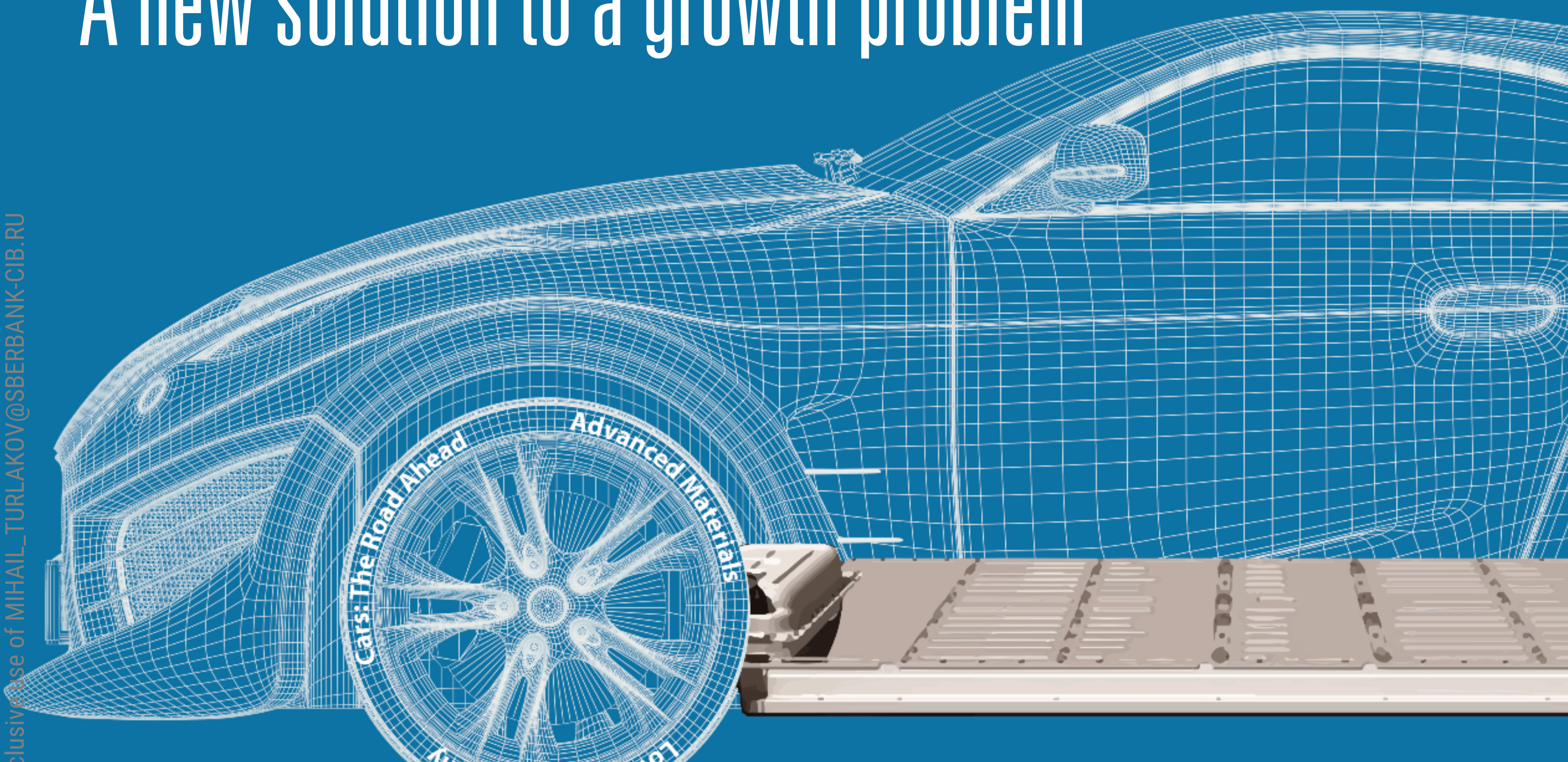
EQUITY RESEARCH | February 9, 2017

Goldman Sachs 高华

CHINA'S BATTERY CHALLENGE

A new solution to a growth problem



China's battery industry is poised for rapid growth and even more rapid change over the next decade, thanks to demand for electric vehicles and government mandates for upgraded technology. By 2025, we expect the Chinese market for EV batteries will reach $20.3bn (13% CAGR). More importantly, we expect a major shift in the primary type of lithium batteries used in Chinese EVs, with repercussions up and down the supply chain. In this report, we lay out why China is moving quickly to nickel-rich "ternary" batteries and how the transition will super-charge growth in select materials and components.

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The Battery Challenge

The battery challenge in China sits at the nexus of multiple trends. Check out the stock implications below or visit our theme pages for related work on The Great Battery Race, Cars: The Road Ahead, The Low Carbon Economy and Advanced Materials.

- Stock initiations – Cangzhou Mingzhu (Buy), Beijing Easpring (Neutral) and GEM (Neutral)
- BYD: Potential to transform into leader in NEV ternary battery in China

Get a 2-minute audio summary from author Frank He. Listen here

THE GREAT BATTERY RACE

Charging the future: Asia leads drive to next-gen EV battery market, Sep 27, 2016

The Great Battery Race, Oct 18, 2015

CARS: THE ROAD AHEAD

Lighter, Faster, Cheaper, Apr 7, 2016

Disruption in China's new car market, Feb 29, 2016

LOW CARBON ECONOMY

Technology in the Driver's Seat, Nov 28, 2016

Electric Vehicles – customer acceptance & continued scaling; check, Apr 7, 2016

ADVANCED MATERIALS

Profiles in Innovation: Advanced Materials—Faster, Stronger, Smaller, Lighter, Sep 27, 2016

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PM Summary: Promising growth, selective opportunities

A major transition is underway in the Chinese battery market, with repercussions up and down the supply chain. Driven by demand for electric vehicles and government mandates for upgraded technology, we forecast the Chinese market for EV batteries will nearly triple in size to reach $20.3bn by 2025. More importantly, we expect a shift in the dominant type of lithium batteries being produced, to so-called ternary batteries built with nickel-rich cathodes that are used more widely outside China (including by Tesla, BMW and Korean automakers) and offer greater energy density. We explore how this shift will bring new opportunities for ternary component makers and suppliers and will reshuffle the Asian-dominated ecosystem of companies leading the charge in EV battery development. We initiate coverage on three leading materials makers, including Cangzhou Mingzhu (Buy) that is well positioned to gain from "wet" separators, the highest margin component in the battery.

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EV sales to increase tenfold in China by 2025...

We forecast China EV sales to jump from 330,000 sales in 2015 to 3.38 mn in 2025E...

China's battery market sits at the intersection of several core investment themes: innovations in advanced materials, the transition to a low carbon economy, and the rise of electric vehicles. With EVs' ability to reduce greenhouse gas emissions by over 50% compared with petroleum vehicles, the government is heavily promoting cleaner transport to help reduce the country's total carbon emissions by 11% over the long run. Supportive policies include waiving the purchase tax, subsidizing EV charging facilities and extending the coverage of pilot cities. This backdrop underpins our autos team's forecast that EV sales in China will rise to 1.87mn in 2020E and 3.88mn in 2025E, a 28% 10-year CAGR rate.

…driving 25% demand CAGR for EV batteries, with ternary the star

...driving the China EV battery market to $20bn by 2025E, and $40bn globally vs. US$30bn market size for entire lithium battery industry worldwide in 2015.

Riding the wave of accelerated EV demand, we believe China's EV battery market will triple in size to $20.3 bn by 2025—comprising half of what we expect will be a $40bn global lithium battery market at that point. Lithium iron phosphate (LFP) is the current prevailing EV battery in China, but government mandates for greater energy density (and thus better driving range on a single charge) are forcing a move toward lithium "ternary" or three-element cathode batteries—namely nickel cobalt aluminum (NCA) and nickel cobalt manganese (NCM). We forecast ternary batteries will grow to 81% of the EV battery market in value by 2025, at which point the next generation of lithium ion batteries will begin to gain traction (See *Charging the future: Asia leads drive to next-generation EV battery market*, published Sept. 27). What's more, our base case assumes no penetration in the market for commercial vehicles such as buses, where safety concerns until recently led the government to restrict subsidies for ternary batteries. Those restrictions have been lifted and in a blue sky scenario in which ternary batteries also gain an 80% share of electric commercial vehicles, we forecast ternary batteries would capture 93% of the overall China EV battery market by 2025, or a CAGR of 47% to Rmb193.2bn (US$28bn).

Ternary to create new opportunities in separators and recycling

See a glossary of battery terms on p.53

The move to ternary batteries not only creates opportunities for nickel-rich cathode suppliers, it also creates a need for component parts and services. For example, ternary batteries favor a different type of separator, which is used to keep the anode and cathode apart and is the highest-margin part of the battery. (See the Exhibit on p.5 for a breakdown of battery components). Chinese manufacturers have traditionally been strongest in the manufacturing of "dry" separators, so-named after the type of extrusion process used to produce them, and have ample room to displace imports for "wet" separators. In addition, the need for cobalt means increased demand for recycling old batteries to recover the scarce metal.

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Nickel-rich cathodes are used in the Tesla Model S given they boost specific energy

Opportunity 1: Nickel-rich cathodes

We expect the growing adoption of nickel rich cathodes will keep improving the specific energy of batteries, with our base case forecasting the ternary cathode market to grow by 37% CAGR in 2016-25E and reach US$5.7bn in 2025E. Under our bull case scenario, if ternary batteries start to penetrate commercial EV's like buses and meet the government's technical standards (such as thermal stability), the addressable market for ternary cathode could reach US$8.1bn in 2025E. Nickel-rich cathodes are the preferred type for high-performance EVs (such as Tesla Model S) and also benefit from lower raw material costs due to less cobalt usage.

Wet separators are preferred for ternary batteries as they are slimmer and have higher energy density than dry separators

Opportunity 2: Wet Separators

Separators—which keep the cathode and anode apart (see exhibit on next page)—come in wet and dry varieties. China is dominated by production of dry separators versus the more advanced wet separators that are slimmer and preferred for ternary batteries given their higher energy density. However, we see ample opportunities for Chinese suppliers to replace imports of wet separators, supported by cost advantages and improving know-how. In addition, companies with advanced manufacturing techniques, such as biaxial stretching, will also benefit first from the transition. We estimate the addressable market for wet separators will reach Rmb10.4bn (US$1.5bn) by 2025, implying a 27% CAGR from 2016-25E.

We see a growing reliance on recycled cobalt due to its scarcity

Opportunity 3: Battery recycling

Given an increasing number of EV batteries will retire after 3-5 years (average life cycle of a EV battery) of service, we expect recycling will play a more important role in the battery value chain considering lithium-ion batteries contain hazardous material. We also see a growing reliance on recycled cobalt due to its tight supply and scarcity. We estimate the retired EV battery market in China will surge from 0.9GWh in 2017 to 111GWh in 2025. We estimate the market size for EV battery reuse and recycling will rise from Rmb8mn (US$1.2mn) in 2017 to Rmb7.8bn (US$1.1bn) in 2025.

China's three leading battery material makers; CZMZ our top pick

Exposure Spotlight

Wet Separator Maker	Cathode Maker	Cathode Maker/Battery Recycler
Cangzhou Mingzhu (Buy) 002108.SZ | 12m. PT: RMB27.00 **Who:** Cangzhou is the country's No. 2 separator maker, and produces biaxial oriented polyamide (BOPA) film for the packing industry and polyethylene (PE) pipeline for the natural gas sector. **View:** We see CZMZ as well-placed to gain from firm demand for wet separators in China and one of the few firms with both dry and wet separator capacity.	**Beijing Easpring** (Neutral) 300073.SZ | 12m. PT: RMB48.40 **Who:** Easpring is the No. 5 battery cathode maker (LCO/NCM) in China and leads in high-end NCM product, with customers covering tier-one Korean, Japanese and Chinese battery cell makers. **View:** As Easpring is the only firm able to produce NCM622-based cathode in China, it is well-placed to meet growing demand for high-energy density EV batteries proposed by the government.	**GEM Co** (Neutral) 002340.SZ | 12m. PT: RMB6.90 **Who:** GEM is a leading battery cathode material maker and recycling solution provider with a strong presence in cobalt and nickel refining. **View:** We see synergy for GEM's battery material and recycling business in terms of raw material sourcing and margin enhancement. Moreover, we think GEM is well positioned to benefit from the growing demand for cobalt recycling and tight cobalt supply in the coming years.

BATTERY MATERIAL 101

LITHIUM BATTERY BREAKDOWN

Goldman Sachs

Lithium batteries, like all batteries, generate an electrical current through an electro-chemical reaction in which ions pass between two electrodes.

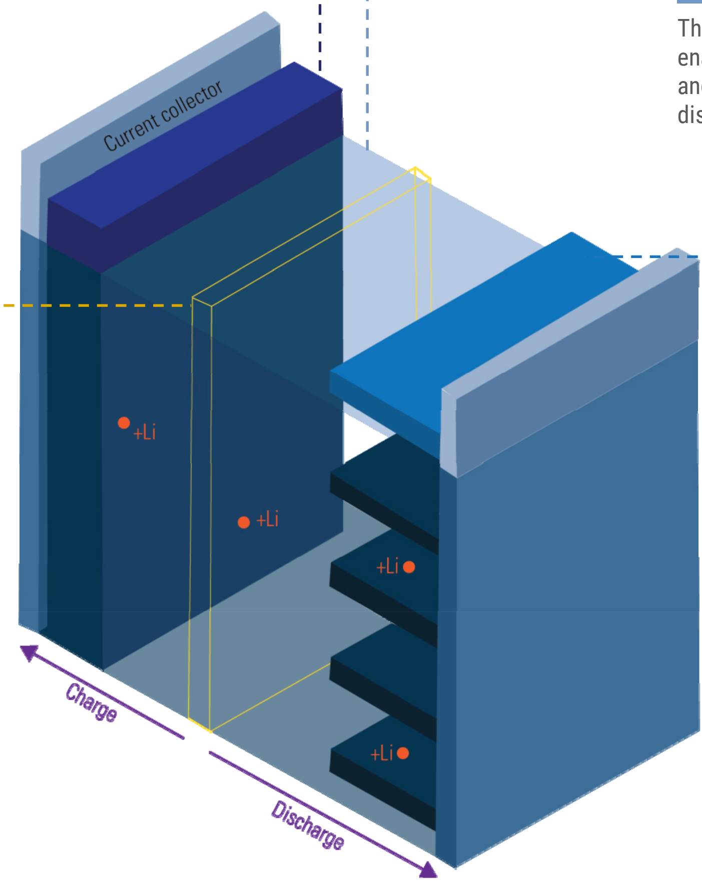
The primary components are:

ANODE

The anode is typically made of layers of graphite between which lithium ions are inserted when the battery is charging through a chemical process known as intercalation. The anode loses electrons when the battery is discharging.

ELECTROLYTE

The electrolyte is a conductive medium that enables lithium ions to move from the anode to the cathode when the battery is discharging and back when it is charging.



SEPARATOR

The separator is a permeable membrane used to keep the anode and cathode apart to prevent short circuit, while allowing the lithium ions to pass through it. There are two main types of separators, "Dry" or "Wet", named for the type of extrusion processes used to create them.

Dry Separator
Often used in large batteries with high safety standards, including most lithium iron phosphate batteries used in commercial electric vehicles such as buses.

Wet Separator
Slimmer than a dry separator and commonly used in high energy density batteries, including ternary batteries.

CATHODE

The cathode gains electrons when the battery is discharging and is the point where the electrical current flows out of the device. When the battery is being recharged, the electrons flow back to the anode. The cathode's material and chemical composition is used to describe the type of battery and plays a role in characteristics such as energy density and capacity.

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Cathode Chemistry

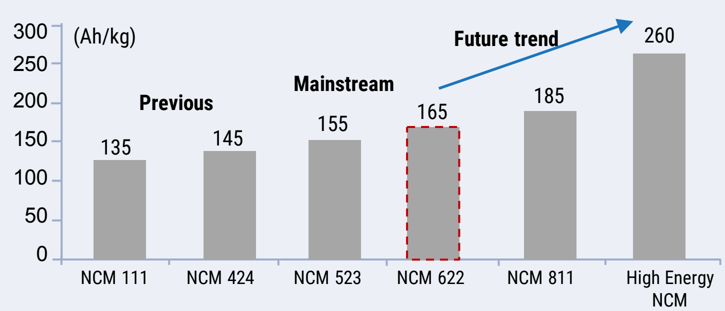
In a "**ternary**" battery, whose name derives from Latin for "three at once," the cathode is typically either nickel, cobalt and aluminum (**NCA**) or nickel, cobalt and manganese (**NCM**). Compared with lithium iron phosphate (LFP) battery, ternary battery offers higher specific energy. It is also a well balanced battery type in terms of power output, capacity, cycle time, cost, material resources, safety, etc, without significant shortcomings. It is therefore the mainstream battery type for Korea and Japanese suppliers and have been widely adopted by global top tier auto OEM's EV models currently, as well as in consumer electronic devices.

Classification of NCM Cathodes

The specific energy benefit offered by ternary batteries varies based on the amount of nickel, cobalt, manganese and/or aluminum used to construct the cathode. NCM cathodes can be classified as 111, 333, 424, 523, 622 and 811, etc. based on the weightings of nickel, cobalt and manganese.

NCM cathodes with higher nickel content (e.g., NCM 622 or 811) generally equate to higher power capacity. Among NCM varieties, 523 is the prevailing technology while Samsung SDI has supplied NCM 622 to BMW's i3 and LG Chem plans to commercialize 811-based NCM batteries after 2018.

Theoretical specific capacity for different NCM cathodes



Source: US DOE, Gao Hua Securities Research.

China's big switch to Electric Vehicles to charge up battery market

Why does China need to ramp up battery production?

World's biggest auto market warming up to Electric Vehicles…

China is driving forward a major switch from petroleum-powered cars towards Electric Vehicles (EVs) as part of efforts to achieve a cleaner environment.

Thanks to raft of government efforts ranging from generous subsidies to rolling out pilot cities that promote these cars, our auto team forecasts EV sales in China will increase 10 fold over the next decade from 330,000 in 2015 to 1.87mn in 2020 and 3.88mn in 2025.

Much of the attraction of EVs is that they generate fewer greenhouse gas emissions and consume less fossil fuel than conventional vehicles. For example, a typical EV requires 20-25kwh electricity to travel 100 km, which is equivalent to 2.2-2.8 liters of gasoline/100km vs. over 6 liters for a conventional internal combustion engine (ICE) vehicle.

The government has been promoting EVs since 2009 but to meet its target, since 2014, it has stepped up a gear to support policies by waiving the EV purchase tax, subsidizing EV charging facilities and extending the coverage of pilot cities. The series of policies involves a number of key regulatory entities such as the State Council, NDRC, Ministry of Finance, Ministry of Industry and Information Technology and Ministry of Science and Technology which we believe demonstrates the government's determination to boost EV adoption.

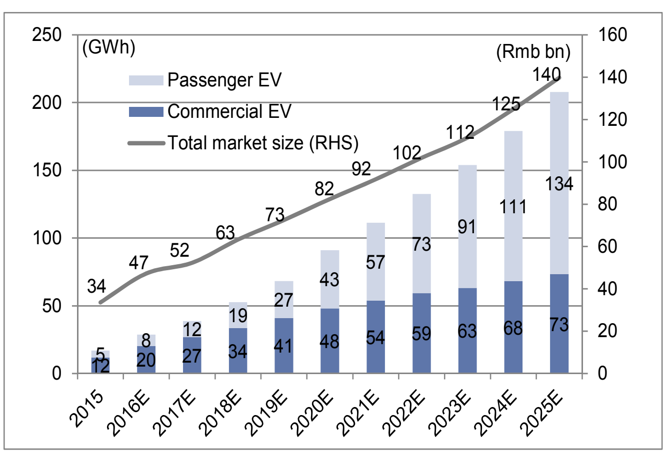
EV battery to be a US$40bn addressable market by 2025E

…with a ramp up in production of batteries set to play a central role

We believe the EV battery market is set to benefit from China's robust EV sales growth in the coming decade. Based on the projection in EV sales and average battery capacity of 95kwh per commercial EV, **EV battery demand in China is set to jump from around 29Gwh in 2016 to 91Gwh in 2020 and 208GWh in 2025, implying 25% CAGR in 2016-25**.

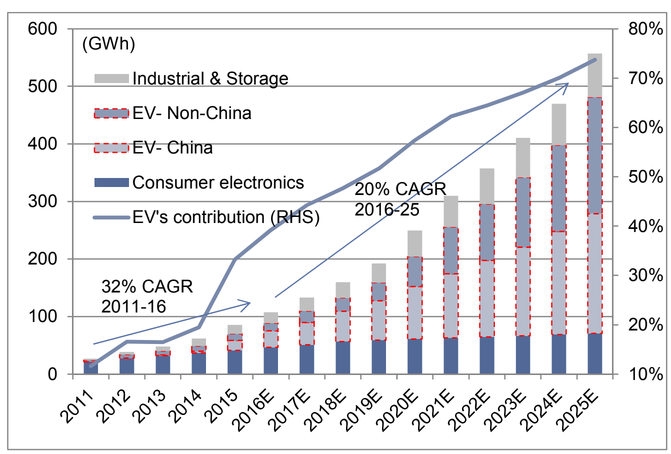
Factoring in the current battery unit price and gradual price decline in the coming years (9% per year in 2016-25), we forecast the addressable market size for EV batteries in China will increase from Rmb47.3bn (US$6.9bn) in 2016 to Rmb139.8bn (US$20.3bn) in 2025. If we factor in the EV demand overseas, we estimate the global market size for EV batteries in 2025 amount to US$40bn, from US$10bn in 2016.

Exhibit 1: We project EV battery market size to reach Rmb140bn (US$20bn) by 2025, vs. Rmb47bn in 2016
EV battery market size forecast in China



Source: Gao Hua Securities Research

Exhibit 2: We estimate EV batteries will account for 74% of global lithium battery demand in 2025, vs. 33% in 2015
Global lithium battery demand forecast



Source: itdcw.com, Gao Hua Securities Research

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EV to cut CO2 by 1 billion tonnes (11% of carbon emissions)

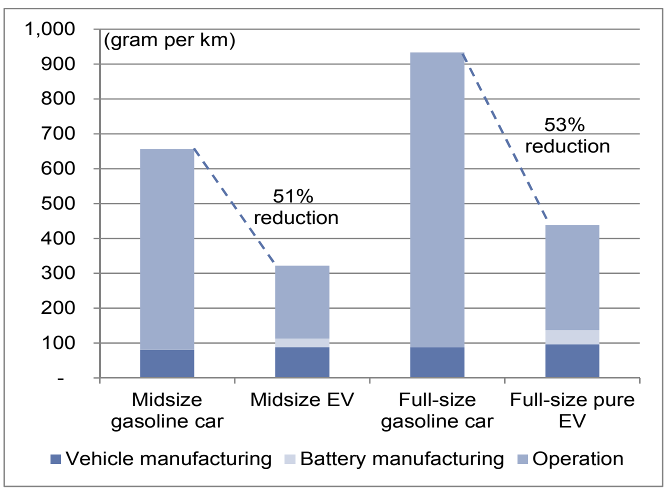
China is the No.1 producer of greenhouse gas emissions globally

While the move by China to embrace EVs is part of a global shift to lower carbon emissions from the transport sector, for China it is especially pressing given it is the No.1 country in the world for greenhouse gas emissions. It released approximately 28% of global carbon dioxide emissions in 2016, 76% higher than the U.S., the 2nd biggest polluter.

EVs in general produce fewer life cycle emissions (from battery and component manufacturing to the operation of EVs) than conventional ICE vehicles because the extra carbon emissions in EV manufacturing parts are largely offset by reduced emissions from driving.

