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BLUEPAPER

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Autos & Shared Mobility

The New Oil: Investment Implications of the Global Battery Economy

The birth of the battery economy is reshaping century-old supply chains and creating a new industrial order. Morgan Stanley worked across 10 sectors to analyze the >$500bn battery TAM, creating a Global Battery Portfolio of 71 names and mapping the value chain from the mine to the highway line.

Sustainability

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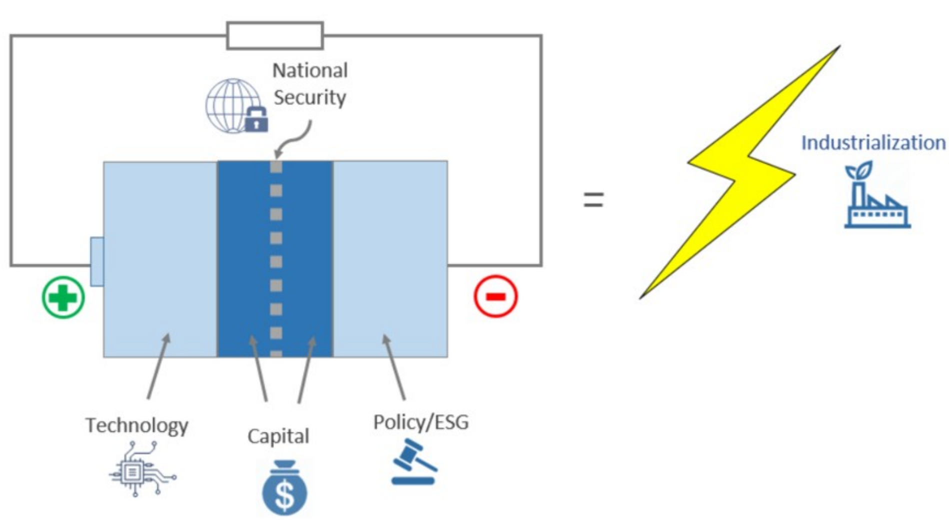
Executive Summary

The world has changed since 2019... transforming the landscape for the global battery market. It can be challenging to stay ahead of the progress across geographies and sectors, especially when compounded by the pace of news flow and press releases that can blur the lines between signal and noise. The Morgan Stanley Global Battery team have collaborated on this Blue Paper to help advance investor thinking about the battery ecosystem, pinpoint what's driving the change right now, introduce a scenario framework, and offer sector/stock level insights for our clients.

The battery industry is highly complex with dozens of mini self-reinforcing (and some self-correcting) supply/demand curves to take into consideration. The chances you will find agreement within the battery community on how everything plays out over the next 10 or 20 years is remote. So what does this report set out to do? Like any good piece of research, we want to answer three questions: **(1)** Why now?, **(2)** What's the framework?, and **(3)** Who's exposed? To that end, we built a proprietary battery total addressable market (TAM) model and a global battery stock portfolio.

- **For our proprietary battery TAM model**, we took a detailed 'bottom-up' approach starting with battery electric vehicle (BEV) / plug-in hybrid electric vehicle (PHEV) sales in vehicle units, building to battery installation demand in GWh/TWh, and finally arriving at commodity demand in kT. We calculate the TAM by multiplying BEV/PHEV unit sales by battery capacity and battery price ($/kWh). Our volume assumptions are based on our global BEV sales forecasts while our capacity, pricing, and chemistry assumptions incorporate our Asia battery team's supply/demand expectations as well as insights from the broader Morgan Stanley battery team. Using these inputs, we arrive at a 2040 electric vehicle (EV) Battery TAM of ~$525bn. In addition, we overlay our global utilities teams' energy storage system (ESS) Battery TAM assumptions to arrive at a 2040 total battery TAM of ~$535bn (ESS Battery TAM is approx. 3% of the total market). For more on our ESS battery estimates, please see Appendix III - ESS Battery Global Update . For a more detailed overview of our EV battery model inputs and outputs, please see Model Inputs & Outputs.
- **For our global battery stock portfolio**, 25 Morgan Stanley equity analysts across 7 sectors in North America, Europe, and Asia nominated their most exposed names across the battery value chain, from the mining of raw materials (upstream) to auto OEMs and recycling (downstream). Beyond categorizing the names by battery value chain, we filtered the 71 stocks in our comprehensive battery portfolio according to tech cycle placement, beneficiary time horizon, durability of moat, and how much is priced in, to provide a more comprehensive perspective. For a deeper dive on our battery portfolio names, please see Building the Morgan Stanley Battery Portfolio . *Note: Our Global Battery Stock Portfolio does not refer to a trading or model portfolio of recommended equity securities, but a selected list of companies that are exposed to the battery ecosystem.*

Exhibit 1: A battery analogy to describe the forces driving battery industrialization



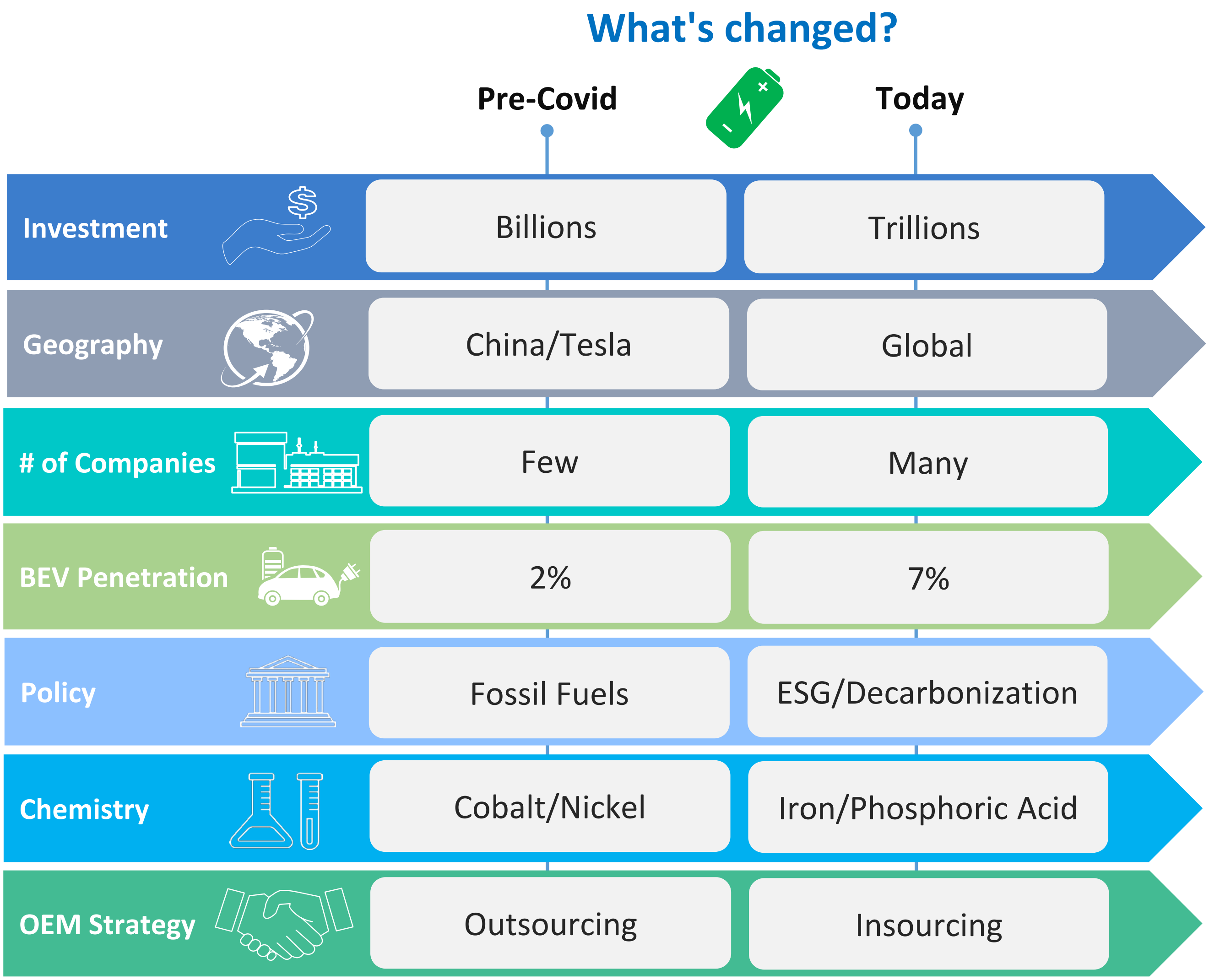
Source: Morgan Stanley Research

The pre-COVID battery world. Global EV penetration was just 2 to 3% and battery costs were following a path of 5 to 7% annual cost decreases. The scope of any BEV production that approached high volume was limited to Tesla and the Asian battery makers. Aggregate investment levels were in the low tens of billions annually, maybe $100 billion over the next 5 years.

The battery world today. While battery costs are still grinding lower, the big change is the quantum of capital and climate-oriented stimulus policies, especially outside of China. So today, the battery story is a global story and the amount of capital involved is 10 to 20x higher than it was pre-COVID. So you take the tech path + policies, add $1 or $2 trillion of capital, and you get the industrialization of the battery economy.

COVID accelerated the development of the battery economy by at least 5, if not 10 years. Just let that sink in... Just 2 years ago, most of our clients thought they could begin deploying capital on batteries well after 2025 or even 2030. The world has changed. Our clients know they must think about this right now.

Exhibit 2: Pre-Covid to Today - What's changed?



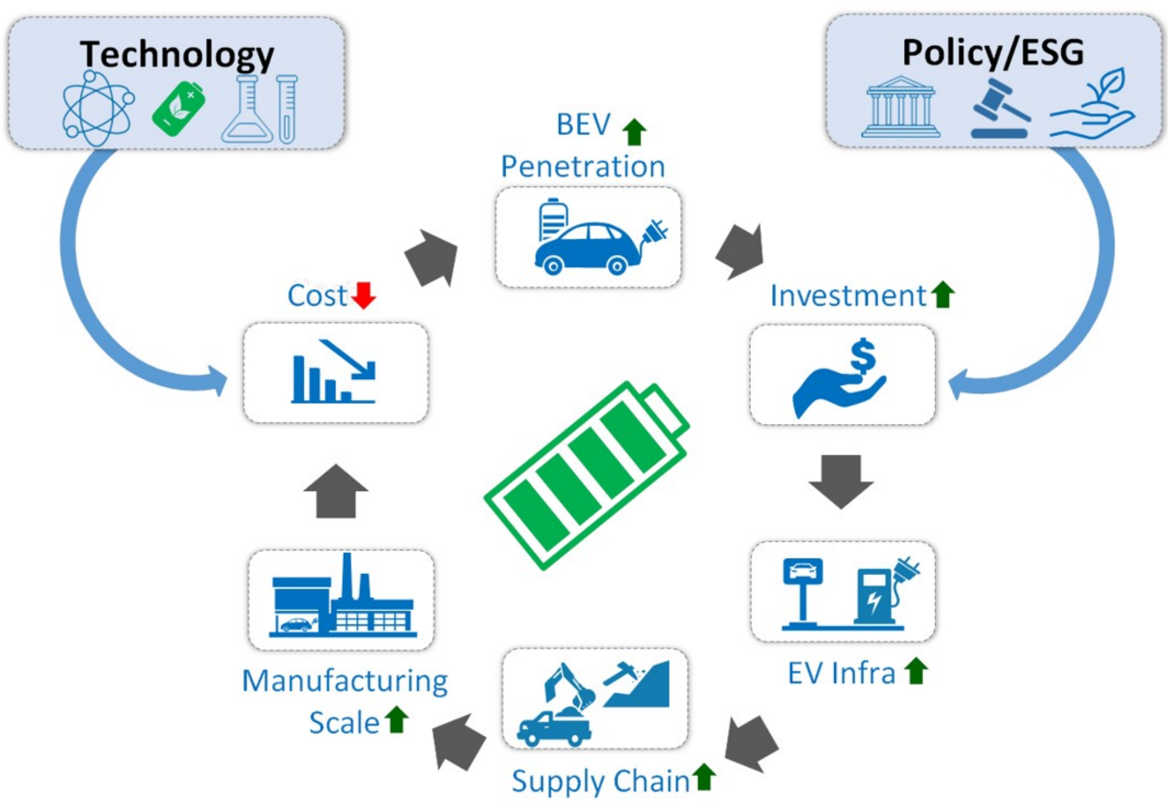
Source: Morgan Stanley Research

This Blue Paper offers a primer on key battery fundamentals, a robust industry framework, tools for sizing the value chain, and a 'call to action' through our Global Battery Portfolio of 71 names across 7 verticals. We see synergistic value in our team's industry analysis of the value chain (across mining, materials, machinery/equipment, packaging, and OEMs) distilled into a first-of-its-kind global battery portfolio of 71 names. This Blue Paper also serves as a primer which includes a host of battery industry foundational content for those who are new to the industry.

Why now? While battery technology has been around for more than two centuries, the state of the art is still maturing. An order of magnitude reduction in the cost of lithium-ion battery technology toward the $100/kWh level over the past 15 years has driven BEV penetration to around 7% globally in 2021. Add a flurry of environmental, social, and governance (ESG) mandates and post-COVID government climate policies... and the game starts to change. And then there's Tesla, which is now the world's most valuable manufacturer with a market cap of ~$1 trillion, sending aftershocks across board rooms and portfolios around the world.

Key drivers? We identify two primary 'force vectors' for change in the global battery industry: **1)** technology and **2)** policy/ESG. Together, these drivers contribute to an industrial 'flywheel' that accelerates capital formation, lowers costs, and, ultimately, provides a path to commercial scale. Today's EVs are beginning to approach the acquisition cost and total cost of ownership (TCO) of prevailing internal combustion engine (ICE) technology. Over the next 5 to 10 years, the emerging battery economy is a story of BEVs becoming vastly superior in cost and capability to internal combustion engine cars.

Exhibit 3: We expect technology and policy/ESG to be the two main drivers of the global battery industry.



Source: Morgan Stanley Research

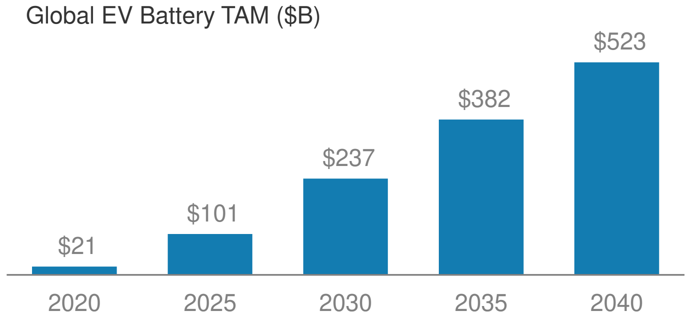
How big? A ~$535bn Total Addressable Market (TAM) by 2040. We built the Morgan Stanley Global Battery model by using our proprietary bottom-up global EV penetration model as well as working with our global battery, commodities, and utilities teams. We assume 86.7% BEV penetration of global light vehicle sales by 2040, producing 93.5mm units annually. We assume a global average battery size of ~75 kWh/unit and pricing of ~$75/kWh by 2040 for an EV battery TAM of ~$525bn. Combined with our global ESS battery TAM, we arrive at a 2040 total battery TAM of ~$535bn. OEMs have directed capex dollars to position themselves to capture market share of this TAM. For example, Ford is allocating $30bn towards EV investment by 2025 (see *here* for more), with Ford's 5% share implying $600bn spent by global OEMs by 2025. Of this $600bn, we estimate roughly half to be directly related to capacitizing and vertically integrating battery capability.

How broad? This story involves multiple sectors across cell manufacturing, specialty chemicals mining, equipment, components, machinery, packaging, and OEMs. We view battery electric vehicles as a 'theme' rather than a single 'industry' which can only be analyzed across the sector stack.

However, not all parts of the battery value chain will keep up with overall TAM growth. The path to a ~$535bn TAM by 2040 may not create wealth evenly across the exposed sectors. A look at the historical returns of battery manufacturers vs. innovators in the consumer electronics market over the past quarter century offers a valuable lesson. Although the market for lithium-ion batteries continues to grow at double-digit rates, returns on invested capital for manufacturers remain low due to capital intensity requirements in scaling production and the constant challenge in developing batteries that are safer, longer-lasting, and higher energy density. For instance, battery manufacturers' return on invested capital in the last decade amounted to just 7%, while innovators reaped the benefits of rechargeable batteries in consumer electronics while delivering disproportionate returns.

We draw upon our experience investing in emerging/new industries in technology. In terms of stocks, there is a very clear road map on how you can make money in these new adoption cycles. Money is typically made first early in a cycle with enablers of the technology – in the Mobile era, think of Qualcomm and ARM enabling cellular connectivity and mobile apps during the Mobile Internet cycle. Subsequently, value creation shifts to the infrastructure/device makers with higher penetration – Samsung and Apple are two leading examples in the Mobile era. Finally, a lot of money is made toward the end of the cycle. Value creation would shift to software and services companies that are able to capitalize on the growing

Exhibit 4: We expect the global EV battery TAM to grow to ~$525B by 2040.



Source: Morgan Stanley Research: Note: excludes ESS

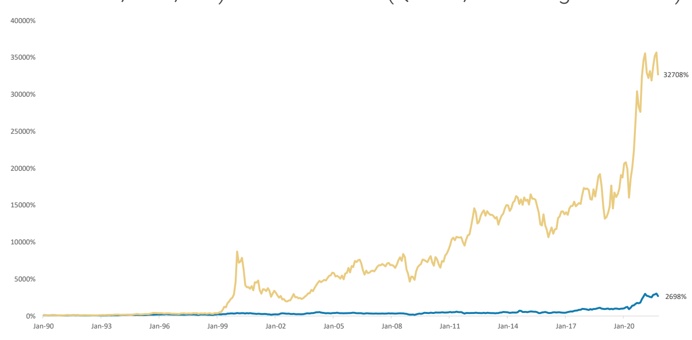
Exhibit 5: We break down the battery value chain by implied unit cost and implied TAM.

Value Chain	Category	% Battery Cost	Implied 2040 TAM ($B)	Unit Cost
Materials*	Cathode	25%	$131	$1,406
	Anode	10%	$53	$563
	Electrolyte/Separator	15%	$79	$844
	Other	10%	$53	$563
Manufacturing	Manufacturing	15%	$79	$844
	Packaging	15%	$79	$844
	Equipment	5%	$26	$281
Labor		5%	$26	$281
Battery		**100%**	**$525**	**$5,625**

**We note that the mining and recycling costs are embedded within the materials costs*

Source: Morgan Stanley Research; Note: assumes 75 kWh capacity and $75/kWh cost by 2040, breakdowns are MS estimates for illustrative purposes

Exhibit 6: Illustrating the power of innovation... the combined market cap change since 1995 for battery manufacturers (SONY, Panasonic, TDK, SDI) and innovators (QCOM, Samsung and AAPL).

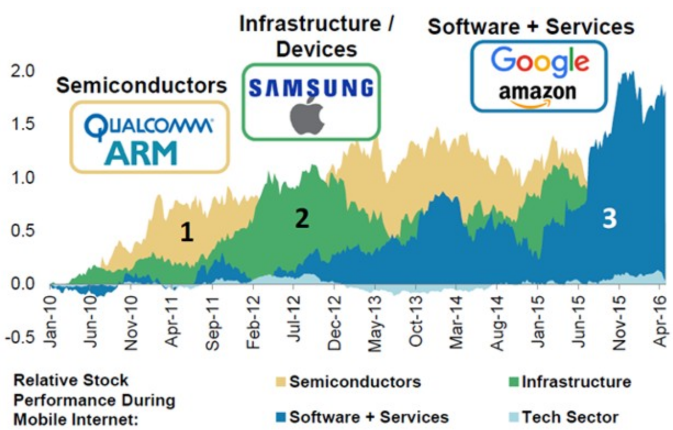


Source: Company data, Morgan Stanley Research

base of EVs. This late stage is exemplified by the FAANG (Facebook, Amazon, Apple, Netflix, Google) trade in the Mobile internet era monetizing that base of ~4 billion internet users. If we fast forward and look at how the 'Ion Era' could play out...

- **Money is first in the enabler**. Companies such as CATL, SK Innovation, and Samsung SDI are the enablers of the batteries that move EVs while analog semiconductor companies such as Wolfspeed (previously Cree), Rohm, and Sensata can be seen as important enablers of the global green economy. We are already a couple of years into these cycles given very robust performance in these stocks but there is probably more legs to the battery trade.
- **Then, money is made in infrastructure and hardware.** This started in the last few quarters with the EV OEMs (Tesla, VW, and GM). Furthermore, it plays into companies providing charging infrastructure or high tech/sustainable battery recycling.
- **And lastly, money is made in software and services.** We think companies who lead the pack in embedding technology and launching new services will be the beneficiaries. This include providers that have the best offering on collecting data through sensors, the ability to gain new insights, and the ability to network in more places in the world and offer those services. Similar to FAANG, we may start to see increasingly technologically advanced OEM offerings (ie. autonomy). But that is more long-term and we would not expect to see that break-out for another few years at least.

Exhibit 7: We compare the battery industry to tech innovation cycles in which (1) the enabler performs first (battery), followed by (2) the infrastructure/hardware, and then (3) services at the end. This normally takes place over a decade in tech.

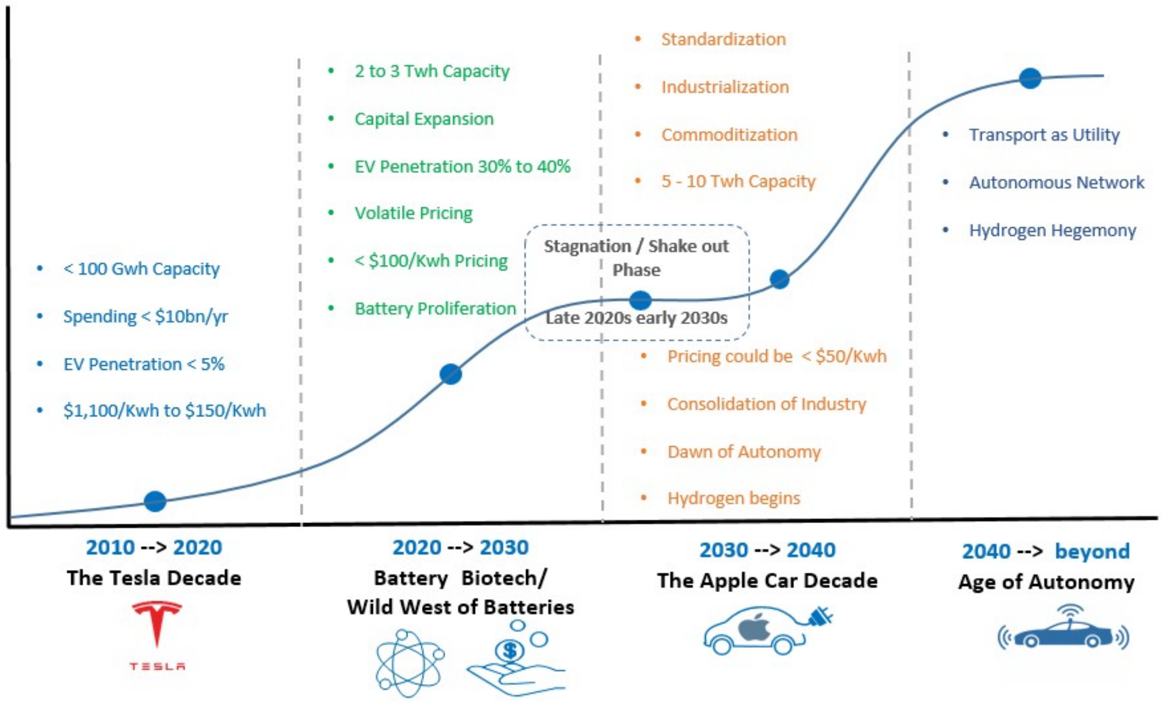


Source: Eikon, Morgan Stanley Research

The timeline of adoption may include a number of interconnected S-curves. We think it's helpful to think in terms of stages of development or 'epochs' as the story of the battery economy unfolds.

- **2010 to 2020: The Tesla Decade.** We believe the most important 'battery event' of the past decade was the emergence of Tesla. Tesla proved that EVs can be made profitably and at scale. At the same time, the industry saw battery costs fall towards $100/kWh from closer to $1,100/kWh at the start of the decade.
- **2020 to 2030: Battery Biotech/'Wild West' of Batteries.** The decade starts with Tesla reaching $1 trillion in market cap, making it the world's most valuable manufacturer - in any industry. This, combined with rapidly rising EV penetration (fueled by lower cost, government stimulus, and ESG) kicks off a rapid period of project financing and JV formation in the battery space. The rising tide seems to lift most boats in the BEV ecosystem, encouraging excess capacity globally. During the middle and latter part of this decade we see the 'balkanization' of the battery industry – governments and regions establish their own secure supplies of battery manufacturing capacity and raw material sourcing… fulfilling national/energy security objectives.
- **2030 to 2040: The Apple Car Decade?** Following an intervening period of stagnation and lower returns, we witness a shake-out of many sub-scale battery players with obsolete/uncompetitive technology, driving significant consolidation. From this point, we expect to see high levels of standardization and commoditization. During this period, we also expect to see well-capitalized new tech players challenge Tesla and what remains of the established EV order.
- **2040 and beyond: Age of Autonomy.** In the very long term, we believe the automobile business model itself is fundamentally transformed into a transport utility where a combination of cheap batteries, renewable energy, and autonomy drive the incremental cost of the vehicle mile traveled to near zero. Outcomes here can include the encroachment of hydrogen at scale, fully autonomous networks, and full electric vertical take-off and landing (eVTOL) / urban air mobility.

Exhibit 8: One Vision of the Battery Economy timeline... (not just up and to the right)



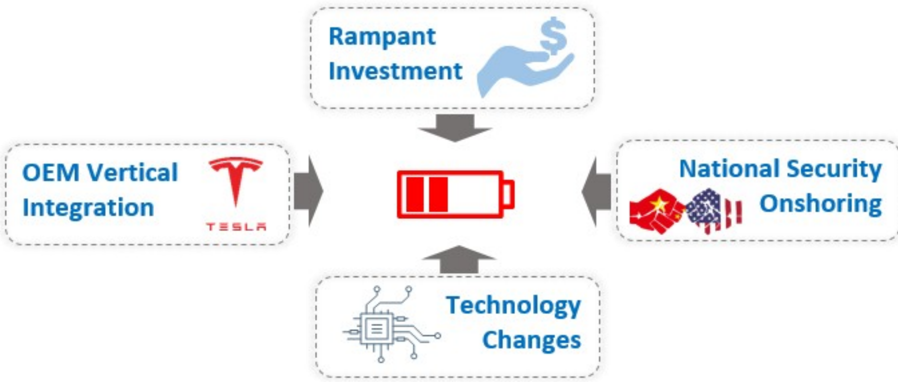
Source: Morgan Stanley Research

Glorified commodity today... Rechargeable battery technologies are central to moving toward a fossil-fuel-free society, yet the battery itself has always been an addendum, a limiting factor, and an expensive means of power. Costs have come a long way since 2010, when battery prices were $1,100/kWh, representing a 90% drop over ten years to about $110/kWh today. But that decrease is not sustainable over the next decade as we shift from a 'fuel-intensive' to a 'material-intensive' energy system. The price will fall and in the end, it won't really matter which battery type prevails – as long as it leads to higher capacity, increased range, and lower price to give the EV industry a large boost. Lithium-ion batteries may have reached technical limits which means there is a limit to the price for longer range cars, and perhaps a motivation for the move toward lithium iron phosphate (LFP) to squeeze every electron in the hope of achieving further incremental gains in lithium-ion versus what the world needs.

... but the future — the $50/kWh battery and below — may lie elsewhere. Technological advances for the last 40 years have been about introducing a chemistry that excelled in a particular aspect rather than creating a battery that was better than all those that had come before. Battery technology is constantly changing, and the pace of change is accelerating exponentially, boosted by capital inflows. As we reach attractive battery efficiency to cost ratios (the main barrier to mass adoption) for solid state batteries by 2024, or lithium-air (water-based electrolyte) by 2035, multiple different innovations offer the promise of even higher step-change improvements. For instance, structural batteries or super-capacitors may be up to the task of carrying the future of the global green economy rather than today's widely used lithium-ion battery. A structural battery doesn't look like a cube or a cylinder; it looks like an airplane wing, car body, or phone case with a thin sheet of woven glass that separates the two electrodes, and these layers are suspended in an electrolyte that is jello-like.

Batteries are an 'earth changing' story with many risks and blind spots. While the development and industrialization of the battery economy are large in both size and scope, fundamentally changing our relationship with transportation, there are many unknowns and risks along the way that investors may be underestimating today. We highlight several factors that can drive commoditization and deflation to levels far below current economic models: **1)** excess investment, **2)** 'balkanization' of the battery business along geopolitical/national-security lines, **3)** OEM vertical integration, and **4)** technology change/obsolescence risk on the way to cell and manufacturing breakthroughs. Similar recent examples of such outcomes can be found in the solar and LED industries. For more, see Appendix II - Learning from the Past.

Exhibit 9: Four potential 'blind spots' for investors looking at batteries include rampant investment, national security onshoring, technology changes, and OEM vertical integration.



Source: Morgan Stanley Research

Capital kills the battery? One of these risks is the rapid pace of investment in the battery industry at a time when we have yet to achieve standardization in technology and the development of mature supply chains. A cursory look at the capex and R&D plans of the world's major automobile manufacturers (OEMs) offers a glimpse into the risks here.

Exhibit 10: Global OEM electrification plans

	Electrification/Battery Plan	Battery Partner	Battery Capacity Guidance	Planned Investment Amount	Battery Timeframe
US OEM Coverage (Adam Jonas)					
Tesla	Announced at its 2020 Battery Day its vertical integration plans starting with its proprietary LMNO battery, announced in Oct 2021 plans to switch to LFP	Panasonic, CATL, Korean player	100 GWh by 2022, 3 TWh by 2030	~$233Bn (projected capex + R&D spend through 2030)	2021 through 2030
GM	JV partnership with Korean player to form battery business Ultium as well as announced recycling partnership with Li-Cycle and partnership with SES (hybrid lithium metal batteries)	Korean player	~30 GWh in Lordstown plant, ~30 GWh in Spring Hill plant	$35Bn for batteries ($5Bn already invested); $27Bn in electric/autonomous vehicles over next 5 years	2020 through 2025
Ford	JV partnership with SK Innovation on batteries through BlueOvalSK, partnership with Solid Power (solid state batteries)	SK Innovation	129 GWh across 3 plants in TN and KY	$30Bn; $11.4Bn battery investment in conjunction with SK Innovation	By 2025
EU OEM Coverage (Harald Hendrikse)					
Stellantis	JV with two Korean players to produce electric vehicle batteries with 2024-2025 SOP target as well as a 1/3 equity partnership with Automotive Cells Company (ACC)	Samsung SDI, ACC, Korean player	23 GWh with Samsung SDI, 120 GWh with ACC, aiming for a minimum of 130 GWh by 2025 & 260 Gwh by 2030	~30Bn EUR	Through 2025
Daimler	1/3 equity partnership in Automotive Cells Company (ACC), linked to construction of CATL facility in Germany	CATL, ACC	120 GWh with ACC	~$8Bn in battery venture; $47Bn in EVs between '22-'30	By 2030
Renault	Partnership with China's Envision AESC and France's Verkor (20% stake) for electric car battery manufacturing	Envision AESC, Verkor, Korean player	9 GWh by 2024, 24 GWh by 2030 with Envision AESC & 10 Gwh by 2026, 20 GWh by 2030 with Verkor	Renault/Envision to invest ~$2.5Bn in gigafactory; 10Bn EUR in car electrification over next 5 years	2021 through 2024
Volkswagen	Investment in EV platform for 70 all-electric models; investment in Quantumscape (solid state batteries); JV with Northvolt (holds 20% shares) to have six 40 Gwh battery cell production plants	CATL, Samsung SDI, Northvolt, SKI, Korean player, QS, Farasis, Gotion	240 GWh with Northvolt	$86Bn in electrification and automation by 2025; 10-year, $14Bn order for one out of six planned factories with Northvolt	Through 2030
Volvo	Exclusive partnership with Northvolt for battery manufacturing in Europe	CATL, Korean player, Northvolt	50 Gwh	$3.5Bn battery factory deal with Northvolt	50% of Volvo Cars' sales will be EV by 2025
BMW	Significant increase in battery cell contracts for i4 sedans, iX SUVs and other models based on demand with Samsung SDI, CATL, and Northvolt, partnership with Solid Power (solid state batteries)	Samsung SDI, CATL, Northvolt	60 GWh with CATL from 2026+	~$24Bn batteries; 30Bn EUR in EV/hydrogen before 2025	Through 2031
Japan OEM Coverage (Shinji Kakiuchi)					
Toyota	Broad investment plan for battery development and production with partners including CATL, BYD, GS Yuasa, Panasonic, and Toshiba	BYD, Panasonic, CATL, GS Yuasa, Toshiba	200 GWh by 2030	~$13Bn; $3.4Bn in batteries in the US through 2030	Through 2030
Honda	Investment into 100% electric vehicles by 2040, including R&D initiatives; partnership with CATL	Ultium (GM), CATL	56 GWh before 2027	~$46Bn for the company total R&D over the next 6 years	By 2040
Nissan	Investment in new EV battery plants in the U.K. and Japan; partnership with AESC	AESC	40 Gwh by 2024	$1.8Bn in EV battery plants; $460mm in AESC plant	By 2024
Korean OEM Coverage (Young Suk Shin)					
Hyundai/Kia	Investment into EV infrastructure in the US; JV partnership with Korean player for battery plant in Indonesia and SK Innovation; Partnership with SES (hybrid lithium metal batteries)	SK Innovation, CATL, Korean player	10 GWh by 2024 (up to 30 GWh)	~$8.5Bn batteries; $1.1Bn for Indonesian battery plant; $35Bn investment in mobility/other technologies by 2025	By 2025

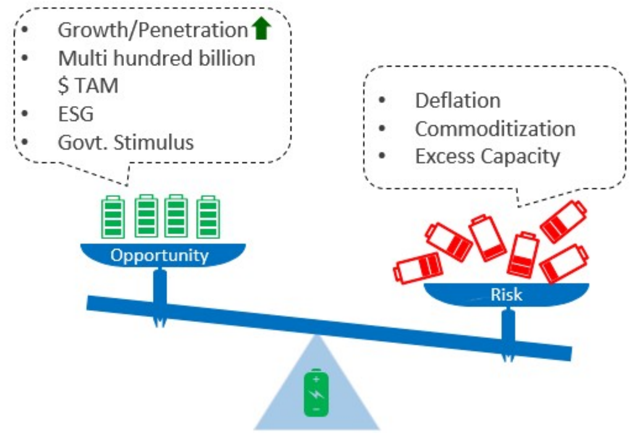
Source: Company data, Morgan Stanley Research

A multipolar world. Battery manufacturing and materials are becoming increasingly important from a strategic perspective. It is unlikely that Europe and North America will continue to rely on China for intermediate battery raw materials processing in the long-term. Both have already taken steps to attract battery cell manufacturers. The next step is to provide support to on-shore battery materials processing capacity. The auto industry is carrying the necessary burden of revolutionizing the battery industry, increasing production scale, and lowering costs, so that batteries can be more widely and cheaply applied in other sectors in the future. These will include new areas such as internet of things (IoT), industrial autonomy, robotics, or defense as well as EV batteries connecting to the electricity grid, given more EVs means more energy consumption and, eventually, increased pressure on grids. Bidirectional charging (two-way charging) helps to enable EV batteries into energy storage points that can be used to balance and settle energy needs. There is also the question whether new standards play a role in creating a new divide for battery makers as the auto, aviation, or utilities industries are heavily regulated.

Bottom line: the story of the battery economy is a story of innovation and growth, offset by commoditization and deflation. We think part of what drives the 'bull case' for EV penetration has the potential to present the 'bear case' for many current participants in today's battery value chain.

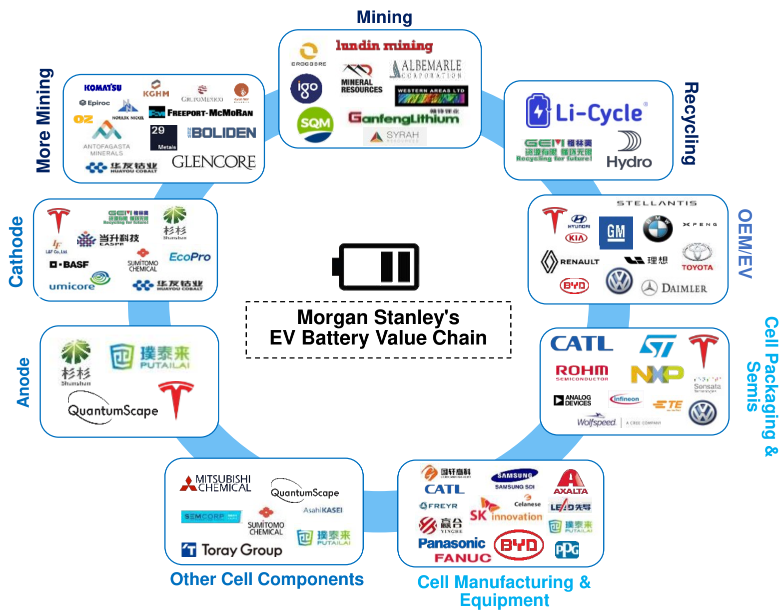
Building the Morgan Stanley Global Battery Portfolio. In collaboration with 25 equity analysts across North America, Europe, and Asia, we identified the companies under our coverage that are best positioned for the exponential growth in the EV battery economy. Our list stands at 71 names across 7 sectors. Out of these names, 20% are rated Underweight, 39% are rated Equal-weight, and 41% are rated Overweight. The median market cap is $18.2B while the median valuation of the Morgan Stanley Battery Portfolio is 19.6x 2022e P/E and 10.2x 2022e EV/EBITDA. With some exceptions, we prefer the OEMs, recyclers, cell/equipment, semis, and mining companies over the battery manufacturers themselves. Amongst the broader group, we are particularly attracted to the 'picks & shovels' and raw material companies exposed to quantity > price. Please see the Building the Morgan Stanley Battery Portfolio section for more.

Exhibit 11: The Battery Economy: Opportunity and Risks in the Balance



Source: Morgan Stanley Research

Exhibit 12: Morgan Stanley's Global Battery Portfolio



Source: Morgan Stanley Research

***Note: Our 2040 EV Battery TAM of $525bn, which we reference several times in this Blue Paper, excludes the ESS Battery TAM. EV Battery TAM accounts for 97% of the Total Battery TAM in 2040. For more on ESS, please see Appendix III - ESS Battery Global Update .**

Introducing the Morgan Stanley Global Battery Team

The Morgan Stanley Global Battery Team includes 30 analysts from 10 sectors (including ESG) across North America, Europe, and Asia-Pacific. Together, we cover every aspect of the battery value chain, from the mining of raw materials to cell components to manufacturing/packaging to electric vehicles and finally to end of life recycling. We believe that batteries are the new oil, and this revolution has the potential to shake up the battery sectors and those directly related: autos & shared mobility, metals & mining, chemicals, technology, machinery, semiconductors, ESG/sustainability, utilities, and commodities. Further in this note in Building the Morgan Stanley Battery Portfolio , we present a list of global, diversified stocks to consider across the battery value chain as the battery arms race begins.

Exhibit 13: Key Members of the Morgan Stanley Global Battery Team

Source: Morgan Stanley Research

Addressable Market Scope & Scale

Pre-Covid to Today - What's Changed?

We believe that Covid-19 significantly accelerated the progress of the global battery economy. Prompted by the rise of decarbonization, governments and corporations across the globe are – perhaps for the first time in history – coordinating efforts to turbocharge the carbon-friendly shift away from ICE and towards BEV. The most likely beneficiary? The global battery industry. Let's break it down:

1. **More capex spending** from OEMs and battery companies will lead to **more battery installation capacity**.
2. **Technological improvements** in energy density, cycle life, range, etc. will continue to accelerate as companies pursue the "ideal battery."
3. **Regulation** is becoming more supportive through BEV subsidies, infrastructure stimulus, and ICE taxes as governments prioritize decarbonization, ESG, and national security – batteries are the new oil.
4. The combination of the above three factors will lead to greater BEV penetration, economies of scale, and ultimately **lower battery costs**.
5. Lower battery costs will drive **industrialization** as batteries become competitive with traditional energy sources.

Exhibit 14: Pre-Covid to Today - What's Changed?

What's changed?

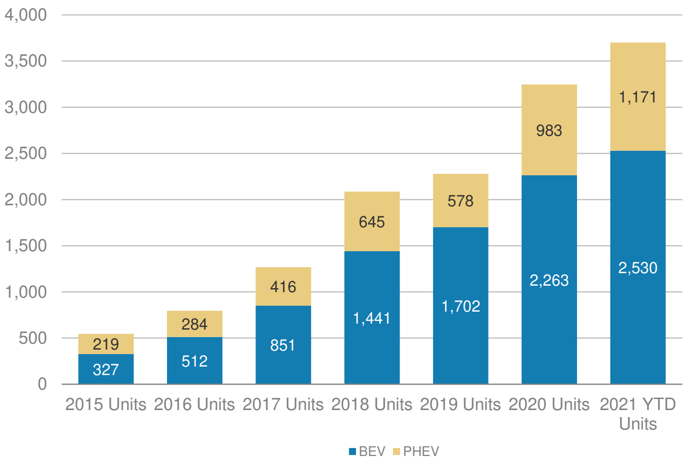
	Pre-Covid	Today
Investment	Billions	Trillions
Geography	China/Tesla	Global
# of Companies	Few	Many
BEV Penetration	2%	7%
Policy	Fossil Fuels	ESG/Decarbonization
Chemistry	Cobalt/Nickel	Iron/Phosphoric Acid
OEM Strategy	Outsourcing	Insourcing

Source: Morgan Stanley Research

Battery installation trends have accelerated globally... As BEV and PHEV global unit sales have accelerated (~25% CAGR from 2019-2021 YTD), global battery installation has increased in tandem. So far in 2021, the largest global battery suppliers by sales are all in Asia (Korean player, CATL, Samsung SDI, and SK Innovation) while top global OEMs with battery capacity are more regionally diverse in the US, EU, and Asia (Tesla, VW, BYD).

Exhibit 15: BEV and PHEV unit sales have increased at a ~25% CAGR from pre-Covid-19 to today...

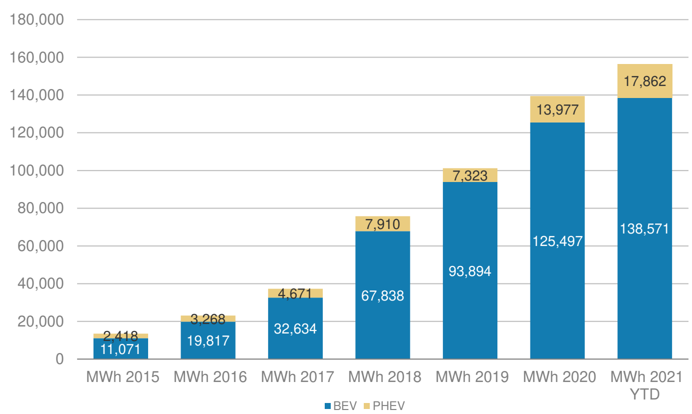
Global BEV + PHEV Unit Sales (000s)



Source: EV-volumes.com, Morgan Stanley Research: Note: as of Aug 2021

Exhibit 16: ... while global battery installation has grown at a ~25% CAGR.

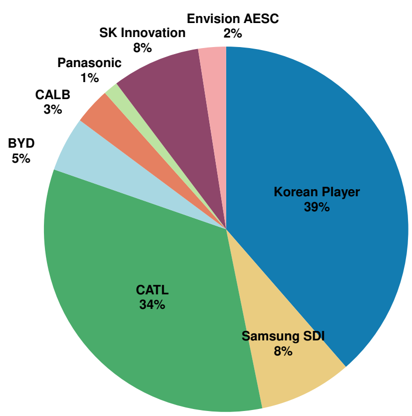
Global Battery Installation (MWh)



Source: EV-volumes.com, Morgan Stanley Research; Note: as of Aug 2021

Exhibit 17: The largest global battery suppliers by sales in 2021 YTD are based in Asia (Korean player, CATL, Samsung SDI, and SK Innovation) ...

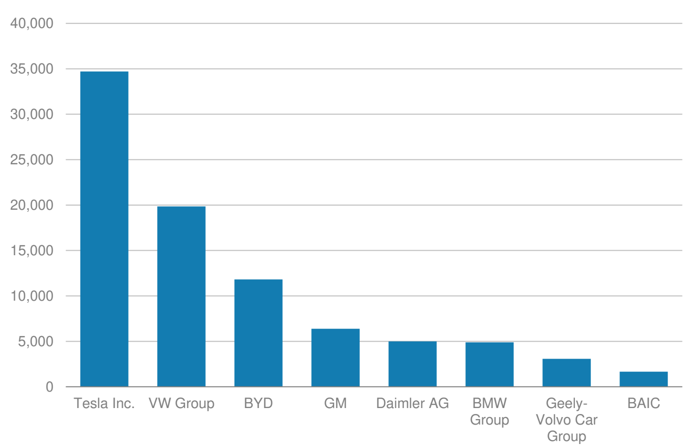
Top Global Battery Cell Suppliers - 2021 YTD



Source: EV-volumes.com, Morgan Stanley Research; Note: as of Aug 2021

Exhibit 18: ... while the top OEMs with battery capacity are more regionally diverse (Tesla, VW, BYD).

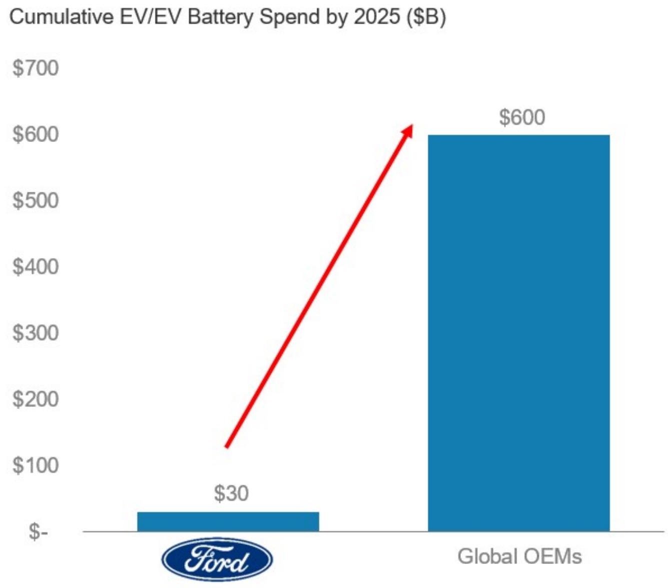
Global OEM Battery Capacity in MWh (2021 YTD)



Source: EV-volumes.com, Morgan Stanley Research; Note: as of Aug 2021

... the industry is preparing to make a multi-billon dollar investment in batteries in the near-term. While these are still extremely early days in the global battery arms race, we point to Tesla's Battery Day in 2020 as a turning point in the battery investment narrative. As we wrote in *Tesla Battery Day and the $22tn EV Infrastructure Boom*, on September 22, 2020, Tesla essentially called on key stakeholders in the EV ecosystem – corporations, investors, governments, policy makers – to help fund the decarbonization of the global transport fleet. Tesla estimated that for today's battery factories to produce 20 TWh of capacity, that would require $2 trillion of investment in battery materials, cell, and manufacturing. About one year later, Ford announced its $30bn investment plan with its JV battery cell maker SK Innovation (BlueOvalSK) through 2025. To contextualize, Ford claims ~5% share of global production and $30bn is nearly 1/2 of its current enterprise value (see *Ford to Spend Nearly 2/3 of Market Cap on BEVs by 2025* for more). $30bn implies global OEM spend to the order of $600bn in the next 4 years.

Exhibit 19: We extrapolate Ford's announced $30B investment plan to $600B global OEM spend on EVs and EV batteries by 2025.



Source: Company data, Morgan Stanley Research

Global OEMs have guided to spending that implies trillions of investment in battery capacity as part of their medium to long term electrification strategies. While Asia represents ~85% of global battery manufacturing capacity today, global OEMs and new entrants are starting to tip the scale towards a more regional balance. Global OEMs have guided towards electrification with plans to both produce electric vehicles and vertically integrate supply chains starting with battery cells. On Tesla's Battery Day in September 2020, Elon Musk highlighted this trend by announcing that Tesla plans to in-source battery production (for more, please see Tesla Battery Day) . As noted below, we estimate that Tesla would invest a cumulative ~$233bn in capex and R&D by 2030, the majority of which we expect will be dedicated to batteries. Given that Tesla was approx 20% of YTD BEV sales as of October 2021, that implies >$1 trillion of cumulative capital invested in batteries by 2030. Looking further, summing our global battery TAM in our MS Global Battery model out to 2040, we estimate a *cumulative* ~$5tn of global battery COGs by 2040.

Exhibit 20: Global OEMs have announced trillions of capital investment and battery JVs in pursuit of their electrification goals.

	Electrification/Battery Plan	Battery Partner	Battery Capacity Guidance	Planned Investment Amount	Battery Timeframe
US OEM Coverage (Adam Jonas)					
Tesla	Announced at its 2020 Battery Day its vertical integration plans starting with its proprietary LMNO battery, announced in Oct 2021 plans to switch to LFP	Panasonic, CATL, Korean player	100 GWh by 2022, 3 TWh by 2030	~$233Bn (projected capex + R&D spend through 2030)	2021 through 2030
GM	JV partnership with Korean player to form battery business Ultium as well as announced recycling partnership with Li-Cycle and partnership with SES (hybrid lithium metal batteries)	Korean player	~30 GWh in Lordstown plant, ~30 GWh in Spring Hill plant	$35Bn for batteries ($5Bn already invested); $27Bn in electric/autonomous vehicles over next 5 years	2020 through 2025
Ford	JV partnership with SK Innovation on batteries through BlueOvalSK, partnership with Solid Power (solid state batteries)	SK Innovation	129 GWh across 3 plants in TN and KY	$30Bn; $11.4Bn battery investment in conjunction with SK Innovation	By 2025
EU OEM Coverage (Harald Hendrikse)					
Stellantis	JV with two Korean players to produce electric vehicle batteries with 2024-2025 SOP target as well as a 1/3 equity partnership with Automotive Cells Company (ACC)	Samsung SDI, ACC, Korean player	23 GWh with Samsung SDI, 120 GWh with ACC, aiming for a minimum of 130 GWh by 2025 & 260 Gwh by 2030	~30Bn EUR	Through 2025
Daimler	1/3 equity partnership in Automotive Cells Company (ACC), linked to construction of CATL facility in Germany	CATL, ACC	120 GWh with ACC	~$8Bn in battery venture; $47Bn in EVs between '22-'30	By 2030
Renault	Partnership with China's Envision AESC and France's Verkor (20% stake) for electric car battery manufacturing	Envision AESC, Verkor, Korean player	9 GWh by 2024, 24 GWh by 2030 with Envision AESC & 10 Gwh by 2026, 20 GWh by 2030 with Verkor	Renault/Envision to invest ~$2.5Bn in gigafactory; 10Bn EUR in car electrification over next 5 years	2021 through 2024
Volkswagen	Investment in EV platform for 70 all-electric models; investment in Quantumscape (solid state batteries); JV with Northvolt (holds 20% shares) to have six 40 Gwh battery cell production plants	CATL, Samsung SDI, Northvolt, SKI, Korean player, QS, Farasis, Gotion	240 GWh with Northvolt	$86Bn in electrification and automation by 2025; 10-year, $14Bn order for one out of six planned factories with Northvolt	Through 2030
Volvo	Exclusive partnership with Northvolt for battery manufacturing in Europe	CATL, Korean player, Northvolt	50 Gwh	$3.5Bn battery factory deal with Northvolt	50% of Volvo Cars' sales will be EV by 2025
BMW	Significant increase in battery cell contracts for i4 sedans, iX SUVs and other models based on demand with Samsung SDI, CATL, and Northvolt, partnership with Solid Power (solid state batteries)	Samsung SDI, CATL, Northvolt	60 GWh with CATL from 2026+	~$24Bn batteries; 30Bn EUR in EV/hydrogen before 2025	Through 2031
Japan OEM Coverage (Shinji Kakiuchi)					
Toyota	Broad investment plan for battery development and production with partners including CATL, BYD, GS Yuasa, Panasonic, and Toshiba	BYD, Panasonic, CATL, GS Yuasa, Toshiba	200 GWh by 2030	~$13Bn; $3.4Bn in batteries in the US through 2030	Through 2030
Honda	Investment into 100% electric vehicles by 2040, including R&D initiatives; partnership with CATL	Ultium (GM), CATL	56 GWh before 2027	~$46Bn for the company total R&D over the next 6 years	By 2040
Nissan	Investment in new EV battery plants in the U.K. and Japan; partnership with AESC	AESC	40 Gwh by 2024	$1.8Bn in EV battery plants; $460mm in AESC plant	By 2024
Korean OEM Coverage (Young Suk Shin)					
Hyundai/Kia	Investment into EV infrastructure in the US; JV partnership with Korean player for battery plant in Indonesia and SK Innovation; Partnership with SES (hybrid lithium metal batteries)	SK Innovation, CATL, Korean player	10 GWh by 2024 (up to 30 GWh)	~$8.5Bn batteries; $1.1Bn for Indonesian battery plant; $35Bn investment in mobility/other technologies by 2025	By 2025

Source: Company data, Morgan Stanley Research

As a key stakeholder in the global EV race, governments are prioritizing decarbonization through BEVs... Globally, governments have instituted supportive initiatives ranging from ICE bans, BEV subsidies, and carbon emissions targets. Essentially, policy makers have implemented initiatives to increase the cost of ICE and decrease the cost of BEV. In the US, the Biden Administration announced in August 2021 that it will target half of the vehicles sold in the US to be battery electric, fuel-cell electric, or plug-in hybrid by 2030. In Europe, the European Commission's 'FIT for 55' plans, announced in July 2021, include a proposed 55% cut in passenger car CO_2 by 2030 and 100% by 2035. In China, EV subsidies have long underpinned the country's EV ambitions, targeting new energy vehicles (NEVs) to represent 20% of total auto sales by 2025 (see *New Energy Vehicles: Charging into Challenges* for more). These incentives support BEV penetration, which in turn supports the battery industry's growth.

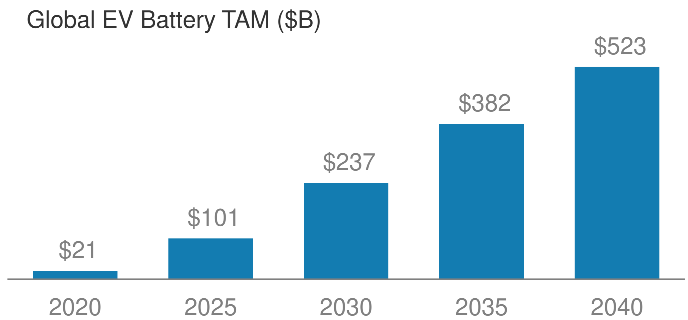
... **setting the stage for more technological breakthroughs to improve battery capacity, energy density, and cycle life**. A key driver of BEV penetration is battery performance. As we discuss in greater depth in Appendix I - Battery Primer , key aspects of battery performance are capacity, energy density, and cycle life. In simple terms, consumers want a battery that has range, efficiency, and longevity. As traditional automakers and new entrants saturate the growing BEV market, a key area of focus has been improving the EV battery according to these metrics. To name one, companies like Quantumscape are working on solid state technology which is considered the next generation of battery technology whereas companies like BYD are improving existing lithium-ion chemistries like LFP, which were previously thought to be capped in terms of performance.

Bottom line. The global investment level for batteries is easily in the trillions of $ over the next decade. The technology is proven and getting better with each generation and greater competition. And governments have never been more supportive. These three factors may drive higher BEV penetration, which will drive economies of scale, and ultimately push battery costs lower. By lower, we mean beyond $100/kWh. Already, we've seen huge improvements to battery cost – Bloomberg NEF reports that battery costs dropped from $1,100/kWh in 2010 to ~$157/kWh in 2019 (~85% reduction). Should battery costs decrease by just half that rate over the next decade, that implies battery costs of at least $90/kWh by 2030 (achieving parity with ICE) to kick off the decade in which we expect BEV penetration to grow the fastest.

Sizing the Market

We estimate that the total addressable market for EV batteries by 2040 will be ~$525bn. Using our estimates, we explore what this means both in and out of the vehicle. First, we contextualize where batteries fit in within the broader electric vehicle ecosystem. Then, we do a deep dive on batteries as a standalone space by breaking the product down into its components.

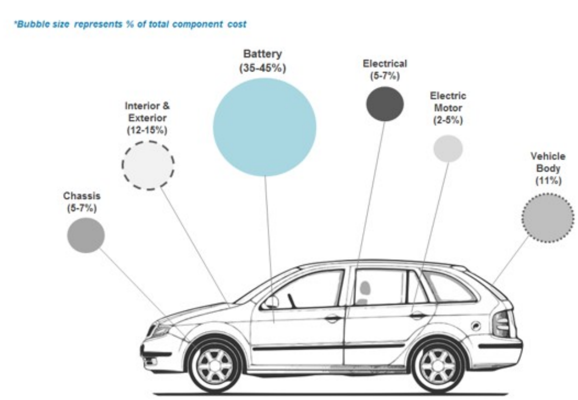
Exhibit 21: Using a 'bottom-up' approach starting with BEV sales penetration, we forecast that the global EV battery TAM will rise to ~$525B by 2040.



Source: Company data, Morgan Stanley Research

Zooming out first. To contextualize, the battery is approximately one-third the cost of today's electric vehicle. The other two-thirds of the EV cost come from the chassis, interior & exterior, electrical, electric motor, vehicle body, and other. On a market basis, flexing our 2040 EV battery TAM estimate of $525bn implies that the 2040 EV TAM is ~$1.6 trillion. On a per unit basis, if we assume that by 2040 an EV's battery capacity is 75 kWh and battery costs are $75/kWh, the battery cost of ~$5.6k (along with other manufacturing improvements) implies a total EV cost of under $20k.

