** **In-Vehicle Wireless Connectivity** **Nanomaterial Supercapacitors** **Over-the-Air Software Updates** **Sensor Fusion** **SiC Transistors** **Solid-State 3D Flash Lidar** **Solid-State MEMS Scanning Lidar**	AI-Optimized Battery Management Augmented Reality GaN-on-Silicon Transistors HD Maps Mono-ECU Architecture Silicon-Dominant Anode Batteries Solid-State Lithium-Ion Batteries	GaO Transistors
moderate	**Head-Up Displays** **High-Brightness Solid-State Headlamps**	CMOS Millimeter Wavelength Radars Driver Monitoring Systems Electric Vehicle Charging Infrastructure Mirrorless Cars	Autonomous Driving Level 3	Wireless Electric Vehicle Charging
low	Adaptive Driving Beam Digital Instrument Cluster			

As of July 2020

Source: Gartner
ID: 441717

Off the Hype Cycle

The following technologies are now mature and have moved off the Hype Cycle:

- Plug-in hybrid electric vehicles
- 48V Mild HEV

We evaluated the following technologies as Obsolete Before Plateau, and we will move them off the Hype Cycle in 2021, as they are now being replaced with newer technologies:

- Mechanical scanning lidar
- Copper foam batteries

The technology names have changed:

- In-vehicle computer is now listed as mono-ECU architecture.

The following technology is removed from the Hype Cycle, as it is just a subset of autonomous driving functions:

- Automatic anti-speeding

On the Rise

GaO Transistors

Analysis By: George Brocklehurst

Definition: A gallium oxide (GaO) transistor is a type of transistor built from a gallium oxide crystal, which offers a high breakdown voltage, thereby gaining the ability to operate at voltages up to 3kV (a review of the most recent progresses of state-of-art gallium oxide power devices). GaO transistors will significantly improve weight, size and efficiency of electric power trains, power conversion modules and high-power inverters used in renewable energy systems.

Position and Adoption Speed Justification: This technology is still in the laboratory research phase and is likely to be most suitable for lower-frequency high-power applications such as AC/DC conversion — voltage tolerance up to 3kV reported. At this scale, applications will be in larger transport, e.g., trucks, rail, ships and industrial power. Significant time and investment will be required to pull this technology through to production and as a comparison it has taken several decades for silicon carbide to achieve the level of maturity it has today from this point.

A key step has been the move from lateral to vertically constructed transistors, required to achieve the density and voltage capabilities for a compelling value proposition. Germany's Federal Ministry or Education and Research (BMBF) in 2019 launched a £2M joint project bringing to the table industrial partners for a complete value chain perspective from manufacturing (AIXTRON) to deployment (ABB Power Grids). Meanwhile, FLOSFIA, a Japanese startup, announced results showing 50% improvement in channel resistance, with their "normally-off" transistors, when compared to silicon carbide. The company has a partnership agreement with DENSO and has signed a domestic distribution agreement with Hakuto and Kyoei Sangyo to initially bring a Schottky barrier diode (SBD) to market.

Supply chain progress includes a joint development between AGC and Novel Crystal Technology with aggressive plans for production launch of 650V diodes in 2021. Diode construction is far simpler than transistors but will help establish a supply chain for materials and help pave the way for commercialization of GaO transistors.

Aside from the power handling capabilities, an attraction of GaO is the availability of native substrates (from molten GaO similar to what has enabled silicon manufacture) at relatively low cost — which inhibited gallium nitride development. However, like gallium nitride, the thermal conductivity of GaO is very low, which will have thermal management considerations. Multiple technological, let alone manufacturing, challenges remain to bring GaO transistors to market.

With initial interest from industrial partners and the beginning of a supply chain for materials this innovation profile is moved a step further up the Peak of Inflated Expectations.

User Advice: Gallium oxide transistors are very embryonic, where progress is required through scientific breakthrough. The value proposition is an extension to those wide bandgap technologies (silicon carbide and gallium nitride) further along in the adoption cycle.

- Users with industrial and field operations using larger equipment and vehicles are likely to be earlier adopters. Users in this category should take the time to understand the implications and benefits of extending electrification to higher power use cases.
- Equipment and manufacturing vendors invested in markets where power density is core to long-term success should consider participation in university developments to improve visibility, learning and tracking of this technology.

It is unlikely that GaO will have any significant market presence in the next 10 years.

Business Impact: GaO has significantly greater power density and twice the voltage rating over silicon carbide simplifying high-power electronics, lowering cost and increasing efficiencies. Improvements using GaO for transistors will lead to electronics which provide large efficiency savings for a wide range of use cases from electric vehicles and transport to industrial grid and renewable energy.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: FLOSFIA; NICT; Novel Crystal Technology; Tokyo University of Agriculture and Technology (TUAT); University at Buffalo

Lithium-Air Batteries

Analysis By: George Brocklehurst

Definition: A lithium-air battery is a type of metal-air battery that uses a lithium metal anode, and oxygen from the air as its cathode. This technology has the greatest energy density claims of the metal-air chemistries that, it is hoped, will revolutionize electric mobility.

Position and Adoption Speed Justification: This technology is still only at lab scale and still has fundamental challenges, which are being addressed at the research level. These challenges are mainly around the cell construction and packaging, requiring greater understanding of the electrochemical processes involved, development of new materials to promote desired reactions and minimizing undesired reactions.

Challenges include:

- Initial implementations are open cell, as they require an inflow and outflow of oxygen, and have only been successfully repeated under "synthesized" air conditions.
- Limitations in the flow of air/oxygen limit the efficiency of the reaction, which results in contamination of the cathode and rapid degradation of the cell.
- Charge voltage differs from discharge voltage by 1.2 volts. This reduces charging efficiency to 70% and increases thermal dissipation. Research solutions are emerging to address this.

Multiple research institutions are looking to solve these commercialization problems with annual breakthrough announcements. This year the Daegu Gyeongbuk Institute of Science and Technology (DGIST) reported a lithium-air cell with increased discharge capacity maintaining its performance for the two-month trial. Other research announcements in the last two years include, a cell design lasting for 700 charge/discharge cycles, from University of Illinois and Argonne National Laboratory (2018), the use of 2D materials as anode catalysts from University of Illinois (2018). Improvements in the discharge process were announced by University of Waterloo pushing lithium air closer to 10 times of current lithium technology.

In addition to these challenges, a 2019 report by researchers from Samsung Advanced Institute of Technology, found that lithium air is very far from reaching theoretical performance expectations. Their findings place lithium air closer to 5 times the specific energy and 2 times the energy density of current state of the art.

Moving from lab-scale breakthroughs to some practical implementation will take 10 years. Samsung Electronics' research brings attention to practical implementation while DGIST's research helps to further address the technology's challenges. As such we take another small step along the Hype Cycle.

User Advice: Lithium-air battery is still embryonic, and progress is being made through scientific breakthroughs therefore recommendations are long range:

- Users should take time to understand how a disruptive step change in battery capability would influence your future scenarios. How would a significant increase in drone or mobile robot autonomy, 10 times the electric vehicle range, hours of UPS uptime impact your business model and value proposition. Taking this thought process will help you to understand how these technologies fit into your longer-term strategy.
- Vendors for which battery performance is the core to long-term strategic success should improve their visibility, learning and tracking of this technology. Understanding the longer-term architectural changes required to support lithium-air batteries will be essential to leverage the benefit. Architectural changes will require a parallel commercial R&D effort to converge with the

emergence of a lithium-air production solution. The progress in aluminum-air commercialization (Phinergy and India Oil Company), may provide some guidance.

This is a key technology for those involved in electric vehicle, transport and drone development to track.

Business Impact: Lithium-air prototypes have been demonstrated to have five times the power density of lithium ion, and up to 10 times is theoretically possible. A tenfold improvement would bring lithium-air battery close to the power density of gasoline. This level of performance would have a transformational impact on drones and electric vehicles. Success of a closed (sealed) cell or solid electrolyte would have broad transformational impacts across multiple end markets.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Cornell University; PolyPlus Battery; University of Cambridge; University of Dallas

Aluminum-Air Batteries

Analysis By: George Brocklehurst

Definition: An aluminum-air battery is a type of metal-air battery that uses an aluminum metal anode, a liquid (water) electrolyte and oxygen from the air as its anode. These are primary cells; once they are depleted, the aluminum anode must be physically replaced. These anodes can be recycled which will help to offset material costs.

Position and Adoption Speed Justification: Aluminum-air batteries have been prototyped for decades with various demonstrations in electric vehicles. To date, due to cost and primary (nonrechargeable) nature of the technology, they have been restricted to military use cases, such as portable satellite communication packs.

Phinergy, an Israeli startup, has demonstrated solutions powering electric vehicles up to 1,000 km — requiring electrolyte top-ups every ~300 km. In 2020 Indian Oil Company (IOC) acquired a minority stake in Phinergy as they partner to develop, produce and sell aluminum-air batteries at scale — as well as reduce its dependence on Lithium as it migrates its transport network to electric. The technology is particularly suited for rollout in India as it does not need a charging infrastructure. IOC can help to develop the infrastructure for cathode replacement and recycling and install the electrolyte filling capability in their refueling stations. In 2018, Phinergy established a $130 million joint venture with China-based Yunnan Aluminium. Yunnan Aluminium has its own EV venture with a target of producing an initial batch of 2,500 vehicles.

Late 2019, an Indian startup Log 9 Materials, closed a series A round of $3.5 million to commercialize its aluminum-air battery technology targeting an aggressive product launch within 2021. They will leverage graphene to achieve 5x size reductions and efficiency improvements on their current prototype EV also claiming a 1,000 km range. Log 9 Materials' initial target will be stationary solutions including substitute backup generators (5KVA equivalent) for telecommunications infrastructure offering lower total cost of ownership.

In the U.K., Founder Trevor Jackson and his company Métalectrique claim a 1,500 mile range and ~ $75/kWh battery. The company is attempting to build U.K. government backing.

Challenges for mainstream adoption remain high requiring a major cost down through anode/cathode development and infrastructure for anode recycling. Additionally, there are very few technology vendors supplying aluminum-air batteries. Further announcements come from research, including a breakthrough from UNIST late in 2018 with advances using a "flow" technology that reduces anode cost and side reactions that are costly to reverse in recycling as well as increasing peak power capability.

With larger partners and other potential vendors joining the ecosystem, this technology moves further up the Peak of Inflated Expectations.

User Advice: Aluminum-air battery technology is more mature than other metal-air chemistries, but the resultant open-cell construction and inability to recharge pose challenges to adoption. Due to the battery construction, this technology is more applicable to larger cell sizes. The strong driver here is the lure of much-higher energy densities that are applicable for electric vehicles, drones and backup energy sources — particularly valuable in regions with intermittent power. Lead users who can mitigate the trade-offs of implementing this technology must proactively collaborate with leading vendors to bring solutions to the market.

Business Impact: Aluminum-air has the highest near-term power density with eight times greater capacity than today's lithium-ion solutions. This has a fundamental impact on electric vehicle autonomy and, therefore, adoption, extending vehicle range up to 1,000 miles on five minutes charging (claimed by Phinergy). Additionally, the recharge process of replacing electrolyte liquid is far quicker and easier than today's electric charging stations. The final cost structure and process for replacing anodes will be a deciding factor.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Fuji Pigment; Log 9 Materials; Métalectrique; Phinergy

Copper Foam Batteries

Analysis By: Bill Ray

Definition: A copper foam battery is based on a hollow foam of copper, increasing the anode surface area and providing a very short diffusion distance. This results in a battery with increased storage capacity and resilience to charging cycles and physical failure (shorting).

Position and Adoption Speed Justification: Using a metallic foam creates a discharge surface of up to 60 times the surface area of rolled or coiled plates used in traditional batteries. The foam is formed like a sponge, with as much as 98% of the volume being void space. Once the copper has been plated with an anode, it is coated with a cathode slurry to create the cell. Copper foam batteries are designed with an energy density of 650 watt hours per liter of volume; for comparison: a lithium battery stores around 230 watt hours per liter. The idea of porous materials being used for battery components is not new — many conventional lead-acid batteries, for example, use lead foam in the anode. Carbon foam is also a popular material, resisting sulfation and corrosion while dramatically increasing the surface area of the battery plates. The density of the foam can be adjusted to trade capacity against charge/discharge rate, enabling batteries to be optimized for specific applications. The challenge in using foam is reliably coating the surface with the anode, then a separator and then the cathode.

Despite the promise of the technology, development continues to be very slow if not entirely moribund. Given the slow development, and lack of market interest in the face of increasingly capable competition, we do not expect this technology to reach the Plateau of Productivity.

User Advice: Several companies are developing techniques and trying to scale them to production. Users interested in the technology should certainly contact Prieto Battery, though the company has, several times, appeared overly optimistic in judging the development time needed to launch a scalable product.

Copper foam should be evaluated alongside other innovative battery technologies, some of which are closer to production.

Business Impact: Better batteries impact a wide range of industries, from electric cars to wearable computing, and copper foam is no exception. The ability to manufacture custom designs for specific applications, trading off capacity against recharge time, offers some intriguing decision points. Consumers may accept a much shorter battery life if charging takes only a moment and, combined with wireless charging, copper foam could change the way that portable power is perceived. Copper foam offers the flexibility for manufacturers to try out such models.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Prieto Battery; Xerion Advanced Battery

Recommended Reading: “Why All the Investor Buzz Around Silicon Carbide and Gallium Nitride?”

“Top Strategic IoT Trends and Technologies Through 2023”

Solid-State Lithium-Ion Batteries

Analysis By: George Brocklehurst

Definition: Solid-state lithium-ion batteries replace the traditional organic solvent electrolyte with a solid one. Moving to a solid-state electrolyte has several advantages, including increased power density, removing unneeded components, such as separators, and removing safety risks in the conventional battery design.

Position and Adoption Speed Justification: Moving to a solid-state electrolyte provides a potential two- to three-times increase in power density, mitigating the fire and explosive hazards seen in traditional lithium-ion cells. Drawbacks of moving to a solid electrolyte include higher electrical resistance limiting efficiency and charge rates as battery sizes are scaled up, typically low temperature performance (although some vendors appear to have solved/mitigated this issue) and side reactions degrading performance with time and charge/discharge cycles.

So far, solid-state lithium-ion batteries have found niche applications requiring smaller batteries, mainly driven by IoT-related trends, e.g., wireless sensor networks, home automation and toy drones. For example, in February this year, Cymbet announced a partnership where its technology would enable disposable data loggers for cold chain logistics monitoring. Low cost and small form-factor battery solutions are now available from Cymbet and Ilika through distribution (with battery die as low cost as $0.2 in volume) and license agreements to self-manufacture.

Within the electric vehicle market several events unfolded in the last 12 months. Dyson killed off plans to launch an electric vehicle in 2021, it is still committed to its solid state battery program but the schedule is less clear. By contrast, China-based OEM, Enovate has announced very aggressive plans to launch an electric sports car in 2021 powered by solid state battery technology from ProLogium. ProLogium, is a startup who closed a $100 million series D round in April this year. Toyota and Panasonic target launch of a production EV with a solid state battery in 2023. Volkswagen who previously invested $100 million in the solid-state startup QuantumScape has expanded that relationship into a joint venture to develop, manufacture and sell the technology. Solid-state batteries are now on the roadmaps of most OEMs, many with either internal developments of stakes in startup companies pioneering alternative solutions in this area. Post-COVID-19, expectations are five and 10 years to see this technology mature and for any sizable share growth within automotive.

With growing adoption of this technology in smaller form-factors and with growing investments/ commitment into larger form-factors from the automotive industry, this profile continues to move toward the Peak of Inflated Expectations.

User Advice: This technology is in production with multiple improvements in the pipeline. Technology leaders in the supply chain are working in parallel with cell development to capture first to market advantages by capitalizing on the improvements of this technology. There are multiple points of engagement to be taken:

- Current solutions provide high energy density and long life ideal for IoT use cases, where five to 10 years' infield use is required. Also, applications requiring repetitive charging cycles will also benefit.