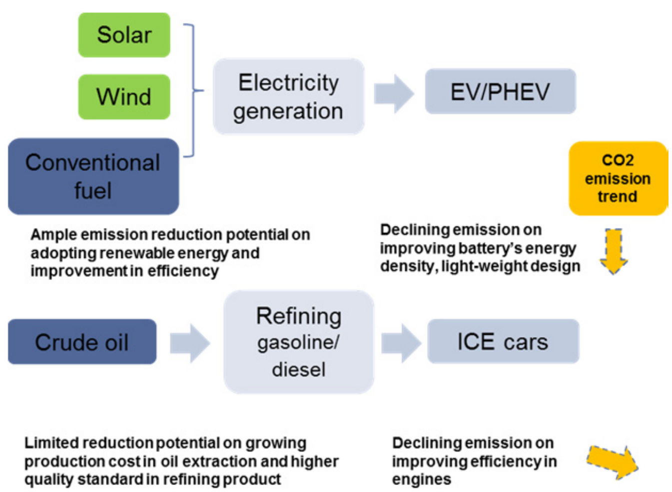
The exact emission reduction depends on the type of electricity generation and vehicle's efficiency. According to the Union of Concerned Scientists, the average life cycle CO2 emission for a gasoline vehicle is 788 grams per km, vs. 377 grams for a pure EV. Based on 15,000km annual travel range per vehicle and 264mn total auto install base in China, we estimate the total CO2 reduction potential in China amounts to 1.0bn tonnes, which represents 11% of China's total carbon emission in 2015. **With the growing application of renewable energy in power generation such as solar and wind, we expect EV will become an even more compelling choice to achieve a lower carbon economy.**

Exhibit 3: EV could reduce life cycle carbon emissions by more than 50% compared to gasoline cars
EV life cycle CO2 emissions per km (fixed)



Source: Union of Concerned Scientists

Exhibit 4: EVs powered by renewable energy set to further reduce life cycle carbon emissions in the future
EV and gasoline/diesel value chain comparison



Source: MIIT, NDRC, Gao Hua Securities Research

Also, growing global interest in environmental protection and reducing air pollution have encouraged governments to set lower emission and gasoline consumption standards over the coming decade. Transportation accounts for 17% of global carbon emissions currently.

The European Union, US, Japan and China all have rolled out long-term greenhouse gas and fuel reduction per mile targets for 2020-25. In China, the State Council is targeting a reduction in the average fuel consumption from 6.7 liters per 100km in 2015 (including EVs) and 5.0 liters by 2020 and 4.0 liters by 2025.

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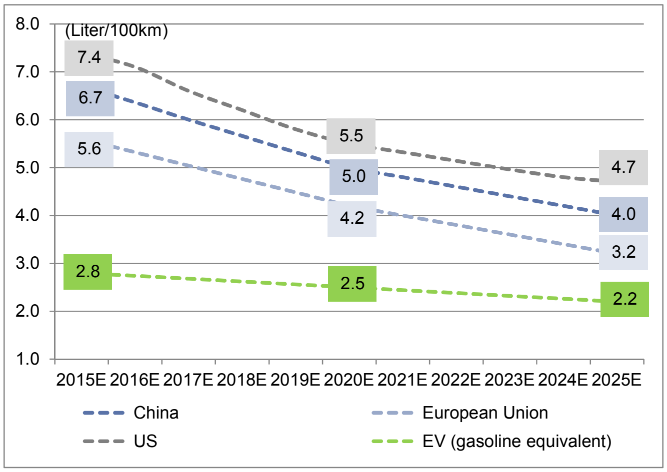
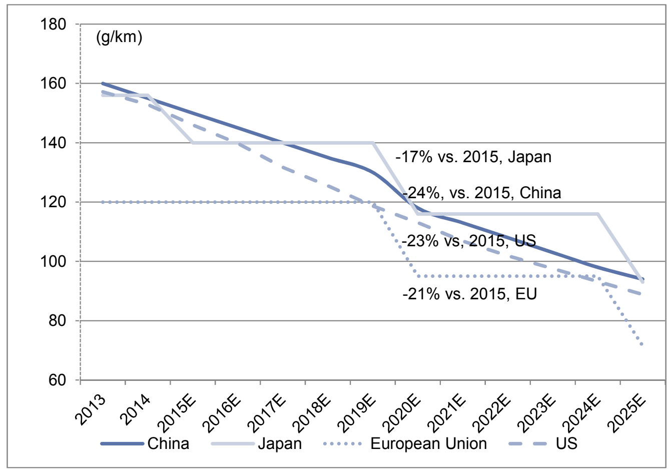
Exhibit 5: Fuel consumption set to decline on adoption of EVs and innovation in engine technology
Fuel consumption per 100km for passenger cars



Source: NDRC, European Commission, EPA, Gao Hua Securities Research

Exhibit 6: Major countries have set aggressive targets to reduce greenhouse gas emissions
CO2 emission target per km by country



Source: NDRC, European Commission, EPA

Supportive policies to put 5mn+ EVs on the road by 2020E

The Chinese government started to promote EVs in 2009 by introducing policies such as subsidies, setting development targets, and assigning pilot cities/provinces that promote EV adoption. Development until 2013 was generally behind schedule, so since 2014 the government has strengthened supporting policies by waiving the EV purchase tax, subsidizing EV charging facilities, and extending the coverage of pilot cities.

Apart from the central government, municipal governments have also provided supportive policies for EVs, including subsidies, preferential issuance of license plates and absence of travel restrictions *(*like in Beijing where regular cars can travel only 4 days of every 5 weekdays).

For details, please refer to the report published on 5 Oct, 2016 *"New credits quotas systems to boost NEV market; BYD well placed"*.

Moreover, in Sep 2016, MIIT said it plans to introduce a new energy vehicle (NEV, which includes EV, fuel cell and other types of vehicles) credit/quota system from 2018, with the aim of boosting NEV penetration. **We estimate EVs will account for 6.3% of China's annual auto sales in 2020, vs. 1.4% in 2015 and estimate accumulative EV install base will reach 5.9mn units in 2020, which could meet the government's 5mn target.**

EV is becoming the new growth driver for lithium batteries

During the 1990s-2010, the global lithium battery industry was boosted by the proliferation of consumer electronic devices such as mobile phones, laptop computers and digital cameras. Its total market size surged from US$5.6bn in 2005 to US$20bn in 2015 (14% CAGR), according to IIT. Consumer electronics accounted for 49% of global lithium battery demand in 2015, followed by 33% for EVs and 18% for industrial & energy storage.

Looking ahead, we believe EVs will emerge to be the new demand driver and we forecast they will represent 74% of global lithium battery consumption by 2025E and achieve a 29% CAGR in 2016-25E. From an incremental demand perspective, **we estimate the EV battery captures 62% of the incremental demand for lithium batteries in 2016, and this ratio will further expand to 77% in 2020E and 94% in 2025E.** For China's EV market in particular, we estimate it accounts for 27% of global lithium battery demand in 2016 and will increase the market share to 37%/37% in 2020E and 2025E.

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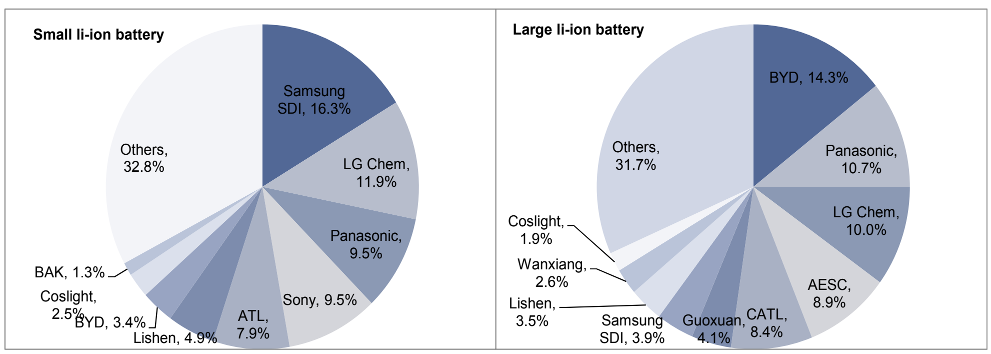
China now the world's largest lithium battery supplier

The lithium battery market was dominated by Japanese companies in the 1990s and early 2000s. Korean companies such as Samsung SDI and LG Chem started to catch up in the 2000s and then become the largest suppliers in 2011. However, thanks to the robust EV demand in China and improving technology and production know-how, Chinese battery material and component manufacturers are gaining market share over Japanese and Korean battery makers today.

China has outpaced Korea to be the largest lithium battery supplier since 2013 and captured over 40% market share in 2015, vs. 31% for Korea and 24% for Japan. Although China has the largest market share, we believe it still has room to improve in terms of quality and lags in high energy density products such as Nickel Cobalt Aluminum ternary batteries (used in Tesla's Model S and X, and discussed in the next chapter). For example, the yield rate for Korean and Japanese suppliers is over 99.9% while that for Chinese companies is generally around 90%.

Exhibit 7: Chinese battery makers have higher exposure to large lithium battery (EV) segment than the small battery segment
Market share of lithium battery cell supplier in 2015



Source: itdcw.com

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Technology: Battery innovation is stepping up a gear

See "BYD Co. (1211.HK): Potential to transform into leader in NEV ternary battery in China" published Feb. 9 for more details.

Energy density the key focus

As China charges ahead with adopting EVs, developments to make batteries travel further before needing a charge and to make them lighter are critical for mainstream EV usage. We believe the ternary battery, namely Nickel Cobalt Manganese (NCM) and Nickel Cobalt Aluminum (NCA), will become the mainstream type and is set to gain market share against the lithium iron phosphate (LFP) battery in the coming years, due to higher energy density potential and the improved travelling range.

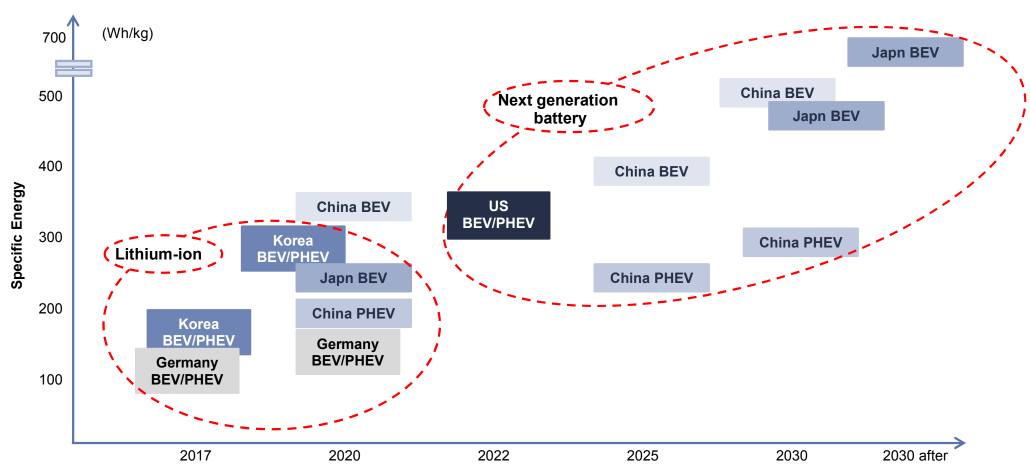
We believe this shift will create three core investment opportunities in the value chain that we explore later in this chapter.

1) Nickel rich cathodes will be in high demand as they have higher energy density although they have high technical entry barriers for manufacturing.

2) Demand will switch from dry separators to wet separators, which are slimmer and preferred in higher energy density batteries.

3) Recycling will play a more important role in the battery value chain considering lithium-ion batteries contain hazardous material. We also see a growing reliance on recycled cobalt due to its tight supply and scarcity.

Exhibit 8: Next-generation battery are needed to fulfill different countries' aggressive targets in improving specific energy in the coming decades
Specific energy development target at cell level by country



Source: USDOE, MIIT, NEDO

China has set an ambitious technical target for EV batteries by 2030

In October, China set a technology roadmap for electric vehicles in China by 2030, requiring the travelling distance per charge for pure EV (also known as BEV) to reach 300km in 2020, and 500km in 2030, vs. a current BEV's mileage of 100-200km. This requires an ongoing improvement in the battery's specific energy and vehicle's lightweight design. The government targets energy density (specific energy – see definition on next page) for pure EV battery cells are 350Wh/kg in 2020 and 500Wh/kg in 2030, compared to the prevailing 130-200Wh/kg for existing lithium batteries. The government has also rolled out an ambitious target for cycle times and production costs, illustrated in Exhibit 9.

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Also, we note other countries such as the US, Japan, Korea and Germany are setting the roadmap for EV's specific energy. In particular, the New Energy and Industrial Technology Development Organization (NEDO) in Japan set a target of 700Wh/kg for 2030.

Exhibit 9: China has set an ambitious development roadmap for EV batteries by 2030
EV battery technology roadmap in China

EV	2020	2025	2030
Specific energy (Wh/kg)	350 cell, 260 system	400 cell, 300 system	500 cell, 350 system
Energy density (Wh/L)	650 cell, 320 system	800 cell, 500 system	1000 cell, 700 system
Specific Power (W/kg)	1000 cell, 700 system	1000 cell, 700 system	1000 cell, 700 system
Cycle time	2000	2000	3000
Cost (Rmb/wh)	0.6 cell, 1.0 system	0.5 cell, 0.9 system	0.4 cell, 0.8 system
PHEV			
Specific energy (Wh/kg)	200 cell, 120 system	250 cell, 150 system	300 cell, 180 system
Energy density (Wh/L)	400 cell, 240 system	500 cell, 300 system	600 cell, 350 system
Specific Power (W/kg)	1500 cell, 900 system	1500 cell, 1000 system	1500 cell, 1000 system
Cycle time	3000 cell, 3000 system	4000 / 10 years cell 3500 /10 years system	5000 / 10 years cell 4000 /10 years system
Cost (Rmb/wh)	1.0 cell, 1.5 system	0.9 cell, 1.3 system	0.8 cell, 1.1 system

Source: Society of Automotive Engineers of China

We believe the new policy will incentivize EV battery makers to keep developing new materials in order to meet these standards. The current primary EV battery types include LFP, NCM and NCA. Since the LFP battery has reached the theoretical limited in specific energy of 160wh/kg, we note the industry's R&D focus has shifted to ternary based cathodes - NCM and NCA.

The specific energy for current NCM/NCA material combination (high voltage, nickel rich cathode, and graphite based anode) is around 280Wh/kg. The introduction of a silicon alloy as an anode could further lift the specific energy to 300-350Wh/kg in the future, but even with this addition NCA/NCM batteries would still not able be able to meet the Chinese government target of 400wh/kg in 2025 and 500wh/kg in 2030.

Therefore, we believe migrating to next-generation batteries is inevitable from 2030. Replacing graphite or silicon anodes with lithium metal anodes, along with the application of solid state electrolytes, could realize long-term goals of high specific energy, in our view. We will discuss in detail in later sections.

Note: Specific energy equals to capacity (Ah/kg) times voltage (V). We thus break down battery specific energy by these two factors in Exhibit 11. We find lithium air offers the highest specific energy mainly due to its high capacity, although lithium air's voltage is lower than lithium ion and lithium metal.

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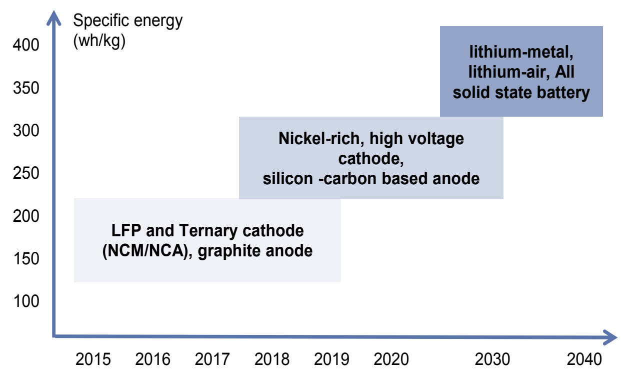
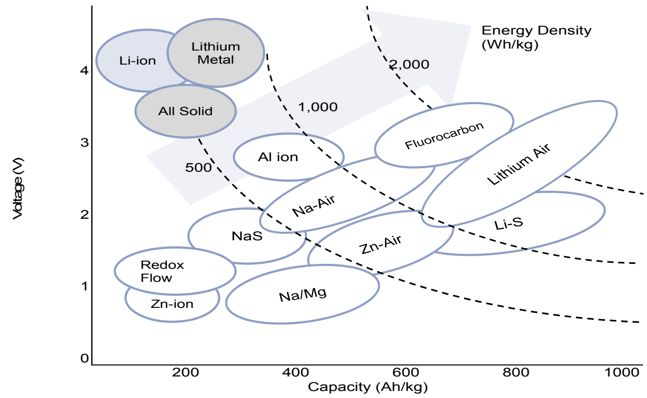
Exhibit 10: Next generation battery will kick-off c.2030
Technology roadmap by 2030 for EV battery



Source: Gao Hua Securities Research

Exhibit 11: Lithium metal and lithium air offer higher energy density than lithium ion
Performance feature comparison



Source: Samsung SDI

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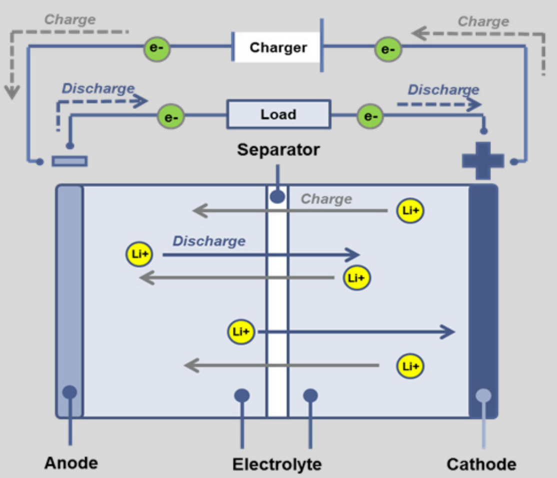
Battery Mechanics

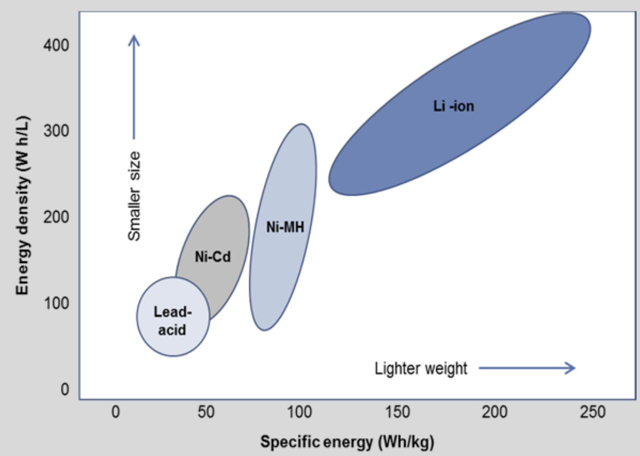
A battery stores and releases electricity through electro-chemical reaction. It consists of four major materials, namely the cathode, anode, electrolyte and separator. Each material has its own function that ensures the battery to work properly. Take the lithium-ion battery as an example, in the charging process, an external power source forces electron and lithium ion to flow from cathode to anode via the electrolyte and separator, and the flow reverses during the discharging process.

Lithium battery mainly consists of the cathode, anode, electrolyte and separator
Battery structure illustration



Source: Gao Hua Securities Research

Lithium battery offers higher energy density and specific energy than peers
Performance matrix comparison for major battery type



Source: Gao Hua Securities Research

Material innovation keeps improving battery performance

The battery was invented by Alessandro Volta in 1799, with copper and zinc used as the cathode and anode. Lead-acid and alkaline batteries were sequentially developed and become the mainstream batteries in 19-20th century, until the lithium-ion battery was commercialized by Sony in 1991. As shown below, we note innovation in new materials as the key driver of improving features such as energy density, specific energy, cycle life, safety, cost and environmental protection. Within the lithium-ion category, we see new material development continuing to enhance battery performance through the introduction of high nickel content cathodes and higher capacity anodes.

The battery has over 200 years of history and the development is associated with innovation in new materials
History of battery material innovation

	Name	Year	Inventor	Cathode	Anode	Electrolyte	Separator
	Voltaic Pile	1799	Alessandro Volta	Copper	Zinc	Brine-soaked paper	N/A
	Daniell cell	1836	John Frederic Daniell			Cooper sulfate/Zinc sulfate	N/A
	Lead acid	1859	Gaston Plante	Lead dioxide	Lead	Sulphuric acid	Wooden venner, Microfiber glass, Rubber, PVC, Polyethelene
alkaline	Nickel Cadmium (NiCd)	1899	Waldemar Jungner	Nickel oxyhydroxide	Cadmium	Potassium hydroxide	
	Alkaline battery	1950s	Lewis Urry	Manganese oxide	Zinc		
	Nickel-metal hydride (NiMH)	1989	Group effort	Nickel hydroxide	Hydrogen-absorbing alloy		
Lithium-ion	Lithium cobalt oxide (LCO)	1991	Sony	Cobalt dioxide	Graphite	Liquid organic solvent (LiPF6, etc)	Polyethylene/ Polypropylene
	Lithium iron phosphate (LFP)	1996	University of Texas	Iron phosphate			
	Lithium polymer	1997	Bellcore	LCO, NCM, LFP etc.		Gelled polymer	
	Lithium Manganese oxide (LMO)	1996	E-one Moli Energy	Manganese		Liquid organic solvent (LiPF6, etc)	
	Nickel Cobalt Aluminum (NCA)	1999	Group effort	Nickel Cobalt			
	Nickel Cobalt Manganese (NCM)	2008					
	Lithium Titanate (LTO)	2008		NCM, LMO, LFP	Lithium titanate		

Source: Company data, Gao Hua Securities Research

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1) Ternary cathodes set to be mainstream in 2017-25E

Traditional LFP batteries capture 73% market share in China's EV battery shipments in 1H16 vs 23% in ternary (Source: d1ev.com)

China's battery market is dominated by the traditional lithium iron phosphate (LFP) battery with local suppliers like BYD and Guoxuan holding a strong technology position in this market. This type of battery has also gained prominence as the government has prohibited more advanced batteries from being used in EV buses before 2017 for safety reasons.

However, we expect the so-called ternary battery, namely Nickel Cobalt Manganese (NCM) and Nickel Cobalt Aluminum (NCA), to become the mainstream type and to gain market share against LFP batteries in the coming years, due to higher energy density potential that will meet regulations and improve the travelling range for EVs. These batteries are also well- balanced in terms of power output, capacity, cycle time (charge and discharge times during the life time of the battery), cost, component material resources (like cobalt nickel, etc*)*, and safety.

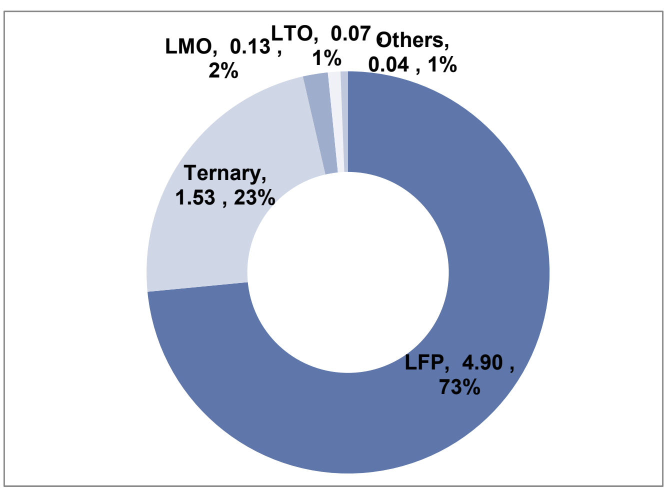
Ternary battery used in Tesla, BMW and Chevrolet Bolt

Ternary batteries are already the mainstream battery type for Korean and Japanese suppliers and have been widely adopted by global top tier auto OEM EV models such as Tesla's Model S/X, BMW i3/i8, Chevrolet Bolt as well as in consumer electronic devices (Exhibit 16). Moreover, Beijing Auto (BAIC) forecasts ternary material production costs will fall below LFP by 2018, thanks to the ongoing improvement of specific energy through material innovation and economies of scale (Exhibit 13).