Exhibit 22: Electric vehicle components by % of total cost



Source: Morgan Stanley Research

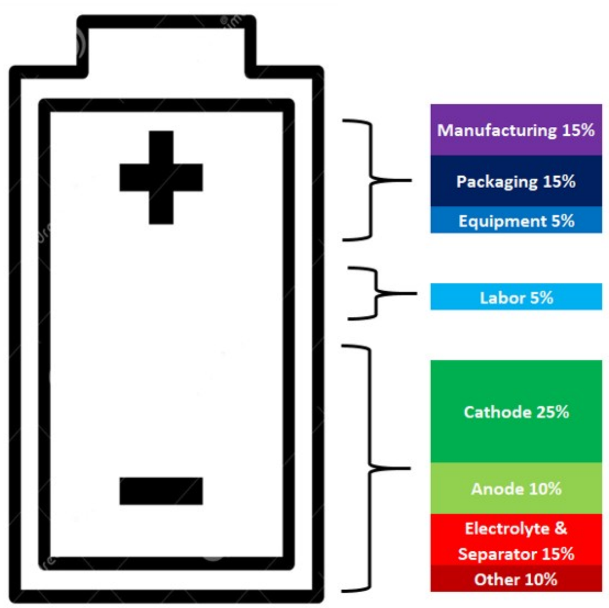
Exhibit 23: EV parts by TAM and per unit cost

EV component	% EV cost	Implied 2040 TAM ($B)	Unit cost
Battery	35%	$525	$ 5,625
Electrical	7%	$110	$ 1,125
Electric Motor	5%	$79	$ 804
Vehicle Body	11%	$173	$ 1,768
Interior & Exterior	15%	$236	$ 2,411
Chassis	7%	$110	$ 1,125
Other	20%	$315	$ 3,214
Total EV	**100%**	**$1,575**	**$ 16,071**

Source: Morgan Stanley Research; assuming 75 kWh battery with $75/kWh cost

Now zooming in… 'double click' on batteries. We break down the EV battery TAM by parts of the battery value chain, estimating mini-TAMs for each category. We estimate that the materials cost is approximately ~60% of the battery cost while the remaining ~40% is attributed to manufacturing, labor, and other. Within the materials cost, we estimate that the most expensive component is the cathode, which is approximately ~25% of the total battery cost (although this will vary across chemistries and as commodity prices fluctuate).

Exhibit 24: Battery component estimated breakdown by cost ($/kWh)



Source: Morgan Stanley Research, Qnovo; Note: these are approximate breakdowns for illustrative purposes

Exhibit 25: Battery value chain by TAM and unit cost.

Value Chain	Category	% Battery Cost	Implied 2040 TAM ($B)	Unit Cost
Materials*	Cathode	25%	$131	$1,406
	Anode	10%	$53	$563
	Electrolyte/Separator	15%	$79	$844
	Other	10%	$53	$563
Manufacturing	Manufacturing	15%	$79	$844
	Packaging	15%	$79	$844
	Equipment	5%	$26	$281
Labor		5%	$26	$281
Battery		**100%**	**$525**	**$5,625**

**We note that the mining and recycling costs are embedded within the materials costs*

Source: Morgan Stanley Research; Note: assuming 75 kWh battery with $75/kWh cost

A true 'cross asset' space, the battery ecosystem is far reaching as a reflection of its transformative potential. Beyond its direct application to electric vehicles and ESS, the global battery industry sits at the nexus of equity sectors, ESG, commodities, and public policy.

- **Sectors.** Within equity sectors, the value battery chain starts with the mining of raw materials, forming the cell components, manufacturing and packaging the cells, delivering the battery to EV automakers, and finally recycling the battery after it has reached the end of its useful life. This encompasses a range of sectors such as batteries, autos, metals & mining, chemicals, semiconductors, technology, and machinery.
- **ESG**. Batteries are related to ESG and sustainability due to their intended usage – the world cannot execute the emissions-reducing shift from ICE to BEV without the battery industry.
- **Commodities**. The commodity sector is a critical aspect of batteries as well – from the actual mining of raw materials to 'urban mining' through recycling – as battery cell components cannot be manufactured without their commodity feedstocks.
- **Public policy**. And finally, batteries are inherently a political space. On one hand, the connection to raw materials brings up geopolitics. Countries do not all possess equal endowments of mission-critical raw materials. The distribution of these key battery commodities across borders is akin to the relationship between Saudi Arabia and oil. On the other hand, batteries may replace oil & gas as an essential energy source. We expect that as BEV penetration accelerates, governments will start viewing batteries as a "utility" that should be domestically grown with important national security implications.

Lessons from the Model T, Solar, and LED

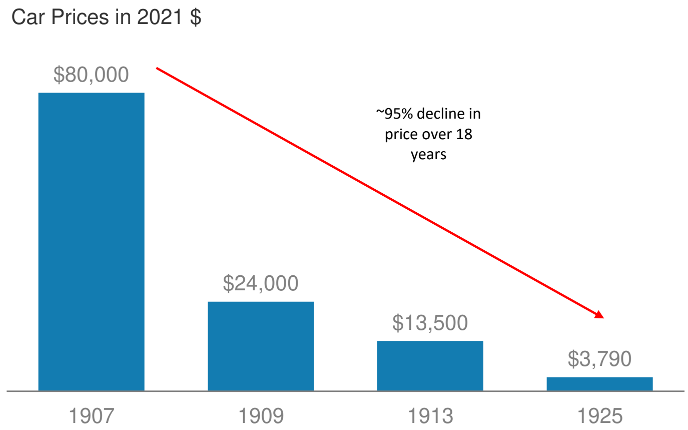
The path to a $525bn global EV battery TAM may not create wealth evenly across the battery value chain and come with unforeseen challenges such as commoditization. Below, we present three cases as warnings of potential pitfalls for battery value chain players – lessons from the Model T from ~110 years ago and lessons from the tech industry (solar and LED) from ~10 years ago.

About 100 years ago, Pre-Model T cars cost around $80k on average (in today's US$). As we wrote in *What's on My Mind? EV Deflation and What Really Finished the Horse & Carriage*, prior to the introduction of the Ford Model T in 1908, gasoline powered automobiles were rather limited in use and extremely expensive. In the year 1907 (the last full year prior to the Model T intro) there were 255 carmakers in the US (223 US owned and 32 foreign according to 'Motor' magazine). The average price of a gasoline car at the time was $2,834, or nearly $80k in 2021 dollars. There were 43k vehicles produced in 1907 for an average production per carmaker of just 169 vehicles per year.

The Model T entry level 'Runabout' cost $825 in 1909 (around $24k in today's dollars) or less than 1/3 the price of the average car at the time. But higher volumes and the moving assembly line brought far greater deflation in the price of the automobile from there. The price of a Model T 'Runabout' fell to $525 by 1913 ($13.5k in today's dollars) and $395 by 1920. By 1925, the average price of a Model T Runabout was $260 ($3,790 in today's dollars) which was around 1/20th of the average inflation adjusted price of a car in 1907.

What's our point? It wasn't the automobile or even the Model T itself that moved horse drawn carriages off of the road, it was manufacturing that drove dramatic levels of deflation. Taking nothing away from Tesla or the ever-growing number of EV players entering the market every month, we have not truly had the equivalent revolution in high volume manufacturing for EVs at this point. Elon Musk said it best during Tesla's 3Q20 earnings calls: "Tesla's long-term competitive strength will be primarily manufacturing. This is counter-intuitive, but I'm quite confident this will be what happens."

Exhibit 26: By 1925, car prices were 1/20th of the price in 1907 due to the impact of the Model T.

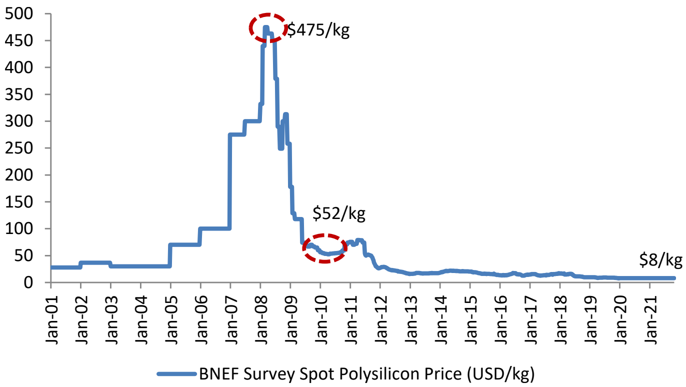


Source: Morgan Stanley Research

Fast forwarding to 10 years ago in the solar industry, polysilicon (a key feedstock for solar panels) was considered extremely complex to manufacture... Similar to the manufacturability of EV batteries today, polysilicon was perceived to have very high barriers to entry to achieve high purity requirements. For 15 years, there were only seven manufacturers (they even bore the nickname as the *'Seven Sisters'*) at scale globally that dominated the industry – most already producing semiconductor grade polysilicon – and each sold out on capacity for the next decade. However, this oligopoly began to crumble from 2005, when new entrants such as GCL-Poly or Daqo New Energy made a less-perfect but cheaper substitute at significantly lower cost. The pricing issue soon dissipated for China's solar PV customers. Today, Chinese companies represent four of the top five manufacturers of polysilicon globally.

...but was quickly commoditized. Given the commodified nature of polysilicon, the sharp price decrease in the Chinese market impacted global pricing. Nationalism also played a big role in driving commoditization as prohibitive duties were introduced from China on polysilicon imports from the United States in 2013. In the end, legacy contracts were re-negotiated and re-priced to adjust to the new entrants' discounts. Exhibit 27 illustrates the impact on polysilicon pricing, which fell by 89% from peak levels of $475/kg by 2010 as China's cheaper substitute caught on to international markets. Prices have remained stable at around $8/kg since 2013. While this significant price breakthrough benefitted consumers, the commoditization eroded margins for producers. For more on this, please see Appendix II - Learning from the Past.

Exhibit 27: Polysilicon prices went from boom to bust as new entrants resulted in excess supply and the industry was hit by a sharp contraction in credit availability post GFC.



Source: Bloomberg, Morgan Stanley Research

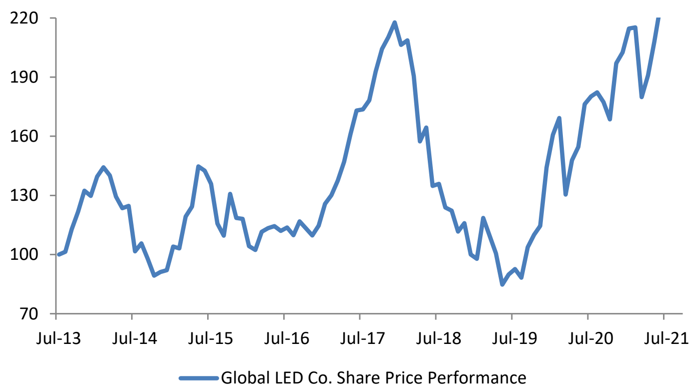
In another part of the tech industry, LED technology brought new competition to the lighting market. The introduction of LED technology to the lighting market led to the emergence of new players, notably Asian companies, to enter what was seen as a high growth and scalable industry. These new entrants first moved to the upstream part of the value chain (highly capex intensive and volume driven – similar to the battery cell or materials) and slowly made their way down the value chain towards the downstream segments (such as packaging for EV today) as the industry matured.

On the one hand, price had to come down to accelerate LED technology penetration... This price decline likely enabled higher levels of penetration simply because there were and still are alternatives to LED lighting which comply with energy efficiency regulations in most cases. As such, and even though the price of lighting equipment was small compared to the total costs of a building, customers have been conscious of maintaining the costs/benefits rather than simply "paying up."

...but the transition to LED slowly eroded one of the historical key drivers of the lighting industry – the replacement market. Because LED was expected to last on average 3-4x longer than existing technology, the more LEDs installed on a global basis translated to a slower lighting replacement cycle. We think this element was largely ignored by the market as the total penetration of LED in the global installed base was small (25% of the lighting market in value was replacement a decade or so ago). The erosion of the replacement cycle partially explains why companies such as Seoul Semiconductor, a market leader in LED bulbs, was already guiding to flat sales in this business as soon as 2019-2020.

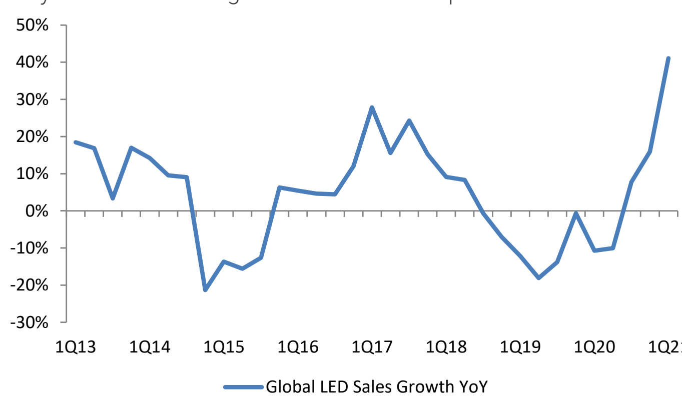
Our point - an unforeseen, 'self cannibalizing' effect? Overall, looking at the share price performance, margins, and growth of the key players since 2017, we sense there has been some disappointment vs initial investor expectations. Also, we note that a significant numbers of large lighting assets have been involved in divestitures (Osram Luminaires, Cree Lighting and General Electric Lighting, Eaton spun off their lighting divisions). However, a fairly consolidated industry and moderating price deflation as well as new TAM from new product adoption (TV, automotive, EUV LED sanitizing) eventually led to a recovery from 2020 onwards. For more on this, please see Appendix II - Learning from the Past .

Exhibit 28: Global LED companies' share price performance were at historical lows in 2019...



Source: Bloomberg, Morgan Stanley Research; Note: share price performance is the average of Sanan, Seoul Semi., and Osram

Exhibit 29: ... as Global LED sales growth moved into negative territory before recovering on new market adoption.



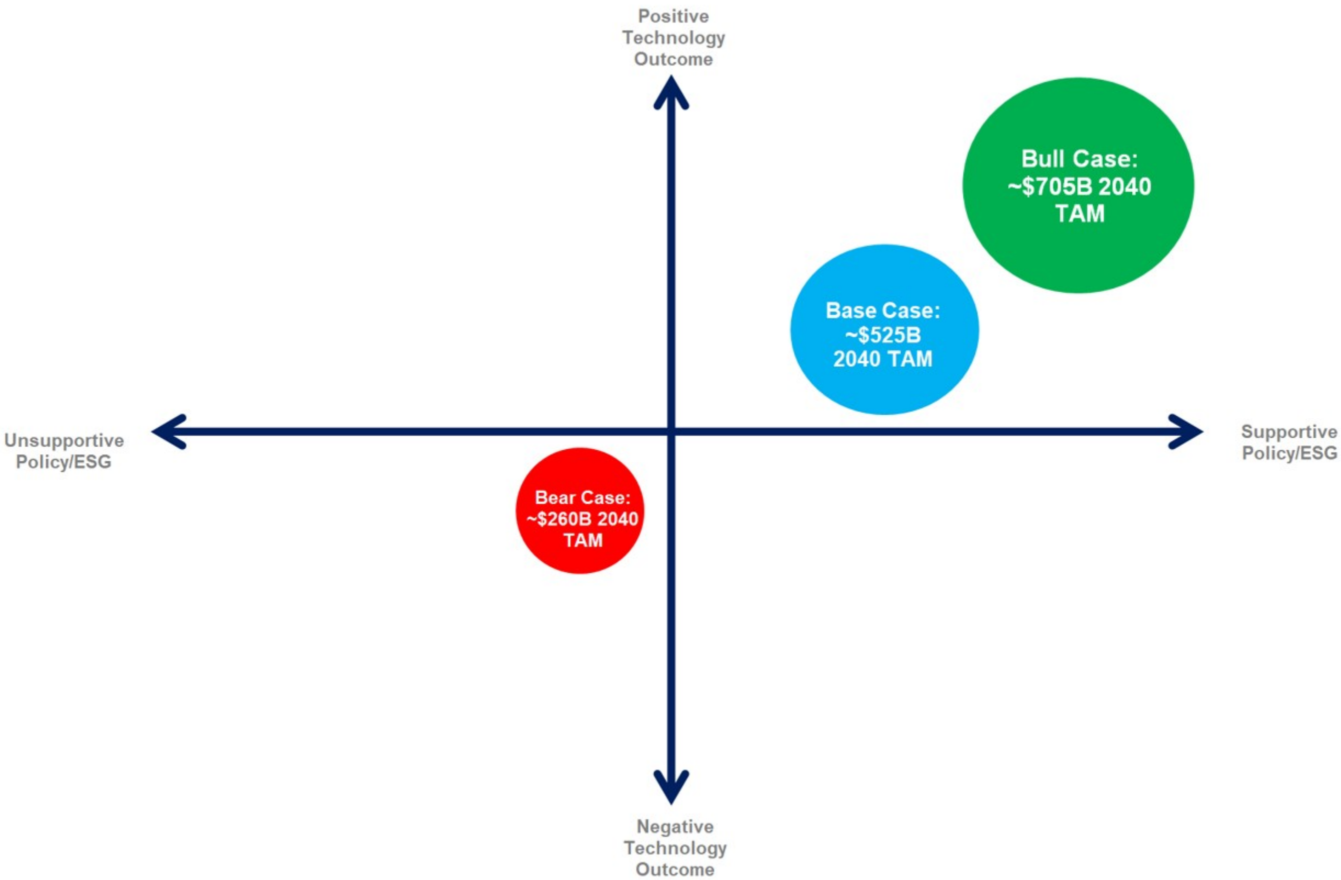
Source: Bloomberg, Morgan Stanley Research; Note: sales growth YoY is the average of Sanan, Seoul Semi, and Osram

Framework & Scenarios

Key Drivers of Future Outcomes...

What will drive the battery market? We condense the drivers of the battery market into two main categories: **1)** technology and **2)** policy/ESG. The relationship between technology and policy/ESG is a complicated one which we explore in our base, bull, and bear scenarios below.

Exhibit 30: Technology and Policy/ESG are likely to drive outcomes in the global battery industry.



Source: Morgan Stanley Research; Note: this orthogonal shows our EV Battery TAM forecasts

Technology. Technology encompasses a variety of drivers including manufacturing scale, cell architecture/chemistry, and commodity pricing. A positive technology outcome implies that the industry has achieved manufacturing scale on high performing prototype(s) at a competitive cost. A negative technology outcome implies that the industry has failed to either produce a high performing prototype, scale it, scale it at a competitive cost, or all of the above.

- **Manufacturing scale:** How well will EV makers be able to scale from building a prototype to manufacturing for mass production? Will the industry reach manufacturing scale that creates economies of scale and reduces cost? Will battery cell suppliers be able to scale according to the capacity guidance some of them have issued?
- **Battery chemistry:** How will battery chemistries, including lithium-ion (LFP, NMC, NCA) and solid state/other technologies, evolve in terms of energy density, cycle life, capacity, and cost? Will the "battery of the future" be able to meet the energy requirements of an increasingly more energy-consuming population to drive human progress? Will these batteries also be considered "safe" enough for mass production and use?

- **Commodity pricing**: How will batteries adjust to the changes in supply, demand, and pricing of its commodity feedstocks? Can capacity meet demand for individual commodities? Will the trends such as the pivot away from certain commodities like cobalt affect the availability of certain types of batteries?

Policy/ESG. Policy encompasses a variety of drivers including government incentives, national security, ESG, and geopolitics. Supportive policy/ESG implies that governments have successfully made decarbonization a priority, providing incentives for batteries and battery infrastructure due to ESG targets and national security concerns. Unsupportive policy/ESG implies that governments provide incentives or funding, if at all, "too little, too late" due to political gridlock or the de-prioritization of decarbonization.

- **Government incentives:** Will governments issue subsidies or other incentives for BEVs that in turn incentivize battery installation as well as create taxes/fines for ICE vehicles? Perhaps as part of an infrastructure package, how highly will governments prioritize building out battery capacity and/or charging infrastructure for BEVs? How will governments ensure that decarbonization remains a focus as political regimes potentially change in the lead up to 2040?
- **National security**: Will governments prioritize batteries as a key energy source that has "utility" like properties? Will governments view batteries as the "new oil" and in turn push battery production to remain onshore and a matter of top national security? Will countries like the US in turn issue incentives to create a domestic, vertically integrated battery industry as a pivot away from the currently Asia-dominated battery industry?
- **Geopolitics**: Will global political regimes enable the mining of critical battery feedstocks such as lithium, cobalt, nickel, and copper? In countries with regime shifts, will the new political leaders adopt anti or pro mining stances, impacting commodity supply and battery capacity for specific chemistries? Will these new political leaders view cross-border trade of their countries' natural resources favorably? Will battery recycling impact the calculus for securing key battery feedstocks?

Introducing the Morgan Stanley Global Battery Model

We present this model as a starting point for understanding the EV battery economy, rather than a definitive forecast. We acknowledge that our inputs may change as batteries scale, and our outputs will change accordingly. Below, we lay out our base, bear, and bull scenarios, key model inputs, and key model outputs.

Please reach out to your Morgan Stanley salesperson if you want us to send you a copy of this proprietary battery model.

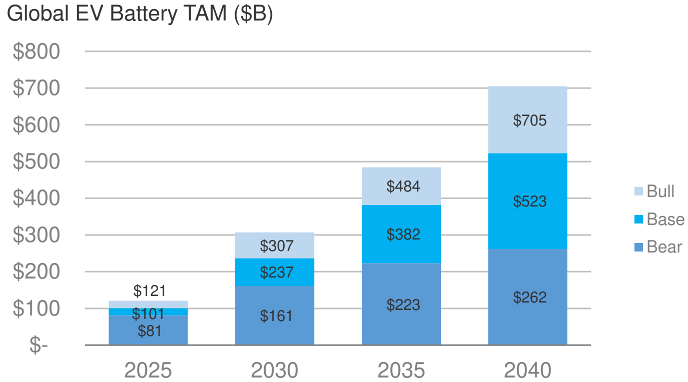
Our model takes a 'bottom-up' approach to the EV battery market:

1. The "bottom" of the battery value chain is electric vehicles. We start by using our global autos & shared mobility team's BEV and PHEV sales penetration forecasts to forecast BEV and PHEV unit sales.
2. From there, we forecast battery installation in GWh by assuming that one BEV or PHEV = one battery installation and making assumptions on battery capacity in kWh across regions.
3. Then, we apply our cathode chemistry mix projections to forecast battery installation demand in kT by chemistry (LFP, NMC, NCA, LMNO/LNO/other).
4. Finally, we use assumptions for lithium, nickel, cobalt, and other commodity % of total cathode mix from our chemicals team to forecast metals demand in kT.

Base, Bear, and Bull Scenarios. Below, we present our base, bear, and bull scenarios for global EV battery TAM and supply & demand. We lay out our EV penetration assumptions, battery installation demand forecasts, and expected TAM out to 2040. We flex the inputs we highlighted above to create bear and bull scenarios.

Exhibit 31: MS Global EV Battery TAM scenarios

Global EV Battery TAM ($B)



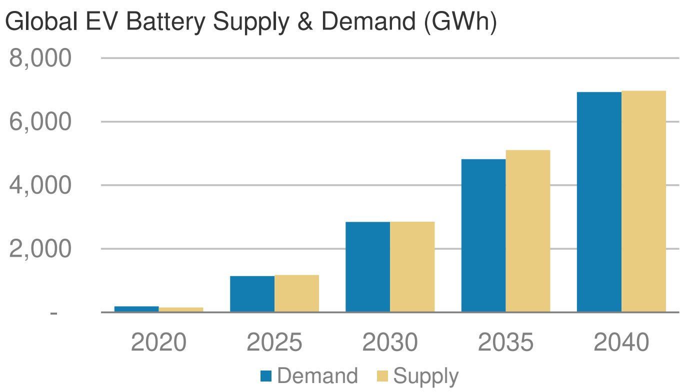
Source: Morgan Stanley Research

Base case. Alongside supportive policy/ESG, our base case assumes that the global battery industry will improve on metrics such as energy density and cycle life, driving the BEV penetration acceleration required to achieve manufacturing scale. We assume that capacity grows from a global average of ~60 kWh to ~75 kWh for

BEVs and remains constant at 15 kWh for PHEVs. We anticipate price declines across chemistries from the 2020 average price of $110/kWh, reaching ~$75/kWh by 2040. Capacity growth and price declines introduce a trade-off: as increases in energy density allow OEMs to pack more cells into a battery to increase range, the cost of the battery increases. Therefore, we model in a slower increase in battery capacity compared to the magnitude of cost reduction. We expect global capacity growth to keep up with global demand as US and EU OEMs grow alongside their Asian peers.

- 2025 TAM: ~$100bn driven by 26% BEV + PHEV sales penetration & 1.1 TWh battery installation demand
- 2030 TAM: ~$235bn driven by 50% BEV+PHEV sales penetration & 2.8 TWh battery installation demand
- 2035 TAM: ~$380bn driven by 71% BEV + PHEV sales penetration & 4.8 TWh battery installation demand
- 2040 TAM: ~$525bn driven by 87% BEV+PHEV sales penetration & 7 TWh battery installation demand

Exhibit 32: Base Case Supply & Demand

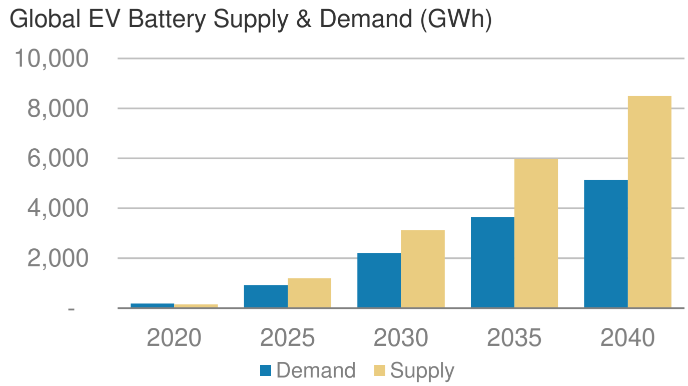


Source: Morgan Stanley Research

Bear case. In a combination of unsupportive policy/ESG and a negative technology outcome, the battery industry struggles to produce a competitive battery that penetrates the market. EV penetration ramps slower than expectations while low-cost supply from Tesla and other battery makers results in an excess supply of batteries selling at or below cost. Battery price drops dramatically, reaching ~$50/kWh by 2040. We note that our bear case favors downstream players such as OEMs over upstream players like mining companies, as they are able to benefit from lower battery costs. We assume that global battery capacity grows at a slower pace than that of our base case, reaching ~70 kWh by 2040. We expect capacity growth to exceed demand, creating an unfavorable supply/demand dynamic for battery manufacturers.

- 2025 TAM: ~$80bn driven by 23% BEV + PHEV sales penetration & 920 GWh battery installation demand
- 2030 TAM: ~$160bn driven by 42% BEV+PHEV sales penetration & 2.2 TWh battery installation demand
- 2035 TAM: ~$225bn driven by 57% BEV + PHEV sales penetration & 3.6 TWh battery installation demand
- 2040 TAM: ~$260bn driven by 70% BEV+PHEV sales penetration & 5.1 TWh battery installation demand

Exhibit 33: Bear Case Supply & Demand

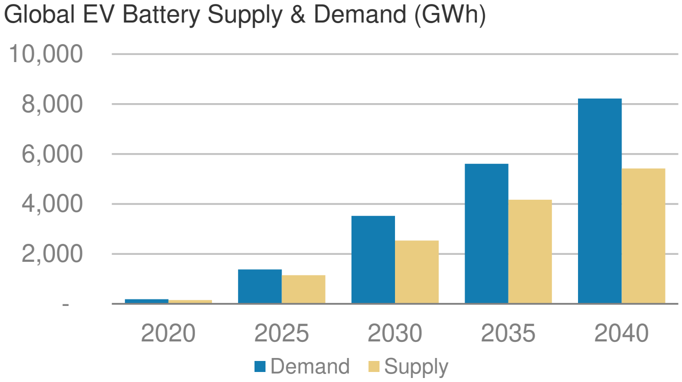


Source: Morgan Stanley Research

Bull case. Supportive regulation and/or positive technology outcomes coincide, bringing high performing batteries to the market at scale on a faster timeline than our base case and at a competitive cost for manufacturers. The battery industry evolves into highly developed supply chains across geographies and a balance of raw material supply/demand, keeping battery prices from falling past $85/kWh. We note that our bull case benefits upstream players like mining companies over downstream players like OEMs as they are able to capture the higher raw material prices. We assume that BEV capacity grows at a faster pace that our base case, reaching 80 kWh by 2040. We also assume that battery prices remain sticky due to the higher cost associated with accelerated technological upgrades, resulting in ~$85/kWh by 2040. We expect growth in capacity, but lagging the accelerated demand growth.

- 2025 TAM: ~$120bn driven by 30% BEV + PHEV sales penetration & 1.4 TWh battery installation demand
- 2030 TAM: ~$305bn driven by 59% BEV+PHEV sales penetration & 3.5 TWh battery installation demand
- 2035 TAM: ~$485bn driven by 78% BEV + PHEV sales penetration & 5.6 TWh battery installation demand
- 2040 TAM: ~$705bn driven by 96% BEV+PHEV sales penetration & 8.2 TWh battery installation demand

Exhibit 34: Bull Case Supply & Demand



Source: Morgan Stanley Research

Summarizing our base, bear, and bull assumptions. Across our scenarios, we flex BEV sales penetration %, BEV capacity, battery price, and global supply. We also include our expectations for key battery characteristics such as energy density (wh/kg) and efficiency (mi/kWh).

Exhibit 35: Base, bull, and bear case assumptions

	Base	Bull	Bear
BEV+PHEV Sales Penetration			
2025	26%	30%	23%
2030	50%	59%	42%
2035	71%	78%	57%
2040	87%	96%	70%
BEV Capacity (kWh)			
2025	65	66	64
2030	68	71	66
2035	71	75	67
2040	74	80	69
Battery Price ($/kWh)			
2025	$ 88	$ 88	$ 88
2030	$ 83	$ 87	$ 73
2035	$ 79	$ 86	$ 61
2040	$ 75	$ 86	$ 51
Global Supply (GWh)			
2025	1,176	1,150	1,196
2030	2,849	2,530	3,119
2035	5,104	4,166	5,974
2040	6,974	5,419	8,495
Battery Characteristics			
Energy Density (Wh/kg)	300-500	700-1000	200-300
Efficiency (mi/kWh)	5-6	6-7	4-5

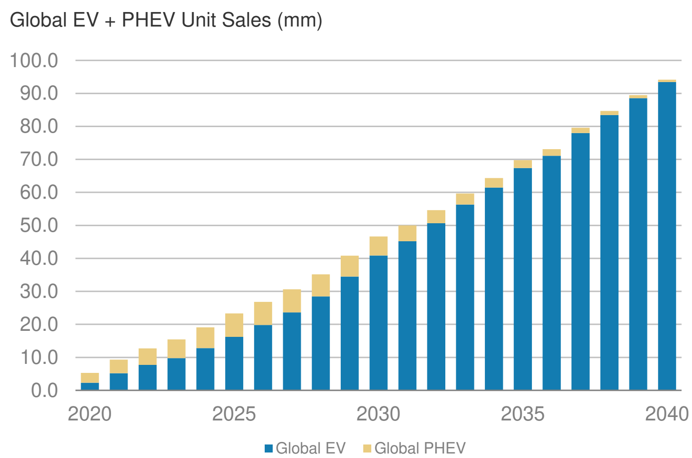
Source: Morgan Stanley Research; Note: battery characteristics are MS estimates for illustrative purposes

Model Inputs & Outputs

Key inputs

1. BEV and PHEV unit sales. We start with our global autos team's BEV penetration forecasts as well as PHEV forecasts. We use these assumptions for unit sales globally as well as regionally.

Exhibit 36: We expect global BEV+PHEV unit sales growth to accelerate most rapidly from 50% in 2030 to 87% in 2040.



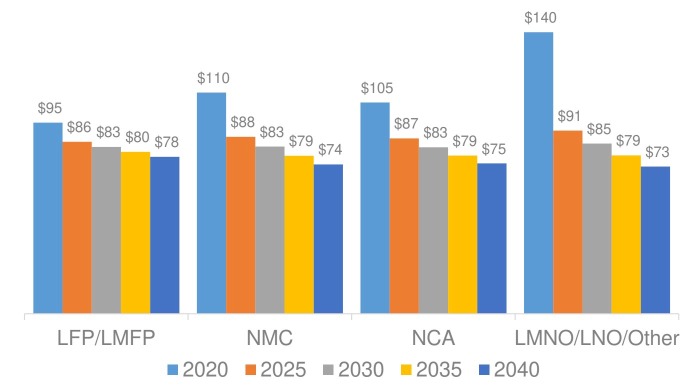
Source: Morgan Stanley Research

2. Capacity (kWh). We assume that global battery capacity grows from ~60 kWh in 2020 to ~75 kWh in 2040 for BEVs and stays constant at 15 kWh for PHEVs.

3. Battery pricing ($/kWh). We assume that battery pricing starts in 2020 at $110/kWh as a blended average across cathode chemistries (LFP $95/kWh, NMC $110/kWh, NCA $105/kWh, LMNO/LNO/Other $140/kWh). By 2025, we assume that battery pricing falls to ~$88/kWh, bringing batteries in parity with ICE. After 2025 we assume that battery pricing declines but at a faster rate for NMC and LMNO/LNO/Other compared to LFP and NCA due to technology upgrades and different starting price points. This results in a chemistry weighted average battery price of ~$75/kWh by 2040.

Exhibit 37: While battery prices currently vary across chemistry (for example, LFP at ~15% discount to NMC)...

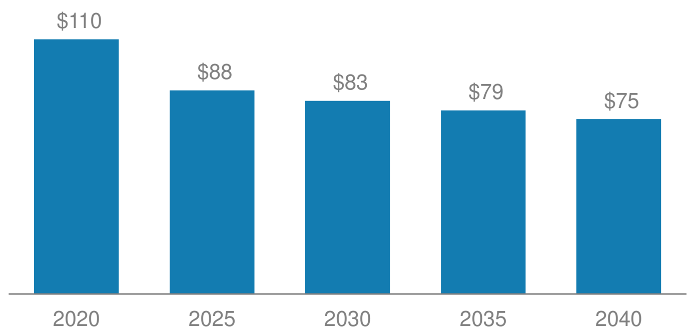
Battery Pricing ($/kWh)



Source: Morgan Stanley Research

Exhibit 38: ... we expect that the chemistry weighted average battery price will drop to $75/kWh by 2040.

Weighted Average Battery Price ($/kWh)

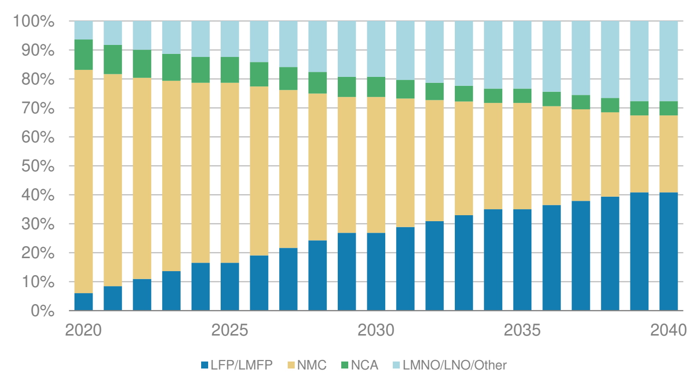


Source: Morgan Stanley Research

4. Cathode chemistry mix. We assume a cathode chemistry mix of 7% LFP, 77% NMC, 11% NCA, and 5% LMNO/LNO/Other in 2020 based off EV-volumes.com actuals. While NMC is currently the incumbent, we expect that it will cede market share to other low-cobalt chemistries like LFP or LMNO/LNO/other. We include solid state technologies in the 'other' category given the uncertain line of sight to commercialization and scaling. By 2040, we expect 40% LFP/LMFP (next generation of LFP which is lithium manganese iron phosphate), 27% NMC, 5% NCA, and 29% LMNO/LNO/other. For LMFP, adding manganese is expected to increase energy density by ~15-20% as LFP is viewed as having limited upside in energy density due to molecular structure constraints.

Exhibit 39: While NMC is currently the incumbent, we expect that it will cede market share to other low-cobalt, high-nickel and alternative chemistries like LFP or LMNO/LNO/other...

Cathode Chemistry Mix



Source: Morgan Stanley Research

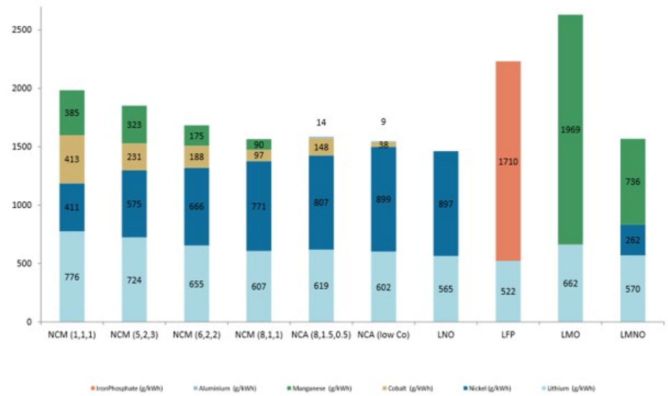
5. Commodity breakdown. We estimate a constant commodity breakdown per chemistry. For example, for LFP, we assume that using a cathode weight of 2.232 kg/kWh, the breakdown is 23% lithium and 77% iron phosphate. For NMC, we assume that the only mix used are NMC 622 and NMC 811 (50/50 from 2020 to 2025 and then 100% NMC 811 from 2025 onwards).

Exhibit 40: Approximate commercial energy density and material requirements for current ternary materials...

	NCM (1,1,1)	NCM (5,2,3)	NCM (6,2,2)	NCM (8,1,1)	NCA (8,1.5,0.5)	NCA (low Co)	LNO	LFP	LMO	LMNO
	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	$LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$	$LiNi_{0.6}Co_{0.2}Mn_{0.2}O_2$	$LiNi_{0.8}Co_{0.1}Mn_{0.1}O_2$	$LiNi_{0.82}Co_{0.15}Al_{0.03}O_2$	$LiNi_{0.94}Co_{0.04}Al_{0.02}O_2$	$LiNiO_2$	LiFePO4	LiMn2O4	LiMn1.5Ni0.5O4
Commercialspecific capacity (mAh/g)	140	150	165	180	175	190	190	140	100	130
Average voltage (V)	3.6	3.6	3.6	3.6	3.6	3.4	3.6	3.2	3.8	4.7
Energy Density cathode material (Wh/kg)	504	540	594	639	630	646	684	448	380	611
Cathode weight (Kg/kWh)	1.98	1.85	1.68	1.56	1.59	1.55	1.46	2.23	2.63	1.64
Nickel (g/kWh)	411	575	666	771	807	899	897			262
Cobalt (g/kWh)	413	231	188	97	148	38				
Manganese (g/kWh)	385	323	175	90					1969	736
Aluminium (g/kWh)					14	9				
IronPhosphate (g/kWh)								1710		
Lithium (g/kWh)	776	724	655	607	619	602	565	522	662	570
Total cathode weight (g/kWh)	**1984**	**1852**	**1684**	**1565**	**1587**	**1548**	**1462**	**2232**	**2632**	**1568**

Source: Morgan Stanley Research estimates

Exhibit 41: ... and the respective metal intensity of the cathode.



Source: Morgan Stanley Research estimates

6. Capacity growth. We assume that capacity will grow globally, but unevenly across regions. Starting in 2025, we assume 5 year capacity growth rates of 20% in China and Korea, 5% in Japan, ~30% in the US, and 40% in Europe. Every five years thereafter, we discount the growth rate by 50-75% to model in slowing capacity growth after an initial ramp up.

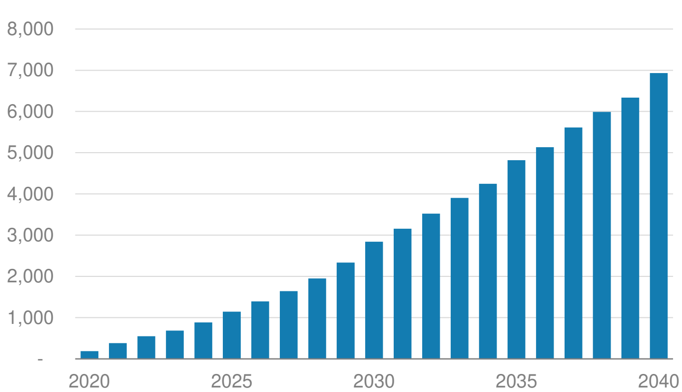
7. Utilization. In translating battery capacity to battery supply, we assume a 75% utilization rate from 2030 onwards due to the existence of 1) low-end and outdated capacity that cannot be sold, and 2) capacity that is built specifically for OEMs that cannot be sold.

Key outputs

1. Battery installation demand. We expect battery demand to increase from ~185 GWh in 2020 to ~7 TWh in 2040. Battery installation demand is calculated as BEV unit sales * BEV capacity + PHEV unit sales * PHEV capacity.

Exhibit 42: We estimate that battery installation demand will increase to ~7 TWh by 2040.

Global EV Battery Installation (GWh)

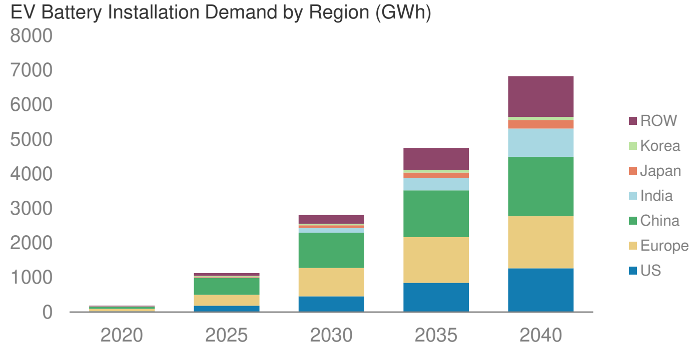


Source: Morgan Stanley Research

We also expect that the EV battery market will become more regionally diverse. Our regional estimates build on our global EV sales penetration model's regional breakdown by layering on capacity and pricing assumptions. In 2020, global battery supply was dominated by China and Korea, which collectively represented ~85% of global capacity, while global demand was dominated by China and Europe. By 2040, we estimate that global EV battery TAM will be more balanced, with China (25%) and Europe (22%) still a substantial part of the mix but also making room for the US (19%) as well as up and coming battery installation markets like India (12%).

Exhibit 43: While EV battery installation demand grows across regions...

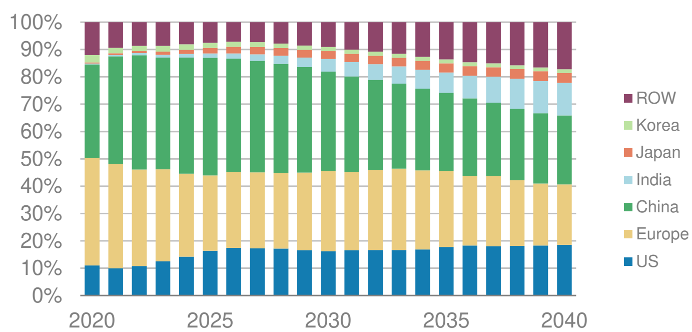
EV Battery Installation Demand by Region (GWh)



Source: Morgan Stanley Research

Exhibit 44: ... we expect EV battery TAM to become more regionally diverse.

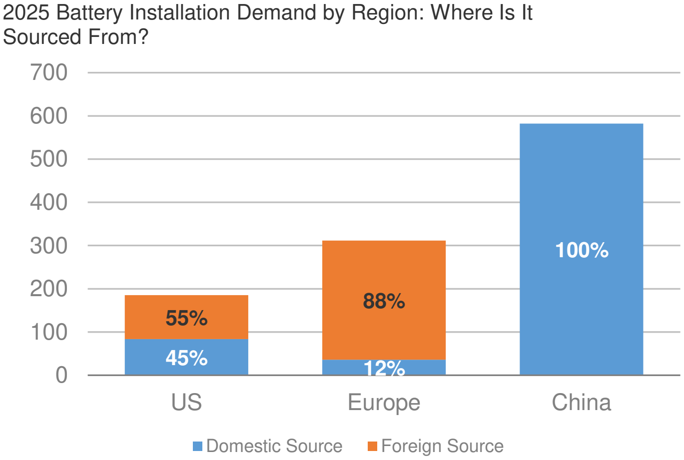
EV Battery TAM by Region (%)



Source: Morgan Stanley Research

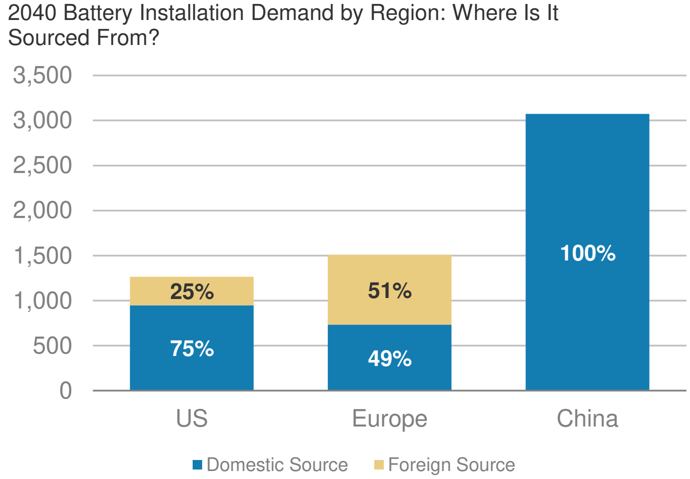
Furthermore, we reflect the "balkanization" of the battery industry by showing the relative domestic vs. foreign sourcing of batteries by region. As previously discussed, we expect that global governments will view batteries as a national security priority as well as an ESG one, and effectively treat the sector like a "utility." This means that as the battery industry matures, regions will start to prioritize the domestic sourcing of battery installation over outsourcing it to other countries. While China is the world's top manufacturer and exporter of battery cells today, we expect that rather than reinforce global battery supply chains, countries will move to "balkanize" the industry by onshoring production.

Exhibit 45: While we expect that in 2025, both the US and EU will source the majority of their battery demand from foreign sources...



Source: Morgan Stanley Research

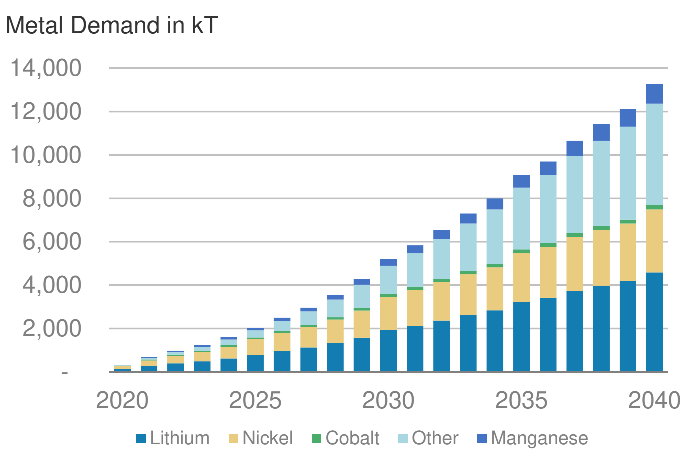
Exhibit 46: ... by 2040 we expect that both regions will push to source more battery supply domestically, reflecting the 'balkanization' of the industry.



Source: Morgan Stanley Research

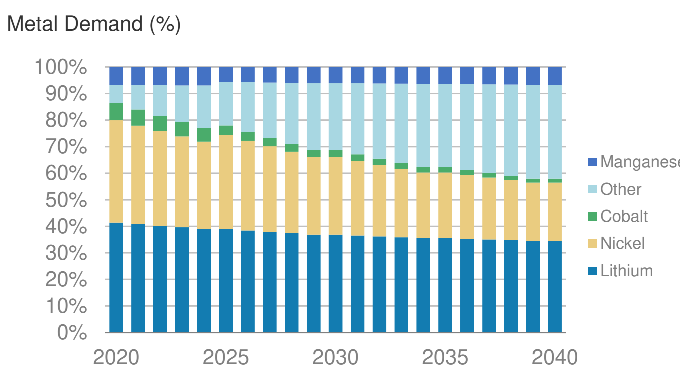
2. Commodity demand. Using the above cathode mix assumptions from our chemicals team, we project metals demand for key feedstocks including lithium, nickel, cobalt, and others. We expect metal demand in kT to increase from ~330 kT in 2020 to ~13,300 kT in 2040. For lithium, we include both lithium from the cathode and lithium from the electrolyte. Overall, while metal demand increases alongside more cathode/battery/BEV demand, we expect to see a lower percentage of cobalt in the chemistry mix as the percentage of manganese increases. We expect lithium demand in percentage terms to remain steady.

Exhibit 47: We expect to see greater demand for key cathode feedstocks such as lithium, nickel, and cobalt...



Source: Morgan Stanley Research: Note: other refers to aluminium and iron phosphate

Exhibit 48: ... we expect to see a declining percentage of cobalt in the mix.



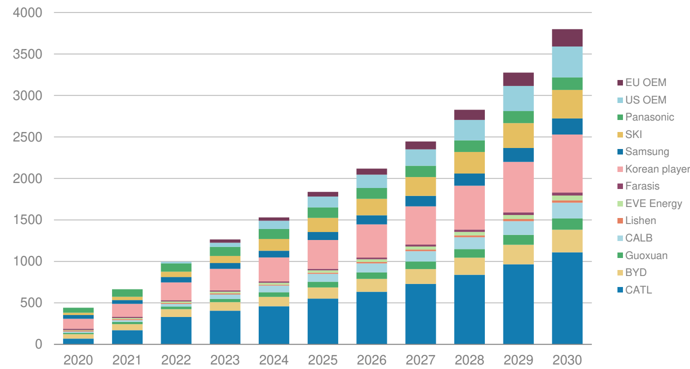
Source: Morgan Stanley Research: Note: other refers to aluminium and iron phosphate

3. Battery capacity/supply: We expect that global battery capacity will grow from ~440 GWh in 2020 to ~9.3 TWh in 2040 while battery supply grows from ~150 GWh in 2020 to ~3 TWh in 2030 and ~7 TWh in 2040. We expect that the capacity increases will follow demand growth.

- **In China**, the main battery suppliers are CATL and BYD along with additional players including Guoxuan, CALB, Lishen, EVE Energy, and Farasis. Besides Farasis, all of these Chinese battery suppliers produce both LFP and NMC cathode chemistries and are expected to have ~1.8 TWh of capacity by 2030. We assume a LFP/NMC split of 50/50.
- **In Korea**, the main battery suppliers are a Korean player, Samsung, and SK Innovation. All 3 of these Korean battery suppliers produce NMC and are expected to have ~1.2 TWh of capacity by 2030.
- **In Japan**, the main battery supplier is Panasonic, which mainly produces NCA and is expected to have ~150 GWh of capacity by 2030.
- **In the US**, we model in growing capacity for US OEMs including Tesla which is expected to produce a 4680, LMNO battery. By 2030, we project ~375 GWh of total US capacity, a significant discount to Tesla's guidance of 3 TWh capacity by 2030.
- **In Europe**, we model in growing capacity for European OEMs including Volkswagen. By 2030, we project ~210 GWh of total European capacity.

Exhibit 49: We expect battery capacity to grow, driven by capacity increases from incumbent battery cell makers in Asia and additional capacity coming online from US and European OEMs.

Global EV Battery Capacity (GWh)



Source: Morgan Stanley Research

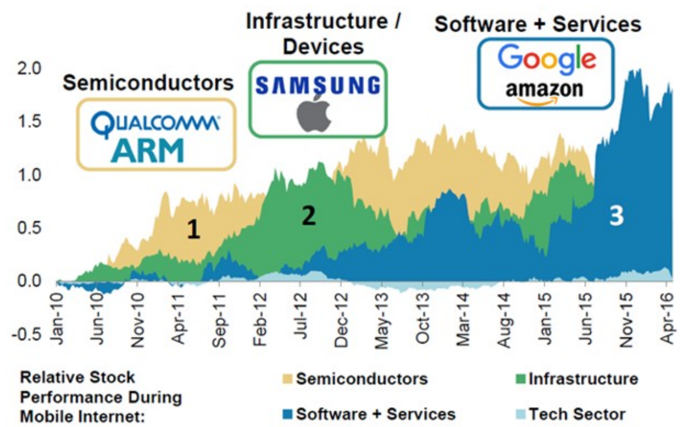
Building the Morgan Stanley Battery Portfolio

Batteries lie at the intersection of multiple highly topical sectors. In collaboration with our global research team, we identified 71 names associated with each part of the battery value chain, starting with the mining of raw materials and ending with recycling. Due to the vertical integration trend among some OEMs and battery cell makers, we note that several battery portfolio names have expanded their business models to include more than one value chain category.

We draw upon our experience investing in emerging/new industries in technology. In terms of stocks, there is a very clear road map on how you make money in these new adoption cycles. Money is typically made first early in a cycle with enablers of the technology – in the Mobile era, think of Qualcomm and ARM enabling cellular connectivity and mobile apps during the Mobile Internet cycle. Then, value creation shifts to the infrastructure/device makers with higher penetration – Samsung and Apple are two leading examples in the Mobile era. Finally, a lot of money is made toward the end of the cycle. Value creation will shift to software and services companies that are able to capitalize on the growing base of EVs. This late stage is exemplified by the FAANG (Facebook, Amazon, Apple, Netflix, Google) trade in the Mobile internet era monetizing that base of ~4 billion internet users. If we fast forward and look at how the 'Ion Era' could play out...

- **Money is first in the enabler**. Companies such as CATL, SK Innovation, and Samsung SDI are the enablers of the batteries that move EVs while analog semiconductor companies such as Wolfspeed (previously Cree), Rohm, and Sensata can be seen as an important enablers of the global green economy. We are already a couple of years into these cycles given very robust performance in these stocks but there is probably more leg on the battery trade.
- **Then, money is made in infrastructure and hardware.** This started in the last few quarters with the EV OEMs (Tesla, VW, and GM). Furthermore, it plays into companies providing charging infrastructure or high tech battery recycling.
- **And lastly, money is made in software and services.** We think companies who lead the pack in embedding technology and launching new services will be the beneficiaries. This include providers that have the best offering on collecting data through sensors, the ability to gain new insights, and the ability to network in more places in the world and offer those services. Similar to FAANG, we may start to see increasingly technologically advanced OEM offerings (autonomy). But that is more long-term and we would not expect to see that break-out for another year or two.

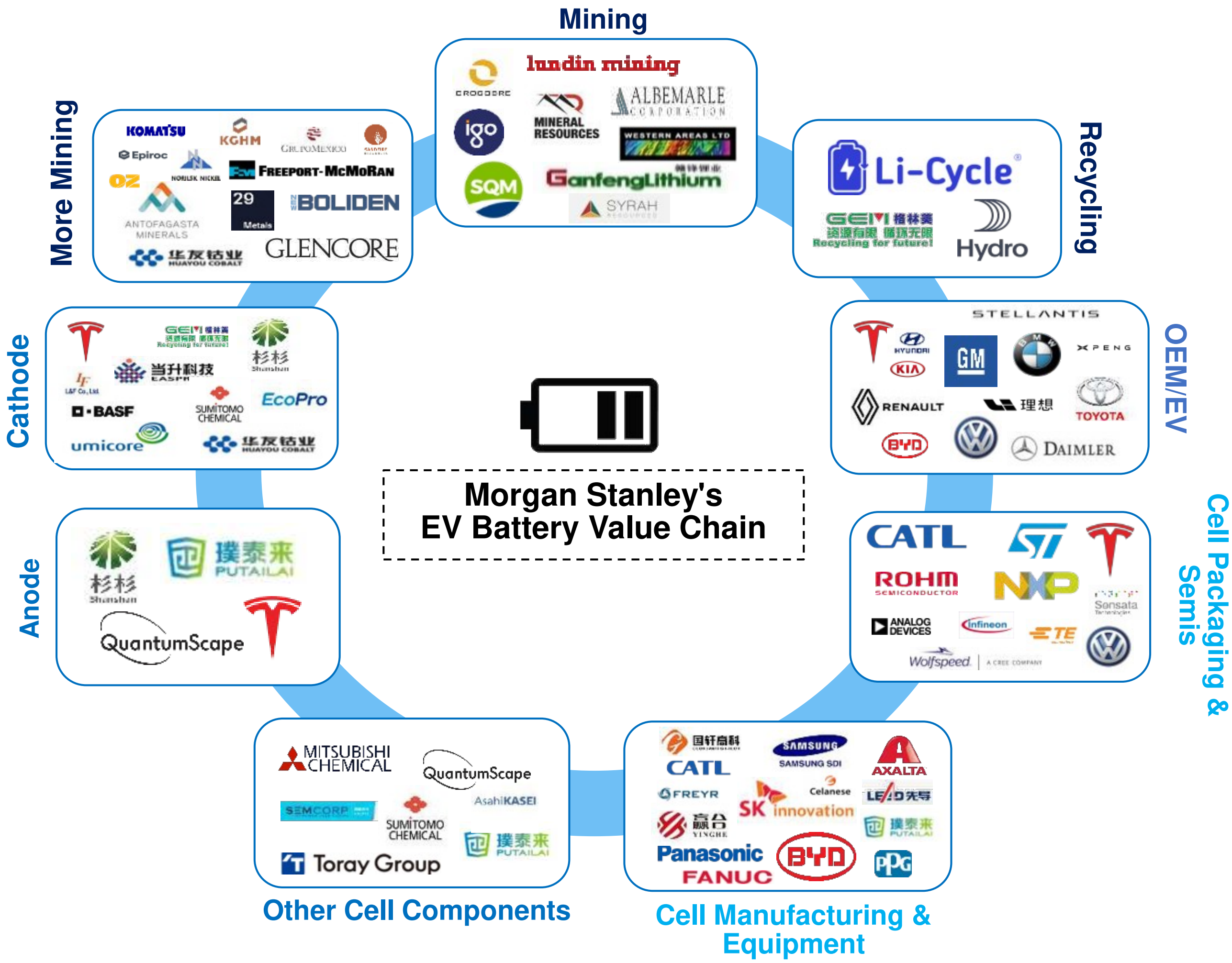
Exhibit 50: We compare the battery industry to tech innovation cycles in which (1) the enabler performs first (battery), followed by (2) the infrastructure/hardware, and then (3) services at the end. This normally takes place over a decade in tech.



