GLG

EBOOK

THE ROAD AHEAD FOR ELECTRIC VEHICLES

Survey and Perspectives

Contents

Introduction

Signs continue to grow that electric vehicles (EVs) will outnumber combustion engine vehicles sooner than we might think. Mercedes-Benz plans to become all electric by the end of the decade, and Hyundai plans to double its portfolio of fuel cell vehicles from three to six within two years. The Chinese auto manufacturer BYD sold 40,116 EVs in June of 2021, 207% more than a year ago, setting a new monthly record. The European Union has proposed phasing out new gas-powered internal combustion engine vehicles by 2035. The times, indeed, are changing.

In this ebook, we compile a handful of complementary and deeply informed perspectives on the current EV market. The following is a sample of the articles we adapted from longer EV events we've produced:

The first article — **Are Electric Vehicles on the Cusp of Mass Adoption in APAC?** — explores the factors driving the EV market in Asia-Pacific. Featuring GLG Network Members with experience at LG Chem Power, CATL, and Volkswagen, the article reveals the Five Golden Rules of Electrification.

Each article in this ebook is only a snapshot of a changing market.

How Electric Vehicle Battery Prices Can Fall in the Coming Decade breaks down the pros and cons of different fuel cell formats. Batteries are the most expensive component in EVs, a fact that greatly impacts profitability for automakers.

In **Winners in the Race to Electric Vehicles**, we look at the characteristics of the best EV manufacturers. What should be done to gain an advantage in this rapidly changing market? What does the marketplace want and how are its participants providing it?

This ebook also takes a deep dive into Tesla and the launch of its "Cybertruck," the market in Europe, the Middle East, and Africa, and EV battery recycling.

Over the last few years and months, GLG has seen increased interest in EVs across the globe. To keep our clients apprised, we will continue to feature our Network Members in webcasts, roundtables, panel discussions,
and teleconferences to provide insight into the complex EV market and its global, wide-ranging impact.

Eric Jaffe
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Are Electric Vehicles on the Cusp of Mass Adoption in APAC?

Dr. Prabhakar Patil, *GLG Network Member and former CEO of LG Chem Power*

Robert Galyen, *GLG Network Member and former CTO of CATL*

Clemens Roettgen, *GLG Network Member and former Director of Corporate Strategy in China at Volkswagen*

With governments around the world seeking to reduce carbon emissions, electric vehicles (EVs) are seeing increased adoption. While internal combustion engines will still be with us for the foreseeable future, a sea change is likely coming when EVs will dominate the roadways.

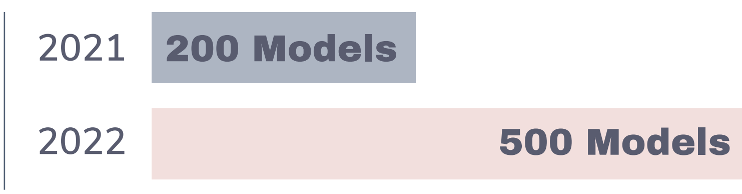
To learn about the current state of EVs in the Asia-Pacific region, GLG hosted a panel of industry leaders formerly with LG Chem Power, CATL, and Volkswagen to share their perspectives on the emerging EV and battery trends. The questions below are a selection from the broader conversation.

By next year, roughly 12% of new vehicles are expected to have some level of electrification.

What is your outlook for EV growth over the next few years?

Dr. Patil: Battery and plug-in hybrids — collectively referred to as EVs — are getting close to the 5 million mark, with maybe 70% battery electric vehicles. Growth seen with plug-in hybrid electric vehicle technology is a result of a growing demand to lower the carbon footprint and enhance the power or acceleration of the vehicles. A significant increase in micro-hybrids is also anticipated, driven by CO2 regulation, particularly in Europe.

Availability of EV Models Increasing



We are going to focus more on passenger and light truck EVs, whose numbers are expected to grow to a global penetration of maybe close to 15% by 2025, with China being close to 20% and Europe maybe overtaking China, getting to 25%. One of the key reasons is the availability of models.

How will this growth affect the lithium-ion battery market?

Dr. Patil: The passenger or light vehicle segment was at about 90 gigawatt hours last year. That's expected to grow to 700 gigawatt hours by 2025. And there are several factors driving this growth that are not going to change. Of course, one is regulation and subsidies. Europe is decidedly moving away from diesel. China has a very strong commitment and desire to dominate in this space, and one of the key enablers, the battery price, is on track to get to $100 a kilowatt-hour. In fact, some are claiming that they've already reached those kinds of levels.

In your view, why is China positioned to be a role model in new energy incentives and taxation policies?

Galyen: Within the next 10 years, China expects to get 40% to 50% of all the vehicles on its roads electrified. Subsidy reduction is not linear, but it does provide a subsidy incentive over the next three years. Key points of the incentive subsidies are based on energy density, which defines a subsidy coefficient to apply against the subsidy base. The three taxes involved are the consumption tax, the purchase tax, and the vehicle and vessel tax.

Suffice it to say that the rest of the world is now trying to catch up on the regulatory and policy part of it. On the infrastructure side, charging is quite important. But the recovery and recycling of these expensive battery systems is also very important as a part of the circular economy.

These are the Five Golden Rules of electrification:

1. Safety
2. Performance
3. Life
4. Cost
5. Environmental

From the OEM perspective, how would changes in the battery and EV market alter your long-term strategy approach?

Roettgen: Original equipment manufacturers (OEM) in the U.S. and Europe are trying to build up know-how in this field, which is totally new to them and not comparable to the know-how they had from [Volkswagen's] production. There will be many more partnerships among different suppliers to keep key aspects of the automotive value chain locally, doing that in different joint ventures, corporations, and, of course, OEM and university corporations as well. The long-term aspiration of any OEM would be to own battery manufacturing and to get the key value parts back integrated. But there are huge challenges to do that.

In China, the strategy is different. A few years ago, China aggressively promoted local manufacturers and gave them a chance to rise against the Asian suppliers that were technologically ahead at that time. That was extremely successful. The OEM ambition is to own at least a share of the margin. So that's why you see a lot of joint ventures and equity investments in the value chain supply.

Where are we at with the reuse and disposal of Li-ion batteries? How is recycling done?