- Larger solutions are coming to market. The significant energy density improvements should motivate OEMs to engage in partnerships now to understand integration and capacity ramp requirements and include in product roadmaps.
- Based on its emerging production status and improvement trajectory, this should be a prominent roadmap technology for any company dependent on batteries e.g., for drones, robots, edge data centers.

Business Impact: The solid-state design has multiple advantages in both performance and safety. From a performance perspective, this technology addresses the conflicting consumer demand for faster charging, while simultaneously wanting longer battery life with two times capacity increase and up to six times faster charging possible. Additionally, a solid electrolyte results in a more stable design leading to longer battery life (approaching 10 years) and the mitigation of the traditional safety issues of cell shorting in liquid-based lithium-ion designs. These advantages have wide-reaching benefits to all battery-based devices — its extended lifetime having particular appeal to electric vehicles and industrial use cases.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: 24M; Cymbet; Fisker; Ilika; Ionic Materials; Panasonic; ProLogium; Quantum Scape; Solid Power; Toyota

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

At the Peak

AI-Optimized Battery Management

Analysis By: Pedro Pacheco

Definition: AI-optimized battery management uses AI to improve battery management aspects like charging and discharging. AI optimizes performance based on different parameters — such as driving needs, temperature or durability impact. This AI-based system can be useful for achieving the sweet spot when dealing with opposing performance requirements like, for instance, extending battery life and fast charging.

Position and Adoption Speed Justification: In recent years, especially in the automotive sector, batteries have been called upon to fulfill several stringent requirements, but several technological limitations remain, such as charging time and charge life. For this reason, AI in tandem with cloud, could play an important role in bridging the gap where intrinsic battery design cannot deliver. As cloud enables swarm data collection from several batteries simultaneously, AI delivers a more cost-effective and quicker predictive algorithm optimization. Doing the same optimization work without AI would entail testing and assessing a large number of vehicle and battery parameters, which would render the project unattractive. However, AI optimization models for batteries is still at an early stage, and its effectiveness depends on several variables, like size of the data pool, battery type, usage profile and optimization parameters.

Automotive OEMs and Tier 1 suppliers are developing this technology, but are at an early stage. Bosch claims its “battery in the cloud” technology can improve battery durability up to 20% due to the use of AI. It is currently running a pilot in China with transportation company DiDi and automotive company Human Horizons with the purpose of validating the technology. Meanwhile, the Toyota Research Institute has teamed up with teams from Stanford University and MIT, announcing this year that their patented AI technology can greatly speed up the time for testing and optimally charge batteries for electric cars.

Google’s Android team worked with Alphabet’s DeepMind in 2018 to incorporate AI battery management back into smartphones, with the purpose of extending the duration of a battery charge.

With only some companies working on it and very few standard applications developed, this innovation is pre-peak. With the demands for improved battery performance and pace of AI development, hype is likely to grow quickly.

User Advice: Demands for battery performance improvement are ever-growing. Companies where batteries are on the critical path for mission-critical projects must assess this technology and identify roadmap entry points.

AI is only as good as the quality and availability of data. For these reasons, limit the scope of early initiatives to one or two projects, and shortlist just a few parameters for optimization. For instance, Li-ion battery durability improvement could offer a good starting point.

Business Impact: Batteries play an important role in sectors like transportation and energy, which are imposing stringent and growing demands on battery technology. AI optimization of battery management and its performance can become crucial to cover the gap between major battery technology steps. At the same time, usage of batteries for some purposes like electric vehicles is still in a relatively early stage. For this reason, AI offers a platform that can adapt to diverse usage patterns as they become clearer — like battery durability and charge/discharge cycles.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Sample Vendors: Bosch; Google; Intellegens; Stem

Recommended Reading: “What a CIO Needs to Know About the Rise of Electric Vehicles”

Wireless Electric Vehicle Charging

Analysis By: Zarko Sumic

Definition: Wireless electric vehicle (EV) charging is based on inductive charging that uses the electromagnetic field (EMF) to transfer energy between two objects. Induction chargers typically use an induction coil to create an alternating EMF from within a charging base station. A second induction coil in the vehicle takes power from the EMF and converts it back into an electrical current to charge the battery. In addition, stationary charging technology can potentially enable dynamic charging for vehicles as they drive down the road.

Position and Adoption Speed Justification: The technology remains in its infancy and can only transfer small amounts of power over very short distances. It is based on an application of magnetic induction, which uses a changing magnetic flux to push electrons and create a current that transfers electricity from an energy source to a battery. The technology, developed at MIT, uses a principle known as strong coupling. Here, the magnetic fields of two properly designed devices with closely matched resonant frequencies can couple into a single, continuous magnetic field to enable the transfer of power from one device to the other efficiently and over a distance range that is useful for real-world applications.

Compared with conventional EV charging, some cost-conscious consumers may still find it less attractive. In addition to higher cost to wireless charging infrastructure EV manufacturers charge an additional fee for wireless charging or offer it as a standard option to the more expensive models. Despite EV market growth and forecasts of much more to come in the next 10 years, early adopters are likely to recharge their EVs at home where there may be less need for wireless charging.

Wireless charging technologies can be divided into three distinct use cases, which map to specific technologies. Stationary charging, which delivers power to a parked vehicle, quasi-dynamic charging, which delivers power to a vehicle temporarily stopped at a traffic signal or rest area, and dynamic charging, which can deliver power to a vehicle in motion. As these use cases differ from the traditional ICE drive train refueling experience, they required change in user experience. The change in user experience, in addition to technology immaturity, is a significant barrier to wireless electric vehicle charging adoption and is responsible for its slow movement over Hype Cycle.

User Advice: Inductive charging carries a far lower risk of electric shock compared with conductive charging, because there are no exposed conductors. The ability to fully enclose the charging connection also makes the approach attractive, where water impermeability is required. Despite different user experience, compare to conventional ICE engine refueling, inductive charging makes charging mobile devices and EVs more convenient. Rather than having to connect a power cable, the unit can be placed on or close to a charging plate, or in the case of dynamic electric vehicle charging (DEVC) drive overcharging path embedded in the road pavement.

One disadvantage of inductive charging is its lower efficiency and increased resistive heating, in comparison with direct contact. Implementations that use lower frequencies or older drive technologies tend to charge more slowly, and generate heat for most portable electronics. Newer approaches, such as one developed at MIT, diminish the transfer losses with ultrathin coils, higher frequencies and optimized drive electronics. Thus, providing chargers and receivers that are compact, more efficient and can be integrated into mobile devices or batteries with minimal change. These technologies provide charging times that are the same as wired approaches, and are rapidly finding their way into mobile devices. The barriers to widespread adoption, such as additional cost both for EV option and charging infrastructure installation, will be difficult to overcome.

If used in conjunction with vehicle-to-grid (V2G) technology, the vehicle battery can supply energy to the grid at periods of peak demand. This requires additional communication between the grid, charging station and vehicle electronics. DEVC (though still in an embryonic phase) can significantly improve the convenience of use for EV and reduced range anxiety, which is one of the main barriers for EV adoption.

Business Impact: The distribution and energy retail domains will have a major impact. The time-coincident charging of many large battery packs could require expensive electric distribution network upgrades. These costs can be mitigated if the charging can be scheduled away from peak electricity demand periods, or during periods when electricity costs are low. The current uses are mostly based on a car driving over a charging mat installed in public or private garages or parking spots. Potential wireless EV charging applications could include creating long strips of inductive charging plates on roads and highways that charge vehicles as they drive over them to enable DEVC. Because there is a small gap between the two coils, inductive charging is one kind of short-distance wireless energy transfer.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: BMW; Evatran (Plugless); Mercedes-Benz; Toshiba; Toyota Motor; WiTricity

Recommended Reading: “Top 10 Trends Driving the Utility Industry in 2020”

“Market Trends: Wireless Charging for Electric Vehicles Creates New Opportunities”

“Business Moment: Home Energy Management and Electric Vehicles Rescue the Power Grid”

Low Earth Orbit Satellite Systems

Analysis By: Bill Menezes

Definition: Low earth orbit satellites currently provide global or regional narrowband voice and data network services, including to areas with little or no existing terrestrial network coverage. LEO systems operate at lower altitudes (1,200 miles or less) than predominant geostationary systems (about 22,000 miles). Planned LEO broadband systems of up to thousands of satellites could support significantly lower latency and, depending on system technology, broadband data speeds that are greater than throughput of current GEO and LEO systems.

Position and Adoption Speed Justification: Demand for low earth orbit (LEO) services is well-defined. A further growth driver is the lower cost of launching smaller LEO satellites, which can cost around $1 million compared with the $50 to $100 million cost of a geostationary (GEO) satellite, and can be clustered on a single launch rocket. But newer and planned systems will move slowly through the Hype Cycle given the lengthy time frames to plan and deploy them and to develop inexpensive directional antennas. Only about 53% of households globally had internet access at YE19, according to the International Telecommunication Union. Lack of broadband access hinders economic growth, thereby limiting enterprise business potential in underserved regions. However, not all of the next-generation LEO systems planned for extending broadband to at least 60% of the world's population in the coming decade will come to fruition. One of the systems closest to commercial deployment — OneWeb's 648-satellite, LEO constellation — halted with OneWeb's March 27 bankruptcy filing.

User Advice: Enterprises with current or planned business interests in remote or underserved global regions should closely follow LEO system development to align narrowband and broadband connectivity requirements for IoT and general data networking with technology capabilities and service availability. Among planned systems:

- OneWeb had launched 74 of its satellites by the time it declared bankruptcy. During 2Q19 the company began the process of trying to sell its radio spectrum, potentially enabling a successor to take over its plan. The system targets downlink speeds of multiple Gbps at round-trip latency of 10 ms to 30 ms. Terminals for fixed and mobile applications would provide a broadband satellite connection plus 2G, 3G and 4G LTE device connections.
- SpaceX venture Starlink as of 2Q19 had launched about 350 of its satellites, with plans to operate a 4,425-satcom LEO constellation providing global broadband internet access. The company scheduled launches of 180 additional satellites in 2020, targeting possible initial commercial service to North America by year's end. Global commercial broadband coverage is targeted for 2024. The full constellation will require more than 100 successful launches.
- Telesat, which already operates a number of GEO satellites, plans a constellation of 300 LEO satellites to provide global broadband connectivity. The Canadian company launched a test satellite in January 2018, targeting full commercial service in 2023.
- Amazon's "Project Kuiper" is seeking regulatory permission for a LEO constellation of 3,236 satellites to provide broadband internet access to underserved areas as well as to Amazon data-dependent services such as AWS. As of 2Q20, there was no announced service date.

Other planned or existing LEO services include those supporting narrowband data for IoT and digital imaging, or satellite phone and messaging services.

Business Impact: Planned LEO satellites will enable broadband connectivity for all remote or underserved geographies for consumer or enterprise use cases. These services also will be able to provide low-latency backhaul for terrestrial technologies such as remote cellular towers and Wi-Fi hotspots. It will possibly spur new development of those networks in areas where high costs have prevented fiber or other wired WAN backhaul connections. These systems will require customer infrastructure such as directional or phased-array antennas at manufacturing volumes large enough to make them cost-effective.

Just as significant is the use case for narrowband IoT, which requires simpler, less expensive ground antennas and only intermittent connectivity to endpoints or gateways that may be served with a small number of satellites rather than global constellations. Enterprise also may benefit for LEO backhaul for private networking in use cases such as manufacturing, healthcare or natural resources.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Amazon; Iridium; ORBCOMM; SpaceX; Telesat

Recommended Reading: "Market Insight: New Satellite Constellations Enable Revenue Opportunity for CSPs to Complement IoT Connectivity Services"

"Satellite Communications Strengthen Resilience Planning"

"Market Trends: New Satellite Constellations Will Provide Revolutionary Opportunities for Connecting the IoT"

Hydrogen Fuel Cells

Analysis By: George Brocklehurst

Definition: A fuel cell is a device that converts chemical potential energy into electrical energy. Hydrogen fuel cells require hydrogen combined with oxygen (air) and produce water, heat and electricity. This technology (when including a hydrogen tank) is an alternate energy source to battery storage.

Position and Adoption Speed Justification: Majority of recent activity has been in transport. With the trucking industry pressure to reduce CO2 emissions reinforced by sharply rising road tax for diesel trucks, it provides motivation to move to greener fuel sources. Fuel cells have greater range and faster refueling than battery power alternatives. There have been a number of announcements around partnerships to develop fuel cell powered trucks including: Daimler Group and Volvo Group's joint venture valued at $650 million announced April 2020; Nikola and VectraIO announced a merger to accelerate production of its battery-electric and hydrogen fuel cell vehicles; Toyota and Hino Motors announced their partnerships with prototypes to hit the roads this year; China backed Foton Motor Group and pledged a $2.6 billion investment targeting 200,000 "new energy" busses and trucks on the road by 2025. Many of these initiatives target the classic eight-truck segment competing alongside the Tesla Semi. In terms of field deployments, Hyundai will launch the first of their fuel cell powered trucks in Switzerland this year as does VDL in a government funded scheme, H2Share, which begins testing fuel cell trucks in the Netherlands.

There have also been deployments and field trials for fuel cells in public transport — similar value proposition to trucking. China is a significant investor in fuel cell technology launching 800 buses since 2018 with more ramping up to the 2022 Beijing Winter Olympics. Outside of China, recent field deployments include: Trolleybuses switch to fuel cell operation in Riga, Latvia and in the U.K. Optare (subsidiary of Ashok Leyland) launches its "H2" fuel cell double-decker bus.

Outside transport fuel cells has lost momentum. There was some traction in U.S. data centers with the support of government incentives, but this fell away when subsidies stopped. Bloom Energy — a longer running vendor and champion of fuel cell technology — during the COVID-19 crisis has been supplying systems to hospitals to provide electricity to temporary facilities. Earlier in the year Bloom launched its "AlwaysON Microgrids" solution offsetting opex challenges through financing options. These systems offer value where grids are susceptible to extended outages.

User Advice: Hydrogen fuel cell systems have much higher energy densities than battery alternatives — compared to gasoline powered engines and as such are 10 times higher than best in-class battery storage. Other benefits over batteries include fast refueling — same as gasoline — and an energy density which scales near 1:1 with volume. A key premise with fuel cells is that it doesn't have the polluting by-products of gasoline, however, the source of hydrogen is something to be aware of as often fossil fuels are used in its production.

- Less attractive for small engine replacements: Expensive equipment, lack of fuel infrastructure and much lower well to wheel efficiencies — 20% to 30% compared to 70% to 90% for battery solutions.
- More attractive for large engine replacements: Energy density scales better than battery alternatives while having a lower carbon foot print to gasoline. Examples include class eight-heavy trucks (versus battery) and backup power (versus gasoline generators). Backup power solutions require additional efficiency enhancing strategies such as thermal energy harvesting to reach acceptable economics, installations can reportedly achieve 50% to 65% efficiency compared to the coal or nuclear power stations with 33% to 45% conversion efficiency.

In summary, the technology is available and emerging. For companies where transport networks form a significant part of operations, engage with leading vendors in this space creating business cases that consider the trajectory of cost and efficiency improvements. Those businesses able to set out their own fueling infrastructure will be better able to adopt earlier.