Source: Eikon, Morgan Stanley Research

We present our 71 battery portfolio names below by value chain. The five main categories of the battery value chain are mining, components, cell, OEM/EV, and recycling. Within the mining category, we filter names by commodities they are exposed to such as lithium, nickel, cobalt, and copper as well as mining equipment names. Within the components category, we filter names by cathode, anode, electrolyte, and separator. Within the cell component, we filter names by manufacturing, packaging, semiconductors, and equipment.

Exhibit 51: Morgan Stanley's Battery Portfolio



Source: Morgan Stanley Research

We estimate the addressable market for each part of the EV battery value chain. We estimate that the total battery cost is comprised of ~60% materials, ~35% manufacturing, and ~5% labor. Within the materials category, we assume that the cost is ~25% cathode, ~10% anode, ~15% electrolyte and separator, and ~10% other (although this will depend on chemistry). Within manufacturing, we estimate that the cost is ~15% cell manufacturing, ~15% cell packaging, and ~5% cell manufacturing equipment. Finally, we assume that the battery is approximately ⅓ the cost of the EV, implying an OEM/EV TAM of ~$1.6 trillion by 2040. We note that the mining and recycling costs are embedded within the materials cost.

Exhibit 52:. We break down our 2040 EV battery TAM base case of $525B by parts of the EV battery value chain.

Value Chain	Category	% Battery Cost	Implied 2040 TAM ($B)	Unit Cost
Materials*	Cathode	25%	$131	$1,406
	Anode	10%	$53	$563
	Electrolyte/Separator	15%	$79	$844
	Other	10%	$53	$563
Manufacturing	Manufacturing	15%	$79	$844
	Packaging	15%	$79	$844
	Equipment	5%	$26	$281
Labor		5%	$26	$281
Battery		**100%**	**$525**	**$5,625**

**We note that the mining and recycling costs are embedded within the materials costs*

Source: Morgan Stanley Research

Mining

Mining Subsector Takeaways

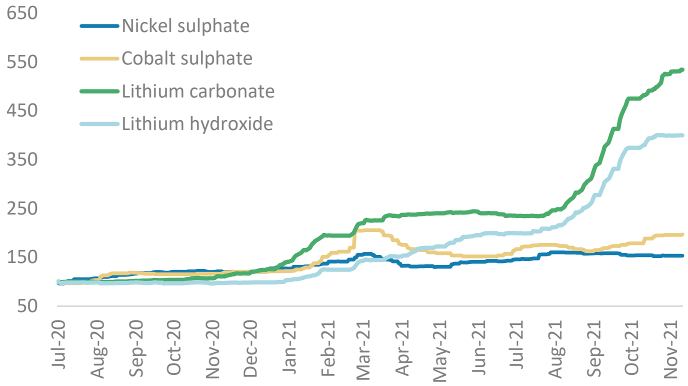
- **Role: Mining of raw materials is the first step in the battery value chain. Battery cells require commodities, including but not limited to lithium, nickel, and cobalt for the cathode as well as copper and aluminum for electrode current collectors.**
- **TAM: The subsector's implied 2040 TAM is embedded within the materials TAM of ~$315bn.**
- **Stocks: For lithium exposure, we highlight Mineral Resources, SQM, Ganfeng Lithium, Orocobre, and Albemarle. For lithium and nickel exposure, we highlight IGO. For copper exposure, we highlight 29Metals, Sandfire Resources, OZ Minerals, Grupo Mexico, Freeport McMoRan, KGHM, and Antofagasta. For copper and nickel exposure, we highlight Glencore, Norilsk Nickel, Boliden, and Lundin Mining. For nickel exposure, we highlight Western Areas. For cobalt exposure, we highlight Huayou Cobalt. For graphite exposure, we highlight Syrah Resources. For mining equipment exposure, we highlight Epiroc and Komatsu.**
- **Supply & Demand: Our team expects the medium term lithium market to be well supplied, nickel to remains tight, cobalt demand to wane due to ESG concerns, and copper demand to grow due to multiple uses in both battery materials and EV charging infrastructure.**

The battery value chain begins with the mining of raw materials for the battery cell, including lithium, nickel, cobalt, and copper. These materials are key feedstocks into lithium-ion batteries with chemistries such as LFP, NMC, and NCA as well as solid state chemistries. In the cathode space, these feedstocks have impacted chemistry preferences. For more, please see *Another EV Jolt.*

- Our team expects **cobalt** demand growth to slow from the EV sector, hitting a peak in 2028, due to ESG concerns around "artisanal mining" and child labor violations in the DRC and the relatively expensive cost (cobalt is ~3x more expensive than nickel and lithium).
- Our team also expects that **copper** will see continued demand growth due to accelerating EV penetration and associated charging infrastructure.
- Our team expects **lithium** to remain well supplied due to new capacity in 2022 and beyond.
- Our team expects **nickel** demand will grow although technology challenges may limit supply growth.

Year-to-date, commodity prices have increased substantially, highlighting the importance of understanding underlying commodity supply and demand for battery investors. Key considerations driving commodity markets (which impact the battery cathode market) include mining approval processes and regulations, geopolitical risk, and the regional imbalance of resource availability (introducing transport/shipping considerations between regions to globally balance) as well as the dynamic nature of battery chemistry mix and technology. On the surface, we expect no lithium bottleneck as EV penetration is met by expanding mine supply, scarcity in copper (due to copper projects that have yet to be developed), a tight nickel market, and a phase out of demand for cobalt as battery chemistry trends tilt away from the commodity (see *Another EV Jolt* and *EV Demand Boost* for more).

Exhibit 53: Battery commodity price indices (Jul-20 = 100)



Source: Morgan Stanley Research, Argus, Bloomberg (Note: Lithium prices are China spot basis)

Lithium Stocks. Lithium is a commodity that is currently used across battery chemistries. We highlight five pure play names (SQM, Ganfeng Lithium, Mineral Resources, Orocobre, and Albemarle) as well as a lithium/nickel play, IGO. As we wrote in *EV Demand Boost*, **SQM** (covered by Javier Martinez de Olcoz Cerdan and Roberto Browne) is a resource rich, low cost, and low capex operator that produces lithium carbonate from lithium brine extracted from the Salar de Atacama with mine contracts that expire in 2030, exposing it to the political situation in Chile. **Albemarle** (covered by Vincent Andrews) is a low-cost, high-quality producer that has production in the Salar de Atacama and Clayton Valley near Silver Peak, Nevada, USA. **Ganfeng Lithium** (covered by Rachel Zhang) is another exposed name, with mines in Australia, Argentina, Mexico, and China, that our team recommends for lithium exposure (see *Opportunity in Divergence* for more). **Orocobre** (covered by Rahul Anand) is a lithium exposed name (100% of revenues) with mining operations and projects across Argentina, Western Australia, and Canada that also has JVs across the value chain with Panasonic and Toyota. **Mineral Resources** (covered by Rahul Anand) also has lithium-exposed revenue (~9% in FY22 with ~54% of our base case valuation from lithium assets). For lithium and nickel exposure, **IGO**'s (covered by Rahul Anand) revenue is exposed to both commodities (~40% lithium in FY22 and ~46% nickel in FY22).

Lithium expected to remain well supplied. Accelerating EV penetration should most directly boost lithium demand. Lithium is not only a key feedstock for lithium-ion cathodes, but may also become a feedstock for solid state batteries should they adopt lithium metal anodes. Furthermore, if lithium-ion cathode chemistries tilt away from nickel and cobalt based mixes towards LFP, which has a higher lithium mix, lithium may become relatively more in demand. In terms of supply, lithium is a quite common mineral and the market is likely to remain balanced going forward due to new expected supply from China and Chile despite near term mine closures due to COVID-19. Currently, while Argentina and Chile are the two main markets for brine (lithium salts are extracted from brine deposits), China is working on building a market as well as Chile is expected to double production. These countries are the top global sources of brine due to their salt flats. In particular, Latin America's "Lithium Triangle" describes the Andean southwest corner of South America, including Argentina, Bolivia, and Chile, that is believed to hold ~60% of the world's lithium (see *here* for more). Another key supplier of lithium is Australia, which was the world's largest supplier of lithium in 2020. Large lithium miners in Australia mine lithium from hard-rock spodumene in Western Australia.

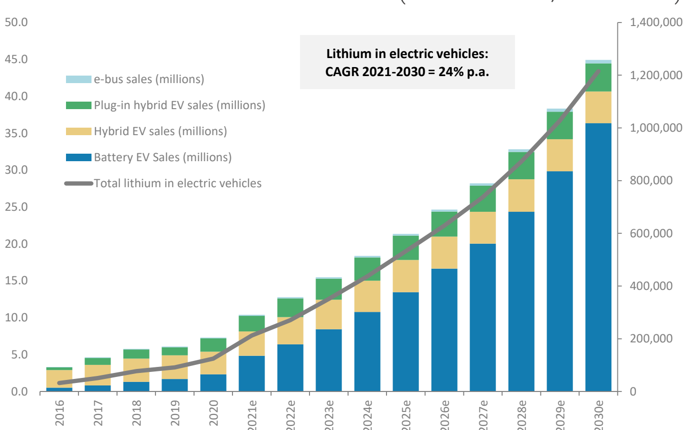
But politics matter both in the short and long term. The Morgan Stanley global lithium team argues that political changes in Chile and Argentina may reshape global lithium supply and the cost curve. The heterodox political environment in the "Lithium Triangle" is bringing back to the table discussions of higher royalties/taxes, and even the nationalization of assets. This is shifting investments to Australia and China (even by SQM) and will likely delay the turning point for prices this cycle (now expected in 2H22), change the shape of the cost curve, and increase long-term prices. Shorter term, we expect the market to remain tight in the next 12 months, but supply is already responding to higher prices, driving a surplus already in 2022 (73kt). This should drive prices lower, probably in the second half of 2022.

And politics is driving our view on lithium equities. The new policies under discussion in Chile will likely affect the profitability and investment plans of local operators, becoming an important factor that will define our order of preference of stocks. In general, what is negative for local LatAm producers and supply should be bullish for lithium prices and Chinese companies, driving our Underweight view on both players exposed to Chile (SQM and ALB) while we think that operations in Asia, Australia and other regions will be favored (Overweight Ganfeng). For more details, please see *Global Lithium: How LatAm Politics May Reshape the Lithium Landscape (22 Jul 2021)*. You can follow our research on lithium here: *Global Lithium Collection*.

Exhibit 54: The top lithium deposits globally are found in the "Lithium Triangle" including Chile and Argentina, China, and Australia.

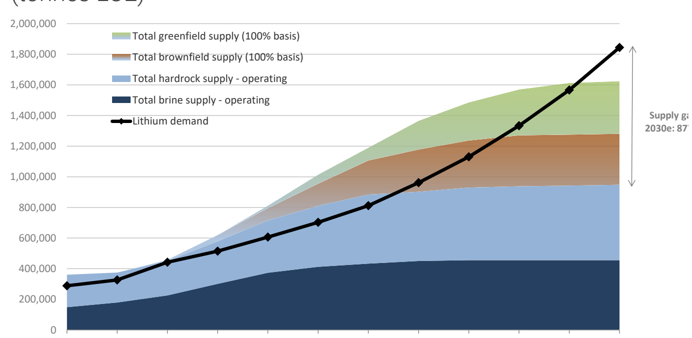
Source: Reuters

Exhibit 55: Lithium in electric vehicles (million vehicle, tonnes LCE)



Source: Morgan Stanley Research estimates; Note: as of September 2021

Exhibit 56: Lithium supply gap and potential project development (tonnes LCE)



Source: Morgan Stanley Research estimates; Note: as of September 2021

Exhibit 57: Lithium supply/demand model

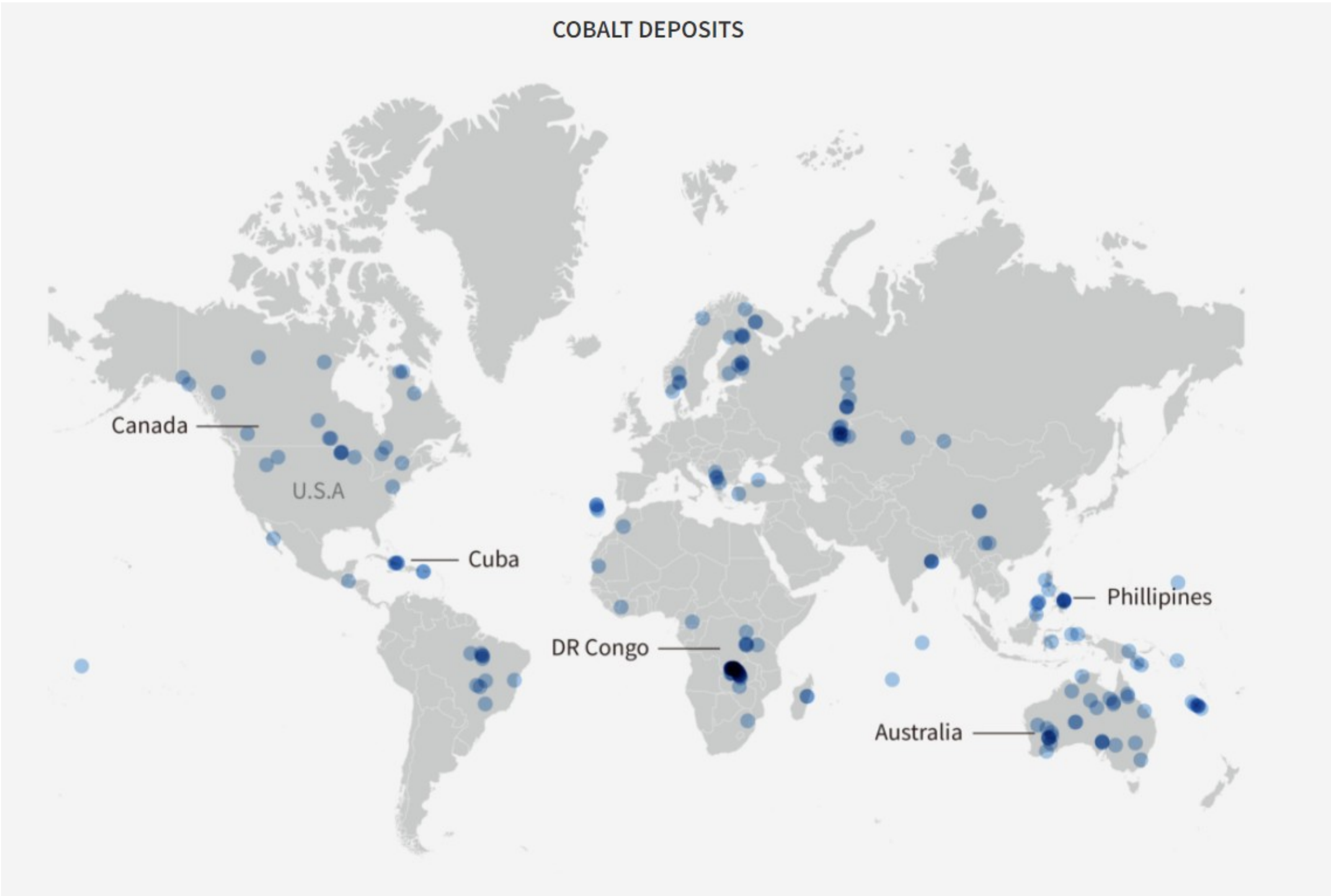
	unit	2020	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
Supply												
Brine/Clay operations	kt	179	226	301	373	412	433	450	455	455	455	455
Brine/Clay expansions/projects (uncommitted)	kt		3	12	25	48	76	102	109	115	121	123
Growth in brine supply	%	*21%*	*27%*	*37%*	*27%*	*16%*	*11%*	*8%*	*2%*	*1%*	*1%*	*0%*
Hardrock operations	kt	196	226	278	341	398	451	452	474	482	487	492
Hardrock expansion/projects (uncommitted)	kt	0	0	4	12	28	47	80	103	122	128	128
Total converted hardrock supply (LCE)	kt	**234**	**219**	**268**	**335**	**404**	**473**	**505**	**523**	**523**	**523**	**523**
Growth in mineral supply	%	*-8%*	*15%*	*25%*	*25%*	*21%*	*17%*	*7%*	*9%*	*5%*	*2%*	*1%*
Total World Supply	**kt**	**414**	**441**	**565**	**713**	**841**	**956**	**1029**	**1059**	**1065**	**1071**	**1073**
Growth in lithium supply	%	*31%*	*6%*	*28%*	*26%*	*18%*	*14%*	*8%*	*3%*	*1%*	*1%*	*0%*
Consumption by end-use												
Rechargeable Battery	kt	201	308	379	469	564	671	820	987	1188	1420	1696
of which Electric Vehicle demand	kt	125	212	270	351	437	532	629	737	872	1027	1215
Growth in battery demand	%	*27%*	*53%*	*23%*	*24%*	*20%*	*19%*	*22%*	*20%*	*20%*	*20%*	*19%*
Industrial Demand	kt	125	134	136	137	139	140	142	143	145	147	148
Total World Demand	**kt**	**326**	**442**	**514**	**606**	**702**	**812**	**962**	**1130**	**1333**	**1567**	**1845**
Growth in lithium demand	%	*13.0%*	*35.5%*	*16.4%*	*17.9%*	*15.9%*	*15.6%*	*18.5%*	*17.5%*	*17.9%*	*17.5%*	*17.7%*
Market balance	**kt**	**88**	**-1**	**51**	**107**	**139**	**144**	**67**	**-71**	**-268**	**-496**	**-772**
Implied global inventory	**kt**	**117**	**115**	**167**	**274**	**412**	**557**	**624**	**553**	**285**	**0**	**0**
Weeks' consumption		19	14	17	23	31	36	34	25	11	0	0
Lithium carbonate (fob Latin America)	**US$/t fob**	**$6,859**	**$10,293**	**$13,250**	**$8,563**	**$7,000**	**$7,050**	**$7,300**	**$7,524**	**$7,674**	**$7,828**	**$7,984**
China spot 99.5% battery-grade	**US$/t**	**$5,683**	**$14,668**	**$16,250**	**$7,750**	**$6,800**	**$6,700**	**$7,446**	**$7,674**	**$7,828**	**$7,984**	**$8,144**
Spodumene price (cif China)	**US/t**	**$453**	**$800**	**$946**	**$583**	**$575**	**$565**	**$610**	**$624**	**$635**	**$646**	**$658**
China spot 56.5% hydroxide	**US/t**	**$6,490**	**$14,186**	**$17,250**	**$8,750**	**$7,800**	**$7,700**	**$8,446**	**$8,674**	**$8,828**	**$8,984**	**$9,144**

Source: Morgan Stanley Research; Note: as of September 2021

Nickel, Cobalt, and Graphite Stocks. Beyond lithium, other commodities are key feedstocks for batteries, especially in the cathode space. For pure play nickel exposure, we highlight **Western Areas** (covered by Rahul Anand) which has revenue 100% exposed to nickel in FY22. While cobalt-rich chemistries are going out of vogue, **Huayou Cobalt** (covered by Rachel Zhang), the largest cobalt refiner in China, is one exposed name. For graphite exposure (the status quo anode material), we highlight **Syrah Resources** (covered by Rahul Anand) which has 100% of its revenue exposed to graphite.

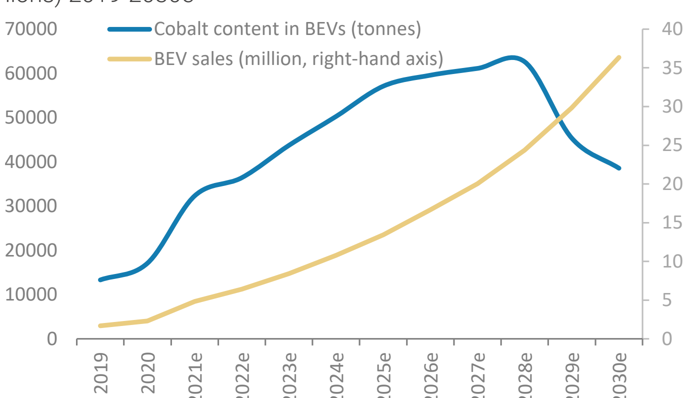
Cobalt is a waning demand story. As the most expensive cathode feedstock with ESG concerns related to "artisanal mining" and child labor usage in the DRC (where >60% of cobalt is mined), cobalt may face waning demand in the long run. In the near term, cobalt remains a key feedstock in cathode chemistries such as NMC, although the trend has shifted towards chemistries that relatively favor nickel over cobalt (even within NMC towards chemistries such as NMC 622 and NMC 811 over NMC 532). Subsequently, the rise of other chemistries that do not use cobalt such as LFP, LMNO, and LNO reinforce the demand shift away from cobalt. Notably, as battery recycling becomes more prevalent, Morgan Stanley's European Chemicals team forecasts a potential supply imbalance in recycled cobalt material from used batteries and the significantly lower cobalt content in new batteries. While supply of cobalt may be abundant due to recycled cobalt and expected capacity (mostly as a by/co-product) from the DRC, the forecasted lack of demand for cobalt from the EV community may cap cobalt prices in the long term. For more on the ESG implications of cobalt, please see How Clean Are EV Batteries?.

Exhibit 58: The DRC is the main global source of cobalt, followed by Australia



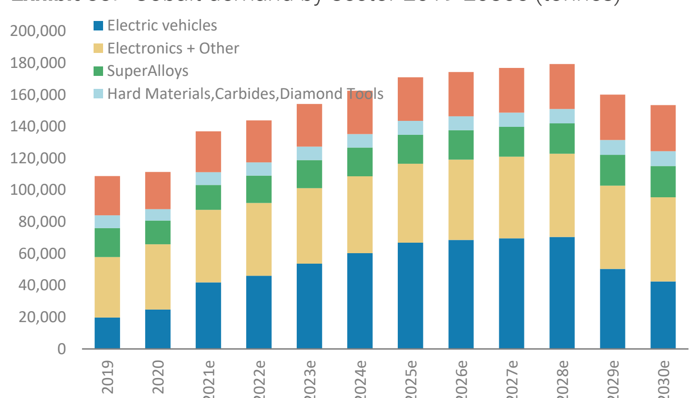
Source: Reuters

Exhibit 59: Cobalt demand from BEVs (tonnes) vs EV sales (millions) 2019-2030e



Source: Morgan Stanley Research estimates; Note: as of September 2021

Exhibit 60: Cobalt demand by sector 2019-2030e (tonnes)



Source: Morgan Stanley Research estimates, Wood Mackenzie, Darton Commodities; Note: as of September 2021

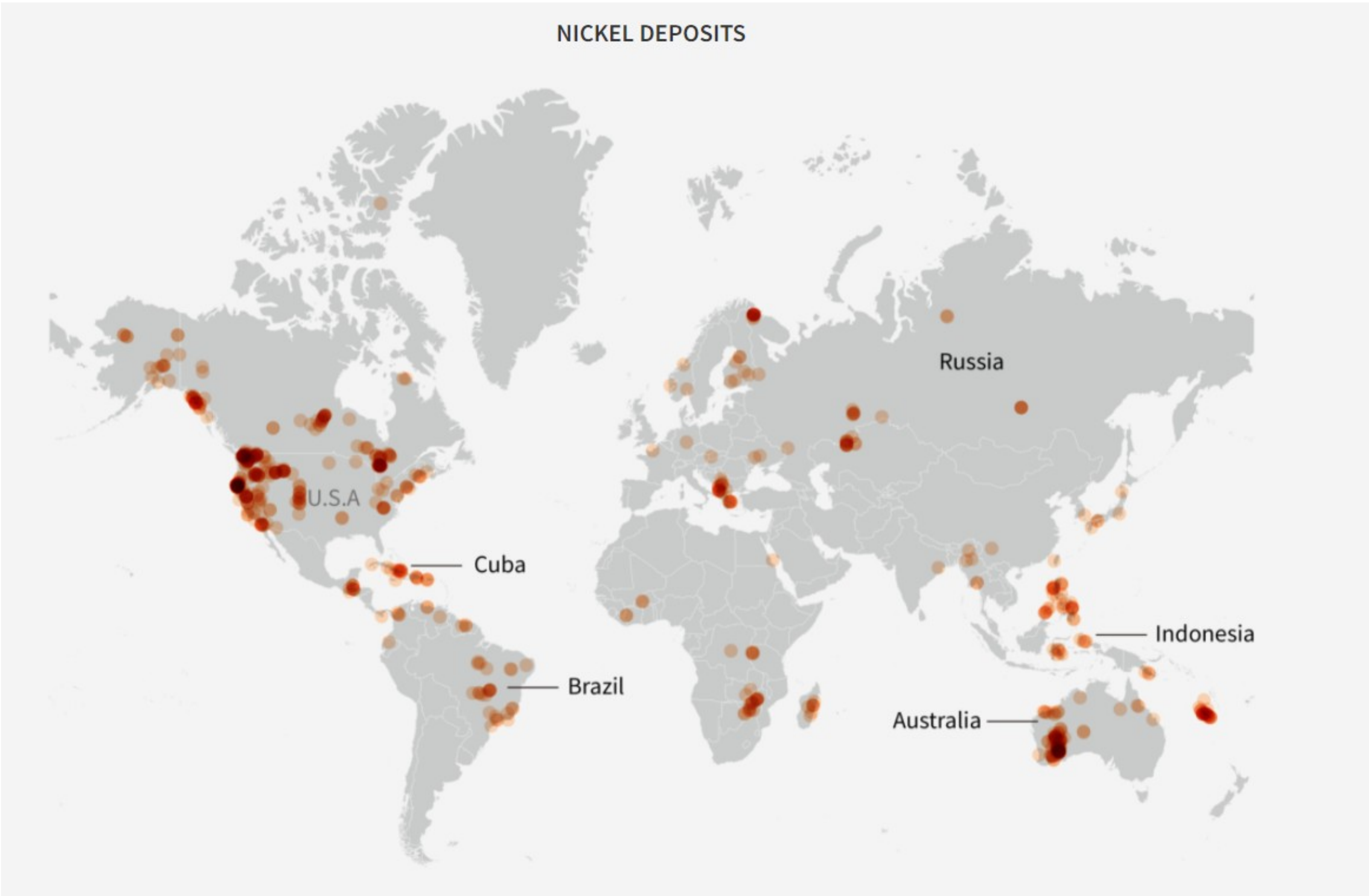
Exhibit 61: Cobalt supply/demand model

	unit	2019	2020	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
World Mine Production	tonnes	**150,808**	**136,216**	**153,469**	**184,475**	**199,823**	**223,616**	**228,615**	**229,337**	**229,425**	**229,426**	**229,602**	**230,303**
YoY change	%	*1.0%*	*-10%*	*13%*	*20%*	*8%*	*12%*	*2%*	*0%*	*0%*	*0%*	*0%*	*0%*
by Country													
DRC		108,698	98,036	114,000	137,000	142,800	156,841	160,270	160,270	160,270	160,270	160,270	160,270
Australia		4,723	4,480	4,630	5,480	5,830	8,702	8,702	8,840	8,877	8,877	8,877	8,877
Canada		2,646	2,100	2,922	3,422	4,297	5,794	5,568	5,568	5,568	5,568	5,568	5,568
China		1,386	1,386	1,385	1,670	2,220	2,250	2,250	2,250	2,250	2,250	2,250	2,250
Russia		4,500	4,300	2,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Zambia		4,400	3,600	4,600	5,100	5,100	4,600	4,100	4,100	4,100	4,100	4,100	4,100
Others		24,454	22,313	23,432	27,303	35,076	40,929	43,225	43,809	43,860	43,861	44,037	44,738
World Refined Supply	tonnes	**129,810**	**121,216**	**130,765**	**153,114**	**165,853**	**185,602**	**192,036**	**192,643**	**192,717**	**192,717**	**192,865**	**193,454**
YoY change	%	*11%*	*-7%*	*8%*	*17%*	*8%*	*12%*	*3%*	*0%*	*0%*	*0%*	*0%*	*0%*
+ battery recycling		*3,750*	*3,713*	*3,898*	*4,093*	*4,502*	*4,953*	*5,448*	*5,821*	*8,088*	*15,517*	*16,774*	*24,102*
Total World Demand	tonnes	**108,809**	**111,456**	**136,982**	**143,919**	**154,238**	**162,540**	**171,044**	**174,289**	**176,865**	**179,406**	**160,090**	**153,471**
YoY change	%	*1.7%*	*2.4%*	*22.9%*	*5.1%*	*7.2%*	*5.4%*	*5.2%*	*1.9%*	*1.5%*	*1.4%*	*-10.8%*	*-4.1%*
Batteries	tonnes	57,910	65,950	87,525	91,884	101,251	108,750	116,584	119,149	121,037	122,881	102,859	95,524
of which EVs		19736	24834	41921	46080	53659	60266	66924	68669	69595	70538	50451	42484
YoY change	%	*2%*	*14%*	*33%*	*5%*	*10%*	*7%*	*7%*	*2%*	*2%*	*2%*	*-16%*	*-7%*
Other	tonnes	50,899	45,506	49,456	52,035	52,988	53,790	54,460	55,140	55,828	56,525	57,231	57,946
YoY change	%	1%	-11%	9%	5%	2%	2%	1%	1%	1%	1%	1%	1%
Market balance (before inventory)	tonnes	**24,751**	**13,472**	**-2,318**	**13,288**	**16,117**	**28,014**	**26,440**	**24,175**	**23,940**	**28,829**	**49,549**	**64,085**
Inventory build	tonnes	13000	7000										
Market balance	tonnes	**11,751**	**6,472**	**-2,318**	**13,288**	**16,117**	**28,014**	**26,440**	**24,175**	**23,940**	**28,829**	**49,549**	**64,085**
Cobalt price	US$/lb	**14.6**	**16.2**	**22.3**	**18.8**	**17.3**	**15.0**	**16.0**	**17.0**	**17.1**	**17.5**	**17.8**	**18.2**
Cobalt price	US$/t	**32,148**	**35,682**	**49,169**	**41,337**	**38,030**	**33,069**	**35,274**	**37,479**	**37,755**	**38,510**	**39,280**	**40,065**

Source: Darton Commodities, CDI, Morgan Stanley Research; Note: as of September 2021

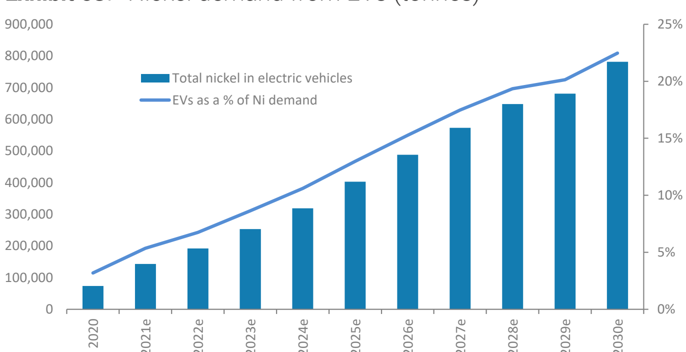
Nickel is a limited supply story tethered to Indonesian production. The main, new source of upcoming nickel supply is from Indonesia's high-pressure acid leach (HPAL) operations which are set to ramp in the next 2-3 years. However, worth noting is that Indonesia's laterite nickel ore needs to follow more complex and costly processing routes to produce so called class 1 nickel, instead of the more common nickel pig iron (NPI) for the stainless steel industry . Furthermore, Indonesian processing is currently primarily powered by coal (similar to China), which can create negative environmental externalities and ESG implications. The supply scarcity is exacerbated by the countries which have simpler nickel sulphate ore processing, such as the US, Canada, and Australia. There, the combined headwinds of slow approval processes and cumbersome development time for new mines may delay high quality nickel from coming to the market in the near term. Should additional, high quality nickel mines come online in the long term, we fear that supply may be met by long term demand headwinds. While nickel is relatively favored now in chemistries such as NMC 811 and NCA, upcoming industry level developments (the rise of LFP which does not include nickel, and lower nickel content cathode chemistries such as LNO/LMNO) may create a scenario in which nickel supply comes online too late and misses the height of nickel in cathode chemistries.

Exhibit 62: Indonesia holds the world's most nickel, followed by Australia



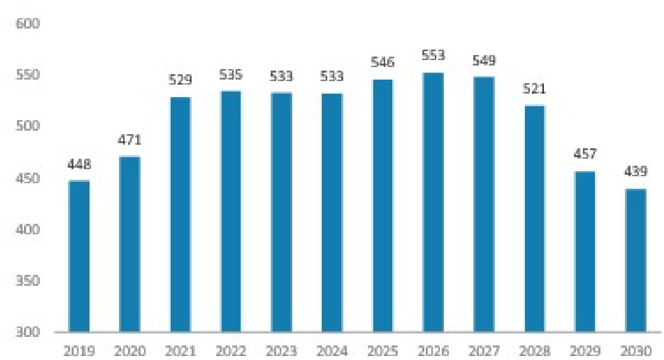
Source: Reuters

Exhibit 63: Nickel demand from EVs (tonnes)



Source: Morgan Stanley Research estimates; Note: as of September 2021

Exhibit 64: Nickel intensity of use (g/kWh)



Source: Morgan Stanley Research estimates; Note: as of September 2021

Exhibit 65: Nickel supply/demand model

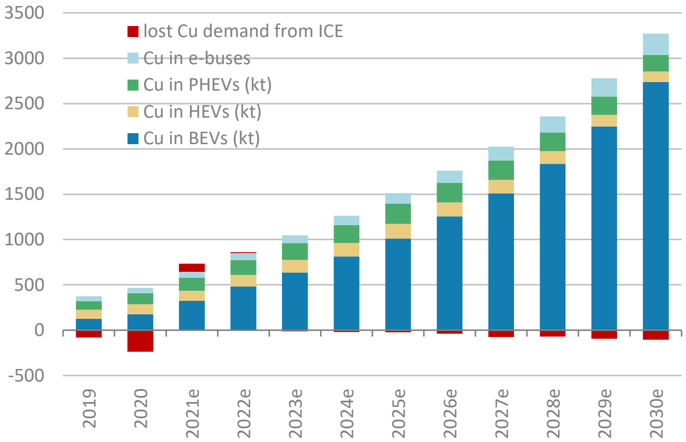
	unit	2019	2020	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
Total Mine Production	kt	**2,545**	**2,646**	**2,656**	**2,889**	**3,069**	**3,060**	**3,058**	**3,073**	**3,079**	**3,087**	**3,095**	**3,105**
World mine production growth rate	%	4.9%	4.0%	0.4%	8.7%	6.2%	-0.3%	0.0%	0.5%	0.2%	0.3%	0.3%	0.3%
Regional Mined Production Breakdown													
Indonesia	kt	811	932	1,014	1,162	1,322	1,352	1,352	1,352	1,352	1,352	1,352	1,352
Philippines	kt	433	415	422	422	422	422	422	422	422	422	422	422
Russia	kt	242	227	184	222	232	232	232	232	232	232	232	232
Canada	kt	168	169	170	177	186	186	186	186	186	186	186	186
New Caledonia	kt	135	133	143	187	194	196	198	196	196	196	196	196
Australia	kt	165	184	143	148	143	116	111	111	111	111	111	111
Brazil	kt	85	102	112	120	121	122	122	129	126	126	125	126
Total world primary availability	kt	**2,400**	**2,499**	**2,610**	**2,822**	**2,950**	**3,025**	**3,084**	**3,097**	**3,105**	**3,075**	**3,121**	**3,121**
World refined availability growth rate	%	7.7%	4.2%	4.4%	8.1%	4.5%	2.5%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total world refined production	kt	2400	2499	2610	2822	2950	3025	3084	3097	3105	3075	3121	3121
China NPI production	kt	**569**	**498**	**446**	**333**	**299**	**299**	**299**	**299**	**299**	**299**	**299**	**299**
Total World Nickel Demand	kt	**2,315**	**2,309**	**2,684**	**2,847**	**2,929**	**3,008**	**3,105**	**3,195**	**3,278**	**3,351**	**3,381**	**3,478**
Primary Nickel in Stainless	kt	1663	1691	1945	2034	2040	2041	2041	2039	2030	2021	2012	2002
Primary Nickel in Non-Stainless (ex-EV)	kt	602	545	595	622	636	647	661	668	675	682	689	694
Nickel in EVs	kt	50	74	144	192	253	319	403	488	573	648	681	781
World Nickel Demand Growth	%	6.0%	-0.2%	16.2%	6.1%	2.9%	2.7%	3.2%	0.0%	0.0%	0.0%	0.0%	0.0%
China Nickel Usage Growth	%	14.9%	3.7%	5.3%	2.9%	0.0%	0.1%	0.3%	-0.2%	-0.6%	-0.6%	-0.6%	-0.7%
World ex-China Usage Growth	%	-4.1%	-7.3%	23.6%	5.8%	1.4%	0.7%	0.6%	0.4%	0.4%	0.3%	0.3%	0.3%
Regional Usage Breakdown													
China	kt	1,267	1,315	1,385	1,425	1,425	1,427	1,431	1,429	1,420	1,412	1,403	1,393
USA	kt	133	114	135	145	151	155	158	160	163	166	168	171
Europe	kt	315	281	316	324	329	332	335	338	339	341	342	343
ROW	kt	601	600	849	954	1024	1094	1181	1269	1356	1433	1468	1570
Refined Nickel Market Balance (before inventory)	kt	**85**	**190**	**-74**	**-25**	**22**	**17**	**-21**	**-98**	**-173**	**-276**	**-260**	**-356**
Reported total commercial stocks	kt	**211**	**295**	**299**	**275**	**296**	**313**	**292**	**194**	**21**	**0**	**0**	**0**
Reported stock to consumption ratio	wks	**4.8**	**6.7**	**5.8**	**5.0**	**5.3**	**5.4**	**4.9**	**3.2**	**0.3**	**0.0**	**0.0**	**0.0**
Refined Nickel Market Balance	kt	**0**	**190**	**-74**	**-25**	**22**	**17**	**-21**	**-98**	**-173**	**-276**	**-260**	**-356**
Price (LME Settlement)	US$/t	**$13,754**	**$13,794**	**$18,474**	**$18,050**	**$15,019**	**$16,617**	**$17,196**	**$17,416**	**$17,367**	**$17,714**	**$18,069**	**$18,430**
	US$/lb	**$6.24**	**$6.26**	**$8.38**	**$8.19**	**$6.81**	**$7.54**	**$7.80**	**$7.90**	**$7.88**	**$8.04**	**$8.20**	**$8.36**
China's share of global refined nickel production	%	35%	31%	28%	24%	22%	22%	22%	22%	22%	22%	22%	22%
China's share of global refined nickel demand	%	55%	57%	52%	50%	49%	47%	46%	45%	43%	42%	42%	40%

Source: Wood Mackenzie, Bloomberg, INSG, Morgan Stanley Research estimates; Note: as of September 2021

Copper Stocks. Copper benefits from its use as a current collector for the anode and its use in infrastructure for charging. For copper exposure, we highlight **29Metals**, **Sandfire Resources**, and **OZ Minerals** (all covered by Rahul Anand) as well as **Grupo Mexico** and **Freeport McMoRan** (covered by Carlos de Alba), **KGHM** (covered by Dan Shaw), and **Antofagasta** (covered by Ioannis Masvoulas). For both copper and nickel exposure, we highlight **Glencore** (covered by Alain Gabriel), **Norilsk Nickel** (covered by Dan Shaw), and **Boliden** and **Lundin Mining** (both covered by Ioannis Masvoulas).

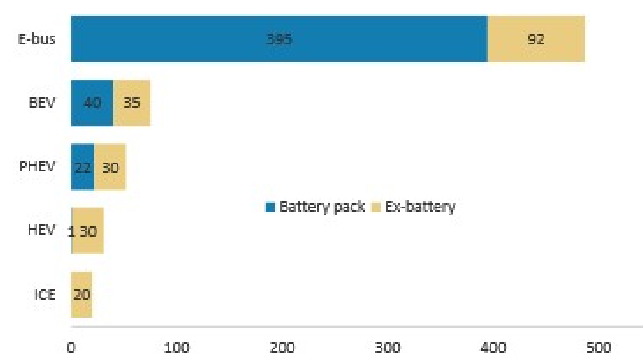
Copper's supply shortage will be dictated by politics. On the demand side, while we may see less copper demand related to ICE's decline, copper will not only be necessary for the anode current collector in the battery pack but also for charging infrastructure. The net increase in copper demand is expected to accelerate with EV penetration. The bottleneck is on the supply side. At the moment, the pipeline of new projects slows significantly after 2023. Chile and Peru are the main two countries with the resources and infrastructure to supply copper to the market. However, both countries are currently negotiating new political strategies including higher taxes for the mining industry, creating uncertainty and potentially resulting in delays in investment in new supply. In particular, the new Peruvian President, Pedro Castillo (elected July 2021), appears to be sympathetic to anti-mining stances. Presidential terms in Peru are 5 years long, and Peru is currently the world's second largest producer of copper. Chile's next presidential election is scheduled for November, with reports of Communist Party candidate Daniel Jadue in the lead (also appears to have an anti-mining bias). Notwithstanding the political lag, mining projects take ~5 years from inception to get production online. In the long term, our commodities team has a relatively bullish outlook on copper prices given the supply uncertainty out of Chile and Peru along with regulatory infrastructure lags in other copper-rich regions. For more, please see *Global Commodities: Copper and Renewables.*

Exhibit 66: Net copper demand growth in electric vehicles (kt)



Source: Morgan Stanley Research estimates, International Copper Association; Note: as of September 2021

Exhibit 67: Copper content in EVs (kg/vehicle)



Source: Morgan Stanley Research estimates, International Copper Association; Note: as of September 2021

Exhibit 68: Copper supply/demand model

	unit	2019	2020	2021e	2022e	2023e	2024e	2025e	2026e	2027e	2028e	2029e	2030e
World Mine Production													
concentrates	Mt	17.1	17.2	18.0	19.3	20.7	21.3	21.4	21.5	21.8	22.0	21.5	21.1
SX/EW	Mt	3.5	3.4	3.2	3.4	3.4	3.2	3.1	3.0	2.8	2.7	2.6	2.5
disruption allowance	%	0.0%	0.0%	2.5%	5.0%	5.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Total Mine Production	Mt	**20.7**	**20.7**	**20.7**	**21.6**	**22.9**	**23.6**	**23.6**	**23.6**	**23.9**	**23.9**	**23.3**	**22.8**
YoY change	%	*-1.0%*	*0.0%*	*0.3%*	*4.3%*	*6.1%*	*2.8%*	*-0.1%*	*0.2%*	*1.1%*	*0.2%*	*-2.5%*	*-2.0%*
Concentrate balance		**-0.3**	**-0.4**	**-0.6**	**-0.7**	**0.0**	**0.4**	**0.1**	**0.2**	**0.5**	**0.5**	**0.1**	**-0.3**
TC/RC contract	US$/t,¢/lb	80.8/8.08	62/6.2	59.5/5.95	62/6.2	70/7	90/9	80/8	85/8.5	96.3/9.6	98.2/9.8	100.2/10	102.2/10.2
composite TC/RC/PP charge	US¢/lb	20.7	15.9	15.3	15.9	18.0	23.1	20.5	21.8	24.7	25.2	25.7	26.2
World Smelter Production													
primary	Mt	16.5	16.6	16.9	17.7	18.9	19.4	19.7	19.7	19.8	19.8	19.8	19.8
secondary	Mt	2.8	3.0	3.2	3.2	3.3	3.4	3.5	3.5	3.5	3.5	3.5	3.5
Total Smelter Production	Mt	**19.3**	**19.6**	**20.1**	**20.9**	**22.2**	**22.7**	**23.2**	**23.2**	**23.3**	**23.4**	**23.3**	**23.3**
imputed concentrate balance	Mt	-0.3	-0.4	-0.6	-0.7	0.0	0.4	0.1	0.2	0.5	0.5	0.1	-0.3
world refinery production													
electrowon	Mt	3.5	3.5	3.1	3.4	3.5	3.3	3.2	3.1	3.0	2.9	2.8	2.8
primary	Mt	18.3	18.6	19.1	19.9	20.7	21.1	21.2	21.2	21.3	21.3	21.3	21.3
secondary	Mt	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.4	1.4	1.4	1.4	1.4
Total Refinery Production	Mt	**23.0**	**23.2**	**23.4**	**24.5**	**25.4**	**25.6**	**25.7**	**25.8**	**25.7**	**25.6**	**25.6**	**25.6**
YoY change	%	*-3.2%*	*1.0%*	*1.1%*	*4.5%*	*3.7%*	*0.8%*	*0.5%*	*0.2%*	*-0.2%*	*-0.4%*	*-0.1%*	*0.0%*
World Copper Demand	Mt	**22.9**	**22.8**	**23.7**	**24.4**	**24.9**	**25.5**	**26.1**	**26.6**	**27.1**	**27.6**	**28.0**	**28.6**
YoY change	%	*-0.3%*	*-0.8%*	*4.1%*	*2.8%*	*2.3%*	*2.1%*	*2.6%*	*1.9%*	*1.8%*	*1.8%*	*1.7%*	*2.0%*
China demand		11.6	12.3	12.5	12.8	13.1	13.4	13.8	14.0	14.3	14.5	14.7	15.0
China's YoY change	%	*4.0%*	*6.8%*	*1.1%*	*2.5%*	*2.4%*	*2.2%*	*3.0%*	*1.8%*	*1.8%*	*1.6%*	*1.5%*	*2.0%*
non-China's YoY change	%	*-4.4%*	*-8.4%*	*7.7%*	*3.2%*	*2.3%*	*1.9%*	*2.1%*	*1.9%*	*1.9%*	*1.9%*	*1.9%*	*2.0%*
Implied Market Balance (before inventory)	Mt	**0.03**	**0.43**	**-0.26**	**0.13**	**0.46**	**0.14**	**-0.38**	**-0.83**	**-1.37**	**-1.96**	**-2.46**	**-3.01**
Refined Stocks End of Period	kt	**947**	**1,126**	**1,071**	**1,199**	**1,662**	**1,806**	**1,422**	**593**	**0**	**0**	**0**	**0**
reported refined inventory change	kt	-253	180	-55	128	463	144	-385	-828	-593	0	0	0
apparent change in unreported inventories	kt	281	247										
Inventory-to-usage rate	wks	**2.2**	**2.6**	**2.4**	**2.6**	**3.5**	**3.7**	**2.8**	**1.2**	**0.0**	**0.0**	**0.0**	**0.0**
Market Balance	Mt	**0.03**	**0.43**	**-0.26**	**0.13**	**0.46**	**0.14**	**-0.38**	**-0.83**	**-1.37**	**-1.96**	**-2.46**	**-3.01**
Price	US$/t	**$5,924**	**$6,178**	**$9,178**	**$8,074**	**$6,724**	**$6,862**	**$7,022**	**$7,099**	**$7,098**	**$7,240**	**$7,385**	**$7,532**
	US$/lb	**$2.69**	**$2.80**	**$4.16**	**$3.66**	**$3.05**	**$3.11**	**$3.19**	**$3.22**	**$3.22**	**$3.28**	**$3.35**	**$3.42**
China's share of global refined copper production	%	39%	39%	40%	40%	42%	42%	42%	43%	43%	43%	43%	43%
China's share of global refined copper demand	%	50%	54%	53%	52%	52%	53%	53%	53%	53%	53%	53%	53%

Source: Wood Mackenzie, Bloomberg, ICSG, Morgan Stanley Research estimates; Note: as of September 2021

Mining Equipment Stocks. Two names that produce machinery and equipment for mining are **Epiroc** (covered by Robert Davies) and **Komatsu** (covered by Yoshinao Ibara). Epiroc plays a key role in the extraction of battery metals and is also building out its own fleet of electric powered mining vehicles. Komatsu is a major producer of construction equipment, ranking second in the industry in terms of global market share. We expect the ongoing sales penetration of electric vehicles to contribute to corresponding demand for mining construction equipment.

Exhibit 69: Summary of Mining Stocks

Value Chain	Subgroup	Stock	Rating	PT	Currency	% Upside / Downside	YTD Perf	Analyst
Mining	Lithium	Albemarle	UW	80.00	USD	-71%	81%	Vincent Andrews
Mining	Lithium	Ganfeng Lithium	OW	189.00 HKD	HKD	33%	36%	Rachel Zhang
Mining	Lithium	Mineral Resources	UW	38.70	AUD	-3%	4%	Rahul Anand
Mining	Lithium	Orocobre	EW	8.65 AUD	AUD	-11%	113%	Rahul Anand
Mining	Lithium	SQM	UW	51.00	USD	-23%	29%	Javier Martinez de Olcoz Cerdan/Roberto Browne
Mining	Lithium/Nickel	IGO	UW	8.25	AUD	-16%	47%	Rahul Anand
Mining	Copper	29Metals	OW	2.90	AUD	7%	NA	Rahul Anand
Mining	Copper	Antofagasta	UW	1,060.00 GBp	GBP	-29%	-1%	Ioannis Masvoulas
Mining	Copper	Freeport McMoRan	EW	32.00	USD	-22%	52%	Carlos de Alba
Mining	Copper	Grupo Mexico	EW	104.00 MXN	MXN	19%	-2%	Carlos de Alba
Mining	Copper	KGHM	EW	160.00	PLN	1%	-18%	Dan Shaw
Mining	Copper	OZ Minerals	EW	23.20	AUD	-9%	33%	Rahul Anand
Mining	Copper	Sandfire Resources	OW	6.60	AUD	10%	18%	Rahul Anand
Mining	Copper/Nickel	Boliden	EW	320.00	SEK	4%	3%	Ioannis Masvoulas
Mining	Copper / Nickel	Glencore	OW	430.00 GBp	GBP	17%	51%	Alain Gabriel
Mining	Copper / Nickel	Lundin Mining	EW	73.00 SEK	SEK	-5%	1%	Ioannis Masvoulas
Mining	Copper/Nickel	Norilsk Nickel	UW	29.00	USD	-5%	-8%	Dan Shaw
Mining	Nickel	Western Areas	EW	2.90	AUD	-6%	14%	Rahul Anand
Mining	Cobalt	Huayou Cobalt	OW	160.00	CNY	37%	34%	Rachel Zhang
Mining	Graphite	Syrah Resources	UW	1.05 AUD	AUD	-20%	35%	Rahul Anand
Mining	Equipment	Epiroc	EW	196.00	SEK	-14%	52%	Robert Davies
Mining	Equipment	Komatsu	OW	3,600.00	JPY	18%	8%	Yoshinao Ibara

Source: Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

Components

Components Subsector Takeaways

- **Role: With the raw materials, the next step in the battery value chain is forming the key components that make up a battery cell: 1) cathode, 2) anode, 3) electrolyte, and 4) separator.**
- **TAM: The implied 2040 TAM of the components subsector is ~$315bn, 60% of our total battery TAM. Within the components subsector, we estimate ~$130bn cathode TAM, ~$55bn anode TAM, $80bn electrolyte and separator TAM, and ~$55bn other materials TAM.**
- **Stocks: For cathode exposure, we highlight Tesla, BASF, Umicore, Easpring, ShanShan, GEM, Ecopro BM, Sumitomo Chemical, L&F, and Huayou Cobalt. For anode exposure, we highlight Putailai, Tesla, Quantumscape, and ShanShan. For electrolyte/separator exposure, we highlight Quantumscape, Mitsubishi Chem, Putailai, Yunnan Energy New Material, Toray, Sumitomo Chemical, and Asahi Kasei.**
- **Supply & Demand: In the cathode space, we expect that supply additions will keep pace with demand as the large, fragmented group of cathode producers increases production and new players enter the mix. In the more concentrated anode space, we expect that the increase in EV penetration will make room for incumbent graphite anode producers as well as new silicon and lithium metal anode producers.**

With the raw materials, the next step in the battery value chain is forming the cell components. Cell components include the cathode, anode, electrolyte, and separator. The cathode is a positively charged electrode whereas the anode is the negatively charged electrode. The raw materials are primarily mined to form cathode chemistries such as NMC, NCA, and LFP. While the anode has traditionally been made out of graphite, companies are looking to other materials such as silicon and lithium metal to enhance energy density.

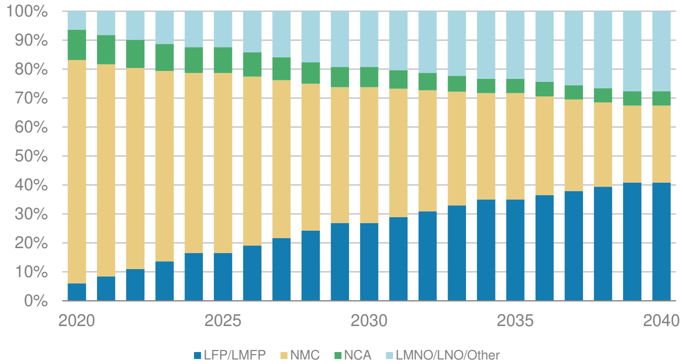
Cathode Stocks. The cathode market has many players which produce different lithium-ion chemistries. Some of the top cathode players include **Umicore** and **BASF** (both covered by Charlie Webb) in Europe, **Tesla** (covered by Adam Jonas) in the US, **Sumitomo Chemical** (covered by Takato Watabe) in Japan, **ShanShan** and **Easpring** (both covered by Jack Lu) in China, **Huayou Cobalt** and **GEM** (both covered by Rachel Zhang) in China, and **L&F** and **Ecopro BM,** supplier to SDI/SKI, (both covered by Ryan Kim) in Korea. As we wrote about in *Cathode Evolution: Do headwinds offset greater EV momentum?*, one trend in the cathode industry is names such as Tesla looking to in-source cathode production. The cathode space is one to watch as chemistries change (NMC/NCA dominance ceding share to low-to-no cobalt chemistries such as LFP, LMNO, and LNO).

Technology remains an important consideration in the cathode market. As we wrote in *Another EV Jolt*, there is a greater awareness that battery technology is fluid. While NMC is a mainstay, LFP has taken share and new technologies such as solid state could still prove disruptive. A few thoughts:

- As it stands, we expect NMC/NCA to remain the dominant technology for now, but remain convinced that a broad spectrum of technologies needs to be utilized.
- A broad technology spread allows cell OEMs to better meet the consumer demand, reduce technology risks, avoid supply chain disruption, and optimize costs.
- This idea has been validated by a number of OEMs that have broadened their technologies into LFP such as Tesla and Renault while new chemistries such as LMNO are being cited as a future technology of choice for companies such as Volkswagen.
- As such, we continue to increase our LFP penetration assumptions to account for both its rising penetration in China as well as an assumption we will see rising penetration of LFP use in Europe for smaller vehicles (Tesla is already selling some LFP based Model 3s in Europe).
- Similarly, we model in increasing penetration of LNO and LMNO. We expect the next generation of high energy dense and low/no cobalt battery technologies will be commercialized as early as 2022/23 depending on the success of commercial scale-up and testing currently underway.

Exhibit 70: In the near term, we expect that chemistries like NMC/ NCA will cede share to less-cobalt intensive chemistries like LMNO and LNO as well as LFP.

Cathode Chemistry Mix



Source: Morgan Stanley Research

We expect that supply additions will keep pace with demand as the large, fragmented group of cathode producers increase production and new players enter the mix. A few other considerations:

1. **Regional Imbalances**. For the most part short-term imbalances will be supplied out of Asia (China and Korea). This has been well anticipated for some time; however, current freight shortages do highlight the need for a localized supply chain. Recently EcoPro BM announced capacity expansion plans in Europe with intention to start up in 2023, which will be the first non European (excluding cell producers) to expand in the region. We expect similar announcements to come in the next 12 months from both Korean and Chinese cathode producers as they look to meet customer needs.

2. **Backward integration set to rise meaningfully**. Recently, we have seen a number of cell producers raise their planned back integrated capacity into cathode materials. For example, at the end of last year Tesla announced at its Battery Day its intention to back integrate cathode materials. Elsewhere, CATL has also made moves to increase backward integration through its JV Lingbo Brunp CATL New Energy, which is in the process of scaling up meaningful NMC capacity with 100kt cited in two phases out to 2024.

Anode Stocks. Compared to the crowded cathode supply market, the anode supply market is more concentrated with fewer players. As we alluded to in *Better Anode, Safer Batteries*, some of the top names to watch in this space include **Putailai** and **ShanShan** (both covered by Jack Lu). Putailai's anode business is in the Apple, Volkswagen, and Contemporary Amperex Technology (CATL) value chains. Beyond graphite, key players in the silicon and lithium metal anode space include **Tesla**, which announced its preference for a silicon anode at its Battery Day in 2020, and **Quantumscape,** which is looking to utilize a lithium-metal anode in its in-development solid state battery. See our *initiation note* for more.