Galyen: It's a matter of the amount of batteries that are coming out of the marketplace that can be recycled to serve as the fuel for the recycling endeavor. You need enough spent batteries for it to become a financially viable operation.

Dr. Patil: I expect commercial-scale recycling to be in place by about 2023. The reuse is something that, ironically enough, is partly challenged by the way the costs are coming down for the new battery, because they're dropped by a factor of two by the time it comes to end of life.

Roettgen: The question of recycling points to the critical question of the residual value of EVs at the end of their life. It's still a little bit unclear how that exactly will play out.

Dr. Patil: One final point on that. There is also going to be legislation globally. It's already there in Europe, where the OEMs will own the batteries at the end of the vehicle life. In fact, the new business model is emerging, which is offering battery as a service, where essentially a third party of the OEM or the battery manufacturer can own the batteries and capitalize on all the residual value, addressing one of the major anxieties on the customer side.

Who is likely to dominate in the charging space?

Galyen: Globally, there will be a split between conductive charging and wireless power transfer charging.

There is an enormous amount of work being put into wireless power transfer charging for a fundamental reason. It takes away the burden of plugging in your electric vehicle.

Dr. Patil: To add to that, batteries will actually play a key role in the charging infrastructure as well, because part of the challenge is lowering your rate, as well as a type of connection you need from the grid. Quite a bit of battery storage is going into the charging facilities that can lower your rate, and then still allow you to meet fast-charge requirements.

Can we expect battery formats to converge and standardize in the future?

Galyen: It is a little bit bewildering in the investment world. Why wouldn't there be standardization on cell sizes? Because there has not been so far.

Roettgen: OEM's are not inclined to standardize because they're trying to differentiate or keep the opportunity to differentiate. The power train used to be a key differentiator between OEMs. That is gone. That's definitely the other force driving that apart.

Dr. Patil: Technology is also still evolving, and you would not want to prematurely standardize.

What to watch next?

Galyen: Nobody has said anything about energy storage systems for the grid. Nobody has said anything about the big marine applications or the heavy-duty industry, or the heavy-duty truck industry. There are lots of new markets that are bubbling up and further enabling car and bus and truck manufacturers, and marina and grid applications are going to be rather large. Battery manufacturers will make their margins on other markets that are ancillary to automotive as well.

Roettgen: There is a new battlefield coming up on the software side. Autonomous driving is one of the functions coming up. But as well, the automotive operating system is where Chinese companies are very successful. There might be a significant shift in industrial politics toward that.

This article is adapted from the August 4, 2020, Remote Convene "Electric Vehicles: On the Cusp of Mass Adoption?"

The Electric Vehicles Race: Tesla vs. Legacy Car Companies

Jeff Yanssens, *President at JAY Engineering and former Chief Engineer of Electrified Vehicles at General Motors*

Dr. Arnold Lamm, *Founder of e-Technologies and former Senior Manager, eDrive Systems at Daimler*

Dr. Claudiu Bucur, *Founder and CEO of Piersica and Former Chief Engineer, Svolt Energy*

Tesla has been on a hot streak. Reacting to the company's latest earnings, CEO Elon Musk said, "We've seen a real shift in customer perception of electric vehicles, and our demand is the best we've ever seen." But with this acceptance of EVs comes increased competition. Almost every major automaker has announced its entry into the electric vehicle market.

To understand the elements at play in the electric vehicle race, GLG's Manager of Client Solutions for Southeast Asia, **Yi Shun Tey**, hosted a panel discussion with three EV experts.

The future belongs to the cell. The cells are improving, becoming safer, and having increased energy density.

Lamm: An article published in Germany's *Focus* found that the ID.3 from Volkswagen (VW) fully competes with Tesla's technology. The ID.3 has the highest energy density in this class size and the highest efficiency, and the scalability of this technology to other platforms is high. Nevertheless, there are points where Tesla is ahead: increasing development speed and boosting software competence. The competition in the EV mass market will increase. This will lead to lower market shares for Tesla, especially in Europe.

Bucur: Tesla revolutionized this field. Historically, GM tried to introduce the EV1, and Toyota successfully commercialized hybrid vehicles. In 2009, Tesla introduced fully electric vehicles before everyone else. Since then, the company has been in the lead. At that time, cells were not optimized for EVs. The cells were from laptops, and the focus since has been on the optimization and development of the pack. That is where Tesla has been leading.

In the beginning, the pack was king, but now it's becoming weaker. In the future, the cells themselves will be structural and solid. Unfortunately, Tesla is not currently the leader at cell chemistry. It will be interesting to see how Tesla remains at the top.

Top EV Competitors

TESLA GM TOYOTA Mercedes-Benz DAIMLER

Yanssens: Claudiu brings up some very good points. Tesla's first-to-market status gave it a competitive advantage. But no matter how hard you try, the second time you do something you're always better at it, the third time is even better, and so on. As Tesla brought out each new model, it was an evolutionary progression of the one before it. The disadvantage that Tesla has is it's the only one in the market, so all the big OEMs can afford to buy cars, tear them down, and learn from them. They don't have to spend all the R&D money that Tesla did.

The other advantage for global OEMs is their ability to scale and reduce structural costs. That's the main reason VW, GM, and Daimler went to modular strategies in their battery packs versus Tesla's approach of one giant battery pack. That scalability will help OEMs be more flexible and come out with models quicker than potentially what Tesla will be able to do. OEMs also have strong relationships in China. Amortizing their R&D costs over two continents will be helpful. There's also parts sharing that can happen between Asia, North America, and Europe for VW. Those are some of the advantages of traditional OEMs, but Tesla's first-to-market advantage can't be understated.

Yi Shun Tey: Legacy auto OEM software is known for millions of lines, wires, and complexity. Meanwhile, new entrants appear to design better software. Will legacy auto OEMs have the capability to face this challenge? How far behind Tesla are they on this aspect?

Lamm: That's a very good point. In Germany, there's a big problem to get the right people to do this job compared with Tesla. VW and Mercedes are starting their own internal software platforms — they are two to three years behind Tesla regarding software competence.