Business Impact: Hydrogen fuel cell technology is likely to have the largest impact on the transport industry. Battery adoption and the "well to wheel" efficiencies claimed to date will make it difficult to significantly penetrate the light vehicle market in any short to medium term. Hydrogen is a more attractive source of energy long term, but requires clean and efficient production methods. Commercialization of the technology for transport and backup power will drive investment into greener and more efficient ways of creating hydrogen, which will broaden its application and disruptive opportunity.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Bloom Energy; Daimler Group; Honda; Hyundai; Nikola; Toyota; Volvo Trucks

Recommended Reading: "Technology Innovation and Global Regulations Drive New Interest in Alternative Fuel Trucks"

Autonomous Driving Level 5

Analysis By: Jonathan Davenport

Definition: Level 5 or "full" automation is a definition established by SAE International that refers to self-driving vehicles that can operate without human intervention in every situation and condition. As a result, there is no longer any requirement for a vehicle to be fitted with pedals, brakes or a steering wheel. The autonomous vehicle system controls all driving tasks.

Position and Adoption Speed Justification: There is great excitement surrounding fully autonomous vehicles. However, achieving full autonomy is incredibly complex, with some believing that Level 5 autonomy is not possible and certainly won't be possible for a decade or more. Level 5 vehicles will further the reach of mobility as a service (MaaS). MaaS vehicles will no longer be limited to certain geofenced areas, and instead will be capable of taking passengers anywhere they want to go. They will have even farther-reaching consequences for the transport and logistics industries, which will no longer require human drivers.

Technology advancements necessary for Level 4 vehicles will be developed further for Level 5 use cases. For an autonomous vehicle, monitoring its environment is core to the technology that allows it to function independently. To gather situational data, vehicles such as those Waymo is developing are fitted with an array of sensors that provide a 360-degree field of view using lidar, camera, radar and other supplementary sensors. These sensors need to be capable of gathering data around the vehicle as it moves to create a 3D picture of the vehicle's surroundings. The ability for the artificial intelligence to understand what it sees through these sensors, along with lowering costs, is where a lot of the investment is being made.

This development needs to build effectively across a variety of conditions. Conditions include daytime, nighttime, and different weather and light conditions to identify dynamic and static objects, including pedestrians, cyclists, other vehicles, traffic lights, construction cones and other road features. So, the improvement between Levels 4 and 5 will be incremental, but nonetheless significant.

Disengagements identify where the vehicle is not capable of dealing with a situation on a road and requires a human to take control. While much testing is done in virtual simulations, a linear decline in disengagements is not necessarily expected, as the more challenging the testing, the higher the likelihood of a disengagement. However, over time, disengagements will decline to a point where companies can prove that their vehicle is safe to operate without human oversight in all conditions.

User Advice: The design of Level 5 vehicles will need to differ from that of their Level 4 counterparts, which were typically focused on geofenced urban and suburban transportation. Level 5 vehicles must be capable of transporting people long distances, allowing the provision of intercity MaaS offerings for the first time.

Trucks should no longer be designed with a cab for a human occupant. Thought will need to be given as to how the change in design will impact aerodynamics and associated fuel economy.

Gartner assumes that, to deliver full autonomous driving functionality, Level 5 autonomous driving ECU must have:

- More than 2000 TOPS of processing capability
- More than 128GB of DRAM
- More than 2TB of nonvolatile storage
- 1 Gbps or faster data link interface

Business Impact: Fully autonomous vehicles have the potential to radically affect lives. Different activities can be undertaken while the vehicle is in motion, while road safety will improve. This may lead to a relaxation of certain safety laws, allowing the vehicle interior to be rethought. As a result, people will seek to utilize their time in a vehicle more productively. This will lead to the vehicle becoming the third living space, where people engage with family and friends, watch videos, play computer games, and work. There is even the potential for autonomous vehicles to lead to services such as haircuts or massages being delivered while in transit between locations, and workouts being undertaken in a vehicle as part of a daily commute.

Industries such as logistics will utilize fully autonomous fleets. This will radically change the distance that vehicles can travel in a single day (as they are no longer limited by driver safety hours). Trucks will look very different to how they do today as they start to be designed without a cab for the driver to sit in.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Apple; BMW; Bosch Group; Mobileye; NVIDIA; Tesla; Uber; Waymo

Recommended Reading: "Maverick* Research: Autonomous Mobile Structures Will Fuel the Sharing Economy"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Utilize Partnerships to Secure a Winning Position in the Autonomous Driving Ecosystem"

"Cool Vendors in Autonomous Vehicle Systems"

"Market Trends: Monetizing Connected and Autonomous Vehicle Data"

GaN-on-Silicon Transistors

Analysis By: George Brocklehurst

Definition: Gallium nitride (GaN) is a compound semiconductor whose properties yield high bandwidth and high-voltage transistors. GaN alone has significant manufacturing challenges therefore it needs a substrate. Previously, silicon carbide has been used which is cost prohibitive for many use cases, therefore moving to a low cost silicon substrate has reduced many barriers to adoption.

Position and Adoption Speed Justification: GaN-on-silicon transistor revenues are still relatively small, $45 million compared to a power transistor TAM of $12 billion, but the supply chain and ecosystem is maturing. A growing number of leading semiconductor vendors have GaN products or supporting chips for its implementation. Most recently, ST the leading vendor of silicon carbide transistors, acquired a majority stake in Exagan, a GaN startup, and announced TSMC as its GaN-on-silicon manufacturing partner.

Highest growth adoption is coming from USB-C charge adapters with multiple third-party vendors announcing new solutions 50% smaller and lighter to those using incumbent silicon technology — OEM solutions will follow. Adoption over the next one to two years will be rapid in this segment taking advantage of 100W capable USB-C power delivery adoption.

Adoption in industrial power supplies has been slower to realize in part due to slower new technology adoption rates in these segments. We are seeing broader field implementations and a growing number of case examples across end markets. These examples are proving opex and capex savings as well as new use cases — and business opportunity — enabled by the technology. Growth rate will build over the next three years in these higher value industrial and automotive use cases to become the dominant segment for this technology.

Within RF infrastructure applications, the key partnership (announced Feb 2019) remains MACOM and ST. The driver here is supporting an attractive cost down versus GaN-on-silicon carbide, ST and MACOM expect 10 to 20 times decrease in cost per power amplifier. This comes at a point when 5G is driving significant content increases with broadening adoption of massive MIMO.

We are close but still not quite at the Peak of Inflated Expectations.

User Advice: This technology is applicable for any roadmap where power density is an inhibitor from a few tens of watts to many kilowatts. High value use cases include edge data centers, on-site renewable energy generation and energy storage, electric transport/vehicles, charging of drone fleets, mobile/warehouse robots and industrial/mechanical automation.

- **Existing use-cases (see business impact section):** Prioritize a business case analysis with some urgency. Leverage existing case examples available online or direct from vendors to clarify returns and benefits from implementing the technology.
- **New and emerging use cases:** Reach back in the value chain to the technology vendors to leverage their learning and expertise on what solutions could look like and the likely benefits realized.

Business Impact: GaN on silicon case examples are demonstrating the end-to-end value of this technology:

- **Electric vehicles:** With multiples savings in space, weight and efficiencies as well as cost savings, GaN will have a significant impact on EV adoption. Onboard chargers demonstrating 3x power density improvement support the fast charge roadmap. As high-power versions are introduced GaN will challenge IGBT and SiC for the power train.
- **Data center:** The ability to double the power density of server supplies and halve losses has a significant impact across the data center spectrum. Enablement of edge data centers in new space restricted locations through to 50% utilization improvement and millions of dollars in opex savings in larger data center operations.
- **Renewable energy and microgrids:** The efficiency and space savings afforded by GaN provide material improvement in the ROI of on-premises renewable energy generation and storage. Case examples show 8% round-trip efficiency increases.
- **RF infrastructure:** Cost savings of moving GaN to silicon often an attractive proposition for RF infrastructure at a time when 5G is driving up to 10x content increases in the Remote Radio Head (RRH).
- **Other use cases of note:** Improvements to wireless power transfer for faster and more frictionless charging of drone fleets. Compact yet higher power motor controllers enabling better integration for factory automation.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Dialog Semiconductor; EPC; Exagan; GaN Systems; Infineon Technologies; MACOM (AppliedMicro); Qromis; Texas Instruments; Transphorm

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

SiC Transistors

Analysis By: George Brocklehurst

Definition: Silicon carbide (SiC) is a compound (silicon and carbon) semiconductor and compared with silicon has 10 times higher breakdown voltage, higher power handling capability and faster high-voltage switching capability. SiC transistors that benefit from these properties are relatively new, brought to production in the last decade. These properties lend SiC transistors to high-voltage power conversion use cases.

Position and Adoption Speed Justification: Manufacturability has been the main adoption inhibitor, as expensive raw materials, a limited supply chain and low yield have kept cost high.

Volume is the key to yield improvements and cost reductions to make this technology more accessible to broader markets.

Significant volume ramp up occurred through 2018 and 2019 as Tesla adopted STMicroelectronics' Silicon Carbide transistors in its Model 3 electric power train. This is the fastest growth business for Silicon Carbide transistors and represents one-third of 2019 revenue in this segment. We are seeing growing design wins with global automotive OEMs for the power train and onboard chargers (which will challenge GaN). Volkswagen and Cree announced their partnership in 2019 and Delphi announced a $2.7 billion order for power train inverters using Cree's transistors. This market is set to grow 45% compound annual growth rate (CAGR) through 2024.

Industrial power modules form the largest end market for SiC with a growing number of cases ranging from 1kW to over 100kW. Growth and adoption rates range from 10 to 20% CAGR through 2024. Faster growth will come from electric vehicle charging infrastructure and electric transport.

Meanwhile, capacity is a growing concern to meet electric vehicle demand. In 2019, Cree announced its intention to invest $1 billion to establish a new 8-inch SiC foundry. STMicroelectronics, market share leader in SiC transistors, announced its acquisition of SiC wafer manufacturer Norstel, extended its Cree supply agreement to $500 million and established a $120 million supply agreement with SiCrystal, a ROHM Group company.

In 2019, SiC transistor revenue edged past 5% share of the DC power transistor market. With ramping volumes, a supply chain set for scale and multiple announced design wins this innovation moves closer to plateau.

User Advice: Multiple established vendors are promoting SiC transistor products; while, early low volumes equate to this being a high-cost technology, volume is ramping. Adoption is more compelling where there is a high value placed on compactness and efficiency of power electronics rates in kW.

The costs of implementing SiC transistors should not be compared stand-alone to incumbent technologies; they should be evaluated at the system level, where aspects such as a simplified thermal/switching design are taken into account. Particularly in industrial applications implications for capex vs. opex must be carefully considered and evaluated against risk appetite for change.

SiC transistors are not a drop in replacement to insulated-gate bipolar transistors (IGBTs), as the electrical interface requires different drive conditions and the benefit is realized only when the surrounding circuitry is optimized. As identified in the adoption section, EVs, industrial power supplies, transportation, EV charging infrastructure and renewables are markets where SiC has a strong value proposition. Competing technologies, such as GaN on silicon, which is increasing in power capability, should also be considered and evaluated.

Business Impact: SiC transistors has significant impacts on key use cases summarized below:

- **Electric vehicles (EV):** Efficiency improvements result in lower battery costs and more miles per charge. ST has cited a 20% improvement in miles per charge as well as reduced battery costs.

- **EV charging infrastructure:** SiC transistors enable greater power delivery and, therefore, opportunity to halve or better the charging time achieved by today's silicon solutions.
- **Renewable energy:** SiC transistors halve power loss directly lowering cost of energy generation. In addition, Infineon Technologies quotes a 20% reduction in system costs due to thermal design simplifications.
- **Industrial Power Supplies:** Up to 10% efficiency improvements in kW power supplies provide for compelling opex improvements — lower runtime and maintenance.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: Cree; Fuji Electric; Infineon Technologies; Microchip Technology; Mitsubishi Electric; ON Semiconductor; ROHM; STMicroelectronics

Recommended Reading: "Market Trends: New Semiconductors Enable Compact and Energy-Efficient Power Converters"

"Why All the Investor Buzz Around Silicon Carbide and Gallium Nitride?"

Sliding Into the Trough

Mono-ECU Architecture

Analysis By: Masatsune Yamaji

Definition: A mono-ECU architecture is a new in-vehicle computer architecture, centralizing the distributed computing functions to an ECU. The central ECU in a vehicle enables high-level autonomous driving capability with powerful processors, and integrates the function of many different ECUs into a single domain controller device.

From this year, Gartner has changed the name of the IP to "Mono-ECU Architecture" from "In-Vehicle Computer."

Position and Adoption Speed Justification: To realize Level 3 or higher autonomy, it is convenient for the vehicle to have a powerful ECU.

Reducing the number of ECUs in a vehicle also cuts power consumption, which is beneficial to increase the range of EV/HEV powertrains.

The current domain-based automotive electronic systems are connected with each other through a bus network. The number of ECUs connected deployed in a vehicle is increasing, with more than 100 units per car in 2020 premium cars. The increasing unit number of ECUs connected requires sophisticated in-vehicle networks requiring a large number of high bandwidth interconnection adding weight and complexity to vehicle designs.

To develop high-level autonomous vehicles, it is considered important to change the system architecture from a bus-based distributed architecture to a central computing architecture with star topology network. The central ECU often bridges the vehicle network with the external network such as the internet as the central gateway device. Firmware in an in-vehicle computer can be updated remotely OTA.

Some advanced automakers such as Tesla adopt mono-ECU architecture already, but the number is still very small. Many automakers still need to launch their new platforms in order to deliver this technology.

User Advice: High-level autonomous vehicles require new system architecture for in-vehicle electronics integrating a wide range of different ECU functions into a centralized ECU to deliver efficient vehicle designs. Automakers must work closely with their major component suppliers to develop mono-ECU architecture that integrate the broad range of functionality spread across current generation ECUs.

Business Impact: Mono-ECU architecture will enable vehicle manufacturers to consolidate the functionality of a wide range of ECUs into a centralized functional block, simplifying in-vehicle electronics designs and reducing the number of connections between various ECUs in a vehicle. With a knock on benefit of reducing wiring loom complexity and weight. The use of an central ECU also enables easier management and update of firmware and software necessary to control the vehicle providing a common software architecture, security and update model for all vehicle functions. This removes the need to manage and update hundreds of ECUs, all with different architectures and update requirements.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Continental; Intel; NVIDIA; Robert Bosch; Tesla

Recommended Reading: "A Guidance Framework for Architecting the Internet of Things Edge"

Automotive Digital Security

Analysis By: Masatsune Yamaji

Definition: Automotive digital security is a holistic approach to protecting a vehicle from internal and/or external threats. Automotive digital security aims to protect all physical assets (vehicle hardware) and cyberassets (such as software and information) within vehicles.

Position and Adoption Speed Justification: Most attacks on vehicles today target vulnerabilities in the keyless entry system mainly, for example, jamming of radio keys. Most of the other risks are not actual, but theoretical, because intrusions to the in-vehicle systems were basically done thorough physical connection.

However, connected car solutions are expanding from traditional use cases such as eCall and infotainment to new use cases such as vehicle-to-vehicle (V2V) communication for collision avoidance and the ability to update software over the air (OTA). These two technologies are essential for evolving self-driving cars, but the automotive industry faces increasing risks of cyberattacks. The introduction of V2V communications, which directly control the vehicle's behavior, and software OTA, which updates rewrite the firmware in ECUs significantly increases the importance of digital security for the automotive industry.

User Advice: In addition to current vehicle security initiatives, automotive industry security and risk management leaders should invest in countermeasures against the cyberrisks of the vehicles as a series of objects and the routes by which the vehicle can be compromised.

Objects to protect should be ECUs (and the semiconductor chips such as MCUs, application processors and memory chips used in ECUs), data storage (such as map data and event data), sensors and actuators, in-vehicle network, and gateway, for example.

Routes to protect should be the V2X network, in-vehicle network (such as CAN bus), connectivity with external devices (such as smartphones), Wi-Fi access and OTA, as well as physical interfaces such as OBD-II and USB.

Ensure the cybersecurity of your autonomous vehicle products and services with development guidance by NIST, the NHTSA, TISAX and Auto-ISAC.