Addressable market: US$5.7 bn in 2025E

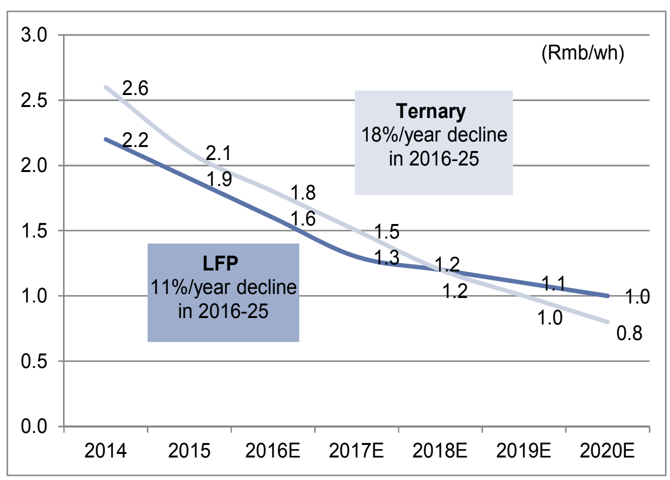
Our base case forecast is for the ternary cathode market to grow by 37% CAGR in 2016-25E and reach US$5.7bn in 2025E. **Under our bull case scenario, if ternary batteries start to penetrate commercial EV's like buses and meet the government's technical standards (such as thermal stability), the addressable market for ternary cathodes could reach US$8.1bn in 2025E.**

Exhibit 12: LFP and ternary dominates the EV battery market in China
EV battery shipment in 1H16 by battery type



Source: d1ev.com

Exhibit 13: Ternary material cost set to fall below LFP from 2018
Cathode production cost forecast



Source: BAIC, Gao Hua Securities Research

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Exhibit 14: Ternary (NCM/NCA) battery generally has higher specific energy than other lithium battery peers
Performance features comparison by lithium battery

	Lithium Cobalt Oxide LCO	Lithium Manganese Oxide LMO	Lithium Iron Phosphate LFP	Nickel Cobalt Manganese NCM	Nickel Cobalt Aluminum NCA
Voltage	3.8V	3.9V	3.4V	3.7V	3.6V
Specific energy (Wh/kg)	150	100-120	110-150	160-250	170-260
Cycle time	>500	>500	>2000	>1500	>1000
Safety	Low	Medium	High	Medium	Low
Cost	High	Low	Medium	Medium	High
Areas of application	Electronics devices	Consumer devices/EV	EV Energy storage	Passenger EV	Passenger EV
Pros	High energy density	High operating voltage high safety	Low cost; high safety	Good power/ energy density Thermally stable	High energy/ density
Cons	Expensive; toxic; low charge/discharge rate	Shortened cycle life at higher tempreture	Low operating voltage; lower energy density	Moderate cost Moderate stability	High cost low safety

Source: Gao Hua Securities Research

Government policy favors ternary material

1) Raising the requirements for specific energy: For the first time, China is requiring pure passenger EV battery systems' specific energy to be higher than 90Wh/kg and commercial EVs' specific energy to be above 85wh/kg (according to a 30 Dec 2016 announcement from MIIT, Ministry of Finance, Ministry of Technology and NDRC). Plus, EVs with over 120wh/kg are entitled to a 10% additional subsidy.

Our view: While we believe LFP is able to meet the minimum 85-90Wh/kg criteria, it has already reached the theoretical limit in specific energy and is difficult to exceed 120Wh/kg to meet the government's increased standards over the coming years. For example, BYD indicates its cell level specific energy for LFP is 135Wh/kg, but has indicated difficulties to reach 120Wh/kg in the pack/system level.

2) Commercial EV's can now use ternary battery. Also, since Jan 2017, the government does not prohibit commercial EVs to use ternary batteries as long as they can meet the technical requirement and pass thermal stability testing.

Our view: We believe this creates market share gain opportunity for ternary batteries vs LFPs.

Exhibit 15: Government encourages higher specific energy and travelling range EVs
Subsidy details related to specific energy and travelling range for 2017-18

	Subsidy (Rmb/kwh)	Adjustment factor Specific energy (wh/kg)			Subsidy cap (Rmb '000)		
		85-95	**95-115**	**>115**	**6m**	**8<L≤10m**	**L>10m**
Non fast-charging pure comemrcial EV	1,800	0.8	1.0	1.2	90	200	300

		Pure EV travelling range (R, km)			
		100≤R<150	**150≤R<250**	**R≥250**	**R≥50**
Passenger EV	(Rmb'000)	20	36	44	N/A
Passenger PHEV	(Rmb'000)			N/A	24

Source: MIIT

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More EV models to launch based on ternary battery. We see a growing adoption of ternary batteries by domestic auto OEMs due to the high specific energy nature and estimate around 70% of new passenger EV models are using ternary batteries (Exhibit 16). In Nov 2016, BYD also plans to add 5-6GWh ternary battery production capacity in 2017.

Although Korean battery makers are not able to supply EV batteries in China, we see other competitive players such as domestic battery producer CATL catching up with the global peers in product quality, thus providing competitive ternary battery solutions for domestic auto OEMs.

Exhibit 16: NCM and NCA are the primary battery type for passenger vehicles
EV models and the battery suppliers

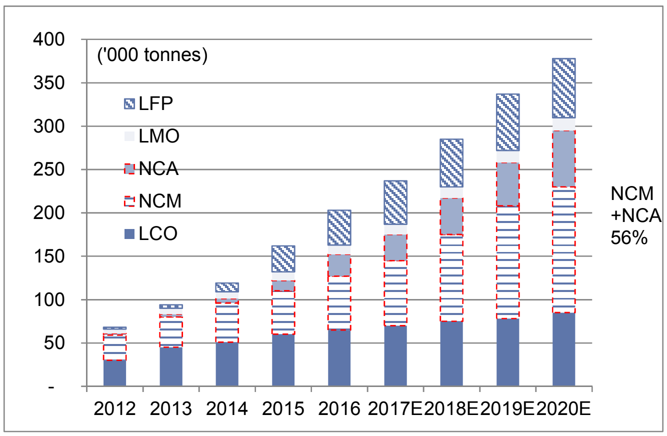
	NCA/NCM car models				
	EV maker	**Car type**	**EV Type**	**Year**	**Battery supplier**
Domestic	**BYD**	Song	PHEV	2017E	BYD
	BMW-Brilliance	530LE	PHEV	2015	CATL
	BAIC	EV200/EU260 EX200/ES210	EV EV	2016 2016	SKI/Pride Power (CATL) BESK (SKI)
	Changan - Ford	Yidong EV	EV	2015	A123 (Wanxiang)
	JAC	iEV6E iEV5	EV EV	2016E 2015	SDI Lishen
	Geely	New Emgrand	EV	2016	CATL
	Kandi	K10/K11D/K12/K17A	EV	2015	Lishen/Do-Fluoride/Tianneng
	Xindayang	ZD D2	EV	2015	Optimum Nano/Tianfeng/Boston
	SAIC	Roewe e950/e550 Roewe e50	PHEV EV	2016 2016	LG/A123 (Wanxiang)
	Chery	Arrizo 7e eQ	PHEV EV	2016 2015	A123 (Wanxiang)
	Zotye	Yun100	EV	2016	Far East First/BAK/Boston Power
	FAW	Besturn B50 VCT-1/Oley EV Hongqi H7	EV/PHEV EV PHEV	2015 2015 2016E	BAK Lishen/Coslight/Panasonic/LG
	GAC	GS4/GS6 GA5	EV PHEV	2016E 2015	A123 (Wanxiang)
Overseas	**Tesla**	Model 3 Model X/Model S P85D	EV	2016 2015	Panasonic
	BMW	i3/i8	EV	2016	SDI
	Toyota	Camry HEV Prius	HEV HEV/PHEV	2015 2016	Panasonic PEVE (Toyota)
	Hyundai	Ioniq	HEV/EV/PHEV	2016	LG/SDI
	Daimler	B250e C350e/E350e/S550e	EV PHEV	2015 2016	SKI
	GM	Chevrolet Bolt Cadillac CT6	EV PHEV	2017E 2016	LG/A123 (Wanxiang)
	VW-Audi	e-Golf Audi A3 e-Tron	EV PHEV	2016E 2016	Panasonic
	Ford	C-Max Energi	PHEV	2016	Panasonic
	Porsche	Cayenne S - E Panamera E-Hybrid	HEV/PHEV PHEV	2016 2016	SDI
	LiFePO4 car models				
	EV maker	**Car type**	**EV Type**	**Year**	**Battery supplier**
Domestic	**BYD**	Tang/Yuan/Qin E6	PHEV EV	2016 2016	BYD
	BYD - Daimler	Denza	EV	2014	BYD
	BAIC	EV160	EV	2016	Pride Power (CATL)
	Changan - Ford	Mondeo C-Max Energi	HEV PHEV	2016E 2016	China Aviation Lithium Battery
	JAC	iEV4	EV	2014	Guoxuan
	Dongfeng	E30/E30L Venucia Chenfeng	EV EV	2015 2014	Lishen BAK
	FAW	Besturn B50	EV/PHEV	2015	BAK

Source: Company data

Robust demand growth ahead: 42% CAGR in 2016-25

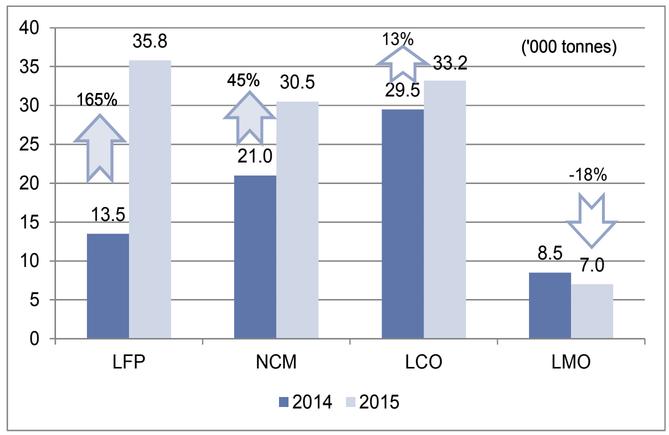
China's demand for ternary cathodes is showing rapid growth. According to GGLB (a lithium battery industry news and research agent), China's lithium battery cathode shipment increased 52% yoy to 63,600 tonnes in 1H16, mainly driven by 123% growth in LFP (23,900 tonnes) and 70% yoy growth in ternary (20,000 tonnes). Looking ahead, we expect overall demand and market size for ternary cathodes will outpace LFP in the coming years. The global cathode material demand will grow from 0.20mn tonnes in 2016 to 0.38mn tonnes in 2020E, implying a CAGR of 17%, according to B3. Ternary based material (NCM+NCA) will capture 56% market share in 2020, vs. 43% in 2016.

Exhibit 17: We expect ternary (NCM+NCA) will represent 56% of global cathode shipment by 2020 vs. 43% in 16'…
Global lithium battery cathode production by type



Source: B3, Easpring, Gao Hua Securities Research

Exhibit 18: …while LCO and LMO are lagging due to slower demand growth in consumer electronics
China's Lithium battery cathode production by type



Source: itdcw.com

We estimate EV-based ternary cathode market size in China. We apply our auto team's EV sales forecast in China from 0.54mn in 2016 to 3.88mn in 2025 to derive our EV battery demand, which leads to a 25% CAGR from 29GWh in 2016 to 208GWh in 2025. We assess the addressable market size for ternary and LFP cathodes in China based on the following scenario analysis (Exhibit 19). Our analysis only focuses on EV related demand.

Base case: Ternary cathode's market share in passenger EVs will increase from 70% in 2016 to 100% in 2020 and it will not be able to supply to commercial EVs before 2025 due to thermal stability reasons. **The ternary cathode demand CAGR is 42% to 303,800 tonnes and an addressable market of Rmb39bn in 2025.** This implies ternary will capture 81% EV battery market share in value by 2025, vs. 34% in 2016.

Bull case: Ternary cathode's market share passenger EV will increase from 70% in 2016 to 100% in 2020 and will start to penetrate into commercial EV from 2018 if it can meet government's technical standards with a market share increase from 30% in 2018 to 80% in 2025. This suggests **a 47% demand CAGR to 436,500 tonnes by 2025. The total addressable market is set to grow at 43% CAGR to reach Rmb56bn in 2025.** This implies ternary will capture 97% EV battery market share in value by 2025, vs. 34% in 2016.

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Exhibit 19: We forecast ternary material market size will increase from Rmb2.2bn in 2016 to Rmb39.2bn in 2025E, implying a 37% CAGR

Estimates of addressable market of ternary cathode

	2015	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E	CAGR 16-25
EV battery market in China												
In Gwh												
Commercial EV	12	20	27	34	41	48	54	59	63	68	73	15%
Passenger PHEV	1	2	3	5	7	14	17	21	25	29	34	41%
Passenger BEV	4	7	9	15	20	29	40	52	66	82	101	35%
Total	**17**	**29**	**39**	**53**	**68**	**91**	**111**	**133**	**154**	**179**	**208**	**25%**
yoy	455%	70%	35%	36%	29%	34%	22%	19%	16%	16%	16%	
In Rmb bn												
Commercial EV	24.8	36.7	40.3	40.2	41.0	38.4	39.7	41.1	41.6	43.5	45.4	2%
Passenger PHEV	1.6	1.9	2.6	5.5	8.7	14.2	15.9	17.4	19.2	21.5	23.8	32%
Passenger BEV	7.3	8.6	9.5	17.5	22.9	29.8	36.2	43.4	50.8	60.0	70.6	26%
Total	**33.6**	**47.3**	**52.4**	**63.3**	**72.6**	**82.4**	**91.8**	**101.9**	**111.5**	**125.0**	**139.8**	**13%**
yoy		41%	11%	21%	15%	14%	11%	11%	9%	12%	12%	
Base case - Ternary demand												
Penetration (%)												
Commercial EV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Passenger EV	50%	70%	80%	90%	90%	100%	100%	100%	100%	100%	100%	
Implied ternary demand ('000 tonnes)	**5.8**	**13.3**	**21.5**	**39.1**	**55.3**	**97.3**	**129.5**	**165.4**	**204.9**	**250.4**	**303.8**	**42%**
In Gwh	2.6	5.9	9.5	17.3	24.5	43.1	57.3	73.2	90.7	110.8	134.4	42%
% of total cathode mkt	15%	20%	25%	33%	36%	47%	51%	55%	59%	62%	65%	
In Rmb bn	1.0	2.2	3.5	6.2	8.6	14.6	18.9	23.4	28.1	33.3	39.2	37%
% of total cathode mkt	25%	34%	40%	50%	54%	66%	70%	74%	77%	79%	81%	
Bull case – Ternary demand												
Penetration (%)												
Commercial EV	0%	0%	0%	30%	50%	60%	80%	80%	80%	80%	80%	
Passenger EV	50%	70%	80%	90%	90%	100%	100%	100%	100%	100%	100%	
Implied ternary demand ('000 tonnes)	**5.8**	**13.3**	**21.5**	**61.8**	**101.7**	**162.4**	**227.1**	**272.7**	**319.3**	**373.8**	**436.5**	**47%**
In Gwh	2.6	5.9	9.5	27.4	45.0	71.9	100.5	120.7	141.3	165.4	193.2	47%
% of total cathode mkt	15%	20%	25%	52%	66%	79%	90%	91%	92%	92%	93%	
In Rmb bn	1.0	2.2	3.5	9.9	15.8	24.4	33.1	38.6	43.8	49.7	56.3	43%
% of total cathode mkt	25%	34%	40%	69%	80%	89%	95%	96%	96%	97%	97%	

Source: Company data, Gao Hua Securities Research

Nickel-rich and high voltage cathode development in focus

The specific energy benefit offered by ternary batteries varies based on the amount of nickel, cobalt, manganese and/or aluminum used to construct the cathode. NCM cathodes can be classified as 111, 333, 424, 523, 622 and 811, etc. based on the weightings of nickel, cobalt and manganese (Exhibit 20).

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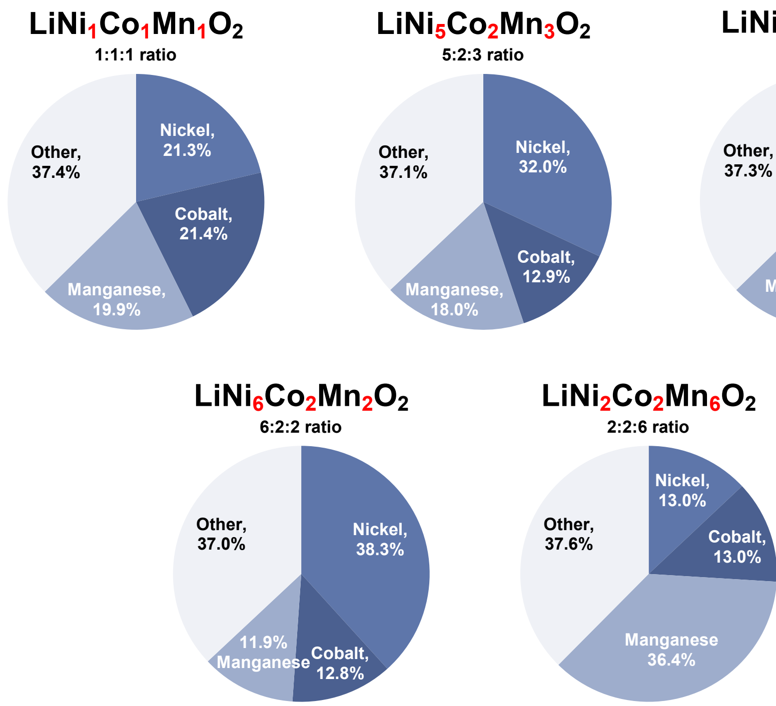
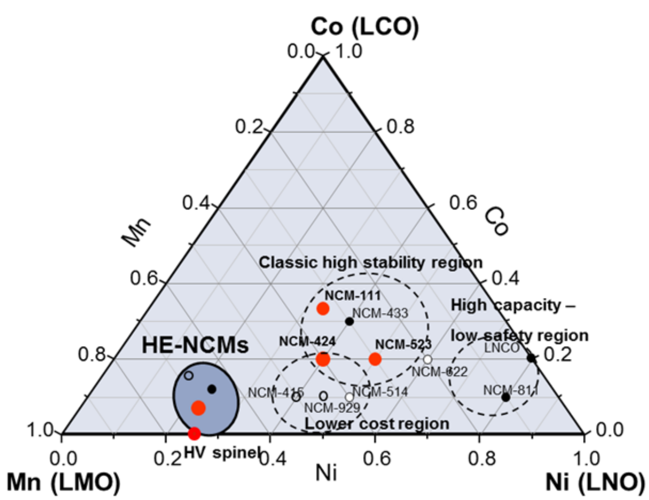
Exhibit 20: Ratio of nickel to cobalt and manganese drive cathode name and properties
Cathode chemical name and major metal component weighting



Source: BASF, Goldman Sachs Global Investment Research.

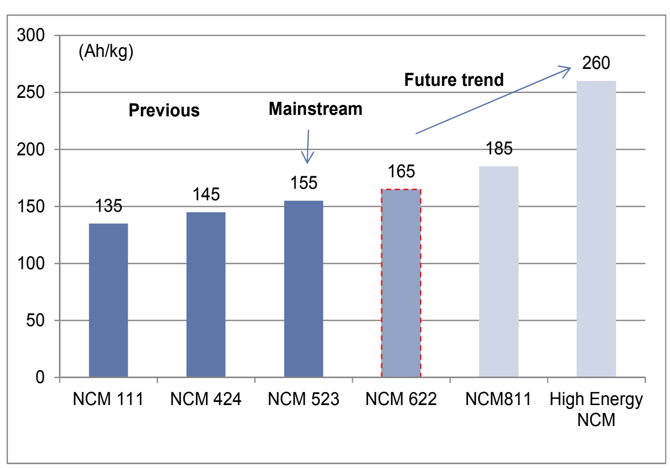
NCM cathodes with higher nickel content (e.g., NCM 622 or 811) generally equate to higher power capacity (Exhibit 20). Among NCM varieties, 523 is the prevailing technology while Samsung SDI has supplied NCM622 to BMW's i3 and LG Chem plans to commercialize 811-based NCM batteries after 2018.

Exhibit 21: NCM is migrating from 523 to 622 and 811 in the coming years
Phase diagram of NCM cathode material



Source: BASF

Exhibit 22: 622 and 811 based NCM have higher energy density than 523
Theoretical specific capacity for different NCM cathodes



Source: US DOE, Gao Hua Securities Research

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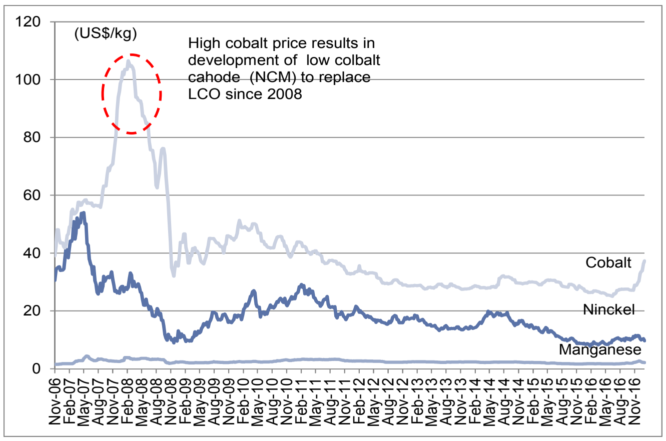
Ample cost reduction potential for NCM cathodes

Since the supply of cobalt is quite concentrated (three countries control 70% of supply) and the cobalt price is high, nickel rich NCMs with low cobalt content can reduce a battery's production cost. Lithium battery makers started to develop NCM to replace LCO (Lithium cobalt oxide) in 2008, when the cobalt price reached over US$100/kg, vs. current US$34/kg). The commercially launched product was NCM111 in 2010 by Korean and Japanese suppliers, and was sequentially migrated to NCM523 along with improving production know-how, which is the mainstream NCM cathode nowadays.

Exhibit 23: Cobalt is more expensive than nickel and manganese
Historical metal price comparison



Source: Bloomberg

Exhibit 24: NCM622/523/424 cathodes have lower overall metal material cost than NCM111 due to lower cobalt content, while NCM226 offers the lowest cost on higher contribution of manganese
Unit metal cost per kg for typical ternary cathode

(Rmb/kg)	NCM111	NCM523	NCM424	NCM622	NCM226	NCA
Lithium	8.71	8.70	8.73	8.66	8.80	8.74
Nickel	18.47	27.67	22.22	33.08	11.20	44.49
Cobalt	50.91	30.52	30.64	30.40	30.88	23.00
Manganese	3.12	2.81	3.76	1.86	5.68	-
Aluminum	-	-	-	-	-	-
Total	**81.2**	**69.7**	**65.4**	**74.0**	**56.6**	**76.2**

Source: Bloomberg, Gao Hua Securities Research

High entry barrier in IP protection and production know-how

The production process for a ternary battery is complicated. The manufacturing of precursor (a kind of raw material to produce final cathode product) plays a critical role in deciding the cathode quality, which is measured by qualities like particle size, particle distribution, surface area and tap density (the bulk density after the material is mechanically tapped). Each production step requires precise control over materials and reaction conditions. As illustrated in Exhibit 25, NCM cathode requires more processing steps than LCO and LFP in general.