Yanssens: This is where complexity hurts. Software engineers at VW, GM, and Daimler must design compatible software that needs to work with more than 20 different models and five different architectures because they all share common modules to reap the benefits of volume and structural cost to save money. That kills companies on the software side. Having a one-model strategy starting out like Tesla did, and not having 20 chief engineers saying they don't like the way the software performs, is a big advantage.

If we had a common operating platform, or three, we could reduce the total cost of the vehicle by almost $500 just through the reduction of R&D budgets for software. Most people don't totally comprehend this. There are hundreds of electric modules in a vehicle. All those modules must talk to each other or to a central computer.

When they do that, they're working on an operating system that the manufacturers have developed internally, so everybody has their own. Every time a supplier wants to provide a module, they must rewrite their code for every manufacturer because it must operate in a consistent manner with that vehicle operating system. If it were like the phone industry where basically there are only two operating systems, they wouldn't have to develop 20 different module software packages.

Bucur: Software is an excellent value for the luxury and mid segments for the current buyers of Tesla cars. It will be challenging moving forward to the large markets where people do not understand the technology, and it will be difficult to work with how advanced the car is. The general driver has a hard time dealing with software-complex vehicles. That's something to keep in mind.

Yi Shun Tey: On the consumer versus commercial vehicle market, how does technology work out for the different traditional OEMs?

Yanssens: GM announced that it won't produce any more internal combustion engine vehicles in the car and SUV range by 2030. That's probably why GM introduced its first electric truck as a Hummer, because it could rely on that brand's cachet to command a more than $100,000 price tag. When you double the size of the battery to support a pickup truck payload, it's $20,000 for the battery at current prices. They're no longer looking at entry-level models as the ones to do EVs because the contribution margin just isn't there to support the cost of the electronics and the battery. Everyone's moving into the high-end electric vehicles. If they sell one, they'll make money. They won't make as much as if they sold the same vehicle as an ICE, but at least they'll be making money on it.

From a commercial side, what I find interesting is the advancement of autonomous vehicles, and the ability for delivery service companies to reduce their total cost of ownership by having AVs. We'll see a rapid rollout of lead/follow-type applications for AV. Potentially what you'll see here in the next three to five years is fleets of trucks running down the highway, where there's only one driver in the front. Almost every delivery service in the world now has an alliance with an AV company. GM started its own freight drop company. Arrival has an alliance with UPS and DHL in Europe. There are different opportunities out there from an electric truck standpoint. Most of the companies are jumping into the electric market for the obvious benefits of being ready for the AV side when it hits. It's just a matter for the final 3% to 5% of the development to get there.

This article is adapted from the March 12, 2021, event "Panel Discussion: Tesla's Competitors & The EV Race — Auto OEMs in the Market."

Survey and Analysis: The Tesla Cybertruck

Tom Croskey, *GLG Network Member and Former Executive Director of Manufacturing Strategy and Planning at General Motors*

In November of last year, Tesla announced the release of the Cybertruck, the company's all-electric pickup truck and the automaker's sixth vehicle since its founding. The truck's reception was initially lukewarm, with critics describing it as "Blade Runner-esque" and "pointy" with a stainless-steel exterior and a triangular roof.

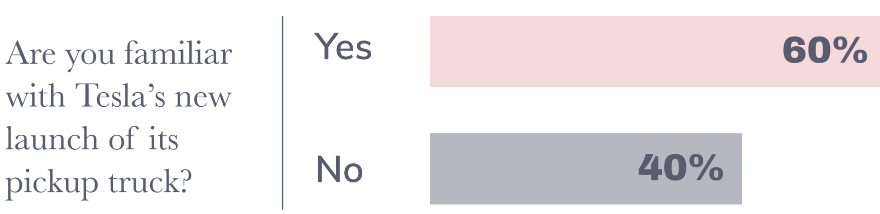
Nonetheless, Tesla is a luxury brand, associated more with indulgence than functionality. This calls into question the company's motivation for entering a marketplace that appears a few steps removed from its established customer base.

To evaluate the marketplace for the Cybertruck, GLG identified a panel of current pickup truck owners and asked them about their sentiments regarding Tesla's offering. We also leveraged GLG's best-in-class expert network, partnering with our Network Member **Tom Croskey**, the former Executive Director of Manufacturing Strategy and Planning at General Motors, to help put the survey data in context.

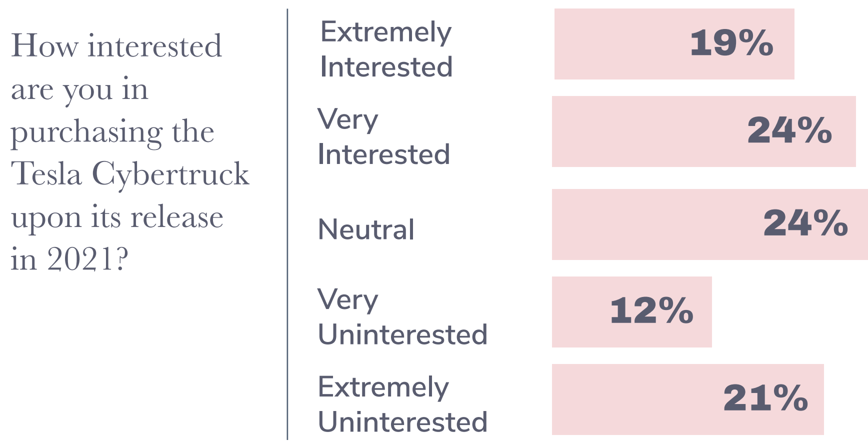
While Tesla's strong 4Q19 production and delivery number helped regain some investor confidence (TSLA market value above $100 billion), bearish investors would likely point to the company's inconsistent execution historically; therefore, with three new vehicles (Model Y, Cybertruck, and Roadster) in the pipeline, it will be interesting to see how quickly Tesla can bring the Cybertruck to market.

Interest in the Cybertruck

Many of our respondents knew about Tesla's Cybertruck offering.



Among those we surveyed, a significant percentage (43%) said they're either extremely or very interested in purchasing a Cybertruck.



Income and the Propensity to Buy

When broken down by income, a little over 30% of those with a household income of $75,000 or higher, and who currently own a pickup truck, said that they are likely to purchase a Cybertruck, versus just 21% of households in the lower demographic.