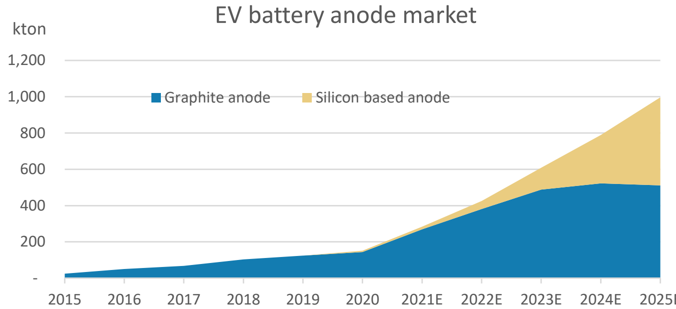
Exhibit 71: Anode companies' products and customer exposure

Company	Main anode products	Main customers	3C / Auto markets
PTL	Synthetic graphite	ATL, CATL, Samsung SDI, Coslight, CALB, Lishen, BYD, Korean player	Appel, Volkswagen, Chinese auto OEMs
Shanshan	Synthetic graphite (mainly) and natural graphite	CATL, Korean player, BYD, Guoxuan High-tech, Lishen, Farasis	Chinese auto OEMs, Chevrolet
Kaijin	Synthetic graphite	CATL, Farasis, Lishen, Wanxlang, JEVE, BAK, Guoxuan High-tech, Great Power	Chinese auto OEMs
Hitachi Chem	Synthetic graphite (mainly) and natural graphite	Panasonic, AESC, Korean player, Samsung SDI	Tesla, Nissan
POSCO Chem	Natural graphite, with synthetic graphite under development	Samsung SDI, Korean player	Hyundai, Chevrolet, Samsung Electronics

Source: Company data, Morgan Stanley Research

The traditionally graphite anode market may increase its energy density through silicon and lithium metal. Our China battery analyst, Jack Lu, forecasts ~50% penetration of silicon based anodes by 2030, a 10x increase from 5% forecasted penetration in 2021. As EV penetration accelerates from 2020 to 2030, the need for anodes for batteries will increase, making room for both graphite and silicon anode growth. We project that by 2025, the overall supply for graphite and silicon anodes will be roughly equal, around 500 kton each, and accelerate to around 1,000 kton each by 2030. We do not include lithium metal in our anode projections due to how nascent that market is (for more, please see *Better Anode, Safer Batteries*).

Exhibit 72: Silicon anodes are projected to catch up in supply with graphite anodes by 2025



Electrolyte Stocks. One key player in the electrolyte space is **Mitsubishi Chem** (covered by Takato Watabe), which holds ~20% global share in electrolytes and the top share in auto-use. A key player in the solid state electrolyte space is **Quantumscape** (covered by Adam Jonas), which has the potential to disrupt the lithium-ion status quo with solid state.

Separator Stocks. Key players in this space include **Yunnan Energy New Material** and **Putailai** (both covered by Jack Lu), and **Toray**, **Sumitomo**, and **Asahi Kasei** (all covered by Takato Watabe). Yunnan Energy New Material is expected to maintain a large global market share in separators although it has started to face competition from other producers. Putailai has a diversified business model serving the EV battery value chain, including synthetic graphite anode products (64% of profit in 2018), separator coating products (17%), battery coating machines (15%), and graphitization and aluminium pouches (4%). Its separator coating segment supplies China's largest EV battery maker, CATL. While the separator market is largely Asia-based, US players in this space include **Quantumscape** (covered by Adam Jonas). Over the past decade, QS has been developing game changing solid state cell technology and has achieved promising results with its patented ceramic separator that enables higher energy density, lower cost, improved safety, and faster charging.

Exhibit 73: Summary of Component Stocks

Value Chain	Subgroup	Stock	Rating	PT	Currency	% Upside / Downside	YTD Perf	Analyst
Components	Cathode	BASF	EW	79.00	EUR	26%	-3%	Charlie Webb
Components	Cathode	Easpring	UW	22.00	CNY	-77%	38%	Jack Lu
Components	Cathode	Ecopro BM	OW	600,000.00	KRW	7%	201%	Ryan Kim
Components	Cathode	GEM	OW	14.70	CNY	42%	35%	Rachel Zhang
Components	Cathode	Huayou Cobalt	OW	160.00	CNY	37%	34%	Rachel Zhang
Components	Cathode	L&F	OW	280,000.00	KRW	22%	212%	Ryan Kim
Components	Cathode	ShanShan	UW	10.69	CNY	-72%	103%	Jack Lu
Components	Cathode	Sumitomo Chemical	OW	730.00	JPY	25%	44%	Takato Watabe
Components	Cathode	Tesla	OW	1,200.00	USD	16%	42%	Adam Jonas
Components	Cathode	Umicore	EW	45.00	EUR	-3%	15%	Charlie Webb
Components	Anode	Putailai	EW	144.50	CNY	-22%	110%	Jack Lu
Components	Anode	Quantumscape	OW	70.00	USD	80%	-22%	Adam Jonas
Components	Anode	ShanShan	UW	10.69	CNY	-72%	103%	Jack Lu
Components	Anode	Tesla	OW	1,200.00	USD	16%	42%	Adam Jonas
Components	Electrolyte	Mitsubishi Chem	OW	1,400.00	JPY	47%	53%	Takato Watabe
Components	Electrolyte	Quantumscape	OW	70.00	USD	80%	-22%	Adam Jonas
Components	Separator	Asahi Kasei	EW	1,350.00	JPY	18%	10%	Takato Watabe
Components	Separator	Putailai	EW	144.50	CNY	-22%	110%	Jack Lu
Components	Separator	Quantumscape	OW	70.00	USD	80%	-22%	Adam Jonas
Components	Separator	Sumitomo Chemical	OW	730.00	JPY	25%	44%	Takato Watabe
Components	Separator	Toray	EW	800.00	JPY	11%	20%	Takato Watabe
Components	Separator	Yunnan Energy New Material	UW	59.50	CNY	-78%	77%	Jack Lu

Source: Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

Cell

Cell Subsector Takeaways

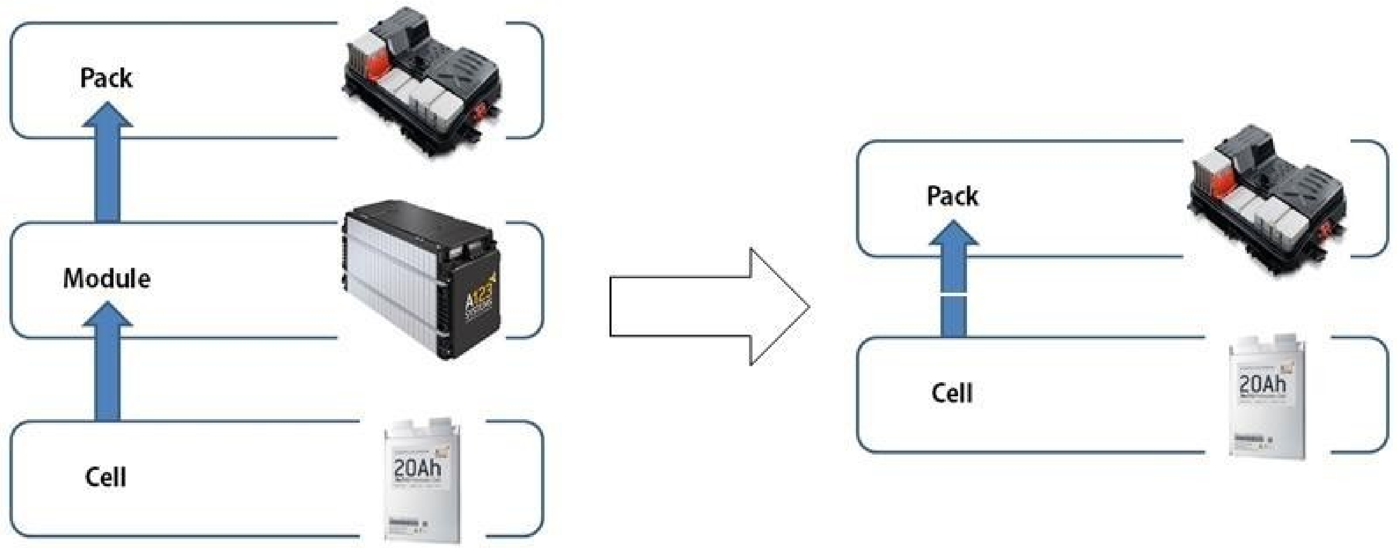
- **Role: Manufacturing the battery cell with the cell components is the next step in the battery value chain. Putting together the cell requires a multi-step manufacturing process and specialized manufacturing equipment. After manufacturing the cell, the cells must be grouped together in modules and packs that are ready for use in electric vehicles.**
- **TAM: We estimate that the 2040 TAM of the cell manufacturing process is ~$80bn, 15% of total battery costs; the 2040 TAM of the packaging process is ~$80bn, 15% of total battery costs; and the 2040 TAM of the cell manufacturing equipment is ~$25bn, 5% of total battery costs.**
- **Stocks: For exposure to cell manufacturing, we highlight SK Innovation and Samsung SDI in Korea, Panasonic in Japan, CATL, BYD, and Guoxuan High-tech in China, and Freyr in Norway. For exposure to cell manufacturing equipment, we highlight Putailai, Axalta Coating, PPG, Celanese, Fanuc, Wuxi Lead, and Yinghe. For exposure to semiconductors, we highlight Wolfspeed (previously Cree), STMicro, Infineon, Analog Devices, TE Connectivity, NXP, Sensata, and Rohm. For packaging, we highlight Tesla, Volkswagen, and CATL.**
- **Supply & Demand: We expect that growth from incumbent battery cell manufacturers in Asia and new entrants from the US and Europe will grow battery capacity to meet increased battery installation demand as EV penetration accelerates in the next few decades.**

With the cell components, the next step in the battery value chain is manufacturing the cell. The vast majority of battery cell manufacturing is concentrated in Asia, specifically in China**.** As the global EV race continues, China's battery sector incumbent advantage in the lithium-ion space may be challenged by domestic challengers, regional challengers, solid state disrupters, and global OEMs who are looking to vertically integrate (see *Two Upgrades; PTL Top Pick* and *No More Upside* for more).

- **China**: As we wrote in *Moving Into Downstream, Upgrade To OW*, CATL has over 2,000 items of patents in EV battery manufacturing, including battery components composition methods, battery assembling, battery equipment design, safety tests, battery packaging as well as charging facility systems. CATL is the only profitable battery major globally with a supply chain ecosystem which helps to maximize the company's profitability. Furthermore, BYD's blade battery (lithium-ion battery with LFP chemistry) has garnered attention due to its reported increase in energy density and cycle life, making it a potential competitor for NMC (see *EV Batteries 'State Of The Union'* and *Blade Battery's First Online Show - Safety Comes First* for more).
- **Korea:** Our Korean batteries, autos, and technology teams cover SK Innovation and Samsung SDI, two of the top Korean battery producers. We expect both names to be beneficiaries of accelerated EV penetration and battery installation demand both globally and in the US. The main risk for Korean manufacturers is market share vs. China as LFP has attained sufficient momentum to begin to challenge NMC. LFP is becoming a more attractive proposition in the EV space, largely due to improvements in energy density weight combined with cell-to-pack technology but also IP patents expiring in 2021, which allows China to expand overseas. This would challenge the 90% perceived market in the US of Korean manufacturers and 70% share in Europe, as mass market EV models adopt low cost LFP batteries. The switch to LFP is also evident in the use of batteries for energy storage, which do not have the energy density demands of EVs.
- **Japan:** Panasonic and Tesla's partnership was the main driver of NCA chemistry demand, which was used in a cylindrical form factor in Tesla's first EVs. However, as the battery industry in the US matures and Tesla progresses its plan to in-source battery production, Panasonic's role in the battery/EV industry may change. As we wrote about in *Tesla And Panasonic: Relationship Maturing?*, Panasonic is an unlikely battery cell provider for Tesla's Shanghai factory.

After the battery cells have been manufactured, the next step is packaging those cells into their final forms. Battery cells must be combined into modules and then packs. They also required a battery management system (BMS) that keeps the battery pack from overheating and short circuiting. Different form factors for battery cells include cylindrical, prismatic, and pouch. Tesla was known for it original cylindrical packaging, but since then OEMs have explored other form factors such as GM Ultium's pouch cells. In China, we believe CATL's new patent for "cell to pack" may amplify advantages of its prismatic cell format and improve product competitiveness. The cell to pack solution can only use prismatic format cells which have a hard aluminium covering, allowing the pack to avoid current prevailing modules sitting in between the cell and pack. Without a module, the energy density at the pack level will further improve, which would help CATL's battery to increase market penetration, in our view. For more, please see *Moving Into Downstream, Upgrade to OW*.

Exhibit 74: CATL is looking to move from conventional cell-module-pack to 'cell to pack.'



Source: CATL, Morgan Stanley Research

Cell Manufacturing Stocks. The cell manufacturing space is currently dominated by Chinese battery manufacturers such as **CATL** and **Guoxuan High-tech** (both covered by Jack Lu) and **BYD** (covered by Tim Hsiao), Korean battery manufacturers such as **Samsung SDI** (covered by Shawn Kim) and **SK Innovation** (covered by Young Suk Shin), and Japanese battery manufacturer **Panasonic** (covered by Masahiro Ono), originally Tesla's NCA battery supplier. CATL and BYD are also cell suppliers to Tesla. A Korean player is a cell supplier to GM (as part of Ultium) while SK Innovation is a cell supplier to Ford (see *The Battery EV Arms Race* for more). **Freyr** (covered by Adam Jonas) is a Norwegian battery company that claims to use a shorter cell manufacturing process (5 steps vs 15 steps) using low-carbon power sources.

Manufacturing Equipment Stocks. The companies that provide manufacturing equipment for the cell manufacturing process, from coating to slitting to calendaring and more, include **Putailai** (covered by Jack Lu) from China, **Wuxi Lead** and **Yinghe** (both covered by Zhuoran Wang) from China, **Fanuc** (covered by Yoshinao Ibara) from Japan, and **PPG, Axalta Coating,** and **Celanese** (all covered by Vincent Andrews) from the US. Putailai, PPG, and Axalta produce coating equipment. Wuxi Lead is one of the largest lithium battery equipment suppliers globally, offering a one-stop solution for battery makers. Yinghe is a leading battery equipment supplier in China with strong market share in front-end equipment such as coating machines. Fanuc provides automated manufacturing systems like robotics for battery manufacturing lines. Celanese has a Engineered Materials business that has seen substantial volume growth from its advanced polymer products in multiple EV production components.

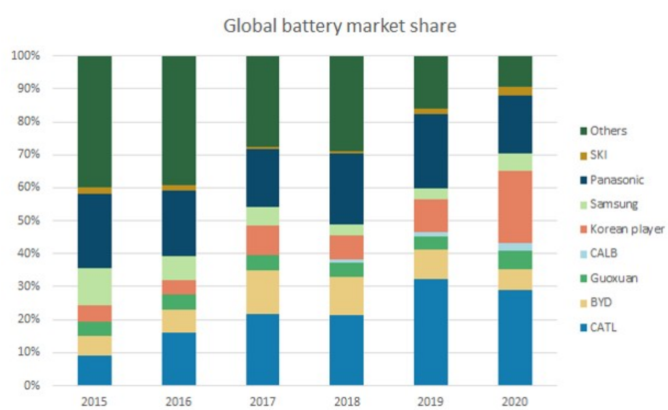
Packaging Stocks. Players in this space include automakers looking to vertically integrate such as **Tesla** (covered by Adam Jonas) and **Volkswagen** (covered by Harald Hendrikse) as well as cell manufacturing companies such as **CATL** (covered by Jack Lu).

Semiconductor Stocks. Silicon carbide, an enhanced form of silicon, can be used in batteries to enhance battery performance and improve driving range. Silicon carbide (SiC) is a wide bandgap semiconductor (stronger insulator than Si) that is formed by a special process that "mixes" carbon with the typical silicon that forms a traditional semiconductor as we know it. The ending result is a material that can withstand higher temperatures, voltages, and frequencies than the traditional Si semiconductor. While SiC manufacturing is still in nascent stages, our semis team is bullish on the space and thinks the shift from silicon to silicon carbide makes sense as a beneficiary of EV market and battery market growth. In this space, we highlight **Wolfspeed** (covered by Joe Moore), **Rohm** (covered by Kazuo Yoshikawa), and **Infineon** and **STMicroelectronics** (both covered by Dominik Olszewski), a silicon carbide provider for Tesla. Other battery power management names (for example, for BMS) include **Analog Devices**, **NXP Semiconductor**, **TE Connectivity**, and **Sensata Technologies** (all covered by Joe Moore). For more, please see *EV Batteries 'State of the Union'* and *Initiate at Overweight: Playing the Handoff from Cyclical to Secular.*

New entrants to increase global battery capacity? We expect that battery capacity will increase from <500 GWh in 2020 to ~4 TWh in 2030 and ~9.5 TWh in 2040, aided by additional capacity coming online from US and European OEMs**.** We estimate that total battery capacity in 2020 was ~43% from China, ~44% from Korea, and ~14% from Japan. What remains to be seen is how well these new entrants can scale and whether they can take share from the current incumbents.

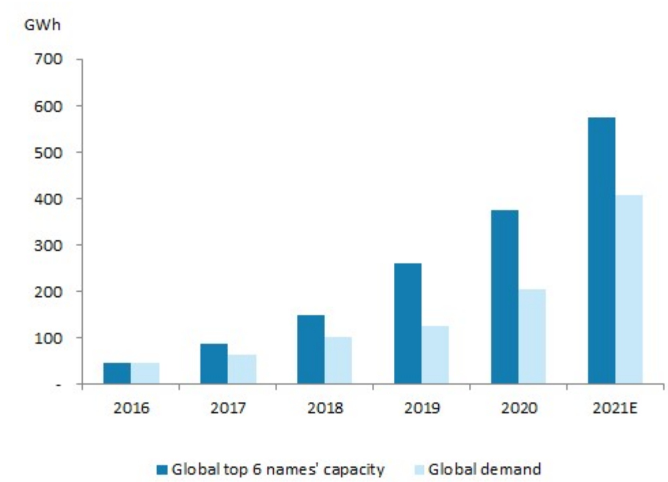
- **In the US**, new entrants beyond Tesla include GM through Ultium, its JV with a Korean player, and Ford through BlueOvalSK, its JV with SK Innovation. Ultium has an early 2022 SOP target for its first factory in Lordstown, OH which is expected to have ~30 GWh capacity. Ultium is in the process of building a second plant in Spring Hill, TN with YE 2023 SOP, and the company expects to have ~30 GWh capacity, resulting in a total capacity of ~60 GWh. BlueOvalSK announced plans to set up plants in Tennessee (2025 SOP) and Kentucky (2026 SOP) as well as one more that has yet to be disclosed, guiding to total capacity of 129 GWh (see *here* for more).
- **In Europe**, new entrants include OEMs such as BMW, Volkswagen, and Daimler as well as Freyr, an EV battery company in Norway. Freyr has guided to 43 GWh of production by 2025 and 83 GWh of production by 2028 through its own Gigafactories and JV Gigafactories. Freyr estimates that by 2030 there will be ~5,300 GWh of battery demand but roughly ~3,700 GWh of supply shortfall, and hopes to position itself as an incremental, low carbon cell producer.

Exhibit 75: Historical EV battery sales market share



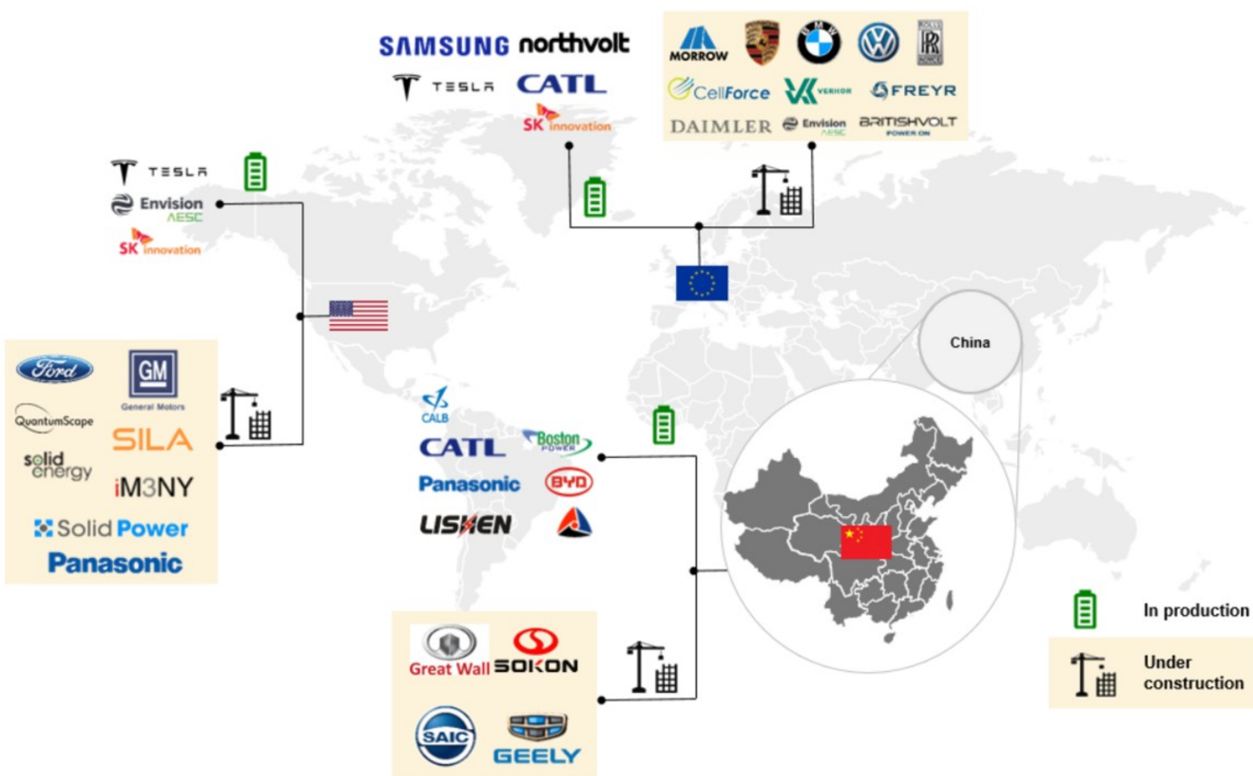
Source: Company data, Morgan Stanley Research

Exhibit 76: The top 6 producers of batteries globally (CATL, BYD, Korean player, Samsung, SKI, Panasonic) have historically had capacity that has outpaced demand.



Source: Company data, Morgan Stanley Research

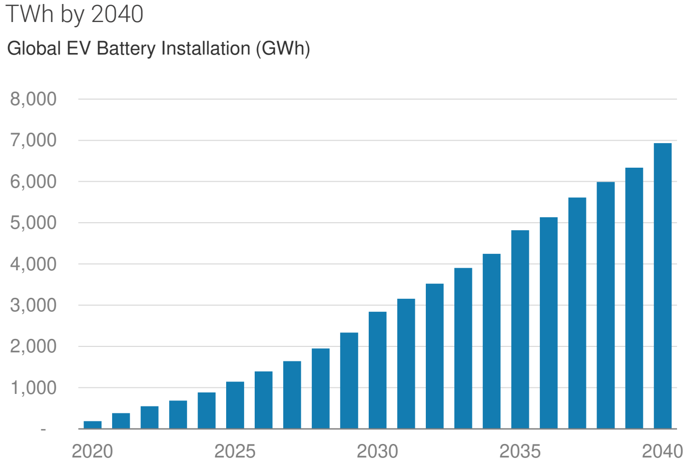
Exhibit 77: New EV Battery capacity and projects announcements in June 2021



Source: Company Data, Morgan Stanley Research

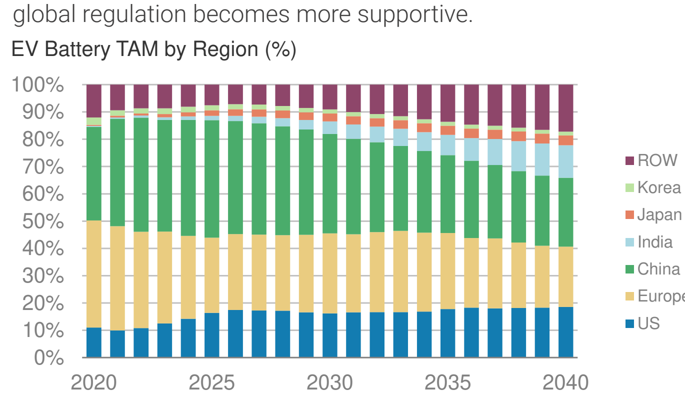
EV battery demand is predominantly driven by battery installation for BEVs and PHEVs. Battery installation is measured in GWh and is driven by BEV/PHEV sales and battery capacity assumptions. We use our global autos team's BEV and PHEV sales forecasts, estimated to grow from 5.3mm unit sales (2.3mm EV / 3mm PHEV) in 2020 to ~94mm unit sales (93.5mm EV / 0.7mm PHEV) in 2040. We assume that BEV batteries have a global average capacity of ~75 kWh whereas PHEV batteries have a capacity of 15 kWh by 2040. Using those assumptions, we project that the global battery installation demand will increase from ~380 GWh in 2021 to ~7 TWh in 2040. Additional, incremental drivers (<10%) of upcoming battery demand are energy storage solutions (ESS) and lead-acid battery (LAB) replacement (see *here* and *here* for more). For more on ESS, please see Appendix III - ESS Battery Global Update .

Exhibit 78: EV Battery Installation is forecasted to increase to ~7 TWh by 2040



Source: Company data, Morgan Stanley Research

Exhibit 79: By 2040, we project that EV battery installation will become more geographically varied as technology scales and global regulation becomes more supportive.



Source: Company data, Morgan Stanley Research; Note: ROW includes Korea and Japan

Exhibit 80: Summary of Cell Stocks

Value Chain	Subgroup	Stock	Rating	PT	Currency	% Upside / Downside	YTD Perf	Analyst
Cell	Manufacturing	BYD	UW	135.00	CNY	-56%	48%	Tim Hsiao
Cell	Manufacturing	CATL	UW	251.00	CNY	-61%	59%	Jack Lu
Cell	Manufacturing	Freyr	OW	18.00	USD	64%	9%	Adam Jonas
Cell	Manufacturing	Guoxuan High-tech	EW	36.40	CNY	-43%	56%	Jack Lu
Cell	Manufacturing	Panasonic	OW	1,900.00	JPY	34%	19%	Masahiro Ono
Cell	Manufacturing	Samsung SDI	EW	720,000.00	KRW	-4%	12%	Shawn Kim
Cell	Manufacturing	SK Innovation	OW	340,000.00	KRW	50%	-2%	Young Suk Shin
Cell	Equipment	Axalta Coating	EW	35.00	USD	6%	17%	Vincent Andrews
Cell	Equipment	Celanese	EW	157.00	USD	-8%	35%	Vincent Andrews
Cell	Equipment	Fanuc	OW	29,000.00	JPY	25%	-9%	Yoshinao Ibara
Cell	Equipment	PPG	EW	175.00	USD	8%	14%	Vincent Andrews
Cell	Equipment	Putailai	EW	144.50	CNY	-22%	110%	Jack Lu
Cell	Equipment	Wuxi Lead	EW	78.90	CNY	-10%	60%	Zhuoran Wang
Cell	Equipment	Yinghe	UW	22.20	CNY	-45%	22%	Zhuoran Wang
Cell	Semiconductor	Analog Devices	EW	179.00	USD	-3%	27%	Joe Moore
Cell	Semiconductor	Infineon	OW	42.50	EUR	-1%	33%	Dominik Olszewski
Cell	Semiconductor	NXP	EW	241.00	USD	11%	34%	Joe Moore
Cell	Semiconductor	Rohm	EW	11,000.00	JPY	-3%	11%	Kazuo Yoshikawa
Cell	Semiconductor	Sensata	OW	73.00	USD	20%	17%	Joe Moore
Cell	Semiconductor	STMicroelectronics	OW	43.50 EUR	EUR	-3%	41%	Dominik Olszewski
Cell	Semiconductor	TE Connectivity	EW	149.00	USD	-9%	37%	Joe Moore
Cell	Semiconductor	Wolfspeed	EW	103.00	USD	-26%	30%	Joe Moore
Cell	Packaging	CATL	UW	251.00	CNY	-61%	59%	Jack Lu
Cell	Packaging	Tesla	OW	1,200.00	USD	16%	42%	Adam Jonas
Cell	Packaging	Volkswagen	EW	185.00	EUR	-2%	27%	Harald Hendrikse

Source: Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

OEM & EV Companies

OEM Subsector Takeaways

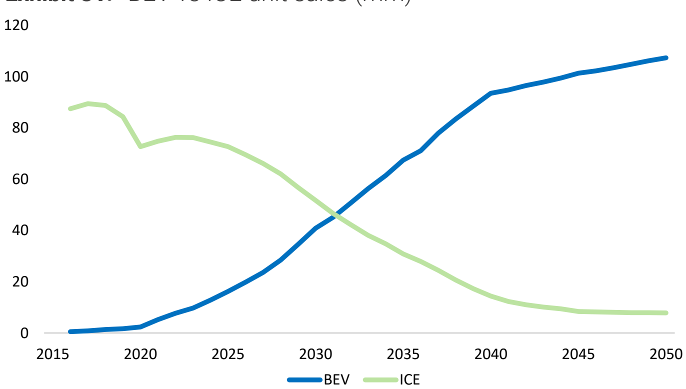
- **Role: After the battery has been packaged to its final form, it is ready to be used in BEVs and PHEVs. OEMs and EV companies, some more vertically integrated than not, will purchase battery cells or packs to insert into their electric vehicles before they hit the road.**
- **TAM: Assuming that the battery is approximately ⅓ the cost of the electric vehicle, we estimate the 2040 TAM for OEMs/EV companies at ~$1.6 trillion.**
- **Stocks: We highlight Tesla and GM in the US, BYD, Xpeng, and Li Auto in China, BMW, Stellantis, Volkswagen, Daimler, and Renault in Europe, Hyundai Motor and Kia in Korea, and Toyota in Japan.**
- **Supply & Demand: We project an accelerated pace of BEV sales penetration out to 2040, which we believe will be met by supply from OEMs who have guided towards more electric vehicle production. We view the main risk to be whether US and European OEMs can catch up with Tesla and their Chinese counterparts in the EV race.**

The final battery pack is then delivered to OEMs to insert into electric vehicles. The Morgan Stanley global autos & shared mobility team covers OEMs and EV-related companies that are direct beneficiaries of the battery ecosystem. The auto sector is undergoing a transition from internal combustion engine (ICE) vehicles to battery electric vehicles (BEV). The team expects global EV penetration, a key driver of battery installation, to accelerate from 3.1% in 2020 to 44.2% by 2030 and to 86.7% by 2040. As the auto market undergoes this transition, the team expects that some automakers may pursue vertically integrated supply chains for BEVs from the battery to the vehicle.

OEM & EV Company Stocks. After the cells are manufactured and packaged into the final battery pack, those batteries are delivered to OEMs and EV companies to insert into their BEVs and PHEVs. OEMs that are diversifying away from ICE vehicles and towards BEV include **BYD** (covered by Tim Hsiao) in China, **Toyota** (covered by Shinji Kakiuchi) in Japan (for more, please see *The Future of Electric Vehicles for J-OEMs*), **Hyundai Motor** and **Kia** (both covered by Young Suk Shin) in Korea, **Volkswagen**, **Stellantis**, **Daimler**, **Renault**, and **BMW** (all covered by Harald Hendrikse) in Europe, and **Tesla** and **GM** (covered by Adam Jonas) in the US. In terms of EV companies, we also highlight **Li Auto** and **XPeng** (both covered by Tim Hsiao) in China.

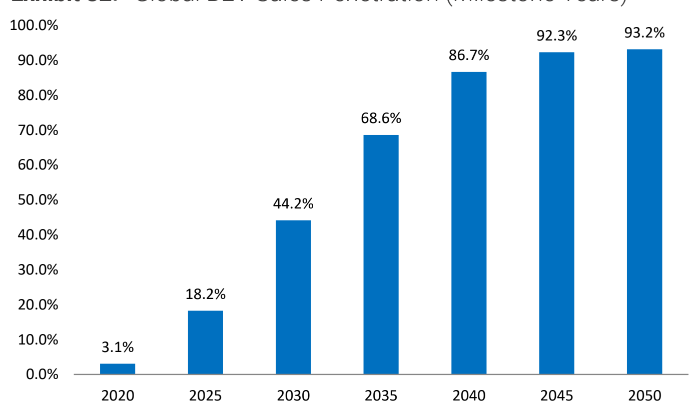
In terms of EV demand, we forecast that EV penetration will rise from 3.1% globally in 2020 to 44.2% in 2030 and 86.7% in 2040. We estimate that the decline in ICE sales and rise in BEV sales will hit equilibrium in the early 2030s – BEV sales penetration will equal ICE sales penetration in 2031. This acceleration in BEV penetration is expected to increase demand for batteries.

Exhibit 81: BEV vs ICE unit sales (mm)



Source: Morgan Stanley Research estimates

Exhibit 82: Global BEV Sales Penetration (Milestone Years)



Source: Morgan Stanley Research estimates

Who will make all these EVs? Electric vehicle supply is currently dominated by Tesla in the US, which has the two top selling EV models (Model 3 and Model Y) and 20% share of the global BEV market YTD 2021. Beyond Tesla, US players include OEMs such as GM (although GM recently recalled the Chevy Bolt due to battery safety issues). On a path to vertical integration, GM operates a JV, called Ultium, with its Korean battery cell supplier (see *Why Ultium Is So Important to GM* and *EV Asset vs. ICE Liability: GM to $80, Ford to UW* for more). Ford also operates a JV partnership, called BlueOvalSK, with a different Korean battery cell supplier, SK Innovation (see *Establishes Battery JV with Ford* and *The Battery EV Arms Race*). EV models currently sold in the US include the Tesla Model 3, Tesla Model Y, and Ford Mustang Mach-E.

In Europe, auto OEMs have guided toward electrification. As we wrote in *BEVs Fully Charged – The Hard Work Starts Now*, all of the major European OEMs have held capital markets days this year to raise BEV targets, and explain to investors and analysts how they will stay relevant in a world that is increasingly going electric. Batteries are key to achieving those goals.

- **BMW**, which hitherto had steadfastly stuck with its "Power of Choice" strategy (offering all powertrains on all models to all regional consumers) has now changed its narrative to one where BEVs will account for 50% of 2030 sales.
- Having previously marginally slimmed down its BEV model ambitions (at least to 2025), **Daimler** is now talking about 100% xEV (BEV and PHEV) sales by 2030E (which will have to be in the UK to meet UK regulations).
- **Volkswagen** had started the whole round of upgrades with its own latest strategic targets presented at its "Power Day" in March – with VW's ambitious plans now targeting 70% European BEV penetration and 60% globally (of which over 80% is EU and China).
- **Renault** then trumped everyone with its European target of 90% by 2030E, with **Stellantis** sticking to a slightly less aggressive target of 70%.

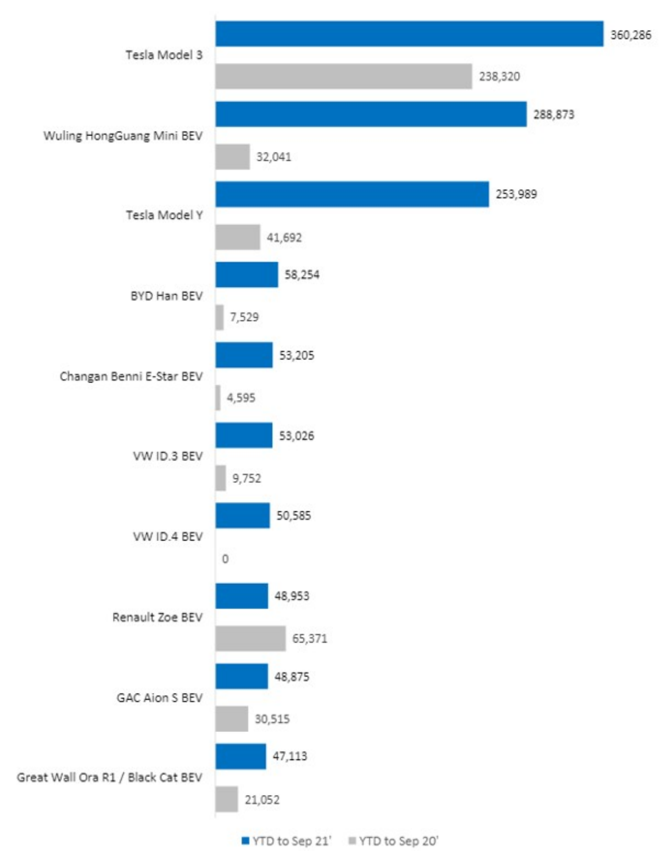
European OEMs are well ahead of MSe EU market forecasts for 2030 of 55%, and in our calculations, will be well ahead of where they need to be to meet 2030 EU CO2 targets. It seems unlikely that we will see further regulatory changes in EU transport CO2 emission targets soon, nor do we expect OEMs to further accelerate their recently published in-house targets. Peak BEV strategy acceleration is likely behind us.

Exhibit 83: Tesla is the top global EV OEM

Rank	Model	YTD Sales	YTD Market Share
1	Tesla	627,417	20%
2	GM	348,179	11%
3	VW	293,925	10%
4	BYD	188,133	6%
5	Hyundai	158,940	5%
6	Stellantis	137,757	4%
7	Ren/Niss/Mits	130,699	4%
8	SAIC	109,751	4%
9	Great Wall	85,255	3%
10	GAC	80,604	3%
Top 10 BEV Sales - YTD		2,160,660	70%
Other BEV Sales		904,815	30%
Total BEV Sales YTD		3,065,475	100%

Source: EV-volumes.com, Morgan Stanley Research; Note: as of September 2021

Exhibit 84: The top model globally is the Tesla Model 3.



Source: EV-volumes.com, Morgan Stanley Research: note: as of September 2021

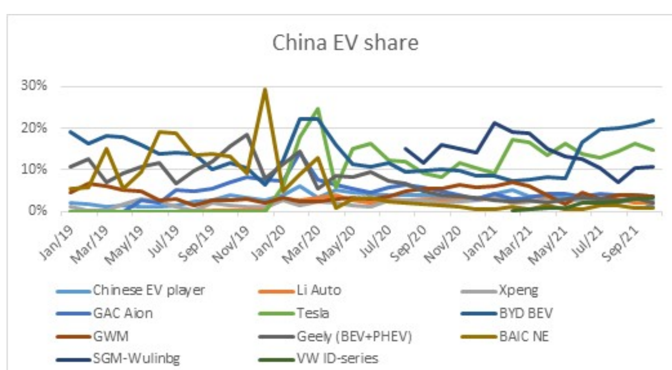
Exhibit 85: European OEM BEV penetration targets

EU OEM	Targets - sales and fleet
BMW	2025: >=25% BEV sales of total group deliveries 2030: BEVs to account for 50% of global sales
Daimler	**xEV share of total group deliveries:** 2025: ~50% xEV sales 2030: ~100% xEV sales
Volkswagen	**BEV share of total group deliveries:** 2020: ~3% BEV sales 2021: ~6% BEV sales 2025: ¬20% BEV sales 2030: ~60% Global BEV sales/ ~70% EU BEV sales
Porsche AG	2020: 17% of vehicles delivered were fully or partially electric 2025: 50% of all new vehicles sold will have an electric motor 2030: more than 80% of the new vehicles will be electric
Audi	By 2025: Add >30 electrified models o/w >20 fully electric models From 2026, Audi will only launch new all-electric models 2033: 100% of sales to be BEV in Europe
Stellantis	**LEV mix of total group deliveries:** 2021: 14% in EU; 4% in the US 2030: 70%+ in EU; 40%+ in the US - predominantly BEV
Renault	2020: BEV + PHEV ~10% of Europe PC mix 2025: 30% BEV in sales mix; 35% hybrid in sales mix in Europe 2030: 90% BEV in Renault sales mix in Europe

Source: Company data, Morgan Stanley Research

In China, BEV penetration is further along than in the US and Europe. As we wrote in *BEVs Fully Charged - The Hard Work Starts Now*, the China BEV market is saturated with players including but not limited to Tesla, VW, BMW, GM, XPeng, Great Wall, GAC, Changan, and BYD. Notably, foreign brands such as Tesla and VW have taken a significant share of China's BEV sales market. In 2021, China's 2021 BEV sales penetration is expected to be 12%, on par with Europe at 10% and beyond the US at 3%.

Exhibit 86: The China BEV market is more advanced than its US and EU counterparts, with many more players all taking 2%-20% market share.



Source: CAAM, Morgan Stanley Research; Note: updated 18Oct21

A quick note: we have included in this portfolio a list of global legacy OEMs that produce BEVs and that have ambitious strategies to grow their BEV penetration. Whilst they undoubtedly need the battery industry to provide capacity for manufacturing battery cells, and provide those cells at ever lower costs, it is not clear at this stage that **1)** these legacy OEMs themselves will benefit directly from the growth in the global battery industry, other than provide an ability for them to transform themselves from 95%+ ICE dependent to being able to compete in BEVs longer term or **2)** which of these legacy OEMs will benefit relatively speaking, when recent strategy announcements are all pushing in the same direction. It has become difficult to differentiate those strategies between beneficiaries and challenged players. At this point, it seems like the pure play BEV OEMs will be the net beneficiaries. That means some of the legacy OEMs will likely be laggards.

Exhibit 87: Summary of OEM/EV Stocks

Value Chain	Stock	Rating	PT	Currency	% Upside / Downside	YTD Perf	Analyst
OEM/EV	BMW	UW	90.00	EUR	-3%	29%	Harald Hendrikse
OEM/EV	BYD	UW	135.00	CNY	-56%	48%	Tim Hsiao
OEM/EV	Daimler	OW	80.00	EUR	-9%	54%	Harald Hendrikse
OEM/EV	GM	OW	75.00	USD	18%	57%	Adam Jonas
OEM/EV	Hyundai Motor	EW	240,000.00	KRW	15%	0%	Young Suk Shin
OEM/EV	Kia	EW	100,000.00	KRW	15%	36%	Young Suk Shin
OEM/EV	Li Auto	OW	39.00 USD	USD	28%	-6%	Tim Hsiao
OEM/EV	Renault	OW	45.00	EUR	31%	-4%	Harald Hendrikse
OEM/EV	Stellantis	OW	19.00	EUR	6%	49%	Harald Hendrikse
OEM/EV	Tesla	OW	1,200.00	USD	16%	42%	Adam Jonas
OEM/EV	Toyota	OW	2,300.00	JPY	11%	31%	Shinji Kakiuchi
OEM/EV	Volkswagen	EW	185.00	EUR	-2%	27%	Harald Hendrikse
OEM/EV	Xpeng	OW	57.00 USD	USD	17%	10%	Tim Hsiao

Source: Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

Recycling

Recycling Subsector Takeaways

- **Role: After the battery has reached the end of its useful life in an electric vehicle, we reach the 'urban mining' part of the battery value chain that closes the loop. Batteries can be recycled and broken down into their original commodity feedstocks – lithium, nickel, cobalt, etc – for reuse in new batteries.**
- **TAM: Similar to the 'earth mining' TAM we referenced above, we estimate that the 2040 'urban mining' TAM is embedded within the materials TAM of ~$315bn.**
- **Stocks: For battery recycling exposure, we highlight Li-Cycle in the US, Norsk Hydro in Europe, and GEM in Asia.**
- **Supply & Demand: Demand for battery recycling is here now. While batteries in EVs have mostly yet to reach the end of their useful lives, the manufacturing scrap associated with battery production is one key source of recycling feedstock that is currently available. We view battery recycling as a 'triple nested ESG bet' that will be necessary in the future, with few players operating in the arena currently.**

Finally, once the battery has been used in the electric vehicle for some time, it will eventually drop to <80% of original capacity after many charging cycles. At that point, the battery has reached the end of its useful life inside an electric vehicle. It must be either be discarded, given a second life (more on that in Appendix I - Battery Primer), or recycled. Battery recycling is the process of taking EV batteries and decomposing it into its components, eventually into the original raw materials (lithium, nickel, cobalt, etc) that can be reused in new batteries. We view this as a a 'triple-nestled ESG bet.' EVs are critical to address climate change, but batteries are 'dirty', particularly the mining of batteries. Battery recycling can help address the problem but current pyro-based battery recycling tech also creates harmful emissions, potentially creating new climate problems faster than we're solving them. And a nearly 100-fold increase in end-of-life battery supply by 2035 creates a mountain of a TAM.

Recycling Stocks. Rounding out the battery value chain, recycling is an important final step to "close the loop" through urban mining.

- In the US, we recently initiated coverage on **Li-Cycle** (covered by Adam Jonas), a North American battery recycling company that uses a hydrometallurgical process that minimizes carbon emissions. For more, please see *Cautiously Selective in EV De-SPAC Land: Initiating LICY at OW, LCID and REE at UW*. Other relevant names in this space include **Redwood Materials** (private, not covered), a private company founded by ex-Tesla CTO JB Straubel (see *here* for our thoughts on Redwood's recently announced partnership with Ford).
- In Europe, as we wrote in *Closing The Loop*, recycling names to watch include **Norsk Hydro** (covered by Ioannis Masvoulas)**,** which recycles aluminium scrap and is involved in EV battery recycling.
- In Asia, we highlight **GEM** (covered by Rachel Zhang), which also employs a hydrometallurgical recycling process. By 2025, the company aims for largely the same amount of nickel raw materials sourced from 1) the self-owned project (QMB project, 50ktpa); 2) recycled metal (~50ktpa); and 3) externally purchased. Beyond GEM, we expect an Asian recycling industry to soon emerge and prevail in the coming years, thanks to government support and growing supply from aging EV batteries (see *EV battery retirement plans* for more).

Exhibit 88: Summary of Recycling Stocks

Value Chain	Stock	Rating	PT	Currency	% Upside / Downside	YTD Perf	Analyst
Recycling	GEM	OW	14.70	CNY	42%	35%	Rachel Zhang
Recycling	Li-Cycle	OW	15.00	USD	13%	29%	Adam Jonas
Recycling	Norsk Hydro	OW	84.00	NOK	29%	66%	Ioannis Masvoulas

Source: Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

Quantifying the Battery Portfolio

For our global battery stock portfolio, 25 Morgan Stanley equity analysts across 7 sectors in North America, Europe, and Asia nominated their most exposed names across the battery value chain from the mining of raw materials to recycling. Below, we summarize the 71 stocks in our battery 'basket' in three ways: 1) descriptive statistics (rating, PT, YTD performance), 2) valuation/financials (market cap, revenue, EBITDA, P/E, and EV/EBITDA), and 3) and our survey results by value chain.

First, we summarize the average rating, PT upside/downside, and YTD performance across the value chain.

Exhibit 89: Descriptive Data Summary

Value Chain	Subgroup	Stock	Ticker	Rating	Ccy	PT	% Upside/Downside	YTD Perf	Region	Analyst
Mining	Lithium	Albemarle	ALB.N	UW	USD	80.00	-71%	81%	USA	Vincent Andrews
Mining	Lithium	Ganfeng Lithium	1772.HK	OW	HKD	189.00	33%	36%	China	Rachel Zhang
Mining	Lithium	Mineral Resources	MIN.AX	UW	AUD	38.70	-3%	4%	Australia	Rahul Anand
Mining	Lithium	Orocobre	ORE.AX	EW	AUD	8.65	-11%	113%	Australia	Rahul Anand
Mining	Lithium	SQM	SQM.N	UW	USD	51.00	-23%	29%	Latam	Javier Martinez de Olcoz Cerdan/Roberto Browne
Mining	Lithium/Nickel	IGO	IGO.AX	UW	AUD	8.25	-16%	47%	Australia	Rahul Anand
Mining	Copper	29Metals	29M.AX	OW	AUD	2.90	7%	NA	Australia	Rahul Anand
Mining	Copper	Antofagasta	ANTO.L	UW	GBP	1,060.00	-29%	-1%	Europe	Ioannis Masvoulas
Mining	Copper	Freeport McMoRan	FCX.N	EW	USD	32.00	-22%	52%	USA	Carlos de Alba
Mining	Copper	Grupo Mexico	GMEXICOB.MX	EW	MXN	104.00	19%	-2%	Latam	Carlos de Alba
Mining	Copper	KGHM	KGH.WA	EW	PLN	160.00	1%	-18%	Europe	Dan Shaw
Mining	Copper	OZ Minerals	OZL.AX	EW	AUD	23.20	-9%	33%	Australia	Rahul Anand
Mining	Copper	Sandfire Resources	SFR.AX	OW	AUD	6.60	10%	18%	Australia	Rahul Anand
Mining	Copper/Nickel	Boliden	BOL.ST	EW	SEK	320.00	4%	3%	Europe	Ioannis Masvoulas
Mining	Copper / Nickel	Glencore	GLEN.L	OW	GBP	430.00	17%	51%	Europe	Alain Gabriel
Mining	Copper / Nickel	Lundin Mining	LUMIN.ST	EW	SEK	73.00	-5%	1%	Europe	Ioannis Masvoulas
Mining	Copper/Nickel	Norilsk Nickel	NKELyq.L	UW	USD	29.00	-5%	-8%	Europe	Dan Shaw
Mining	Nickel	Western Areas	WSA.AX	EW	AUD	2.90	-6%	14%	Australia	Rahul Anand
Mining	Cobalt	Huayou Cobalt	603799.SS	OW	CNY	160.00	37%	34%	China	Rachel Zhang
Mining	Graphite	Syrah Resources	SYR.AX	UW	AUD	1.05	-20%	35%	Australia	Rahul Anand
Mining	Equipment	Epiroc	EPIRa.ST	EW	SEK	196.00	-14%	52%	Europe	Robert Davies
Mining	Equipment	Komatsu	6301.T	OW	JPY	3,600.00	18%	8%	Japan	Yoshinao Ibara
Mining Median							**-5%**	**29%**		
Components	Cathode	BASF	BASFn.DE	EW	EUR	79.00	26%	-3%	Europe	Charlie Webb
Components	Cathode	Easpring	300073.SZ	UW	CNY	22.00	-77%	38%	China	Jack Lu
Components	Cathode	Ecopro BM	247540.KQ	OW	KRW	600,000.00	7%	201%	Korea	Ryan Kim
Components	Cathode	GEM	002340.SZ	OW	CNY	14.70	42%	35%	China	Rachel Zhang
Components	Cathode	Huayou Cobalt	603799.SS	OW	CNY	160.00	37%	34%	China	Rachel Zhang
Components	Cathode	L&F	066970.KQ	OW	KRW	280,000.00	22%	212%	Korea	Ryan Kim
Components	Cathode	ShanShan	600884.SS	UW	CNY	10.69	-72%	103%	China	Jack Lu
Components	Cathode	Sumitomo Chemical	4005.T	OW	JPY	730.00	25%	44%	Japan	Takato Watabe
Components	Cathode	Tesla	TSLA.O	OW	USD	1,200.00	16%	42%	USA	Adam Jonas
Components	Cathode	Umicore	UMI.BR	EW	EUR	45.00	-3%	15%	Europe	Charlie Webb
Components	Anode	Putailai	603659.SS	EW	CNY	144.50	-22%	110%	China	Jack Lu
Components	Anode	Quantumscape	QS.N	OW	USD	70.00	80%	-22%	USA	Adam Jonas
Components	Anode	ShanShan	600884.SS	UW	CNY	10.69	-72%	103%	China	Jack Lu
Components	Anode	Tesla	TSLA.O	OW	USD	1,200.00	16%	42%	USA	Adam Jonas
Components	Electrolyte	Mitsubishi Chem	4188.T	OW	JPY	1,400.00	47%	53%	Japan	Takato Watabe
Components	Electrolyte	Quantumscape	QS.N	OW	USD	70.00	80%	-22%	USA	Adam Jonas
Components	Separator	Asahi Kasei	3407.T	EW	JPY	1,350.00	18%	10%	Japan	Takato Watabe
Components	Separator	Putailai	603659.SS	EW	CNY	144.50	-22%	110%	China	Jack Lu
Components	Separator	Quantumscape	QS.N	OW	USD	70.00	80%	-22%	USA	Adam Jonas
Components	Separator	Sumitomo Chemical	4005.T	OW	JPY	730.00	25%	44%	Japan	Takato Watabe
Components	Separator	Toray	3402.T	EW	JPY	800.00	11%	20%	Japan	Takato Watabe
Components	Separator	Yunnan Energy New Material	002812.SZ	UW	CNY	59.50	-78%	77%	China	Jack Lu
Components Median							**17%**	**42%**		
Cell	Manufacturing	BYD	002594.SZ	UW	CNY	135.00	-56%	48%	China	Tim Hsiao
Cell	Manufacturing	CATL	300750.SZ	UW	CNY	251.00	-61%	59%	China	Jack Lu
Cell	Manufacturing	Freyr	FREY.N	OW	USD	18.00	64%	9%	USA	Adam Jonas
Cell	Manufacturing	Guoxuan High-tech	002074.SZ	EW	CNY	36.40	-43%	56%	China	Jack Lu
Cell	Manufacturing	Panasonic	6752.T	OW	JPY	1,900.00	34%	19%	Japan	Masahiro Ono
Cell	Manufacturing	Samsung SDI	006400.KS	EW	KRW	720,000.00	-4%	12%	Korea	Shawn Kim
Cell	Manufacturing	SK Innovation	096770.KS	OW	KRW	340,000.00	50%	-2%	Korea	Young Suk Shin
Cell	Equipment	Axalta Coating	AXTA.N	EW	USD	35.00	6%	17%	USA	Vincent Andrews
Cell	Equipment	Celanese	CE.N	EW	USD	157.00	-8%	35%	USA	Vincent Andrews
Cell	Equipment	Fanuc	6954.T	OW	JPY	29,000.00	25%	-9%	Japan	Yoshinao Ibara
Cell	Equipment	PPG	PPG.N	EW	USD	175.00	8%	14%	USA	Vincent Andrews
Cell	Equipment	Putailai	603659.SS	EW	CNY	144.50	-22%	110%	China	Jack Lu
Cell	Equipment	Wuxi Lead	300450.SZ	EW	CNY	78.90	-10%	60%	China	Zhuoran Wang
Cell	Equipment	Yinghe	300457.SZ	UW	CNY	22.20	-45%	22%	China	Zhuoran Wang
Cell	Semiconductor	Analog Devices	ADI.O	EW	USD	179.00	-3%	27%	USA	Joe Moore
Cell	Semiconductor	Infineon	IFXGn.DE	OW	EUR	42.50	-1%	33%	Europe	Dominik Olszewski
Cell	Semiconductor	NXP	NXPI.O	EW	USD	241.00	11%	34%	USA	Joe Moore
Cell	Semiconductor	Rohm	6963.T	EW	JPY	11,000.00	-3%	11%	Japan	Kazuo Yoshikawa
Cell	Semiconductor	Sensata	ST.N	OW	USD	73.00	20%	17%	USA	Joe Moore
Cell	Semiconductor	STMicroelectronics	STM.PA	OW	EUR	43.50	-3%	41%	Europe	Dominik Olszewski
Cell	Semiconductor	TE Connectivity	TEL.N	EW	USD	149.00	-9%	37%	USA	Joe Moore
Cell	Semiconductor	Wolfspeed	WOLF.N	EW	USD	103.00	-26%	30%	USA	Joe Moore
Cell	Packaging	CATL	300750.SZ	UW	CNY	251.00	-61%	59%	China	Jack Lu
Cell	Packaging	Tesla	TSLA.O	OW	USD	1,200.00	16%	42%	USA	Adam Jonas
Cell	Packaging	Volkswagen	VOWG_p.DE	EW	EUR	185.00	-2%	27%	Europe	Harald Hendrikse
Cell Median							**-3%**	**30%**		
OEM/EV		BMW	BMWG.DE	UW	EUR	90.00	-3%	29%	Europe	Harald Hendrikse
OEM/EV		BYD	002594.SZ	UW	CNY	135.00	-56%	48%	China	Tim Hsiao
OEM/EV		Daimler	DAIGn.DE	OW	EUR	80.00	-9%	54%	Europe	Harald Hendrikse
OEM/EV		GM	GM.N	OW	USD	75.00	18%	57%	USA	Adam Jonas
OEM/EV		Hyundai Motor	005380.KS	EW	KRW	240,000.00	15%	0%	Korea	Young Suk Shin
OEM/EV		Kia	000270.KS	EW	KRW	100,000.00	15%	36%	Korea	Young Suk Shin
OEM/EV		Li Auto	LI.O	OW	USD	39.00	28%	-6%	China	Tim Hsiao
OEM/EV		Renault	RENA.PA	OW	EUR	45.00	31%	-4%	Europe	Harald Hendrikse
OEM/EV		Stellantis	STLA.MI	OW	EUR	19.00	6%	49%	Europe	Harald Hendrikse
OEM/EV		Tesla	TSLA.O	OW	USD	1,200.00	16%	42%	USA	Adam Jonas
OEM/EV		Toyota	7203.T	OW	JPY	2,300.00	11%	31%	Japan	Shinji Kakiuchi
OEM/EV		Volkswagen	VOWG_p.DE	EW	EUR	185.00	-2%	27%	Europe	Harald Hendrikse
OEM/EV		Xpeng	XPEV.N	OW	USD	57.00	17%	10%	China	Tim Hsiao
OEM/EV Median							**15%**	**31%**		
Recycling		GEM	002340.SZ	OW	CNY	14.70	42%	35%	China	Rachel Zhang
Recycling		Li-Cycle	LICY.N	OW	USD	15.00	13%	29%	USA	Adam Jonas
Recycling		Norsk Hydro	NHY.OL	OW	NOK	84.00	29%	66%	Europe	Ioannis Masvoulas
Recycling Median							**29%**	**35%**		

Source: Company data, Morgan Stanley Research: Note: prices as of 12Nov21; Ratings: OW=Overweight, EW=Equal-weight; UW=Underweight

Next, in terms of financials and valuation, we summarize the market cap, revenue, EBITDA, P/E multiple, and EV/EBITDA multiple for 2021 and 2022 by value chain.