Business Impact: High-profile cyberattacks create compromises in the automotive industry which have a big impact on brand and reputation. Although rare to date, these attacks have driven early digital security spend in the automotive industry. Growing attention from governments may lead to potential regulation. Safety regulations and general safety management impacts of digital security overlap due to the cyber-physical dependency of digital infrastructure. Digital security will continue to be a barrier to entry to digital business. In the longer term, these emerging digital security technologies will enable digital ecosystems to be trustworthy, safe and resilient.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Cradlepoint; CriticalBlue; ESCRYPT; Intel; Irdeto; Karamba Security; Penta Security Systems; Syncsort; Xage Security

Recommended Reading: "Market Trends: IoT Edge Device Security, 2020"

"Security of Networks and Endpoints for Technical Professionals Primer for 2019"

Solid-State 3D Flash Lidar

Analysis By: Masatsune Yamaji

Definition: Solid-state 3D flash lidars contain arrays of laser emitters and optical receivers. In principle, solid-state 3D flash lidar operates similar to a camera with a flash. Wherein, the laser lights emit from the lidar, spread into objects and surroundings, are captured by photo diode arrays or image sensors and are finally processed to form a 3D mapping point cloud using time-of-flight algorithm.

Position and Adoption Speed Justification: Solid-state 3D flash lidars have emerged to solve the cost, size and complexity issues of scanning lidars. Solid-state 3D flash lidars are semiconductor-based with no moving parts. The result is a small device, that is less complex to manufacture and is better packaged for mass production, thus improving yields and reducing costs. The critical issue with solid-state 3D flash lidars is the limited field of view (FOV) because it cannot rotate and scan the surroundings like a scanning-type lidar does. The solution for limited FOV is having multiple solid-state 3D flash lidars in a car, and this requires advanced and faster image processing capability.

Mechanical lidar is currently very expensive and the capability of mass production determines the cost. With many vendors developing solid-state 3D flash lidars, further improvements in scale will increase the yield rates, speed up mass production lead time and thus reduce costs. Therefore, over time it will be more affordable for mass market vehicles to have multiple solid-state 3D flash lidars. In addition, range with flash lidar is significantly shorter than the scanning lidar. Solid-state flash 3D lidar will be used with MEMS-based lidar to cover longer distance.

The position of solid-state 3D flash lidars on this Hype Cycle is moving maturer, sliding into the trough because vendors are continuously improving performance with new releases; however, the size and cost have reduced over the past year.

User Advice: Automotive makers should include solid-state 3D flash lidars as part of their roadmap design because of the potential low cost and small form factor, which promotes better car designs. Automakers should understand that solid-state 3D flash lidars will not replace radar or cameras, but rather they complement each other with their advantages for better safety.

Service providers should identify business opportunities with solid-state 3D flash lidars vendors. For example, offering cloud-based processing and traffic data mining with 3D mapping point cloud data from solid-state lidars.

Business Impact: Solid-state 3D flash lidar enables vehicles' upgrade to a higher level of driving automation at affordable prices. In addition, the low cost and lightweight, solid-state 3D flash lidar has the potential to be widely adopted in manufacturing automation, logistics delivery and drones.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Advanced Scientific Concepts (ASC); Continental; LeddarTech; Oryx Vision; Ouster; Quanergy Systems

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

Silicon-Dominant Anode Batteries

Analysis By: George Brocklehurst

Definition: This innovation replaces the anode of a lithium-ion battery with silicon. Silicon has a theoretical 10 times greater capacity for storing lithium ions over today's graphite anodes. This profile focusses on silicon-dominated anodes as opposed to anodes infused with silicon oxide to boost capacity as used by Tesla.

Position and Adoption Speed Justification: Claims from companies and research teams range from three to 10 times greater energy storage density than current lithium-ion batteries — the former is more realistic in the short term. The technology's main challenge is that a fully charged silicon anode swells by over 100%, which in turn creates lifetime, reliability and mechanical issues.

While large corporations are developing and evaluating this technology — examples Panasonic (supplies Tesla), LG Chem and 3M — it is emerging providers that appear to be making progress in moving toward commercialization. Enovix secured a further investment $45 million to ramp production of its 3D cell architecture, which boosts energy density and cycle life of silicon anode batteries. Another silicon anode startup, Sila Nanotechnologies, also secured $45 million funding and expect to be supplying its first customers within a year. Finally, Enevate, who focuses on electric vehicle charging solutions and work on a technology license model, announced its fourth generation silicon anode technology declaring sufficient maturity to scale to gigafactory scale.

Further improvements include using silicon nanowires to increase twice the specific energy and four to five times the energy density. Initially, this will be high cost and targeting very high value applications. By example, Amprius Technologies has developed such technology partnering with — and recently receiving investment from — Airbus Defense and Space. This will implement the technology for high altitude pseudo satellites and other similar initiatives.

Multiple startups gaining investment moves this innovation along the Hype Cycle. However, timing is critical — versus other battery technologies gaining momentum — for how this technology navigates the trough to get mainstream.

User Advice: This is a near-term-battery technology which with the advances in other solutions — e.g., momentum building in solid state lithium-ion batteries — is at risk of missing its window and prescale will have a premium cost. For companies involved in high-value use cases for battery technology should engage with emerging providers and understand roadmap and production schedules versus other solutions. Adoption costs must be considered carefully. For cost sensitive areas engagement with emerging providers should look to understand cost value trajectories when evaluating roadmap entry points.

Business Impact: While theoretical improvements are large near term examples are closer to 50% improvements weighted against a much higher cost. These performance improvements can still have a very meaningful impact on many use cases, but cost will be a strong inhibitor within the next three years. The ability of this technology to break out of high value use cases to have a broader impact will depend on its ability to find momentum and outpace other innovations to scale.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: 3M; Amprius Technologies; Enevate; Enovix; LG Chem; Nexeon; Panasonic; PNNL; Sila Nanotechnologies

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

Mirrorless Cars

Analysis By: Masatsune Yamaji

Definition: A mirrorless car replaces the rear-view mirror and the side-view mirrors with camera monitoring systems.

Position and Adoption Speed Justification: "Mirrorless cars" can increase more in-vehicle space with the same body width. It can also improve the energy efficiency by reducing the air resistance.

Adopting the cameras for side monitoring will assist the lane changing, and is also an inevitable step to realize the Level 3 (or higher level) autonomous driving systems.

Several governments such as Japan and the European Union updated legislation to allow mirrorless cars. For the first time, vehicle OEMs could design a car that utilizes camera monitoring systems in place of conventional side-view mirrors.

On the other hand, NHTSA, which has been studying the possibility for more than a decade, says camera monitoring systems may also introduce new safety risks. A five-year agency study of the technology on heavy-duty vehicles found display screens were too bright, making it harder for drivers to see objects on the road ahead.

Lexus ES shipped in 2018 had a camera system instead of mirrors, and the mirrorless system is expanding to more affordable cars now.

Mirrorless cars will have more than three cameras (rear and both sides) in the future to eliminate all the blind spots.

These multiple cameras that support mirrorless cars can also be used to support autonomous driving functionality.

The position of the technology moved ahead to "peak-trough midpoint" this year. The adoption is growing in new car models — not at a huge pace but consistently. In some cases, it's already even getting to more mainstream models like the Honda e.

User Advice: Rear-view camera module vendors should extend their target market to the camera modules for mirrorless cars. The camera modules for this application must have both video data outputs — one for display for the driver, and one for machine vision.

It would be better to integrate AI capability in the camera module for collision warning as well. Sensors will be used for autonomous driving in the future.

Business Impact:

- Mirrorless cars can improve fuel efficiency due to its improved aerodynamics.
- Vehicle design will be refreshed.
- The camera monitoring systems used in mirrorless cars are much safer than using mirrors because the camera views are wider, thus, eliminating blind spots.
- The camera system for mirrorless cars will have collision warning capability, using AI technology.
- The width of mirrorless cars can be much narrower.
- Mirrorless cars will require more displays for the camera system, which the driver can access inside the vehicle.
- The camera modules replacing mirrors will be used for the sensors of autonomous driving in the future.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: BMW; Daimler Group; Honda; JVCKENWOOD Group; Mitsubishi Motors; Toyota Motor

Recommended Reading: "AI Multisensory Tech in Automotive HMIs, Part 2: Visual Immersion"

"Market Insight: Roadmap for Semiconductor Technologies in Machine Vision for Autonomous Vehicles — When to Invest"

Autonomous Driving Level 4

Analysis By: Jonathan Davenport

Definition: A vehicle classified as Level 4 using the SAE International rating system must be capable of self-driving operation without the need for a human driver. However, Level 4 vehicles cannot drive in all conditions, such as driving during snow or heavy rain, nor will these vehicles be able to deal with all road types or junctions. It is expected that most Level 4 vehicles will operate as part of a mobility fleet in geofenced areas, without steering wheels or pedals.

Position and Adoption Speed Justification: Despite huge leaps forward in Level 4 autonomous driving, large-scale commercial solutions are still a number of years away. Simulation is being used to test challenging maneuvers and situations. For example, Waymo announced in July 2019 that it had driven the equivalent of 10 billion miles in a virtual environment to refine the neural networks that underpin the autonomous vehicle perception models. Plus, governments are continuing to issue permits to allow on-road testing of Level 4 vehicles. In China, a new 62-mile-long highway with dedicated lanes for autonomous vehicles has been announced.

However, the challenges of creating autonomous vehicles should not be underestimated. High-profile accidents, such as the Uber vehicle that was involved in a fatal collision in Arizona in 2018, show the need for improved validation of the technology. This, coupled with the need for regulatory approval, highlights the challenges that the industry still faces to bring a mainstream Level 4 solution to market.

Despite these challenges, automotive manufacturers aim to commercialize the technology for consumer use early in the next decade. This leaves several years of hype between today and when a product is available for use by consumers.

User Advice: It is expected that the economics of Level 4 automation will make private ownership cost-prohibitive, certainly to begin with. As a result, Level 4 autonomous vehicles need to be designed for mobility as a service (MaaS) fleets or other commercial purposes, such as logistics, material or cargo handling.

Many see the widespread adoption of MaaS to be driven by the emergence of Level 4 vehicles, coupled with other macroenvironmental trends, such as:

- Growing urbanization
- Increased use of public transportation, taxis and bikes by young people
- The growth in “as a service” solutions

Level 4 vehicles will not be able to handle all road conditions and situations. As a result, these fleets will likely operate in geofenced areas, where the operator is confident that the vehicles are capable of handling every situation they will encounter. In situations where the vehicle is unable to continue driving, it will need to initiate a “safety protocol.” The safety protocol will require the AI system to be capable of assessing the least dangerous maneuver and bring the vehicle to a halt at the side of the road. In such situations, vehicles may be remotely piloted, utilizing teleoperation systems.

To see mass adoption of Level 4 vehicles, work is also needed to:

- Help the general public trust autonomous vehicles
- Ensure the right legal framework is put in place to support a smooth transition of these vehicles onto the world's roads

Level 4 vehicles would not require steering wheels, accelerator and brake pedals, or mirrors. But they may have them to overcome issues around regulation and to help drive the car in exceptional environmental conditions.

To deliver autonomous driving functionality, Gartner assumes Level 4 autonomous driving ECUs must have:

- More than 200 TOPS of processing capability
- More than 48GB of DRAM
- More than 512GB of nonvolatile storage
- 100 Mbps or faster data link interface

Developers of autonomous vehicle systems should look for use cases, such as mining, agriculture or airports where autonomous vehicles can operate in restricted areas safely without regulatory restrictions. Use these implementations to drive early revenue and gather data and insights to improve the performance of self-driving systems.

Business Impact: Level 4 automation could lead to dramatic changes in how people move around and what activities they are able to engage in while in the vehicle. The introduction of Level 4 MaaS vehicles will start people's migration from owning their vehicle (automotive customers) to instead becoming consumers of transportation provided by third-party fleets. This will impact retention and significantly change the profile of automotive OEMs' customer base, especially in urban and suburban areas. Vehicle OEMs will increasingly sell to mobility providers, or they may become providers themselves, owning the fleet of cars they build.

The vehicles in autonomous fleets may become commoditized. To address this risk, the automotive industry needs to prepare for the migration to autonomous fleets and consider how customer relationships and brand loyalty should be nurtured.

People travelling in the vehicles will be able to shop online, work on a laptop, watch video content and engage with other passengers in a way that has never before been possible. This will transform time that was previously "wasted," such as on commutes into work, making people far more productive.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Alibaba Group; Aptiv; Baidu; Ford Motor; General Motors; Intel; Mercedes-Benz; NVIDIA; Volvo Cars; Waymo

Recommended Reading: "Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem"

"Market Insight: Choosing the Right Technology Ecosystem Is Critical for Successful Autonomous Vehicle Products"

"Use Autonomous Vehicle Automation Levels and Usage Scenarios for Your Product Alignment Strategy"

"Cool Vendors in Autonomous Vehicle Systems"

"Market Trends: Monetizing Connected and Autonomous Vehicle Data"

"Utilize Partnerships to Secure a Winning Position in the Autonomous Driving Ecosystem"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

In-Vehicle Ethernet

Analysis By: Masatsune Yamaji

Definition: In-vehicle Ethernet includes IEEE automotive Ethernet standards such as 100BASE-T1, 1000BASE-T1 and 1000BASE-RH.

In-vehicle Ethernet technology is standardized by IEEE, allowing multiple in-vehicle systems to communicate over a single bus. Systems such as infotainment, advanced driver assistance systems (ADASs), automated driving and onboard diagnostics can simultaneously access information over a single, shielded and unshielded twisted-pair cable from 100 Mbps to 1 Gbps.

Position and Adoption Speed Justification: The idea of using Ethernet in automobiles continues to gain traction among automakers, suppliers and technology companies. The continued growth of connected vehicles, ADASs software defined vehicles, trends toward less ECUs and their subsequent data transport demands is leading to increased network communication needs in automobiles. The challenge for automakers, suppliers and technology companies is to find suitable technologies that can handle large data bandwidth reliably, quickly and at an efficient cost. One of the technologies that promises to address these requirements is in-vehicle or automotive Ethernet.

By using Ethernet to eliminate the need for multiple shielded cabling, which is typical for automobiles' communication technologies today, automotive companies can reduce in-vehicle networking costs by 80% and cabling weight by up to 30%. Reduced cabling weight is becoming an important benefit in addressing stricter fuel efficiency requirements around the world.

The technology was standardized by IEEE already by the efforts of early adoption of BroadR-Reach Ethernet technology.

User Advice: Automotive organizations should consider in-vehicle Ethernet as a cost-effective, yet capable, data networking technology for automobiles that can eventually replace more customized and costly network technology options, such as Media Oriented Systems Transport (MOST). Evaluate the benefits and disadvantages of potential single-source versus multisource vendor scenarios when considering in-vehicle Ethernet.

Business Impact: In-vehicle Ethernet can reduce technology costs for automotive data networking requirements. It can accelerate data communication speeds to support emerging connected vehicle offerings and video sensor data from ADASs or infotainment applications. Automotive Ethernet will also shorten the time for OTA software update drastically.

However, a big hindrance to going to Ethernet has been the need to conduct an entire redo of the electrical system architecture, which is a giant task for automakers. In addition, Ethernet typically is associated with more-centralized computing, rather than a CAN bus and distributed ECUs.

Ethernet-enabled communications for entire connected vehicle systems may elevate data security concerns. Automotive organizations should explore this potential issue by establishing firm guidelines on how to deal with cybersecurity, as well as the legislative considerations related to it (which are still emerging). Vendors join Open Alliance SIG to accelerate the adoption of in-vehicle Ethernet.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Bosch; Broadcom; Continental; Marvell; Microchip Technology; NXP Semiconductors

Recommended Reading: “Forecast Analysis: Wired Interface Semiconductors, Worldwide”

“Market Share Analysis: Wired Connectivity (Interface Functions and Controllers), Worldwide, 2019”

Solid-State MEMS Scanning Lidar

Analysis By: Masatsune Yamaji

Definition: A solid-state micro-electromechanical system (MEMS)-based scanning lidar replaces moving parts with silicon-based hardware and integrates an application-specific integrated circuit (ASIC) to reduce the size of the entire module. The lidar creates a 3D map of its surroundings by emitting millions of laser dots per second and measuring the time it takes for the laser to bounce back.