30% of respondents in the higher-income tiers who are also current pickup truck owners indicated they are "Likely" or "Very Likely" to purchase a CyberTruck.

21% of respondents in the lower-income tiers who are also current pickup truck owners indicated they are "Likely" or "Very Likely" to purchase a CyberTruck.

Unsurprisingly, the numbers reinforce the fact the Cybertruck is targeted toward higher-income individuals. "There's not much Tesla can do here when it comes to reaching people with lower income," said Croskey. "When they're buying a vehicle, their top purchase criteria is price. It is going to be difficult to get down and get those lower-income buyers."

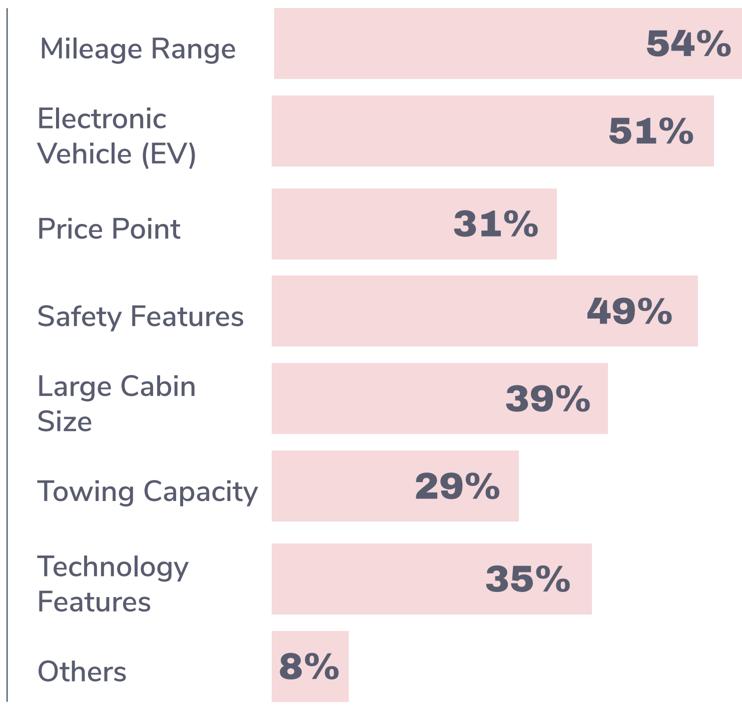
Croskey is also doubtful that the higher-income numbers are completely reflective of the truth: "You have to consider that respondents are much more aggressive on what they are 'interested in buying' than what they typically buy and pay in the marketplace. Answers like this sometimes come from a wish list rather than a firm financial commitment."

Mileage Range

Among the respondents interested in Tesla's offering, 54% identified "mileage range" as an important feature.

Croskey points out, in their purchase decision, customers will have to consider that the Cybertruck's specified range for non-towing trips is likely much lower when drivers are towing. Towing capacity scores low among those interested in a Cybertruck (29%).

What features about the Tesla Cybertruck are you most interested in?



Croskey said, "Consumers are going to be concerned about things like towing capacity and range because while Tesla has announced range and towing and hauling capacities for their vehicle, they haven't blended those attributes.

"For example, a 300-mile EV battery range in the non-towing mode actually equates to about 100-mile range when towing. What's your risk profile on range anxiety there? Range anxiety is basically the equivalent of the fear of running out of charge, it's the mileage buffer you leave between your position and the nearest charging station.

> There's no doubt Tesla is a leader in battery and efficiency performance. Competing electric trucks like Ford and GM will be close, but not likely equal.

"If I'm going cross-country — and I might only want to fast charge because I can fast charge in less than an hour; the last 20% of a charge takes significantly longer than the first 80% — that leaves me with an 80-mile range. If I use 5 or 10 miles for range anxiety, my towing range drops to 75, 60 miles. The truth is that EV trucks, whether it's Tesla or Ford, will have significantly less towing capacity and range than a traditional internal combustion vehicle.

"The fact that over half of the survey respondents said the top thing they want to understand about the Tesla was mileage range tells me that is the issue that all the original equipment manufacturers will need to think about."

Preorders and Sales

Elon Musk has said there have been 250,000 preorders for the Cybertruck, a significant number that may not play out in real sales. "I'm not that surprised by this number," Croskey said. "But the deposits are returnable — and a lot less than the company asked for a Model 3 or Model S. I believe the conversion rate will be much less."

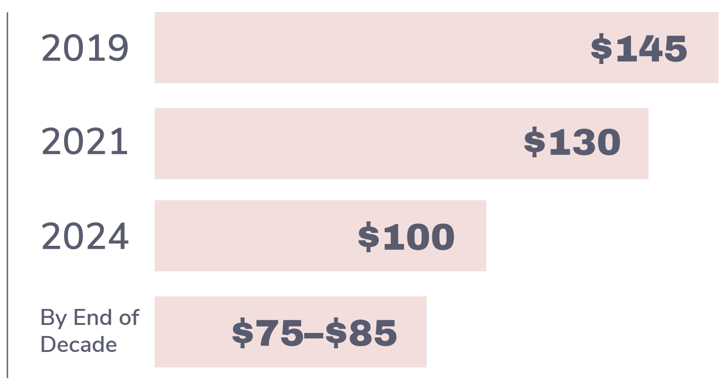
This article is based on a survey of pickup truck owners conducted late in 2019. The information provided is for informational purposes only. The findings are not representative of the industry, rather an illustration of a sample drawn from an existing panel of consumers.

How Electric Vehicle Battery Prices Can Fall in the Coming Decade

Gregory MacLean, *GLG Network Member and former Lead Engineer for Advanced Battery Cells at General Motors*

At the 2016 General Motors shareholders meeting, Mark Reuss — who would become GM's President in 2019 — told shareholders that the company was paying $145 per kilowatt-hour for the LG Chem cells used in the Bolt EV, which was coming out later that year. Today, those same cells are probably about $130 per kilowatt-hour. That's still too expensive, but with materials changes and production improvements, as well as vertical integration between GM and LG Chem, the price should go down to about $100 per kilowatt-hour by 2024 at the latest.

Kilowatt-hour Shift (price per kilowatt-hour)



> Energy cells are the most expensive component and therefore impact profitability for automakers.