Exhibit 90: Valuation Summary

Value Chain	Stock	Mkt Cap ($B)	Revenue ($B)		EBITDA ($B)		P/E		EV/EBITDA	
			2021	2022	2021	2022	2021	2022	2021	2022
Mining	Albemarle	$32.3B	$3.3B	$3.7B	$0.8B	$1.1B	69.7x	52.7x	39.5x	31.5x
Mining	Ganfeng Lithium	$5.3B	$1.2B	$1.9B	$0.4B	$0.9B	65.2x	39.8x	62.9x	32.4x
Mining	Mineral Resources	$5.5B	$2.7B	$2.3B	$1.4B	$0.5B	6.7x	26.1x	5.2x	10.5x
Mining	Orocobre	$4.5B	$0.1B	$0.3B	$0.0B	$0.2B	NM	29.5x	90.5x	19.2x
Mining	SQM	$14.1B	$2.7B	$3.9B	$1.0B	$1.6B	43.5x	25.0x	20.1x	13.2x
Mining	IGO	$5.4B	$0.7B	$0.5B	$0.3B	$0.2B	38.9x	22.8x	9.8x	19.1x
Mining	29Metals	$0.9B	$0.5B	$0.5B	$0.1B	$0.1B	179.7x	50.4x	9.4x	7.2x
Mining	Antofagasta	$18.2B	$7.2B	$5.8B	$4.4B	$3.0B	14.2x	27.3x	5.3x	7.9x
Mining	Freeport McMoRan	$60.5B	$23.0B	$23.7B	$10.8B	$10.4B	12.9x	13.0x	6.4x	6.5x
Mining	Grupo Mexico	$33.2B	$14.8B	$13.5B	$8.9B	$6.9B	9.0x	11.4x	4.2x	5.2x
Mining	KGHM	$8.0B	$7.6B	$6.5B	$2.5B	$2.1B	5.7x	6.9x	3.4x	3.4x
Mining	OZ Minerals	$6.2B	$1.4B	$1.5B	$0.8B	$0.9B	16.3x	13.9x	7.9x	6.8x
Mining	Sandfire Resources	$1.8B	$0.6B	$0.6B	$0.3B	$0.4B	6.0x	11.4x	1.3x	0.6x
Mining	Boliden	$9.5B	$7.9B	$6.9B	$1.9B	$1.9B	9.7x	10.6x	5.3x	5.5x
Mining	Glencore	$62.4B	$204.0B	$204.9B	$20.0B	$19.8B	6.8x	6.8x	5.0x	4.6x
Mining	Lundin Mining	$6.5B	$3.2B	$2.9B	$1.8B	$1.5B	8.1x	10.4x	4.5x	5.1x
Mining	Norilsk Nickel	$46.4B	$17.9B	$18.0B	$11.8B	$12.6B	5.9x	5.7x	4.8x	4.6x
Mining	Western Areas	$0.7B	$0.2B	$0.2B	$0.1B	$0.1B	NM	29.7x	8.3x	6.9x
Mining	Huayou Cobalt	$22.8B	$5.8B	$7.4B	$0.9B	$1.2B	36.5x	34.4x	24.8x	19.8x
Mining	Syrah Resources	$0.5B	$0.0B	$0.1B	$0.0B	$0.0B	NM	NM	NM	NM
Mining	Epiroc	$29.9B	$4.6B	$5.4B	$1.3B	$1.5B	39.1x	33.6x	23.9x	20.0x
Mining	Komatsu	$26.7B	$23.0B	$25.0B	$3.8B	$4.8B	15.3x	11.1x	8.5x	6.5x
Mining Median		**$8.7B**	**$3.3B**	**$3.8B**	**$1.1B**	**$1.3B**	**14.2x**	**22.8x**	**7.9x**	**6.9x**
Components	BASF	$66.7B	$89.7B	$83.6B	$13.4B	$11.6B	10.3x	13.4x	6.3x	7.3x
Components	Easpring	$6.9B	$0.6B	$0.8B	$0.1B	$0.2B	75.4x	54.0x	50.4x	34.4x
Components	Ecopro BM	$10.3B	$1.2B	$2.0B	$0.1B	$0.2B	112.7x	72.3x	52.2x	34.8x
Components	GEM	$7.9B	$3.6B	$5.6B	$0.5B	$0.7B	32.1x	21.1x	17.4x	13.4x
Components	Huayou Cobalt	$22.8B	$5.8B	$7.4B	$0.9B	$1.2B	36.5x	34.4x	24.8x	19.8x
Components	L&F	$6.7B	$0.9B	$2.1B	$0.0B	$0.2B	355.6x	64.8x	64.8x	19.7x
Components	ShanShan	$10.0B	$1.9B	$2.1B	$0.3B	$0.3B	115.2x	104.9x	35.7x	34.3x
Components	Sumitomo Chemical	$8.7B	$24.3B	$24.8B	$3.5B	$3.6B	7.4x	6.8x	6.4x	6.1x
Components	Tesla	$1023.1B	$50.9B	$66.9B	$8.7B	$12.8B	171.7x	130.9x	132.9x	89.4x
Components	Umicore	$13.2B	$4.9B	$4.8B	$1.6B	$1.3B	14.6x	20.4x	8.9x	11.6x
Components	Putailai	$20.6B	$1.3B	$1.8B	$0.4B	$0.5B	77.3x	58.3x	51.5x	38.8x
Components	Quantumscape	$16.4B	$0.0B	$0.0B	-$0.1B	-$0.2B	NM	NM	NM	NM
Components	ShanShan	$10.0B	$1.9B	$2.1B	$0.3B	$0.3B	115.2x	104.9x	35.7x	34.3x
Components	Tesla	$1023.1B	$50.9B	$66.9B	$8.7B	$12.8B	171.7x	130.9x	132.9x	89.4x
Components	Mitsubishi Chem	$12.9B	$34.9B	$36.4B	$4.9B	$5.2B	8.6x	7.5x	7.5x	6.9x
Components	Quantumscape	$16.4B	$0.0B	$0.0B	-$0.1B	-$0.2B	NM	NM	NM	NM
Components	Asahi Kasei	$14.4B	$22.0B	$23.1B	$2.9B	$3.0B	9.7x	11.2x	6.4x	6.0x
Components	Putailai	$20.6B	$1.3B	$1.8B	$0.4B	$0.5B	77.3x	58.3x	51.5x	38.8x
Components	Quantumscape	$16.4B	$0.0B	$0.0B	-$0.1B	-$0.2B	NM	NM	NM	NM
Components	Sumitomo Chemical	$8.7B	$24.3B	$24.8B	$3.5B	$3.6B	7.4x	6.8x	6.4x	6.1x
Components	Toray	$10.6B	$20.1B	$21.0B	$2.2B	$2.3B	12.7x	11.5x	8.0x	7.4x
Components	Yunnan Energy New Material	$39.1B	$1.1B	$1.5B	$0.5B	$0.6B	162.0x	120.0x	84.9x	64.7x
Components Median		**$13.8B**	**$2.7B**	**$3.5B**	**$0.5B**	**$0.7B**	**75.4x**	**54.0x**	**30.2x**	**19.8x**
Cell	BYD	$90.0B	$34.6B	$43.9B	$3.1B	$4.2B	186.0x	97.0x	45.6x	38.6x
Cell	CATL	$238.9B	$18.1B	$24.8B	$3.3B	$5.2B	186.8x	125.0x	71.5x	45.4x
Cell	Freyr	$1.3B	$0.0B	$0.0B	-$0.1B	-$0.1B	NM	NM	NM	NM
Cell	Guoxuan High-tech	$13.1B	$1.4B	$1.6B	$0.3B	$0.3B	222.6x	168.6x	46.8x	38.9x
Cell	Panasonic	$31.2B	$66.8B	$68.8B	$5.4B	$5.8B	11.1x	10.0x	4.8x	4.1x
Cell	Samsung SDI	$43.3B	$11.6B	$14.5B	$1.5B	$1.8B	41.2x	34.4x	30.6x	25.8x
Cell	SK Innovation	$17.5B	$38.3B	$47.3B	$3.1B	$3.4B	36.5x	15.4x	8.0x	7.6x
Cell	Axalta Coating	$7.6B	$4.5B	$5.1B	$0.9B	$1.0B	18.8x	15.2x	11.7x	10.0x
Cell	Celanese	$18.9B	$8.6B	$9.1B	$2.8B	$2.5B	9.3x	10.6x	8.4x	9.1x
Cell	Fanuc	$42.0B	$6.7B	$7.4B	$2.4B	$2.9B	25.0x	19.6x	14.6x	11.7x
Cell	PPG	$38.4B	$16.6B	$18.9B	$2.6B	$3.0B	24.1x	20.3x	17.1x	14.2x
Cell	Putailai	$20.6B	$1.3B	$1.8B	$0.4B	$0.5B	77.3x	58.3x	51.5x	38.8x
Cell	Wuxi Lead	$21.9B	$1.5B	$2.1B	$0.3B	$0.4B	91.7x	66.9x	76.5x	56.4x
Cell	Yinghe	$4.2B	$0.7B	$0.9B	$0.1B	$0.1B	64.8x	47.2x	35.7x	25.2x
Cell	Analog Devices	$99.1B	$7.3B	$10.0B	$3.3B	$4.8B	28.8x	25.6x	19.1x	12.9x
Cell	Infineon	$64.8B	$12.8B	$14.9B	$3.5B	$4.6B	29.6x	22.1x	16.0x	12.3x
Cell	NXP	$57.9B	$11.0B	$11.8B	$4.1B	$4.1B	20.6x	18.9x	14.8x	12.6x
Cell	Rohm	$10.5B	$3.9B	$4.0B	$1.0B	$1.1B	22.0x	21.4x	7.7x	6.9x
Cell	Sensata	$9.6B	$3.8B	$4.0B	$0.9B	$1.0B	17.5x	15.3x	11.2x	9.8x
Cell	STMicroelectronics	$47.4B	$12.6B	$14.0B	$3.3B	$3.8B	21.6x	18.1x	12.0x	10.4x
Cell	TE Connectivity	$53.6B	$14.9B	$15.6B	$3.5B	$3.6B	25.2x	23.3x	14.1x	15.9x
Cell	Wolfspeed	$16.2B	$0.6B	$0.7B	$0.0B	$0.0B	NM	NM	NM	NM
Cell	CATL	$238.9B	$18.1B	$24.8B	$3.3B	$5.2B	186.8x	125.0x	71.5x	45.4x
Cell	Tesla	$1023.1B	$50.9B	$66.9B	$8.7B	$12.8B	171.7x	130.9x	132.9x	89.4x
Cell	Volkswagen	$45.0B	$282.0B	$297.2B	$42.8B	$44.4B	6.7x	6.4x	1.8x	1.6x
Cell Median		**$38.4B**	**$11.0B**	**$11.8B**	**$2.8B**	**$3.0B**	**28.8x**	**22.1x**	**16.0x**	**12.9x**
OEM/EV	BMW	$65.0B	$127.9B	$158.5B	$21.2B	$22.3B	6.3x	7.5x	2.8x	2.8x
OEM/EV	BYD	$90.0B	$34.6B	$43.9B	$3.1B	$4.2B	186.0x	97.0x	45.6x	38.6x
OEM/EV	Daimler	$109.1B	$197.5B	$213.9B	$30.8B	$29.6B	7.5x	7.9x	3.6x	3.5x
OEM/EV	GM	$92.0B	$128.7B	$148.9B	$17.8B	$21.1B	9.9x	8.9x	5.2x	4.2x
OEM/EV	Hyundai Motor	$37.2B	$98.2B	$98.5B	$9.5B	$9.4B	7.2x	7.7x	10.7x	10.6x
OEM/EV	Kia	$29.5B	$59.5B	$60.3B	$6.5B	$7.0B	7.3x	7.6x	3.5x	2.8x
OEM/EV	Li Auto	$30.6B	$24.2B	$46.3B	-$2.0B	-$0.1B	NM	NM	NM	NM
OEM/EV	Renault	$11.8B	$53.7B	$59.4B	$6.7B	$8.0B	8.0x	4.3x	2.5x	1.8x
OEM/EV	Stellantis	$65.0B	$171.3B	$186.0B	$23.7B	$24.9B	5.5x	5.1x	2.7x	2.6x
OEM/EV	Tesla	$1023.1B	$50.9B	$66.9B	$8.7B	$12.8B	171.7x	130.9x	132.9x	89.4x
OEM/EV	Toyota	$304.7B	$286.3B	$298.0B	$34.1B	$37.5B	11.5x	10.5x	11.8x	10.4x
OEM/EV	Volkswagen	$45.0B	$282.0B	$297.2B	$42.8B	$44.4B	6.7x	6.4x	1.8x	1.6x
OEM/EV	Xpeng	$37.9B	$19.4B	$38.1B	-$5.6B	-$7.6B	NM	NM	NM	NM
OEM/EV Median		**$65.0B**	**$98.2B**	**$98.5B**	**$9.5B**	**$12.8B**	**7.5x**	**7.7x**	**3.6x**	**3.5x**
Recycling	GEM	$7.9B	$3.6B	$5.6B	$0.5B	$0.7B	32.1x	21.1x	17.4x	13.4x
Recycling	Li-Cycle	$2.2B	$0.0B	$0.0B	$0.0B	$0.0B	NM	NM	NM	NM
Recycling	Norsk Hydro	$14.6B	$17.8B	$22.6B	$3.2B	$4.5B	9.4x	6.3x	5.2x	3.4x
Recycling Median		**$7.9B**	**$3.6B**	**$5.6B**	**$0.5B**	**$0.7B**	**20.8x**	**13.7x**	**11.3x**	**8.4x**

Source: Company data, Morgan Stanley Research: Note: prices as of 12Nov21

Finally, to provide a more qualitative/strategic perspective, we asked analysts to categorize the 71 stocks in our portfolio according to tech cycle placement, beneficiary time horizon, durability of moat, and how much is already priced in.

Exhibit 91: Morgan Stanley Global Battery Portfolio Survey Summary

Value Chain	Stock	Tech Cycle Categorization			Beneficiary Time Horizon				Durability of Moat - Conviction?				Priced in?		
		Enabler	*Infrastructure/ Hardware*	*Recurring Revenue/Services*	*Immediately*	*Near Term (3-5yrs)*	*Medium Term (5-7yrs)*	*Long term (7yrs +)*	*Very Strong*	*Strong*	*Neutral*	*Questionable*	*Not priced in*	*Somewhat priced in*	*Fully priced in*
Mining	Albemarle	0	1	0	1	0	0	0	1	0	0	0	0	0	1
Mining	Ganfeng Lithium	1	0	0	1	0	0	0	1	0	0	0	0	1	0
Mining	Mineral Resources	1	0	0	1	0	0	0	1	0	0	0	0	0	1
Mining	Orocobre	1	0	0	1	0	0	0	1	0	0	0	0	0	1
Mining	SQM	1	0	1	1	1	1	0	1	0	0	0	0	0	1
Mining	IGO	1	0	0	1	0	0	0	1	0	0	0	0	0	1
Mining	29Metals	0	1	0	0	1	0	0	0	1	0	0	1	0	0
Mining	Antofagasta	1	0	0	0	1	0	0	0	0	1	0	0	0	1
Mining	Freeport McMoRan	0	1	1	0	1	0	0	0	1	0	0	0	1	0
Mining	Grupo Mexico	0	1	1	0	1	0	0	0	1	0	0	0	1	0
Mining	KGHM	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Mining	OZ Minerals	0	1	0	0	1	0	0	0	1	0	0	0	1	0
Mining	Sandfire Resources	0	1	0	0	1	0	0	0	1	0	0	1	0	0
Mining	Boliden	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Mining	Glencore	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Mining	Lundin Mining	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Mining	Norilsk Nickel	1	0	0	0	1	0	0	0	0	1	0	0	0	1
Mining	Western Areas	1	0	0	1	0	0	0	0	1	0	0	0	1	0
Mining	Huayou Cobalt	1	0	0	1	0	0	0	0	0	1	0	0	1	0
Mining	Syrah Resources	1	0	0	1	0	0	0	0	0	0	1	0	0	1
Mining	Epiroc	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Mining	Komatsu	0	1	0	1	0	0	0	0	1	0	0	0	1	0
Mining Total		**15**	**7**	**3**	**10**	**13**	**1**	**0**	**6**	**9**	**6**	**1**	**2**	**12**	**8**
Components	BASF	1	0	0	0	1	0	0	0	0	0	1	1	0	0
Components	Easpring	0	1	0	0	0	1	0	0	0	1	0	0	0	1
Components	Ecopro BM	1	0	0	1	0	0	0	1	0	0	0	0	1	0
Components	GEM	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Components	Huayou Cobalt	1	0	0	1	0	0	0	0	0	1	0	0	1	0
Components	L&F	1	0	0	1	0	0	0	1	0	0	0	0	1	0
Components	ShanShan	0	1	0	0	0	1	0	0	0	1	0	0	0	1
Components	Sumitomo Chemical	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Components	Tesla	1	1	1	1	0	0	0	1	0	0	0	1	0	0
Components	Umicore	1	0	0	0	1	0	0	0	0	0	1	0	0	1
Components	Putailai	0	1	0	0	0	1	0	0	1	0	0	0	1	0
Components	Quantumscape	1	0	0	0	1	0	0	0	0	0	1	0	1	0
Components	ShanShan	0	1	0	0	0	1	0	0	0	1	0	0	0	1
Components	Tesla	1	1	1	1	0	0	0	1	0	0	0	1	0	0
Components	Mitsubishi Chem	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Components	Quantumscape	1	0	0	0	1	0	0	0	0	0	1	0	1	0
Components	Asahi Kasei	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Components	Putailai	0	1	0	0	0	1	0	0	1	0	0	0	1	0
Components	Quantumscape	1	0	0	0	1	0	0	0	0	0	1	0	1	0
Components	Sumitomo Chemical	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Components	Toray	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Components	Yunnan Energy New Material	0	1	0	0	0	1	0	0	1	0	0	0	0	1
Components Total		**16**	**8**	**2**	**5**	**11**	**6**	**0**	**4**	**7**	**6**	**5**	**3**	**14**	**5**
Cell	BYD	1	1	0	0	1	0	0	0	1	0	0	0	0	1
Cell	CATL	1	1	0	0	0	1	0	0	1	0	0	0	0	1
Cell	Freyr	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Cell	Guoxuan High-tech	0	1	0	0	0	1	0	0	0	1	0	0	1	0
Cell	Panasonic	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Cell	Samsung SDI	1	0	0	1	1	0	0	0	0	0	1	0	0	1
Cell	SK Innovation	1	1	0	1	0	0	0	0	1	0	0	0	1	0
Cell	Axalta Coating	0	1	0	0	1	0	0	0	0	1	0	1	0	0
Cell	Celanese	0	1	0	1	1	0	0	0	1	0	0	0	1	0
Cell	Fanuc	0	1	0	1	0	0	0	0	1	0	0	0	1	0
Cell	PPG	0	1	0	0	1	0	0	0	0	1	0	0	1	0
Cell	Putailai	0	1	0	0	0	1	0	0	1	0	0	0	1	0
Cell	Wuxi Lead	1	1	0	1	1	0	0	1	0	0	0	0	1	0
Cell	Yinghe	1	1	0	1	1	0	0	0	1	0	0	0	1	0
Cell	Analog Devices	1	0	0	0	1	1	1	0	1	0	0	0	1	0
Cell	Infineon	1	1	0	0	1	0	0	0	1	0	0	0	1	0
Cell	NXP	1	0	0	0	1	1	1	0	1	0	0	0	1	0
Cell	Rohm	0	1	0	0	1	1	0	0	1	0	0	1	0	0
Cell	Sensata	1	0	0	0	1	1	1	0	1	0	0	1	0	0
Cell	STMicroelectronics	1	1	0	0	1	0	0	0	1	0	0	0	1	0
Cell	TE Connectivity	1	0	0	0	1	1	1	0	1	0	0	0	1	0
Cell	Wolfspeed	1	0	0	0	1	1	1	0	1	0	0	0	1	0
Cell	CATL	1	1	0	0	0	1	0	0	1	0	0	0	0	1
Cell	Tesla	1	1	1	1	0	0	0	1	0	0	0	1	0	0
Cell	Volkswagen	0	1	0	0	0	1	0	0	0	1	0	0	1	0
Cell Total		**17**	**17**	**1**	**7**	**17**	**11**	**5**	**2**	**18**	**4**	**1**	**5**	**16**	**4**
OEM/EV	BMW	0	1	0	0	0	1	0	0	0	1	0	0	1	0
OEM/EV	BYD	1	1	0	0	1	0	0	0	1	0	0	0	0	1
OEM/EV	Daimler	0	1	0	0	0	1	0	0	0	1	0	0	1	0
OEM/EV	GM	1	0	0	0	1	0	0	0	1	0	0	1	0	0
OEM/EV	Hyundai Motor	0	1	1	1	0	0	0	0	0	1	0	0	1	0
OEM/EV	Kia	0	1	1	1	0	0	0	0	0	1	0	0	1	0
OEM/EV	Li Auto	0	1	0	1	0	0	0	0	1	0	0	0	1	0
OEM/EV	Renault	0	1	0	0	0	1	0	0	0	1	0	0	1	0
OEM/EV	Stellantis	0	1	0	0	0	1	0	0	0	1	0	0	1	0
OEM/EV	Tesla	1	1	1	1	0	0	0	1	0	0	0	1	0	0
OEM/EV	Toyota	1	0	0	0	0	1	0	0	1	0	0	1	0	0
OEM/EV	Volkswagen	0	1	0	0	0	1	0	0	0	1	0	0	1	0
OEM/EV	Xpeng	0	1	1	1	0	0	0	0	1	0	0	0	1	0
OEM/EV Total		**4**	**11**	**4**	**5**	**2**	**6**	**0**	**1**	**5**	**7**	**0**	**3**	**9**	**1**
Recycling	GEM	1	0	0	0	1	0	0	0	1	0	0	0	1	0
Recycling	Li-Cycle	0	0	1	0	0	1	1	0	0	0	1	1	0	0
Recycling	Norsk Hydro	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Recycling Total		**2**	**0**	**1**	**0**	**2**	**1**	**1**	**0**	**2**	**0**	**1**	**2**	**1**	**0**

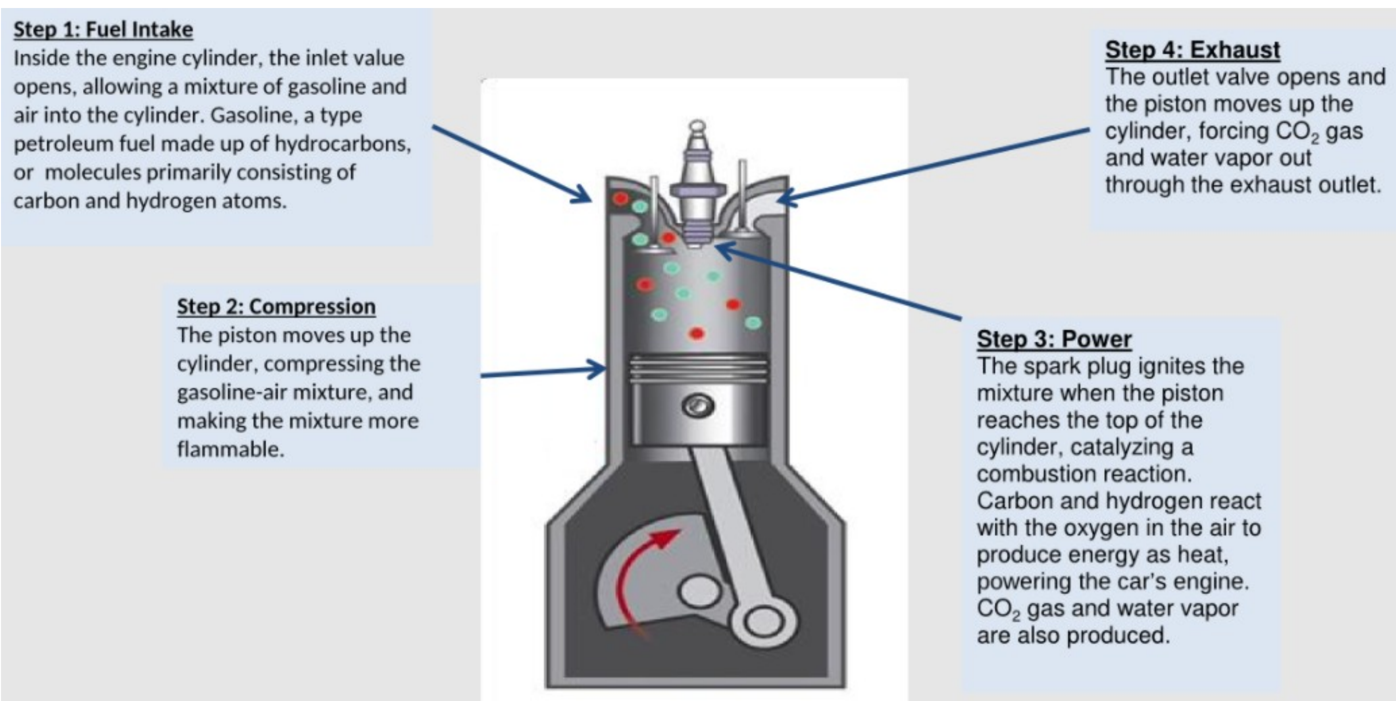
Source: Company data, Morgan Stanley Research; Note: some analysts chose to select more than one option per category

How Clean Are EV Batteries?

Jessica Alsford & Mark Carlucci

How do batteries and autos intersect with climate? As we wrote in *The Climate Opportunity of Auto 2.0: How Big Tech Drives Faster EV Adoption***,** the average car produces nearly 5 metric tons of CO2 per annum. According to the US Environmental Protection Agency (EPA), 1 gallon of gasoline converts to 8.9kg of CO2 and the average car in the US drives 11,500 miles per year. Assuming 22.2 mpg — the estimated average real-world fuel economy of the US vehicle parc — the EPA's estimates imply over 500 gallons of gasoline consumed per vehicle per annum, equivalent to 4.6 metric tons of CO2 per vehicle per year (518 gallons x 8.9kg/gallon). The vast majority of an auto company's emissions are Scope 3, due to the carbon intensity during the use of the end product – the combustion engine car. As OEMs transition away from combustion engines and towards EVs, their total carbon footprint should materially fall. We quantify the estimated CO2 emissions impact below. Please see *here* for more.

Exhibit 92: The Conversion from Gasoline to CO2 in Internal Combustion Engines



Source: Morgan Stanley Research

On the surface, switching from ICE to BEV is projected to reduce CO2 emissions. As we wrote in *The Global Auto Climate Opportunity: Is Your Car Company 'CLEAN'?*, we estimate the industry's CO2 emissions in Gt using a 'top down' approach. We start with our global autos team's BEV penetration forecasts. Global BEV sales are expect to grow at 11% CAGR from 2021 to 2050 off of a low base of 2021 global BEV penetration of 6.5%. We project BEV sales penetration of 44.2% in 2030, 86.7% in 2040, and 93.2% in 2050. In our base case, we forecast the crossover point between ICE and EV sales to occur around 2031. However, this is for EV sales. To allow for EV penetration of miles traveled, we must allow greater time to seed the car parc and this depends also on the pace of scrappage/replacement of ICE vehicles on the road, as well as the use cases (miles traveled assumptions per EV vs. ICE). While our BEV sales penetration forecast is 93.2% by 2050, our BEV parc penetration forecast is only 77.2%.

Exhibit 93: Based off of our accelerated BEV sales penetration forecasts, we estimate that CO2 emissions will fall from 3.7 Gt in 2021 to 1.2 Gt in 2050.

Global Autos Data - MSe		2021	2025	2030	2040	2050
Total Unit Sales (mm)		80	89	93	108	115
CAGR (%)			*2.7%*	*0.8%*	*1.5%*	*0.7%*
Total Car Parc (mm)		1,225	1,276	1,311	1,387	1,324
EVs as % of Sales		**6.5%**	**18.2%**	**44.2%**	**86.7%**	**93.2%**
EV Sales (mm)		5	16	41	93	107
EVs as % of Parc		**0.9%**	**3.9%**	**12.9%**	**47.2%**	**77.2%**
EV Parc (mm)		11	50	170	655	1,023
ICE Miles (bn)		11,907	12,727	13,090	10,036	5,996
EV miles (bn)		75	397	1,675	9,854	22,761
Total Miles (bn)		11,983	13,124	14,765	19,891	28,758
ICE mpg		28.4	30.0	32.7	38.6	45.5
EV Efficiency (Miles/KwH)		3.00	4.00	5.00	6.00	7.00
Total EV TwH		25	99	335	1,642	3,252
ICE Fuel Gallons (bn)		419	424	401	260	132
CO2 Emissions (Gt)	8.9	3.7	3.8	3.6	2.3	1.2

1 gallon of gasoline = 8.9kg of CO2 emitted

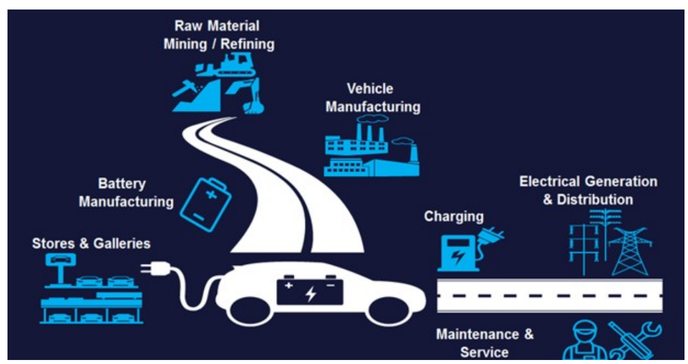
Source: Morgan Stanley Research

Sustainability Perspective of Batteries

Battery value chain introduces a new layer of emissions. Batteries require a complex and energy intensive value chain – ranging from mining to manufacturing operations. As a result, the magnitude of lifecycle emissions reductions of EVs relative to ICE vehicles represents an area of debate for investors. Many variables will determine the "greenness" of a battery – and in turn, EVs vs. ICE – including location of mining and manufacturing operations, energy mix used to power operations, and logistics and shipping requirements. Moreover, the value chain has other environmental considerations, including land disturbances from mining and water usage.

As a result, we see variability in relative decarbonization potential of EVs vs. ICE vehicles. According to data from the IEA, lifecycle emissions of EVs average ~50% of those of ICE vehicles – but can potentially decline an additional 25% through the usage of lower emission power generation (see *The Role of Critical Minerals in Clean Energy Transition*). Data from the IEA indicates that battery assembly and minerals comprise 2.6-4.0 t/CO_2e per vehicle, assuming a base and high case range for battery emissions of 35 kg of CO_2e/kWh and 70 kg of CO_2e/kWh, respectively. Relative to the IEA's estimate for ~36 kg of CO_2e/kWh for ICE fuel, the remaining relative decarbonization potential for EVs hinges on the emissions profile of electricity used to charge batteries.

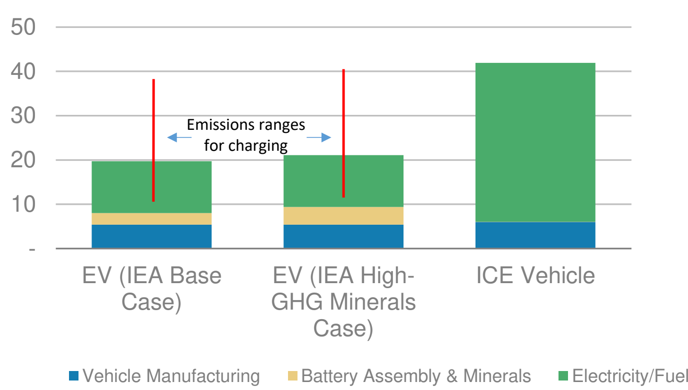
Exhibit 94: The battery value chain contains multiple ESG considerations..



Source: Morgan Stanley Research

Exhibit 95: Much of the decarbonization potential for EVs hinges on the emissions profile of electricity sourced for charging. Based on IEA data, below shows EV emissions vs. ICE vehicles.

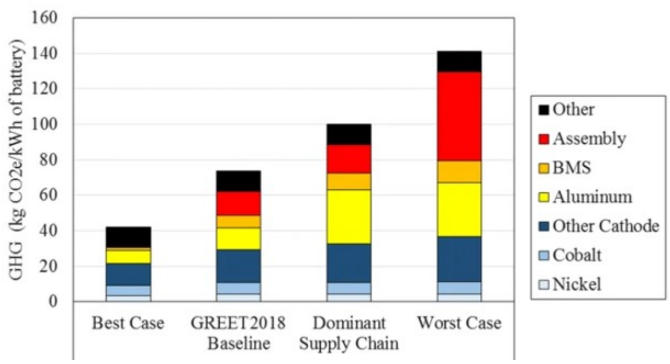
Emissions Profile: EVs vs. ICE Vehicles (tonnes CO_2e)



Source: International Energy Agency; The Role of Critical Minerals in Clean Energy Transitions; https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions; Reproduced by Morgan Stanley Research

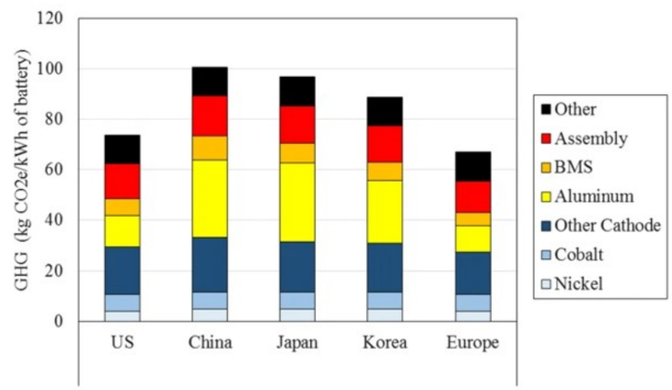
Much depends on the region of battery mining and production. China and emerging market regions still rely heavily on coal and fossil fuels for power generation. As a result, the emissions profile of value chains in these regions could be higher than those incorporating a greater share of renewable energy. According to a publication from the Argonne National Laboratory (see *here*), assessed emission scenarios for a 27 KWh NMC_{111} battery range from ~40 kg of CO_2e/kWh to ~140 kg of CO_2e/kWh. In the baseline (US-focused), the emissions profile is ~75 kg of CO_2e/kWh. In the currently dominant supply chain (China-focused), the emissions profile is ~100 kg of CO_2e/kWh. Separately, the study assessed country-specific supply chains. Battery production in the US and Europe represented the lowest emission supply chains, in large part the result of less carbon intensive electrical grids relative to other regions.

Exhibit 96: In a study from the Argonne National Laboratory, battery emission scenarios range from ~40 kg of CO_2e/kWh to ~140 kg of CO_2e/kWh. . .



Source: Kelly, J.C., Dai, Q. & Wang, M. Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. *Mitigation Adaptation Strategies Global Change* 25, 371-396 (2020). https://doi.org/10.1007/s11027-019-09869-2

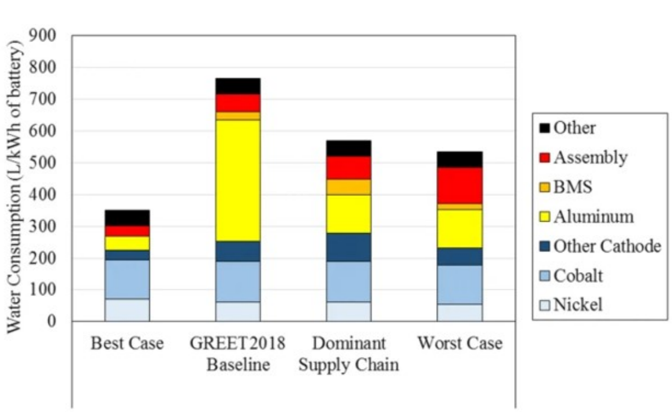
Exhibit 97: . . . largely dependent on the region of the battery supply chain.



Source: Kelly, J.C., Dai, Q. & Wang, M. Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. *Mitigation Adaptation Strategies Global Change* 25, 371-396 (2020). https://doi.org/10.1007/s11027-019-09869-2

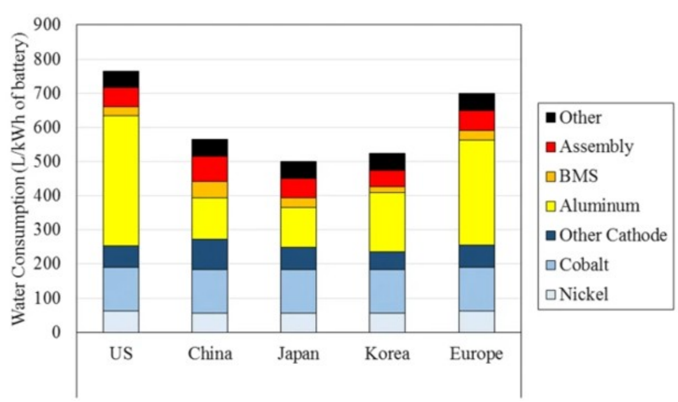
Battery production is similarly water intensive. For instance, 35% of lithium extraction occurs from salt lakes – a process that drills and pumps brine to the surface, then uses solar energy to evaporate water from salt ponds. Some of the world's major salt-lake lithium mines are located in Argentina, Chile, and China, where there is medium to high risk of water scarcity, according to our analysis of water risk data from the World Resources Institute (see *Will Cathode Evolution Drive the EV Revolution?*). This could have both environmental and social consequences, as local communities compete for use of limited water resources. Similar to CO_2 emissions, water consumption can vary widely. The same study from the Argonne National Laboratory identifies water consumption by region. Much of the difference is the result of hydroelectric power usage, which reflects evaporation from the associated water body.

Exhibit 98: In a study from the Argonne National Laboratory, water consumption scenarios range from ~350 L/kWh to ~750 L/kWh. . .



Source: Kelly, J.C., Dai, Q. & Wang, M. Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. *Mitigation Adaptation Strategies Global Change* 25, 371-396 (2020). https://doi.org/10.1007/s11027-019-09869-2

Exhibit 99: . . . largely dependent on the region of the battery supply chain.



Source: Kelly, J.C., Dai, Q. & Wang, M. Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. *Mitigation Adaptation Strategies Global Change* 25, 371-396 (2020). https://doi.org/10.1007/s11027-019-09869-2

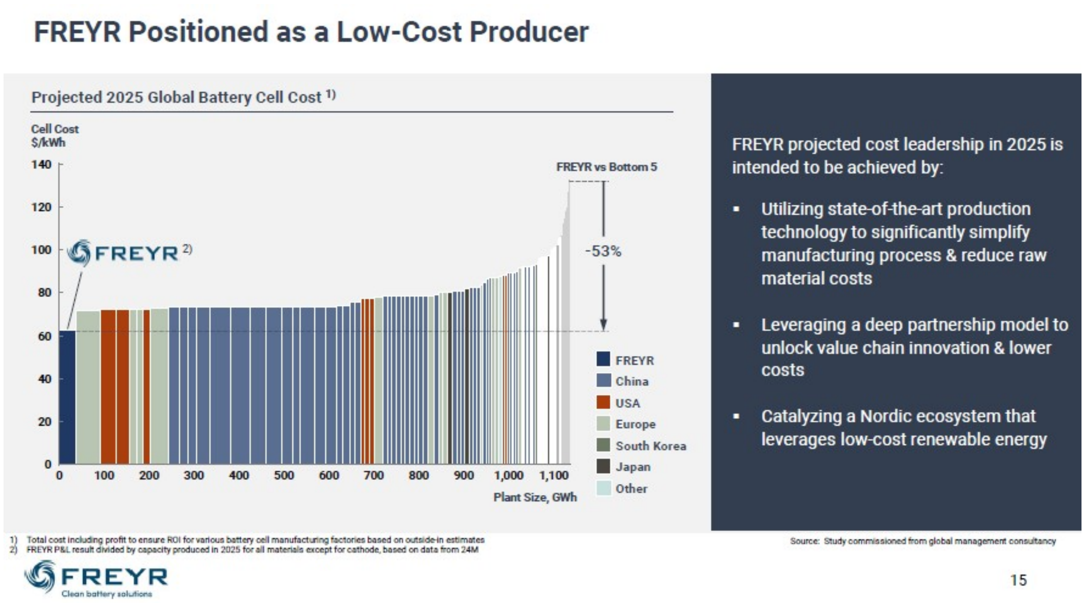
Beyond the environment, batteries are associated with social considerations as well. Batteries require raw materials that are often mined in areas of the world with political instability and less stringent labor laws than developed markets – as we explored in *Will Cathode Evolution Drive the EV Revolution?*. Most notably, >60% of mining for cobalt, a key input in lithium ion batteries, occurs in the Democratic Republic of the Congo – a region characterized by an unstable political regime and scrutinized mining practices, including child labor.

How to "green" batteries? Key levers to improve the sustainability profile of batteries includes lower carbon mining (see *Decarbonising Mining*) and manufacturing (in large part through renewable energy sourcing), lower resource intensity, and responsible mining practices. For battery suppliers and OEMs, this means forming supply chains that reflect these efforts and offer disclosure on carbon emissions and responsible and ethical operational performance. Tesla, for instance, is a member to industry alliances that seek to promote more sustainable and transparent supply chains.

Battery recycling will also become increasingly important. As already noted, we see a nearly 100-fold increase in end-of-life battery supply by 2035. Post-consumption recycling of minerals used in EV batteries is needed for products to have an environmentally positive life-cycle. Collection of electronic waste has proven difficult and much ends up in developing countries where the waste is not processed appropriately - leading to health and environmental problems. The size and cost of EV batteries should make this type of battery recycling somewhat easier – though at present, battery recycling is still at a nascent stage. Effective battery recycling should avoid end of life emissions (such as in current pyro-based processes) and provide a second use for raw materials that reduces the need for carbon intensive mining practices. As discussed further in Appendix I - Battery Primer , the hydrometallurgical battery recycling process offers a solution – breaking down fully discharged battery cells into plastics and black mass (electrode materials), then processing that black mass in acid leaching to extract pure metals.

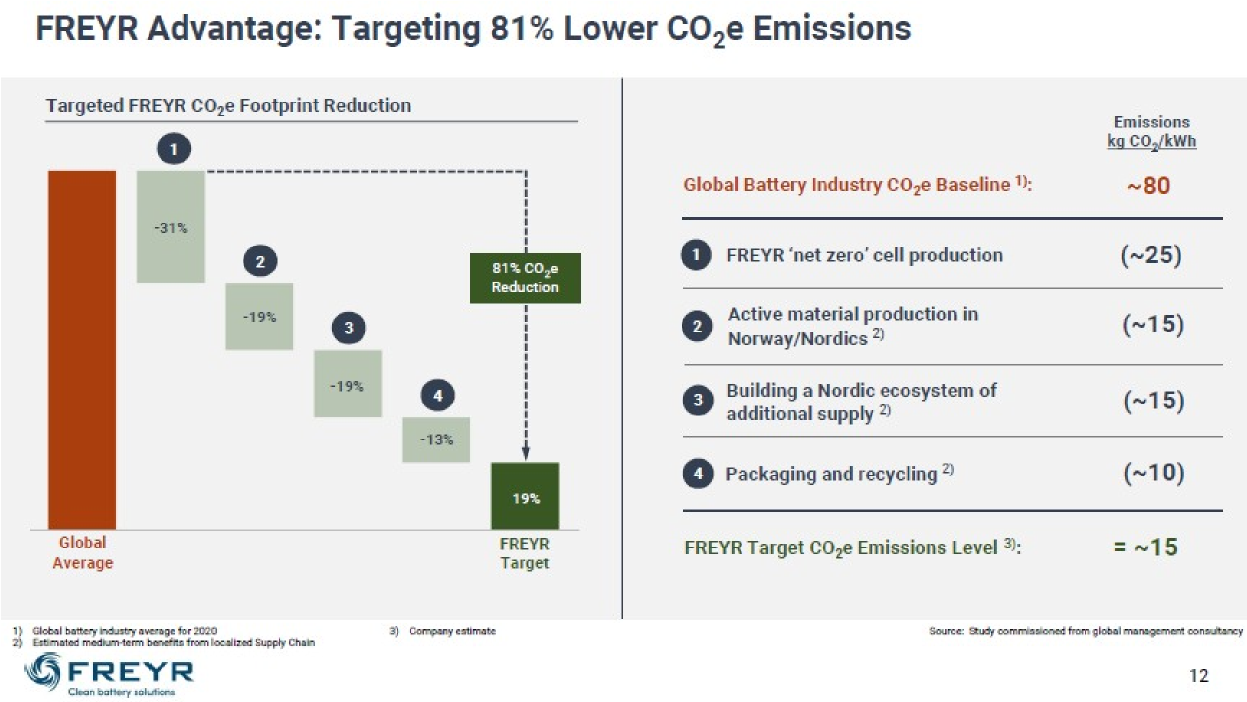
Enter FREY. Freyr strives to be the lowest carbon emitting and lowest cost battery cell producer in the world. By leveraging the 24M manufacturing process, reduced raw material costs, a partnership based model that leads to lower costs, as well as cheap Nordic low-cost renewable energy, Freyr intends to be the lowest cost battery cell producer on a $/kWh basis based on 2025 cost estimates. When coupled with low-cost renewable energy and lower logistic costs to Europe, Freyr targets a cost of $62/kWh, which is 20% below the estimated global average cost in 2025, with carbon emissions of just 15 kg CO2e/kWh, which is significantly below the global average of ~75 kg CO2e/kWh. European legislation on local sourcing with low environmental impact plays very much to Freyr's advantage as it scales to address the important stationary storage market (ESS) medium-term and EV market longer term. While currently pre-revenue, we believe the stock will be driven by management's ability to clip milestones on the factory build-out and production ramp in Northern Norway. For more, please see our Freyr *initiation note*.

Exhibit 100: FREY targets battery lifecycle emissions of 15 kg CO2e/kWh compared to the global average of ~75 kg CO2e/kWh.



Source: Company Presentation, Morgan Stanley Research

Exhibit 101: FREY Targets 81% Lower CO2e Emissions



Source: Company Presentation, Morgan Stanley Research

Appendix I - Battery Primer

Battery Basics

What is a battery? Fundamentally, a battery electric vehicle (BEV) is powered by a battery pack made up of individual cells. Each cell has 4 components: **1)** cathode, **2)** anode, **3)** separator, and **4)** electrolyte. The cathode is a positively charged electrode while the anode is a negatively charged electrode. The separator keeps the two electrodes apart. The electrolyte is a medium that facilitates the movement of ions. Within a battery cell, electrons flow from the negatively charged anode to the positively charged cathode.

Exhibit 102: The structure of one battery cell

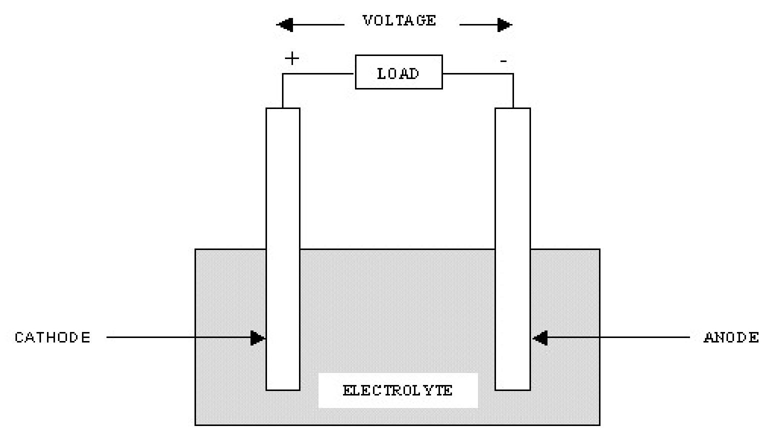
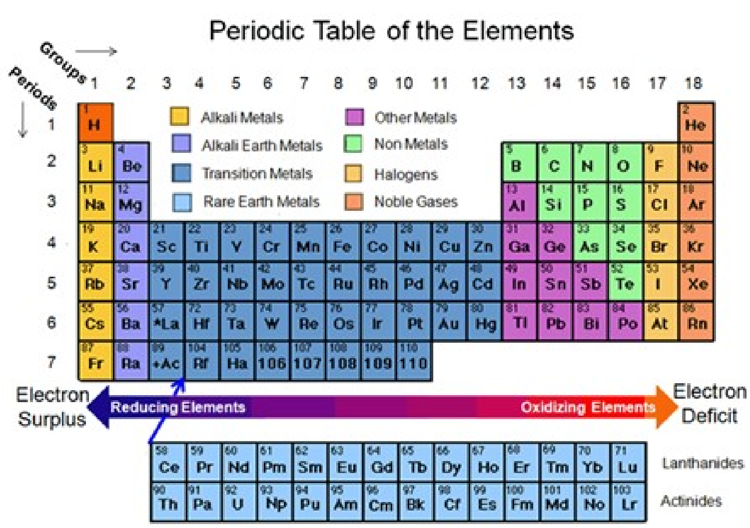


Figure 1: Components of a Cell

Source: University of Washington

Raw material components? For lithium-ion batteries, different raw materials are used for each of the components. For the anode, graphite (a crystalline form of carbon in a hexagonal structure which is the most stable form) is the most common material used, although some companies are progressing lithium metal and silicon anodes. For the cathode, metal oxides that are combinations of lithium, cobalt, nickel, manganese, and aluminum are most widely used. Common cathode chemistries include lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum (NCA), and lithium iron phosphate (LFP). The electrolyte is usually created using acidic salts and solvents such as sulfuric acid. The separator is usually created using a porous, polyolefin material like polyethylene or polypropylene, although some companies have experimented with other materials such as aramid.

Exhibit 103: Lithium is the lightest metal in the periodic table and has an electron surplus, which gives it high electrochemical potential.



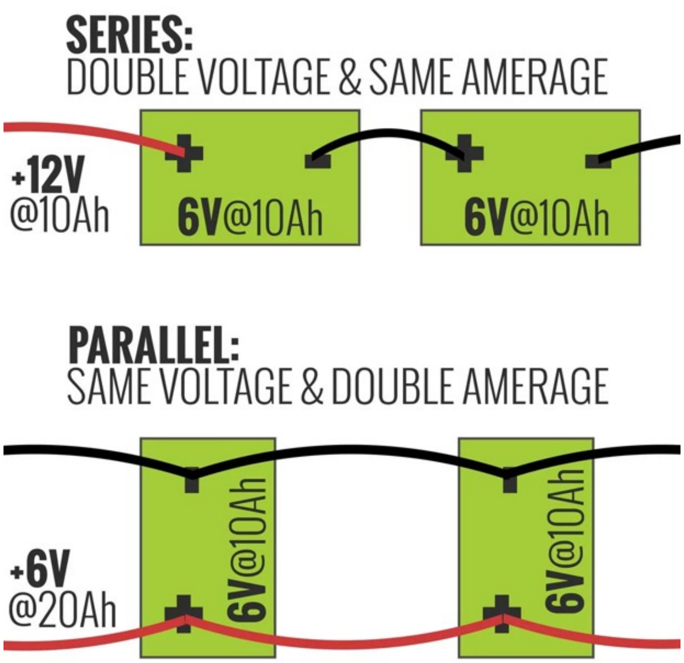
Source: Electropaedia

What is the chemical process? Batteries generate power through the flow of electrons, negatively charged ions. When the battery is discharging, electrons flow from anode to cathode. When the battery is charging, electrons flow from cathode to anode. The amount of power produced when a battery is discharging is defined by 1) the current and 2) the voltage. Current (measured in amps) is the rate at which the charge is flowing and defined by the number of electrons. Voltage (measured in volts) is the force of electrons, also known as the difference in charge between two points. Generally, electricity wants to move from higher to lower voltage. Beyond the process of charging and discharging, batteries may encounter another chemical reaction called thermal runaway. Thermal runaway occurs when one cell in a battery overheats, combusts, and spreads to other cells to cause a battery pack explosion.

How are battery cells organized? Battery cells are organized in different formations, form factors, modules, and packs. Combined with a battery management system (BMS), this yields an EV battery. To start, two possible formations are parallel and series.

- In a **parallel** formation, cell 1's anode is attached to cell 2's anode resulting in the same voltage and double the capacity.
- In a **series** formation, cell 1's anode is attached to cell 2's cathode resulting in double the voltage and the same capacity.

Exhibit 104: Series and parallel formations are two ways to combine individual cells to increase voltage, capacity, or both.

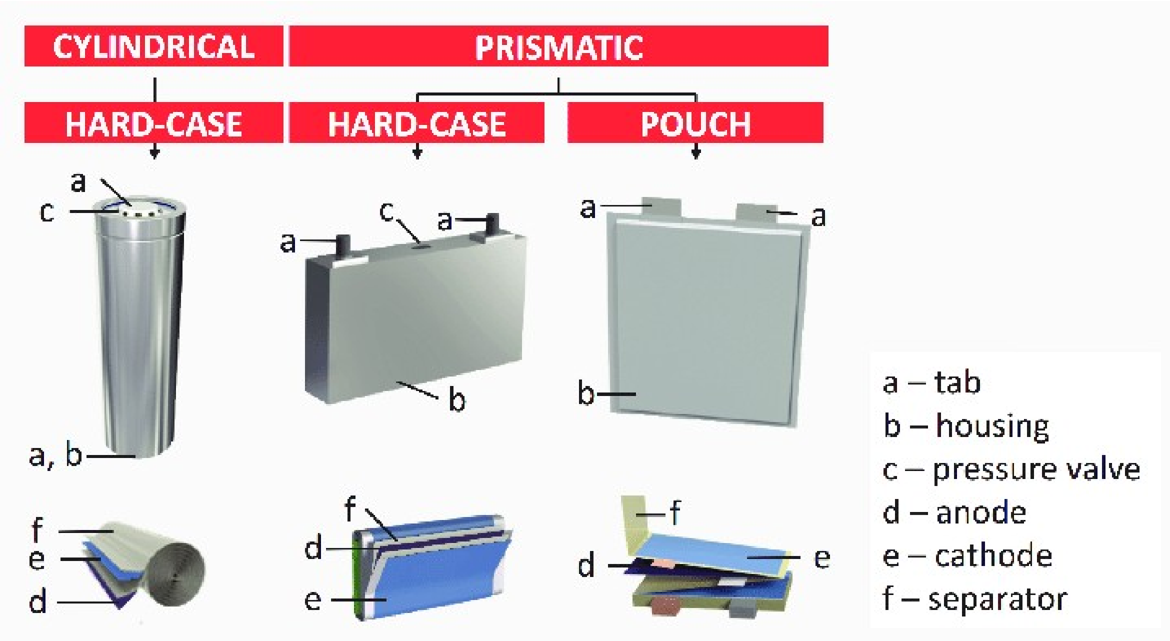


Source: Minder Research

Batteries also have different form factors:

- **Cylindrical:** The anode, separator, and cathode are sandwiched and rolled up into a cylindrical shape. This form factor is ideal for evenly distributing internal pressure (good thermal management) and mechanically stable, meaning that the impact of one cell going bad is more isolated. Furthermore, while this form factor is not ideal for space efficiency and packaging density because of its circular shape, the space cavities allow coolant to easily circulate within the pack. Common types of cylindrical form factor batteries include 18650 type (18mm diameter x 65mm height) and 21700 type (21mm diameter x 70mm height). Notably, Tesla vehicles using Panasonic cells were packed using this form factor.
- **Prismatic**: Similar to the cylindrical form factor, prismatic form factor batteries are rolled up and pressed to fit in a metallic rectangular form with aluminum or steel casing. The downside of this form factor is that near the corners, the battery may be more stressed. The box like shape is space optimal for layering but more challenging for thermal management, which may result in the battery dying faster. Furthermore, prismatic form factors have no space cavities which increases contagion risk should one cell go bad. Compared to cylindrical form factors, prismatic form factors can be more expensive and expand with use. This form factor is used by Samsung SDI and CATL.
- **Pouch**: Similar to the prismatic form factor, pouch form factor batteries have the same shape but no rigid enclosure. Instead, pouch cells are covered by a sealed flexible foil such as a soft polymer aluminum plastic film or shell. This is the most minimalistic approach to packaging to reduce weight, and also leads to increased flexibility. Pouch cells can be stacked rather than jelly rolled. Pouch cells also require space allocation for swelling (up to 10% after 500 cycles) as well as a support structure and distance from sharp edges. Because of the flexible exterior, pouch cells are more likely to expand rather than explode because of the lack of a hard enclosing. However, pouch cells are generally more costly, have less storage power, and a short lifespan (vulnerable to higher temperatures) than prismatic or cylindrical cells. This form factor is used by SK Innovation and another Korean player.

Exhibit 105: Three common form factors for battery cells include cylindrical, prismatic, and pouch.