Position and Adoption Speed Justification: Solid-state MEMS-based scanning lidar is designed to replace mechanical spinning lidar. With little or even no moving parts, solid-state MEMS-based scanning lidar is cheaper and more reliable. The size is also smaller through the use of fully integrated chips. Although the field of view is limited, the cost benefit of MEMS allows one vehicle to use multiple solid-state MEMS-based scanning lidars. In the long run, almost all electronic semiconductor components, including the laser beam, control circuitry, MEMS mirror, detectors and computing application-specific integrated circuit (ASIC), will run on a single chip. This will lead to even lower cost when it achieves mass production. The major application is in automotive.

Solid-state MEMS-based scanning lidar is moved ahead a few steps in the Hype Cycle position this year. Various technologies for lidars are competing each other today, but we believe that it will climb to the enlightenment stage soon. This is because an increasing number of vendors have released new versions of solid-state MEMS-based lidars with better performance and lower cost over the past year.

User Advice: For lidars deployed for automotive use cases, there are various lidar solutions that are competing with each other, and autonomous vehicle makers must work with solution providers to evaluate the quality and cost. In addition, building information modeling (BIM) software vendors must develop new algorithms to analyze the point cloud collected by solid-state lidar.

Autonomous things developers, such as service robot OEMs, should start the evaluation of solid-state MEMS scanning lidar for future product planning.

Business Impact: For lidars deployed for automotive use cases, there are various lidar solutions that are competing with each other, and autonomous vehicle makers must work with solution providers to evaluate the quality and cost. In addition, building information modeling (BIM) software vendors must develop new algorithms to analyze the point cloud collected by solid-state lidar.

Autonomous things developers, such as service robot OEMs, should start the evaluation of solid-state MEMS scanning lidar for future product planning. Solid-state MEMS-based scanning lidar can be used as simultaneous localization and mapping (SLAM) technology to create 3D modeling. It can be applied in industrial automation, security and surveillance, logistics, automotive, 3D mapping, and drone flight management.

Unlike current mechanical lidar placed on the roof of automotive, the solid-state lidar is very small and embedded in the surface of the automotive technology, which means that vehicle designs are not negatively impacted by the incorporation of these sensors.

The other major application area for solid-state lidar is drones. Mechanical lidar was used for BIM to create 3D point for high-resolution modeling. However, since the payload of drone is limited, it's hard to use mechanical lidar in drone. With solid-state lidar, drone can be very useful in inspection to provide real-time construction quality control. Also, it can be used for obstacle avoidance for intelligent flight operations.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Blickfeld; Innoviz; LeddarTech; Luminar Technologies; MicroVision; RoboSense

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

Electric Vehicle Charging Infrastructure

Analysis By: Zarko Sumic

Definition: The electric vehicle (EV) charging infrastructure, or Electric Vehicle Supply Equipment (EVSE), is a component of the overall system that supplies electric energy for the recharging of EVs and plug-in hybrid EVs. Several different means of providing electricity to charge EV batteries exist, including slow residential AC charging and fast commercial DC charging. Ownership models include publicly accessible municipal or commercial charging points or private ones, including those owned by EV manufacturers and individuals.

Position and Adoption Speed Justification: Although most rechargeable EVs and equipment can be recharged from a domestic wall socket, there is additional need for publicly accessible charging options. Some of the public charging options support faster charging at higher voltages and currents than are available from domestic supplies. Charging stations for EVs may not need much new infrastructure buildup in developed countries. There are three distinct types of charging infrastructure:

1. Residential charging stations: An EV owner plugs in when he or she returns home, and the car recharges overnight. A home charging station usually has no user authentication and no incremental metering requirement, and may require wiring a dedicated circuit for faster charging.
2. Charging while parked (including public charging stations) — A commercial venture for a fee or free, offered in partnership with the owners of the parking lot. This charging may be slow or high speed and encourages EV owners to recharge their cars while they take advantage of nearby facilities. It can include parking stations, parking at malls, small centers and train stations (or for a business's own employees).
3. Fast charging at public charging stations >40 kW, delivering over 60 miles (100 kilometers) of range in 10 to 30 minutes. These chargers may be at rest stops to allow for longer-distance trips. They may also be used regularly by commuters in metropolitan areas and for charging while parked for shorter or longer periods. Common examples are CHAdeMO, SAE Combined Charging System and Tesla Superchargers.

According to the International Energy Agency Global EV outlook in 2019, the total number of charging points, or EVSE outlets, exceeded 5.2 million in 2018, up 44% from 2017. Most of this increase was in private charging points (90%). Publicly accessible fast chargers numbered 144 000, and slow public chargers numbered almost 400,000 by the end of 2018. In 2018, China remained the country with the largest installed publicly accessible charging infrastructure.

User Advice: EV charging stations are integrated in the electricity system and, as such, are subject to power sector regulation. The regulatory structure has strong implications for the ownership structure and organizational arrangements of emerging charging infrastructure. In markets where there is a significant government sponsorship for EV adoption, such as in many European countries, utilities (mostly distribution network operators) are encouraged to invest into electric charging infrastructure (the investment can be recovered through regulated distribution tariffs). By operating EV charging infrastructure, utilities are getting better insight and some control over EV charging implications on existing electricity delivery infrastructure.

It's important to consider electric-grid-related challenges once the number of EVs grows. Recharging a large battery pack presents a high load on the electrical grid, but this can be scheduled for periods of reduced load or reduced electricity costs. To schedule the recharging, either the charging station or the vehicle can communicate with the utility via the smart grid communications backbone. Many plug-in vehicles allow the vehicle operator to control recharging through a web interface or smartphone app. Furthermore, in a vehicle-to-grid scenario, the vehicle battery can supply energy to the grid at periods of peak demand.

In markets where there is strong public and policymakers support for EV, the network operator may explore an option in which EV charging will be treated as an extension of energy delivery infrastructure with a traditional investment recovery model. In some markets, utilities may approach EV charging as an unregulated business opportunity. In each case, the ability to gather consumption patterns will help utilities mitigate the impact on the distribution grid, and may eventually result in additional opportunity for revenue growth as electricity starts to displace gasoline as the preferred transportation fuel. Consequently, oil companies are taking an interest in EV charging networks as well.

Business Impact: EV charging infrastructure has multiple implications for utility companies. Depending on the role that a utility company wants to have in the electrification of transportation, the business impact can be minimal (in the case of charging infrastructure that is owned and operated by a third party). Or it can be significant, as in the case of a utility company wanting to manage and operate its own EV charging infrastructure. If the utility company wants to play an active role, the major area of impact will be delivery (charging infrastructure life cycle management) and retail (customer service, metering and billing). The impact of EV charging on distribution networks can be mitigated with timing control to avoid periods of peak demand and improve grid utilization. Thus, ownership of the EV charging infrastructure provides network operation benefits in addition to commercial benefits, such as increased energy sale.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: ABB; Blink Charging; ChargePoint; Enel X; GE; innogy; Siemens; Tesla

Recommended Reading: "Top 10 Trends Driving the Utility Industry in 2020"

"Business Moment: Home Energy Management and Electric Vehicles Rescue the Power Grid"

"Electric Vehicle Charging: 5.4 Million Charging Points, With 2.2 Million Dedicated IoT Connections by 2025"

Vehicle-to-Vehicle Communications

Analysis By: Jonathan Davenport

Definition: Vehicle-to-vehicle (V2V) communication is the wireless transmission of data via dedicated short-range communications (DSRC) or cellular vehicle-to-everything (C-V2X) between vehicles.

Position and Adoption Speed Justification: V2V communications is slipping into the Trough of Disillusionment. Automakers continue to lack direction from a regulatory standpoint. For example, in 2019 the European Commission (EC) and the transport committee of the European Parliament both backed competing solutions. In the U.S. market, at the end of 2019, the Federal Communications Commission (FCC) lost its patience with the auto industry's low utilization of the 5.9GHz spectrum, which had been reserved for DSRC-based V2X for approximately 20 years. The FCC is now proposing to take >50% of this spectrum and repurpose it for other Wi-Fi-based use cases. Some of the spectrum will still be held back for vehicle safety use cases, but opens the possibility that it could be enabled for cellular-based V2X (C-V2X).

The DSRC and C-V2X technologies aren't compatible; thus, the lack of consensus may lead to a hybrid, dual-mode approach in some markets to ensure maximum interoperability among vehicles and infrastructure, with DSRC or C-V2X being sold in parallel, depending on OEM decisions. China will likely establish C-V2X as its technology for V2V, creating an important global shift that may well tip the scale in favor of C-V2X over the long term. In support of this, Geely Auto Group announced its plans to launch the first mass-produced C-V2X-enabled vehicles in China together with Qualcomm in 2021.

More broadly, there appears to be a move toward C-V2X. Toyota, which has already deployed DSRC technology in Japan, announced in April 2019 its decision to halt plans to install the technology to its cars in the U.S. (making a U-turn on a previous decision). Ford Motor Company said in January 2019 that it planned to deploy C-V2X in all new U.S. vehicle models beginning in 2022. The future technological evolution of V2V has yet to gain global consensus, as proponents of C-V2X (Ford Motor Company and Audi) have gained favor among several OEMs and are actively conducting trials of LTE-based C-V2X solutions. However, Volkswagen announced in October 2019 that its Golf model will have DCRC-based technology, making it the first mass market vehicle to be equipped with such technology adding further confusion to which technology will "win."

User Advice: V2V communications can play a crucial role in not only improving traffic safety and flow by allowing vehicles in transit to send data about vehicle position, road conditions and traffic conditions to one another over an ad hoc mesh network. Drivers may simply receive a warning, or the vehicle itself may take preemptive actions, such as braking to slow down in an automated way. Regulatory mandates will help drive adoption in most markets, but a number of OEMs have already deployed V2V as part of an effort to differentiate their products and enhance driver safety (notably, Toyota, Cadillac and now VW). Direct willingness of consumers to pay for the technology is extremely limited, so penetration of V2V technology will be increasingly accepted as standard functionality across and within vehicle types.

Until global or regional consensus can be reached about DSRC or C-V2X, OEMs and automotive Tier 1 suppliers must prepare to deploy different technologies in different markets — depending on regulatory mandates and local market adoption trends. Regardless of technology implementation, OEMs must look to develop stronger relationships with governments at national and local levels to ensure the integration of V2V technologies is quickly established. They must determine the cost implications, and then design alternative deployment use-case models that can offset initial investments since the technology may become mandatory. OEMs should also engage with a clearly defined set of national government agencies (such as the U.S. Department of Transportation [DOT]) and engage in city trials to explore the technology's potential.

Communications service providers (CSPs) should lobby governments and automakers to push for the cellular standard. Revenue from the low-latency-based use case may help pay back investments in 5G and provide an angle to elicit government funding for rural rollout of 5G technology. CSPs also need to ensure that they can monetize their spectrum asset for V2V communications, even when messages do not travel across the cellular network.

Business Impact: V2V use cases enable safer driving performance with low latency (in the range of less than 10 ms) communications would have tremendous business and public safety impacts if implemented on a large scale and in an interoperable way. V2V technology is a key ingredient to realize the safety benefits of connected vehicles and future automated vehicles. The V2V functionality can supplement vehicle sensor capabilities with information from other vehicles on the road, thus warning of hazardous road conditions, collisions and changes in traffic patterns. The V2V communications technology represents crucial safety inputs that cannot be captured by conventional vehicle sensors, allowing drivers and vehicle systems to adjust driving strategies and initiate emergency maneuvers to ensure safety of passengers and other traffic participants. Furthermore, the ability of vehicles to communicate with one another could be used for innovative traffic management systems and help improve traffic flow.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Autotalks; Bosch Group; Continental; DENSO; Ericsson; Huawei; Nokia; NXP Semiconductors; Qualcomm; Siemens

Recommended Reading: "Market Insight: Roadmap for V2X Technologies for Autonomous Driving — When to Invest"

"Toolkit: Top 10 Trends in Automotive and Smart Mobility for 2020"

"Market Trends: 5G Opportunities in IoT for Communications Service Providers"

"5G Will Overtake Alternatives to Provide V2X Connectivity"

"The Top 10 Wireless Technologies and Trends That Will Drive Innovation"

"Market Insight: How Mobile Operators Should Accelerate 5G Impact on Autonomous Vehicle Design"

Driver Monitoring Systems

Analysis By: Jonathan Davenport

Definition: A driver monitoring system (DMS) is an in-vehicle system that employs sensing technologies and analytics to monitor head and body pose, eye state, attention, drowsiness, emotions, and impairment. This system can also identify drivers. DMSs are used not only to prevent accidents caused by fatigue or distraction, but also to ensure effective handovers between the vehicle and the human in semiautonomous driving situations. Other applications include multimodal user interfaces with gestures or gaze in combination with voice.

Position and Adoption Speed Justification: DMSs have been implemented in some premium vehicles for more than 10 years. The technology has three broader applications:

- *Distraction monitoring* — If the DMS becomes aware of a distraction, it can inform other systems of the driver's condition (for example, altering the following distance for automatic cruise control systems).
- *Intention* — By monitoring head and eye movement, the DMS can inform lane-keeping solutions that the driver intends to change lanes, thus allowing a smooth maneuver if the driver seeks to move lanes without using an indicator signal.
- *Gesture* — Video cameras within the DMS can be used for gesture recognition to, for example, when the driver lights a cigarette or picks up a mobile phone.

Work is also underway to enable DMSs to support:

- *Driver identification* — The DMS can be used to identify drivers. This identification can be used to offer personalized services, such as adjusting seat and mirror positions. The tension of seat belts can also be adjusted based on the size, gender or age of occupants.
- *Voice* — The DMS is capable of recognizing where a driver is looking, which can be linked to voice-based virtual assistants to allow location-specific questions, such as "What is that?" mouth movement or voice recognition is used to determine who is giving the command.

DMS technology is now common within fleet operations as companies seek to fulfill their duty of care to staff and other road users by ensuring that drivers operate vehicles safely. Alerts from the DMS can be used by fleet managers to educate drivers on safe behaviors while behind the wheel. Euro NCAP is encouraging automakers to include DMS in their vehicles now and the European Commission's new general safety regulations (GSR) will mandate driver drowsiness and attention monitoring/distraction recognition for all new vehicles applying for type approval from July 2022. The rate of penetration of DMS could be raised further if regulations (like the UNECE 79) are put in place that require DMS.

User Advice: DMS can be used to get the driver's attention back on the road when he or she is distracted or to suggest the driver take a break when tired. Furthermore, DMS can be integrated into fleet management solutions or usage-based insurance applications. Integrating DMS into these types of applications creates an opportunity to educate people about safe driving practices.

The automotive industry should also be utilizing DMS to monitor driver attention when the car is driving itself. DMS should be used to ensure drivers maintain concentration on the road during Level 2 autonomous driving. For Level 3 applications, DMS supports a smooth machine-human handover, by tailoring the period of time necessary to perform a handover based on the activity the driver is engaged in.

The ability for a vehicle to recognize occupants will allow digital personalization of the vehicle environment. With the rise of mobility-as-a-service offerings, the ability to perform identification and identify who is in the vehicle (not just the person who made the booking) by utilizing the DMS will ensure a smooth and rapid personalization of the vehicle. This sort of personalization is expected to be important for retention purposes.