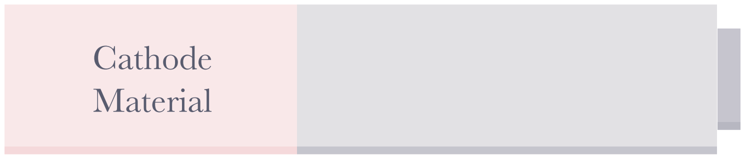
At that stage, we'll reach a break-even point as far as profitability for a $25,000 sedan, and it puts SUVs and trucks at a similar level of profitability as their internal combustion engine counterparts. That's very good news for automakers.

Near the end of the decade, cell costs could go down to $75 to $85 per kilowatt-hour, which will require major materials changes and volume increases. At that price point, electric sedans, SUVs, and trucks are actually more profitable than equivalent internal combustion engine vehicles, meaning original equipment manufacturers will no longer want to make the latter.

Energy Cells: What Must Be Done

But there's a long way to go before we get to that point.

Approximately 70% to 80% of a cell’s cost is in its materials, with the cathode material making up as much as 40% of that. Because of the high materials cost to the overall expense of battery cells, there’s a lot of new, low-cost, high-capacity, high-energy materials being developed.



There are currently three main types of cell formats: cylindrical (used by Tesla), prismatic can, and pouch (basically a polymer aluminum laminate material that’s used to encase the cells or the electrodes for the cell). It should be noted that heat is the number one killer of any battery chemistry — it’s what causes degradation, loss of capacity, and early failure to occur.

Here are the pros and cons of each:

Cylindrical

Pros: high energy density, because of the winding material used to make the cells; being metal cans, they’re fairly robust

Cons: the shape of battery packs causes loss of energy density (round cells in a rectangular box); tends to be heavier due to extra material needed to hold large number of cylindrical cans in place; low capacity means more cells needed in battery packs compared with other cell formats; cans can violently vent; not suited for future chemistries, especially solid state

Notable suppliers: Panasonic, LG Chem, Samsung SDI, Saft

Prismatic

Pros: robust; many suppliers, making it cost competitive

Cons: made of heavy metal that causes battery packs to be weighty; internal design changes will be needed for future cell chemistries

Notable suppliers: Panasonic (and subsidiary Sanyo), Samsung SDI, CATL, Northvolt, BYD

Pouch

Pros: intrinsically low cost because of the polymer laminate material, which also makes it lighter weight; unable to be made into thick cells so more easily controlled thermally; longer life than other formats; seem better suited for future chemistries due to their ability to expand and contract; safer due to lower melting point, leading to fewer gas and smoke emissions

Cons: more care needed for handling cells

Notable suppliers: LG Chem, SK Innovation, Envision AESC, Farasis, Coslight, Wanxiang A123

Over the years, companies have increased the nickel content while lowering cobalt, which boosted energy density while reducing the price. Will nickel in the cathode materials be the next to go? There are environmental reasons to do that, as some soluble nickel compounds can cause cancers if they get into the drinking water.

One way to do that is by introducing 5-volt cathode materials, which usually contain no or low amounts of nickel. The big draw of these is that it will reduce the number of cells in the battery pack, which could lead to huge savings if companies are able to reduce 15% of the cells in a pack. Unfortunately, there are no good 5-volt materials at the moment. On the other side of the separator are anode materials. A lot of work is being done on lithium metal-based systems and silicon electrodes of 90%-plus silicon as their composition.

Other Ways to Reduce Energy Cell Costs

To keep costs low, producers should consider localizing the supply of components for the cells, including electrolyte separator, cathode, and anode materials. Transportation costs could be reduced if cell production is located next to auto plants.

Vertical integration is another method to keep costs down, in particular joint ventures between cell manufacturers and OEMs.

Future of Electric Vehicles: Silicon-Based Anode Cells?

But what will make the biggest difference is the development of better battery technologies. The one with the most promise is silicon-based anode type cells. They have better energy and power performance compared with lithium-ion cells, because they use a liquid electrolyte and thin separator material. However, cycle life for anode type cells is not as good as lithium-ion cells.

Most companies will agree that at least in the short term there will likely be a switch from lithium-ion to higher-energy-density silicon anode type cells. That is at least until solid-state batteries are commercially viable for the automotive industry. But by that time, they may have a tough entry into the automotive industry due to improvements to silicon cells. Already, they're well above 800 watt-hours per liter. By the end of the decade, they'll likely be at 1,000 watt-hours per liter with a cost per kilowatt-hour similar to lithium-ion cells.

This electric vehicle industry article is adapted from the May 25, 2021, GLG Teleconference "Electric Vehicle Battery Cell."

Europe Is Leading the Way in Electric Vehicle Adoption

Philippe Chain, *former Chief Electric Vehicle Strategist at Renault, Cofounder of Verkor*

Franck Mourge, *former Program Director for Electric, Commercial and Pick Up Vehicles at Nissan North America*

Adam Panayi, *Managing Director at Rho Motion*

Electric vehicles are set to see increased adoption as regulations restricting carbon dioxide emissions become standard across Europe, batteries become more efficient, and the cost of purchase falls. Because it seems like electric vehicles may have reached a tipping point, GLG conducted a video panel with three EV experts to discuss the current state of the market and what the future may hold. Below are edited excerpts from our broader discussion.

Adam, let's start with you. Can you bring us up to speed in terms of the design of EVs, and — perhaps the key part — the development of batteries?

Adam Panayi: The key discussion this year has been effectively the return of the lithium iron phosphate battery (LFP) — that's a non-cobalt, non-nickel battery. When the industry started, that was the key technology and we moved into nickel-cobalt-manganese batteries and — outside of the bus and some of the commercial vehicle sectors — LFP fell out of favor. But now, it's making a bit of a comeback in passenger cars. There are a number of new types of vehicles coming into the market.

In China you're seeing a few subcompacts and compact vehicles — which lend themselves to using LFP — being brought into the market. We've also heard that Tesla is using LFP in its battery packs sourced from CATL for its Chinese manufacturing. While that story seems to be currently overstated, it is a development that's coming. It feeds into this narrative that they're offering a different type of vehicle there for a different market segment.

> The passenger car market for electric vehicles is becoming more diverse.