Source: ResearchGate

Exhibit 106: Pros and cons of different form factors

	Pouch	Cylindrical	Prismatic
Pros	High energy density, customizability	Low cost, easily replaceable	High durability, high safety
Cons	High cost, vulnerable to external shock	Low packing efficiency, need complex BMS	High cost, no flexibility
Cathode	NMC	NMC, NCA	NMC, LFP
Key Producers	SK Innovation, Korean player	Panasonic, Samsung SDI, Korean player	Samsung SDI, CATL
Key OEMs (Models)	GM (Chevy Bolt), Hyundai (Kona), Renault (ZOE)	Tesla Model S, Tesla Model X, Tesla Model 3	BMW (i3), BYD (Song), VW (eGolf)

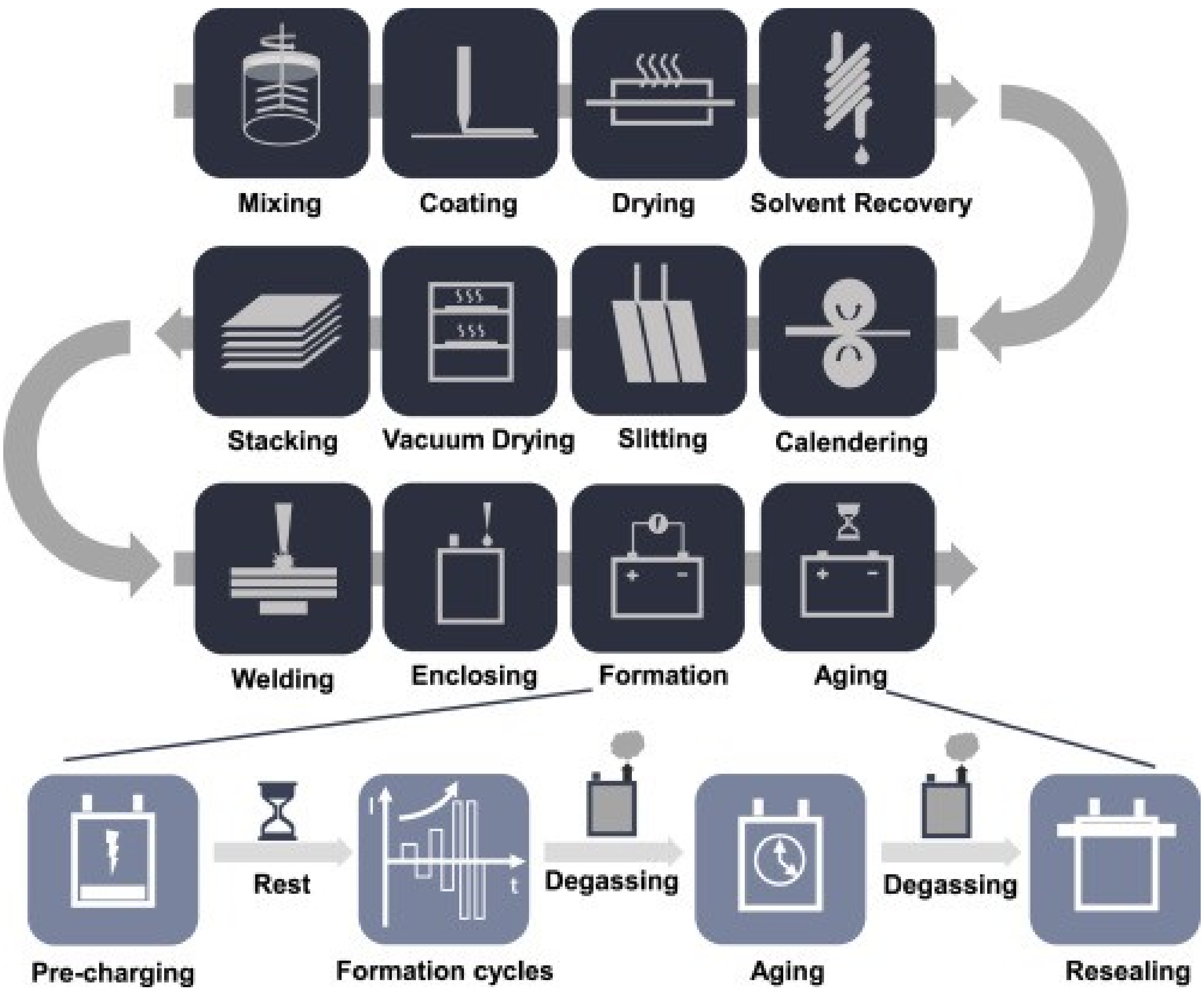
Source: Company data, Morgan Stanley Research

Tesla's 4680 cell could be the next disrupter? As we wrote in *Could 4860 Cylindrical Disrupt Battery Landscape?* and reference in Tesla Battery Day , Tesla's Battery Day last year unveiled a new technology - a larger-size 4680 cylindrical cell with a silicon anode, tabless structure, and dry electrode as well as a larger-scale, standardized, and more efficient production line. Recent news flow has showcased that progress is on track. We have seen many industry reshuffles in the EV battery supply chain in the past five years, including the transition from dry to wet separator types, the transition from natural graphite to synthetic graphite, and the transition from LFP to NMC and then back to LFP again. Next could be the battery cell form factor. The previous 1865/2170 cylindrical cells were too small to be controlled by many auto OEMs' BMS (battery management system), except Tesla. But we believe the larger 4680 size has potential with lower cost, higher energy density, and more standardized manufacturing. It could be possible to substitute current prismatic and pouch cells if 4680 proves the best option. We believe the market appreciates the ODM business model of the current battery makers, which has been reflected in high valuation multiples. If Tesla was able to define the battery and outsource manufacturing, the current battery majors' business model would likely be disrupted, shifting from an ODM to an OEM model. The bargaining power of current battery makers would be materially weakened as well. For the battery material segment, cylindrical cells may be able to adopt cheaper natural graphite mixed with silicon. The synthetic graphite market could also be negatively affected, if 4680 cells are a viable substitute for prismatic and pouch.

Battery Manufacturing

What is the EV battery value chain? The EV battery value chain starts with the mining of raw materials from the earth and ends with battery recycling. After mining, the manufacturing process includes creating the components (cathode, anode, separator, electrolyte), manufacturing the cells, packaging the cells into modules, equipping the modules with a battery management system (BMS), and finally arriving at a battery pack.

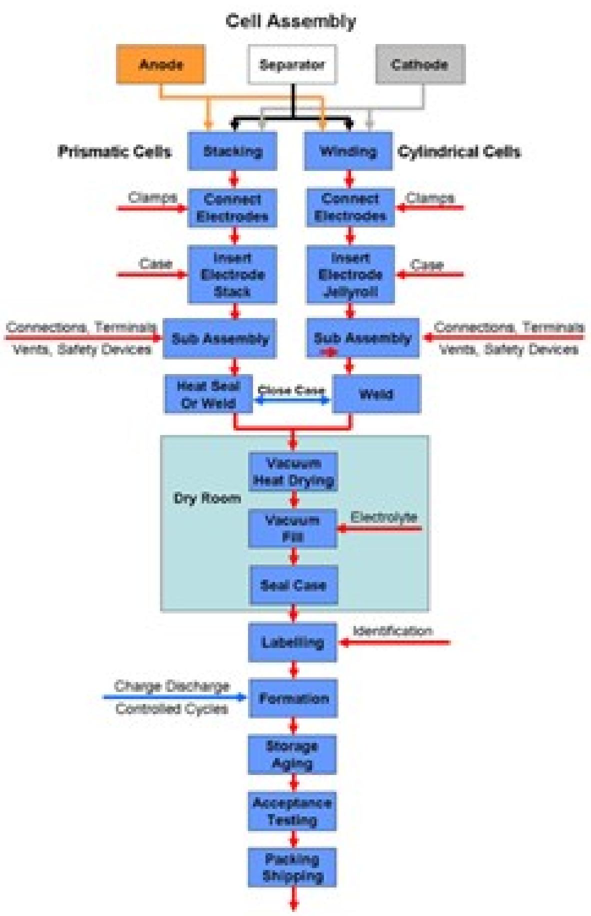
Exhibit 107: Battery manufacturing process for pouch production



Source: Science Direct

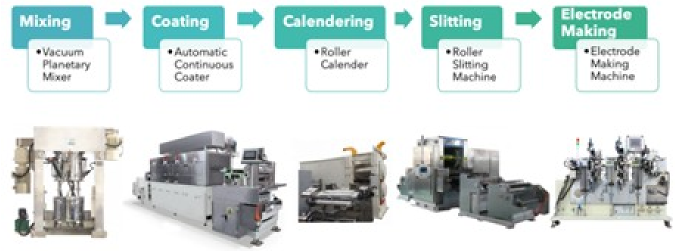
Deep dive on battery manufacturing. Electrode production consists of various steps including mixing, coating, calendaring and compressing, slitting and electrode making, and drying. Mixing is the process in which active materials and dry additives are mixed and then dispersed into a wet solvent to produce a slurry. There are separate mixing processes for anodes and cathodes because the oppositely charged materials cannot be combined. Coating is the process by which the anode slurry is applied to a copper strip and a cathode slurry is applied to an aluminum strip. Because the energy capacity of the anode is often lower than that of a cathode, the thickness of the coating layers may be different to ensure that the energy storage per unit area is matched. Next, cell assembly consists of adding the separator, packaging, electrolyte filling in a vacuum dry room, and sealing the case. Depending on form factor, the step by step of cell assembly may vary. Finally, cell finishing includes formation (first charge and discharge), degassing, aging, and testing. Progress in the battery manufacturing space focuses on streamlining these 10-15 steps into fewer steps and accelerating the process of converting cells to modules to packs.

Exhibit 108: The cell assembly process has 10-15 steps and differs by form factor.



Source: Electropaedia

Exhibit 109: Electrode manufacturing steps



Source: Medium

Where does battery manufacturing take place? The vast majority of battery manufacturing takes place in China. According to the US Department of Energy, China has the highest cell manufacturing capability at 567 GWh vs the nearest comparison of the US at 59 GWh. When comparing regionally, Asia's manufacturing capability of 634 GWh far exceeds that of Europe at 52 GWh and the US at 59 GWh. This regional distribution is relevant from a national security standpoint and from a carbon emissions standpoint. Battery manufacturing remains a carbon intensive process, and the majority (~57% in 2020) of China's energy mix is fulfilled by coal.

Exhibit 110: China leads the world in battery manufacturing capacity.

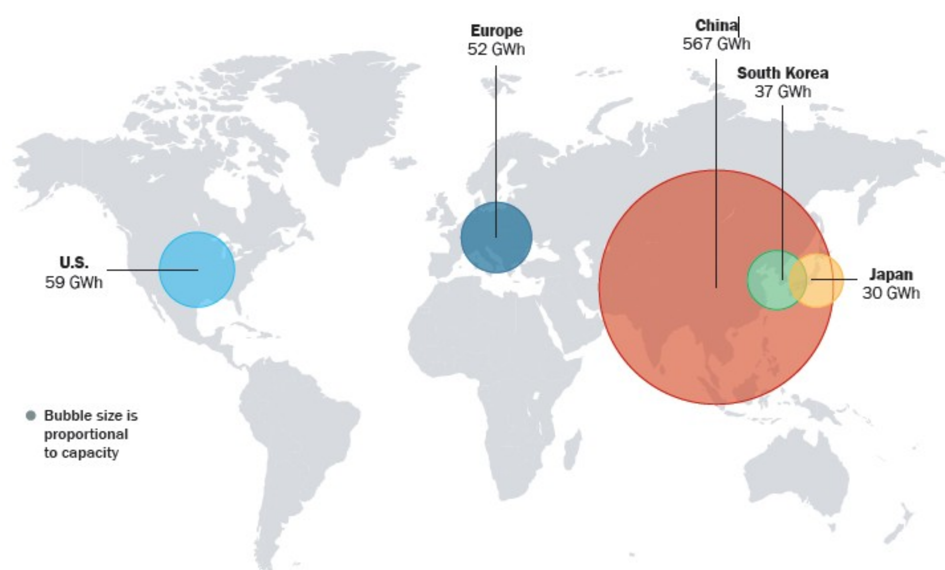
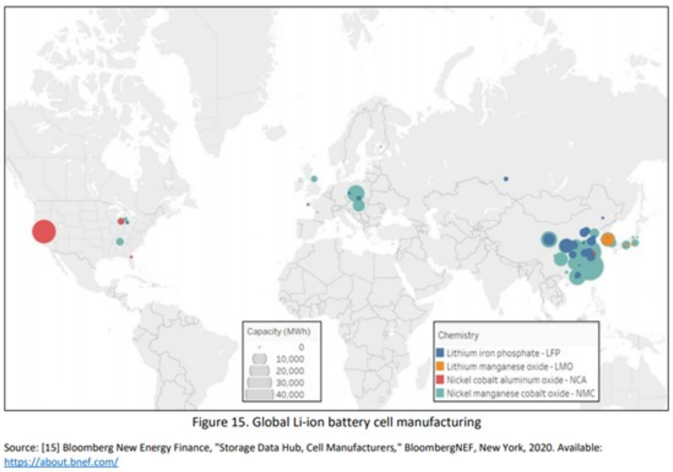


FIGURE 6. Cell manufacturing capacity by country or region.
Source: "Lithium-Ion Battery Megafactory Assessment", Benchmark Mineral Intelligence, March 2021.[32]

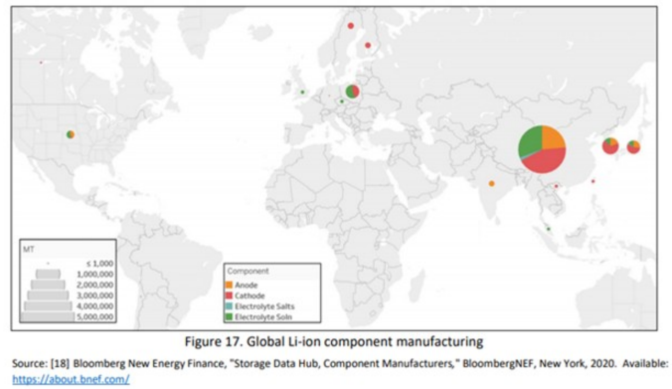
Source: DOE

Exhibit 111: Global landscape of lithium-ion battery manufacturing by chemistry



Source: Bloomberg NEF, DOE

Exhibit 112: Global landscape of lithium-ion battery manufacturing by component

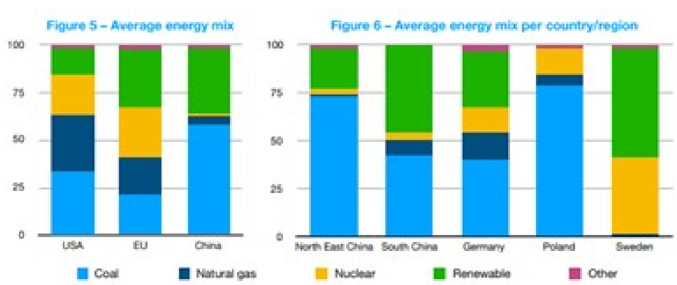


Source: Bloomberg NEF, DOE

How 'green' is battery manufacturing? While batteries are crucial to powering electric vehicles meant to cut greenhouse gas (GHG) emissions, the raw materials mining, refining, and manufacturing processes for batteries can be both energy and carbon intensive. The carbon intensity of these processes is highly dependent on the energy source used (coal, renewables, etc.) during manufacturing and charging along with the distance from manufacturing point to end user (transportation fuel cost). Depending on geography and country, different factories and plants in different locations have different energy sources. In particular, Norway is known for using predominantly hydro-electric energy to power its grid. This makes Norway an ideal location for carbon-friendly companies like Freyr to set up shop (see *initiation note*). Freyr is targeting ~15 kg CO2e/kWh (~80% reduction from the status quo). Other players such as Tesla and CATL have taken note as well. Tesla reportedly intends to use solar power at its Gigafactory in Nevada, with similar plans for its Gigafactories in Europe and China. According to some reports, CATL is also looking to power its future German plant, in partnership with Daimler, with renewable energy.

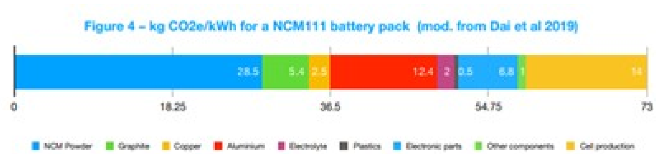
Beyond grid decarbonization, how else can we decrease carbon intensity? Battery second life is one way to reuse batteries to extend useful life and minimize carbon intensity. EV batteries, in their first lives, are used until they are typically at 75-80% of their original capacity. After their capacity drops below this floor, these batteries could have a "second life" supporting the electric grid especially as intermittent renewables become more widespread. The widespread use of batteries in this application may increase the lifetime use of the battery and reduce greenhouse gas emissions related to the battery by ~40%.

Exhibit 113: Different countries and regions have different energy mixes which impact the carbon intensity of their manufacturing processes.



Source: Circular Energy Storage

Exhibit 114: The cells are the majority of the energy and carbon footprint in producing lithium-ion batteries (mining, conversion, refining).



Source: Transport Environment

Exhibit 115: Battery second life, recycling, and grid decarbonization are some of the ways to minimize GHG emissions from batteries.

Table 3. Potential reductions in greenhouse gas emissions resulting from improvements in battery manufacturing and use

Development	Percent change in battery manufacturing emissions	Percent change in life-cycle g CO_2e/km
Larger electric vehicle battery	+33% to +66%	+18%
Battery second life	N/A	-22%
Battery recycling	-7% to -17%	-4%
Projected grid decarbonization	-17%	-27%
Greater battery energy density	-10% to -15%	-6%

Source: International Council on Clean Transportation

Exhibit 116: Under certain assumptions for the aforementioned factors, batteries may achieve ~90 g CO2e/km in the future.

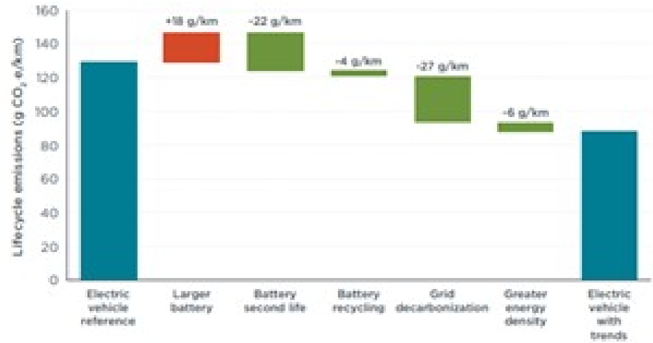


Figure 3. Potential changes in battery manufacturing greenhouse gas emissions (compared to reference 2017 electric vehicle) resulting from increased pack size and improvements in battery manufacturing and use.

Source: International Council on Clean Transportation

What is battery recycling? Battery recycling is another way to minimize carbon intensity from batteries. Battery recycling matters because, as per Cairn ERA, an energy consulting firm, "To make the batteries the world needs in 10 years, the industry will need 1.5 million tons of lithium, 1.5 million tons of graphite, 1 million tons of battery-grade nickel and 500,000 tons of battery-grade manganese. The world produces less than a third of each of those materials today. New battery materials sources are highly valued and desperately needed." The battery recycling process is key for ESG because burning battery raw materials is not only potentially dangerous but may create more CO2 emissions. The hydrometallurgical battery recycling process sidesteps this pitfall. In this process, fully discharged battery cells are broken out into plastics and black mass (electrode materials). Then, the black mass is processed in acid leaching to extract pure metals using water based solutions. The battery raw materials are not burned in this process, therefore avoiding additional CO2 emissions.

Where are we in scaling battery recycling? Battery recycling remains at a nascent stage. Currently, few EV batteries have reached the end of their useful lives. That said, several early stage companies such as Li-Cycle and Redwood Materials (founded by ex-Tesla CTO JB Straubel) have focused on scaling battery recycling in the US while in Europe, mining names such as Norsk Hydro have also gotten involved. In China, GEM is an exposed name that conducts hydrometallurgical recycling while CATL recently reported plans to build an Rmb32bn battery recycling integrated project over the next 6 years. As EV penetration accelerates and more batteries reach the end of their lifetimes, scaling battery recycling may also require some government support. A future technical consideration for battery recycling is designing battery cells for disassembly to make them easy to recycle.

Battery Technology

What is the ideal battery? The ideal battery optimizes for several factors: **1)** high energy density, **2)** fast charging time, **3)** long cycle life, **4)** robust consumer safety, and **5)** low cost.

1. **Energy density** is measured in wh/kg (gravimetric) or wh/liter (volumetric) and describes how much energy is held per space as a measure of general energy and space efficiency. Batteries that are able to compress more energy into small spaces are optimal. We estimate that batteries currently have energy densities of ~200 wh/kg.
2. **Charging time** is a measure of how many minutes it takes for a battery to go from no charge to a >80% charge. Similar to filling up a gas tank at a gas station, EV users will likely prefer a faster charging experience rather than waiting for hours to re-charge. We estimate that batteries currently require ~1 hour to charge 100 kWh with the goal of 5-15 min to charge 100 kWh. More on charging below in **Battery Technology**.
3. **Cycle life** is a measure of how many times a battery can be charged until the battery is at <80% of its original capacity. We estimate that batteries currently can withstand 1000 cycles.
4. **Consumer safety** is a key consideration for batteries. Some temperature hazards such as thermal runaway may result in an unlikely battery explosion, creating consumer safety concerns. Improving battery mechanics and materials, such as using a solid state electrolyte, to protect from those safety concerns will support the commercialization of EVs.

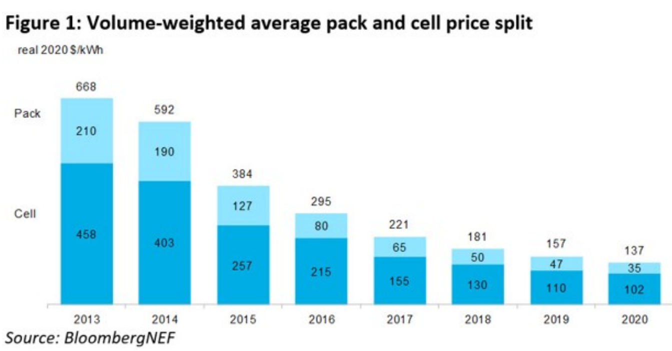
Exhibit 117: Ideal battery characteristics

Factors	Unit	Current	Goal
Energy density	watt hours/kg or liter	~200 Wh/kg	~1000 Wh/kg
Fast charging time	minutes	60 min to charge 100 KWh	5-15 min to charge 100 KWh
Cycle Life	numbers of charges	1000	3000
Safety Metrics		temperature hazard (thermal runaway)	solid state electrolyte

Source: Morgan Stanley Research; Note: cycle life is number of charges until the battery is <80% of original capacity, these are MS Research estimates to illustrate potential battery industry growth.

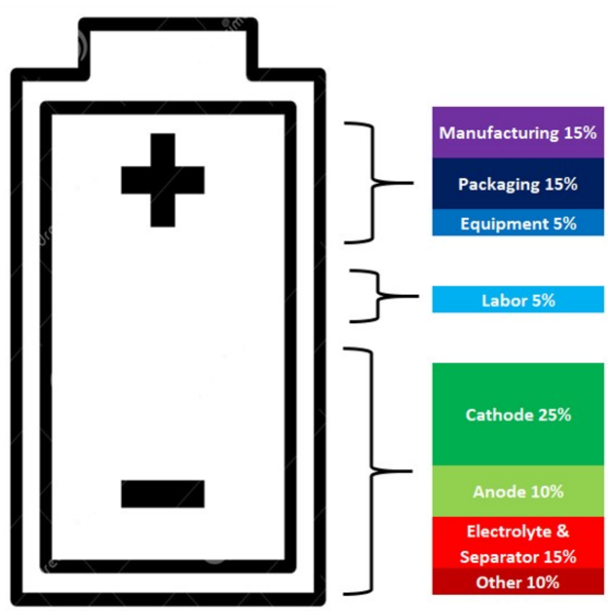
Battery cost. A major part of the battery's optimization function is its cost. According to Bloomberg NEF, battery costs have fallen dramatically since 2010 from $1,100/kWh in 2010 to ~$157/kWh in 2019. Cost decreases have been driven by economies of scale in expanding production and innovations in battery chemistry while manufacturers look to use less expensive cathode materials (away from using relatively expense cobalt). The DOE projects that cost parity with ICE will require a battery cost of <$100/kWh, a goal that is projected by the mid 2020s. The battery cost is approximately one third of the cost of the EV. Using Tesla Model X's 75 kWh battery for illustrative purposes, this implies that a 75 kWh battery multiplied by $100/kWh target cost will yield a $7.5k implied battery cost and $22.5k implied EV cost at the targeted level. Doing a deeper dive into what comprises the battery cost with a bottom-up approach, we estimate materials costs comprise ~60% of the total battery cost. Within the materials costs, we estimate that the cathode is the most expensive at ~50% of the materials cost. Therefore, this implies that the cathode is roughly ½ of ½ of the total battery cost, equivalent to ~25%. The unique cathode cost per battery depends on its chemistry which depends on the commodities (lithium, cobalt, nickel, aluminum, manganese).

Exhibit 118: Battery pricing has decreased significantly in the past decade, almost reaching ICE parity levels of $100/kWh.



Source: Bloomberg NEF

Exhibit 119: Battery costs are mostly material costs (~60%), including the cathode, anode, electrolyte, and separator.



Source: Morgan Stanley Research, Qnovo; Note: breakdowns are MS estimates for illustrative purposes

Cathode commodity risk. For lithium-ion batteries, the composition of the cathode opens up batteries to significant commodity risk. YTD, commodity prices have increase significantly, putting pricing pressure on cathode production. Scanning the most common commodities used in cathodes, cobalt is the most expensive feedstock. At ~$50k/ton, cobalt is ~3x more costly than lithium and nickel. Furthermore, cobalt has an ESG angle. Cobalt is mostly mined in the Democratic Republic of the Congo (DRC) which is characterized by political instability, power outages, and alleged child labor usage (see *here* for more). For more on commodity supply and demand, please see Mining .

Exhibit 120: Commodity summary with 4Q21 MS price forecasts

Commodity	Element	2021e forecast ($/ton)	Long term forecast ($/ton)	Comments
Lithium	Li	$10,293	$7,468	New supply brought in by higher prices is expected to outpace demand in the medium term due to new players in Argentina and Australia.
Cobalt	Co	$49,169	$37,475	Used in standard NMC and NCA chemistries, cobalt is the most expensive cathode material, comes almost entirely from the DRC and is mined in association with child labor.
Nickel	Ni	$18,472	$17,238	While EVs claim a low amount of global nickel demand, the general trend towards high nickel/lower cobalt chemistries implies that nickel may play role in the EV battery space in the medium term.
Copper	Cu	$9,180	$7,045	EVs may increase copper demand through both usage in the battery and for wiring in charging infrastructure.

Source: Morgan Stanley Research

Exhibit 121: Commodity supply by country is an important factor in battery cell production from a national security perspective.

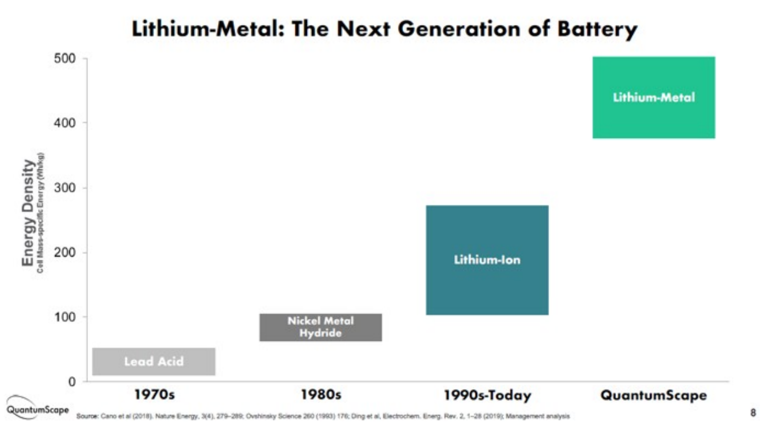
TABLE 1. Comparison of U.S. mineral reserves and manufacturing capacities verses the world.

Element	U.S. Reserves (1000 Metric tons)	World Reserves (1000 Metric tons)	Total Manufacturing Capacity with U.S. reserves (GWh)	Total Manufacturing Capacity with world reserves (GWh)
Lithium	750	21,000	7470	209,163
Cobalt	53	7100	703	94,164
Nickel	100	94,000	167	156,510
Manganese	230,000	1,300,000	3,271,693	18,492,176

Source: DOE US National Blueprint for Lithium Batteries

Technology history. Batteries have progressed from primary phase, single use batteries that are not-rechargeable, to secondary phase, rechargeable batteries such as lead acid and nickel, to lithium-ion and solid state. The current status quo of batteries is lithium-ion, which has relatively higher energy density compared to that of previous batteries, but remains relatively expensive, requires safety measures, and is varied depending on cathode chemistry. Solid state, which has improved metrics in terms of energy density, cycle life, and safety, may be the next phase of batteries.

Exhibit 122: Due to the structural limitations of lithium-ion, some companies and experts have contended that the next generation of batteries is lithium-metal.



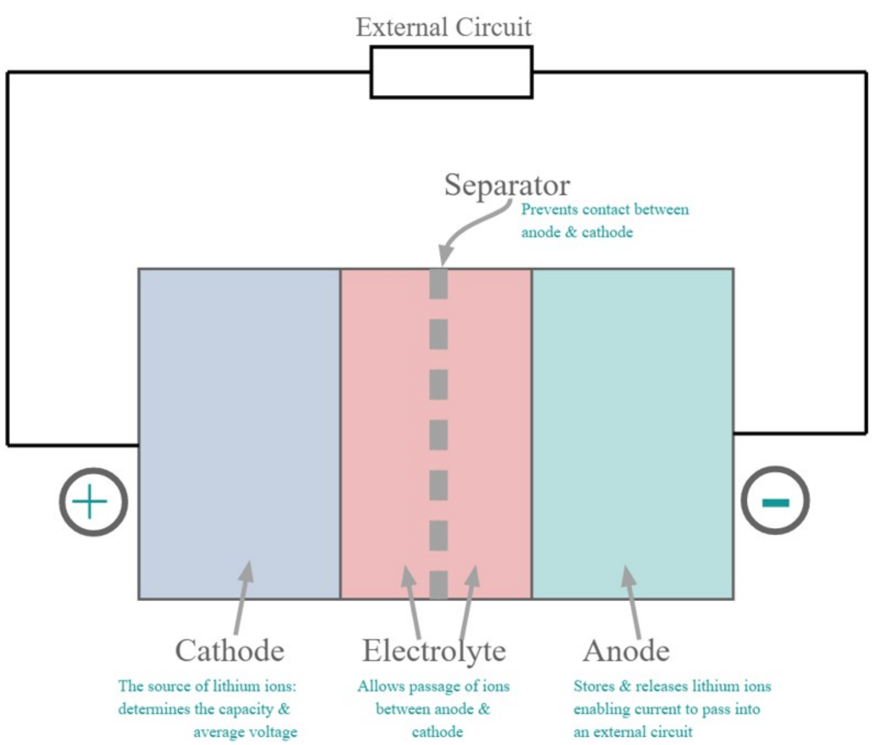
Source: Quantumscape

What is a lithium-ion battery? Lithium-ion (li-ion) batteries consist of a graphite anode, a metal oxide cathode, and a separator with a liquid electrolyte solution. The key feature of this battery is the cathode chemistry, which is lithium based. As an element, lithium is highly reactive in its purest form but stable as part of a metal oxide. What does it mean for lithium to be reactive? Lithium has one electron in its outer shell and wants to lose this electron, translating into high electrochemical potential. Mechanically, the charging and discharging reaction occurs when lithium as a part of a metal oxide is induced to separate into this lone electron (negatively charged) and a lithium-ion (positively charged). In the charging process, after attaching the battery to a power source, lithium ions flow through the electrolyte towards the anode while electrons are guided through the external circuit and land in the graphite anode. In the discharging process, after attaching a load, lithium-ions and electrons undo the previous motion because lithium wants to return to its steady state. The process is reversed and lithium reverts to its metal oxide form. On the cathode side, aluminum acts a current collector while on the anode side, copper acts a current collector. Overall, the main benefits of lithium-ion batteries are its relatively high energy density, long cycle life, reasonably short charge times, and low self-discharge while its main detractors may be some sensitivity to temperature (high and low) and safety considerations.

Types of lithium-ion batteries. Lithium-ion batteries vary by their cathode chemistries. Common cathode chemistries include lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), and lithium iron phosphate (LFP). For some chemistries, 3 numbers after the abbreviation will also provide a characteristic. For example, NMC 811 indicates lithium nickel manganese cobalt oxide with a 8:1:1 proportion for nickel, manganese, and cobalt in the mix. Cathode manufacturers can alter the composition of cathodes by choosing different chemistries, but also by adjusting the relative weighting within chemistries.

Lithium-ion cathode comparison. NMC is the current incumbent cathode chemistry in terms of energy density and cycle life. Another emerging chemistry is LFP, which was traditionally viewed as a low-end version of NMC due to its lower energy density. However, recent reports out of China from battery producers such as CATL and BYD indicate that technological strides have been made with LFP. In particular, BYD's Blade battery uses a LFP cathode and is reported to have high energy density and cycle life, comparable to its more high-end NMC peer. Our battery team in Asia believes that while nickel content may be higher due to the trend towards NMC 811 and away from cobalt, many OEMs are concerned about nickel supply in the future and also the cost for nickel in the case that there will be

Exhibit 123: To charge lithium-ion batteries, lithium ions will travel through the electrolyte towards the negatively charged anode while electrons flow from the stable lithium-metal oxide towards the positive charge.



Source: Electronics Notes

a supply shortage (see *Charts of the Day: LFP vs NCM* and *Battery Tech - The LFP Renaissance* for more). Therefore, LFP batteries such as BYD's Blade battery may become more popular due to their relative cheapness, energy density/cycle life improvements, and avoidance of a nickel supply shortage (see *EV Batteries 'State Of The Union'* and *Blade Battery's First Online Show - Safety Comes First* for more).

Low or no cobalt chemistries also include Lithium manganese oxide (LMO), Lithium nickel oxide (LNO), and Lithium manganese nickel oxide (LMNO). These chemistries contain no cobalt and include manganese, a safe and stable chemistry with lower energy density. LMO was notably used in the Nissan Leaf, which struggled with distance per charge but was high on safety metrics. LNO (lithium nickel oxide) is reportedly being developed by JMat and BASF. Most notably, Tesla's new LMNO battery was revealed at their 2020 Battery Day, which could be commercialized as early as 2022/23.

What is a solid state battery? In lithium-ion batteries, safety issues may arise if the liquid electrolyte (which is flexible for swelling) becomes flammable. Addressing this issue, solid state batteries use a solid electrolyte instead of a a liquid one. This solid electrolyte may also play the role of the separator, saving space. While solid state batteries remain nascent in development, they are expected to have potentially ~3x higher energy density than that of lithium-ion, lower risk of explosion, potential space saving applications due to reduced safety components, higher battery capacity, and faster charging time. Essentially, solid state is expected to surpass lithium-ion on all relevant metrics. Specifically, solid state batteries are also expected to bypass the dendrite problem that some lithium ion batteries have. Dendrite are "whiskers" that form when lithium and electrolyte material combine (when lithium ions travel through the electrolyte towards the anode) that can rupture the separator if they become big enough, potentially causing a short circuit. Materials used in solid state electrolytes include inorganic or ceramic material such as sulfides, oxides, phosphates, and solid polymers (as well as reports of American battery pioneer John Goodenough experimenting with glass). Currently, commercially available solid state batteries are small, thin, and expensive with limited use (for example, in pacemakers). One company leading the charge is Quantumscape. Quantumscape's solid state battery utilizes a solid electrolyte and an appearing "in situ" anode. For more on advanced battery technology, please see *EV Batteries 'State of the Union'.*

Exhibit 124: Different types of lithium-ion batteries

Chemistry	Lithium Nickel Manganese Oxide	Lithium Nickel Cobalt Aluminum Oxide	Lithium Iron Phosphate	Lithium Cobalt Oxide	Lithium Manganese Oxide	Lithium Titanate Oxide
Short form	NMC	NCA	LFP	LCO	LMO	Li-titanate
Nominal voltage	3.60V (3.70V)	3.60V	3.20, 3.30V	3.60V	3.70V (3.80V)	2.40V
Specific Energy	150–220Wh/kg	200-260Wh/kg	90–120Wh/kg	150–200Wh/kg	100–150Wh/kg	70–80Wh/kg
Cycle life (ideal)	1000–2000	500	1000–2000	500–1000	300–700	3,000–7,000
Thermal runaway	210°C(higher when empty)	150°C (higher when empty)	270°C (safe at full charge)	150°C (higher when	250°C (higher when empty)	One of safest Li-ion batteries
Packaging (typical)	18650, prismatic and pouch cell	18650	26650, prismatic	18650, prismatic and pouch cell	prismatic	prismatic
History	2008	1999	1996	1991 (Sony)	1996	2008
Applications	E-bikes, medical devices, EVs, industrial	Medical, Industrial, Tesla's battery of choice	Stationary with high currents and endurance	Mobile phones, tablets, laptops, cameras	Power tools, medical devices, powertrains	UPS, EV, solar street lighting
Comments	High capacity and high power. Market share is increasing. Also NCM, CMN, MNC, MCN	Highest capacity with moderate power. Similar to Li-cobalt.	Flat discharge voltage, high power low capacity, very safe; elevated self-discharge.	High energy, limited power. Market share has stabilized.	High power, less capacity; safer than Li-cobalt; often mixed with NMC to improve performance.	Long life, fast charge, wide temperature range and safe. Low capacity, expensive.

Source: Battery University, Morgan Stanley Research

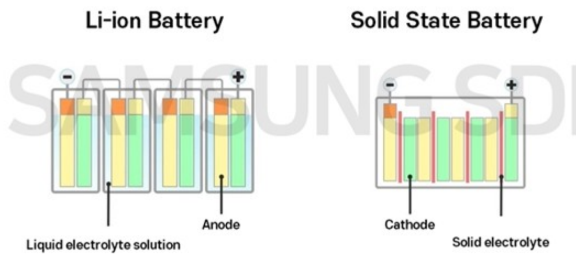
Exhibit 125: Battery chemistry applications

Battery Chemistry			Battery Suppliers 2020 / 2021	BEV & PHEV Applications 2020 / 2021
NMC	Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$ Cathode	Anhui Zhouzhihang, Envision AESC, BYD, CALB, CATL, CENAT, China BAK, Farasys, Forever New Energy, Hefei Guoxan, Huizhou Blueway, EvE Energy, Korean player, Lishen, Lixing, Neusoft Reach, Panasonic, Samsung SDI, Soundon New Energy, Shunzhihang Energy	BAIC (BJEV), BMW, BYD, Changan, Chery, Daimler, Dongfeng, FAW, Stellantis, Ford, GAC, Geely, GM, Great Wall, Honda, Hozon, Hyundai-Kia, JAC, JLR, JMC, Mitsubishi, NIO, Nissan Leaf Gen-2, Porsche, Renault, SAIC, Smart, Streetskooter, Tesla Model-3 (MIC), M
NCA	Lithium Nickel Cobalt Aluminium Oxide	$LiNiCoAlO_2$ Cathode	Panasonic	Tesla Model-S, Model-X, Model-3 (non-MIC), Model-Y (non-MIC), Subaru Crosstreck, Toyota Corolla (MIC) & RAV4
LFP	Lithium Iron Phosphate	$LiFePO_4$ Cathode	Ankao Suzhou, BYD, CALB, CATL, Citic MGL, Hefei Guoxuan, Lishen, Tianjin EV-Energy, Tianjin Hawtai EVE, Great Power, SVolt, Jinpaike	BAIC (BJEV), BYD, Changan, Chery, Daimler, Dongfeng, GAC, GM, JAC, SAIC, Tesla Model-3 (MIC), Xpeng, Wuling, GM-SAIC, Great Wall Motors, Lingbox
LMO	Lithium Manganese Oxide	$LiMn_2O_4$ Cathode	Envision AESC, GS Yuasa, Korean player, Wanxiang 123	Chery, Nissan Leaf Gen-1 & eNV-200, Renault Twizy, Mitsubishi Outlander, Samsung SM3, PSA
LTO	Lithium Titanate (NMC based)	$Li_4Ti_5O_{12}$ Anode	GS Yuasa	Mitsubishi i-Miev, Citroen C-Zero, Peugeot iOn
LMP	Lithium Metal Polymer (NMC, NCA or LCO based)	Metal/ Polymer Electrolyte	Bollore, other	Bollore Blue Car, Citroen Mehari EV, Hyundai Tucson FCEV

Source: EV-volumes.com, Morgan Stanley Research: Note: as of August 2021

What about the anode? While battery technology up to recently has focused on the cathode, anode developments have begun to gain momentum as well. In particular, companies have begun to experiment with replacing graphite anodes with lithium metal or silicon anodes. We estimate that anodes comprise ~5-10% of the total battery cost (in comparison to cathodes at ~25%). In theory, anodes can hold up to 10x more electrons with 20-40% higher energy density when replaced with silicon or lithium metal. In reality, some challenges arise. Silicon absorbs lithium ions during charging and can swell up to 3-4x, causing the surface to crack and energy storage performance to drop. While lithium metal does not have this expansion problem and is lighter than graphite, it is relatively expensive, an inherently reactive element, and may have dendrite problems. Graphite anodes have been the status quo while being less energy dense because they do not have this expansion problem and are relatively cheap. Potential solutions include using a partial graphite replacement.

Exhibit 126: Comparison of lithium-ion vs solid state batteries



Source: Samsung SDI

Exhibit 127: Silicon anodes may be a sweet spot between graphite and lithium metal in terms of energy density and stability.

Silicon-based anodes offer more energy density than graphite and more stability than lithium.

ANODE MATERIAL	SPECIFIC CAPACITY, (mA h)/g	VOLUME CHANGE, %	BENEFITS	CHALLENGES
Lithium	3,862	None	Highest energy density; light	Unstable; slow charge rate
Silicon	3,600	320%	High energy density	Capacity fade due to damage from expansion and contraction
Aluminum	2,235	604	Better energy density than graphite	Worse energy density and more expansion than silicon
Tin	990	252	Stabler than silicon	Worse energy density than silicon
Graphite	372	10	Stable; widely used	Poor energy density

Source: *Prog. Mater. Sci.* 2014, DOI: 10.1016/j.pmatsci.2014.02.001; C&EN research.
Note: (mA h)/g is a measure of the amount of charge (electrons) per gram of material.

Source: Chemical & Engineering News

Exhibit 128: Both silicon and lithium metal anodes present opportunities for battery cost reductions.

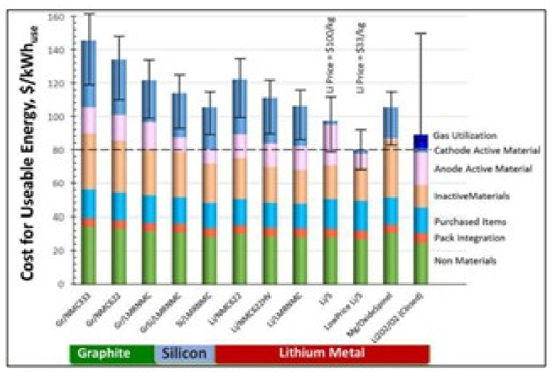


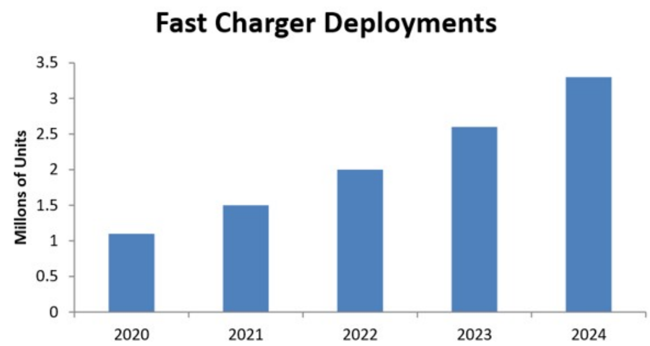
Figure 19. Potential for future battery technology cost reductions
Source: [19] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office, "Batteries: 2019 Annual Progress Report," U.S. DOE, Washington, D.C., DOE/EE-1987, 2020. Available: https://www.energy.gov/eere/vehicles/downloads/2019-annual-progress-report-batteries.

Source: DOE

What is lithium sulfur and lithium air? While neither of these chemistries are commercially available yet and unlikely to come to market in the near term, lithium sulfur and lithium air are two chemistries that companies are exploring in efforts to make a more efficient battery. Lithium sulfur is a combination of a lithium metal anode and sulfur cathode (both lithium and sulfur have low atomic weight) that has double the energy density potential of traditional lithium-ion batteries. Sulfur is a relatively cheap element but has low conductivity, yielding potentially lower cycle life and degradation. Lithium-air is a combination of a lithium metal anode, bespoke electrolyte, and an air cathode - lithium and air exchange electrons and ions. Because of how light air is, lithium air has potentially very high energy density (comparable to gasoline) although it has not yet been fully or commercially demonstrated.

What is silicon carbide and why is it relevant? Silicon carbide (SiC) is a wide bandgap semiconductor that is a stronger insulator than silicon and is formed by a special process that mixes the traditional silicon with carbon. Silicon carbide, which is well suited to high voltage applications and can operate at higher temperatures, has the potential to improve on-board fast charging and inverters for batteries. It has the potential to result in 5-10% cost saving benefits vs silicon (assuming an 80 kWh battery at $100/kWh cost, that translates to $400-$800 of savings). In terms of commercial availability, Tesla is currently using silicon carbide traction inverters with ST Micro as its SiC inverter supplier. However, SiC is more difficult to manufacture than Si; SiC is still in early stages and there are no dedicated tools yet for making it with multiple manufacturing steps. The question remains how scalable SiC is in years to come in order to support a reliable supply ecosystem for a larger market beyond just Tesla (see *here* and *here* for more).

Exhibit 129: Wolfspeed, a semiconductor company covered by Joe Moore, expects the faster charger installed base to reach 3.3mn by 2024



Source: Company data, Morgan Stanley Research

Exhibit 130: Wolfspeed's Fast-Charging Opportunity ($mn)

		Cree Share				
		20%	25%	30%	35%	40%
2024 Units	600	$ 90	$ 113	$ 135	$ 158	$ 180
	700	$ 105	$ 131	$ 158	$ 184	$ 210
	800	$ 120	$ 150	$ 180	$ 210	$ 240
	900	$ 135	$ 169	$ 203	$ 236	$ 270
	1,000	$ 150	$ 188	$ 225	$ 263	$ 300

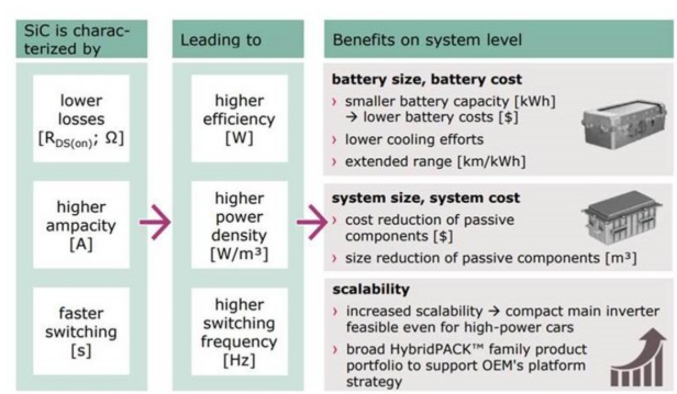
Source: Company data, Morgan Stanley Research

Exhibit 131: Illustrative cost savings for OEMs from Silicon Carbide

Element	Saving / Cost
5 - 10% battery savings *(80kWh battery x $102/kwh battery cost)*	+ $400 - 800
Space & weight saving *(battery & inverter)*	$ +
Cooling requirement saving	$ +
Incremental cost of using Silicon Carbide	- $200
= Savings per car	> $200 - 600
For 100k cars, OEM saves	$20m - 60m

Source: Cree, Morgan Stanley Research

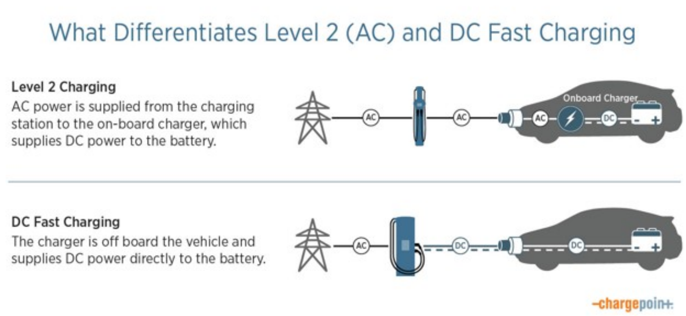
Exhibit 132: What does Silicon Carbide (SiC) offer for OEMs?



Source: Infineon presentation

How does charging infrastructure impact batteries? Charging speed for EVs can be impacted by the battery voltage. Higher voltage batteries can be charged at higher rates. According to sources, 400 V EVs charge around 150 Kw while 800 V EVs charge up to 350 Kw. Taking note, automakers are starting to produce higher voltage EVs. Leading the way is the Porsche Taycan (800 V) while Lucid plans to produce a 920 V EV and other EV players are expected to follow suit. Taking a step back, fast charging is key to mass EV adoption. Different levels of charging exist, from Level 1 (2-5 miles of range per 1 hour charge) to DC fast charging (60-80 miles of range per 20 min charge). DC refers to "direct current" meaning the type of power that batteries use. Because typical household outlets use AC, DC fast charging converts AC ("alternating current") power to DC power within the charging station and delivers DC power directly to the battery. This compares to Level 2 charging (10-20 miles of range per 1 hour charge), in which AC is converted to DC inside the EV through on "onboard charger" that is more time consuming. Currently, the charging infrastructure landscape is fragmented. It consists of multiple charging plug types (CCS, CHAdeMO, Tesla Supercharger) with multiple players including Tesla, Chargepoint, ElectrifyAmerica, and many more.

Exhibit 133: DC fast charging capabilities are essential for widespread battery use.

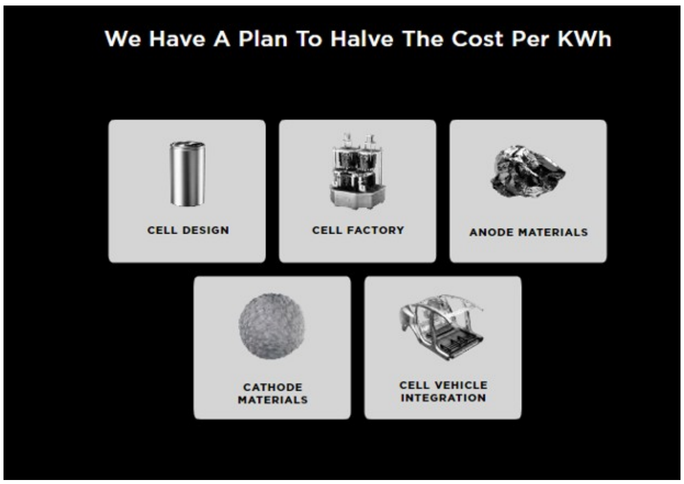


Source: Chargepoint

Tesla Battery Day

Why was Tesla Battery Day a turning point? On September 22, 2020, Tesla hosted a Battery Day during which it solidified the company's strategic shift towards vertical integration. Just as Tesla had committed to making the best cars in the world from designing vehicles and factories from the ground up, Tesla announced that it intends to tackle batteries as well, vertically integrating its supply chain. Tesla's stated goal is to halve the $/kWh cost of batteries through 5 avenues: **1)** cell design, **2)** cell factory, **3)** anode, **4)** cathode, and **5)** cell vehicle integration (please see here, here, and here for additional, previously published reports on this topic).

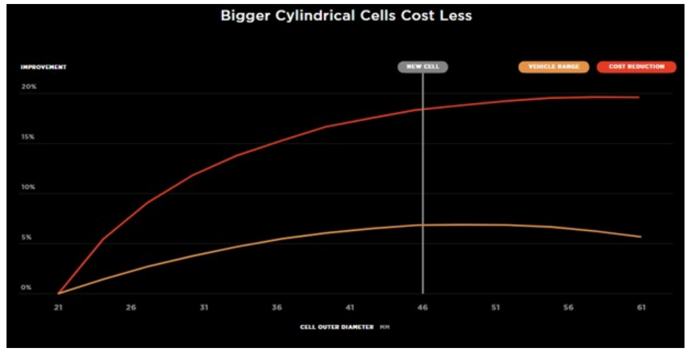
Exhibit 134: Tesla's Battery Day plan to halve the cost per kWh



Source: Tesla, Morgan Stanley Research

Cell design. Tesla intends to use a large, tabless cylindrical form factor which increases the width of cells to minimize costs and streamline the manufacturing process (tabs usually slow down the process). A low cost form factor, this cell design is meant to overcome thermal issues and shorten the distance electrons need to travel, from 250mm to 50mm electric path length. In terms of manufacturing, this cell design takes existing foils, laser powders them, and enables dozens of connections through a shingled spiral shape. The dimensions of the cell are 80mm in length x 46mm in diameter, yielding the 4680 cylindrical cell design. All in all, this cell design is expected to yield 6x more power, 5x more energy, and increase range by 16%. In terms of $/kWh, this translates to a **14% reduction**.

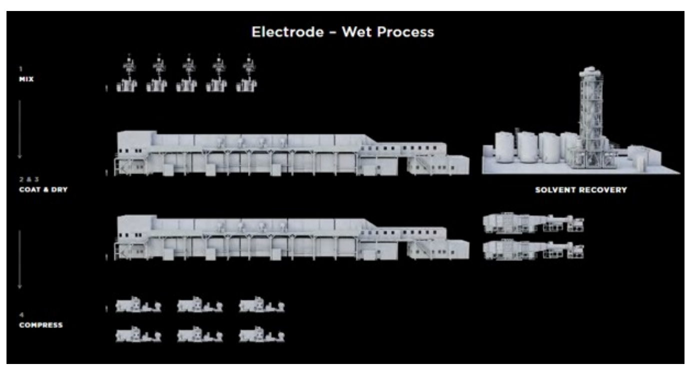
Exhibit 135: 4680 cylindrical cell design



Source: Tesla

Cell factory. Manufacturing innovation in both the cell manufacturing process and manufacturing capacity is a driver of Tesla's lower cost battery. In terms of cell manufacturing, conventional processes require electrodes to go through a wet process in which powders are mixed with water and/or solvent before going into a large drying oven. Tesla's process skips the wet step and takes the mixed power directly from dry mix to coating. Essentially, it changes the wet process to a dry process in which powder is turned into film. Although there is still progress to be made in perfecting and scaling this process, it is expected to have a 10x footprint reduction and 10x energy reduction. In terms of manufacturing capacity, Tesla intends to operate a high speed, continuous motion assembly with 1 assembly line yielding 20 GWh which is 7x line output. As Elon Musk said, "Tesla will be head and shoulders above anyone else in manufacturing, that is our goal." This capacity improvement is expected to yield a 86% decrease in formation investment and 75% decrease in formation footprint along with a 75% decrease in investment per GWh and 10x smaller footprint per GWh. Tesla plans to have 100 GWh capacity in 2022 and 3 TWh capacity by 2030. All in all, this is expected to yield a **18% reduction** in $/kWh.

Exhibit 136: Wet process

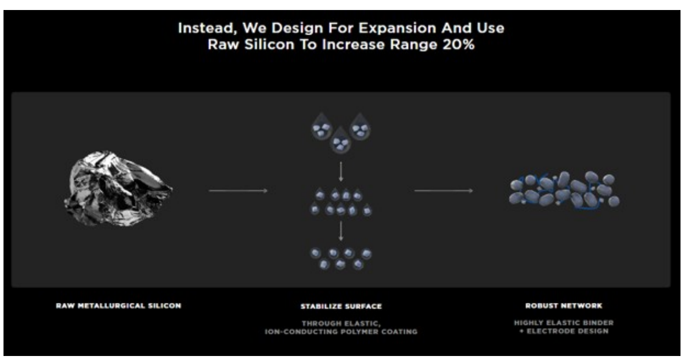


Source: Tesla

Quick note: Tesla is targeting 3 TWh of battery capacity by 2030. According to our Korean Battery Analyst Young Suk Shin, the company says the going rate for 10 GWh of battery capacity is approximately $600mm. Applying Tesla's 69% targeted savings to this figure (implying $174mm/10 GWh) to the 3 TWh target implies over $50bn of battery capacity investment needed for Tesla alone and $350bn for the industry to get to 20 TWh (see here for more).

Anode materials. Tesla's anode of choice is silicon. Silicon is the most abundant element in the world after oxygen and stores ~9x more lithium than graphite (the status-quo anode feedstock) does. Silicon's biggest challenge is its expansion problem - silicon expands ~4x when full of lithium, creating energy retention and safety degradation after many cycles. Tesla intends to use raw metallurgical silicon (not engineered) and design it for expansion at a cheaper cost than that of other, more processed silicon. The company intends to do this by taking the raw metallurgical silicon, stabilizing the surface through elastic, ion-conducting polymer coating, and creating a highly elastic binder and electrode design. This is expected to increase range by 20%. In terms of $/kWh, this is expected to translate into a 5% reduction.

Exhibit 137: Tesla's anode of choice is silicon

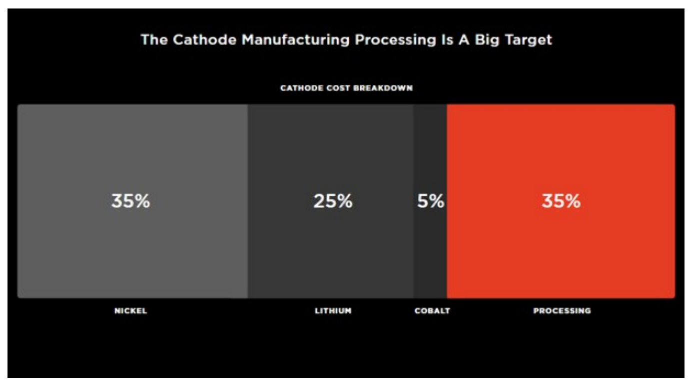


Source: Tesla, Morgan Stanley Research

Cathode materials. Tesla acknowledges that nickel is the cathode feedstock that maximizes for cheapest price and highest energy density. Therefore, its cathode is expected to increase nickel content with novel coatings and dopants while not including cobalt, a relatively more expensive but stable feedstock. This is expected to yield a 15% reduction in $/kWh cathode cost reduction. Elon Musk also mentioned the potential for a cathode tiering system: 1) iron for medium range vehicles (long cycle life), 2) nickel manganese for long range vehicles, and 3) high nickel for mass sensitive vehicles like the CyberTruck and semi. Additionally, Tesla addresses the 35% of the cathode cost which is transferring the raw materials to final form. In terms of infrastructure, Tesla is expected to build out its own cathode facility in North America and utilize local supply chains to decrease miles traveled, and operate on-site lithium conversion that is sulfate free. As Elon Musk said, "lithium is not like oil," meaning that every vehicle in the US can be turned into an electric one just using the amount of lithium available in the US (for example, in Nevada). In terms of recycling potential, Tesla claims that directly consuming nickel powder simplifies the metal refining and recycling process as recycling elements from cells is more desirable than from raw ores. All in all, Tesla's cathode approach is expected to yield a 66% reduction in investment, 76% reduction in process cost, and zero waste water. In terms of $/kWh, this is expected to yield a **12% reduction**.

Note: Tesla guided to maximizing nickel in batteries, which suggests ultimately all lithium used in its batteries will be lithium hydroxide (because the higher % nickel content used, the lower the temperature it requires in cathode sintering – lithium carbonate cannot be completely decomposed in the low-temperature sintering process), hence likely increasing the cost for brine producers which typically produce carbonate which needs to be converted to hydroxide (see here for more).