Even though DMS technologies are already available, remedial action for drowsiness is mostly dependent on the driver. Improved integration with advanced driver assistance systems (ADASs) will be important to accelerate the adoption of DMS. Gartner forecasts that by 2025, 28% of new vehicles will be sold with a DMS system up from less than 1% in 2019. Government regulation would further accelerate adoption of this type of system.

Business Impact: DMS is an automotive safety technology that could have a significant impact on reducing motor vehicle accidents caused by driver fatigue or distraction. Driver alertness is a crucial factor in a significant proportion of road accidents, according to research studies such as those conducted by The Royal Society for the Prevention of Accidents (RoSPA). Current solutions still mostly rely on the driver to act on the system's warnings. DMS will play an important role in the adoption of semiautonomous vehicles, by verifying that the driver is able to resume manual control if necessary or if the autopilot function should take control of the vehicle. Future additional uses of the cabin camera of a DMS could be for facial recognition, using face scan as a biometric starting key for the car to acknowledge and authorize the driver. This feature could increase vehicle security and reduce thefts. More advanced solutions will need complex algorithms, so semiconductor vendors need to work in partnership with software providers and system integrators.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Eyesight Technologies; Jungo Connectivity; Seeing Machines; Sony Depthsensing Solutions; Tobii; TriLumina

Recommended Reading: "Invest in 3 Critical Semiconductor Enablers for a Successful Driver Monitoring System Product Portfolio"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"AI Multisensory Tech in Automotive HMIs, Part 1: Smell"

"AI Multisensory Tech in Automotive HMIs, Part 2: Visual Immersion"

"AI Multisensory Tech in Automotive HMIs, Part 4: Emotion AI"

"Market Insight: IoT-Based Digital Personalization, Part 1 — Improve Customer Retention"

"Market Insight: IoT-Based Digital Personalization, Part 2 — Architecture for Automotive Customer Retention"

"Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem"

"Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies"

"Market Trends: Machine Vision Will Be the Game Changer Across Markets"

Nanomaterial Supercapacitors

Analysis By: George Brocklehurst

Definition: A nanomaterial supercapacitor is a type of electrical capacitor that stores more energy than current supercapacitor technologies. The nanomaterials enable both greater electrode area, and thinner separators. Nanomaterial supercapacitors can one day approach the energy density of nickel-cadmium rechargeable cells, but can rapidly charge and discharge, making them suitable for many energy bridging applications.

Position and Adoption Speed Justification: A few parties are now leveraging graphene electrodes to significantly increase electrode surface density. The most notable progress has been made by Skeleton Technologies who offers solutions with four times the power density of existing solutions using their proprietary curved graphene. Following an investment of €25M into a new German plant last year the company is manufacturing approximately 1.5 million cells per year. Skeleton Technologies is currently supplying version one of its product in several form factors, including custom designs for specific customers. These are used in applications such as active suspension in cars and intrawarehouse logistics robots. Other use cases have been enabled by supply chain partners working directly with OEMs, including China's CRRC supplying electric trains that can run on super capacitors alone by 30-second top-up charges at each stop.

Other developments pursue a lithium-ion battery replacement by creating hybrid super-capacitors, using both electrochemical and electrostatic energy storage. However, these have been unable to capture the advantages in power and energy density without the trade-offs resulting in a middle ground solution. One startup ZapGo, based in Oxford, is developing a graphene-ion supercapacitor, with higher voltage capability than traditional super capacitors with energy densities approaching lithium-ion. Most recently, 2019, ZapGo announced a joint venture with AS Green Cube Innovation in Norway to implement their technology into EV charging infrastructure by mid-2020.

Skeleton Technologies' progress in establishing volume supply and demonstrated value in an expanding array of use cases moves this technology out of the Trough of Disillusionment.

User Advice: Nanomaterial supercapacitors are in production and should be evaluated for use cases requiring fast energy capture, burst mode power and high-speed charging. This is still an emerging technology with ongoing energy density and capacity improvements that should be tracked to understand when new high value use cases are enabled. Power density is the key advantage over other storage solutions where power bursts are created in either control or capture use cases e.g., in automotive electric turbo versus regenerative breaking. Mainstream solutions are fairly mature, but limited. Those looking for innovation must partner with vendors of emerging high power density solutions in order create truly compelling opportunities. Working with vendors like Skeleton Technologies, who have broad visibility of use cases is recommended to assess value as well as identify opportunities for adoption.

Hybrid supercapacitors are a key technology to track as a battery replacement. It is likely that this will initially enter the market through mobile robots and possibly hybrid vehicles with lower-power electric drive trains.

Business Impact: Nanomaterial supercapacitors offer superior energy efficiency and performance to the electronic functions within which they are implemented, e.g., better supplying peak power requirements while allowing a primary battery to be optimized for energy density. These benefits provide significant value for electric vehicles (seeing implementation in electric buses, e.g., China) by extending range and helping to reduce charge times — both of which are significant barriers to adoption.

Leveraging nanomaterials for smaller supercapacitors offer benefits to end markets influenced by IoT trends, where the energy density of such a capacitor is sufficient to power an endpoint as its primary source. Benefits include a much longer life, lower risk and simpler energy storage solution, significantly reducing life time operational costs for an IoT endpoint network.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: AVX; Cornell Dubilier Electronics; elna; Eaton; KEMET; NICHICON; Panasonic; Skeleton Technologies; Vishay Intertechnology; ZapGo

Recommended Reading: "Cool Vendors in Technology Innovation Through Power and Energy Electronics"

"Market Trends: IoT Endpoints Will Need New Technologies to Achieve Scale"

"Emerging Technology Analysis: Energy Harvesting Enables Autonomous IoT Endpoints"

Augmented Reality

Analysis By: Tuong Nguyen

Definition: Augmented reality (AR) is the real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects and presented using a mobile, head-mounted-type display or projected graphics overlays. It is this "real world" element that differentiates AR from virtual reality. AR aims to enhance users' interaction with the environment, rather than separating them from it.

Position and Adoption Speed Justification: Current technology is best suited for purpose-built, specialized solutions. As such, position and adoption speed will vary by vertical and industry. Current horizontal tasks seeing the most traction are task itemization, visual design and context-based work instruction. This profile represents a homogeneous view of AR implementations across market segments.

Market interest is growing steadily, but AR continues to struggle with mismatched expectations (vendors promising solutions beyond current capabilities) and poor implementations (for example, solutions delivered without immersive development [3D design and interface] knowledge or workflow integration, or not mapped to business value or need). Current solutions are better described as AR-inspired solutions — experiences that contain elements of AR to offering limited, purpose-built capabilities. AR adoption continues mainly in enterprise applications. Consumer-facing implementations are still struggling to show consumers consistent value. Better hardware, coupled with more compelling use cases, is needed before further progress can be made.

Based on Gartner inquiry (25% increase in inquiries in 2019 over 2018) and industry news, B2B AR continues to gain traction as more enterprises are seeing the value of using AR in their workflow. Moreover, a Gartner 2020 CIO survey indicates that 27% of respondents are currently using, or evaluating/exploring AR. HMD sales reflect the burgeoning pilot deployments. Advancements in HMD hardware (lighter, more durable, safer, etc.) will provide more compelling hands-free use cases for AR as well.

User Advice: Organizations looking to implement AR experiences should:

- Decide on the audience for your AR experience. Internal- and external-facing solutions are not transposable.
- Restrict initial trials to a specific task or goal. Set benchmarks against unaugmented solutions to understand risks and benefits.
- Set the business goals, requirements and measurements for your AR implementation before choosing a provider.
- Rich and robust offerings can bring value only if you have a clear intention for the deployment. For external-facing implementations, use AR as an extension of your brand and experience. For internal-facing implementations, use AR as a tool that will enhance employee job function.

This could include, for example, delivering context-specific information at the point of need for mobile workers, better leveraging experts (using one-to-many video support) in plant and maintenance operations, or enhancing business processes via AR-based training and instruction.

Business Impact: AR bridges the digital and physical world and provides cognitive augmentation for user. AR provides a digital filter to enhance the user's surroundings with relevant, interesting and/or actionable information. This has an impact on both internal- and external-facing solutions. For example, internally, AR can provide value by providing checklists for training and maintenance or for remote telestration in see-what-I-see video collaborations. Externally, it offers brands, retailers and marketers the ability to seamlessly combine physical campaigns with their digital assets. As such, AR is broadly applicable across many markets, including gaming, industrial design, digital commerce, marketing, mining, engineering, construction, energy and utilities, automotive, logistics, manufacturing, healthcare, education, customer support, and field service.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Apple; Atheer; Google; Librestream; Microsoft; PTC; Scope AR; Ubimax; Upskill; Wikitude

Recommended Reading: "Venture Capital Growth Insights: Immersive Technologies"

"Emerging Technology Analysis: Augmented and Mixed Reality Opportunity for 3D Design Software and Vertical ISVs"

"Quality Is the Key to Avoiding 'Digital Distortion' With Your Augmented Reality Strategy"

"Competitive Landscape: Head-Mounted Displays for Augmented Reality and Virtual Reality"

"3D Design and Device Convenience Hinder AR and VR Adoption"

"Augmented and Virtual Reality in the Digital Workplace: Top Use Cases"

"Market Opportunity Decision Framework for Tech CEOs: Augmented Reality and Virtual Reality Use Cases"

"Competitive Landscape: Augmented Reality Tools for Enterprise, 2018"

"Market Guide for Augmented Reality"

"Market Trends: Advancements in Immersive See-Through Technologies Will Differentiate Augmented Reality Glasses"

Over-the-Air Software Updates

Analysis By: Michael Ramsey

Definition: Over-the-air (OTA) software updates refer to methods of using wireless communications technologies to distribute new software or firmware updates and/or configuration settings to automobiles' various computing systems, including infotainment systems and electronic control units. OTA software updates typically leverage dedicated server locations to send and manage the updates to all automobiles in a given region, or by model and year.

Position and Adoption Speed Justification: OTA updates are proliferating, primarily for head-unit software, though they still are not used widely in the automotive industry. Automakers are adopting the technology, but have differing approaches, including using cellular networks and home Wi-Fi to deliver the updates. Most automakers today are performing some level of OTA software updates, but are typically addressing bugs on a semiannual basis and not adding content. In the past year, BMW and Mercedes have begun to add more-advanced OTA capabilities. Tesla is the most advanced in its approach, using a continuous deployment method, including regular firmware updates to operational controls and safety-critical functions.

OTAs will benefit from wider adoption of embedded 4G connectivity and, eventually, 5G connectivity. OTA offers the ability to repair and upgrade vehicles at a low cost relative to dealership visits and offers high completion rates for recalls. It also creates an aftermarket opportunity to maintain vehicles over a long period of time. The potential savings to automakers by using OTAs to complete vehicle repairs could be as high as $15 billion annually on a global basis, according to some vendors that have made estimates.

The technology is limited by connections to vehicles, as well as data security and software validation concerns by the automakers. Most automakers are not set up to do regular deployment of new software on a large number of different models. In addition, there could be resistance from dealers, as OTA updates represent a potential loss of their service business.

User Advice: Automotive companies must stop using a simple ROI equation for introducing OTA. These updates must be done to facilitate and implement many advanced technologies and new business models. CIOs should work with engineering and business partners to ensure that teams are set up to create and test new software on a constant basis, rather than just reacting to whatever problems may exist on vehicles in the fleet. In addition, automotive companies must invest in a new system for developing software that puts an emphasis on continuous deployment, rather than multiyear deployment cycles.

Cybersecurity is paramount, and an emphasis should be placed on software that can operate independent of a network-based security monitoring system. Automakers must determine whether it is more advantageous to build their own OTA infrastructure solution, partner with a provider for a solution or use a hybrid approach. Automakers should look for vendors that can execute OTA updates securely and efficiently to minimize network demand and limit the cost of downloads.

Business Impact: The use of OTA software updates in the automotive industry can reduce service and maintenance, and product and warranty costs, including reducing the need for costly vehicle recalls. It also improves product differentiation and consumer satisfaction during the vehicle ownership phase, and provides new revenue opportunities — for example, adding new applications and enhancing vehicle capabilities and performance.

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Adolescent

Sample Vendors: Airbiquity; AT&T; Aurora Labs; Engis; HARMAN; HERE Technologies; Intel; Kymeta; Microsoft; Verizon

Recommended Reading: “Toolkit: Use Scenarios to Plan for the Future of Smart Mobility 2025”

“Three Ways Automakers Can Successfully Deliver Over-the-Air Updates”

HD Maps

Analysis By: Jonathan Davenport

Definition: High definition (HD) maps are developed as an additional layer on top of traditional navigation maps to provide details necessary for autonomous vehicles to adapt their driving strategy, plan maneuvers, localize and improve the comfort of driving. HD maps are not designed to be read by humans, but rather by a computer. These maps provide a centimeter-level accuracy of 3D road geometry, boundaries and permitted traffic routes, along with semantic information about the environment (for example, position of traffic lights and road signs).

Position and Adoption Speed Justification: The majority of autonomous vehicle system developers believe that the level of accuracy, detail and information of existing navigation maps are not sufficient to enable autonomous driving, and these maps were not built for this purpose. However, as HD maps move into the Trough of Disillusionment, some companies (most notably, Tesla) are developing a counterargument to this notion and are not investing in HD map technology for its autonomous vehicle system.

Building large-scale HD maps that are available with a significant worldwide coverage area and keeping them up to date will require detailed mapping know-how, storage and computing resources for automated processing. The process of generating these HD maps must be bootstrapped initially by using specialized collection fleets or crowdsourcing of raw features. When autonomous vehicles with high-quality sensor setups are available, the data from those vehicles can be used to continuously extend and update the maps. As those vehicles will not be available in large numbers for several years, the whole problem of generating HD maps will need several years to develop.

In the long run, we expect that HD maps will be standardized across manufacturers and become a commodity. Activities for standardization are happening (for example, in the Navigation Data Standard (NDS) Association), but they are not yet completed. There is also the potential of de facto standards emerging from innovators in this field like Waymo or DeepMap.

User Advice: CIOs and IT leaders working on autonomous driving can generate their own map data or work with startups in this field for development purposes and quick demonstrations.

When planning a large-scale rollout of autonomous vehicle services, CIOs and IT leaders must ensure the coverage and standardization of the HD maps. They should also plan for different international regulations, especially considering China, because mapping is strictly regulated there.

Companies with an existing fleet — equipped with advanced sensors, such as cameras and radars — can leverage the data from this fleet to a certain degree. They can also ramp up their activities to establish the data collection and map-building cycle in cooperation with traditional mapping companies, IT companies or startups in this area.

Business Impact: HD maps are targeted mainly at autonomous driving for passenger vehicles, but they can easily be used and extended for other forms of transportation. It must be noted that self-driving cars must be capable of working in situations in which the map is not correct due to changes in the environment. Using HD maps for autonomous driving is usually not considered a safety-relevant feature, but it can help to make driving much more comfortable.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Artisense; AutoNavi; Baidu; Civil Maps; DeepMap; HERE Technologies; mapper; NavInfo; TomTom; Waymo

Recommended Reading: "Cool Vendors in Autonomous Vehicle Systems"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

"Market Trends: Monetizing Connected and Autonomous Vehicle Data"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"HD Map Systems Require Three Critical Semiconductor Technologies to Enable Autonomous Vehicles"

"Market Guide for Indoor Location Application Platforms"

Climbing the Slope

Mechanical Scanning Lidar

Analysis By: Masatsune Yamaji

Definition: Mechanical scanning lidar contains laser emitters, receivers and other supporting components in a module. These components rapidly rotate emitting laser lights that spread out up to 360 degrees, and bounce off objects. The returning laser light is captured by photo diode arrays, and then by using a time-of-flight algorithm, a 3D point cloud of the environment. This design is often bulky and fragile and costs thousands of dollars.

Position and Adoption Speed Justification: Mechanical scanning lidar started to gain traction after Google adopted Velodyne Lidar's solution for its self-driving car prototype in 2012. Audi used Valeo's mechanical scanning lidar for its A8 model in 2017, which is the first production light vehicle with lidar.