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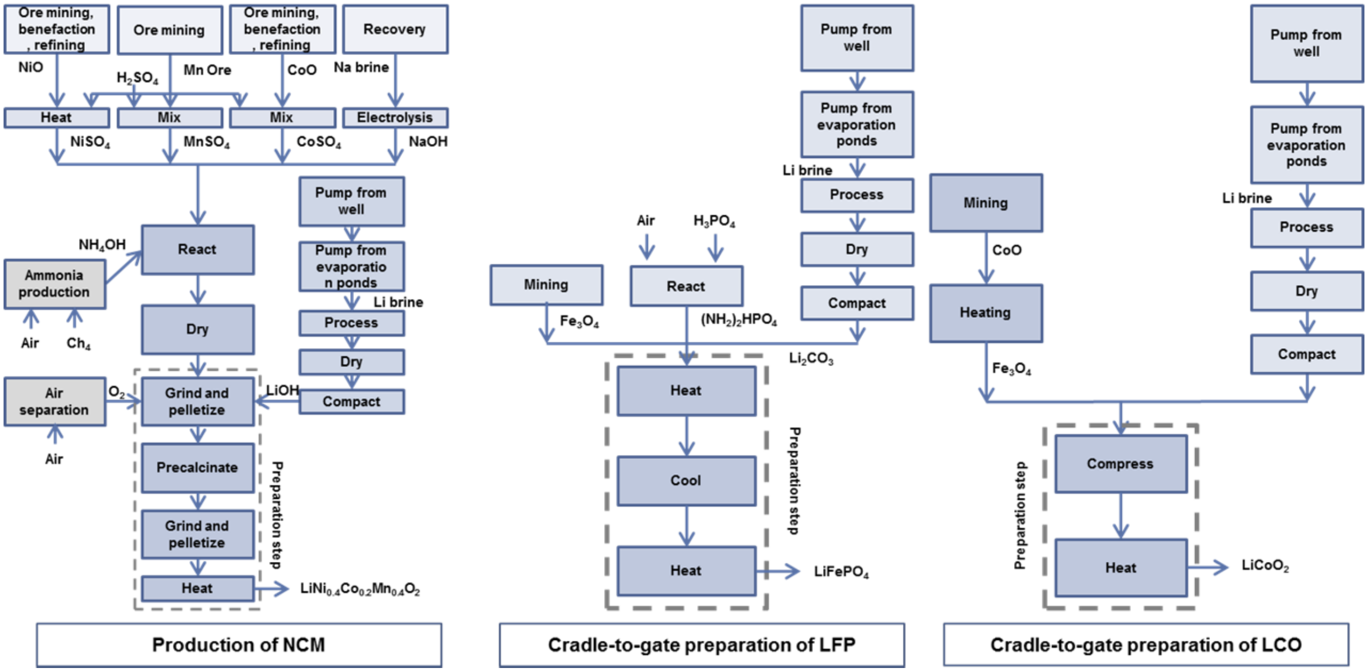
Exhibit 25: NCM has a more complicated manufacturing process than LCO and LFP
Manufacturing process for NCM, LCO and LFP



Source: Argonne National Laboratory

Supply dynamics: shortage in NCM622 and NCA

Japanese and Korean companies lead the high-end ternary cathode production, such as Nichia, Umicore and Sumitomo Metal mining. Nichia is able to produce NCM811 while Chinese companies are still in the early stage of commercializing NCM622 and NCA. According to GGLB, **NCM622 and NCA account for only 5% of total ternary cathodes in China and over 75% of the total is mainly NCM523 in 2016, with the remaining mainly as NCM111.**

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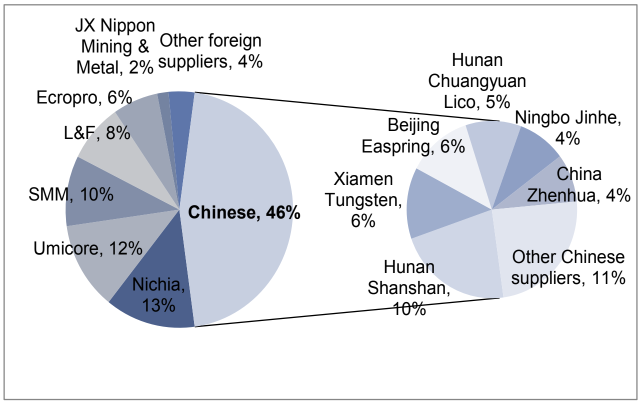
Exhibit 26: Chinese suppliers captured 46% of the global ternary cathode market in 2015

Global ternary cathode production capacity market share



Source: itdcw.com

Exhibit 27: NCM622 and NCA are in short supply, while NCM523 is the mainstream type

Capacity breakdown of ternary cathode makers in China

(th tonne) Company	Ticker	NCM622 capacity	NCM523 capacity	NCA capacity	Other NCM capacity	Comments
Shanshan	835930.NEEQ	-	23.4	-	-	Internal 5,000tonne precusor capacity; Self-licensed
Changyuan Lico	600390.SH	-	10.0	0.2	-	
Reshine	600232.SH	-	-	-	5.0	Licensed from 3M
Easpring	300073.SZ	2.8	4.0	-		NCA in R&D cooperating with GSE
Tungsten*	600549.SH	-	3.0	-	2.0	NCA capacity in contsruction
Ronbay*	n/a	-	5.1	0.5	3.4	
Kelong*	n/a	-	3.0	-		
Zhenhua*	000733.SZ	-	3.0	-	2.0	
Bamo-tech*	n/a	-	9.0	0.3	6.0	
Tianjiao Tech*	002070.SZ	-	2.1	-	1.4	
CITIC Guoan MGL	000839.SZ	-	4.5	-	-	Self-licensed;Top 10 EV battery supplier ytd 2016 with shipment of 203MWh
Shenhua Tech	300432.SZ	-	0.6	-	-	
BTR	835185.NEEQ	-	-	3.0	-	Largest anode supplier in the world with market share of 24.6% in 2015
GEM	002340.SZ	-	5.0	-	-	15,000tonne NCM precusor capacity; 5,000tonne NCA precisor capacity; GEM Wuxi licensed from AGC Glass;
Keheng	300340.SZ	-	1.7	-	-	Self-licensed
Libode	002045.SZ	-	-	0.3	1.0	Self-licensed
Tianli Energy	833757.NEEQ	-	5.0	-	-	
Total		**2.8**	**79.3**	**4.3**	**20.8**	
As % of total		**3%**	**74%**	**4%**	**19%**	

*Company with capacity of several type NCM are assigned to 60% weight of NCM523 and 40% to others

Source: GG-LB, company data, Gao Hua Securities Research

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Tesla: looking to take the cost and volume lead with in-house scale

Gigafactory: key to cost reduction and EV production

Tesla's overall objective of its Gigafactory (Tesla's battery plant) in Nevada is to (1) decrease battery pack costs to $100/kWh by 2020 and (2) ensure supply of battery cells for its Model 3 volume goals. In order to do so, the company is ramping up its facility in phases. At present, Tesla expects to ramp up battery cell production to 35GWh by 2018 as well as be able to increase pack production of 50GWh. This should drive a cost reduction in cells by 30% from current levels. Specifically, the company believes that it can achieve the cost reduction through supply chain consolidation, which would eliminate intermediate products, reduce logistics and packaging costs, and reduce tariff duties incurred. Further, the company believes it can achieve learning curves through improving the manufacturing process, which would increase labor efficiency and energy density over-time, as well as improve cell rejection rates. That said, we expect most of the cost benefits to come from scale, as infrastructure costs are a significant portion of the cell cost. To that end, the company believes that additional phase build-outs of the plant can drive incremental battery cell throughput, and ultimately believes the Gigafactory could have 3 x outputs of its 2018 targets. Lastly, Tesla also believes it can drive better time from lab innovation to production, achieving time compression with its own in-house battery cell supply.

NCA batteries and a new size– the 2170 cell

Tesla formally announced the commencement of mass production of its new 2170 battery cell at the Gigafactory on January 5, 2017. These cells were developed jointly with Panasonic, and are currently being produced for the Powerwall 2.0 and Powerpack 2.0 (brand names of energy storage products), with cell production for the Model 3 expected by the company to start in advance of the vehicles in 2Q17. The company retooled the size of the cells to 21mm in diameter and 70mm in length from the previous 18mm / 65mm in order to improve energy density. **This resulted in an approximate doubling in charge from 3000mAh to 6000mAh, while volume increased only ~50%, from 66cm^3 to 97cm^3.** We believe that the company chose an NCA battery over and NCM battery because of the higher energy density, which is required for the bursts of power used in an EV, as well as the lower amount of cobalt required in the NCA battery.

Panasonic and other strategic partnerships

Tesla has a long-standing relationship with Panasonic, as it has produced battery cells since the production of the Roadster. The relationship was expanded upon with the Gigafactory, with Panasonic providing capex in return for a long-term purchase order, as well as headcount, intellectual property, and production expertise. Tesla has left the option for additional partners open, but has not yet made any official statements. Specifically, the company has said that other partners can manufacture electrodes at the Gigafactory. *(Written by GS analyst David Tamberrino)*

2) Separators: Getting slimmer with high margins

A critical component for the lithium ion battery is the separator as its key function is to keep the cathode and anode apart to prevent electrical short circuits, and enables lithium ion to pass through the electrolyte in the battery.

There are two types:

- **Dry separators** are more suitable for a large size battery with high safety standards, such as commercial EV (LFP) and electric tools. The thickness for the dry separator can reach 40μm (micrometers, equal to 1×10^{-6} of a meter) while the wet separator is less than 20μm (Exhibit 29).
- **Wet separators** are slimmer than dry separators, and thus the preferred type for high energy density batteries, such as portable consumer electronics and passenger EVs (ternary battery). Although wet separators have a higher tendency to shrink under high temperature, the introduction of ceramic coating has largely solved the safety issue.

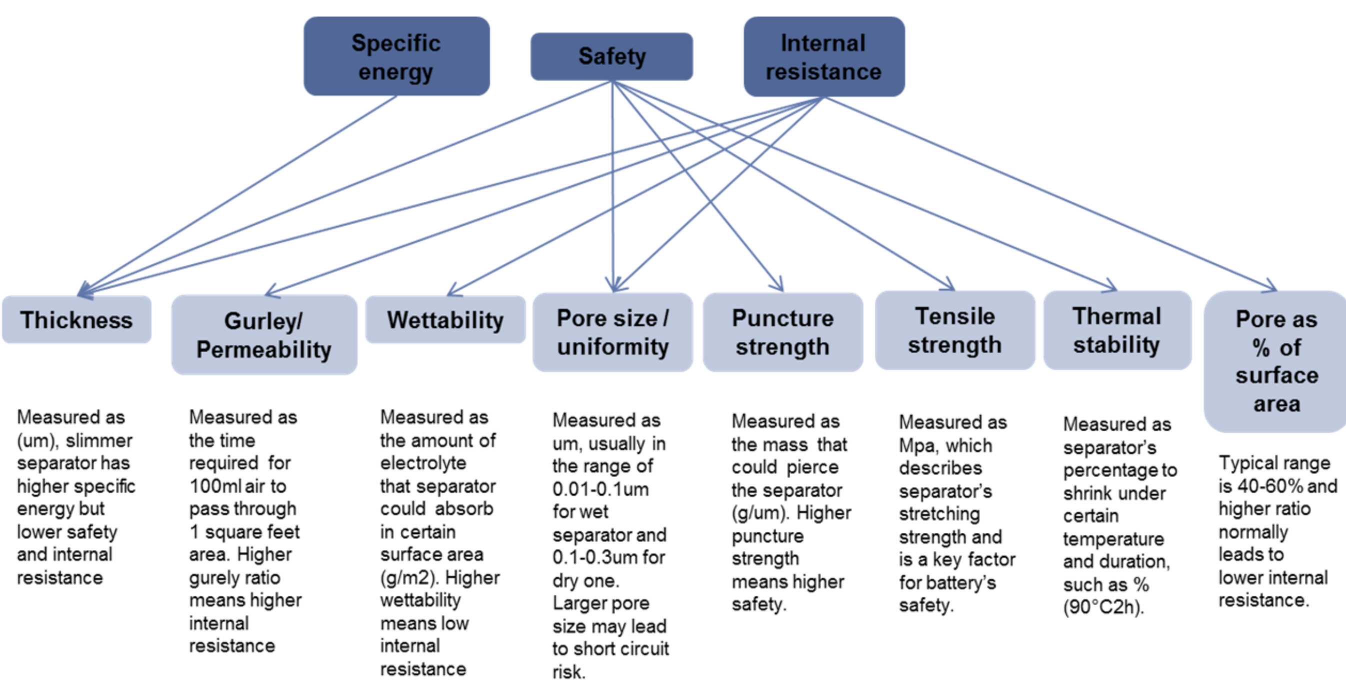
Similar to ternary batteries, China is lagging behind in the switch to wet separators due to processing know-how. China's global market share on wet separator is only 22% in 2015, which is much lower than the other major battery materials, yet it's one of the most high margin products in a battery.

Addressable market: Rmb10.4bn by 2025

We expect demand for wet separators to tick up as China makes the shift from LFP to ternary batteries. We estimate the addressable market for wet separators will reach Rmb10.4bn by 2025, implying a 27% CAGR during 2016-25. If the ternary battery can be successfully applied in EV buses, then we forecast a Rmb14.6bn market size for wet separators by 2025, a 40% increase from our base case.

Exhibit 28: There are a number of key performance features that separators need to fulfill in order to achieve high specific energy, safety and a low internal resistance rate

Key performance measurements for separators



Source: Gao Hua Securities Research

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However, we see ample opportunities for Chinese suppliers to replace imports, supported by cost advantages and improving technical know-how. As shown in Exhibit 35, the selling price for Chinese separator is at a significant discount to global average price. Despite the generally lower product quality, we think increasing production line speed may also explain Chinese suppliers' competitive cost structure (Exhibit 36). Also, by importing advanced equipment in recent years that should also help Chinese suppliers catch up on product quality.

Exhibit 29: Wet separators are in high demand on growing requirements for specific energy/energy density.

Performance comparison between dry and wet processed separators for Cangzhou Mingzhu

	Dry	Wet
Raw material	Polypropylene (PP)	
	Polyethylene (PE)	Single layer PE
	PP and PE composite	
Thickness (µm)	12-40	5-16
Thermal stability	Higher	Lower
Porosity (%)	38-40	34-40
Puncture strength (gf)	228-627	240-600
Tensile Strength (kgf/cm2)	1,410-1,453	1,590-2,450
Gurly Value (s/100cc)	200-610	80-220
Areas of applications	LFP EV battery	High performance
	Energy storage	electronic devices
	Electric tools	and Evs
Pros	High power density	Good mechanical properties
	High safety	Strong chemical resistance,
	Low cost	abrasion resistance, wettability with
		organic solvent
Cons	Low energy density	Lower thermal stability
Major suppliers	Celgard, Ube	Asahi Kasei
	Senior	Toray/Tonen
	Zhongke Science	SK, Senior

Source: Company data, Gao Hua Securities Research

Wet separators addressable market: Rmb10.4bn by 2025

In 2015, China's separator production increased 86% yoy to 765mn m^2, mainly driven by 150% and 71% yoy growth in wet and dry separators. Wet separator captured 25% market share in 2015, vs. 19% in 2014. Looking ahead, we expect it will continue to gain market share along with the proliferation of the ternary-based EV battery.

In our base case, we assume 20m^2 separator consumption for every kwh battery and wet separator captures 100% share in the ternary battery segment. **We project the wet separator will achieve 62% market share in 2025 (2.9bn $m^{2)}$ and a demand CAGR of 30% during 2016-2025. Accordingly, we estimate the addressable market for wet separators will reach Rmb10.4bn by 2025, implying a 27% CAGR during 2016-25.**

We see demand upside if the ternary battery can be successfully applied in EV buses, thus further accelerating the shift from dry to wet separators. **Our bull case scenario follows the same assumptions in the ternary cathode and would suggest a Rmb14.6bn market for wet separators by 2025, a 40% increase from our base case.**

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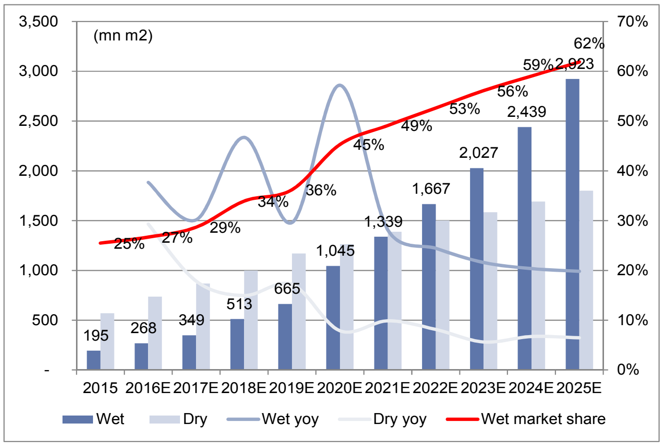
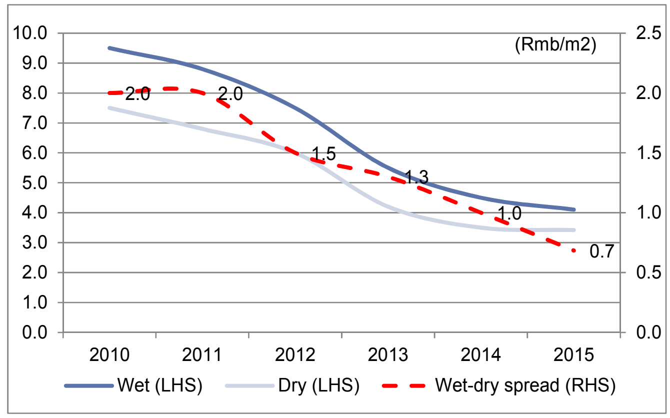
Exhibit 30: We forecast wet separator will reach 62% market share in 2025, vs. 25% in 2015
Wet and dry separator demand forecast in China



Source: Gao Hua Securities Research

Exhibit 31: The spread between wet and dry separators is narrowing, facilitating market share gain for wet separators
Price trend for wet and dry separator in China



Source: Company data, Gao Hua Securities Research

Exhibit 32: We project wet separators' addressable market will reach Rmb10.4bn by 2025, implying a 27% CAGR in 2016-25
Separator addressable market estimates

EV Battery in China (Gwh)	2015	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E	CAGR 16-25
Commercial EV	12	20	27	34	41	48	54	59	63	68	73	15%
Passenger PHEV	1	2	3	5	7	14	17	21	25	29	34	41%
Passenger BEV	4	7	9	15	20	29	40	52	66	82	101	35%
Total	**17**	**29**	**39**	**53**	**68**	**91**	**111**	**133**	**154**	**179**	**208**	**25%**
Yoy	455%	70%	35%	36%	29%	34%	22%	19%	16%	16%	16%	
Base case tenary's penetration												
Commercial EV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Passenger EV	50%	70%	80%	90%	90%	100%	100%	100%	100%	100%	100%	
Implied EV battery demand - base case (Gwh)												
Ternary	**2.6**	**5.9**	**9.5**	**17.3**	**24.5**	**43.1**	**57.3**	**73.2**	**90.7**	**110.8**	**134.4**	**42%**
LFP	14.3	22.4	28.7	34.9	43.2	47.5	53.4	58.7	62.6	67.6	72.7	14%
Others	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	3%
Total	**17.4**	**28.8**	**38.8**	**52.7**	**68.2**	**91.1**	**111.3**	**132.5**	**153.9**	**179.1**	**207.8**	**25%**
EV Separator demand (mn m2)												
Wet separator	51	117	191	346	490	861	1,146	1,464	1,814	2,216	2,689	42%
Dry separator	297	459	585	709	875	961	1,080	1,187	1,265	1,365	1,468	14%
Total	**348**	**576**	**775**	**1,055**	**1,364**	**1,822**	**2,226**	**2,651**	**3,079**	**3,581**	**4,157**	**25%**
Yoy		65%	35%	36%	29%	34%	22%	19%	16%	16%	16%	
Total separator demand in China (mn m2)												
Auto	348	576	775	1,055	1,364	1,822	2,226	2,651	3,079	3,581	4,157	25%
Non-Auto	417	438	460	483	507	532	548	565	582	599	617	4%
Total separator	**765**	**1,014**	**1,235**	**1,538**	**1,871**	**2,354**	**2,774**	**3,215**	**3,661**	**4,180**	**4,774**	**19%**
ASP- wet (Rmb/m2)	4.8	4.5	4.4	4.3	4.2	4.2	4.0	3.9	3.8	3.7	3.6	-3%
ASP- dry (Rmb/m2)	4.0	3.8	3.7	3.6	3.5	3.5	3.4	3.3	3.2	3.1	3.0	-3%
Market size (Rmb mn)												
Wet separator	936	1,208	1,541	2,216	2,815	4,337	5,392	6,509	7,677	8,964	10,419	27%
Dry separator	2,280	2,764	3,192	3,597	4,130	4,367	4,655	4,883	5,004	5,180	5,350	8%
Total	**3,216**	**3,972**	**4,733**	**5,813**	**6,945**	**8,704**	**10,046**	**11,392**	**12,681**	**14,144**	**15,769**	**17%**
Bull case - tenary's penetration												
Commercial EV	0%	0%	0%	30%	50%	60%	80%	80%	80%	80%	80%	
Passenger EV	50%	70%	80%	90%	90%	100%	100%	100%	100%	100%	100%	
Market size (Rmb mn)												
Wet separator	936	1,208	1,541	3,085	4,552	6,730	8,870	10,217	11,511	12,977	14,606	32%
Dry separator	2,280	2,764	3,192	2,872	2,683	2,373	1,756	1,793	1,809	1,835	1,861	-4%
Total	**3,216**	**3,972**	**4,733**	**5,958**	**7,235**	**9,103**	**10,626**	**12,010**	**13,320**	**14,813**	**16,467**	**17%**

Source: Company data, Gao Hua Securities Research

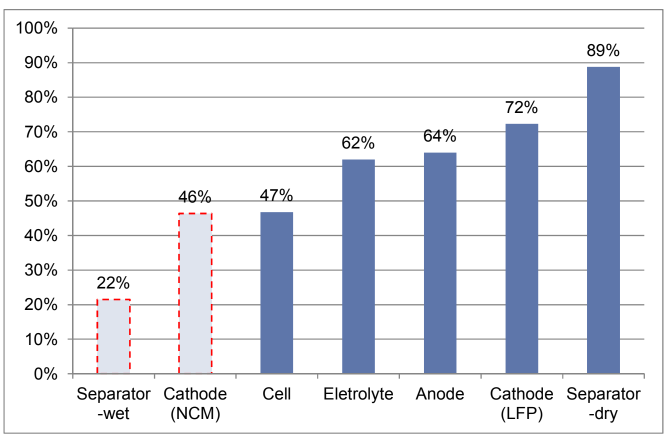
High technical entry barriers

Although China has abundant capacity for manufacturing separators and average utilization rate for the capacity is below 60% in 2015, it still relies heavily on wet separator import. Separator makers' profitability and returns are also generally higher than other material makers, due to high entry barriers in knowledge to meet all the above-mentioned performance requirements.(Exhibit 34-36) China's global market share on wet separator is only 22% in 2015, which is much lower than the other major battery materials. We believe the low yield rate due to difficulties in reaching the high level of uniformity is also a reason to explain the low utilization rate for Chinese suppliers.

We believe one of the key technology gaps between Chinese and overseas suppliers relates to the pore size uniformity of the product. This requires separator makers to have sophisticated know-how in producing pores. Among the major manufacturing methodologies, uniaxial stretching based dry process and wet process have high pores uniformity, which are developed by US (Celgard) and Japanese (Asahi Kasei, Tonen) suppliers. On the other hand, the biaxial stretching based dry process that was invented by the Chinese Academy of Sciences has a lower cost and high mechanical strength, but the pore's uniformity level is low.

However, Chinese companies are now able to use both synchronous and asynchronous stretching methods. Synchronous stretching generally has higher uniformity than asynchronous, but the production process is more complicated.

