The Next Auto Revolution

It took mankind more than 110 years after Henry Ford's Model T was first produced in 1908 before we would see another automotive revolution, one which is about to unfold before our eyes. Future cars will be intelligent, internet-connected and eventually autonomous. In the next 10-15 years, the developed world together with China will see an increasing level of driving automation and internet-connected vehicles. Completing this revolution will be the successful introduction of autonomous cars. To this end, China has set clear targets of 50% L0-L2 autonomous vehicles and a connected-car penetration of 10% by 2020. This paper combines APS' resources in Japan, China, and Singapore with those of Rothschild Asset Management Inc., to analyse what the next decade holds for this space and seek out opportunities for investment alpha.

The automotive industry is on the verge of a major revolution comparable in effect to Henry Ford's assembly line transformation. The only difference this time is that we have two major technological advances in the works that could revolutionise the entire automotive industry and also have effects on other industries. The two technological advances that are unfolding are the electrification of powertrains to produce Electric Vehicles (EVs), and the increasingly digitised way of driving with advanced driver-assistance systems (ADAS) that would pave the way for fully autonomous vehicles (AVs).

While these two technological advances are taking place independently, together they can dramatically influence the structure as well as future of the automotive industry. These two phenomena could mean that automated electric vehicles are where the future of cars would be. There will be big winners and losers in not just the auto sector but also in the tech, semiconductor and mining sectors. It is still early days with many uncertainties regarding the advancement of these technologies. People tend to underestimate the pace of change. Smartphones are a good example of this. This industry is changing at the speed of Moore's Law. The uncertainties and the perception gap afford us with opportunities to invest and benefit from this structural trend but we need to be very selective.

Electric Vehicles: The electrification of the powertrain

Governments around the world are using different ways to increase the adoption of electric vehicles. Several countries in Europe have stated their intention to stop selling Internal Combustion Engine (ICE) vehicles from 2040. China has been providing massive subsidies and is proposing a dual-credit system to boost the adoption of New Energy Vehicles (NEV) with the target of selling 2 million NEVs by 2020. India has also set an aggressive target to achieve 40% EV penetration by 2032. Additionally, a number of countries including the US, Japan and China are currently offering subsidies on electric vehicles to reduce the current price difference with ICE vehicles. Today, EVs are more expensive than ICE vehicles and will require government subsidies to drive penetration. The price differential will narrow as technology quickly progresses, and we expect EVs to be price competitive with ICE vehicles in the next 5 to 10 years.

Drivers of EV adoption

Government auto-related environmental regulations are one of the major drivers that will boost EV penetration. The US, China, Japan and Europe require their automakers to reduce CO_2 emissions by 30%-40% of 2015 levels by 2025. While automakers are making existing ICE vehicles more fuel efficient and developing EV vehicles, the government will have to use both carrot and stick to increase EV penetration to meet the CO_2 requirements. China is proposing a dual- credit system, whereby i) automakers will need to earn minimum NEV credits by selling NEVs based on their ICE vehicle sales volume, and ii) according to the Corporate Average Fuel Consumption (CAFC), automakers will require a fuel consumption cut of 23% by 2020 and another 20% cut by 2025. We expect these initiatives to boost NEV penetration in China to about 7% in 2020, which is quadruple of the 500,000 vehicles in 2016 which amounted to a 2% penetration. Additionally, in certain Tier 1 cities, the local government is making it harder for buyers to purchase ICE vehicles, making them more likely to purchase electric vehicles.

Government subsidies on the other hand act as a carrot, making it less expensive for consumers to purchase NEVs. The US has been offering USD7,500 of federal subsidies on EVs while Japan has been offering a USD100 subsidy per kWh for EV batteries. The Chinese central government has been giving generous subsidies for NEVs, while local governments can provide additional subsidies capped at 50% of the central government's subsidy. The table below illustrates China's current level of subsidies for NEVs, and it is still uncertain if they will maintain these levels in 2018. We are also uncertain as to what will happen to the subsidies after 2020.

1000RMB

Type	Driving Range	2013	2014	2015	2016	2017	2018	2019	2020
EV	80≦R＜150	35	33	32	–	–	–	–	–
	100≦R＜250	–	–	–	25	20	20	15	15
	150≦R＜250	50	48	45	45	36	36	27	27
	R≧250	60	57	54	55	44	44	33	33
PHEV	R≧50	35	33	32	30	24	24	18	18
FCV	–	200	190	180	200	200	200	200	200

Source: MIIT

A few challenges on the road for wide EV adoption:

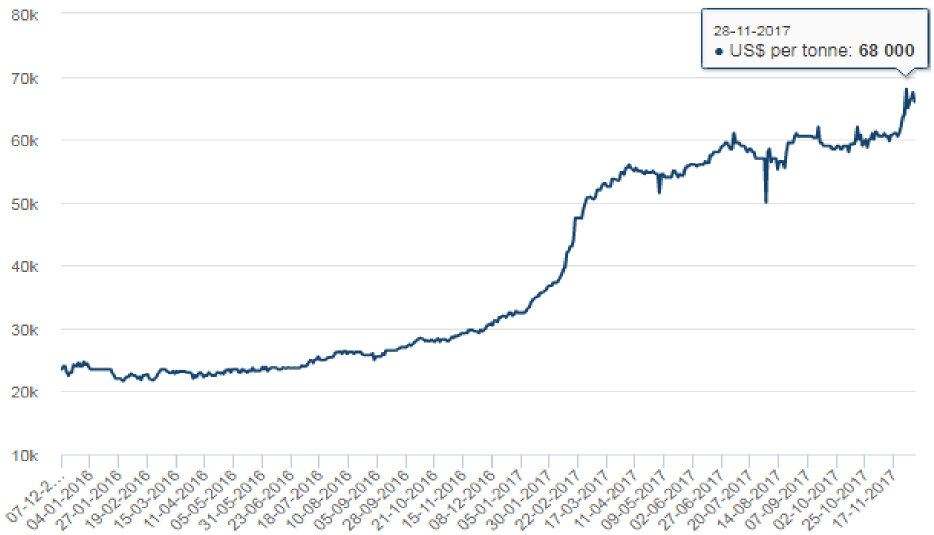
The biggest challenges in accelerating the adoption of electric vehicles today is their cost in comparison to the ICE vehicles. The other drawbacks would be the limited flexibility with the vehicles – limited range and lack of infrastructure to support these vehicles – both from charging to servicing the vehicles.

Today a typical electric mid-range sedan with a 60kWh battery is about $10-15k more expensive compared to an ICE vehicle in the US. The cost differential is mostly due to the difference in the cost of the powertrain. According to a teardown analysis done by UBS of the Chevy Bolt, about $10k of the $16.5k price difference with the VW Golf came from the EV powertrain (Bolt powertrain cost was about $16.4k compared to $6.5k for VW Golf's ICE powertrain).

The general understanding is that electric vehicle adoption will accelerate when the cost differential narrows to the point where breakeven can be achieved in about 3 years. With the estimated cost saving of $1k per year from using an EV instead of an ICE vehicle, we should expect faster adoption when the price difference drops to about $3k per vehicle. This would require the battery pack cost to drop to $100 per kWh from the current price of around $200-225 per kWh.

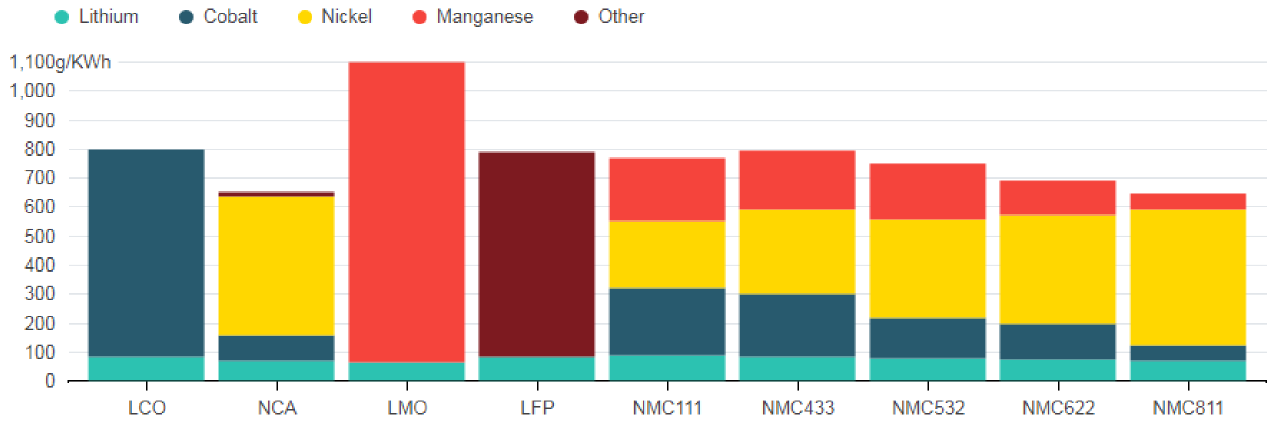
We estimate that the battery cost to drop on average about 10% per year. Changes in the chemical composition of the battery chemistry and improvements in the engineering would be the main drivers of cost reduction. Changes in the materials composition of the batteries will be critical as currently about 50-60% of the total lithium-ion battery cost is materials cost. Within the battery, the cathode is the biggest cost item with about 50% of the materials cost. The chemical composition of the cathode has evolved over the years. It is currently expected that two types of cathodes will be main stream: i) NCM (Nickel, Cobalt, Manganese), which is adopted by many cathode producers, and ii) NCA (Nickel, Cobalt, Aluminium) cathode battery, which is used in Tesla's cars. NCA batteries are produced by Panasonic and Sumitomo Metal Mining.

The cost of lithium batteries will be affected by prices of materials such as lithium, cobalt and nickel. Cobalt is regarded as having a higher risk of shortages, and its price has increased significantly since the middle of 2016.