On the anode side, we've seen a transition from a purely synthetic graphite to a blend of synthetic natural flake graphite, and the inclusion of silicon. I should also mention silicon dominance and potentially solid-state batteries as well. But as a quick overview, that's what I see in terms of battery chemistry development in the last year or so.

One of the main arguments we hear against EVs is that the car doesn't go far enough. What effect do these batteries have on range?

Philippe Chain: The range of new models of electric vehicles has been continuously increasing and is now reaching a sort of standard — about 400 kilometers of range, which seems to be enough for most people to consider buying an EV. We can see this in all the new coming electric vehicles on the market, be it from Hyundai, or the Volkswagen Group, and even Nissan, of course, and all the others.

The return of LFP is linked to a different, interesting trend. For many people, cars with 400 or 500 kilometers of range may be too much. They don't need to carry so much battery; they simply don't need that much capacity. It's likely that we'll see some shorter-range cars that have a much lower price tag. The Renault short-range, low-cost vehicle — I believe it's called K-ZE in China and will probably be called Dacia Spring when it comes to Europe — could be the first example of that.

Battery costs are going down, which will soon make electric vehicles an economically reasonable choice.

In the first half of 2020, we've seen the penetration of EVs rise in Europe. Is this a trend that's here to stay or will it fall back to a more normal level?

Philippe Chain: I completely expect these trends to continue, expand, and maybe even explode. Consider that European CO2 regulations are virtually forcing original equipment manufacturers (OEMs) to offer these cars. Up to now infrastructure has been a barrier to adoption, and that also is now significantly lifting.

But I'd like to mention the fourth aspect, which is actual customer demand. In my opinion, this is oftentimes underrated or underestimated. Electric cars really offer a superior user experience, and you can see this in many customer satisfaction surveys. Anecdotally, I've heard many times that once you move to an electric vehicle, you never go back to an internal combustion. There are many reasons for that: silence, acceleration, smoothness, and, of course, the fact that they are environmentally friendly vehicles. In my mind, that will be the most powerful driver of adoption.

Once the barriers are lifted, which is happening now, the public will really enjoy and show enthusiasm for these cars. In the auto industry, that's always the main driver: actual customer demand.

Electric vehicles are a big disruption for garages and mechanics.

As EVs become more commonplace, other industries — garages, mechanics, breakdown services, etcetera — will all have to adapt to them. Can you speak to that briefly?

Franck Mourge: You don't have oil or spark plugs to change on the vehicle, which is, in the end, a major issue for the dealer because they're losing revenue here. You drive an electric vehicle differently; you break less and rely on deceleration to recharge your battery. The brakes don't wear out. In terms of maintenance, it's very low. You still have crashes and things that sometimes bring in interesting revenue, but for both dealer and OEM, it's definitely down from the combustion engine. They must reinvent themselves for this new reality.

For many European countries, 2030 is the deadline they have set for when they'll turn off the sales of combustion engines and switch to electric vehicles. What sort of penetration do you think we're going to see in the market 10 years hence?

Adam Panayi: We look at it at a national level, from the legislative level, and then we look at OEMs and their plans. For the battery-electric and plug-in hybrid electric worldwide, we're looking at about 30% penetration by 2030. This doesn't really agree with the narrative we hear about entirely banning the combustion engine by then, but you have to differentiate between a target that has been signed off and mandated and one that is just a headline grabber.

Philippe Chain: I completely agree. In my opinion, 30% would be a minimum by 2030. I expect the trend to amplify as adoption grows.

Franck Mourge: I agree with Philippe. If you take it at the global level, 30% can make sense. But if you consider it regionally, I'm sure in Europe, Asia, and some other markets the penetration will be much higher. Even today an electric vehicle is more economical than a combustion engine if you drive a reasonable mileage per day. When the costs reach the parity between combustion engine and electric vehicle, it will make little sense to buy a combustion engine. The combination of economic sense and increased regulations will be the triggers that launch an explosion of EV adoption.

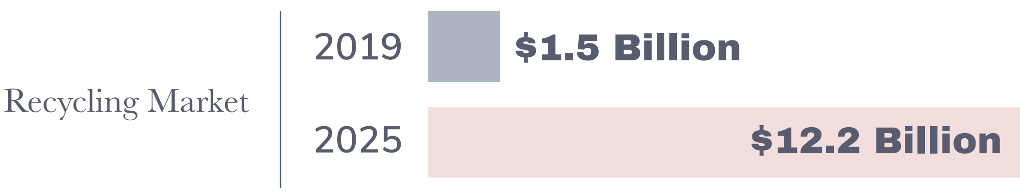
This article is adapted from the July 29, 2020, GLG Video Panel "European Electric Vehicles Market: Update and Outlook."

The Economics Around Lithium-Ion Battery Recycling Are Strong and Growing

Patrick Curran, *GLG Network Member and Chief Executive Officer at Lithium Recycling Systems*

The market around the recycling of lithium-ion batteries is huge and growing, mostly thanks to electric vehicles. Surely, a lot of other lithium-ion batteries get recycled, including from phones and power tools, but the majority comes from EVs.

In 2019, it was estimated that the recycling market was worth $1.5 billion. The projected amount of available lithium-ion batteries to be recycled in 2020 was 460,000 metric tons — a large amount compared with previous years. By 2025, the market for recycling is expected to grow to $12.2 billion. After that, it should remain at an estimated 8% growth rate. To put that in perspective, the world is at equilibrium with lead acid batteries — the number of batteries that get produced is the number of batteries that come back for recycling. The market grows only along with new vehicle sales, and EVs are expected to take over in the coming decade.



Most electric vehicle batteries won't have a second life, but Tesla is pushing it.

Some of Tesla's batteries get tested, confirmed they're functional, and then reused in an EV. They may come back and test as functional, but they're not good enough to go into a car. These may be repurposed for power storage in a house.

The lifetimes of EV batteries are long, much longer than lead acid (2 to 4 years for LAB vs. an estimated 10 years for LIB). The batteries coming back for recycling vs. the amount being produced will not be at equilibrium for a long time. It won't be until the EV market plateaus, and 8 to 10 years have gone by to allow the old batteries to come back.