Exhibit 33: China's market share in wet separators and NCM cathodes is lower than other battery materials
China's market share in key battery materials in 2015



Source: GGLB, Gao Hua Securities Research

Exhibit 34: Separator makers generally have higher margin and return
Financial comparison for Chinese material makers

Gross margin	2013	2014	2015	1H16
Anode	13%	12%	11%	18%
Cathode	26%	26%	28%	30%
Separator	**37%**	**38%**	**42%**	**50%**
Electrolyte	32%	29%	28%	33%
ROE				
Anode	4%	7%	7%	4%
Cathode	10%	8%	16%	7%
Separator	**8%**	**8%**	**15%**	**10%**
Electrolyte	10%	9%	11%	8%

Source: Company data

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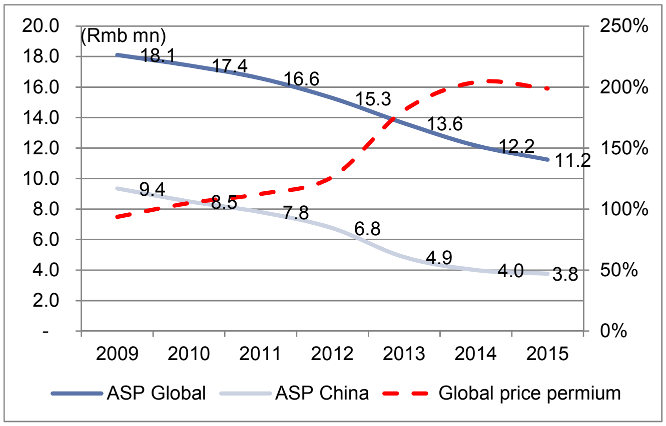
Exhibit 35: Chinese companies offer material price discounts in separators against global peers
Price comparison between overseas and domestic separators



Source: CCID, Gao Hua Securities Research

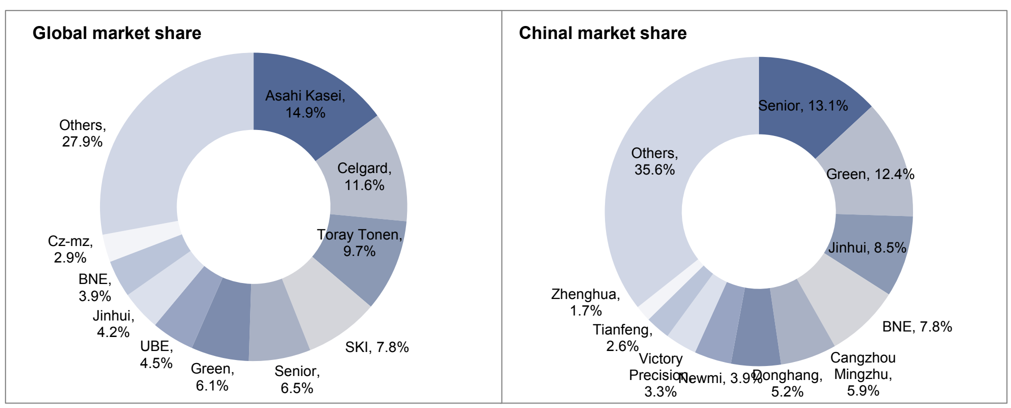
Exhibit 36: Chinese companies are catching up in separator production know-how
Operating matrix comparison

Company	Stretching method	Source of Equipment	Production line speed	Pros / Cons
Asahi Kasei	Synchronous	Japan	10-35m/min	High uniformity, nomal speed, not easy for adjustment
Tonen	Synchronous	Japan	10-25m/min	High uniformity, nomal speed, not easy for adjustment
SK	Asynchronous	Japan, Korea	10-40m/min	High stength, high speed low uniformity
Early domestic suppliers	Synchronous	Domestic	10-20m/min	Low speed, low stability
Domestic latest suppliers	Asynchronous	Japan, Germany US, Korea	20-40m/min	High speed, low uniformity
Cangzhou Mingzhu	Synchronous	Imported	20-35m/min	High uniformity, normal speed, not easy for adjustment

Source: Company data, Gao Hua Securities Research

Although quite a few Chinese separators makers are planning to increase wet separator's capacity, we see industry consolidation taking place and high technical entry barriers will favor companies with leading cost structure and technology. Also, it normally takes 1-2 years to become qualified separator suppliers for battery cell makers.

Exhibit 37: Japan and Korea are leading the global separator market while Chinese companies are catching up
Market share of global and China's separator



Source: Company data, Gao Hua Securities Research

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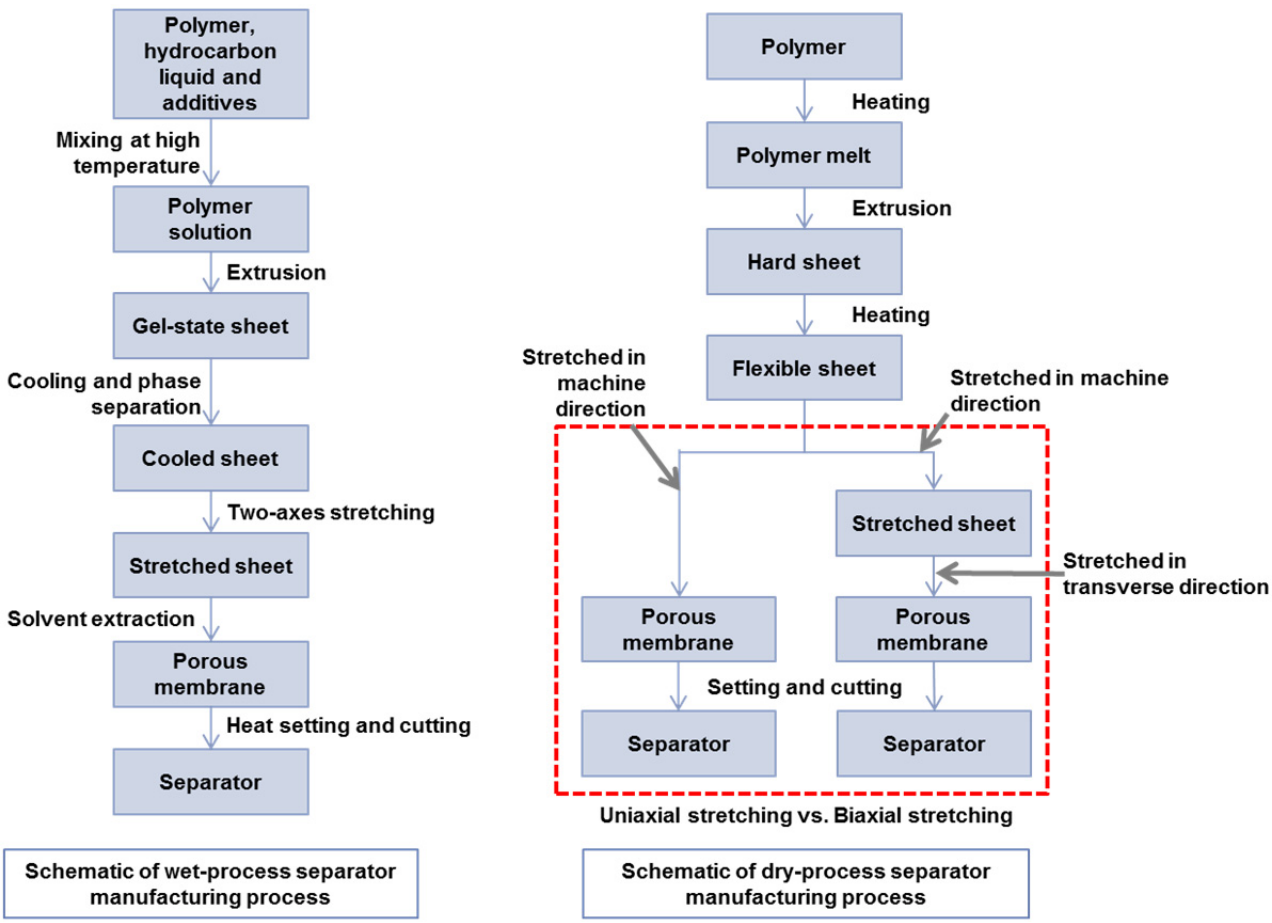
Exhibit 38: Wet based separators are becoming the key focus for major Chinese suppliers
Separator capacity breakdown for major separator makers in China

Domestic separator capacity (mn m3)		2016E		
Company	**Ticker**	**Dry**	**Wet**	**Major clients**
Senior		130	30	LG Chem, BYD, Guoxuan, Lishen
Zhongke Science and Tech		150	80	LG Chem, BYD, Lishen, BAK
Jinhui Hi-tech		-	112	BYD, BAK
BNE	002631.SZ	120	60	China Aviation, Coslight
Cangzhou Mingzhu		65	55	BYD, China Aviation
Donghang		60	-	Narada, Guangdong Great Power
Newmi Tech	831742.NEEQ	30	50	Optimum Nano, LG Chem, Lishen, Coslight
Victory Precision	002426.SZ	-	230	CATL, LG Chem, SDI
Tianfeng		70	30	Huanyu Power, AEE
Shandong Zhenghua		70	-	
Donggao	300444.SZ	-	30	BYD, Lishen, Far East First
Shanghai Energy New Material		-	100	ATL, BYD, LG Chem,Samsung SDI
Hongtu Separator	835844.NEEQ	-	110	Lishen, Sinopoly Battery
Jinli New Energy	831161.NEEQ	-	20	
Sinoma	002080.SZ	-	140	BYD, ATL, Eve Battery
A-top		-	58	
Huiqiang New Energy		50	-	BYD, Do-Fluoride, Guangdong Great Power
Great Southeast	002263.SZ	60	-	
Total		**805**	**1,105**	
As of total %		**42%**	**58%**	

Source: Company data, Gao Hua Securities Research

Exhibit 39: Wet processed separator generally has more complicated manufacturing process than dry separator
Manufacturing process for dry and wet separators



Source: Senior, Gao Hua Securities Research

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3) Battery recycling: Rapid growth on cobalt shortage, environment

Given more and more EV batteries will retire once their useful life comes to an end, we expect recycling will play a more important role in the battery value chain. In particular, we see a growing reliance on recycled cobalt given tight supply and a scarcity of the resource.

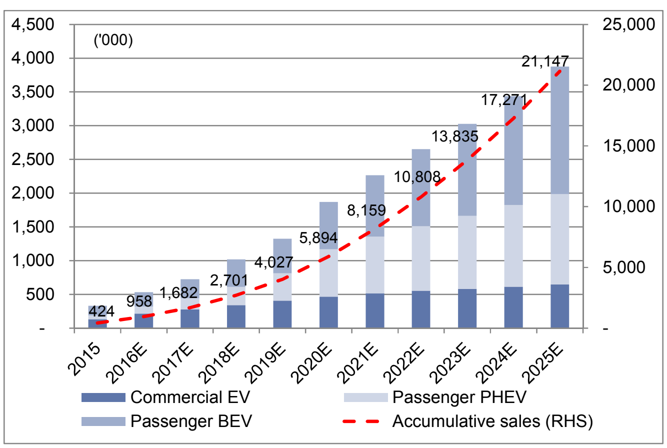
Effective life is just 3-5 years, with retired batteries used elsewhere or recycled

Recycling is needed for energy conservation and environmental protection. The designed life cycle for a typical lithium battery is around 20 years. But an EV battery's effective duration is 3-5 years as the actual capacity will decrease to 80% of original, limiting the travelling distance of an EV. Therefore, those retired batteries can be utilized in other applications, such as energy storage for utilities and low-speed EVs or to be recycled to make new high performance batteries. The lithium battery is toxic and hazardous to the environment if it is not properly treated. Also, materials like cobalt, nickel and lithium are finite resources on earth and can be recovered for new battery use. Moreover, recycling reduces energy consumption and carbon/sulfur emission by avoiding mining and certain manufacturing processes. According to Argonne National Laboratory, recycling could reduce sulfur oxide emission by 70-85% and save 55-60% energy consumption. Therefore, recycling is becoming a more critical part for a sustainable battery ecosystem.

Addressable market: Rmb7.8bn in 2025E

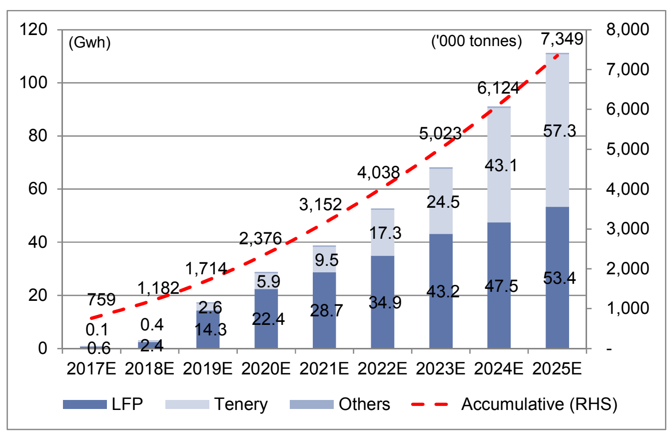
EV battery recycling demand set to increase from 2017. Our auto team forecasts China's accumulated EV install base will reach 5.9mn in 2020 and 21.1mn in 2025, vs. 0.4mn in 2015. This implies the cumulative EV battery install base will increase from 24GWh in 2015 to 301Gwh in 2020 and 1,655Gwh in 2025. Assuming the average duration for an EV battery is 4 years, we estimate the retired EV battery in China will surge from 0.9GWh in 2017 to 29GWh in 2020 and 111GWh in 2025, or equivalent to 7.3mn tonnes/year. Based on residual value of Rmb17,000/tonne for NCM/NCA cathode and Rmb3,000/tonne for LFP cathode, **we estimate the cumulative market size for EV battery reuse and recycling will jump from Rmb8mn in 2017 to Rmb7.8bn in 2025.**

Exhibit 40: We project cumulative EV sales will reach 21.1mn by 2025
EV sales forecast in China



Source: MIIT, Gao Hua Securities Research

Exhibit 41: We expect cumulative retired EV battery will reach 111GWh or 7.3mn tonnes in 2025
EV battery install base forecast



Source: Gao Hua Securities Research

Supportive recycling policies on the rise. China is currently adopting a system that EV makers take the majority of responsibility to recycle batteries. In early December, MIIT released the draft of Interim Measures for EV Battery Recycling requiring EV manufacturers to take initiatives to recycle batteries and to build recycling networks. In addition, retired EV batteries should be reused in other applications such as energy storage, rather than direct

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disassembly. Companies will be prohibited from the qualified directories for battery makers if they do not follow the policy.

At the municipal level, Shanghai announced a subsidy of Rmb1,000/pack for batteries recycled by EV makers in June 2014 while Shenzhen announced that it will subsidize no more than 50% of the recycling account of EV makers. The provision of the recycling account is Rmb20/kWh.

Looking at developed countries policy framework, the battery recycling market is more market-oriented, supplemented by government regulations. In Japan, battery makers pioneered recycling before regulations were released. In 1994, Japanese battery makers started to recycle batteries via retail dealers, auto 4S stores, gas station, etc. In 2000, the Japanese government required companies to recycle Ni-MH and Li-ion batteries and would subsidize companies as an incentive. Companies established entities particularly for recycling. For example, Nissan and Sumitomo formed 4REnergy to recycle batteries. Additionally, industry unions are also established to promote recycling business.

In the US, non-profit organizations (NPOs) and industry associations play a more important role. Rechargeable Battery Recycling Corporation (RBRC) is an NPO mainly to promote the recycling of rechargeable batteries via networks of retail customers, communities, corporations and the public sector. The Portable Rechargeable Battery Association (PRBA) is formed by battery companies, including Energizer, Panasonic, SAFT, Sanyo and Varta Batteries, to promote both a recycling business and related regulations.

In Germany, regulations require that all parties along the value chain have corresponding responsibilities to recycle batteries. Particularly, battery producers and the German Electrical and Electronics Industry Association (ZVEI) together established the GRS Batterien Foundation as the common collection scheme for battery recycling in 1998 under Section 6 of the German Batteries Act (BattG).

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Exhibit 42: Chinese government started to issue supportive policies for battery recycling
Policy summary for battery recycling

	Policy roadmap		
	Date	Policy	Key points
National level	Jul-12	Energy-saving and New Energy Automotive Industry Development Plan	Clearly proposed to develop battery recycling management approach, to establish cascade utilization system, to guide the battery manufacturers to strengthen the recycling of used batteries, and to encourage the development of specialized recycling companies;
	Jul-14	The General Office of the State Council on Accelerating the Application of EV Guidance	Proposed to explore the use of funds, deposits, forced recycling, etc. to promote recycling system;
	Mar-15	Automotive Battery Industry Standard Conditions	Both pack makers and EV makers shall research on recycling plans;
	Jan-16	Policy on EV Battery Recycling Techniques 2015	An explicit extension of the producer responsibility system was adopted;
	Feb-16	Standard Conditions of Comprehensive Utilization of Waste EV Battery	Emphasized that EV makers take the major responsilibity in recycling process;
	Feb-16	Interim Measures of Comprehensive Utilization of Waste EV Battery	Added EV batteries, fuel cells and solar cells into the recycling battery directory; Recycling companies shall have certain license on harzardous waste disposal;
	Nov-16	Policy for Waste Battery Pollution Prevention and Control Technology	EV makers shall take initiative to recycle batteries and to build recycling networks; Batteries shall be first re-used before disassembly; Companies will be prohibited from the qualified directories if they don't follow the rule;
Municipal level	Jun-14	Shanghai: "Interim Measures to Encourage the Purchase and Use of EV"	Bonus of Rmb1,000/pack for recycling batteries
	Jan-15	Shenzhen: Policies and Measures for the Promotion and Application of EV	Provision of Rmb20/kWh for recycling batteries
	Sep-16	Shenzhen: Supporting Financial Policies to Promote EV	Subsidy 50% of cost associated with recycling batteries

Source: ESCN

Specialist is required for battery recycling. Used batteries can be either (1) refurbished (change electrolyte and switch module, etc.) for tiered utilization, or (2) recycled to retrieve materials (cobalt, lithium, nickel, etc.) to make new batteries. (Exhibit 43)

In the value chain, specialty energy storage companies and utilities play the major roles to gradient utilization of EV batteries, with data and service support from auto OEMs/battery makers. Meanwhile auto OEMs and battery makers normally take responsibility for refurbishment as they have the best knowledge in assessing and tracking their battery's conditions from manufacturing to operation. In addition, the recycling part normally

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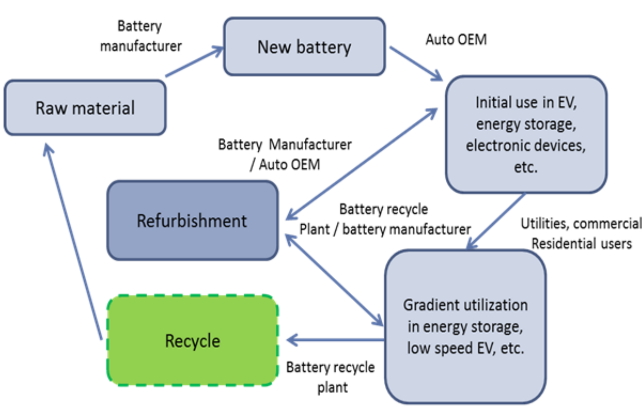
requires specialized companies to participate, given it generally requires sophisticated processing know-how and a government license to meet certain environmental standards.

For example, Nissan works with energy storage solution provider Green Charge Networks to sell energy storage products based on Nissan Leaf batteries to commercial users. General Motors also plans to use the Chevy Volt battery to power its Enterprises Data Center. For Tesla, the company can reuse approximately 10% of the battery pack by weight, such as the case and electronic components, before the pack is recycled. Tesla works with Kinsbursky Brothers to recycle about 60% of the battery pack. In Europe, Tesla started to work with Umicore for battery recycling and it saves over 70% of carbon dioxide emission by recovering and refining the metals.

The business model works for energy storage in tiered utilization. We try to assess the economic benefits of tiered utilization in the energy storage industry, such as demand side application for price arbitrage in peak-valley hours. We believe the economics depend on. **(1) Power tariff spread between peak and valley hours**. Commercial and industrial users' in certain regions such as Jiangsu, Guangdong and Shanghai, have over Rmb0.7/kwh price gap during day and night hours.**(2) Remaining cycle time.** The designed cycle life for a lithium ion EV battery is over 2,000 times, and we estimate the remaining cycle life when the battery reaches the retired stage (80% of original capacity) is around 1,000-1,500, assuming charge/discharge cycle every 1-2 days for typical users**. (3) Purchase cost for the battery**, which varies by quality. For high quality EV batteries, the selling price is measured by Rmb/Ah or Rmb/unit while for low quality products, it is in Rmb/tonne. Our channel checks suggest the average selling price is around Rmb15,000/tonne.

Accordingly, our sensitivity analysis shows if investment cost (including battery procurement and refurbishment expenses) is below Rmb700/kwh and the peak-valley tariff gap is in the range of Rmb0.6-0.7/kwh, retired batteries are able to achieve positive benefits for energy storage users based on different cycle time scenarios (1,000-1,500).

Exhibit 43: Used batteries can be either refurbished or recycled to minimize energy and material waste
EV battery recycle system



Source: Gao Hua Securities Research

Exhibit 44: We see economic benefits for using retired EV battery if investment cost falls below Rmb700/kwh
Sensitivity analysis on EV battery economics

Tariff gap (Rmb/kwh)	0.7				
cycle	Investment cost (Rmb/kwh)				
time	300	500	700	900	1,100
1,000	260	60	(140)	(340)	(540)
1,100	316	116	(84)	(284)	(484)
1,200	372	172	(28)	(228)	(428)
1,300	428	228	28	(172)	(372)
1,400	484	284	84	(116)	(316)
1,500	540	340	140	(60)	(260)

Tariff gap (Rmb/kwh)	0.6				
cycle	Investment cost (Rmb/kwh)				
time	300	500	700	900	1,100
1,000	180	(20)	(220)	(420)	(620)
1,100	228	28	(172)	(372)	(572)
1,200	276	76	(124)	(324)	(524)
1,300	324	124	(76)	(276)	(476)
1,400	372	172	(28)	(228)	(428)
1,500	420	220	20	(180)	(380)

Source: Gao Hua Securities Research

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Metal recycling is a profitable business. NCM/NCA cathodes consist of the most valuable metal material for recycling companies to retrieve from the retired batteries, including cobalt, nickel, lithium, manganese, and aluminum. Since LFP's chemical elements are generally low value (iron and phosphate) and in sufficient quantities on earth, they are not the business focus for recycling companies. For a typical NCM battery, cathode accounts for approximately 40-50% of the battery by weight. Nickel, cobalt and manganese on average accounts for 26%, 16% and 22% of cathode weight for NCM battery respectively, and we estimate the total value that can be recovered is over Rmb50,000/tonne based on the spot metal price and assuming 90% recovery ratio. Recycling companies normally set the purchase price at 60-70% of the key metal material value that can be recovered to ensure around 20% gross margin after factoring in the processing expenses.

Reliance on recycled material will increase over time, propelled by diminishing resources available for mining. We identify cobalt with the highest supply shortage if an extensive recycling system is not implemented while nickel's low reserve and high value contribution to NCM cathodes requires high recycling even without the demand from EV batteries. We expect lithium recycling will become more necessary in the long-term on robust EV related demand growth.

Cobalt: China's cobalt annual production was around 7,200 tonnes in 2015 and its reserves are only 80,000 tonnes (1% of global market share). But its total refined volume is 39,000 tonnes, suggesting heavy reliance on imports. Also, battery demand accounts for 40-50% of global cobalt demand. Therefore, the growing adoption of ternary batteries in EVs will drive fast consumption over time, thus requiring more recycling to fulfill the demand. We forecast cobalt consumption in China's EV batteries will increase from 1,900 tonnes in 2016 to 35,200 tonnes in 2025E. We estimate cobalt represents 45-50% of NCM cathode material value currently. The global reserve to production ratio is 57 years for cobalt.

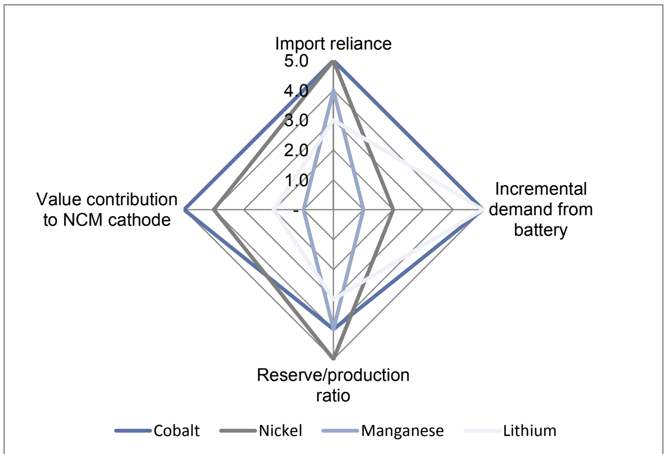
The cobalt recovered from recycling is around 3,000-4,000 tonnes (as of 2015) in China, representing 10% of total demand. In the US, recycled cobalt from purchased scrap accounts for 28% of total consumption in 2015, according to the US Geological Survey.