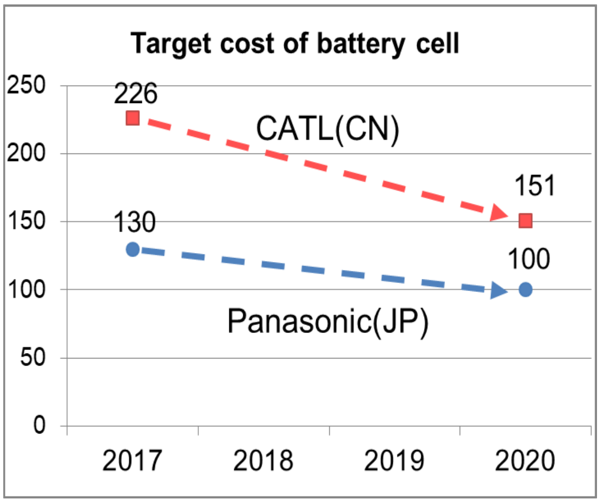
Source: LME

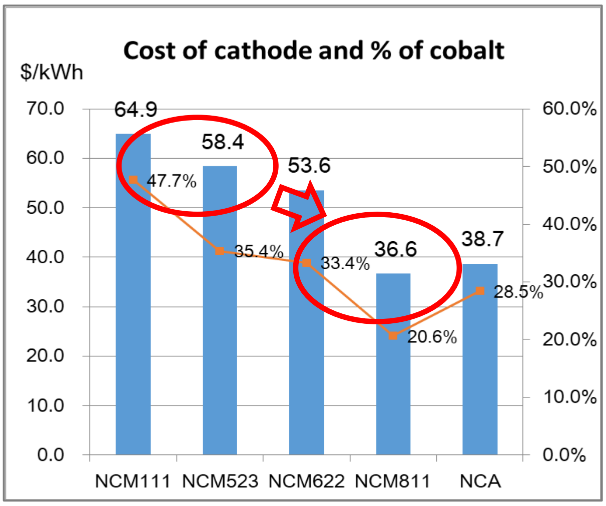
Based on our analysis of cobalt producers, supply is not the immediate risk as Chinese producers still have capacity to increase production. The recent increase in cobalt price has partly been due to new regulations in China pushing auto manufacturers away from cobalt-free Lithium Iron Phosphate cathodes to NCM cathodes that use high concentrations of cobalt. The chart below illustrates the chemical composition of different types of EV battery cathodes and also the portion of cobalt used in different cathodes. We believe the hike in cobalt prices will spur cathode and battery manufacturers to shift from NMC (111, 532, 622) to NMC811 or NCA cathodes. We believe the success of this migration is the key to reducing battery costs.



Source: Bloomberg New Energy Finance

We believe that the battery cost is the most important factor that will drive EV adoption and needs to be monitored carefully. If the cost of batteries does not decline, EVs cannot be sold to consumers at a viable price. We estimate that CATL, the largest battery supplier in China, sells battery cells at CNY1,500 per kWh (about USD225) with their operating cost of around CNY900/kWh (about USD136). CATL will try to slash the selling price by a third to CNY1,000/kWh about USD150) as their operating cost drops to CNY600-700/kWh (USD90-USD105) by 2020. This is still higher than the current price of Panasonic batteries (USD130/kWh) as shown below because of the difference of weighting of Cobalt in NCA (Panasonic) and NCM523 or 622 for CATL. The current Chevy Bolt which uses LG Chemical batteries based on NCM622 cathode, where the cell costs around USD145/kWh.





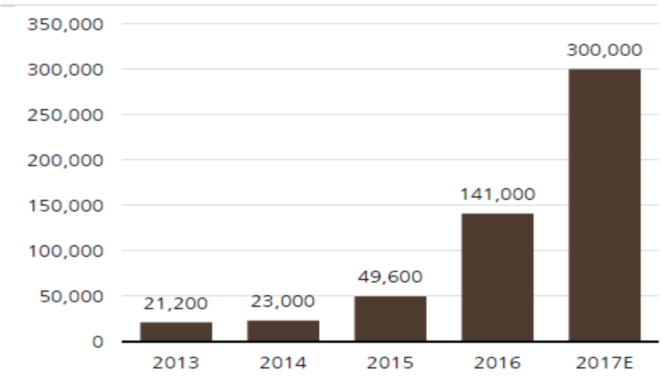
Source: APS, Nomura, Bloomberg. Material costs are based on the price at 5th Dec 2017
NCM523 means the weighting of material is Nickel 50%, Cobalt20%, Manganese 30%

Battery cells are connected and assembled into modules, which in turn are combined to form a battery pack. The cost of manufacturing accounts for 40% of the cost of a battery pack. In addition to reducing the materials cost of the battery cathode, improvements in the manufacturing yield of battery packs will also be critical in lowering the cost of a battery pack, which will make EVs more economical.

Making EVs price competitive with ICE vehicles will not be sufficient in itself. For EV adoption to accelerate, the infrastructure build-up will need to keep pace at the very least. For urban EV use, most users can charge their vehicles overnight at their homes but for longer distance travel, a countrywide rollout of charging stations will be needed. Additionally, the technological advances for quick charging and wireless charging are still in their infancy and will be critical for increased adoption of EVs.