Recyclable Materials in Electric Vehicle Batteries

There are three main components that can come back for recycling. The first is unspent cathode material, which has nickel, manganese, and cobalt. With any factory, there is a certain reject rate for this material, and it's very valuable. The facility would want to capture the value of that and/or get that nickel, manganese, and cobalt off the cathode and recycle it back upstream within the factory.

Second is unspent lithium-ion batteries. These are rejected in the factory for whatever reason, and the company making the batteries wants to recycle those or capture the value. It'll send them out for recycling, sell them, and either let the recycler do whatever it wants with the material or perhaps send them off for processing and ask to have the nickel, manganese, and cobalt returned.

The third is spent LIB batteries, which are starting to come back for recycling but the volume percentage vs. current production is very low. In these cases, car companies hire third parties to replace the batteries, likely under warranty, and they are then contracted to be recycled.

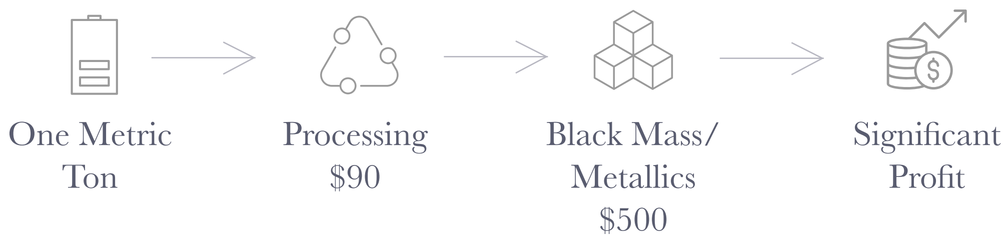
The Types of Recyclers

There are two main types of recyclers. The first is companies that already recycle other things, including Umicore Corp. in Belgium and Glencore in Switzerland. The other is companies that recycle only lithium-ion batteries. Of those, there are two different varieties: ones that take any type of lithium-ion battery and others that focus only on EVs. Some of these EV-focused companies concentrate only on unspent coated cathode that has not been put into a battery yet, while others concentrate on unspent cells or unspent modules to then get recycled for the auto company. A third group focuses on spent cells. New companies are coming into the market every day.

From a high level of how these recycling companies operate, first they have a source of material. That could be a contract with General Motors to get unspent coated cathode, unspent batteries, or some combination. Comparatively, the lead acid battery space is mostly brokers going around and collecting batteries, then feeding them to recycling operations. Once a company has a source, the economics can change depending on the contract, whether it involves getting material for free or paying for it, or a tolling contract where an automaker pays the recycler by the metric ton of batteries or material that it processes and returns.

The Costs of Recycling

The cost to break the battery down is similar to lead acid, mostly because the process uses similar equipment, and the operating expenses are comparable — about $100 to $200 per metric ton of the black mass paste. Black mass (the mixture of nickel, manganese, and cobalt oxides with carbon) makes up about 60% of the incoming battery weight. When you adjust for that, it's about $90 per metric ton of converting the incoming batteries. Of this 60%, half is carbon and the other half is either spent or unspent metal oxides, cobalt, nickel, and manganese, plus miscellaneous pieces of plastic and metal. The cobalt consists of about 5% to 10%, depending on the manufacturer. About $300 per metric ton of the incoming battery unit is the black mass that sells on the open market, or $500/MT of the actual black mass.



The aluminum and copper are quite valuable. If you consider the amount of copper and aluminum that are in the battery, multiply that by 30% of London Metal Exchange prices, and you get approximately $450 per metric ton for the copper and $53 for the aluminum. That adds almost as much value to what's coming out of this process as the black mass does. It's important for recyclers to take both of those into account because they almost equal the value of the black mass.

One metric ton of incoming batteries will cost approximately $90 for processing, with black mass selling for about $300 or more and the metallics for about $500. That's a profitable recycling operation.

This article is adapted from the April 28, 2021, GLG Video Panel "Lithium Batteries — Recycling and Disposal."

Winners in the Race to Electric Vehicles

Martin Murray, *President, Murray EV Consultants and former Director of Electrification Propulsion Global Program Management at General Motors*

Today, EVs are seen as both green and hot, utilitarian and cool.

Until eight years ago, automakers saw electric cars as an expensive way to meet efficiency requirements. Then, Tesla introduced high-performance, high-priced electric cars and everything changed. That, of course, has encouraged market growth and introduced new challenges for car and truck manufacturers, as well as for component manufacturers serving the auto industry.

For makers of components in many vehicle subsystems — body, chassis, interior, cabin cooling and comfort, and the low-voltage electrical system — electrification won't make a big difference because those systems aren't much affected by the power source. The biggest changes will be in propulsion systems, where the engines and transmissions that we know today will evolve into traction drive units, batteries, and electronics that link everything together. The following are a few of the potential winners in this coming shift.

Winners: Makers of lightweight body, chassis, and interior materials.

The reason lightweight materials are so important is because batteries are big and heavy, making weight reduction in the rest of the car a must. There is going to be a strong focus on light-weighting with aluminum, composites, magnesium, and other kinds of structures like carbon fiber, which we already see being applied quite extensively by BMW. Cost continues to be the limiting factor for reducing the weight of electric car batteries. Until there is a fundamental shift in technology that permits a much higher level of energy density at a reasonable cost, there is not going to be an affordable battery that is smaller or lighter than what is in the market currently. Similarly, fuel cell systems have a lot of merit in terms of efficiency and emissions reductions, but they're expensive and need an energy storage buffer. We are probably a long way off from adoption.

Winners: Familiar industrial names; probably few new ones.

All of the 10 largest, current automotive suppliers are deeply engaged in electrification activities. Other giant companies that never provided propulsion system parts to the industry are moving to do so. But newcomers, no matter how large, probably will find that breaking into the auto industry is harder than it looks, because the knowledge and experience needed to provide quality parts under the contract terms required by global original equipment manufacturers (OEMs) is onerous.

Different kinds of pressure and changes are being felt by many smaller companies. In Germany, for example, these companies make honing machines, cam-turning machines, and fillet rolling machines for crankshafts. All of these companies have to come to terms with a future where there will be reduced growth and potential shrinkage in internal combustion engine manufacturing facilities.