Nickel: China's nickel production is 100,000 tonnes in 2015, accounting for 4% of global supply, but it captures 40% market share in consumption worldwide. This suggests China has a heavy reliance on imports. We estimate Nickel represents 30-40% of the value of NCM cathodes. On the other hand, the battery market only represented low single digits of total nickel consumption in 2015, with close to 70% used in stainless steel manufacturing. That said, we believe the EV battery market will not be a key demand driver that leads to potential shortage in nickel. In the US, 45% of the nickel consumed is recovered from recycling.

Manganese: China relies heavily on manganese imports as it produces 3,000 tonnes of manganese but incurred 10,000 tonnes demand in 2015. (vs. 44,000 tonnes reserves). But battery is an immaterial contributor to demand as the steel industry captures over 60% of the total manganese currently and recovery is mainly through steel scrap. Also, to recover manganese from batteries requires low processing costs as we estimate it accounts for less than 5% of the NCM cathode value.

Lithium: China is rich in lithium resources as it captures 23% of global reserves (14mn tonnes). Although EV battery is the key driver for lithium consumption growth (over 40% of total consumption), global reserves could support 431 years of current lithium demand, making recycling not an urgent task. In addition, we estimate lithium represents approximately 10% of total NCM cathode value. We estimate EV battery demand in China will increase lithium mineral consumption from 2,200 tonnes in 2016 to 27,400 tonnes in 2025, vs. global production of 32,500 tonnes in 2015. Therefore, we see lithium recycling demand in the long term.

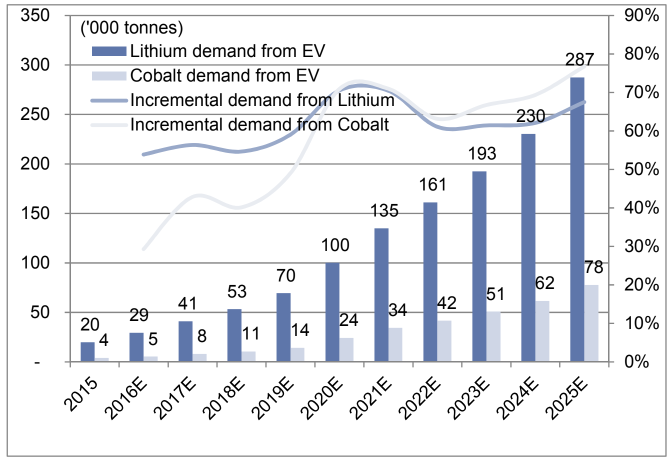
Exhibit 45: Our scorecard based analysis indicates cobalt and nickel have higher recycling demand
Scorecard for metal recycling demand



Note: 5 indicates the highest level

Source: USGS, Gao Hua Securities Research

Exhibit 46: EV is becoming the major demand driver for lithium and cobalt
Lithium and cobalt demand from EV



Source: Company data, Gao Hua Securities Research

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Hydrometallurgy process set to gain share

Compared to recycling traditional Pb-acid/Ni-MH batteries, recycling Li-ion batteries is more complicated due to a wider variety of materials used in the cell. The major metal in Pb-acid battery is Lead, while a lion-ion battery contains lithium, nickel, cobalt, etc. In China, disassembly of the battery is the main way to recycle batteries, compared to being reused in energy storage. The generic process of recycling batteries includes three stages: 1. Pretreatment of battery scrap; 2. Separation of each material; 3. Extraction of each metal. In the pretreatment stage, battery scrap will be mechanically filtered in order to get fine parts with precious metals. Major pretreatment methods include pre-discharging, mechanical separation and heat treatment. In the separation and extraction process, the major technology path can be divided into two categories (pyrometallurgy and hydrometallurgy) according to different working environments. Lastly, metals will be recovered through electrolysis.

Pyrometallurgy vs. Hydrometallurgy

Pyrometallurgy: Also known as high temperature metallurgy, the process extracts metals by heating electrode parts and adding fluxes (chemical catalyst added to help melting metals) to form alloys. Common fluxes added include SiO_2, SiC, Al_2O_3, MgO, CaO and CaF. Pyrometallurgy has the advantage of the lowest cost due to less pretreatment on battery scrap. However, unit energy consumption, arising from the required high temperature working environment is much higher. In addition, the environmental risk of secondary pollution is high. For example, burning plastics will release dioxin, which is classified as a highly hazardous material. Currently, Umicore and BARTEC are the major companies adopting this methodology.

Hydrometallurgy: Unlike pyrometallurgy, hydrometallurgy consumes less energy, since heating and fluxes are replaced by hydrochloric acid. Metals are recovered via leaching and extraction at room temperature. H_2SO_4 and H_2O_2 are the commonly used solutions. The advantage of hydro process is a higher recovery rate, since primary materials can be individually extracted by using corresponding solutions. Moreover, hazardous emissions can be minimized and only wastewater needs treatment. On the contrary, hyrdrometallurgy requires higher purity of battery scrap, which incurs higher cost on pretreatment. In China, GEM is currently adopting this methodology.

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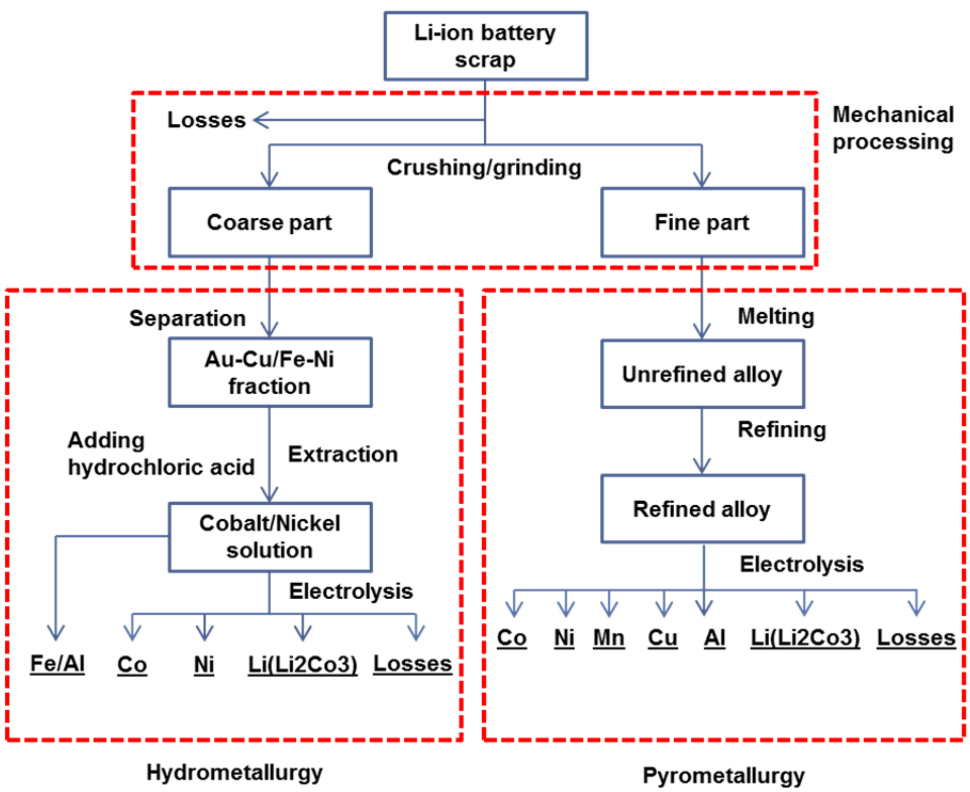
Currently, the majority of the recycling companies are adopting the pyrometallurgical process, mainly because of lower cost and scalability. However, following the recent price trend of lithium and other metals, it's becoming more favorable to apply the hydrometallurgical process, since higher value derived from precious metals can well cover the processing cost. Considering neither of the two is a perfect process to recycle batteries, a mix of both is applied by some companies, like AEA Technology. During the mixed process, fine parts of battery scrap can be pyrometallurgically processed, while coarse parts will be further separated and be hydrometallurgicaly processed along with the waste produced during the pyrometallurgical process. Biological process is another way to be considered, which extracts metals via microorganism leaching. However, due to a lack of cultivation medium, it can be hardly used in a large scale. Overall, we believe the technical process will shift to hydrometallurgy due to its ability to extract more precious metals, while pyrometallurgy still maintains a significant part.

Exhibit 47: A mixed process can combine the advantages of both pyrometallurgy and hydrometallurgy to recover precious metals

The process to recycle battery scrap by adopting the mixed process



Source: The Chinese Journal of Nonferrous Metals

Exhibit 48: Comparison of major recycling technologies

	Cost	Pretreatment	Recovery rate	Scope of operation	Environmental risk
Pyrometallurgy	Low	Not necessary	Low	Large	High
Hydrometallurgy	High	Necessary	High	Medium	Medium
Biological process	High	High necessary	High	Small	Low

Source: Company data, Gao Hua Securities Research

Graphene to enable fast charging and longer cycle life

Learn more about Graphene in our *Profile in Innovation - Advanced Materials* report published Sept. 27 2016

Graphene is a new type of advanced material that is in the early stage of commercialization. For lithium batteries, graphene is used to help electrical conductivity, enabling faster charging and a longer cycle life and receiving wider recognition for its use. **We estimate an Rmb6.3bn addressable market by 2025E.**

Graphene has superior performance features

Graphene can be use in a wide variety of sectors. In flexible displays, graphene is likely to replace indium-tin oxide (ITO) anode sas graphene is bendable and has a high electrical conductivity and transparency. In semiconductors, graphene is likely to replace silicon to become the next-generation transistor material due to lower energy consumption, faster computing speed and slimmer size. In pharmaceuticals, graphene is used as a biosensor to detect various biomolecules of diseases. However, those potential applications are still in the early development stage, due to high production costs and lack of scalable production approach, thus have not yet been commercialized.

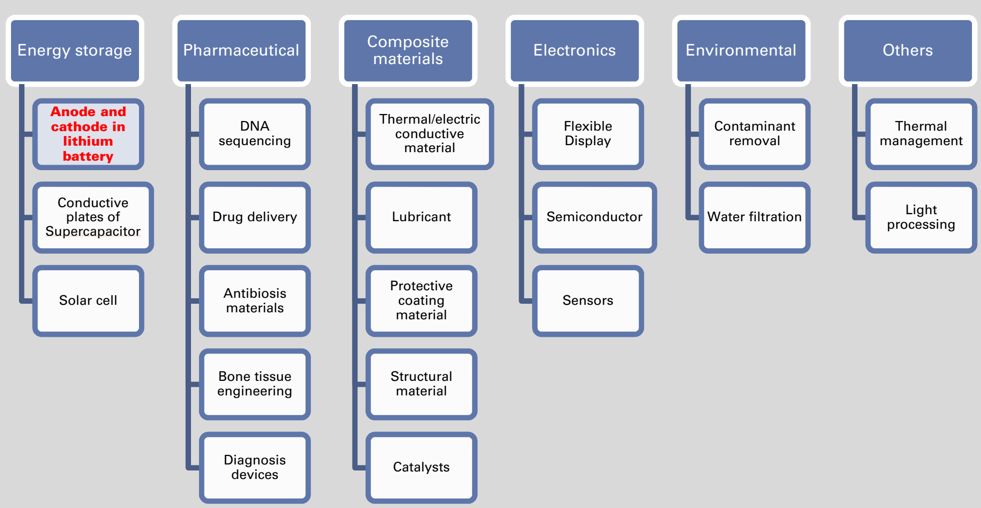
Graphene is mechanically robust and has higher thermal and electrical conductivity than most other materials

Key properties for graphene

	Unit	Graphene	Notes
Mechanical properties			
Thickness	Nanometer	0.345	The thinnest material in the world
Density	mg/m2	0.77	1 m2 of paper is 1,000 times heavier than graphene
Tensile Stength	GPa	130	0.4GPa for structured steel
Young's modulus (Stiffness)	mn psi	150	29 psi for steel and 152-175 for diamond
Thermal conductivity	W/mK	3,000-5,000	429 and 401 for silver and cooper
Electrical mobility	cm2/Vs	200,000	100 times higher than silicon
Optical transmittance		97.7%	

Source: Company data, Gao Hua Securities Research.

Graphene has various applications that can be developed based on physical and chemical features



Source: Gao Hua Securities Research.

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For anode material, it is normally made by natural or artificial graphite, and mesocarbon microbeads (MCMB). However, graphene is an ideal material that can be used to deposit lithium ions and its theoretical capacity is 740-780Ah/kg, which his almost twice as much as traditional graphite. But due to a low charge/discharge rate and unstable performance during cycling, pure graphene is not able to replace graphite for anodes currently. By combining graphene with other materials, it can create a composite for anodes that generally has good performance features. For example, the capacity for graphene-phosphate based anodes can reach capacity of 1,400Ah/kg.

Charging time can be reduced to 13-15 mins from 300-360 mins using graphene electrodes, according to Dongxu Optoelectronic

For conductive additives, it is normally coated on electrodes to improve its electric conductivity, which **enables a lower internal resistance, and thus improves rate capacity and charge/discharge stability, resulting in less charging time. Also, it prevents damage on electrodes, enhances cycle time and reduces the working temperature of battery.** For example, Dongxu Optoelectronic Technology launched a portable battery (4,800mAh capacity) with graphene coating on cathode in Sep 2016. The company claims the charging time can be reduced to 13-15min vs. 300-360min for conventional product. Meanwhile, the cycle time could increase from 500 to 3,500. (Exhibit 49) Although fast charging might not be a killer application for consumer electronics, we believe fast charging together with longer mileage are the critical factors to enable wider adoption of EVs.

Graphene set to gain share in conductive additive materials. The conventional materials for conductive additives (an additive to enhance cathode/anode's electrical conductivity) include carbon black, graphite, and carbon nanotube. Graphene is a competitive substitute to other carbon materials, thanks to its high specific surface area (SSA measured as m^2/g). As illustrated in Exhibit 50, graphene as a conductive additive combined with LFP cathode is able to create lower electric resistivity compared to carbon black and carbon nanotube.

Also, we are seeing the pricing point for graphene becoming quite competitive. The prevailing graphene price for conductive additives is US$230-250/kg in 2015, which is comparable to carbon nanotube's (a kind of carbon material in a form similar to a tube) selling price. We expect the graphene price will decline gradually by approximately 8% per year to US$165/kg by 2020, thanks to improvement in production know-how and economies of scale. In addition, graphene generally requires only 25% of the amount comparing to carbon nanotube to realize the same conductivity, which enhances graphene's cost competitiveness.

Exhibit 49: Dongxu's graphene battery has faster charging speed and cycle life than conventional product
Product features of Dongxu's graphene battery

Product features	Lithium battery with graphene coating in cathode	Conventional lithium battery
Battery capacity (mAh)	4,800	4,800
Charging time (min)	**13-15**	**300-360**
Cycle time	Over 3,500	Over 500
Working Temperature (degree celsius)	-30 to +85	0-60

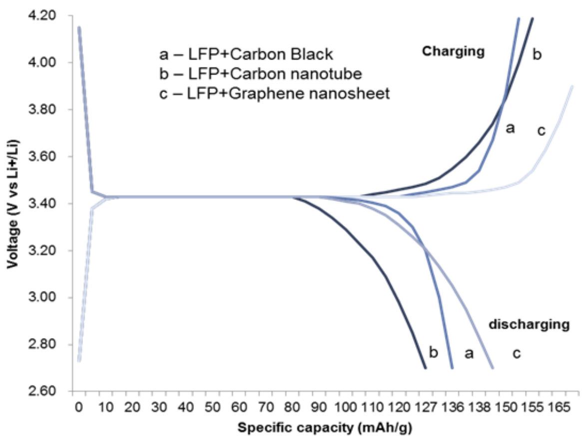
Source: Company data

Exhibit 50: Graphene combined with LFP has the lowest electric resistivity
Electric resistivity comparison

Electric resistivity of LFP cathode (Ω·cm)			
% of additives	Graphene	Carbon nanotube	Carbon black
1%	2.10	20.50	82.40
2%	0.80	11.60	51.70
3%	0.40	2.10	29.80
4%	0.35	1.20	22.40
5%	0.17	1.20	10.60
6%	0.16	0.90	8.30

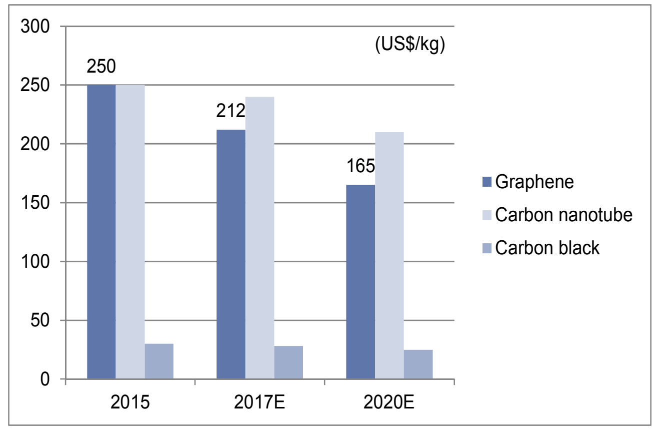
Source: Ningbo Morsh

Exhibit 51: Graphene provides higher specific energy at same charge/discharge voltage
Voltage and specific energy performance for different conductive additive combination with LPF



Source: Chongqing University

Exhibit 52: We expect graphene price will fall below carbon nanotube from 2017, supporting further market share gain potential
Price comparison for major conductive additives



Source: Ningbo Morsh, Gao Hua Securities Research

LFP is the major application area for graphene - Rmb6.3bn addressable market by 2025
Among major cathode types, the LFP cathode has lower conductivity (10^{-10} -10^{-9} S/cm) than other mainstream cathode materials (10^{-1}-10^{-6} S/cm). Therefore, graphene is now being adopted by leading LFP battery makers, such as BYD and Guoxuan High-Tech.

We also estimate the addressable market size for graphene as a conductive additive for LFP EV batteries. As shown in Exhibit 53, our base case assumes LFP will maintain 100% market share in the commercial EV market segment through 2025 while losing market share to ternary (NCM/NCA) batteries in passenger EVs. Accordingly, we project LPF cathode demand to reach 164,400 tonnes by 2025, implying a 14% CAGR in 2016-25. As 1kg of cathode normally requires 0.004kg of graphene slurry (4% graphene content), we estimate the implied market size for graphene as a conductive additive will reach Rmb6.3bn by 2025, vs. Rmb633mn in 2016, a 29% CAGR.

The technical entry barriers include (1) the need for graphene to be dispersed well among LFP particles, otherwise the agglomeration of graphene will block the diffusion of lithium ions. (2) Graphene's conductivity, which also depends on the number of graphene layers, with ideal layers at 6-9. This requires advanced production know-how to maintain the quality.

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Exhibit 53: We forecast the market size for graphene as a conductive additive will reach Rmb6.3bn in 2025, implying a 29% CAGR in 2016-25

Addressable market estimates for graphene based conductive additives

EV Battery in China (Gwh)	2015	2016E	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E	CAGR 16-25
Commercial EV	12	20	27	34	41	48	54	59	63	68	73	15%
Passenger PHEV	1	2	3	5	7	14	17	21	25	29	34	41%
Passenger BEV	4	7	9	15	20	29	40	52	66	82	101	35%
Total	**17**	**29**	**39**	**53**	**68**	**91**	**111**	**133**	**154**	**179**	**208**	**25%**
Yoy	455%	70%	35%	36%	29%	34%	22%	19%	16%	16%	16%	
LFP's penetration - base case												
Passenger EV	50%	30%	20%	10%	10%	0%	0%	0%	0%	0%	0%	
Commercial EV	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Implied EV battery demand (Gwh)	**2015**	**2016E**	**2017E**	**2018E**	**2019E**	**2020E**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**	**CAGR 16-25**
Ternary	**2.6**	**5.9**	**9.5**	**17.3**	**24.5**	**43.1**	**57.3**	**73.2**	**90.7**	**110.8**	**134.4**	**42%**
LFP	14.3	22.4	28.7	34.9	43.2	47.5	53.4	58.7	62.6	67.6	72.7	14%
Others	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	3%
Total	**17.4**	**28.8**	**38.8**	**52.7**	**68.2**	**91.1**	**111.3**	**132.5**	**153.9**	**179.1**	**207.8**	**25%**
LFP cathode demand ('000 tonnes)	**32.4**	**50.6**	**64.8**	**78.8**	**97.5**	**107.3**	**120.6**	**132.7**	**141.5**	**152.8**	**164.4**	**14%**
Graphene content as % of cathode	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	**0.4%**	
Demand for graphene additives (tonnes)	**130**	**203**	**259**	**315**	**390**	**429**	**483**	**531**	**566**	**611**	**657**	**14%**
Yoy		56%										
Graphene as % of slurry	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	
Demand for graphene slurry (tonnes)	3,240	5,063	6,483	7,884	9,753	10,726	12,064	13,268	14,149	15,277	16,436	14%
Graphene slurry price (Rmb/kg)	68	63	58	53	49	45	43	42	41	40	38	-5%
Market size for graphene additives (Rmb mn)	**2,203**	**3,167**	**3,731**	**4,175**	**4,751**	**4,807**	**5,244**	**5,595**	**5,787**	**6,061**	**6,326**	**8%**
Penetration of graphene additives	5%	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%	
Actual market size for additives (Rmb mn)	**110**	**633**	**1,492**	**2,505**	**3,801**	**4,807**	**5,244**	**5,595**	**5,787**	**6,061**	**6,326**	**29%**

Source: MIIT, Gao Hua Securities Research

Exhibit 54: There are pros and cons for each production process of graphene

Manufacturing methodology for graphene

Manufacturing Method	Description	Advantages	Disadvantages
Chemical vapor deposition (CVD)	CVD is a way of depositing precursor gaseous reactants (usually methane or ethanol) onto a substrate in a reaction chamber at high temperature. A reaction occurs that create graphene film on the substrate surface.	CVD method is able to produce high purity, large surface area, monolayer graphene film and is the common solution for applications in semiconductor and optoelectronic industry.	• The performance features and structure of graphene film is affected by substrate. • Production cost is high.
Micromechanical exfoliation	To pull graphene sheet from graphite flake using adhesive tape. To achieve single layer graphene requires multiple exfoliations. The graphene is deposited on silicon wafer.	Simple manufacturing process	• Difficult to control graphene's quality and size • Not suitable for mass productions
Epitaxial growth	To grow graphene patterns on templates etched into silicon carbide (SiC) substrate. This is realized by removing silicon atoms from the substrate at high temperature and vacuum, leaving the carbon lattice in the surface.	Can be grown in large wafers and patterned for use in electronics manufacturing.	• High production cost • Request sophisticated manufacturing process • Separation from substrate a hurdle.
Carbon dioxide reduction	Oxidation of graphite using strong oxidizing agents helps layer separation, which can be dispersed in the water. Then to reduce oxide from the graphene oxide by chemical, thermal and electrochemical approach.	• Simple manufacturing process • Low production cost • A scalable method for mass production	• Heating process damages the structure of graphene as carbon dioxide is released, thus affecting the performance features of graphene. • Not easy of dispersion

Source: Company data, Gao Hua Securities Research

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Next-generation battery: lithium metal + solid state electrolyte

Beyond 2025, we expect commercialization of next-generation technology such as all solid state and lithium air to further improve energy density. NCM/NCA is an advanced form of lithium ion battery, with around 500Wh/kg theoretical limit in specific energy that could meet the Chinese government's requirement by 2030. Beyond 2030, we expect next-generation batteries with lithium metal anodes and solid state electrolytes will emerge as the prevailing battery type to continue lifting performance features.

Lithium as an anode has much higher power capacity than graphite/silicon

The theoretical specific capacity for lithium is 3,860Ah/kg, which is 10 times as much as graphite (380Ah/kg) and is more than double the capacity of a silicon-carbon anode (1,500An/kg). This is partly because the graphite based anode only provides host structures for lithium ions that do not contribute energy storage themselves. But lithium metal does not have an alien host structure and consists purely of lithium ions, which significantly saves anode space and weight.