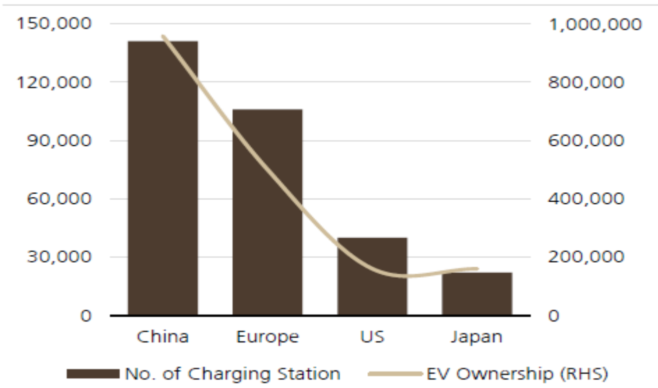
China is well positioned in the expansion of its charging infrastructure, with continuous investment from the government, OEM firms, utilities companies, and service station operators. China has more public EV charging points than any other nation, and has aggressive plans to build more public charging stations in the next several years. That number is on track to more than double in 2017 from a year ago, as shown in the chart below. It will also mean that China will soon have roughly one charging station for every 3 EVs, compared with roughly one station for every 7 EVs in the developed markets of Europe, the US and Japan.

Numbers of charging stations in China



Source: China National Energy Administration

Numbers of charging stations in major markets



Source: China National Energy Administration

Note: Most of the numbers are up to 2016 year end, subject to data availability.

Besides investing heavily and rapidly in charging station infrastructure, China also has a prominent role in standardizing charging infrastructure, partly through sheer weight of numbers. Tesla announced in late 2017 that its cars sold in China will come with a dual-port design that includes a charging port compliant with the GB standard, which is used by public EV charging points in China. The other port features a connector type most commonly used in Europe, which equipped earlier Tesla models sold in China. Standardization is expected to further improve the efficiency and utilization of public charging plots.

New developments that could boost EV adoption

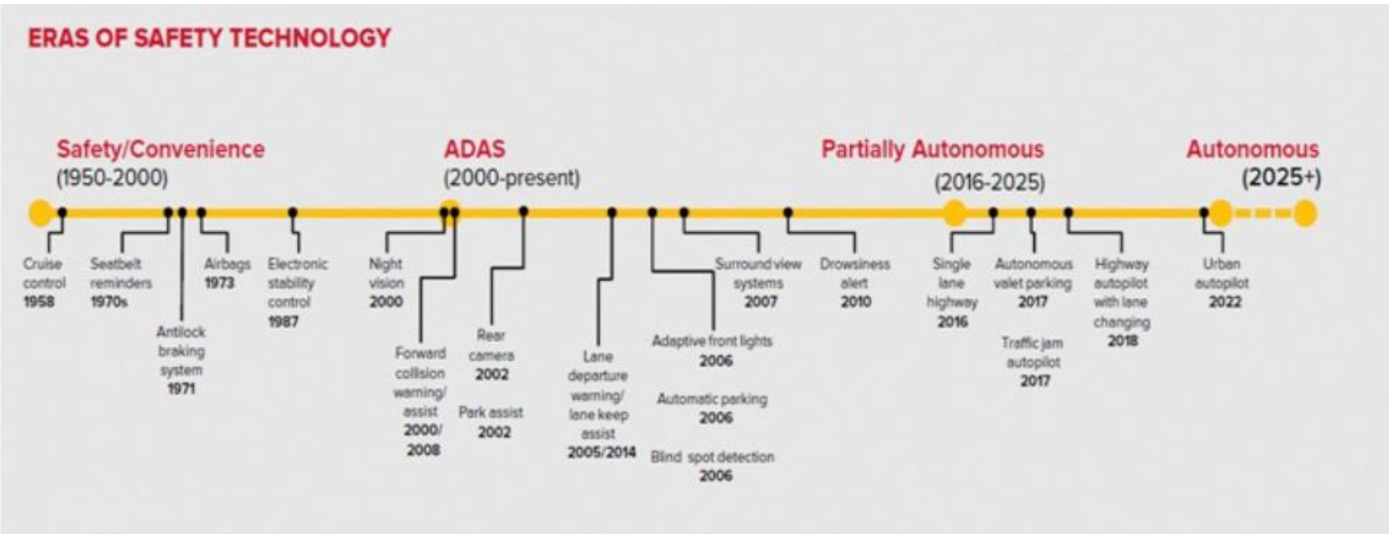
While near-term improvements in battery technology are expected to drive down battery costs gradually and help make EVs price competitive in the next 5-10 years, the industry is working on other battery technologies which could further expedite EV penetration if successful. Some of these technologies would also make EVs a much better overall value proposition to the customer compared to current day ICE vehicles. One of the more promising technologies currently under development would be the commercialisation of solid state batteries. Solid state batteries would not only be cost effective but would also be safer compared to today's EV batteries, on top of having more charge cycles and higher energy density. Toyota and Volkswagen are currently working on the technology but it is not likely to be commercialised in the next few years. Other major battery technologies under development include

i) metal-air technology where the cathode is made out of air and hence would significantly reduce cost and weight, and ii) lithium-sulfur-based battery which is expected to have higher energy density and cost less.