Winners: Those who have mastered the complexity of electric propulsion systems.

The winners in this area will be those who have the largest R&D budgets to accommodate the natural needs of electric propulsion, which are simplification, cost reduction, and space minimization. While electric propulsion systems can have 90% fewer components than those in internal combustion engines, the complexity and performance requirements of those limited number of parts — which include magnets, laminates of steel, and very complex geometries of copper and other materials — are great. The winners here are likely to be existing suppliers who are improving processes and increasing efficiencies to build new products.

In China, there's a concern that electric vehicles could lead to environmental problems after their batteries are dumped.

Winners: Supply chain members who consider recycling and its ramifications.

They are creating recycling requirements that are potentially extremely burdensome. The battery design must be not only created to allow for total recycling and/or reuse, but also the details of the design have to be transferred to the after-market industry. After that, the battery can be either safely recycled or reused, based on its original design concept. This will have a big impact on suppliers and OEMs, because it could affect up-front designs, as well as raise questions about the control of intellectual property. Other countries may impose their own recycling and environmental standards, which makes recycling and other environmental concerns important for companies involved in electric cars.

Neither Winners nor Losers: Hybrids.

While Volkswagen, General Motors, and others see a shift from internal combustion engines to fully electric vehicles, Toyota and Ford continue to see a future for hybrids. They are likely to remain on the scene for the next two decades. Lately, their sales have decreased in the U.S., mostly due to lower fuel costs, while remaining strong in Japan because the electric infrastructure there is not strong enough to support a high density of electric vehicles.

This article is adapted from the October 15, 2019, GLG Teleconference "Electric Vehicles: Roadmap for Suppliers."

About Robert Galyen

Robert Galyen recently retired from his position as Chief Technical Officer of the world's largest battery company, Contemporary Amperex Technology Company Ltd. During his seven-year tenure, Galyen helped grow the company to over 25,000 employees and secure its position as the world's largest manufacturer of lithium-ion batteries. In 2015, China awarded Galyen with the prestigious "Friendship Award" and bestowed upon him in 2014 the title of "National Distinguished Expert." He also serves on the board of the Lugar Center for Renewable Energy at Indiana University.

About Prabhakar Patil

Dr. Prabhakar Patil was the Chief Executive Officer of LG Chem Power Inc. until September 2015. Prior to this, Dr Patil spent 27 years at Ford Motor Company. From 1998 to 2003 he was the Chief Engineer for the Hybrid Escape Vehicle Platform, Ford's first-production hybrid electric vehicle. Dr. Patil holds a bachelor's degree from IIT Bombay and a master of science in engineering and a PhD in engineering from the University of Michigan. He has 18 patents, published 27 articles, and received the Henry Ford Technology Award in 1991 for his work in electric vehicle power train development. He was elected a Fellow by the Society of Automotive Engineers in 2007.

About Clemens Roettgen

Clemens Roettgen is currently working as a free advisor and consultant. He was previously Director of Corporate Strategy at Volkswagen Group China. Prior to this, Clemens served as GM, Sales China, ASEAN, Taiwan, and Hong Kong from Volkswagen's Germany offices. In this role, he was responsible for sales in the China region and volume planning/product planning departments for China and ASEAN. Before this he was Head of Volume Planning, Sales China, ASEAN, Taiwan, Hong Kong for the firm. He previously spent several years in increasingly more senior roles focused on market steering and coordinating sales teams for the region.

About Arnold Lamm

Arnold Lamm has more than 30 years' experience in the automotive market. He served as the Senior Manager Fuel Cell & Battery-Technology/eDrive Systems at Daimler. In this role, he helped lead Daimler's future business unit and was involved with the electric vehicle battery segment. After leaving Daimler, Arnold established his own consulting firm, e-Technologies GmbH, where he currently serves as the CEO.

About Claudiu Bucur

Claudiu Bucur started a battery technology company called Piersica that focuses on next-generation solid-state lithium-on batteries. Previously, Bucur was Chief Engineer – Solid Electrolyte – Lithium-ion batteries at Svolt Energy Technology Co. Ltd. Before this, he served as Chief Engineer, Project/Technical Director – Solid Battery Electrolytes at Great Wall Motor Co. Ltd. He has also held positions at Toyota Motor North America and Agricultural Research Service.

About Jeff Yanssens

Jeff Yanssens is currently President at JAY Engineering LLC. He currently focuses his efforts in the new energy field, where he concentrates his efforts on EV subsystems and fuel cell applications. Prior to this, Jeff held the position of Vehicle Chief Engineer Electrified Vehicles while working at General Motors Company. He has held other roles at General Motors, including Senior Manager Chassis Validation, Engineering Group Manager – Advanced Vehicle Development Center, and Engineering Program Manager.

About Tom Croskey

Tom Croskey was the Executive Director of Manufacturing Strategy and Planning at General Motors from March 2010–September 2017. In that role, he was responsible for determining the location for GM manufacturing sites and allocation of products. He also enabled effective site sections through profit and cost projections. He handled tariff and foreign exchange implications, handled JV divestiture negotiations, and leveraged GM's growth and global footprint to lower manufacturing costs.

About Greg MacLean

Greg MacLean, PhD, is the former Lead Engineer and BOM family owner for advanced battery cells at General Motors. The cells are used in all of GM's 48V, HEV, PHEV/EREV, and EV battery packs and vehicles. While at GM, Greg was also responsible for benchmarking the battery cells used by GM's OEM competitors, as well as those being developed by the major cell manufacturers around the world.

About Patrick Curran

Patrick Curran is Chief Executive Officer at Lithium Recycling Systems, specializing in the disposal and recycling of lithium-based and lead-acid batteries. Patrick has 13 years of experience in the battery recycling sector. Previously, he was a Plant Manager at Exide Technologies, one of the largest lead-acid battery equipment manufacturers in the world.

About Martin Murray

Martin Murray spent 30 years at General Motors. He served most recently as Director of the Electrification Propulsion Global Program Management at General Motors, until February 2019. Prior to this, he held numerous positions in electrification at General Motors, including Director of Electrification Engineering PATAC, Senior Manager Battery Pack Engineering, Global Program Manager of Energy Storage Systems, and Director of Hybrid and Electric Powertrains, International.