This type of lidar can achieve high resolution with up to 64 laser beams and thus support a 360-degree field of view. In addition, the long-range detection of this lidar can compete with radar, up to 200 meters. Its laser beams can be designed to be more powerful for longer-range detection and yet will not hurt human eyes because of constant rotating and its inability to stand still.

The most critical issue for this lidar is that the module of mechanical scanning lidar is bulky, containing various sensors and mechanical moving components, and this is reflected in the cost. The price of a typical mechanical scanning lidar could run into tens of thousands of dollars, a price range similar to a regular car. In addition, lidar is placed on the roof of the car to "see" surroundings better, but that creates another issue — lidar doesn't detect up-close objects because of dead zones around it or the car. Therefore, additional costs need to be incurred for extra sensors attached to the front and back of the vehicle.

Various vendors have offered new versions of mechanical scanning lidars with incremental improvements on performance and physical size at lower prices. However, the current market size is quite small and the demand is shifting from mechanical lidar to new technologies such as MEMS lidar and solid-state lidar. Therefore, Gartner has changed the status of this technology to "Obsolete Before Plateau" this year.

User Advice: Automakers should use mechanical scanning lidar as benchmark when surveying and designing autonomous driving tools. Mechanical scanning lidar in automotive is too cost-prohibitive but its strengths — higher resolution and long-range detection — are critical for safety.

Business Impact: Mechanical scanning lidar in automotive could be displaced with other lidar technologies but its strengths can be exploited in other use cases including civil engineering and surveying, geological and environmental monitoring, etc.

Benefit Rating: Low

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: Ibeo Automotive Systems; Luminar Technologies; Valeo; Velodyne Lidar

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

Sensor Fusion

Analysis By: Amy Teng

Definition: Sensor fusion is a process that aggregates and "fuses" many disparate sensor inputs to increase sensor data accuracy and/or sensing coverage for the system to develop insights and decisions. A sensor fusion solution usually includes a set of sensors, a hardware sensor hub, a fusion engine and a software sensor fusion stack.

Position and Adoption Speed Justification: Sensor fusion for automotive and industrial systems has been prevalent for decades. Sensor fusion also exists in smartphones and tablets where the sensor data has been interpreted by OS allowing app developers access through APIs.

During the past few years, sensor fusion has evolved to include lidar, radar and visual sensing for autonomous cars, SLAM (simultaneous localization and mapping) for drones and robots, and six degrees of freedom (6DoF) visual and 3D audio immersion for (head mounted displays) HMDs.

Technology evolution of autonomous things and Internet of Things (IoT) will keep on pushing the number and the diversity of sensor and sensing technology to a higher level, driving continuous enhancement of sensor fusion technology. Sensor fusion algorithms' development has been benefited by the growing leverages of artificial intelligence/machine learning (AI/ML) technology. When this combined with improved sensor accuracy and advanced computational power of sensor engine, sensor fusion can analyze faster and better than before. Therefore, we moved its position a bit forward

User Advice: Sensor fusion software stacks can be derived from three resources: open source, sensor companies and software companies who focus on serving customers who have sensor fusion requirement. Sensor fusion software can be ported to a variety of different hardware platforms, ranging from application processors, general purpose microprocessors and microcontrollers, programmable logic, integrated combo sensors, and purpose-built devices like Microsoft's customized holographic processing unit (HPU) for HoloLens. Consider discrete, low-power sensor hub solution to offload the process of main processor when designing for power constraint and long battery life applications.

Build a central platform to manage sensor fusion algorithms across different products and applications to gain reuse efficiency. For example, a smartwatch and wristband can share same algorithm for detecting a wearer's gesture and posture, the two devices can also share the same voice actuated algorithm with smart speakers.

Leverage AI/ML to accelerate the pattern recognition of sensor signals and shorten sensor fusion development time.

Sensor fusion can also offer reduced size and weight, which is particularly important in drone applications.

Business Impact: Sensor fusion technology is a key element of enabling real-time contextual analysis because it comprehends the status of a system. Additionally, leverages AI/ML and clever manipulation of different types of input sensors to train model will explore new algorithms, resulting in new insights or new applications unseen before. For example, fusion of sound waves and surface vibration of sound source can create a new type of noise-cancellation device.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: CEVA (Hillcrest Labs); CyweeMotion; Kionix; Knowles; NXP; Qualcomm; QuickLogic; Renesas; STMicroelectronics; TDK (InvenSense)

Recommended Reading: "Cool Vendors in Novel Sensors"

"Cool Vendors in Novel Sensors"

"Market Trends: Supplying Intelligent Sensors for the IoT Takes Cooperation, Integration and Software"

Autonomous Driving Level 3

Analysis By: Jonathan Davenport

Definition: Level 3 autonomy, as defined by SAE International's 0 to 5 rating system, refers to systems that assume full control of a vehicle in limited situations. For example, systems will handle all driving tasks on limited-access highways or under certain speed limits. Human drivers are required to assume control of the vehicle in situations outside the defined parameters.

Position and Adoption Speed Justification: The adoption of Level 3 autonomous vehicles is nascent. The first volume-production Level 3 autonomous vehicle was announced by Audi in 2017. Audi's AI traffic jam pilot is capable of operating autonomously on highways and multilane motorways with a physical barrier separating the two directions of traffic, where vehicles are travelling at speeds of less than 37 mph. Although Audi has its traffic jam pilot feature ready for sale, legislation has impeded consumer adoption and it has now abandoned its plans to introduce the Level 3 traffic jam pilot feature into its A8 vehicles.

There is extensive R&D being invested in autonomous driving, and more solutions are expected to come to market over the next few years. For example, other Level 3 autonomous use cases could include self-parking with no human behind the wheel and truck platooning, but commercial solutions have not yet been released.

Unlike the partial autonomy delivered by Level 2, drivers in a Level 3 vehicle no longer need to monitor the car permanently. Depending on current national regulations, they can turn to other activities, such as looking out the window or watching video content on the vehicle's onboard infotainment system. The semiautonomous system will recognize when the ambient conditions no longer match the range of functions of the system, and it will inform the driver that they must retake control from the vehicle. The driver then must accept control back from the vehicle (the handover), within a defined period of time. The fact that drivers are free to engage in recreational activities when the vehicle is driving autonomously causes some to question how alert and capable they will be of taking over driving when the system prompts them to.

Despite the technology emerging to support semiautonomous driving, the takeup is expected to be slow. Legislation and the high costs of the technology are two factors that will slow uptake. In some countries, such as the U.K., it is currently illegal to use the traffic jam pilot. So local regulations and legislation need to be updated to reflect the changing technological landscape.

Some think that Level 3 will never reach maturity and instead will be overtaken by Level 4 and 5 vehicles. Much of the comfort and convenience that Level 3 vehicles gives to drivers is likely to be offered through advanced Level 2 systems (termed Level 2+), with the driver still in ultimate control of the vehicle, de-risking deployments for automakers.

User Advice: Automotive manufacturers (such as Audi, General Motors, Mercedes-Benz and Tesla) and technology and service providers that are investing in Level 3 automation need to pay particular attention to the machine-human handover. For vehicles to be allowed to work at Level 3, it is important that they have the capability to hand over control back to humans in certain circumstances. This handover must be done safely and effectively. “Situationally aware platforms” will emerge that can be used to deliver safe handovers from machines to humans. These systems will need to monitor the current environment, forecast future environments and support handovers. This three-step cycle needs to form a circular process so that the machine can assess when it is capable of retaking control and operating autonomously again. Once the vehicle is capable of operating autonomously, the human can choose to hand control back to the machine.

This will require investment in driver monitoring systems to understand user engagement/concentration levels.

The situationally aware platform can be used to conduct only planned handovers where the driver has several seconds to retake control. In an emergency situation, there won’t be time for a human to retake control. The vehicle must be designed to use safety protocols in critical situations, where the time for a planned handover falls below preset thresholds, handling actions autonomously.

To deliver autonomous driving functionality, as well as support a smooth machine-human handover, Gartner assumes Level 3 autonomous driving ECUs must have:

- More than 20 TOPS of processing capability
- More than 24GB of DRAM
- More than 256GB of nonvolatile storage
- 100 Mbps or faster data link interface

Business Impact: Level 3 automation isn’t transformational for the automotive industry, as it can be sold only as an expensive add-on. In the long run, it could lead to dramatic changes in how mobility is delivered and serve as a steppingstone to a more transformational Level 4 technology deployment.

The primary benefit of Level 3 automation for consumers is in time saved. It will provide drivers improved comfort levels on journeys by allowing them to engage in nondriving activities while on the highway, either for productivity or entertainment. Likewise, automated parking is a useful and convenient application. For business/commercial applications, Level 3 autonomy mostly resides in trucking, where reducing the load on a driver could be an incentive for truck drivers and fleet operators to adopt it.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Audi; General Motors; Mercedes-Benz; Mobileye; NVIDIA; Tesla

Recommended Reading: "Market Insight: Cracking the Semiautonomous Machine-Human Handover Problem"

"Market Insight: Use Situationally Aware Platforms to Enable Safe Autonomous Vehicle Handovers"

"Cool Vendors in Autonomous Vehicle Systems"

"Market Trends: Monetizing Connected and Autonomous Vehicle Data"

"Utilize Partnerships to Secure a Winning Position in the Autonomous Driving Ecosystem"

"Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

Digital Instrument Cluster

Analysis By: Masatsune Yamaji

Definition: A digital instrument cluster replaces electromechanical gauges with a digital display that allows the driver to select how information is presented for the primary dashboard instruments in a vehicle. The type, quantity and appearance of information — such as speed, engine rpm, fuel quantity and navigation directions — can be changed to suit different driving conditions and user preferences.

Position and Adoption Speed Justification: Many automobile manufacturers, including Volkswagen, BMW, Mercedes-Benz and Jaguar Land Rover, have already replaced traditional gauges with LCDs or AMOLED screens that display digital information designed to mimic the look of a conventional instrument cluster. As the use of digital display technology and graphics processors for instrument clusters expands, it opens up the possibility that the instrument panel's layout, color and other aspects of its appearance can be set according to user preferences. A digital instrument cluster can be integrated with other systems in the automobile, such as the infotainment head unit and a head-up display, for a more seamless user experience.

In the past few years, adoption of digital instrument clusters has proceeded even in the affordable car market. A lot of emerging Chinese local Tier 1 companies have joined this market and produced low-price digital clusters for local customers. The quality of these low-end products is not as good as in the luxury car market, but affordable car manufacturers can attract many car buyers with some additional costs for digital instrument clusters. The expanding digital clusters have light RTOSs rather than multimedia-capable general-purpose OSs, making the cost reasonable.

The adoption is rapidly proceeding, so we moved the position to the Slope of Enlightenment in this year. The display panels shift now from LCD to AMOLED, which enables better performance against backlight, hence, enabling greater freedom in terms of dashboard design. Also in several cases, automakers are starting to merge digital instrument cluster to center display stack.

User Advice: Digital instrument cluster technology offers some potential for product differentiation, and it aligns well with growing consumer expectations for a greater degree of user customization based on consumer experiences with other electronic products, such as smartphones. These benefits should be weighed against the additional cost of the system and the investment required for product development. In addition, the degree of user configurability must be carefully considered with respect to its impact on driver attentiveness, and effective mitigations for driver distraction should be designed into the system.

Instrument cluster designers must ensure that critical information, such as speed, can be effectively displayed over the full range of environmental conditions in which the vehicle will be operated. Some LCD screens can be affected by temperature extremes, and many countries have a legal requirement that vehicles are equipped with an operating speedometer.

Business Impact: The primary business impact of this technology is as a product differentiator among automobile manufacturers, and it represents an opportunity for incremental profit if sold as a high-margin option. A dynamic display can present critical information in a way that is more easily interpreted by the driver. For example, a warning icon could grow in size to dominate the display as a hazard became more imminent. Instrument clusters incorporating such dynamic information presentation might have a positive impact on safety, but it must be implemented in a manner that is not distracting to the driver. Initially, this feature was made for high-end luxury and sport-oriented models and models aimed at younger buyers. However, adoption is spreading to even affordable models, especially in China, as the technology is perceived as having strong differentiation.

Benefit Rating: Low

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: Bosch; Japan Display; JVCKENWOOD Group; Kyocera Group; MARELLI; Sharp; Visteon

Recommended Reading: “SWOT: Luxoft, IT Services, Worldwide”

“Market Insight: Autonomous Driving Creates Opportunities for AI-Enabled Personal Technologies”

In-Vehicle Wireless Connectivity

Analysis By: Masatsune Yamaji

Definition: Robust in-vehicle wireless connectivity offers an alternative to conventional in-vehicle wired connectivity, such as controller area network (CAN). This technology can reduce the wire harness.

Position and Adoption Speed Justification: Automotive electronics systems contain many different modules, such as controllers, sensors and actuators. Some of them operate independently, but most modules communicate with each other based on robust wired network technologies, such as CAN, local interconnect network (LIN), FlexRay, Media Oriented System Transport (MOST) and Ethernet. These network technologies have accelerated vehicle computation, but connecting these modules has led to a large and heavy wire harness. This has become a big issue for automobile physical design, and it impacts fuel economy. Automakers have already been replacing some connectivity in the body electronics and instrument cluster with new robust wireless connectivity technology, such as Bluetooth 5 and IEEE 802.15.4. Chip vendors are also trying to introduce their proprietary robust wireless technologies, such as SmartMesh. This trend of using wireless connectivity is expected to continue.

User Advice: Automakers should consider the replacement of conventional in-vehicle wired connectivity with wireless, realizing benefits beyond the reduction of the wire harness. Wireless technologies are often considered “unreliable” compared with wired ones, but modern wireless technologies can mitigate this concern, while the risk of physical damage to the wire harness can be removed by using wireless.

Multiplexing communications technologies, such as Ethernet, can also reduce the number of wires used for the backbone network in vehicles. Wireless is used more often on the edge.

Business Impact: Currently, the weight of a wire harness represents about 2% of the total car weight. Reducing the wire harness directly improves fuel efficiency and reduces manufacturing costs. In addition, wire harness reduction will create more space in the car, enabling a more flexible design. For example, if the wire harness for battery management is removed, electric vehicles (EVs) will be able to have more battery cells and extend their driving distance per charge. SmartMesh, a wireless connectivity technology from Analog Devices, has been introduced to the battery management system for EVs to realize this benefit.

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: Analog Devices; Cypress; NXP Semiconductors

Recommended Reading: “Forecast Analysis: Wireless Connectivity Semiconductors, Worldwide”

CMOS Millimeter Wavelength Radars

Analysis By: Masatsune Yamaji

Definition: Complementary metal-oxide semiconductor (CMOS) radar integrated circuit (IC) is made with a monolithic silicon CMOS process. CMOS brings lower-cost radar solutions over the incumbents and lowers the barriers to adoption to more mainstream vehicle autonomous features.

Radar is an important sensor for an advanced driver assistance system (ADAS) as it delivers accurate distance and motion of object information. However, it is not easy for automakers to use multiple radars in a car due to the cost.

Position and Adoption Speed Justification: Forty-nine percent of the cars sold in 2018 had some autonomous driving capability such as adaptive cruise control (ACC), automatic braking, lane keeping, blind-spot monitoring and rear detection. Radar is one of the most important components used to realize these features. These applications are no longer only for luxury car models; however, the cost of radar modules is still an inhibitor in the affordable car market.

The cost of front radar module has already decreased to nearly $70 in 2019 from nearly $200 in 2009. This is a result of the transition from gallium arsenide (GaAs) to silicon germanium (SiGe)-based radar IC, which is much less expensive. GaAs and SiGe are high-performance, but high-cost, manufacturing processes. Therefore, emerging use cases requiring high performance often start in these processes. Comparatively, CMOS has lower bandwidth for analog implementations. However, once successful, due to CMOS low cost and ability to further integrate other functions in a system, it is rapidly adopted.