Advanced driver-assistance systems (ADAS) to Autonomous Vehicles – Time to take our hands off the steering wheel

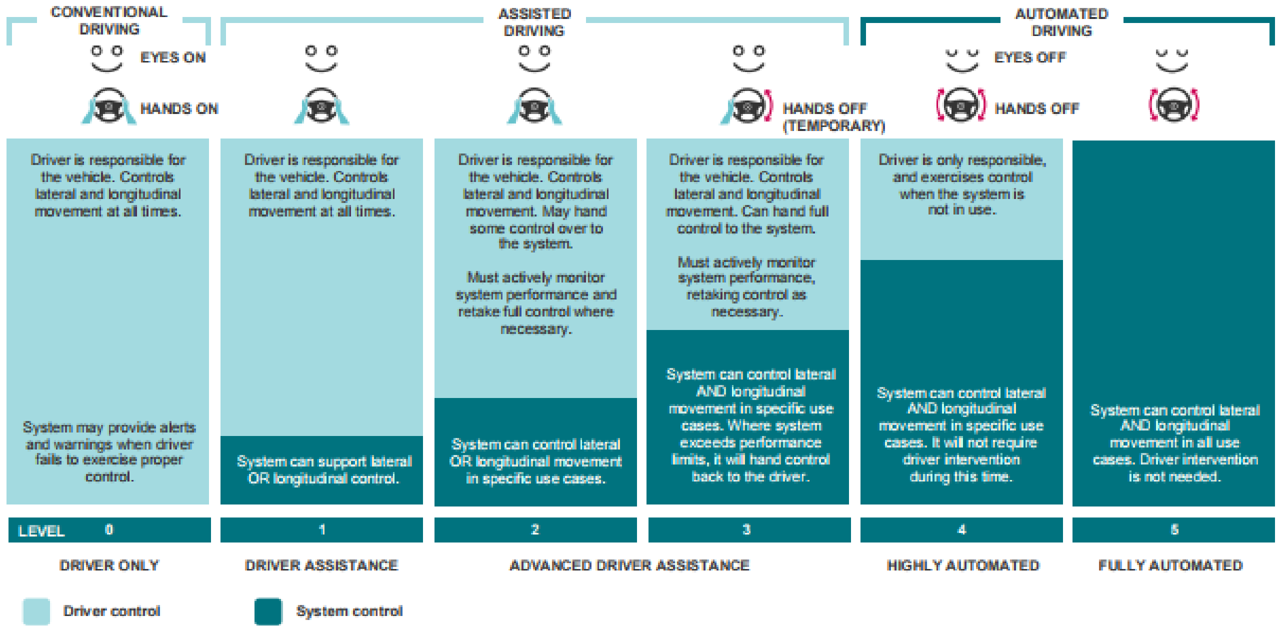
While electric vehicles are changing the heart or the powertrain of the automobile, ADAS is changing the brain of the automobile. Driving an automobile is changing from being completely a human effort, to one where the user is assisted by technology for tasks such as monitoring the road space and also taking actions autonomously. The level of technological assistance in our vehicles will continue to increase, starting with assisted driving which will then evolve to partial autonomous driving and then finally to fully autonomous driving. While the timing of the wide spread commercialisation of Autonomous Vehicles (AVs) is anyone's guess, we are certain about the shift towards partial and fully automated vehicles.

The initial need for developing ADAS features came from the desire to build safer vehicles. The initial ADAS features not only improved safety but also provided assistance to the driver and improved the driving experience. The current ADAS features help in increasing fuel efficiency, warning drivers when the vehicles stray from their lanes. They can also apply the brakes in the case of emergencies to avoid accidents. Some of the ADAS features available today include autonomous-emergency braking system, adaptive cruise control, forward-collision warning, lane-departure warning, parking assistance, rear-view monitoring, etc. Below is an illustrative timeline of when the features were introduced in our vehicles. While some of the features like cruise control, forward collision warning and parking assistance have been in the market since the 2000s, only recently have these systems been enhanced with greater functionalities and controls.



Source: The Boston Consulting Group.

The industry widely measures the level of vehicle automation using the SAE's (Society of Automotive Engineers) 6-tier[1] standard. Level 0 implies no automation, while level 5 implies full automation in all driving scenarios, which is popularly known as an Autonomous Vehicle. Today, most production vehicles are within the L0-2 tiers. L2 is partial automation, where multiple driver assistance systems control steering and speed under some conditions, with the driver doing everything else. The figure below illustrates the difference between conventional driving and fully automated driving.



Source: PTOLEMUS[2]

Automakers are bullish and trying to claim top spot in the race for autonomous driving

According to a BCP forecast, we should see initial testing of highway autopilots with lane changing in 2018 and urban autopilot in 2022. Automakers around the world are making bold claims on getting fully autonomous cars to the market in the near future. Waymo, which was formerly Google's self-driving car project, has said that it would increase its AV testing fleet to 600 cars. This includes autonomous ride sharing provided for free to families in Phoenix, Arizona in the US that started this year[3].GM recently announced that it intends to offer an autonomous robotaxi service in 2019. Daimler earlier this year announced that it expects to offer AVs within five years. VW recently launched its new Audi A8 model that offers the L3 "Traffic Jam Pilot" mode for speeds up to 60km/hr. It is also the first OEM to be granted an AV testing license in New York. Similarly, Toyota has mentioned that it expects to offer L4 AVs in early 2020. In China, most OEMs have claimed that they would start offering L3 vehicles in 2019-2020, in line with their global peers. Baidu, a tech company, has taken the lead in AI-related fields similar to Waymo in