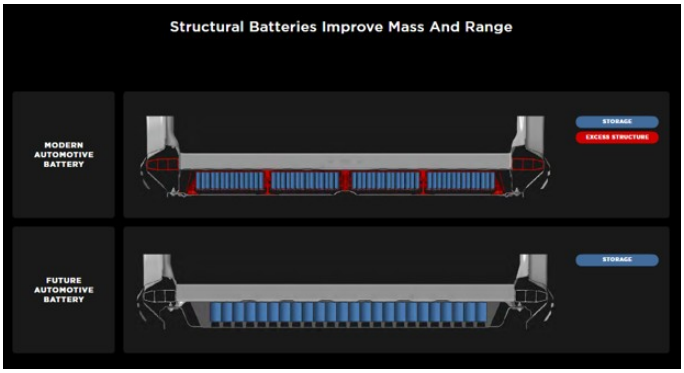
Exhibit 138: Cathode manufacturing process by cost



Source: Tesla

Cell vehicle integration. The last piece of the puzzle, cell vehicle integration uses gigacasting to make the battery dual use. Tesla aims to use the battery both as an energy device and as part of the vehicle's structure. Using the Gigapress, the largest casting machine ever made, Tesla intends to produce vehicles like toy cars by casting the shape of the vehicle using a proprietary alloy (doesn't require heat treating or coatings) and single body casting. This de-complicates the car by decreasing the parts per car by 79. This is meant to improve the storage capacity, mass, and range of vehicles – 10% mass reduction, 14% range increase opportunity, and 370 fewer parts. This also translates to a 55% reduction in investment per GWh and 35% reduction in floorspace at the factory. Net, in $/kWh terms, cell vehicle integration is expected to yield a **7% reduction**. Totaling the $/kWh reduction estimates, Tesla's plan implies a **56% $/kWh reduction total**. For more on this, please see our Gigapress primer in *Next Step… a Manufacturing Revolution? Price Target to $1,200, Reiterate OW.*

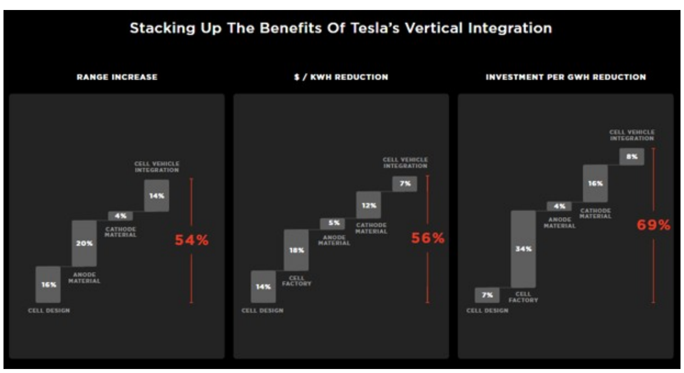
Exhibit 139: Tesla's battery will have dual use as both an energy device and part of the vehicle's structure



Source: Tesla, Morgan Stanley Research

To summarize, Tesla's battery is expected to have a 54% increase in range, 56% decrease in $/kWh, and 69% decrease in investment per GWh. Long term, Tesla aspires to replace about 20 million vehicles/year at ~$25,000 with extreme performance and range. Given the average vehicle lasts 15 years, Tesla estimates that it will need 150 TWh minimum capacity to transition all vehicles to electric. Finally, Tesla mentioned it intends to continue its relationship with existing battery suppliers (Panasonic, Korean player, CATL), but is looking to decrease to weighted average cost of batteries by pursuing its own design.

Exhibit 140: Summarizing Tesla's plan



Source: Tesla, Morgan Stanley Research

Implications. As mentioned in a previous report, we think the main takeaway from Tesla's Battery Day was that Tesla's battery tech is outpacing current growth in supply and it's time to spend significantly (see here). Essentially, Elon Musk issued a "call to arms" for more investment in the battery tech space from relevant players, including investors, industry, suppliers, engineering talent, and government. One important government player to watch, to be discussed in the next section, is Argonne National Laboratory.

National Security Implications

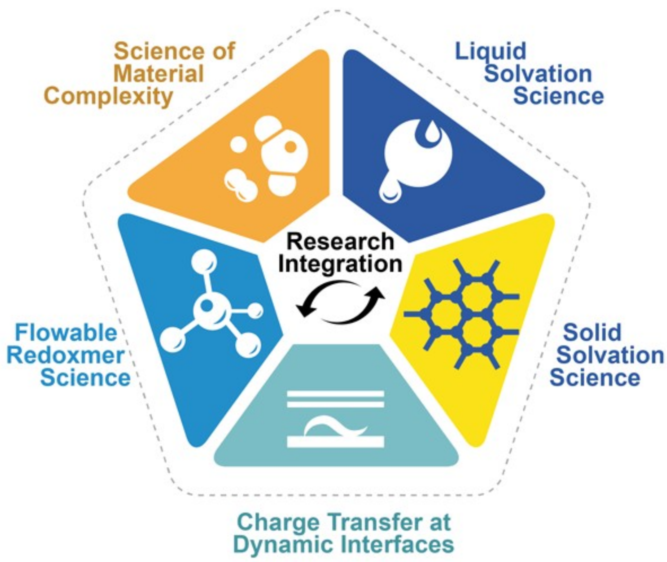
"This is a storage moment. Electric cars, grid storage, and battery-powered planes are creating a market that is exploding. To meet this market demand requires a diversity of batteries that can be applied for a diversity of uses. In JCESR, our researchers are designing transformative materials atom-by-atom and molecule-by-molecule, getting us that much closer to ***the U.S. leading*** *this important market transformation."* - George Crabtree, Joint Center for Energy Storage Research (JCESR) Director

Argonne National Laboratory is the US Department of Energy (DOE) partner of choice for battery leadership in the US. Founded in 2012, the DOE's Energy Innovation Hubs represent the center of government sponsored research on batteries. One of these hubs, the Joint Center for Energy Storage Research (JCESR - pronounced 'J-Caesar'), focuses on developing the "next generation, beyond lithium" ion battery. This hub was the result of a successful proposal submitted by Argonne to create batteries that are 5x more powerful and 5x cheaper within 5 years. JCESR combines the brainpower of 5 DOE national laboratories, 5 universities, and 4 private companies.

Through JCESR, Argonne's mission has shifted from a government-funded nuclear power pioneer during wartime to a sustainable energy partner to governments in peacetime. In 2018, the DOE announced its decision to renew the JCESR for another 5 years. Annual funding is expected to be $24mm, for a total of $120mm over the five year renewal period. The original funding was $120mm from the DOE and $35mm from then Governor Pat Quinn of Illinois.

Operationally, JCESR is split in 5 "thrusts" which represent different research areas under the organization's missions. The 5 "thrusts" are **1)** liquid solvation science, **2)** solid solvation science, **3)** flowable redoxmer science, **4)** charge transfer at dynamic interfaces, and **5)** science of material complexity. These thrusts are coordinated and supported by the Research Integration function, which also monitors each thrust's progress towards JCESR's mission. Argonne National Laboratory, originally a nuclear power laboratory tracing its roots to the Manhattan Project, currently has over 125 patents in areas, including advanced cathode, anode, electrolyte, and additive components for a series of different types of batteries, including lithium-ion, lithium-air, lithium-sulfur, sodium-ion, and flow.

Exhibit 141: The Joint Center for Energy Storage Research (JCESR) operates 5 "thrusts" in its mission to develop "next generation, beyond lithium" batteries.



Source: JCESR

In addition to sponsoring national laboratories for battery research, the DOE recently published a "National Blueprint for Lithium Batteries" in June 2021. The blueprint specifies 5 goals to achieve the DOE's vision for the lithium battery supply chain: "By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term US economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements."

1. Secure access to raw and refined materials and discover alternatives for critical minerals for commercial and defense applications.
2. Support the growth of a US materials processing base able to meet domestic battery manufacturing demand.
3. Stimulate the US electrode, cell, and pack manufacturing sensors.
4. Enable US end-of-life reuse and critical materials recycling at scale and a full competitive value chain in the US.
5. Maintain and advance US battery technology leadership by strongly supporting scientific R&D, STEM education, and workforce development.

On net, we view the national security angle for the battery industry to be an important one. As we have previously written, we expect that national sponsorship will become increasingly more important for battery companies as batteries are seen more as a "utility" and matter of national security. Through both government grants and blue papers, the US Department of Energy lends credibility to our view that battery leadership will be a national priority.

Exhibit 142: The DOE's view of the US position in lithium batteries

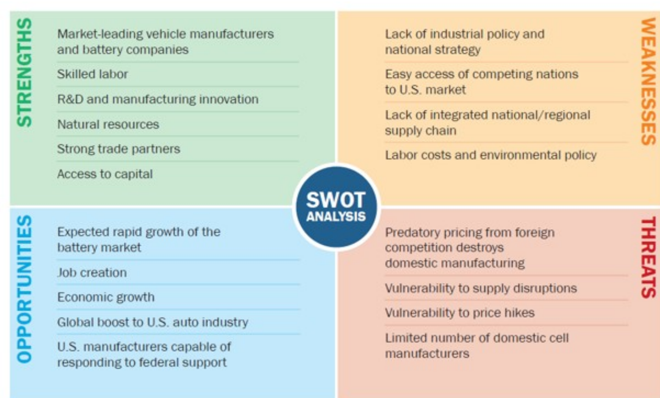


FIGURE 4. Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis of the U.S. position in global battery manufacturing.

Source: DOE

Exhibit 143: The DOE intends to implement its vision for US leadership in the lithium battery supply chain

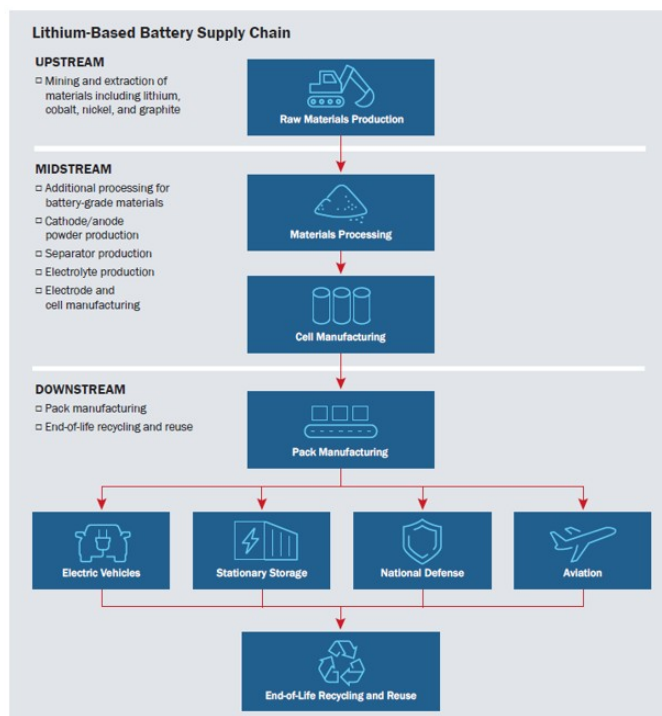


FIGURE 5. Steps in the lithium-battery material supply chain.

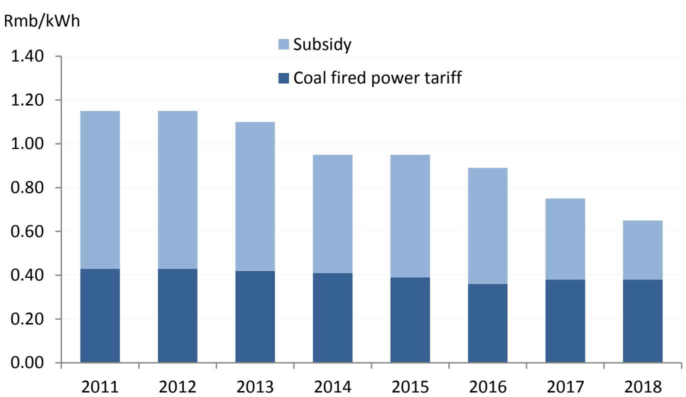
Source: DOE

Appendix II - Learning from the Past

Lessons Learned from the Solar Industry and Polysilicon

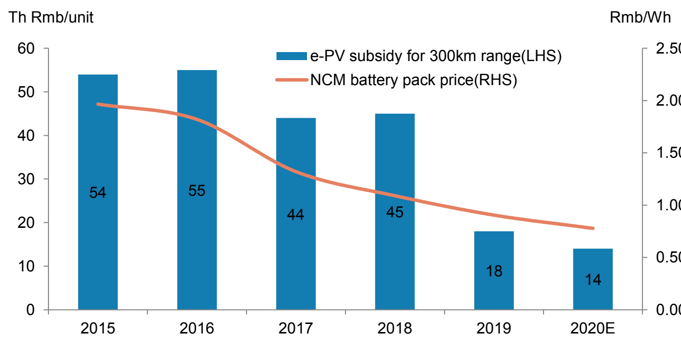
Similarities – both solar and EV are subsidy driven industries at early stages of penetration. Polysilicon is a key raw material in the solar photovoltaic (PV) supply chain, similar to battery as a key component to EVs today. To produce solar modules, polysilicon is melted at high temperatures to form ingots, which are then sliced into wafers and processed into solar cells and solar modules. Similar to EV batteries today, polysilicon was unable to keep up with solar panel demand a decade ago. However, solar power is not economical due to its relatively higher cost compared to that of coal or nuclear fired power plants. Governments granted subsidies to encourage the development of the solar industry. Similarly, EVs are not economical compared to ICE cars today, at least not yet. Governments around the world have been pushing forward EV development through extensive subsidy policies. Both industries likely face subsidy cuts every year, potentially causing margin contraction if costs are unable to match price declines throughout the value chain.

Exhibit 144: China solar power on-grid tariffs: subsidized by government



Source: NDRC, Morgan Stanley Research

Exhibit 145: China EV government subsidy reduction schedule



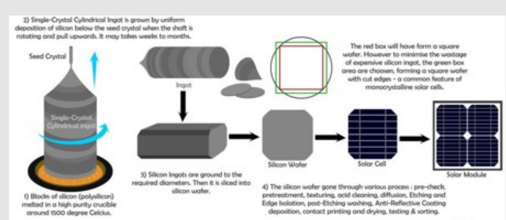
Source: Ministry of Industry and Information Technology (MIIT), Gaogong Industry Research Institute (GGII), Morgan Stanley Research (e) estimates

Polysilicon was considered extremely complex to manufacture... Just like the manufacturing quality of EV batteries today, polysilicon was perceived to have very high barriers to entry to achieve high purity requirements. There were only a handful of manufacturers at scale globally – most already producing semiconductor grade polysilicon – and each sold out on capacity for the next decade. However, this turned out to be less of an issue for solar PV customers based in China as new entrants such as GCL-Poly made a less-perfect but cheaper substitute at significantly lower cost and hence pricing. In many ways, recent order wins in cheaper LFP batteries for shipment outside of China could be seen as a milestone challenging the status quo in premium NMC/NCA EV batteries.

Did you know

Solar-grade polysilicon typically has purity levels of 6N (99.9999% pure) to 8N (99.999999%) and it is used to make solar cells. Electronic-grade polysilicon has higher purity levels of 9N (99.9999999%) to 11N (99.999999999%) for producing silicon wafers to manufacture semiconductor chips.

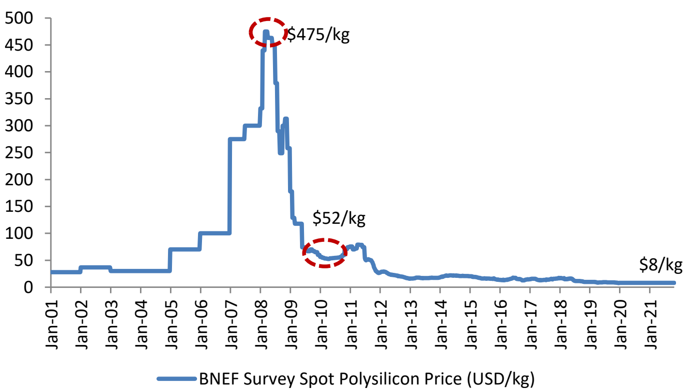
Exhibit **146:** Polysilicon Factory Production Flow Chart



Source: Heng Xing Technology

… but was quickly commoditized. Given the commodity nature of polysilicon, the sharp price decrease in the Chinese market impacted global pricing as well as the existing large order backlog and long-term 'take-or-pay' contracts from established manufacturers. In the end, previous contracts were re-negotiated and re-priced to adjust to new entrants' discounts. Exhibit 4 illustrates the impact on polysilicon pricing, which fell by 89% from peak levels of $475/kg by 2010 as China caught on to international markets and is currently stable/ recovered at around $8/kg since 2013. From a demand perspective, we also note key similarities between the solar and EV markets in that large funding was a key requirement driving solar farms/projects, which eventually gave way during the Great Financial Crisis in 2008. In terms of funding for the EV value chain today, there is a race for investments and capital that is accelerating.

Exhibit 147: Long-term polysilicon price – boom to bust as new entrants drove excess supply and hit by sharp contraction in credit availability post GFC



Source: Bloomberg, Morgan Stanley Research

Or the LED Industry All Over Again?

What happened: new technology enabled new competition/commoditization and offset key market dynamics. The emergence of LED technology in the lighting market allowed the emergence of new players, notably Asian companies, to enter what was seen as a high growth and scalable industry. These new entrants first moved to the upstream part of the value chain (highly capex intensive and volume driven - similar to the battery cell or materials) and slowly made their way down the value chain toward the downstream segments (such as packaging for EV today) as then industry became more mature leading up to 2017. The common view was that this new competition drove prices down and impacted the industry for good. This view was partially true, but a bit simplistic.

On one hand, price had to come down to accelerate LED technology penetration – without this price decline, we would be unlikely to see the current level of penetration on new sales simply because there were and still are alternatives to LED lighting which comply with energy efficiency regulations in most cases. As such, and even though the price of lighting equipment is small vs the total costs of a building, customers have been conscious of maintaining the costs/benefits rather than just simply to "pay up."

However, the transition to LED has slowly eroded one of the historical key drivers of the lighting industry, i.e., the replacement market. Because LED is expected to last on average 3-4x longer than existing technology, the more LEDs are installed on a global basis, the slower the rate of the lighting replacement cycle. We think this element was largely ignored by the market as the total penetration of LED in the global installed base was small, forgetting that about 25% of the lighting market in value was replacement a decade or so ago. We think this erosion of the replacement cycle partially explains why a company such as Seoul Semiconductor, a market leader in LED bulbs, was already guiding for flat sales in this business as soon as 2019. By 2020, more attractive price points and performance drove new applications and adoption in markets such as TV, tablets, smartphone and automobiles. This in turn drove a rebound in outperformance from the lows in 2019.

What can we learn from the transition to LED? We think the move from ICE to EV will not be as challenging, but there are some interesting conclusions that need to be remembered. We are not ready to draw a one-to-one parallel between the transition from conventional to LED lighting and the transition to EV batteries - at least, not at this stage.

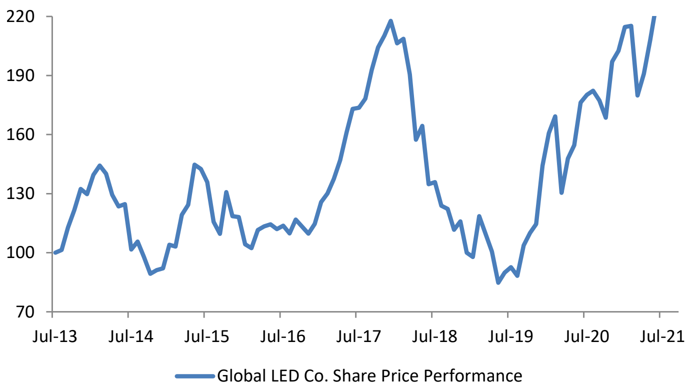
For the moment, there is no evidence of a meaningful competitive push from new EV battery entrants. Generally speaking, we see technology and auto OEM supply chain channels as fairly robust barriers to entry in EV batteries, at least in the developed markets. We also see the importance of the safety and range as a barrier to entry for new players, especially outside China. But this is not impossible or sustainable as many new players (such as CATL or BYD in China) are already emerging with interesting offerings in the Western OEM space.

Also, we note the fundamental difference about the replacement cycle – LED has made it much longer. But in the case of EV batteries, we think the lifecycle is probably less relevant vs ICE, and it is expected to remain fairly similar. This is an important driver for why growth in the lighting market started to decelerate so quickly, despite relatively modest LED penetration of the total installed base.

That said, we think price deflation will be a feature of the transition to EV and could represent a challenge vs usual price declines to reflect costs and the EV industry drive to reach total cost of ownership parity with the ICE industry. Also, one of the headwinds to profitability for EV batteries may be similar to the transition to LED challenge of running two different portfolios – at the time, R&D had to step up to build up a new product range and SG&A had also stepped up to adequately market the new range. Though less emphasis was put on the conventional offering, it was still needed to support cash and margin generation within the lighting industries as the lack of scale and investments needed was making the LED offering only modestly profitable. We think this transition phase may exist in the EV battery manufacturing business, and we have seen companies already stepping up R&D and reporting margin dilution from its EV battery business or delays in achieving breakeven operating margin for companies in Korea. But with the speed of EV transition being slower than that of LED, we believe it might now be better managed for the transition to EV.

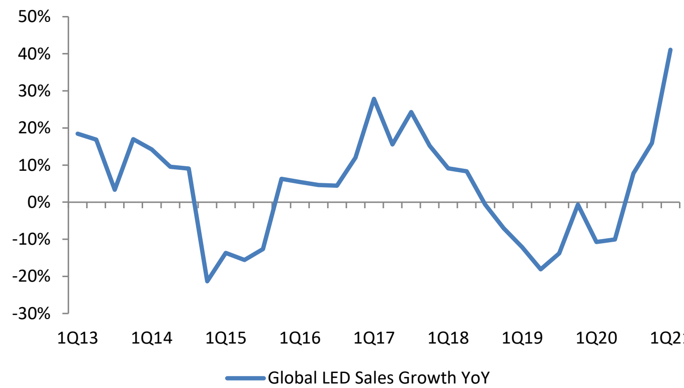
Looking back – never a straight line. Overall, looking at the share price performance of the key players in the sector since 2017, but also margin patterns and especially growth, we sense there has been some disappointment vs initial investor expectations. Also, we note that a significant numbers of large lighting assets have been involved in a sale process (Osram Luminaires, Cree Lighting and General Electric Lighting, Eaton spin off its lighting division).

Exhibit 148: Global LED Companies' Share Price Performance at Historical Low in 2019



Source: Bloomberg, Morgan Stanley Research; Note: share price performance is the average of Sanan, Seoul Semi and Osram

Exhibit 149: ... as Global LED Sales Growth Moved in Negative Territory and bottomed in 3Q19



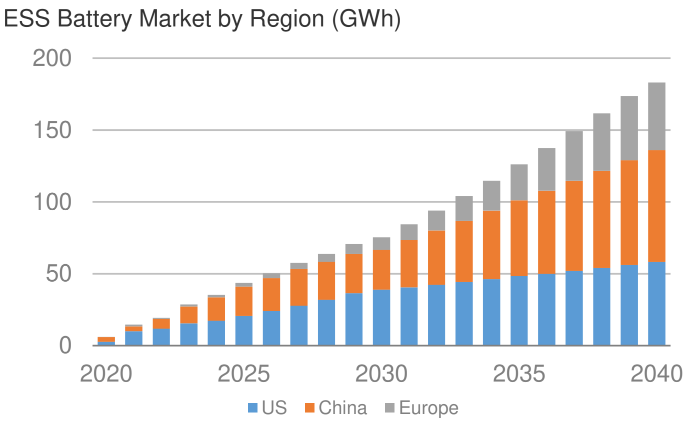
Source: Bloomberg, Morgan Stanley Research; Note: sales growth YoY is the average of Sanan, Seoul Semi and Osram

Appendix III - ESS Battery Global Update

Stephen Byrd, Jack Lu, and Rob Pulleyn

We present a global energy storage system (ESS) battery update to complement our EV battery analysis. For global markets, our China, US, and European analysts forecasted total stationary energy storage deployment for batteries to be 75 GWh annually by 2030 and ~185 GWh annually by 2040. In 2040, we expect that the ESS battery market will be 43% China, 32% US, and 26% Europe.

Exhibit 150: Global ESS Battery Market Forecasts

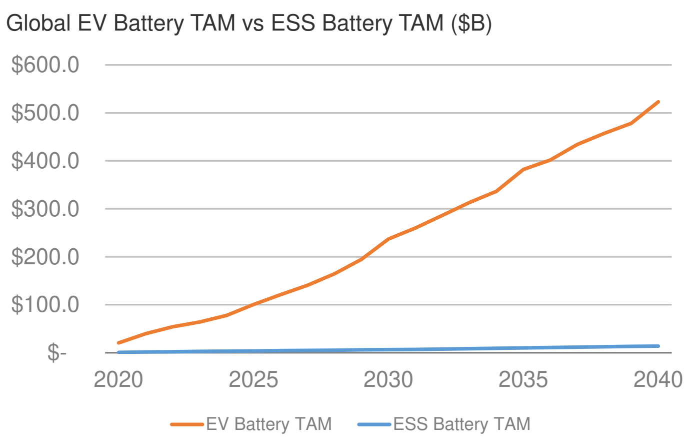


Source: Morgan Stanley Research

Applying the battery pricing assumptions used in our EV battery TAM model, we project the global ESS Battery TAM out to 2040. By 2040, we estimate the global ESS Battery TAM will be $13.8bn and 3% of the EV Battery TAM (~$525bn). We estimate that the global total battery TAM (ESS + EV) in 2040 will be ~$535bn.

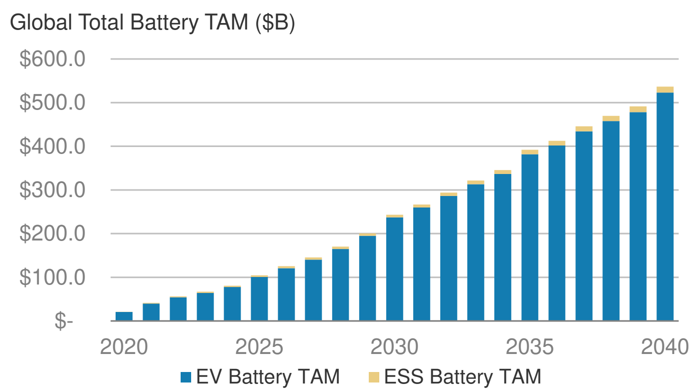
- In 2025, the ESS Battery TAM is $3.8bn and 4% of the EV Battery TAM.
- In 2030, the ESS Battery TAM is $6.3bn and 3% of the EV Battery TAM.
- In 2035, the ESS Battery TAM is $10.0bn and 3% of the EV Battery TAM.
- In 2040, the ESS Battery TAM is $13.8bn and 3% of the EV Battery TAM.

Exhibit 151: Global EV Battery TAM vs ESS Battery TAM



Source: Morgan Stanley Research

Exhibit 152: Global Total Battery TAM



Source: Morgan Stanley Research

China

China's ESS TAM expected to be 28 GWh by 2030 and 77 GWh in 2040. China has already set a target of 30 GW (30-60 GWh) ESS deployment by 2025, implying annual incremental volume of 10-15 GWh, ~3% of China's EV battery TAM. We believe this target properly reflects the feasibility of ESS deployment under China's regulated power system, from both a technical and economical perspective.

We build a comprehensive model to test the cost curve of ESS deployment with rising solar installation in China, considering battery technology upgrade with improving cycle life, potential cost reduction of battery, PCS, and other ESS parts as well as changes in ESS duration hours. With this model, we can also test what power price level needs to be to drive different levels of ESS deployment.

ESS' levelized cost of energy (LCOE) is a function of duration hours. For a solar plus ESS project, more energy stored means higher LCOE. To achieve a 12% IRR, if we make ESS deployment be 50% of solar capacity with 1 duration hour, or 25% of solar capacity with 2 duration hours, we need to raise on-grid power price by >30%. In addition, we also need to assume battery cycle life will improve to 12 years of cycle life vs. current ~8 years in real world. More ESS deployment from there requires more power tariff hikes.

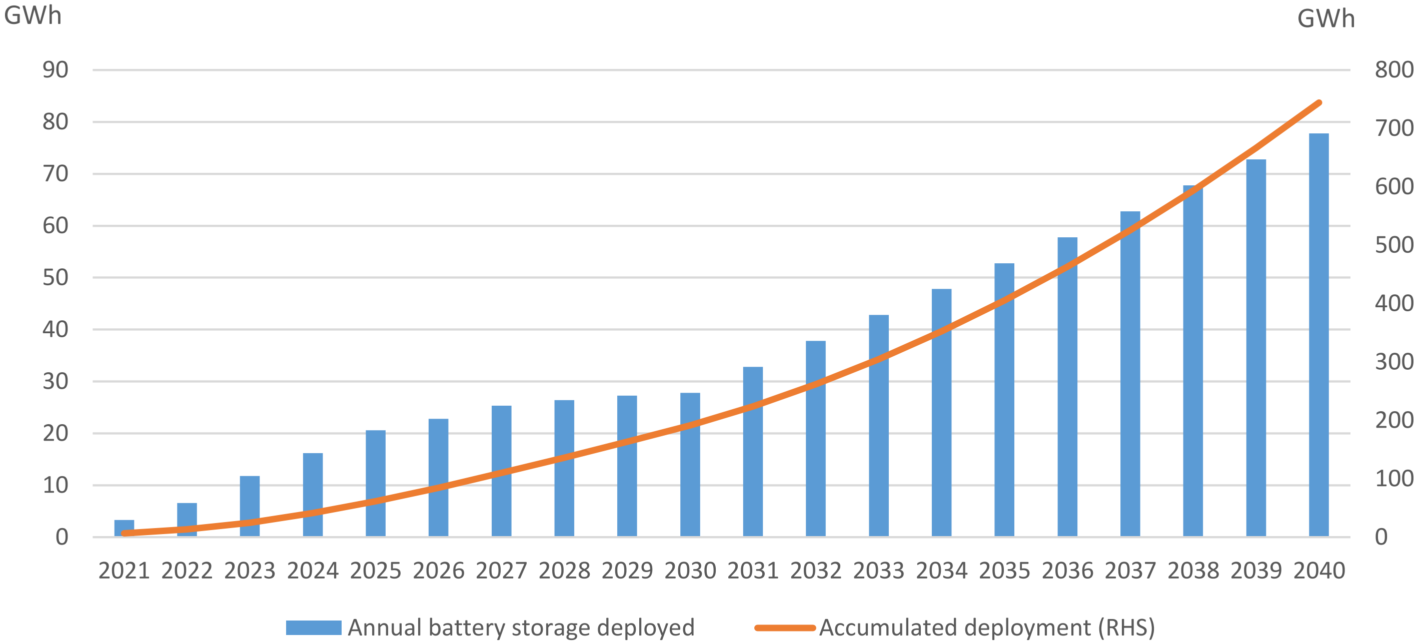
With an assumption of ~30% power price hike in the future to allow ESS deployment to be 25% of new solar installation with 2 duration hours, we forecast the accumulated deployment to reach 75 GWh by 2025, which is ahead of China's target of 30 GW (likely 30 - 60 GWh). We further estimate the accumulated deployment to be 194 GWh in 2030 and 750 GWh in 2040. This implies ~28 GWh annual volume in 2030 and 77 GWh in 2040, 3-4% of China's EV battery TAM.

Exhibit 153: LCOE of battery storage rises significantly as storage energy increases, requiring higher power price to support its economics

Stationary battery storage economical analysis	2020	2025E	2030E
Solar power capacity (MW)	1,000		
Solar utilization hours	1,160	1,276	1,392
Battery storage deployed MW as % for solar power	15%	50%	100%
Battery storage deployed (MW)	150	500	1000
Storage duration per day (hours)	1	1	4
Storage capacity (MWh)	150	500	4000
Initial investment (Rmb mn)	386	1181	4520
Annual cash flow (NPV=0) (Rmb mn)	51	157	600
Operating expenditures (Rmb mn)	12	35	136
Required revenue (Rmb mn)	63	192	735
Annual storage energy (GWh)	31	102	818
Annual solar energy (GWh)	1,160	1,276	1,392
Energy storage ratio %	3%	8%	59%
LCOE (Levelized cost of electricity) (Rmb/kWh)	**0.05**	**0.15**	**0.53**
As % of on-grid power tariff	14%	38%	132%

Source: Morgan Stanley Research estimates

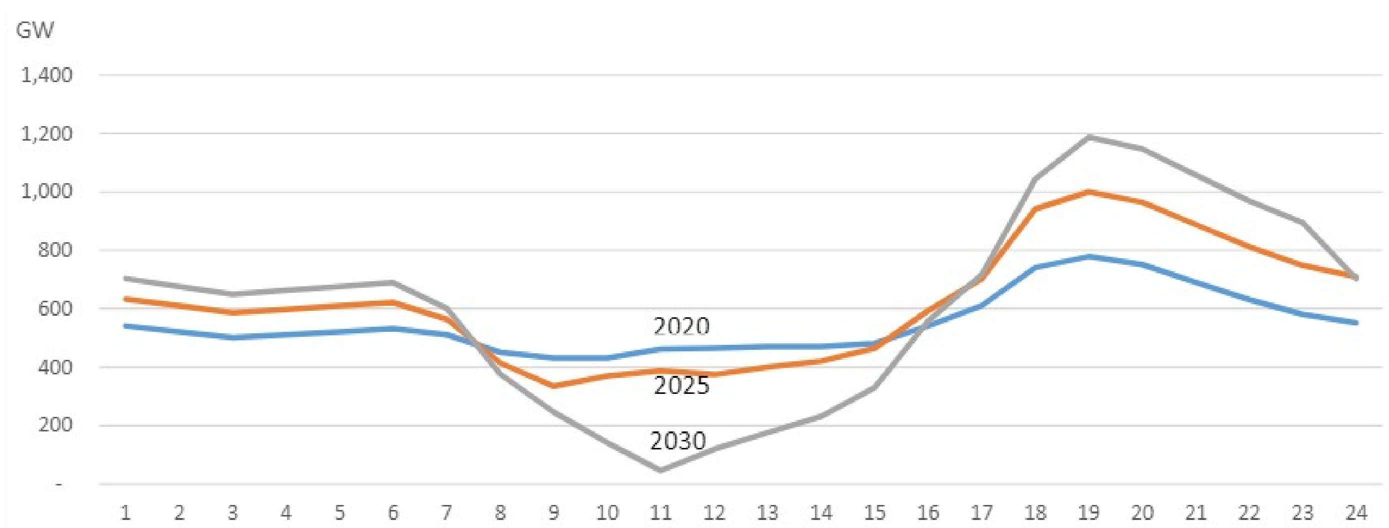
Exhibit 154: China- battery storage TAM



Source: Company data, Morgan Stanley Research

Who will pay for ESS after net load evolves to 'duck curve'? China's daily electric load is provided by coal IPPs, hydropower, solar, wind, and nuclear over a 24-hour period. As the proportion of solar and wind contributions rises, the net load (total load-solar-wind) will be disturbed and transform into a duck shape curve, illustrating that storage duration needs to rise to balance the electricity load. Under this duck curve scenario, LCOE of ESS will surge with >4 duration hours as illustrated above, and China needs to double power tariff to make ESS economical. However, China has been cautious to raise power price historically and would rather IPPs make a loss amid coal price inflation, for economy and social welfare. The worst case for battery companies is that they may benefit from China's robust demand for energy storage but will not really get paid.

Exhibit 155: China's coal IPPs load curve to evolve from 'camel' to 'duck' shape

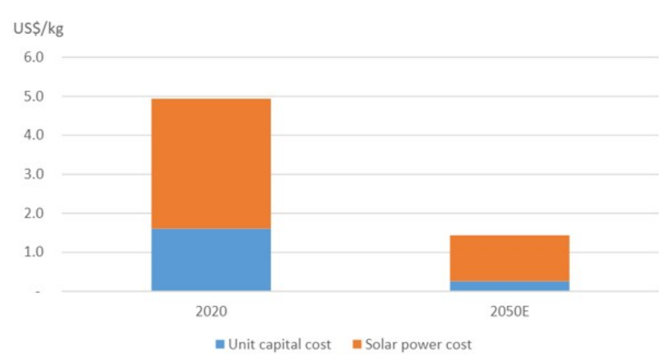


Source: Morgan Stanley estimate

Where could we be wrong? If current LFP battery technology continues to improve cycle life to >10k times or over 20 years, LCOE of ESS could be cheap enough to trigger much larger adoption than expected. With that level of cycle life, the EV game may also be over as the battery cost within an EV is almost free then. Technology is the key risk for our ESS TAM calculation. Besides, our assumption is based on lithium-ion battery technology, and if new battery technology with more attractive cost and performance are innovated, the LCOE of ESS should be materially lowered which could create larger ESS TAM.

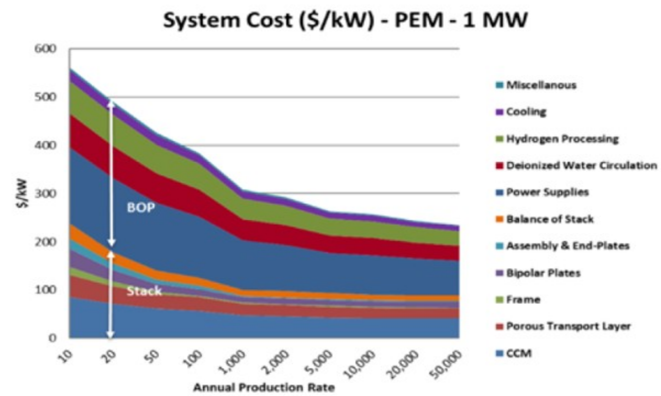
Solar plus electrolyzer could be a better solution. Solar plus water electrolyzer, which stores energy in hydrogen, could be a better solution in ESS market. It will not see costs surge as energy storage increases given that water can be recycled. Rather, it will likely see significant cost efficiencies as scale increases. We expect a combination of solar, electrolyzer and fuel cell power generation to reach an on-grid cost of Rmb0.65/kWh if solar costs drop to Rmb0.2/kWh in future. The cost of hydrogen at the moment is still high at more than Rmb35/kg. But if the solar cost continues to drop to Rmb0.2/kWh in future, hydrogen production by electrolyzers would reduce cost to Rmb9.8/kg, on our estimate. Meanwhile, the electrolyzer unit capital cost should also reduce significantly due to scale-up, current density improvement and an increase in energy conversion efficiency, as well as cost reductions in components such as PEM (proton exchange membrane) and catalysts. Electrolyzer producers can achieve a cost reduction of over 50% if the production rate increases from 10MW/year to 1GW/year (production unit from 10 units/year to 1000 units/year), according to a study conducted by the National Renewable Energy Laboratory (NREL). Large manufacturing scale will reduce unit fixed costs, improve utilization of equipment and yield rate, and allow for the adoption of automation and more advanced manufacturing technology.

Exhibit 156: Green hydrogen cost produced by electrolyzers



Source: NREL, IRENA, Morgan Stanley (E) estimate

Exhibit 157: Cost curve of PEM projected by the NREL



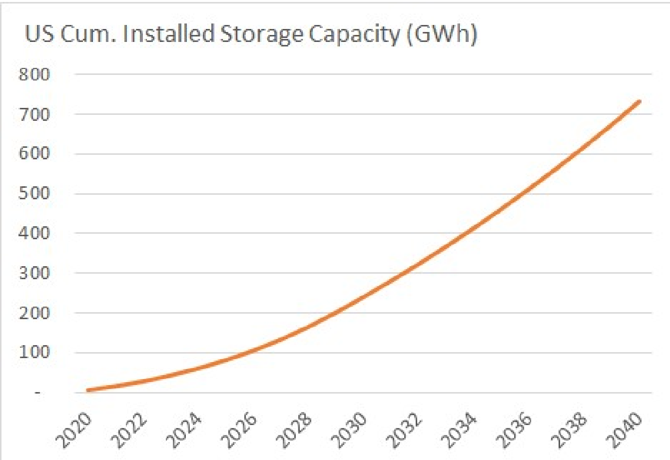
Source: NREL, IRENA; Note: Currency is US$

For more details, please see *Contemporary Amperex Technology Co. Ltd.: ESS Opportunity Overstated; Downgrade to UW (30 May 2021)*

United States

In the US, we continue to see strong demand for FTM and BTM battery storage for years to come. The US is one of the largest markets for energy storage globally, with potential to reach over 80 GW of storage installed by 2030 vs. just 2.7 GW in 2020. Our US Utilities and Clean Tech team projects net additions to the US energy storage market to grow at a 25% CAGR from '20-'40, driven by (1) the continuously improving economics of renewables + battery storage both at grid scale (front-of-the-meter or FTM) and residential/commercial (behind-the-meter or BTM), (2) increased storage penetration required to manage renewable energy asset intermittency and grid reliability, and (3) increased demand for decarbonization solutions in the Corporate and Industrial sectors as well as demand for distributed generation (DG) solutions to help lower utility bills. We would expect upside to our storage estimates in the event a standalone federal investment tax credit (ITC) for energy storage is passed into law in the upcoming budget reconciliation process in Congress, which would further improve the cost economics of storage investments for developers.

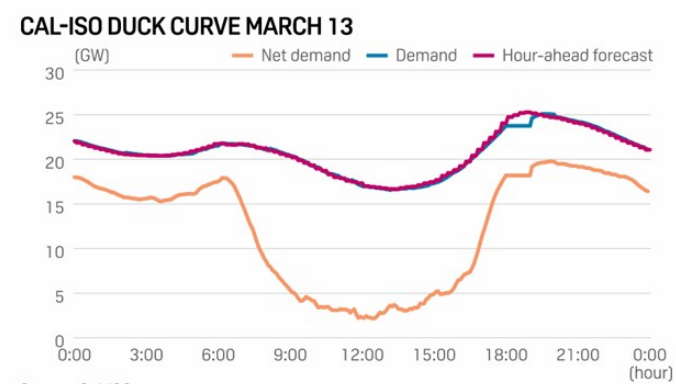
Exhibit 158: We project cumulative installed ESS capacity in the US to approach 700 GWh by 2040



Source: Morgan Stanley Research

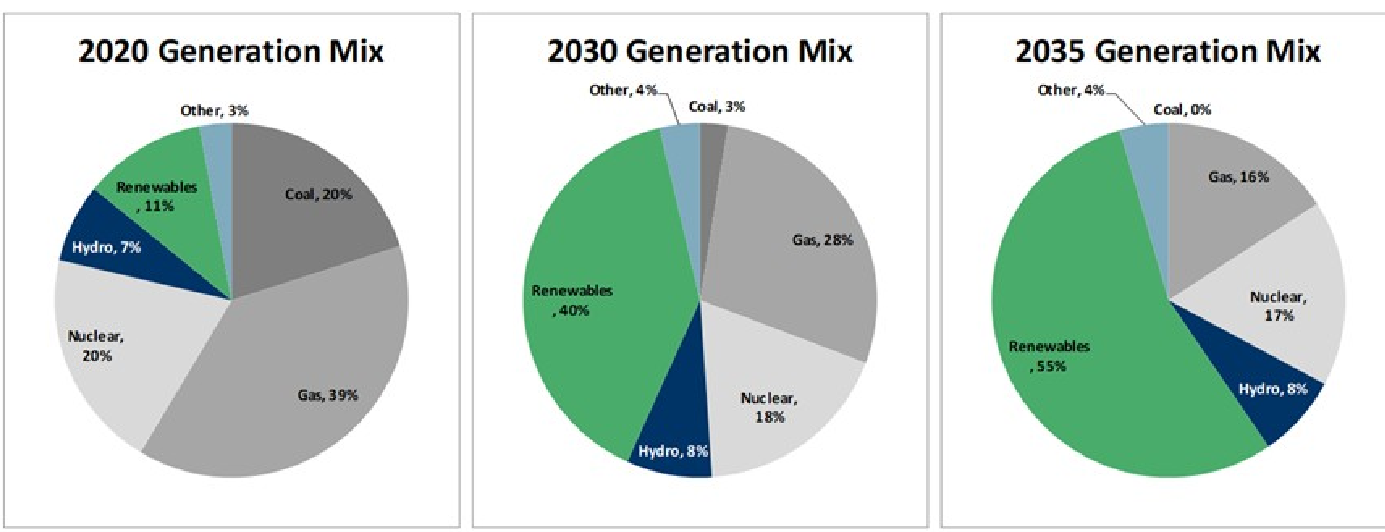
We think the benefits of battery storage are broader than appreciated. This perspective becomes especially important to understand as renewable energy penetration increases. As wind and solar energy become an increasingly important part of the US power generation mix (driven primarily by favorable economics, state-level clean energy goals, and federal tax credits that have continued to be extended), storage helps address a couple of key issues: the mismatch between when renewable energy is produced and when consumers want the power, and the inherent intermittency of renewable energy. The California "duck curve" is a useful starting point to understand the role of storage. This curve, shown below, highlights that net power demand from consumers (net of the large amount of solar power produced in the middle of the day) will fluctuate more widely throughout the course of the day/evening. Energy storage can help by storing excess power produced by solar midday/early afternoon (and wind at night) and releasing the stored electricity in the early evening and morning. We see grid scale storage as being vital to stabilizing the grid as renewables continue to increase penetration in the US and globally.

Exhibit 159: The California "Duck Curve" Shows that Net Demand for Power Falls Dramatically Midday as Solar Reduces the Need for Power from the Grid - Energy Storage Can Redirect Excess Solar Power to the Evening Peak Demand Period



Source: CAISO, S&P Market Intelligence

Exhibit 160: Projected US Power Generation Mix by Fuel Type – A Major Shift Playing Out Which Will Drive Incremental Demand for Battery Storage



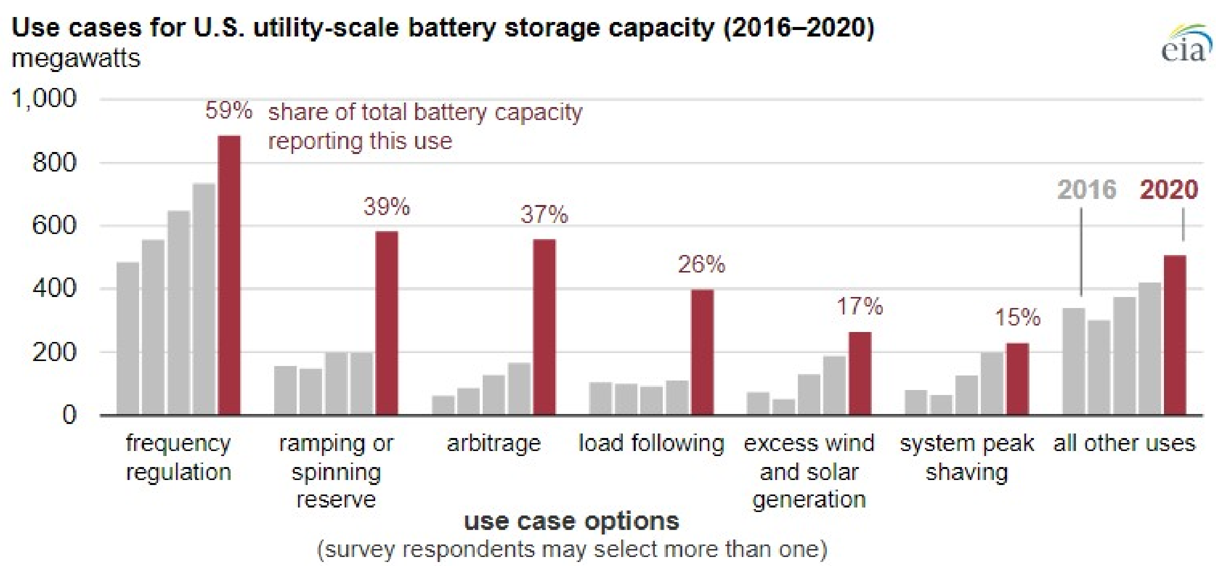
Source: EIA, SNL Financial, Morgan Stanley Research estimates

Ever-increasing grid complexity also drives demand for "smart" battery storage solutions that can properly optimize asset use. As more and more distributed generation resources (rooftop solar, fuel cells, virtual power plants, bi-directional EV charging) increase their market share of overall generation in the US, the complexity of the grid will evolve with them. Given that electricity is a commodity that must be consumed instantaneously (absent any form of storage), as more technologies produce and consume electricity in a distributed manner, storage acts as ideal clean resource that does not suffer the intermittency of renewables and can not only fill in the gaps for renewables, but can take advantage of pricing arbitrage opportunities as well as providing back up power. To do this optimally, market participants have to invest in "smart" storage with AI enabled software that is able to dispatch opportunistically when prices are high and charge when power prices are low. As the value proposition for distributed generation increases, particularly for residential customers, we view this unique aspect of storage as driving incremental demand and its use cases expanding as the complexity of the grid continues to evolve.

BTM applications for battery storage will grow as incumbent utility bills continue to increase. We believe distributed energy with storage poses a significant long-term risk to utility business-models. In California for example, utility bills continue to increase >5% per year (from an already extremely high base of $0.20-0.27/kWh), distributed energy costs continue to decrease 5-15% per year, and grid reliability issues persist, we believe distributed energy will pose a significant risk to the utilities as well as in other areas of the US where the "economic wedge" of solar + storage continues to increase. We see a significant risk that residential utility customers will opt for rooftop solar combined with energy storage, which effectively results in the utility bill for non-solar customers rising even faster (due to the need for utilities to spread their fixed costs over a smaller remaining customer base), which in turn provides an even greater incentive for utility customers to switch to solar + storage. The incentives to switch are large, with solar installers able to offer customers power for ~$0.15/kWh (25-40% cost savings). For commercial customers, we believe fuel cell technologies such as Bloom's (BE) solid oxide fuel cell are the biggest threat to the utilities. In the event that net metering policies in the US are significantly altered and customers are able to sell back power for much less than the current status quo, we see this as driving incrementally more demand for BTM battery storage that is paired with rooftop solar.

What could the future of ESS look like? Form Energy is a start-up company that has developed an iron-air based long duration battery storage technology. While this is in very early stages and has yet to reach full commercial viability, the company claims potential to get to a capital cost of just $10-20 per kWh of energy storage (vs lithium ion costs that are in the range of $200/kWh today) and with a product that is designed for up to 100 hours of storage (vs. many grid scale battery's today in the 4-6hr range). At these projected economics, if the product sufficiently works without degradation, we believe long duration storage would be quite competitive against natural gas-fired generation and could vastly accelerate the shut down of legacy gas and coal plants while improving the scale of decarbonization on the global energy landscape.

Exhibit 161: Over time, use cases for storage assets in the US have become more diverse and complex



Source: EIA

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(as of October 31, 2021)

The Stock Ratings described below apply to Morgan Stanley's Fundamental Equity Research and do not apply to Debt Research produced by the Firm.

For disclosure purposes only (in accordance with FINRA requirements), we include the category headings of Buy, Hold, and Sell alongside our ratings of Overweight, Equal-weight, Not-Rated and Underweight. Morgan Stanley does not assign ratings of Buy, Hold or Sell to the stocks we cover. Overweight, Equal-weight, Not-Rated and Underweight are not the equivalent of buy, hold, and sell but represent recommended relative weightings (see definitions below). To satisfy regulatory requirements, we correspond Overweight, our most positive stock rating, with a buy recommendation; we correspond Equal-weight and Not-Rated to hold and Underweight to sell recommendations, respectively.

	Coverage Universe		Investment Banking Clients (IBC)			Other Material Investment Services Clients (MISC)	
Stock Rating Category	Count	% of Total	Count	% of Total IBC	% of Rating Category	Count	% of Total Other MISC
Overweight/Buy	1501	43%	411	47%	27%	670	43%
Equal-weight/Hold	1515	43%	392	45%	26%	682	44%
Not-Rated/Hold	0	0%	0	0%	0%	0	0%
Underweight/Sell	510	14%	77	9%	15%	197	13%
Total	3,526		880			1549	

Data include common stock and ADRs currently assigned ratings. Investment Banking Clients are companies from whom Morgan Stanley received investment banking compensation in the last 12 months. Due to rounding off of decimals, the percentages provided in the "% of total" column may not add up to exactly 100 percent.

Analyst Stock Ratings

Overweight (O). The stock's total return is expected to exceed the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.

Equal-weight (E). The stock's total return is expected to be in line with the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.

Not-Rated (NR). Currently the analyst does not have adequate conviction about the stock's total return relative to the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.

Underweight (U). The stock's total return is expected to be below the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.

Unless otherwise specified, the time frame for price targets included in Morgan Stanley Research is 12 to 18 months.

Analyst Industry Views

Attractive (A): The analyst expects the performance of his or her industry coverage universe over the next 12-18 months to be attractive vs. the relevant broad market benchmark, as indicated below.

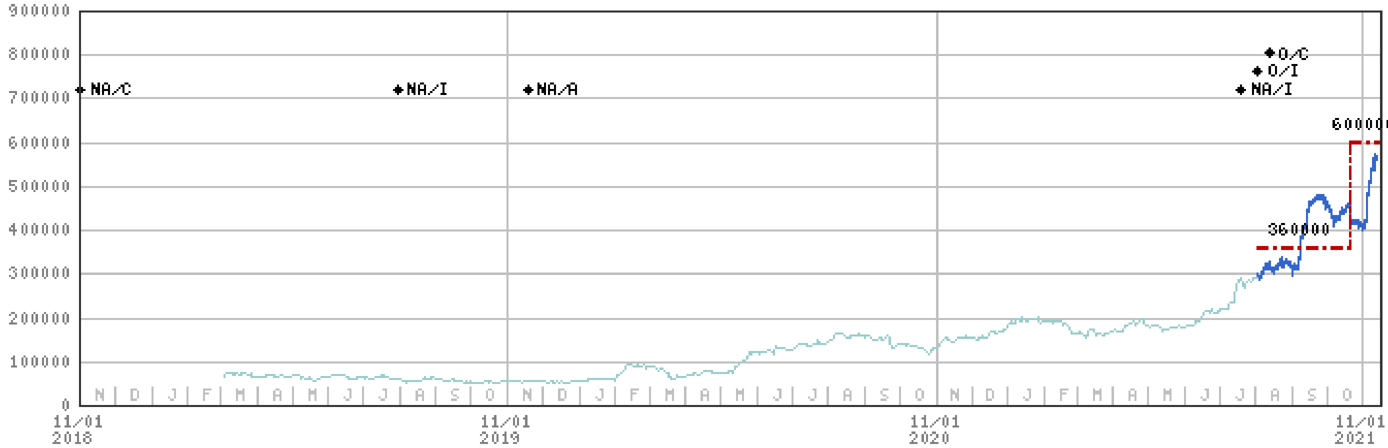
In-Line (I): The analyst expects the performance of his or her industry coverage universe over the next 12-18 months to be in line with the relevant broad market benchmark, as indicated below.

Cautious (C): The analyst views the performance of his or her industry coverage universe over the next 12-18 months with caution vs. the relevant broad market benchmark, as indicated below.

Benchmarks for each region are as follows: North America - S&P 500; Latin America - relevant MSCI country index or MSCI Latin America Index; Europe - MSCI Europe; Japan - TOPIX; Asia - relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.

Stock Price, Price Target and Rating History (See Rating Definitions)

Ecopro BM (247540.KQ) - As of 11/14/21 in KRW
Industry : S. Korea Technology



Stock Rating History: 11/1/16 : NA/I; 11/26/17 : NA/C; 7/30/19 : NA/I; 11/18/19 : NA/A; 7/19/21 : NA/I; 8/3/21 : O/I; 8/12/21 : O/C

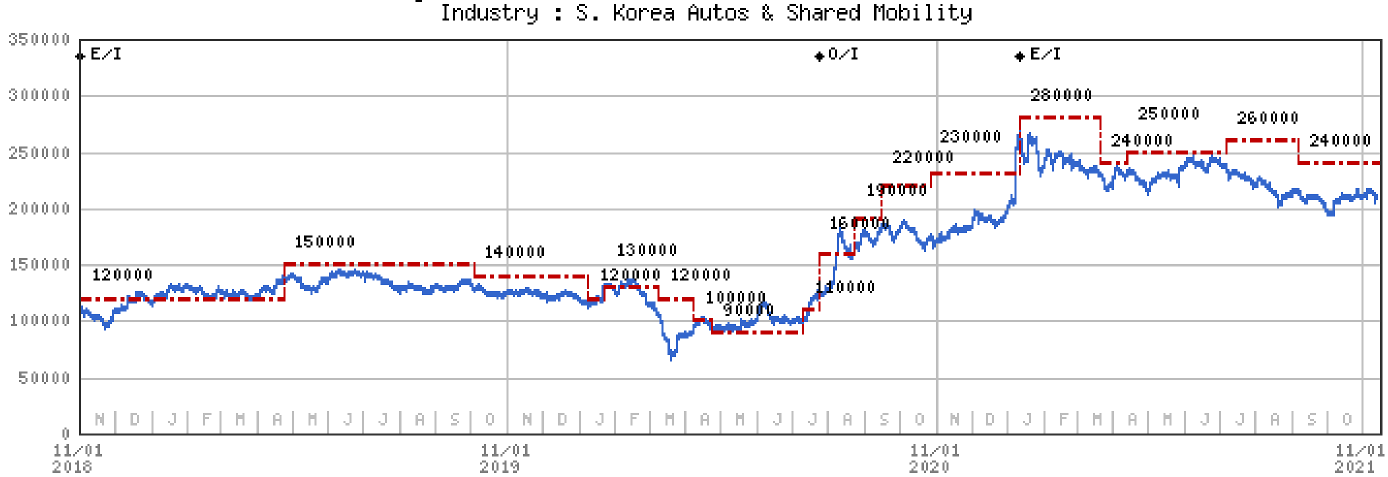
Price Target History: 8/3/21 : 360000; 10/20/21 : 600000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target -- No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst) — Stock Price (Covered by Current Analyst) —
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.