Material combination varies for lithium metal battery currently. Based on cathode type, a lithium metal battery can be classified as lithium intercalant, lithium sulfur (Li-S), and lithium air (Li-air). The cathode can contain either lithium or no lithium materials, since lithium is provided in the anode. The typical cathode material includes titanium disulfide (TiS_2), vanadium oxide (VO_x), LCO, LFP, NCA, etc. Carbon/sulfur is applied for Li-S batteries while oxygen is the major reactive material for cathodes.

Up to 10,000Wh/kg specific energy potential ahead. The lithium intercalant battery is able to generate specific energy of 400-500Wh/kg, according to SolidEnergy. In 2015, Dyson acquired a 100% stake in a solid state battery company called Sakti3 for US$90mn. Sakti3 was able to produce a solid state battery cell with 400wh/kg specific energy in 2014, vs. 250wh/kg for the 18650 NCA battery used by Tesla. Also, SolidEnergy, a startup company from MIT claims its lithium metal battery could achieve volumetric density of 1,200Wh/L and gravimetrical density of 400Wh/kg. Moreover, Li-S battery has 500Wh/kg in commercial cells and has been used in the aerospace industry, but its volumetric density is lower than the lithium ion battery. On the other hand, the Li-air battery has a theoretical specific energy of 10,000Wh/kg, which is similar to gasoline. But if we factor in the engine and gas weight, as well as the Carnot efficiency, Li-air's specific energy actually exceeds gasoline. (Exhibit 56)

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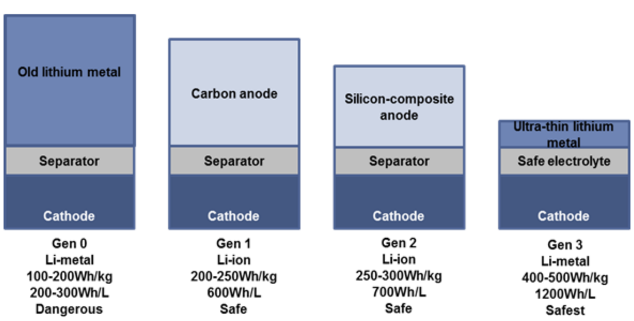
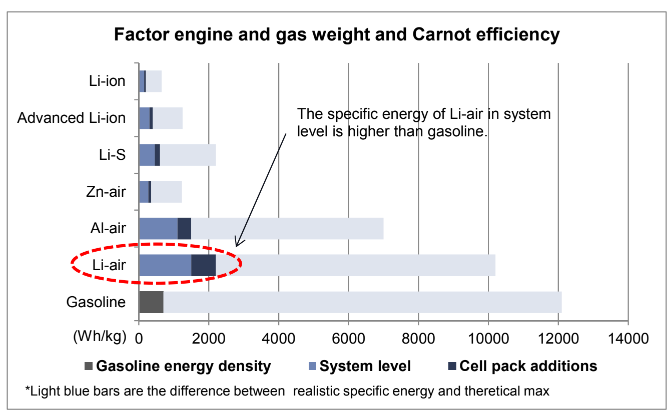
Exhibit 55: Lithium metal anode improves volumetric and gravimetric energy density
Evolution of lithium batteries from an anode perspective



Source: SolidEnergy, Gao Hua Securities Research

Exhibit 56: Li-air has higher specific energy than gasoline in vehicle system level
Specific energy comparison



Source: University of Florida

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Solid State Electrolyte enables the proliferation of lithium metal

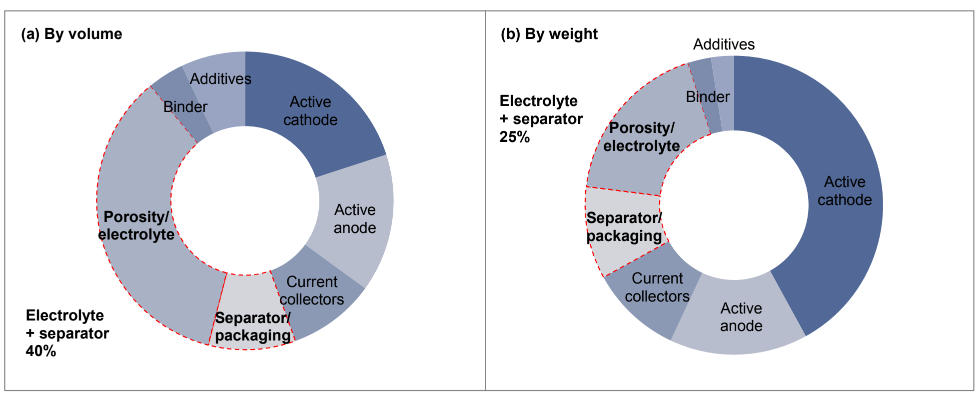
The development of the lithium metal battery can be traced back to the 1970s. But due to technical challenges, it was not able to be commercialized in the past 20 years. When an electrolyte is in an organic carbonate liquid, it reacts with lithium metal to form mossy, dendrite-like structures that can pierce through the separator and lead to accidents, causing safety concerns. Also, it forms unstable solid-electrolyte interphase (SEI) layers that consume both electrolytes and lithium metal, thus leading to low charge/discharge efficiency ratios and cycle life (less than 500 times so far). **Therefore, replacing liquid electrolytes with solid state has become a focus today, which could unlock the high energy density potential for lithium metal.**

It is safer than liquid electrolyte. The existing liquid electrolyte is flammable and is the primary reason that causes battery's fire and explosion accident. For example, Samsung's Galaxy Note 7 accident is mainly due to pressure placed on plates that contains battery cells, thus leading to direct contact between the cathode and anode. When the cathode and anode touches, it can trigger thermal runway, which is a chemical chain reaction causing increasing temperatures. To replace liquid electrolytes with solid non-flammable materials could prevent direct contact of cathode and anode and lift the safety level. Solid electrolytes have high resistance to extreme temperatures. The working temperature is -20 to +60 degrees Celsius while that for solid state is -40 to +100.

It offers higher energy density than conventional lithium ion batteries. For a typical lithium-ion battery, the separator and electrolyte account for 40% of volume and 25% of weight (Exhibit 57) In essence, the solid electrolyte replaces the liquid electrolyte and separator and narrows the distance between the cathode and anode. The thickness of solid electrolytes in solid state batteries could be only over 10 micrometers (um), thus reducing the bulkiness of the battery. In addition, a solid electrolyte enables adoption of higher voltage cathodes/anodes, thus increasing the battery's energy density.

Exhibit 57: Solid electrolytes can replace liquid electrolytes and separators in the lithium ion battery

Volume and weight breakdown by material for lithium-ion battery



Source: Company data, Gao Hua Securities Research

Multiple roadmaps to tackle technical challenges. Conventional lithium-ion batteries liquid electrolyte mainly consist of organic solvents with lithium salt (lithium hexafluorophosphate, $LiPF_6$ mainly). In solid state electrolytes, the chemical contents differ, including solid polymer (polyethyelene oxide (PEO)), lithium phosphorus oxynitride (LiPON), sulfide compounds (sulfide ceramic), etc. (Exhibit 58)

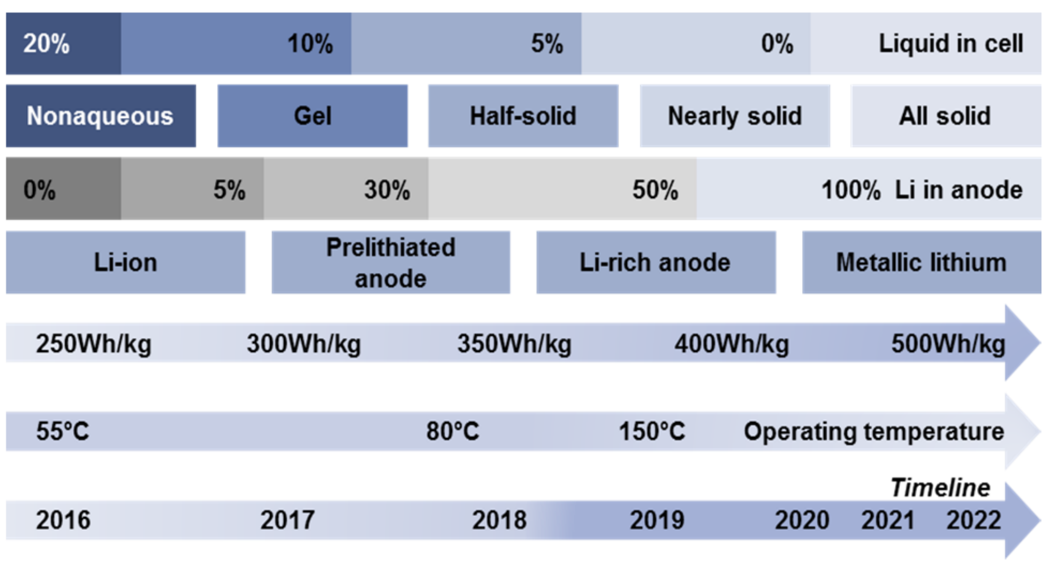
The design for solid electrolyte material remains challenging for scientists as various physical and electrochemical properties need to be satisfied. **The major challenges include low conductivity, high working temperature, high production cost, etc.** We see pros and cons for each type of material:

Exhibit 58: Each advanced material has its pro and cons in creating next-generation lithium battery
Pro and cons for each advanced material in solid state battery universe

Material type	Pros	Cons
Polyethyelene oxide (PEO)	High conductivity, low resistivity under high temperature. It can be processed into thin film form.	Working voltage for PEO is 3.8V, thus it is difficult to match with high voltage high specific energy cathode materials. Modification in material is needed. Also, the working temperature for PEO is 60-85 °C, which requires sophisticated thermal management system
Lithium phosphorus oxynitride (LiPON)	Is the prevailing material for small scale solid battery production nowadays. It can be processed to thin film form. LiPON generally has good physical, chemical and thermal stability.	Its electrical conductivity for LiPON is around 2 x 10-6 S/cm under normal temperature, which is 3-4 orders of magnitude worse than liquid electrolyte's LiPF6 is 10-2 to 10-3 S/cm.
Sulfide ceramics	Has high conductivity at room temperature and is flexible in form factor	Sulfide is sensitive to air and easy to conduct oxidation reaction. Also, ceramics requires great pressure to maintain contact with the electrode. Therefore, liquid additives are introduced to enhance the contact between electrolyte and cathode

Source: Gao Hua Securities Research

Exhibit 59: Liquid or gel additives are likely to be introduced at the early development stage of solid state battery
Roadmap from liquid to all-solid state



Source: China Academy of Sciences, Gao Hua Securities Research

We see a number of companies in the technology and auto value chain engaging in the R&D of solid state batteries, such as Samsung, Sony, Toyota, etc. (Exhibit 59) The technology roadmap varies, in terms of anode, cathode and electrolyte combination.

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Exhibit 60: We see a diversified technology roadmap for solid state batteries
Key initiatives by solid state battery developers

Company/Institute	Anode	Solid eletrolyte	Cathode	Comment
Bollore Hydro-Quebec	Lithium	PEO + Lithium salt	LFP $Li_xV_3O_8$	100Wjh/kg pack level specific energy Target production capacity of 300Mwh
SEEO + Bosch	Lithium	PEO + Lithium salt	LFP, NCA	Target specific energy 300Wh/kg Developing mass production capacity of PEO thin film
Sakti3 + Dyson	Lithium alloy	LiPON	Not disclosed	Target 500Wh/kg, adopt PVD coating method for eletrolyte thin film
Samsung	Graphite/ lithium	Sulfidic ceramic eletrolyte	NCM with Li2ZrO3 coating	175Wh/kg in lab, can utilize the existing Lithium-ion production facility
Toyota	Graphite/ Lithium/LTO	Sulfide	LCO, NCA LNMO	Has demonsration vehicles in cargo transportation
SolidEnergy	Ultra-thin lithium metal	Solid polymer and ionic liquid	LCO	400Wh/kg and 1200Wh/L
Hitachi Zosen + Honda	Graphite/ lithium	$Li_7P_3S_{11}$ (LPS)	NCA, LNMO	Aim to mass production by 2020
Sony	Graphite	Sulfide	NCM	500Wh/L for demo product The thickness of electrolyte is 35um

PEO:polyethylene oxide
LiPON: lithium phosphorus oxynitride
$Li_xV_3O_8$: lithium-vanadium-oxide
PVD: physical vapor deposition
Li_2ZrO_3: lithium zicronium oxide
LTO: lithium Titanate
LNMO: lithium nickel manganese
LPS:lithium thiophosphate

Source: CATL, Gao Hua Securities Research

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Companies in the value chain

Chinese companies are actively engaged in the lithium-ion battery value chain. We highlight a group of 30 leading companies, both domestic and overseas (Chinese companies listed in HK and Japan), from upstream resource suppliers to midstream battery material makers and cell/pack makers.

Exhibit 61: Stock coverage along the battery value chain
Ratings and TPs for GS covered companies

Company	Curreny	Ticker	Rating	Current price	Target price	Upside/ downside
Geely	HKD	0175.HK	Buy*	10.26	10.35	0.9%
LG Chem	KRW	051910.KS	Buy*	277,500	345,000	24.3%
Cangzhou Mingzhu	RMB	002108.SZ	Buy	20.93	27.00	30.9%
GEM	RMB	002340.SZ	Neutral	6.25	6.90	10.4%
Toray	JPY	3402.T	Neutral	979.50	1,050	7.2%
BYD (H)	HKD	1211.HK	Neutral	43.65	44.52	2.0%
Beijing Easpring	RMB	300073.SZ	Neutral	47.98	48.40	0.9%
Freeport-McMoRan	USD	FCX	Neutral	15.83	16.00	1.1%
SAIC	RMB	600104.SS	Neutral	25.39	21.82	-14.1%
Samsung SDI	KRW	006400.KS	Neutral	122,000	105,000	-13.9%
Tesla	USD	TSLA	Neutral	251.33	190.00	-24.4%

*Conviction list
**Price as of Feb 6, 2016, except for Freeport-McMoRan and Tesla as of Feb 3, 2016

Source: Gao Hua Securities Research

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Cangzhou Mingzhu: Risks to our investment case and our 12-month P/E-based target price of Rmb27.0 include capacity ramp-up delay in wet separator and lower BOPA film pricing on new capacity addition. See "Riding on robust separator demand growth; initiate at Buy" published Feb. 9 for more details.

Beijing Easpring: Risks to our investment case and our 12-month P/E-based target price Rmb48.4 include higher-than-expected demand for NCM622 cathode (upside) and margin pressure in raw material price hikes such as cobalt and nickel (downside). See "Ternary cathode leader; focus on margin visibility; initiate at Neutral" published Feb. 9 for more details.

GEM: Risks to our investment case and our 12-month P/E-based target price Rmb6.9 include higher demand for NCM/NCA cathode/ precursors (upside) and tight working capital cycle and delay in subsidy payments on electronic waste recycling (downside). See "Well-placed in cobalt recycling value chain; initiate at Neutral" published Feb. 9 for more details.

Exhibit 62: We set out an investment framework to pick the winners in the battery material value chain
Investment framework on battery material

	Upstream resources		Midstream material				Downstream
	Lithium	N/C/M	Cathode	Anode	Electrolyte	Separator	Cell/pack
Overall attraction	Average	High	High	Average	Average	High	Average
Investment positives	Robust demand for ltihium based battery. Lithium is a small portion of total battery cost	Tight supply for cobalt in the coming decade. Limited resources drives reycling demand	Tight supply for nickel-rich cathode. NCM and NCA the becoming the focus	Concentrated market supply with top 3 suppliers controlling >50% share	Growing concerns on battery safety brings about demand for high quality eletrolyte, leading to industry consolidation	High demand for wet separators; Ample import replacement opportunity	Policy favors domestic cell/pack makers with leading scale and technology
Investment concerns	Demand/supply is generally balanced, with limited further price upside	Demand/supply is generally balanced for nickel and manganese	Margin pressure due to upstream raw material price volatility	Limited technology differentiation leads to low margin/return among material sub-sectors	Liquid electrolyte is likely to be replaced by solid state in the coming decade. Raw material volatility	Dry separator may face price competition on over-supply	LFP capacity is facing over-supply issues due to demand shift to ternary
Entry barrier	Average	Average	High	Average	Average	High	High
Supply concentration	High	High	Average	High	Average	Average	Average

Source: Gao Hua Securities Research

Exhibit 63: Chinese battery material suppliers have entered major battery makers supply chain
Battery material supplier chain (companies in blue are China domestic players)

	Battery company	Cathode supplier	Anode supplier	Separator supplier	Electrolyte supplier
Overseas	Samsung SDI	Samsung SDI	Shenzhen BTR	Toray	Panax-Etec
		L&F	Hitachi-Chem	Asahi Kasei	CapChem
		Ecopro	Mitsubishi Chemicals	SKI	Guotai Huarong
		Umicore	Toya Tanso		Tianjin Jinniu
		Reshine New Material	Shanghai Shanshan		
		Beijing Easpring		Shanghai Energy New Materials	
		Ningbo Jinhe			
	LG Chemicals	L&F	Shenzhen BTR	Toray	Guotai Huarong
		Umicore	Hitachi Chemical	Asahi Kasei	Panax-Etec
		LG Chemicals	Mitsubishi Chemical	SKI	LG Chemicals
		Reshine New Material	Shanghai Shanshan	Celgard	
		Beijing Easpring	Kimwan Carbon	Zhongke Science & Tech	
		Hunan Shanshan		Newmi Tech	
		Ningbo Jinhe		Shanghai Energy New Materials	
		Bamo-tech		Shenzhen Senior Tech	
	Panasonic	Nichia	Hitachi Chemical	Asahi Kasei	Mitsubishi Chemicals
		Sumitomo Metal Mining	Shenzhen BTR	Celgard	UBE
		Umicore	Toya Tanso	Ube	CapChem
		Xiamen Tungsten			Guotai Huarong
	Sony	Nichia	Shenzhen BTR	Toray	Mitsubishi Chemicals
		Umicore	JFE	Asahi Kasei	CapChem
		Mitsui Kinzoku	Shanghai Shanshan	SKI	Guangzhou Tinci Materials
		Beijing Easpring			Tianjin Jinniu
	Hitachi	Beijing Easpring	Hitachi-Chem	UBE	Mitsubishi Chemicals
		Nichia	Shinetsu	Asahi Kasei	
	AESC	Mitsui Kinzoku	Hitachi-Chem	Asahi Kasei	Mitsubishi Chemicals
		Nippon Denko	Kureha	Celgard	
		Nichia		UBE	
	LEJ	Nichia	Showa Denko	Toray	Mitsui Chemicals

Source: Company data, GGLB

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Lithium/Nickel/Cobalt/Manganese resource

Jiangxi Ganfeng Lithium Co (002460.SZ, NC): The company is a leading player in lithium resource supply in China. It primarily engages in lithium mining and provides both industrial grade and battery grade lithium metal, lithium carbonate and related lithium products. The company is actively involved in upstream activities. At the end of 2015, Ganfeng acquired a 49% stake of RIM Australia, which holds lithium ore reserves of more than 20mn tonnes. In Aug 2016, the Company's 4,500 tonne a year NCM precursors came into production, officially expanding in to the cathode business. In addition, Ganfeng announced in July 2016 it will invest Rmb302mn in an additional 20,000 tonnes of lithium hydroxide capacity. Currently, the company has capacity of lithium hydroxide of 12,000 tonne, lithium metal of 1,500 tonnes and owns lithium ores in Australia, Canada and Latin America.

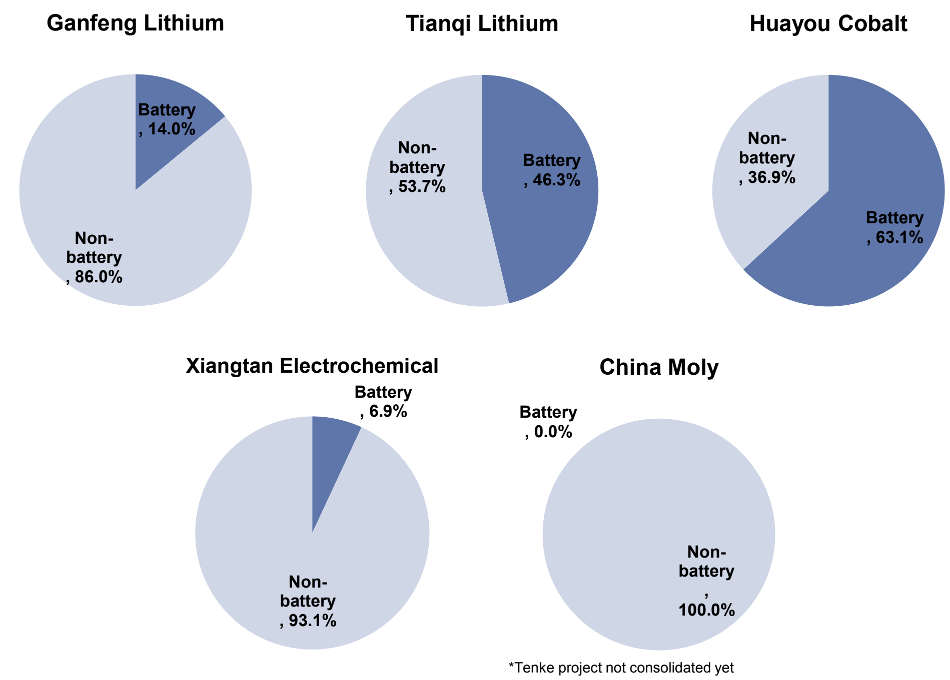
Tianqi Lithium Industries Inc (002466.SZ, NC): Tianqi and Ganfeng are the major two China-based companies principally engaged in lithium products. Tianqi provides lithium carbonate and derived lithium products on different grades and also manufactures agricultural equipment. Tianqi currently has two production bases in Sichuan and Jiangsu, with total capacity of 34,200 tonnes, including lithium carbonate, lithium hydroxide, lithium metal and lithium chloride. In Sep 2016, Tianqi invested around Rmb200mn in Western Australia to build 24,000 tonnes of new capacity of lithium hydroxide. Tianqi also holds a minority interest in Talison Lithium, the largest lithium ore owners based in Australia.

Zhejiang Huayou Cobalt Co (603799.SS, NC): Huayou was founded in 2002 and focuses on cobalt and copper mining and smelting. Its main products include cobalt oxide, cobalt carbonate, cobalt hydroxide and cobalt sulfate. Huayou entered into the cathode material business in 2016. Currently, the company has 6,000 tonnes of NCM precursor capacity and is expected to reach 20,000 tonnes by 2017.

Xiangtan Electrochemical Scientific Co. (002125.SZ, NC): The company is the largest producer of manganese dioxide in China and also produces electrolytic manganese metal, battery materials and other related energy materials. It expanded into the cathode material business in 2016 via its associate with LFP capacity of 10,000 tonnes.

China Molybdenum Co (3993.HK, RS; 603993.SS, NC): China Moly is the largest molybdenum producer in China, located in Luoyang, Henan Province. It also produces tungsten. In November 2016, China Moly completed the acquisition of a 56% stake in the Tenke copper/cobalt project in the Congo from Freeport-McMoRan (FCX, Neutral, US$15.06), for a total consideration of US$2.65bn.

Exhibit 64: Lithium/Cobalt producers generally have higher exposure to battery business
Battery business sales as % of total sales



Source: Bloomberg, Company data

Exhibit 65: Major resource players also have access to precursor production
Exposure to different battery raw resources

	Lithium	Nickel	Cobalt	Maganese	Precursor/ cathode
Ganfeng	√				√
Tianqi	√				
Huayou			√		√
Xiangtan				√	√
China Moly			√		

Source: Company data

Cathode makers

Beijing Easpring Material Tech (300073.SZ, Neutral, last close: Rmb50.78): Easpring is one of the top 5 battery cathode makers (LCO and NCM) in China in terms of production capacity and is the leader in high-end NCM products, with customers covering tier-one Korean, Japanese and Chinese battery cell makers such as Samsung SDI, LG Chem, SKI, Panasonic, BYD, Lishen, etc. Easpring is the only company that is able to produce the NCM622-based cathode in China. Currently the company has 11,800 tonnes of ternary cathode capacity, of which 2,000 tonnes are NCM622.