[1] https://www.sae.org/news/3544/

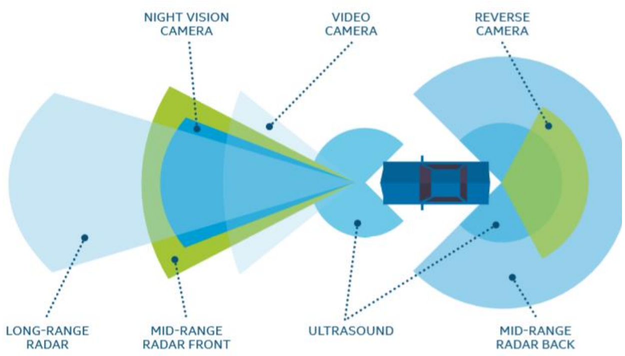
[2] The levels of assistance and automation are adapted from the Society of America Engineers J3016 Standard "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems" http://standards.sae.org/j3016_201401/).

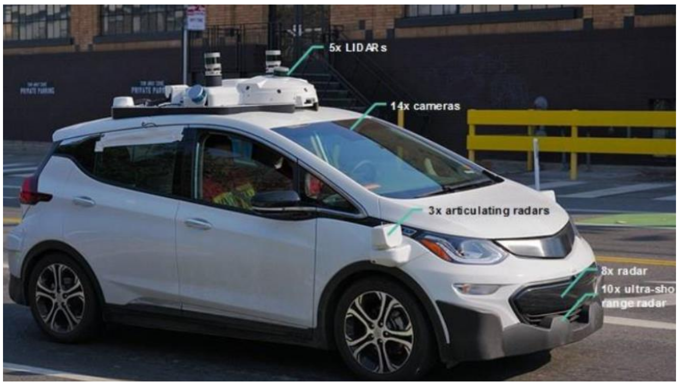
[3] https://waymo.com/apply/

the US. BAIC has partnered with Baidu to mass produce L3-capable autonomous vehicles from 2019, and L4 AVs from around 2021[4].

The nuts and bolts of AV

Software and hardware technology are both critical for the increasing penetration of ADAS and AV. ADAS features includes physical sensors such as the radar, LIDAR, ultrasonic, cameras and night-vision devices that allow vehicles to monitor the environment in all directions. The inputs from the physical sensors feed into the sensor fusion algorithms to create a map of the possible obstructions around, and work out the possible actions that the vehicle needs to take. The diagram below shows different physical sensors in an ADAS enabled vehicle. As vehicles increase in automation, more of these sensors will be added to the vehicles. For example, if an L2 vehicle would use 17 sensors (no LIDAR), experts estimate that an L3 vehicle would use about 27 sensors (1 LIDAR). The quantity of camera and radar sensors used in an L3 car would double from L2 automobile. In the case of ultrasound sensors, L2 cars would use around 8 and L3 cars would use about 10 sensors.





Source: Intel and General Motors.

The physical sensors in the ADAS/AV vehicles have an overlapping role to play but their distinctive features make each sensor critical to overcome each other's weaknesses. Below are some of strengths and weaknesses of the sensors used in the AV sensor suites.

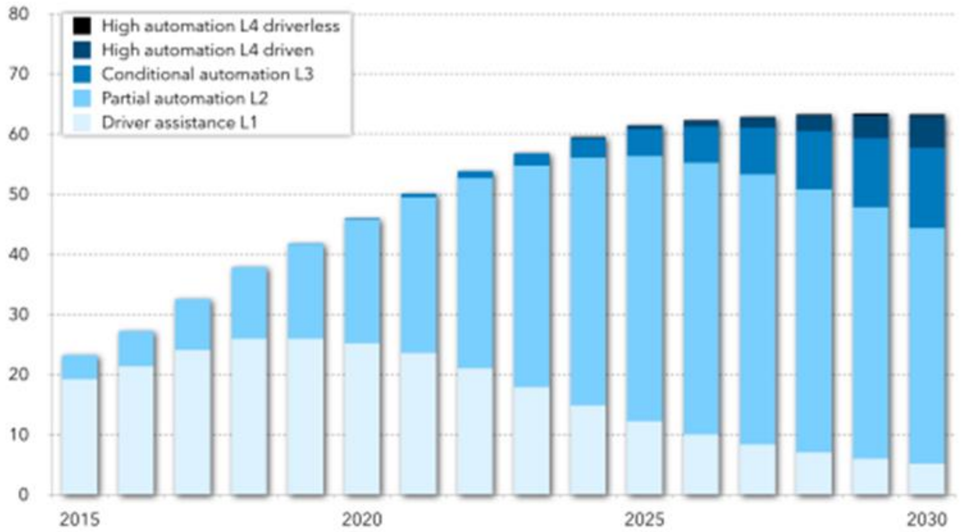
Sensor	Medium	Range	Strengths	Weaknesses
Camera	Visible light	0-80m	+ Very high resolution + Able to see in colour + Inexpensive and readily available	+ Affected by lighting & weather conditions
LIDAR	Infrared laser	1-1000m	+ Can measure distance very accurately + Able to generate 3D point cloud + Able to generate point cloud in 3D + Can be used to detect and track objects + Effective in low light or glare	+ Cannot see in colour + Can struggle in inclement weather + Generates large amounts of raw data + Relatively low resolution + Very high cost + Prone to poor reliability
Radar	Radio waves	0.2-280m	+ Enables long-range measurement of distance and velocity + Able to generate point cloud in 3D + Sees through fog, rain or snow + Lighter data load than camera or LIDAR	+ Lower resolution, lower angular accuracy + Cannot be used to identify or label objects + Mainly senses metallic surfaces, and can pass through some objects (e.g. humans)
Ultrasonic	Ultrasound	0-4m	+ Enables measurement of distance at low cost	+ Very short range

Source: Corporate websites and Bernstein Research.