As the result, more units of radar modules will be used in each car in the future.

By covering 79GHz, automotive radars are becoming better in resolution as well, regardless of the manufacturing process.

We saw smooth progress in the development of CMOS millimeter wavelength radar, and moved forward the technology maturity to some extent in this year.

User Advice: Automobile manufacturers should recognize the decreasing costs and increasing benefits of an onboard radar system against other available light-based technologies. While the cost of cameras and imaging technology is falling considerably, and lidar technology is catching up, the cost and resolution of automotive radar has drastically improved.

Users must prioritize the investment in mmWave radar solution, if the end equipment moves fast and needs long-distance sensing.

Business Impact: Automotive radar and other sensor technologies will be important in the development of autonomous vehicles. Cost of the hardware is one of the biggest obstacles to broader adoption. CMOS radar can be used to monitor the area around the car at a low cost. The 79GHz radar technology, which will soon be commercialized, is useful for both short-range and long-range sensing. Unlike optical sensing such as laser-based and camera-based systems, radar functions in low visibility conditions and at night. Capitalizing on multiple radar systems, as well as cameras and other sensing technologies, will enable 360-degree monitoring of the area around the car. This enhances safety and enables advanced driver assistance features that will not only warn drivers of hazards, but also intervene in the control of the vehicle to avoid a collision or mitigate its effects.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Analog Devices; DENSO; Infineon Technologies; NXP Semiconductors; Texas Instruments

Recommended Reading: "Top 10 Strategic Technology Trends for 2020: Autonomous Things"

"Momentum and Demand Build for Autonomous Trucking"

Adaptive Driving Beam

Analysis By: Masatsune Yamaji

Definition: Adaptive driving beam (ADB) is a smart automotive headlight, sensing surroundings and adjusting lights accordingly. ADB uses onboard cameras to detect objects around the vehicle and then dims/shifts the lights for oncoming and preceding vehicles with a matrix LED headlight automatically. This is very different from adaptive headlamp, which switches between low and high beam automatically.

Position and Adoption Speed Justification: ADB is designed to solve a most critical safety issue — the glare that high beam creates for oncoming vehicles. In addition ADB has the potential to replace adaptive headlamp. Both the systems rely on onboard camera to capture lights for analysis. But adaptive headlamp could cause some issues during switching — since the onboard camera would not capture light at the moment of refresh, it won't identify any objects around the vehicle.

Carmakers such as Audi, Mercedes-Benz and Toyota Motor have started to adopt ADB, but there are several challenges ahead. ADB is a system combining lights, cameras and electronic controllers, and working seamlessly within a system in a fast-moving environment is critical for reliability and safety. In addition, ADB is a new technology and is not easily and fully understood by policymaking authorities. For example, ADB is still prohibited in the U.S.

The evolving speed of the technology is accelerating, so we moved the position to more mature stage. ADB will hit the plateau since it has been used for several years already by German carmakers — now even cascading to their more basic models.

User Advice: Carmakers and Tier 1 suppliers should include the ADB feature when planning vehicle roadmaps because ADB can enhance driving safety. Particularly, trucks, buses or long-haul driving vehicles should adopt ADB to reduce car accidents as long hours of night driving could be very tiring, rendering drivers unable to immediately judge and react to the switch of low and high beam.

ADB providers and automakers should also continue to identify obstacles to ADB adoption. Relevant technology improvement progress is important. ADB is not just an evolving lighting technology but also expanding to imaging processing technologies.

Regional regulation issue is another obstacle to ADB adoption, particularly in the U.S. But the reliability of ADB is enhanced by improving technologies and can determine how policymakers change regulations. In anticipation of policy change, carmakers and Tier 1 should prepare in advance to gain early entry advantage. For example, Audi has featured ADB-ready headlamps that can activate ADB via software upgrade once the policy changes.

Business Impact: Currently, ADB is not mandatory for any vehicle and most drivers are not fully aware of the benefits of using ADB. Costs of ADB will be higher than existing automotive headlights because ADB requires more components to process signals between ADB and cameras. Therefore, ADB would be affordable to adopt for only luxury models.

Benefit Rating: Low

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: 01Booster; HELLA; KOITO MANUFACTURING; Lumileds; MARELLI; Texas Instruments; Valeo

Recommended Reading: “Top 10 Trends Driving the Utility Industry in 2020”

“Market Share Analysis: Image Sensors, Worldwide, 2019”

Entering the Plateau

Head-Up Displays

Analysis By: Masatsune Yamaji

Definition: A head-up display (HUD) is a transparent display using light-emitting diode or other display projection technology to display customizable information and images (for example, speed data and warnings). It displays such content within a driver’s line of vision onto a windshield or other surface viewed by passengers (such as side windows).

Position and Adoption Speed Justification: HUDs are beginning to be offered on large-volume vehicle brands and models, and not exclusively as optional features. Recent R&D work is focusing on combining augmented reality (AR) with HUD technology to enable enhanced information management in the driver’s view, including social and point-of-interest data. Automakers are also working on offering aftermarket solutions to retrofit existing vehicles with the technology. This work emphasizes HUDs’ role in providing broader driver information features. Vendors are also developing emerging and advanced HUD technologies that use laser technology to directly project images onto a surface, and that provide higher resolutions and more color choices. The growing importance of human-machine interface (HMI) solutions for connected vehicle applications and the desire for distraction-minimizing technologies will continue to elevate the importance of HUDs in automobile applications.

High-definition (HD) video will also be used for AR navigation in the automotive space.

The technology is already mature enough to reach plateau, but the adoption rate is still not high.

This is because automakers provide HUDs as an option, and not many car owners use the HUDs.

The situation remains in 2020, so we did not change the position of this technology in the Hype Cycle this year.

User Advice: Automotive companies should increasingly develop and deploy HUDs as a potential HMI solution in automobiles. HUDs will create differentiated and less-distracted customer experiences — especially when combined with other user interface technologies, such as speech recognition and haptics.

Application developers can make HUD technology more compelling to users by adopting AR.

Business Impact: HUDs can address driver distraction issues by:

- Keeping drivers' eyes on the road
- Providing better information management
- Creating better user experiences for consuming vehicle-specific performance data and digital content in automobiles

These benefits are critical to automotive companies, because they help to meet legislative mandates regarding driver distraction. HUDs can also create differentiation and revenue opportunities as automakers can charge for these technologies as vehicle options.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Sample Vendors: Bosch; Continental; Delphi Technologies; Garmin; Making Virtual Solid; Pioneer; Texas Instruments

Recommended Reading: "Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest"

High-Brightness Solid-State Headlamps

Analysis By: Masatsune Yamaji

Definition: High brightness (HB) solid-state headlamps represent an evolution of traditional headlamp technology in which the halogen and high-intensity discharge (HID) lamps are substituted for LED and laser technologies. HB solid-state headlamps have light emitting diodes or laser diodes, instead of the halogen and HID lamps traditionally used as headlamps, allowing them to be more energy efficient and easier to maintain.

Position and Adoption Speed Justification: Solid-state headlamp is beneficial because the long lifetime of the device reduces the risk of burning out of the lighting device, and the load to replace the lamps. It also reduces the energy consumption and the CO2 emission. Problem with solid-state LED headlamps is that they need an optical projector to form clear light cutoffs, and without projector, it can blind the oncoming traffic. The cost of projector is a major inhibitor of this technology in budget cars. That's the reason most manufacturers are replacing HIDs with LEDs but conversion from halogen is very limited.

HB solid-state headlamps are becoming popular, reaching about 44% penetration on a total light vehicle production unit basis, as of 2019. This will increase to 83% by 2024.

These headlamps are made with LEDs; however, some luxury cars will have headlamps that have both LED and laser for greater illuminating distance.

Significant cost reduction in LED lighting due to the increasing production scale accelerates the penetration to even affordable cars. Major LED chip vendors are seeing profit in this market, and they are now enhancing laser diode production for better profitability.

Headlamps with some laser diodes will expand to 15% of cars, including medium and affordable models during the next 10 years.

User Advice: Automotive manufacturers need to redesign the heat dissipation structure of HB solid-state headlamp systems to suit new vehicle designs. HB solid-state headlamps can be designed to produce a segmented beam pattern. These individual segments can be turned off in response to sensor inputs to avoid blinding an oncoming driver, while maintaining full illumination of the road ahead and to the side.

Automotive Tier 1 suppliers should consider adopting HB solid-state headlamp systems as standard to reduce power consumption, make driving safer with their faster response time and take advantage of design flexibility. HB solid-state headlamps have a distinct advantage over traditional halogen and HID lamps that need more housing space. For more cost reduction, it is worthwhile to switch to the emerging chip suppliers, for example, in China. There are many LED chip vendors in China, showing strength in low pricing.

LED and laser diode chip vendors and packaging companies need to improve the brightness of the HB solid-state headlamp systems and keep reducing costs to increase their penetration of this market. To improve the profitability, it is good for LED chip vendors to shift their investment to laser diode production.

We saw smooth progress in the development and cost down in the LED headlamp market, and moved forward the technology maturity to some extent in this year.

Business Impact: Manufacturers have long used halogen and HID lamps for the headlamp systems (low and high beams) of light vehicles to keep costs down. However, use of HB solid-state lamps is rapidly expanding in midclass cars to affordable cars. HB solid-state headlamps have several advantages over traditional headlamps that offer significant differentiation to automotive OEMs that take a lead in adopting this technology:

- **Lower power consumption:** HB solid-state headlamps have the potential to reduce power consumption by more than 50% compared with HID headlamps.
- **Longer life:** HB solid-state headlamps last three to five times longer than HID headlamps.
- **Faster response times:** HB solid-state headlamps respond much faster than HID headlamps.
- **Longer light range:** HB solid-state headlamps using laser diodes can illuminate 600 meters, twice as long as HID headlamps or HB LED headlamps.

Benefit Rating: Moderate

Market Penetration: 20% to 50% of target audience

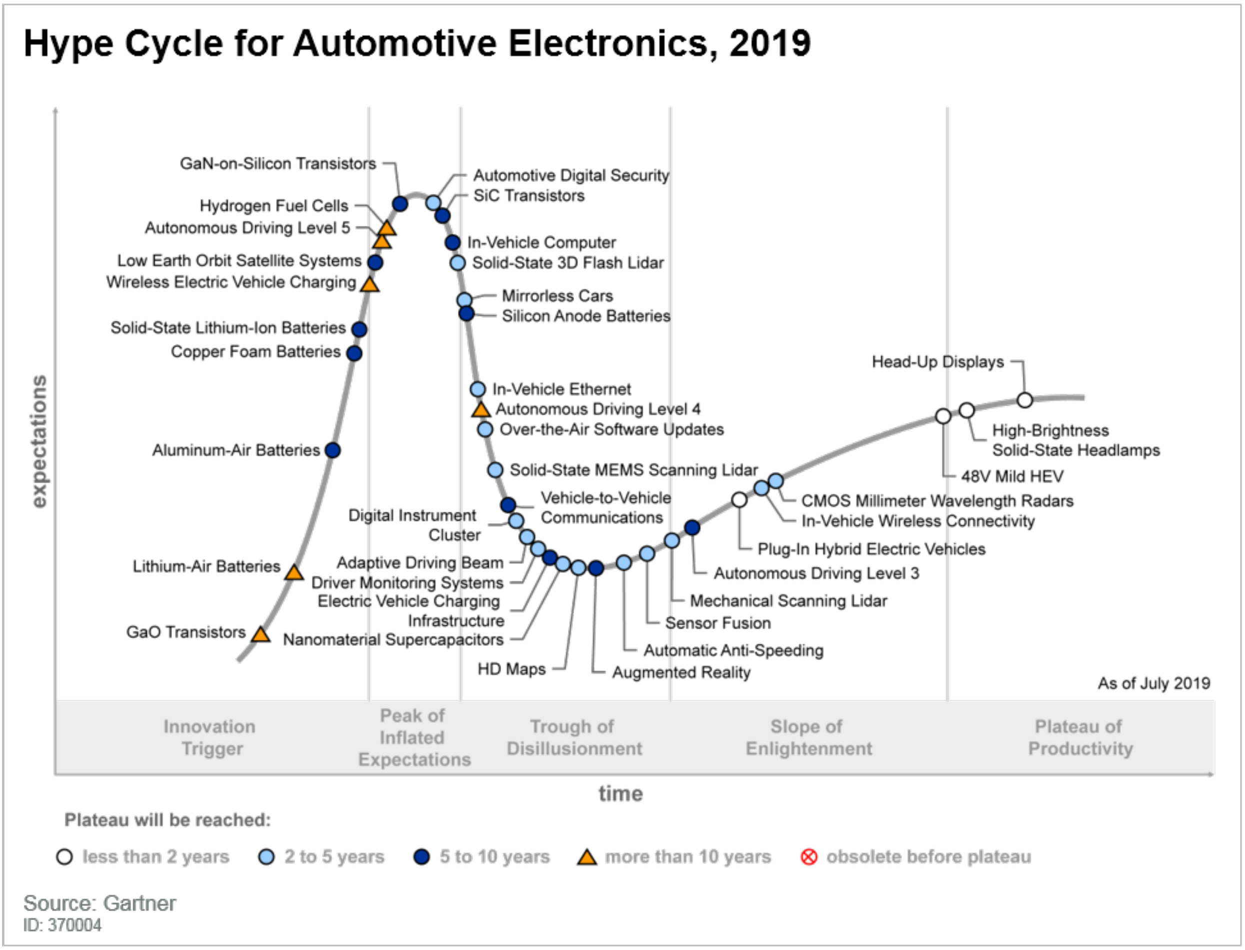
Maturity: Mature mainstream

Sample Vendors: Cree; Lumileds; Nichia; OSRAM; Stanley Electric

Recommended Reading: "Market Insight: Roadmap for AMOLEDs and Micro-LEDs in Immersive Experience — How to Evaluate and When to Invest"

Appendixes

Figure 3. Hype Cycle for Automotive Electronics, 2019



Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 1. Hype Cycle Phases

Phase	Definition
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant press and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the technology is pushed to its limits. The only enterprises making money are conference organizers and magazine publishers.
Trough of Disillusionment	Because the technology does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the technology's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the technology are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the technology to reach the Plateau of Productivity.

Source: Gartner (July 2020)

Table 2. Benefit Ratings

Benefit Rating	Definition
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2020)

Table 3. Maturity Levels

Maturity Level	Status	Products/Vendors
Embryonic	▪ In labs	▪ None
Emerging	▪ Commercialization by vendors ▪ Pilots and deployments by industry leaders	▪ First generation ▪ High price ▪ Much customization
Adolescent	▪ Maturing technology capabilities and process understanding ▪ Uptake beyond early adopters	▪ Second generation ▪ Less customization
Early mainstream	▪ Proven technology ▪ Vendors, technology and adoption rapidly evolving	▪ Third generation ▪ More out-of-box methodologies
Mature mainstream	▪ Robust technology ▪ Not much evolution in vendors or technology	▪ Several dominant vendors
Legacy	▪ Not appropriate for new developments ▪ Cost of migration constrains replacement	▪ Maintenance revenue focus
Obsolete	▪ Rarely used	▪ Used/resale market only

Source: Gartner (July 2020)

Gartner Recommended Reading

Some documents may not be available as part of your current Gartner subscription.

Understanding Gartner's Hype Cycles

Hype Cycle for Connected Vehicles and Smart Mobility, 2020

Toolkit: Create Your Own Hype Cycle With Gartner's Innovation Database

2019 CIO Agenda: An Automotive Perspective

Cool Vendors in AI in Automotive and Smart Mobility

AI Multisensory Tech in Automotive HMIs

Toolkit: Top 10 Trends in Automotive and Smart Mobility for 2020

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