GEM Co (002340.SZ, Neutral, Rmb6.22): GEM is a leading battery cathode material maker and recycling solution provider with a strong presence in cobalt and nickel refining. The company captures close to 10% market share in China's battery recycling industry (as of 2015) and accounted for 33% of China's cobalt refining volume in 2015. GEM operates 7 recycling centers across China. In 2012, GEM acquired Jiangsu KLK to expand along the

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cobalt value chain. The company's product "KLK 9995" has been registered on LME and began trading in 2010. Currently, GEM has 10,000 tonnes of NCM cathode and 10,000 tonnes of NCM precursor and is expected to reach 15,000 tonnes on both materials. In addition, GEM produces around 3,500 tonnes of cobalt powder/plate, 2,000 tonnes of nickel powder, 20,000 tonnes of electrolytic copper, 3,000 tonnes of tungsten and 20,000 tonnes of engineered woods.

Shanshan Energy (835930.NEEQ, NC): Shanshan has the largest cathode capacity in China with 28,000 tonnes, focusing on LCO, LMO and ternary cathodes. Its customers cover top batteries makers including CATL, Panasonic and Lishen. Its parent company Ningbo Shanshan (600884.SS, NC) operates in three business segments including battery material, garments and venture capital. Ningbo Shanshan is also a leading player in anodes (Shanghai Shanshan), and electrolytes (Dongguan Shanshan). The company currently has anode capacity of 15,000 tonne and an additional 35,000 tonnes is under construction. Anode major customers include LG Chem, Sony, Lishen, BAK and BYD. In addition, Shanshan provides electrolytes via its plants in Guangdong and Hebei with total capacity of 15,000 tonnes and is also researching on a new type of electrolyte matching the new type of cathode such as LTO.

Xiamen Tungsten (600549.SS, NC): Xiamen Tungsten is principally engaged in the smelting, processing and distribution of tungsten, molybdenum and related metal products, as well as cathode and property development business. Xiamen Tungsten operates along the whole value chain of tungsten from mining to recycling, capturing more than 50% of market share (as of 2015) in light-used tungsten wire, according to company data. Currently, Xiamen Tungsten has cathode capacity of around 10,000 tonnes per annum, with 5,000 tonne for NCM. It is investing in an additional 20,000 tonnes of ternary cathode capacity, with expected operation in 2019.

Kingray New Materials Science & Tech (600390.SS, NC): Kingray primarily operates in cathode materials and manganese business, and is one of only a few Chinese companies owning patents in NCA cathode production. It is a member company of China Minmetals Corporation, China's largest metals and mineral company. Kingray operates its cathode business through its subsidiaries Changyuan Lico and Jinchi Material. Kingray is a supplier to Panasonic NCA cathode and has total cathode capacity of around 20,000 tonnes a year.

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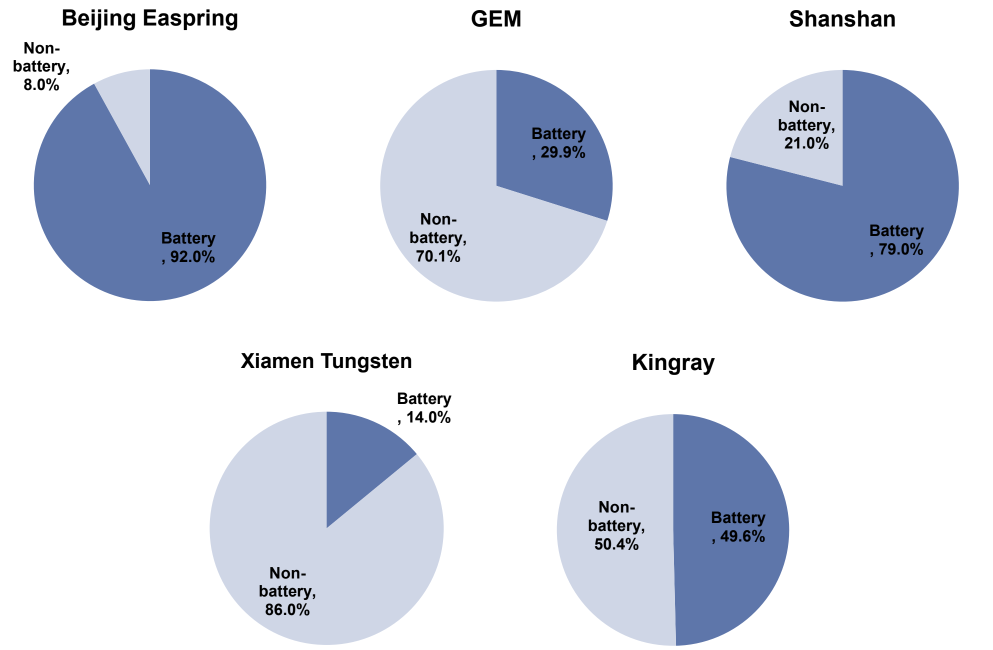
Exhibit 66: Among cathode players, Shanshan has the most extensive exposure to the battery material value chain, including cathodes, anodes and electrolytes
Battery business sales as % of total sales (2015)



Source: Bloomberg, Company data

Anode makers

Shenzhen BTR New Energy Material (835185.NEEQ, NC): BTR, controlled by China Baoan (000009.SZ, NC), is the largest anode maker in the world, accounting for 25% market share globally, according to ITDCW. BTR currently has anode capacity of 30,000 tonnes per annum and is a major supplier to Samsung SDI, LG Chem, Panasonic, Sony and BYD. BTR also engages in the research and development of graphite related products. Its parent company, China Baoan, is a Shenzhen-based comprehensive enterprise, investing in real estate, biological pharmacy and high technology.

Hunan Shinzoom Technology (831086.NEEQ, NC): Shinzoom is a leading anode producer in China based in Hunan. Its anode capacity has expanded to 12,000 tonnes a year since 1Q16 with customers including BYD, CATL and Far East First. It listed on China's OTC market in 2014 and was acquired by Hunan Zhongke Electric (300035.SZ, NC) in Dec 2016. Before that, Beijing Easpring was its largest shareholder with a 33% stake.

Jiangxi Zeto New Energy Tech (831980.NEEQ, NC): Zeto was founded in 2008 and mainly produces artificial/natural graphite and LiB anodes. Listed on the Chinese OTC market in 2015, Zeto currently has anode capacity of between 7,000 tonnes and 8,000 tonnes a year under construction. Zeto is one of the major suppliers to BAK battery, a Chinese battery maker. Zeto also provides anodes to energy storage companies.

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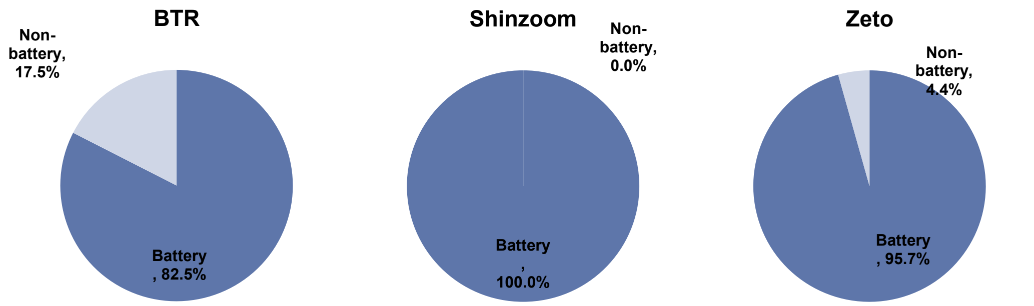
Exhibit 67: No pure anode player is listed in the A share market
Battery business sales as % of total sales



Source: Bloomberg, Company data

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Separator makers

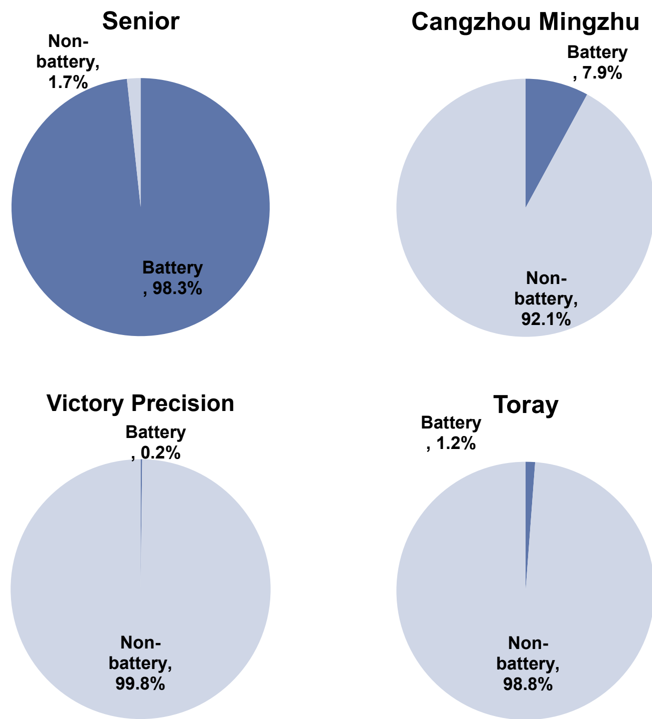
Shenzhen Senior Technology Material (300568.SZ, NC): Senior is the top separator manufacturer in China and the first to develop both dry and wet process technology in separator manufacturing. Its major customers include LG Chem, BYD, Guoxuan and Lishen. Senior has around 150mn m2 capacity in total and its JV with Guoxuan is expected to add an additional 80mn m2 wet-process capacity and be fully operational in 2018. It became publicly-traded in Dec 2016 and is the only company purely focusing on battery separator manufacturing. For 9M16, Senior's revenue reached Rmb382mn, yoy 39% and net income of Rmb124mn, 80% yoy.

Cangzhou Mingzhu (002108.SZ, Buy, Rmb20.63) CZMZ is a leading advanced material maker focusing on the R&D and manufacturing of battery separators, biaxial oriented polyamide (nylon) (BOPA) film for the packing industry and polyethylene (PE) pipeline for the natural gas sector. CZMZ is the second biggest separator player in China in terms of revenue as of 2015 and one of the few companies that has both dry and wet separator capacity in China; with major customers including BYD, ATL, China Aviation and Lishen. Currently, Cangzhou has separator capacity of 105mn m2 in wet-process and 50mn m2 in dry process. The company is also one of the largest BOPA film producers in China with capacity of 28,500 tonnes a year.

Suzhou Victory Precision Manufacture (002426.SZ, NC): Victory Precision acquired a 51% stake in Suzhou Greenpower New Energy Materials in 2015, a wet-process focused separator producer with 4 production lines and expects 220mn m2 capacity in total by the end of 2016. Its customers cover BYD, LG Chem, etc. Victory Precision increased its stake in Greenpower to 85% in the end of 2016. Victory Precision mainly operates in the research, development, design, manufacture and distribution of structural modules in flat panel televisions, PC and laptops.

Toray (3402.T, Neutral, JPY964): Toray is a hybrid chemical maker specializing in organic synthetic chemistry, polymer chemistry and biochemistry. Its wholly-owned subsidiary, Toray Battery Separator Film, is the world's No. 2 supplier of li-ion battery separators with a market share of 20%, second to Asahi Kasei. According to our Japan team, Toray currently has around 270mn m2 capacity with production bases in Japan and Korea and will reach over 300mn m2 by 2017.

Exhibit 68: Senior and Cangzhou Mingzhu are the only two players in the A share market share with main business in separators
Battery business sales as % of total sales



Source: Bloomberg, Company data

Electrolyte makers

Guangzhou Tinci Materials Tech (002709.SZ, NC): Tinci Materials is the No.1 battery electrolyte maker in China in terms of sales volume (as of 2015), according to GGLB. It is also engaged in the research, development, production and sale of fine chemical materials. Tinci entered the electrolyte business in 2015 and now has three electrolyte (lithium hexafluorophosphate) production bases in Guangdong Province with total capacity of 33,000 tonnes a year. Tinci has entered into the supply chain of Sony, BYD and CATL and is also expanding to LFP cathodes and the recycling area.

Shenzhen Capchem Technology (300037.SZ, NC): Founded in 2002 and listed in 2010, Capchem is the No. 2 leader in battery electrolytes with capacity of 20,00 tonnes a year. Capchem's main products include capacitor chemical series, lithium ion battery chemical series, organic fluorine chemicals series and semiconductor chemicals series. Its customers extend to Samsung SDI, Panasonic, Sony, BYD, etc. Capchem's battery business recorded sales of Rmb 347mn in 1H16, yoy 105%.

Do-Fluoride Chemicals (002407.SZ, NC): Do-Fluoride mainly provides inorganic fluoride products including cryolite, anhydrous aluminum fluoride, anhydrous hydrofluoric acid and lithium hexafluorophosphate. Do-Fluoride has extensive exposure in the battery value chain compared to its peers. Its roots are in electrolyte (3,000tonne), cell/pack (100mn Ah including LMO, Ternary and LFP), and BMS business. Its major customers include BYD and King Long.

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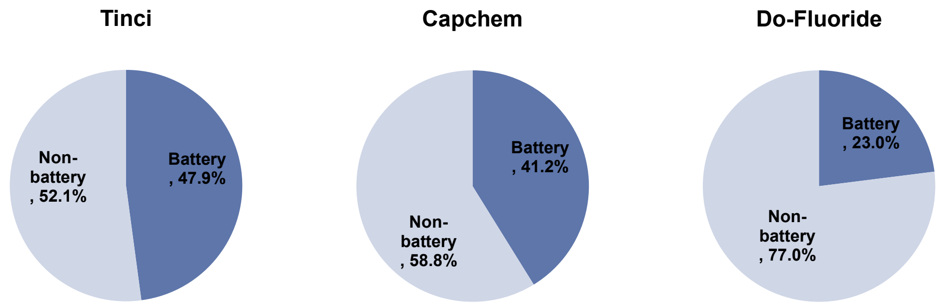
Exhibit 69: Three players comprise a significant part of China's electrolyte business
Battery business sales as % of total sales (2015)



Source: Bloomberg, Company data

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Cell/Pack makers

See "BYD Co. (1211.HK): Potential to transform into leader in NEV ternary battery in China" published Feb. 9 for more details.

BYD (1211.HK, Neutral, HK$42.6; 002594.SZ, NC): BYD is the largest NEV car maker globally, operating in three major business divisions including automobiles, handset components & assembly services, as well as the rechargeable battery business. BYD is also the largest battery maker in China with annual capacity of 10 GWh (for its own internal use). BYD currently uses mostly LFP batteries in its EV car products and is shifting to ternary batteries, starting with the model Song, released in 2016. Our auto team expects BYD to reach 16 GWh (10 GWh in LFP and 6 GWh in ternary) by 2017. Taking advantage of its technical superiority, BYD also actively develops other new energy products such as solar farm, wind turbines, energy storage station, LED and electric forklifts.

Contemporary Amperex Technology Co., Limited (CATL) (private): CATL is the No. 2 battery maker in China, founded in 2011, with a market share of 24% in 1H16 in China. It's the only company in the BMW battery supply chain. Other customers include Geely (0175.HK, CI-Buy, HK$8.87), BAIC (NC) and SAIC (600104.SS, Neutral, Rmb24.74). CATL's production bases are located in Qinghai and Jiangsu with 7.5GWh capacity (both LFP and ternary). CATL is also the largest private battery maker in China, with investors including China Merchants and Shenzhen Venture Capital Co.

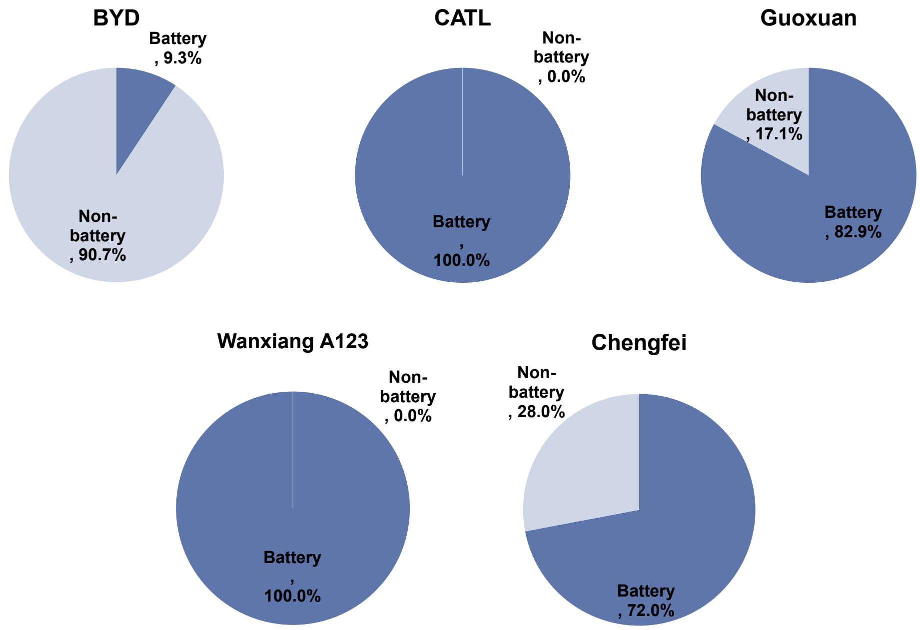
Guoxuan High-tech Power Energy (002074.SZ, NC): Guoxuan is a leading value-chain integrated player in China, covering cathodes, separators, cell/packs, and battery management systems (BMS). Guoxuan mainly produces LFP batteries with annual capacity of 2.5GWh and is investing in 1GWh ternary capacity in Qingdao. Guoxuan mainly sells batteries to commercial vehicle makers such as Zhongtong Bus, JAC and Shanghai Sunwin (JV of SAIC and Volvo), capturing a market share of 10%. Its backdoor listing in the A-share market was in 2014 and the company is also engaged in the electric equipment business.

Wanxiang A123 (not listed): A123 System, a wholly owned subsidiary of Wanxiang Group, is a developer and manufacturer of LFPs/ternary batteries with capacity around 2GWh. Its customers include Cherry and Geely. The company was founded in 2001 based on battery material developed at Massachusetts Institute of Technology (MIT), and went public on the NASDAQ in 2009. In Aug 2012, A123 filed bankruptcy and was acquired by Wanxiang Group, the largest automotive components company in China by revenue. In 2014, Wanxiang also won the bankruptcy auction for the assets of Fisker Automotive, one of the world's first PHEV makers.

Sichuan Chengfei Integrate (002190.SZ, NC): Chengfei is a leading auto parts company in China, owned by Aviation Industry Corporation of China, a central government owned aero defense company. It operates a battery business via its subsidiary, China Aviation Lithium Battery (CALB) based in Henan. CALB currently has around 3GWh capacity and is investing in an additional 2GWh plant in Jiangsu. CALB provides LFP batteries to King Long, Zhongtong Bus, Dongfeng Motor and etc. In addition, CALB is actively involved in upstream business. It formed a JV with Cangzhou Mingzhu to produce wet separators in 2016.

Exhibit 70: BYD is the largest battery maker in China, but battery business only accounts for 9.3% of revenue in 2015. The following players are more focused on battery in main business

Battery business sales as % of total sales



Source: Bloomberg, Company data

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Appendix: Glossary of terms

Cathode: The electrode that receives electrons through the discharge process, the negative side. Cathode's material and chemical composition is used to describe the type of battery.

Anode: The electrode that releases electrons on discharge, the positive side.

Separator: A barrier between the positive (anode) and negative (cathode) electrodes to prevent electrical short-circuits.

Dry Separator: Often used in large batteries with high safety standards, including most lithium iron phosphate batteries used in commercial electric vehicles such as buses.

Wet Separator: Slimmer than a dry separator and commonly used in high energy density batteries, including ternary batteries.

Electrolyte: A conductive medium that enables lithium ions to move from the anode to the cathode when the battery is discharging and back when it is charging.

Ternary Battery: A type of battery whose cathode is typically either Nickel Cobalt Manganese (NCM) or Nickel Cobalt Aluminum (NCA). It offers high specific energy.

Nickel Cobalt Manganese (NCM): A type of cathode material containing certain proportions of nickel, cobalt and manganese. Its formula is $LiNi_xCo_yMn_zO_2$. Common combinations of x, y, z are 1/1/1, 5/2/3, 6/2/2 and 8/1/1.

Nickel Cobalt Aluminum (NCA): A type of cathode material containing certain proportions of nickel, cobalt and aluminum. Its formula is $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$.

Lithium Iron Phosphate (LFP): A type of cathode material containing $LiFePO_4$. LFP is one of the safest li-ion battery cathodes, but with low specific energy.

Lithium Cobalt Oxide (LCO): A type of cathode material with a chemical formula of $LiCoO_2$. LCO has high specific energy and high cost due to high cobalt content.

Graphene: A single atomic layer of graphite arranged in a hexagonal lattice. It is the world's first 2D (single layer) material.

Energy Density: The amount of energy (Wh) that a battery can deliver per unit of volume, similar to specific energy.

Electric Vehicle (EV): An automobile that is powered by electric energy stored in rechargeable batteries. Lithium ion batteries are the mainstream power source for EVs.

Plug-in Hybrid Electric Vehicle (PHEV): A type of hybrid vehicle using batteries that can be recharged by plugging it into an external source of electric power. Similar to Hybrid Vehicles (HVs), PHEVs have series and parallel drivetrains. A PHEV's battery volume is larger compared to that of a HV, but smaller compared to that of an EV. Driving distance for PHEVs depends on the battery size.

kWh(Kilowatt-hour): Unit measure of energy use or discharge over a specific period of time.

kW (Kilowatt): Unit measure of energy use or discharge at a moment of time.

Pyrometallurgy: A technical process for battery recycling through melting metals under high temperature.

Hydrometallurgy: A technical process for battery recycling using solutions to extract metals in the battery.

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Innovation & Disruption

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Drones

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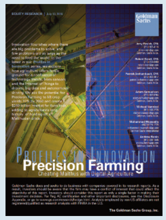
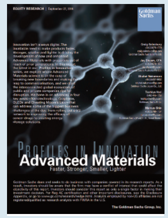
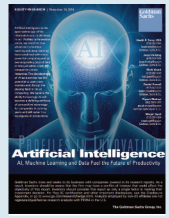


Advanced Materials

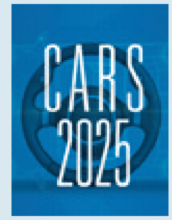


Artifical Intelligence



5G

Cars



Internet of Things

Rise of the Asian Consumer

Chinese Consumer

Chinese Millennials

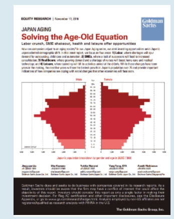
Chinese Tourist Boom

China Logistics

India Consumer

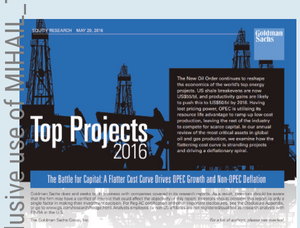
India Internet

Japan Aging

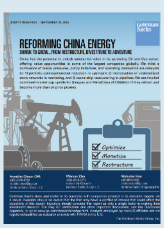


Old China Commodities

Top Oil & Gas Projects



Reforming China Energy



Chinese Demand & The Copper Supply Glut

New Old China: 4R's Beyond 2016

The Future of Finance

Future of Finance

Blockchain

Asia Digital Banking

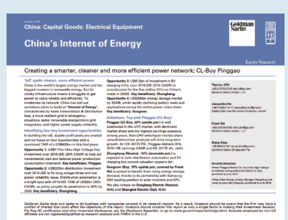
The Low Carbon Economy

Tech in the Driver's Seat

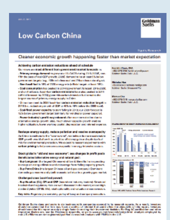
The Great Battery Race

China Enviroment

China Internet of Energy



Low Carbon China



Music's Return to Growth

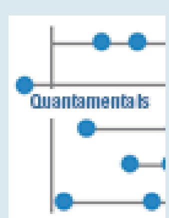
Opportunity

Risk

Shenzhen: Incubating a 'New China'

Apple Suppliers' Dilemma

Asian Quantamental



SUSTAIN

Corporates' Strategic Challenge

Credit

China's Domestic Bond Market

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