[4] https://www.nextbigfuture.com/2017/11/baidu-baic-adding-autopilot-to-electric-cars-in-2018-l3-self-driving-in-2019-and-l4-in-2021.html

The drivers of ADAS and AV

The industry for ADAS-related components is expected to have a CAGR of between 20% and 30% for the next few years, according to consensus industry forecasts. According to PTOLEMUS consulting group's estimate, by 2025 there will be over 100 million vehicles on the road with ADAS features, and by 2030 there will be more cars with ADAS features than without.



Source: PTOLEMUS

The growth in ADAS will be driven by government regulations to increase safety and OEMs trying to add value and appeal to customer's comfort. According to research conducted by the US National Highway Traffic Safety Administration, 94% of serious crashes in the US were due to human error. While passive safety features such as seat belts and air bags are currently mandatory, the US and Europe are working on making active safety ADAS features such as automatic emergency braking mandatory. We expect the number of other active safety ADAS features such as adaptive cruise control, self-park, and lane assist will become mandatory in the future[5]. For instance, in China, the Ministry of Industry and Information Technologies (MIIT) has set clear targets of 50% penetration for L0-L2 AVs and 10% for connected cars by end 2020 to improve road safety. The adoption of ADAS will also be accelerated as drivers seek more comfort and convenience. In addition, the use of ADAS features would have the added benefit of improving driver scores, thereby reducing insurance premiums.

ADAS and AV have their own set of challenges

One of the biggest challenges today with the wider adaption of ADAS features is the associated costs. According to one estimate, the cost of ADAS features to move a vehicle up a category to L3 will make it 80% more expensive than an L2 car, while an L4 vehicle will cost about 350% more than an L3 car. The saving grace is that the cost of sensors is dropping rapidly. Likewise, a LIDAR system currently costs tens of thousands of dollars, but the price is expected to drop to a few hundred dollars in the future. The figure below illustrates GM's expectation of LIDAR cost and its effective range as of November 2017. The fall in LIDAR costs will accelerate the penetration of L3 ADAS features.

[5] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

Currently Available LIDAR	• Effective range: 1x • Cost: ~$20,000 • Quality Issues
Next Gen LIDAR	• Expected effective range: ~1.25x • Cost: ~$10,000
Strobe + GM + Cruise	• Expected effective range: ~2.5x • Cost: ~$300

Source: General Motors

The other challenge the industry faces is the lack of AV legislation and related standards. While US has made some progress, China is just starting to define its strategy and lay its technology road map. According to China's current legislation, for L0-L2 vehicles, the responsibility for safe operation currently rests with the driver. For L4 and L5 vehicles, the manufacturers will bear the responsibility. However, the responsibility for L3 is still vague and presents a legal grey area. Going forward, we can expect manufacturers to include driver-facing cameras in their cars to avoid liability from unpredictable driver behaviour.

Level of automation	0	1	2	3	4	5
Human driver engagement	Fully engaged	Hands or feet off	Hands and feet off	Eyes off	Mind off	No driver
Machine engagement	None	Assisted	Partially automated	Highly automated	Fully automated	Autonomous (100% control by machine)
Responsibility	Human driver	Mainly human driver		?	Mainly machine	Machine

Source: Gao Hua Securities Research and GS Research.

The world of autonomous vehicles

While AV development is still in its early days, we should expect to see initial adoption in controlled urban settings for taxi and ride sharing purposes. Existing cars sit idle as much as 90% of the time, but this could change. Driverless cars might facilitate greater car sharing, since your car could pick you up. Greater sharing could in turn bring the cost down. Additionally, we can also expect early adoption in long-haul highway trucks. While manufacturers such as GM have plans to launch autonomous robotaxis in 2019, it will take a few more years for AVs to see material penetration. But as AV penetration increases, many industries are expected to be disrupted. Most OEMs and technology companies such as Uber and Lyft are looking to develop their technology for robotaxis that would offer autonomous ride-sharing services in limited urban areas. With increasing vehicle utility, the demand for vehicles is expected to be impacted negatively. Additionally, the real estate industry is also expected to be impacted. Increasing ride sharing and lower vehicle ownership could result in less need for parking space. AVs could also potentially make commuting less stressful and make suburban living more attractive.

Autonomous Electric Vehicles
While an autonomous vehicle can either be ICE-powered, an electric vehicle or a hybrid, we believe that the two technologies will be integrated in the cars of the future. There are many synergies between the technology implemented in electric vehicles and what will be incorporated in fully autonomous systems. Additionally, most OEMs are increasing their focus on offering electric vehicles and it would make sense for them to build their new autonomous vehicles on the EV platform. For example, GM in their November 2017 presentation on AVs made it clear that they would link their autonomous driving effort to their electric vehicles. Tesla has been the early adopter in developing electric cars and now claims that all of their cars are self-driving ready[6].