Hyundai Motor (005380.KS) - As of 11/14/21 in KRW
Industry : S. Korea Autos & Shared Mobility



Stock Rating History: 11/1/16 : O/I; 3/30/17 : E/I; 11/30/17 : O/I; 10/11/18 : E/I; 7/24/20 : O/I; 1/12/21 : E/I

Price Target History: 8/25/16 : 160000; 7/26/17 : 150000; 9/8/17 : 140000; 11/30/17 : 200000; 1/26/18 : 190000; 6/23/18 : 170000; 10/11/18 : 135000; 10/25/18 : 120000; 4/24/19 : 150000; 10/3/19 : 140000; 1/9/20 : 120000; 1/23/20 : 130000; 3/9/20 : 120000; 4/8/20 : 100000; 4/24/20 : 90000; 7/10/20 : 110000; 7/24/20 : 160000; 8/24/20 : 190000; 9/16/20 : 220000; 10/27/20 : 230000; 1/12/21 : 280000; 3/22/21 : 240000; 4/13/21 : 250000; 7/7/21 : 260000; 9/7/21 : 240000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target -- No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst) — Stock Price (Covered by Current Analyst) —
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

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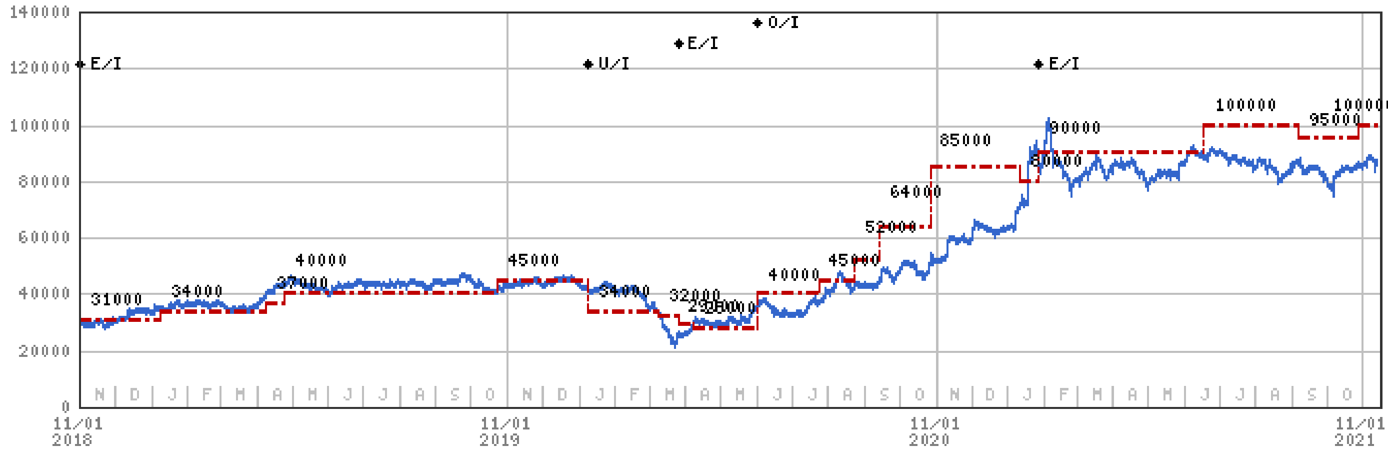
Kia Corp. (000270.KS) - As of 11/14/21 in KRW
Industry : S. Korea Autos & Shared Mobility



Stock Rating History: 11/1/16 : E/I; 1/9/20 : U/I; 3/26/20 : E/I; 6/2/20 : O/I; 1/28/21 : E/I

Price Target History: 8/25/16 : 45000; 1/26/17 : 40000; 7/27/17 : 36000; 9/8/17 : 35000; 1/26/18 : 30000; 10/11/18 : 35000; 10/26/18 : 31000; 1/9/19 : 34000; 4/9/19 : 37000; 4/25/19 : 40000; 10/24/19 : 45000; 1/9/20 : 34000; 3/9/20 : 32000; 3/26/20 : 29000; 4/8/20 : 28000; 6/2/20 : 40000; 7/24/20 : 45000; 8/24/20 : 52000; 9/14/20 : 64000; 10/27/20 : 85000; 1/12/21 : 80000; 1/28/21 : 90000; 6/18/21 : 100000; 9/7/21 : 95000; 10/28/21 : 100000

Source: Morgan Stanley Research   Date Format : MM/DD/YY   Price Target   No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst)   Stock Price (Covered by Current Analyst)
Stock and Industry Ratings (abbreviations below) appear as ♦ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

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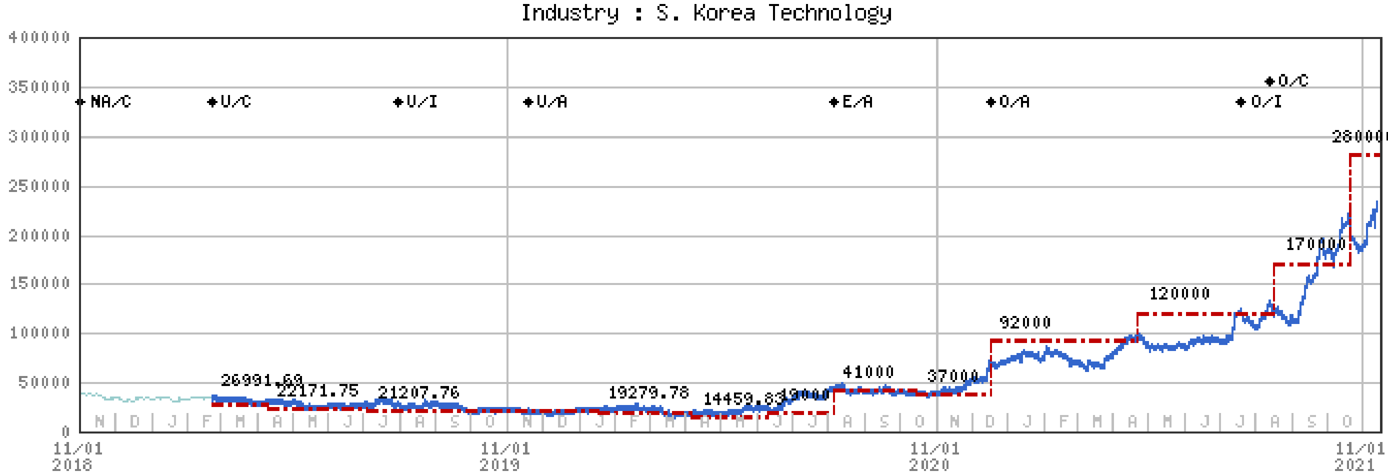
L&F Co Ltd (066970.KQ) - As of 11/14/21 in KRW
Industry : S. Korea Technology



Stock Rating History: 11/1/16 : NA/I; 11/26/17 : NA/C; 2/21/19 : U/C; 7/30/19 : U/I; 11/18/19 : U/A; 8/5/20 : E/A; 12/17/20 : O/A; 7/19/21 : O/I; 8/12/21 : O/C

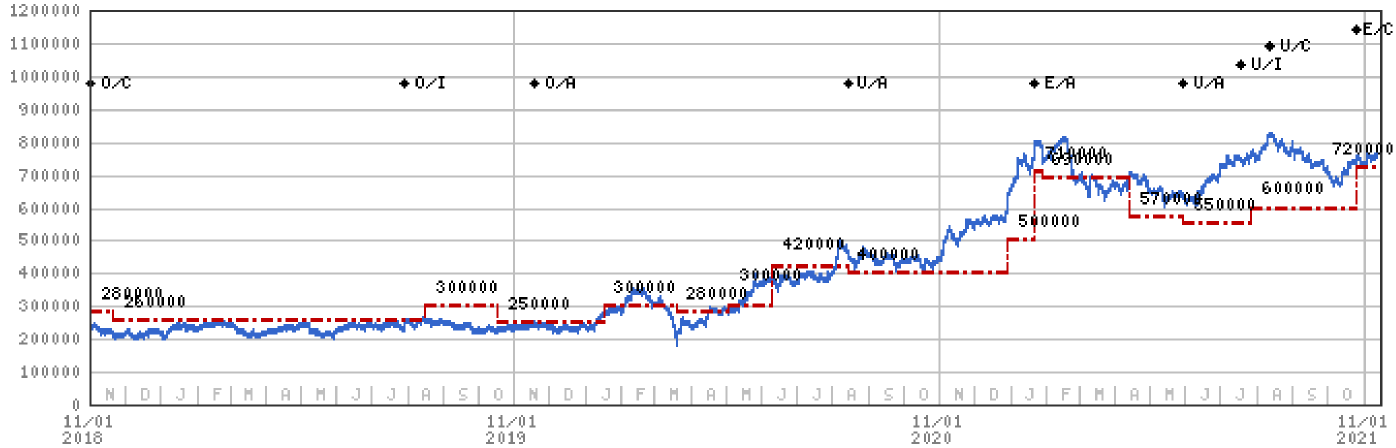
Price Target History: 2/21/19 : 26991.69; 4/10/19 : 22171.75; 7/4/19 : 21207.76; 1/17/20 : 19279.78; 4/6/20 : 14459.83; 6/10/20 : 19000; 8/5/20 : 41000; 10/16/20 : 37000; 12/17/20 : 92000; 4/22/21 : 120000; 8/17/21 : 170000; 10/20/21 : 280000

Source: Morgan Stanley Research   Date Format : MM/DD/YY   Price Target   No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst)   Stock Price (Covered by Current Analyst)
Stock and Industry Ratings (abbreviations below) appear as ♦ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.

Samsung SDI (006400.KS) - As of 11/14/21 in KRW
Industry : S. Korea Technology



Stock Rating History: 11/1/16 : U/I; 2/15/17 : E/I; 5/30/17 : O/I; 11/26/17 : O/C; 7/30/19 : O/I; 11/18/19 : O/A; 8/14/20 : U/A; 1/22/21 : E/A; 5/30/21 : U/A; 7/19/21 : U/I; 8/12/21 : U/C; 10/26/21 : E/C

Price Target History: 6/2/16 : 86000; 2/15/17 : 120000; 5/30/17 : 196000; 8/9/17 : 210000; 12/7/17 : 230000; 2/13/18 : 200000; 6/25/18 : 270000; 9/10/18 : 280000; 11/21/18 : 260000; 8/16/19 : 300000; 10/18/19 : 250000; 1/17/20 : 300000; 3/19/20 : 280000; 5/4/20 : 300000; 6/10/20 : 420000; 8/14/20 : 400000; 12/30/20 : 500000; 1/22/21 : 710000; 1/28/21 : 690000; 4/14/21 : 570000; 5/30/21 : 550000; 7/27/21 : 600000; 10/26/21 : 720000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target -- No Price Target Assigned (NA)
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Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

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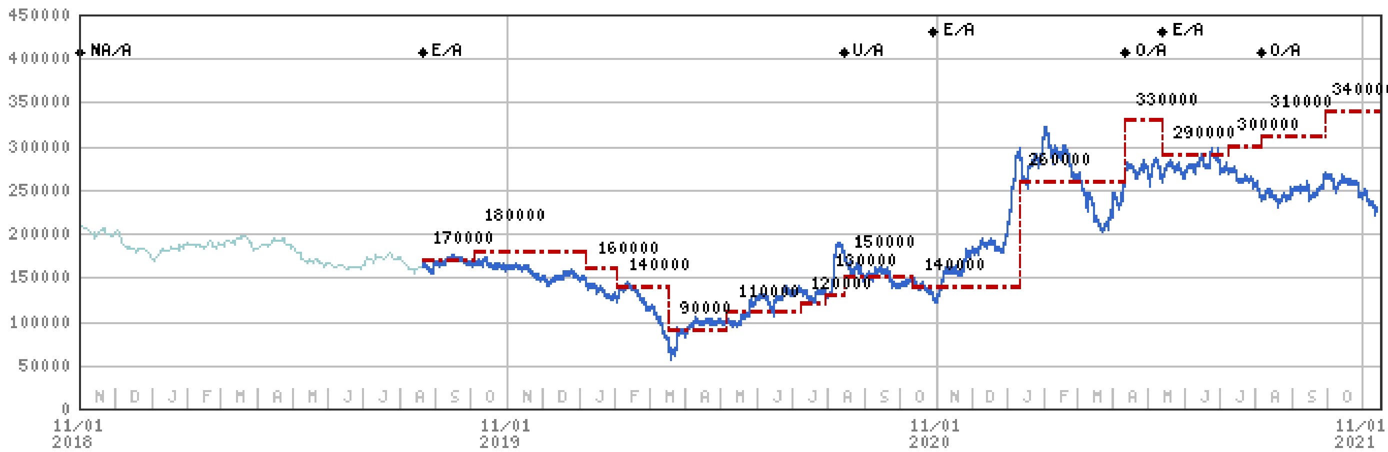
Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.

SK Innovation Co Ltd (096770.KS) - As of 11/14/21 in KRW
Industry : S. Korea Energy & Materials



Stock Rating History: 11/1/16 : O/A; 9/13/18 : NA/A; 8/20/19 : E/A; 8/14/20 : U/A; 10/30/20 : E/A; 4/12/21 : O/A; 5/13/21 : E/A; 8/5/21 : O/A

Price Target History: 4/1/16 : 200000; 4/26/17 : 210000; 11/3/17 : 240000; 5/17/18 : 270000; 9/13/18 : NA; 8/20/19 : 170000; 10/3/19 : 180000; 1/7/20 : 160000; 2/3/20 : 140000; 3/18/20 : 90000; 5/6/20 : 110000; 7/8/20 : 120000; 7/29/20 : 130000; 8/14/20 : 150000; 10/12/20 : 140000; 1/11/21 : 260000; 4/12/21 : 330000; 5/13/21 : 290000; 7/8/21 : 300000; 8/5/21 : 310000; 9/30/21 : 340000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target -- No Price Target Assigned (NA)
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Indicators and trackers referenced in Morgan Stanley Research may not be used as, or treated as, a benchmark under Regulation EU 2016/1011, or any other similar framework.

INDUSTRY COVERAGE: Autos & Shared Mobility

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
Adam Jonas, CFA		
Adient PLC (ADNT.N)	U (03/17/2021)	$47.22
American Axle & Manufacturing Holdings Inc (AXL.N)	U (03/24/2021)	$9.73
Aptiv Plc (APTV.N)	O (03/30/2020)	$170.50
Asbury Automotive Group Inc (ABG.N)	E (07/26/2021)	$184.72
AutoNation Inc. (AN.N)	E (09/28/2021)	$128.68
BorgWarner Inc. (BWA.N)	U (11/09/2020)	$48.25
Carmax Inc (KMX.N)	O (07/10/2018)	$148.81
Carvana Co (CVNA.N)	O (02/26/2021)	$294.43
Ferrari NV (RACE.N)	O (05/09/2019)	$258.57
Fisker Inc (FSR.N)	O (08/09/2021)	$21.16
Ford Motor Company (F.N)	U (01/29/2021)	$19.50
FREYR Battery SA (FREY.N)	O (08/03/2021)	$10.97
Garrett Motion Inc (GTX.O)		$7.46
General Motors Company (GM.N)	O (04/09/2018)	$63.40
Group 1 Automotive, Inc (GPI.N)	E (07/26/2021)	$207.06
Lear Corporation (LEA.N)	O (11/09/2020)	$183.52
Li-Cycle Holdings Corp. (LICY.N)	O (09/13/2021)	$13.30
Lithia Motors Inc. (LAD.N)	U (02/09/2021)	$322.82
Lordstown Motors (RIDE.O)	U (10/04/2021)	$5.68
Lucid Group Inc (LCID.O)	U (09/13/2021)	$43.93
Magna International Inc. (MGA.N)	O (10/14/2021)	$86.43
Microvast Holdings Inc. (MVST.O)	U (08/03/2021)	$9.69
Penske Automotive Group, Inc (PAG.N)	E (07/26/2021)	$112.16
Quantumscape Corp (QS.N)	O (02/11/2021)	$38.81
REE Automotive Ltd (REE.O)	U (09/13/2021)	$3.87
Romeo Power, Inc. (RMO.N)	++	$4.53
Sonic Automotive Inc (SAH.N)	E (11/14/2019)	$51.00
Tenneco Inc. (TEN.N)	U (03/30/2020)	$13.10
Tesla Inc (TSLA.O)	O (11/18/2020)	$1,033.42
Visteon Corporation (VC.O)	U (03/22/2018)	$124.00
Billy Kovanis		
Avis Budget Group Inc (CAR.O)	U (10/13/2021)	$267.03
Harley-Davidson Inc (HOG.N)	U (04/22/2021)	$38.39
Polaris Inc. (PII.N)	O (01/19/2021)	$124.25
Victoria A Greer		
Goodyear Tire & Rubber Company (GT.O)	E (04/16/2021)	$23.55

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* Historical prices are not split adjusted.

INDUSTRY COVERAGE: S. Korea Autos & Shared Mobility

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Young Suk Shin		
Hankook Tire & Technology Co Ltd (161390.KS)	O (04/08/2020)	W42,300
Hanon Systems (018880.KS)	E (10/14/2021)	W14,300
Hyundai MOBIS (012330.KS)	O (10/14/2021)	W247,500
Hyundai Motor (005380.KS)	E (01/12/2021)	W209,000
Kia Corp. (000270.KS)	E (01/28/2021)	W86,500
Mando (204320.KS)	O (10/14/2021)	W61,800
SNT Motiv Co. Ltd. (064960.KS)	O (09/28/2017)	W50,100

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INDUSTRY COVERAGE: China Autos & Shared Mobility

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Jack Yeung		
BAIC Motor (1958.HK)	U (03/12/2021)	HK$3.17
Brilliance China Automotive (1114.HK)	U (03/12/2021)	HK$7.30
Dongfeng Motor Group (0489.HK)	O (05/11/2020)	HK$7.18
FAW Car Company Limited (000800.SZ)	U (07/11/2015)	Rmb10.69
Geely Automobile Holdings (0175.HK)	O (09/01/2021)	HK$25.30
Great Wall Motor Company Limited (601633.SS)	E (07/23/2021)	Rmb59.18
Great Wall Motor Company Limited (2333.HK)	O (07/23/2021)	HK$32.80
Guangzhou Automobile Group (601238.SS)	U (10/23/2019)	Rmb16.94
Guangzhou Automobile Group (2238.HK)	O (05/05/2020)	HK$7.41
Joey Xu, CFA		
Anhui Jianghuai Automobile (600418.SS)	U (08/03/2020)	Rmb14.82
Chongqing Changan Automobile (000625.SZ)	O (11/18/2020)	Rmb20.09
Chongqing Changan Automobile (200625.SZ)	O (11/18/2020)	HK$5.23
Jiangling Motors Company (000550.SZ)	U (12/01/2016)	Rmb16.18
Jiangling Motors Company (200550.SZ)	E (12/09/2020)	HK$7.86
SAIC Motor Corp. Ltd. (600104.SS)	E (01/14/2020)	Rmb21.14
Shelley Wang, CFA		
Baoxin Auto Group (1293.HK)	E (01/14/2020)	HK$0.82
Cango Inc. (CANG.N)	E (08/11/2020)	$4.49
China MeiDong Auto Holdings Ltd (1268.HK)	O (04/22/2020)	HK$38.90
China Yongda Automobiles Services (3669.HK)	O (07/25/2019)	HK$12.40
China Zhengtong Auto Services (1728.HK)	U (09/13/2021)	HK$0.97
Foryou Corporation (002906.SZ)	E (12/02/2020)	Rmb47.23
Huizhou Desay SV Automotive Co Ltd (002920.SZ)	E (12/02/2020)	Rmb109.52
Zhongsheng Group Holdings (0881.HK)	O (10/12/2021)	HK$66.85
Tim Hsiao		
BAIC BluePark New Energy (600733.SS)	E (07/15/2021)	Rmb11.97
BYD Company Limited (002594.SZ)	U (06/08/2021)	Rmb294.94
BYD Company Limited (1211.HK)	U (06/08/2021)	HK$294.00
Changzhou Xingyu Automotive Lighting Sys (601799.SS)	E (03/13/2020)	Rmb214.27
EHang Holdings Ltd (EH.O)	E (10/19/2021)	$25.32
Fuyao Glass Industry Group (600660.SS)	E (12/01/2016)	Rmb47.82
Fuyao Glass Industry Group (3606.HK)	E (12/01/2016)	HK$44.65
Huayu Automotive (600741.SS)	O (09/08/2020)	Rmb26.74
Li Auto Inc. (LI.O)	O (08/24/2020)	$30.40
Minth Group Limited (0425.HK)	O (08/24/2015)	HK$32.55
NavInfo Co Ltd (002405.SZ)	O (02/19/2021)	Rmb15.80

Nexteer Automotive Group (1316.HK)	O (10/22/2020)	HK$10.08
Ningbo Joyson Electronic Corp (600699.SS)	O (12/02/2020)	Rmb22.22
NIO Inc. (NIO.N)	O (08/26/2020)	$42.67
XPeng Inc. (XPEV.N)	O (01/29/2021)	$48.53
Zhejiang Sanhua Intelligent Controls (002050.SZ)	O (01/15/2020)	Rmb24.99
Zhengzhou Yutong Bus Co (600066.SS)	E (04/17/2020)	Rmb11.41

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INDUSTRY COVERAGE: Consumer Electronics

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Masahiro Ono		
Casio Computer (6952.T)	O (12/02/2020)	¥1,641
Japan Display (6740.T)	U (05/18/2020)	¥38
Nintendo (7974.T)	O (04/07/2020)	¥50,200
Panasonic (6752.T)	O (10/11/2017)	¥1,419
Sharp (6753.T)	U (03/23/2021)	¥1,325
Sony Group Corp (6758.T)	O (07/28/2021)	¥14,095
Yamaha (7951.T)	E (12/02/2020)	¥6,510

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INDUSTRY COVERAGE: S. Korea Technology

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Ryan Kim		
Advanced Process Systems Corp (265520.KQ)	O (04/09/2020)	W23,350
Duk San Neolux Co Ltd (213420.KQ)	O (04/09/2020)	W57,000
Ecopro BM (247540.KQ)	O (08/03/2021)	W564,500
Ecopro Co Ltd (086520.KQ)	E (02/21/2019)	W151,100
Iljin Materials (020150.KS)	O (02/21/2019)	W108,500
L&F Co Ltd (066970.KQ)	O (12/17/2020)	W232,100
Posco Chemical Co Ltd. (003670.KS)	U (04/27/2021)	W145,500
Solus Advanced Materials Co Ltd (336370.KS)	O (05/11/2021)	W102,000
Wonik IPS Co Ltd (240810.KQ)	O (09/07/2020)	W38,050
Shawn Kim		
LG Display (034220.KS)	E (03/19/2020)	W20,700
LG Electronics (066570.KS)	E (11/04/2020)	W124,500
LG Innotek (011070.KS)	E (07/19/2021)	W257,000
Samsung Electro-Mechanics (009150.KS)	E (05/12/2021)	W169,500
Samsung Electronics (005935.KS)	O (11/18/2019)	W66,200
Samsung Electronics (005930.KS)	O (11/18/2019)	W71,400
Samsung SDI (006400.KS)	E (10/26/2021)	W754,000
Samsung SDS (018260.KS)	E (06/23/2017)	W155,000
Seoul Semiconductor (046890.KQ)	U (04/04/2018)	W15,150
SK Hynix (000660.KS)	U (08/12/2021)	W111,000

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INDUSTRY COVERAGE: Technology - Semiconductors

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Dominik Olszewski, CFA		
ams AG (AMS.S)	E (12/10/2020)	SFr 18.68
ASM International NV (ASMI.AS)	E (06/19/2019)	€424.30
ASML Holding NV (ASML.AS)	O (06/19/2019)	€752.60
Infineon Technologies AG (IFXGn.DE)	O (05/28/2020)	€42.65
Soitec SA (SOIT.PA)	E (03/12/2021)	€234.80
STMicroelectronics NV (STM.PA)	O (06/19/2019)	€44.92

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INDUSTRY COVERAGE: Semiconductors

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
Joseph Moore		
Advanced Micro Devices (AMD.O)	++	$147.89
Aeva Technologies Inc (AEVA.N)	E (07/19/2021)	$8.70
Ambarella Inc (AMBA.O)	O (03/29/2016)	$195.45
Amphenol Corp. (APH.N)	E (08/23/2020)	$84.02
Analog Devices Inc. (ADI.O)	E (09/13/2021)	$184.79
Broadcom Inc. (AVGO.O)	O (11/19/2019)	$563.22
Intel Corporation (INTC.O)	E (10/22/2021)	$50.31
Marvell Technology Group Ltd (MRVL.O)	E (09/14/2015)	$73.48
Microchip Technology Inc. (MCHP.O)	O (10/19/2020)	$83.35
Micron Technology Inc. (MU.O)	E (08/12/2021)	$77.30
NVIDIA Corp. (NVDA.O)	++	$303.90
NXP Semiconductor NV (NXPI.O)	E (04/08/2021)	$217.82
ON Semiconductor Corp. (ON.O)	E (08/03/2021)	$58.60
Qorvo Inc (QRVO.O)	O (06/16/2020)	$160.50
Qualcomm Inc. (QCOM.O)	O (06/16/2020)	$164.94
Sensata Technologies Holding N.V. (ST.N)	O (12/13/2020)	$60.77
Silicon Laboratories Inc. (SLAB.O)	E (01/19/2021)	$202.98
Skyworks Solutions Inc (SWKS.O)	E (11/28/2018)	$164.56
Te Connectivity Ltd (TEL.N)	E (09/23/2019)	$164.31
Teradyne Inc (TER.O)	O (12/10/2020)	$146.19
Texas Instruments (TXN.O)	U (04/13/2020)	$190.08
Western Digital (WDC.O)	O (01/23/2020)	$60.56
Wolfspeed, INC (WOLF.N)	E (12/07/2020)	$139.55
Xilinx (XLNX.O)	++	$213.80

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INDUSTRY COVERAGE: Japan Semiconductors

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Kazuo Yoshikawa, CFA		
Advantest (6857.T)	E (12/07/2020)	¥10,110
DISCO (6146.T)	E (07/22/2015)	¥34,300
Horiba (6856.T)	E (04/19/2021)	¥7,300
HOYA (7741.T)	O (06/18/2021)	¥17,940
Micronics Japan (6871.T)	U (07/04/2019)	¥1,756
Nikon (7731.T)	E (07/14/2020)	¥1,192
Renesas Electronics (6723.T)	O (11/26/2019)	¥1,490
Rohm (6963.T)	E (12/06/2019)	¥11,390
SCREEN Holdings (7735.T)	E (10/25/2021)	¥11,610
Shimadzu (7701.T)	E (04/14/2020)	¥4,755
Tokyo Electron (8035.T)	O (07/23/2019)	¥58,190
Tokyo Seimitsu (7729.T)	E (03/18/2021)	¥5,270
Toshiba (6502.T)	++	¥4,900

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INDUSTRY COVERAGE: Greater China Technology Semiconductors

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Charlie Chan		
ACM Research Inc (ACMR.O)	O (01/22/2020)	$105.64
Advanced Micro-Fabrication Equipment Inc (688012.SS)	E (08/26/2021)	Rmb167.68
Alchip Technologies Ltd (3661.TW)	O (05/14/2021)	NT$1,235.00
ASE Technology Holding Co. Ltd. (3711.TW)	E (10/12/2021)	NT$105.50
ASM Pacific (0522.HK)	E (10/12/2021)	HK$84.35
Chipbond Technology Corp (6147.TWO)	E (05/20/2021)	NT$68.20
Chunghwa Precision Test Tech (6510.TWO)	U (11/02/2021)	NT$731.00
Global Unichip Corp (3443.TW)	U (02/12/2020)	NT$570.00
GlobalWafers Co Ltd (6488.TWO)	O (12/02/2020)	NT$799.00
Jiangsu Changjiang Electronics Tech (600584.SS)	U (10/12/2021)	Rmb32.10
King Yuan Electronics Co Ltd (2449.TW)	E (10/12/2021)	NT$42.15
Maxscend Microelectronics Co Ltd (300782.SZ)	U (01/11/2021)	Rmb302.50
MediaTek (2454.TW)	O (01/04/2021)	NT$1,025.00
Nanya Technology Corp. (2408.TW)	E (08/12/2021)	NT$70.30
Phison Electronics Corp (8299.TWO)	E (05/20/2021)	NT$400.50
Silergy Corp. (6415.TW)	U (05/20/2021)	NT$5,140.00
SMIC (0981.HK)	E (08/10/2021)	HK$22.35
StarPower Semiconductor Ltd (603290.SS)	E (04/20/2021)	Rmb445.15
TSMC (2330.TW)	E (06/18/2021)	NT$608.00
UMC (2303.TW)	O (09/14/2020)	NT$63.40
Universal Scientific Ind. (Shanghai) (601231.SS)	O (08/04/2015)	Rmb14.83
Vanguard International Semiconductor (5347.TWO)	U (02/26/2021)	NT$153.50
Will Semiconductor Co Ltd Shanghai (603501.SS)	E (09/10/2021)	Rmb272.00
WIN Semiconductors Corp (3105.TWO)	U (02/04/2021)	NT$352.00
Daisy Dai, CFA		
Hangzhou Silan Microelectronics Co. Ltd. (600460.SS)	O (10/08/2021)	Rmb66.75
Shanghai Fudan Microelectronics (1385.HK)	E (07/19/2021)	HK$26.50
Yangjie Technology (300373.SZ)	E (10/08/2021)	Rmb53.67
Daniel Yen, CFA		
ASMedia Technology Inc (5269.TW)	O (05/14/2021)	NT$1,755.00
Aspeed Technology (5274.TWO)	O (04/29/2020)	NT$2,920.00
Bestechnic Shanghai Co Ltd (688608.SS)	O (04/23/2021)	Rmb240.79

Chipsea Technologies Shenzhen Corp (688595.SS)	U (07/19/2021)	Rmb106.91
Egis Technology Inc (6462.TWO)	U (04/23/2020)	NT$116.50
Espressif Systems (688018.SS)	U (07/19/2021)	Rmb186.33
GigaDevice Semiconductor Beijing Inc (603986.SS)	E (10/19/2021)	Rmb166.78
Macronix International Co Ltd (2337.TW)	U (10/19/2021)	NT$42.85
Montage Technology Co Ltd (688008.SS)	E (05/05/2021)	Rmb76.23
Novatek (3034.TW)	U (05/20/2021)	NT$470.00
Nuvoton Technology Corporation (4919.TW)	O (07/19/2021)	NT$138.50
Parade Technologies Ltd (4966.TWO)	O (03/03/2019)	NT$1,975.00
Realtek Semiconductor (2379.TW)	O (08/03/2018)	NT$542.00
Shenzhen Goodix Technology Co Ltd (603160.SS)	U (06/16/2020)	Rmb111.98
Sino Wealth Electronic (300327.SZ)	O (07/19/2021)	Rmb70.28
Winbond Electronics Corp (2344.TW)	U (10/19/2021)	NT$30.15
WPG Holdings (3702.TW)	U (04/09/2021)	NT$52.00
Ray Wu, CFA		
Advanced Wireless Semiconductor Co (8086.TWO)	O (01/11/2021)	NT$151.50
China Resources Microelectronics Limited (688396.SS)	O (04/20/2021)	Rmb65.75
Hua Hong Semiconductor Ltd (1347.HK)	E (05/20/2021)	HK$46.95
Powerchip Semiconductor Manufacturing Co (6770.TWO)	U (07/12/2021)	NT$74.70
RichWave Technology Corp. (4968.TW)	O (10/26/2021)	NT$305.00
Silicon Motion (SIMO.O)	E (08/12/2021)	$69.00
Wafer Works Corp (6182.TWO)	O (04/20/2021)	NT$67.40

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INDUSTRY COVERAGE: China Energy & Chemicals

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Albert Li		
China BlueChemical (3983.HK)	E (09/10/2021)	HK$2.37
China Oilfield Services Ltd. (2883.HK)	O (03/17/2021)	HK$6.80
China Oilfield Services Ltd. (601808.SS)	U (03/17/2021)	Rmb14.88
Kingfa Sci&Tech Co Ltd (600143.SS)	E (09/02/2021)	Rmb12.65
LB Group Co Ltd (002601.SZ)	O (01/13/2021)	Rmb26.91
Offshore Oil Engineering (600583.SS)	O (03/17/2021)	Rmb4.38
Qinghai Salt Lake (000792.SZ)	U (09/10/2021)	Rmb24.94
Shandong Sinocera Functional Material (300285.SZ)	O (07/30/2021)	Rmb44.41
Sinofert Holdings (0297.HK)	O (01/11/2017)	HK$1.16
Sinopec Engineering Group Co Ltd (2386.HK)	O (04/22/2020)	HK$3.59
Sinopec Oilfield Service Corp (1033.HK)	E (03/17/2021)	HK$0.69
Sinopec Oilfield Service Corp (600871.SS)	U (06/02/2020)	Rmb2.10
Skshu Paint Co Ltd (603737.SS)	O (11/02/2021)	Rmb132.47
Yantai Jereh Oilfield Services Group (002353.SZ)	O (03/17/2021)	Rmb42.88
Jack Lu		
Beijing Easpring Material Technology Co (300073.SZ)	U (11/08/2019)	Rmb91.98
Beijing SinoHytec Co Ltd (688339.SS)	O (01/20/2021)	Rmb281.27
Bluestar Adisseo Co (600299.SS)	O (06/29/2020)	Rmb12.49
China Petroleum & Chemical Corp. (600028.SS)	E (03/17/2021)	Rmb4.10
China Petroleum & Chemical Corp. (0386.HK)	O (05/12/2021)	HK$3.77
CNOOC (0883.HK)	O (03/17/2021)	HK$8.12
Contemporary Amperex Technology Co. Ltd. (300750.SZ)	U (05/30/2021)	Rmb620.00
Guanghui Energy (600256.SS)	E (09/23/2021)	Rmb6.24
Guoxuan High-Tech (002074.SZ)	E (04/26/2021)	Rmb57.51
Hengli Petrochemical Co Ltd (600346.SS)	O (10/29/2020)	Rmb21.18
Hengyi Petrochemical Co Ltd (000703.SZ)	E (07/02/2021)	Rmb10.47
Ningbo Shanshan Co. Ltd. (600884.SS)	U (09/09/2019)	Rmb36.51
PetroChina (601857.SS)	U (03/17/2021)	Rmb4.81
PetroChina (0857.HK)	O (03/17/2021)	HK$3.54

Rongsheng Petrochemical Co Ltd (002493.SZ)	E (10/19/2021)	Rmb15.61
Shanghai Putailai New Energy Tech Co Ltd (603659.SS)	E (08/06/2021)	Rmb175.00
Sinopec Shanghai Petrochemical Co Ltd (0338.HK)	O (09/30/2020)	HK$1.74
Sinopec Shanghai Petrochemical Co Ltd (600688.SS)	U (06/09/2015)	Rmb4.21
Wanhua Chemical (600309.SS)	O (07/02/2021)	Rmb97.52
Yunnan Energy New Material Co Ltd (002812.SZ)	U (01/17/2020)	Rmb261.38
Zhejiang Longsheng Group (600352.SS)	E (04/10/2019)	Rmb12.82
Zhejiang NHU Co. Ltd. (002001.SZ)	O (06/29/2020)	Rmb28.35
Zhejiang Runtu (002440.SZ)	O (03/01/2018)	Rmb9.11

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INDUSTRY COVERAGE: Greater China Materials

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Hannah Yang, CFA		
Luoyang Glass Co Ltd (1108.HK)	O (07/14/2021)	HK$12.46
Luoyang Glass Co Ltd (600876.SS)	O (07/14/2021)	Rmb23.90
MMG Ltd (1208.HK)	E (09/30/2021)	HK$3.12
Shandong Pharmaceutical Glass Co. Ltd. (600529.SS)	O (01/04/2021)	Rmb41.08
Rachel L Zhang		
Aluminum Corp. of China Ltd. (601600.SS)	O (11/30/2020)	Rmb5.32
Aluminum Corp. of China Ltd. (2600.HK)	O (11/30/2020)	HK$4.10
Angang Steel Company Limited (0347.HK)	O (11/28/2013)	HK$3.70
Angang Steel Company Limited (000898.SZ)	O (01/09/2018)	Rmb3.66
Baoshan Iron & Steel (600019.SS)	O (01/16/2016)	Rmb6.50
China Jushi (600176.SS)	O (12/22/2020)	Rmb16.91
China Molybdenum (3993.HK)	O (09/24/2019)	HK$4.51
China Molybdenum (603993.SS)	E (09/24/2019)	Rmb5.57
CSG Holding Co., Ltd. (000012.SZ)	E (07/30/2020)	Rmb9.41
Flat Glass Group Co Ltd (6865.HK)	O (07/30/2020)	HK$38.35
Flat Glass Group Co Ltd (601865.SS)	O (07/30/2020)	Rmb46.02
Ganfeng Lithium Co. Ltd. (002460.SZ)	E (06/16/2020)	Rmb152.70
Ganfeng Lithium Co. Ltd. (1772.HK)	O (06/16/2020)	HK$138.80
GEM Co Ltd (002340.SZ)	O (02/23/2021)	Rmb10.13
Jiangxi Copper (0358.HK)	O (09/24/2019)	HK$13.40
Jiangxi Copper (600362.SS)	E (09/24/2019)	Rmb23.10
Lee & Man Paper Manufacturing (2314.HK)	E (06/29/2021)	HK$5.75
Maanshan Iron & Steel (0323.HK)	E (03/24/2021)	HK$2.81
Maanshan Iron & Steel (600808.SS)	E (03/24/2021)	Rmb3.76
Nine Dragons Paper (2689.HK)	E (11/06/2020)	HK$9.73
Shandong Nanshan Aluminium Co. (600219.SS)	O (11/30/2020)	Rmb4.15
Tianqi Lithium Industries Inc. (002466.SZ)	++	Rmb95.70
Tongling Jingda Special Magnet Wire Co (600577.SS)	O (10/18/2021)	Rmb9.25
Xinyi Glass Holding Limited (0868.HK)	E (09/30/2021)	HK$21.95
Zhejiang Huayou Cobalt Co Ltd (603799.SS)	O (02/23/2021)	Rmb112.10
Zhuzhou Kibing Group Co Ltd (601636.SS)	E (09/30/2021)	Rmb15.40
Sara Chan		
FangDa Carbon New Material Co. Ltd. (600516.SS)	O (01/05/2021)	Rmb10.20
Shandong Gold Mining Co. Ltd (600547.SS)	U (11/06/2018)	Rmb20.72
Shandong Gold Mining Co. Ltd (1787.HK)	E (11/06/2018)	HK$15.36
Zhaojin Mining Industry (1818.HK)	E (03/25/2021)	HK$6.70
Zhongjin Gold Corp. Ltd. (600489.SS)	U (04/04/2019)	Rmb8.58
Zijin Mining Group (2899.HK)	O (07/09/2019)	HK$10.80
Zijin Mining Group (601899.SS)	E (03/24/2021)	Rmb10.56

Yujie Wang		
China Steel Corp. (2002.TW)	O (06/29/2021)	NT$33.65

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INDUSTRY COVERAGE: Metals & Mining

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Alain Gabriel, CFA		
Anglo American Plc (AAL.L)	E (09/17/2021)	2,850p
BHP Group PLC (BHPB.L)	++	1,923p
Glencore PLC (GLEN.L)	O (09/17/2021)	362p
Glencore PLC (GLNJ.J)	O (09/17/2021)	ZAc 7,376
Rio Tinto Plc (RIO.L)	E (03/14/2016)	4,514p
Dan Shaw		
Fresnillo PLC (FRES.L)	E (03/25/2019)	962p
KGHM Polska Miedz SA (KGH.WA)	E (12/09/2020)	PLN 152.75
Ioannis Masvoulas, CFA		
Antofagasta (ANTO.L)	U (03/23/2021)	1,460p
Aurubis AG (NAFG.DE)	U (11/30/2020)	€77.90
Boliden (BOL.ST)	E (06/08/2020)	SKr 302.90
Lundin Mining Corp. (LUMIN.ST)	E (03/23/2021)	SKr 74.30
Lundin Mining Corp. (LUN.TO)	E (03/23/2021)	C$11.02
Norsk Hydro ASA (NHY.OL)	O (12/09/2020)	NKr 62.72

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INDUSTRY COVERAGE: Latin America Metals & Mining

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
Carlos De Alba		
CAP S.A. (CAP.SN)	E (03/23/2021)	Ch$7,420.00
Compania de Minas Buenaventura S.A. (BVN.N)	U (11/15/2020)	$7.89
CSN Mineracao (CMIN3.SA)	E (09/28/2021)	R$6.11
Grupo Mexico S.A.B. de C.V. (GMEXICOB.MX)	E (03/23/2021)	M$87.08
Industrias Penoles S.A.B. de C.V. (PEOLES.MX)	E (12/09/2020)	M$263.97
Minera Frisco, S.A.B. de C.V. (MFRISCOA1.MX)	U (05/30/2011)	M$3.72
Nexa Resources SA (NEXA.N)	E (10/28/2021)	$9.36
Southern Copper Corp. (SCCO.N)	U (08/03/2020)	$62.46
Vale (VALE.N)	E (09/28/2021)	$12.55

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INDUSTRY COVERAGE: Chemicals

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
Angel Castillo		
Avient Corporation (AVNT.N)	E (12/14/2020)	$59.17
Ecovyst Inc. (ECVT.N)	E (05/04/2021)	$12.96
Element Solutions Inc (ESI.N)	E (10/01/2021)	$25.79
Huntsman Corp (HUN.N)	O (09/29/2020)	$33.79
Olin Corp. (OLN.N)	E (03/03/2021)	$64.42
Trinseo S.A. (TSE.N)	E (05/26/2021)	$58.57
Westlake Chemical Corp (WLK.N)	E (01/09/2018)	$104.51
Lisa H De Neve		
International Flavors & Fragrances (IFF.N)	O (04/11/2021)	$152.58
Vincent Andrews		
Air Products and Chemicals Inc. (APD.N)	O (02/09/2020)	$310.00
Albemarle Corporation (ALB.N)	U (02/26/2018)	$276.40
Axalta Coating Systems Ltd (AXTA.N)	E (12/09/2015)	$32.95
Celanese Corp. (CE.N)	E (10/08/2012)	$170.13
CF Industries (CF.N)	E (05/25/2016)	$64.57
Chemours Co (CC.N)	E (01/30/2018)	$33.16
Corteva Inc. (CTVA.N)	O (12/14/2020)	$48.70
Diversey Holdings, Ltd. (DSEY.O)	O (04/19/2021)	$14.43
Dow Inc. (DOW.N)	E (12/01/2019)	$60.06
DuPont De Nemours Inc. (DD.N)	E (05/26/2021)	$80.72
Eastman Chemical Co (EMN.N)	O (01/17/2019)	$115.86
Ecolab Inc. (ECL.N)	E (08/15/2017)	$235.67
FMC Corporation (FMC.N)	E (05/20/2019)	$106.09
ICL Group Ltd (ICL.N)	E (11/03/2014)	$8.74
Intrepid Potash (IPI.N)	U (10/03/2013)	$44.27
Linde PLC (LIN.N)	O (02/09/2020)	$337.02
LyondellBasell Industries N.V. (LYB.N)	O (12/01/2019)	$95.39
Mosaic Company (MOS.N)	E (03/16/2016)	$37.39
Nutrien Ltd (NTR.N)	E (12/11/2018)	$68.31
PPG Industries Inc. (PPG.N)	E (11/01/2019)	$161.64
RPM International Inc. (RPM.N)	E (12/14/2020)	$93.66
Sherwin-Williams Co. (SHW.N)	O (03/19/2014)	$331.40
Tronox Holdings Plc-Class A (TROX.N)	E (01/30/2018)	$24.72
Venator Materials PLC (VNTR.N)	E (01/30/2018)	$3.33

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INDUSTRY COVERAGE: Electronic Chemicals

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Takato Watabe		
Dexerials (4980.T)	E (03/29/2019)	¥3,455
JSR (4185.T)	O (08/15/2017)	¥4,350
Kuraray (3405.T)	U (04/03/2018)	¥1,057
Nissan Chemical (4021.T)	E (06/11/2018)	¥6,940
Nitto Denko (6988.T)	U (03/29/2019)	¥8,580
Shin-Etsu Chemical (4063.T)	O (07/27/2016)	¥20,275
SUMCO (3436.T)	O (12/02/2020)	¥2,419
ZEON (4205.T)	O (10/23/2014)	¥1,357

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INDUSTRY COVERAGE: Diversified Utilities / IPPs

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
David Arcaro, CFA		
Public Service Enterprise Group Inc (PEG.N)	O (07/02/2020)	$62.17
Stephen C Byrd		
AES Corp. (AES.N)	O (03/23/2020)	$24.72
American Electric Power Co (AEP.O)	O (03/10/2020)	$82.02
Exelon Corp (EXC.O)	O (08/27/2019)	$54.40
MGE Energy, Inc. (MGEE.O)	E (09/09/2020)	$77.83
NextEra Energy Inc (NEE.N)	E (04/14/2020)	$86.31
NRG Energy Inc (NRG.N)	O (09/06/2019)	$35.70
Vistra Energy Corp (VST.N)	O (03/25/2019)	$19.65

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INDUSTRY COVERAGE: Clean Tech

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/12/2021)
David Arcaro, CFA		
Maxeon Solar Technologies Ltd. (MAXN.O)	E (08/09/2021)	$22.98
Laura Sanchez		
TPI Composites Inc. (TPIC.O)	O (10/21/2020)	$23.66
Stephen C Byrd		
Array Technologies Inc (ARRY.O)	E (03/29/2021)	$26.55
Bloom Energy Corp. (BE.N)	E (01/12/2021)	$34.15
First Solar Inc (FSLR.O)	U (11/04/2020)	$110.92
Hannon Armstrong (HASI.N)	E (02/03/2016)	$64.08
Plug Power Inc. (PLUG.O)	O (10/13/2021)	$43.14
Shoals Technologies Group (SHLS.O)	E (02/22/2021)	$35.25
Solaredge Technologies Inc (SEDG.O)	O (01/21/2021)	$362.41
SunPower Corp (SPWR.O)	U (02/04/2021)	$32.09
Sunrun Inc (RUN.O)	O (03/10/2021)	$58.66

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INDUSTRY COVERAGE: General Machinery

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Lisa Jiang		
Hoshizaki Corp (6465.T)	E (05/14/2019)	¥9,050
Makita (6586.T)	U (03/12/2021)	¥5,300
NSK (6471.T)	O (10/01/2021)	¥758
Tadano (6395.T)	U (10/31/2019)	¥1,152
Yoshinao Ibara		
Daikin Industries (6367.T)	U (11/27/2020)	¥25,550
Hitachi Construction Machinery (6305.T)	E (09/03/2020)	¥3,690
Komatsu (6301.T)	O (12/01/2017)	¥3,051
Kubota (6326.T)	E (10/12/2010)	¥2,433
Shimano (7309.T)	E (05/29/2014)	¥32,160

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INDUSTRY COVERAGE: China Industrials

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Joy Zhang		
Hefei Meyer Optoelectronic Technology (002690.SZ)	O (05/14/2020)	Rmb42.92
Shenzhen SC New Energy Technology Corp (300724.SZ)	O (02/05/2021)	Rmb103.00
Suzhou Maxwell Technologies Co Ltd (300751.SZ)	O (02/05/2021)	Rmb672.00
Weifu High-Technology Group Co Ltd (200581.SZ)	E (06/14/2019)	HK$15.19
Weifu High-Technology Group Co Ltd (000581.SZ)	E (06/14/2019)	Rmb21.98
Kevin Luo, CFA		
Anhui Heli Co., Ltd. (600761.SS)	O (09/01/2015)	Rmb11.98
Beijing New Building Materials PLC (000786.SZ)	O (08/23/2021)	Rmb28.52
CCCC (601800.SS)	U (05/19/2021)	Rmb7.20
CCCC (1800.HK)	O (07/21/2017)	HK$4.09
Centre Testing International Group (300012.SZ)	O (10/19/2021)	Rmb26.78
China Lesso Group Holdings Ltd (2128.HK)	O (08/31/2020)	HK$11.68
China Railway Construction (601186.SS)	O (07/20/2016)	Rmb7.37
China Railway Construction (1186.HK)	O (01/28/2016)	HK$4.91
China Railway Group (601390.SS)	O (03/27/2020)	Rmb5.28
China Railway Group (0390.HK)	O (09/01/2017)	HK$3.74
China Railway Signal & Communication (3969.HK)	O (08/19/2016)	HK$2.66
China State Construction Engineering (601668.SS)	O (06/02/2015)	Rmb4.76
CIMC (2039.HK)	O (12/08/2016)	HK$14.10
CIMC (000039.SZ)	O (03/02/2017)	Rmb16.05
CIMC Enric Holdings (3899.HK)	E (08/25/2021)	HK$9.33
CRRC Corp Ltd (1766.HK)	O (09/21/2016)	HK$3.65
CRRC Corp Ltd (601766.SS)	O (08/02/2018)	Rmb6.02
Gold Mantis Construction (002081.SZ)	O (11/17/2020)	Rmb5.88
Haitian International Holdings Limited (1882.HK)	O (03/06/2015)	HK$21.25
Hangcha Group Co Ltd (603298.SS)	O (10/13/2021)	Rmb17.18
Hollysys Automation Technologies (HOLI.O)	O (04/08/2015)	$15.26
Impro Precision Industries Ltd (1286.HK)	E (08/02/2019)	HK$2.08
Jiangsu Guomao Reducer Co Ltd (603915.SS)	O (02/01/2021)	Rmb42.09
Jiangsu Hengli Hydraulic Co.Ltd (601100.SS)	E (02/27/2020)	Rmb82.23
Leader Harmonious Drive Systems (688017.SS)	O (02/01/2021)	Rmb160.00
LK Technology Holdings Ltd (0558.HK)	E (08/17/2021)	HK$18.38
Lonking Holdings Limited (3339.HK)	U (05/14/2021)	HK$2.17
Ningbo Zhongda Leader Intelligent Trans (002896.SZ)	U (03/12/2021)	Rmb22.30
Oriental Yuhong (002271.SZ)	U (11/17/2020)	Rmb42.22

Raytron Technology Co., Ltd. (688002.SS)	E (08/25/2021)	Rmb77.30
Sany Heavy Industry Co., Ltd. (600031.SS)	E (02/27/2020)	Rmb22.19
Shenzhen Inovance Technology (300124.SZ)	E (10/25/2017)	Rmb70.49
Sinotruk (Hong Kong) Limited (3808.HK)	E (01/28/2021)	HK$10.86
Times Electric (3898.HK)	O (01/28/2016)	HK$45.90
WeiChai Power (2338.HK)	E (09/08/2021)	HK$13.30
WeiChai Power (000338.SZ)	E (09/08/2021)	Rmb15.25
Weixing New Building Materials (002372.SZ)	U (05/04/2021)	Rmb19.60
Wuhan Guide Infrared Co. Ltd. (002414.SZ)	E (06/24/2021)	Rmb24.36
XCMG (000425.SZ)	E (06/08/2021)	Rmb6.04
Yangzijiang Shipbuilding (Holdings) Ltd. (YAZG.SI)	O (03/31/2016)	S$1.29
Zhejiang Dingli Machinery Co Ltd. (603338.SS)	U (02/27/2020)	Rmb68.20
Zoomlion Heavy Industry (1157.HK)	O (03/01/2019)	HK$5.30
Zoomlion Heavy Industry (000157.SZ)	O (02/27/2020)	Rmb6.92
Zhuoran Wang, CFA		
DR Laser (300776.SZ)	O (02/05/2021)	Rmb164.00
Estun Automation Co Ltd (002747.SZ)	O (12/07/2020)	Rmb28.75
Han's Laser (002008.SZ)	O (09/21/2020)	Rmb42.80
Hongfa Technology Co Ltd (600885.SS)	E (05/12/2020)	Rmb77.27
Huagong Tech Co. Ltd. (000988.SZ)	O (09/21/2020)	Rmb30.40
Raycus Fiber Laser (300747.SZ)	O (09/21/2020)	Rmb58.88
Shanghai STEP Electric (002527.SZ)	U (11/13/2019)	Rmb8.25
Shenzhen Yinghe Technology (300457.SZ)	U (01/10/2020)	Rmb35.57
Siasun Robot & Automation (300024.SZ)	U (06/02/2021)	Rmb10.20
Wuxi Lead Intelligent (300450.SZ)	E (06/02/2021)	Rmb83.93

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INDUSTRY COVERAGE: Australia Materials

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Rahul Anand, CFA		
29Metals Ltd (29M.AX)	O (08/02/2021)	A$2.70
Alumina Limited (AWC.AX)	O (07/09/2019)	A$1.88
BHP Group Ltd (BHP.AX)	++	A$37.46
Deterra Royalties Ltd (DRR.AX)	O (06/03/2021)	A$4.02
Evolution Mining (EVN.AX)	E (09/29/2021)	A$4.16
Fortescue Metals Group Ltd. (FMG.AX)	U (09/11/2020)	A$15.94
IGO Ltd (IGO.AX)	U (06/15/2021)	A$10.04
Iluka Resources Ltd (ILU.AX)	E (12/10/2020)	A$9.14
Mineral Resources Limited (MIN.AX)	U (09/11/2020)	A$41.17
Newcrest Mining (NCM.AX)	O (03/02/2020)	A$25.44
Northern Star Resources (NST.AX)	E (03/24/2021)	A$10.64
Orocobre Ltd. (ORE.AX)	E (09/25/2018)	A$9.57
OZ Minerals Ltd (OZL.AX)	E (08/02/2021)	A$25.51
Regis Resources (RRL.AX)	O (02/09/2021)	A$2.15
Rio Tinto Limited (RIO.AX)	E (11/07/2019)	A$91.84
Sandfire Resources Ltd (SFR.AX)	O (02/09/2019)	A$6.09
South32 Ltd (S32.AX)	O (05/16/2019)	A$3.50
South32 Ltd (S32J.J)	O (05/16/2019)	ZAc 3,924
Syrah Resources (SYR.AX)	U (12/10/2020)	A$1.30
Western Areas (WSA.AX)	E (06/23/2021)	A$3.14
Whitehaven Coal Ltd (WHC.AX)	O (03/27/2018)	A$2.44

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INDUSTRY COVERAGE: Autos & Shared Mobility

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Harald C Hendrikse		
Aramis Autos (ARAMI.PA)	O (07/28/2021)	€17.00
BMW (BMWG.DE)	U (04/16/2021)	€93.48
Daimler (DAIGn.DE)	O (02/01/2019)	€88.83
EDAG Engineering Group AG (ED4.DE)	E (10/26/2021)	€11.80
Europcar Mobility Group (EUCAR.PA)	E (06/01/2020)	€0.51
Renault (RENA.PA)	O (11/12/2021)	€34.29
Stellantis (STLA.MI)	O (02/04/2021)	€17.95
Stellantis (STLA.N)	O (03/10/2021)	$20.47
Volkswagen (VOWG_p.DE)	E (09/30/2014)	€188.38
Volvo (VOLVb.ST)	U (01/18/2017)	SKr 207.90
Victoria A Greer		
Autoliv (ALV.N)	E (09/24/2021)	$102.31
Continental AG (CONG.DE)	E (05/29/2020)	€108.22
Faurecia SA (EPED.PA)	O (01/15/2021)	€46.50
Gestamp Automocion SA (GEST.MC)	E (04/16/2021)	€4.10
Hella KGaA Hueck & Co (HLE.DE)	U (01/15/2021)	€62.32
Michelin (MICP.PA)	O (10/03/2018)	€134.10
Nokian Renkaat OYJ (TYRES.HE)	U (04/06/2020)	€33.51
Pirelli & C SpA (PIRC.MI)	E (04/06/2020)	€5.79
Schaeffler AG (SHA_p.DE)	U (12/16/2019)	€8.22
Valeo SA (VLOF.PA)	O (05/29/2020)	€28.33
Veoneer Inc (VNE.N)	++	$35.29

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INDUSTRY COVERAGE: Utilities

COMPANY (TICKER)	RATING (AS OF)	PRICE* (11/15/2021)
Arthur Sitbon, CFA		
CEZ (CEZP.PR)	E (02/21/2019)	CZK 735.00
Corporacion Acciona Energia Renovables (ANE.MC)	O (08/09/2021)	€31.15
EDF (EDF.PA)	O (01/08/2021)	€12.61
EDP Energias de Portugal SA (EDP.LS)	O (01/20/2021)	€4.84
EDP Renovaveis (EDPR.LS)	E (01/20/2021)	€22.72
Enagas SA (ENAG.MC)	U (09/15/2020)	€20.08
NEL ASA (NEL.OL)	O (04/09/2021)	NKr 19.67
Neoen SA (NEOEN.PA)	E (08/26/2021)	€37.04
Red Electrica Corporacion SA (REE.MC)	U (09/15/2020)	€18.06
SUEZ (SEVI.PA)	++	€19.68
Veolia (VIE.PA)	++	€29.98
Voltalia SA (VLTSA.PA)	E (08/26/2021)	€20.85
Christopher Laybutt		
Centrica (CNA.L)	O (10/07/2021)	66p
ContourGlobal PLC (GLO.L)	E (11/03/2020)	190p
Drax Group Plc (DRX.L)	E (11/03/2020)	548p
ENEL (ENEI.MI)	E (03/16/2021)	€7.15
Italgas SpA (IG.MI)	E (03/16/2021)	€5.60
National Grid plc (NG.L)	O (11/03/2020)	982p
Pennon Group (PNN.L)	E (11/03/2020)	1,219p
Severn Trent (SVT.L)	O (06/29/2021)	2,822p
Snam SpA (SRG.MI)	U (03/16/2021)	€5.02
SSE (SSE.L)	O (11/03/2020)	1,657p

Terna - Rete Elettrica Nazionale SpA (TRN.MI)	U (03/16/2021)	€6.80
United Utilities Group PLC (UU.L)	U (06/29/2021)	1,071p
Igor Kuzmin		
Ignitis Grupe AB (IGNq.L)	O (11/12/2020)	€20.50
Robert Pulleyn		
E.ON (EONGn.DE)	U (12/11/2020)	€11.05
Endesa SA (ELE.MC)	E (08/17/2021)	€19.44
ENGIE (ENGIE.PA)	O (10/19/2020)	€13.38
Iberdrola SA (IBE.MC)	O (05/06/2021)	€10.20
Naturgy (NTGY.MC)	E (09/15/2020)	€22.66
Orsted A/S (ORSTED.CO)	O (11/10/2020)	DKr 890.80
RWE AG (RWEG.DE)	O (11/29/2019)	€33.23

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