Source: General Motors presentation November 2017.

Investment opportunities from EV and ADAS adoption:

The future of the automobile industry is changing in a dramatic way. With the increasing penetration of EV, ADAS and eventual adoption of AVs, there will be winners and losers in not just the auto component industry but also in other industries. Technology companies are playing a big role in transitioning the industry as we have seen in the case of Waymo, Tesla, Apple, Uber, and Baidu. Most traditional OEM companies will simply play the part but companies that are not investing in technology might be relegated to just assembling the vehicles – a low value adding and low margin business. Software developers, semiconductor makers, wireless internet systems providers, and manufacturers of critical parts would be the winners from ADAS and AV.

A similar theme applies to the EV supply chain. Being the most critical component, batteries will drive the investment opportunity – from mining companies to component manufacturers to technology companies. On the other hand, we could also see a trickle-down effect for the entire parts industry. For example, electric vehicles use 60% fewer parts than gasoline cars; we could see even fewer parts for autonomous vehicles, which might not even need pedals or steering wheels.

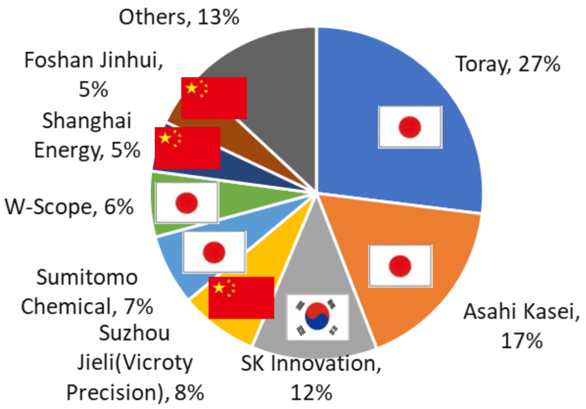
[6] https://www.tesla.com/blog/all-tesla-cars-being-produced-now-have-full-self-driving-hardware

The EV battery supply chain is mostly dominated by Asian companies. For example, in the global battery market, Panasonic was the largest supplier in 2016. Chinese companies like CATL and BYD are looking to aggressively increase capacity by 2020. Korean companies like LG Chemical and Samsung SDI are also expanding capacity.

With increasing competition, the industry is expected to get commoditised. We believe the key to picking winners will be by accurately measuring the “manufacturing yield”.

For example, based on build-up for 30 Chinese and Japanese battery separator makers, total production capacity for wet separators will be 12 billion square meters in 2020, which is far above the total estimated demand of 1.9 bn sq m, assuming only the wet type is used. For example, Tesla’s Model 3 uses 500 sq m of separator. If 4 million EVs and PHEVs are sold in 2020, it only requires around 2 bn sq m of battery separator. It is clear that battery separator supply is more than ample.

Global battery separator market share by production capacity(wet type, 2016)



Note: Above figures based on passenger EVs only
Source: APS, SNE Research, Nomura

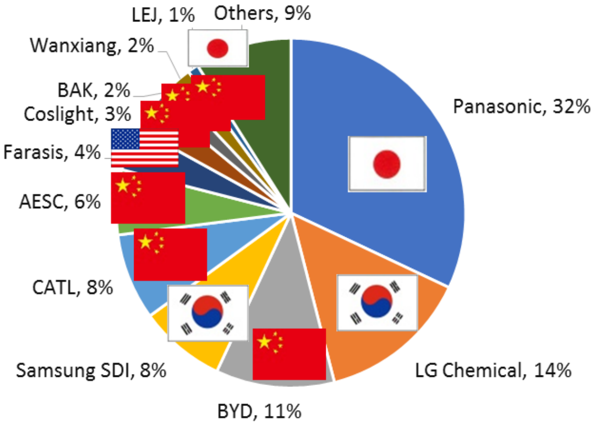
Demand of separator							mil ㎡/year
			2016	2017E	2018E	2019E	2020E
Scenario1. EV+PHEV			405	532	741	1,056	1,921
EV	500	㎡	319	411	565	825	1,539
PHEV	300	㎡	86	121	176	231	382

Source: APS Research

Our conversations with Japanese separator producers as well as the largest maker of separator manufacturing equipment indicate that most Chinese separator makers have yields of 30%-40%, significantly lower than their Japanese peers who lie in the 70%-80% range. We understand that the Chinese players will take several years to catch up. This implies that the actual output in China is currently significantly below the sum of planned capacity.

This also applies to the supply and demand of batteries. There are at least 40 EV battery suppliers in China. If we sum up their production plans, total capacity will be more than 250GWh in 2019, which is far above estimated domestic demand of 80GWh. We are less upbeat about Chinese manufacturers with weak technology. Global automobile OEMs generally require stringent quality standards like TS16949. When investing in Chinese battery makers, we should always avoid the "low quality, low ROI" companies.

Global EV battery market share (2017-YTD)



This is one of the examples of how deep bottom-up research is crucial when investing in the battery supply chain in Asia. EVs is the industry where we believe that APS can take advantage of having research bases in both China and Japan.

With all these in mind, we have already invested in a high-quality battery separator manufacturer in China. We are also conducting research on some Asian companies that can capture the opportunities in the EV battery space, as well as in the ADAS supply chain.

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