Energy Storage Trade And Manufacturing

A Deep Dive

February 2021

BloombergNEF

Contents

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Section 1. Executive Summary

549GWh/year

Global battery cell manufacturing capacity, 2020

50%

A cathode's share of total cell-manufacturing costs

$400 million

U.S. battery imports in August 2020

The following is an in-depth examination of current battery storage manufacturing and trade trends produced under an ongoing partnership between BloombergNEF and the Energy Security & Climate Change Program at the Center for Strategic and International Studies in Washington. This report focuses exclusively on the battery storage industry and offers a deeper-dive look at current global competitive dynamics. Similar reports covering the solar PV and wind sectors have been published separately and are also available for download at CSIS.org and BNEF.com.

1. Lithium-ion battery manufacturing plants produce cells. These can be integrated into modules, packs and racks depending on the end-use.
2. Component materials directly used in battery production include the cathode, anode, separator, and electrolyte. Key battery metals include lithium, nickel and cobalt.
3. Global commissioned battery cell manufacturing capacity quintupled between 2013 and October 2020, reaching 549GWh/year. Some 78% of global commissioned cell manufacturing capacity is located in China.
4. Pack assembly capacity is relatively flexible: production does not tend to be fully automated and the output highly depends on the shifts and working hours of local labor. It tends to be located near end-use demand centers.
5. China, Japan and South Korea all benefitted from an existing consumer battery manufacturing base, and the accompanying upstream supply chain.
6. Processing capacities across four key battery components are highly concentrated in China, Japan and Korea. The long-standing battery industries across these countries have fostered robust upstream production capacities for major components. Even as battery makers construct cell-manufacturing plants in new markets such as Europe, they still rely on the component-processing capabilities from facilities in Asia.
7. The cathode is a critical component in the battery value chain as it determines battery performance and accounts for roughly 50% of cell-manufacturing costs. China, Japan and South Korea jointly hold nearly 94% of current cathode processing capacity globally.
8. Most anode processing capacity can support both consumer and EV battery production. Only five countries have trackable anode processing capacities: China, Japan, South Korea, the U.S. and India. China accounts for 78% of current commissioned anode-processing capacity globally.
9. Some 95% of separator capacity is located in China, Japan and South Korea. Separator manufacturing tends to be located close to cell manufacturing. The battery industry is racing to develop and deploy a coated separator technology. This will require substantial cooperation between cell and component manufacturers.
10. Electrolytes are liquid, hard to transport, and therefore often produced near cell-manufacturing facilities. Roughly 62% of existing electrolyte capacity is located in China.

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Leading companies with capacity in the U.S. include Japanese company Mitsubishi Chemical, South Korea's Enchem and Soulbrain and Germany's BASF.

11. Refineries to process key metals in batteries are typically not located near mines, but rather near chemical-processing or battery-production plants. Argentina, Chile and Australia are leading lithium producers. The Democratic Republic of Congo largely controls the world's mined cobalt supply. Indonesia and the Philippines have plentiful nickel production. China is the world leader in refining all three of these battery metals.
12. The U.S. has some cell manufacturing capacity but also imports cells, packs and fully-integrated stationary storage systems from elsewhere.
13. Supply chain strategies for leading suppliers of li-ion batteries in the U.S. vary considerably. To understand how value does or does not accrue locally through the manufacturing of a battery, we examine the value break-out of a typical Tesla/Panasonic battery and compare it to one made by a typical Korean manufacturer.
14. For a Tesla/Panasonic battery, a relatively high percentage of the value accrues to the U.S. due to Tesla's local manufacturing plants. Its partnership with Panasonic ensures that about the same value accrues to Japan.
15. By contrast, Korean manufacturers LG Chem, Samsung SDI or SK Innovation have markedly different supply chains. The share of product for their batteries made in the U.S. is lower. Most of the pack is made in Korea, meaning more value accrues there.

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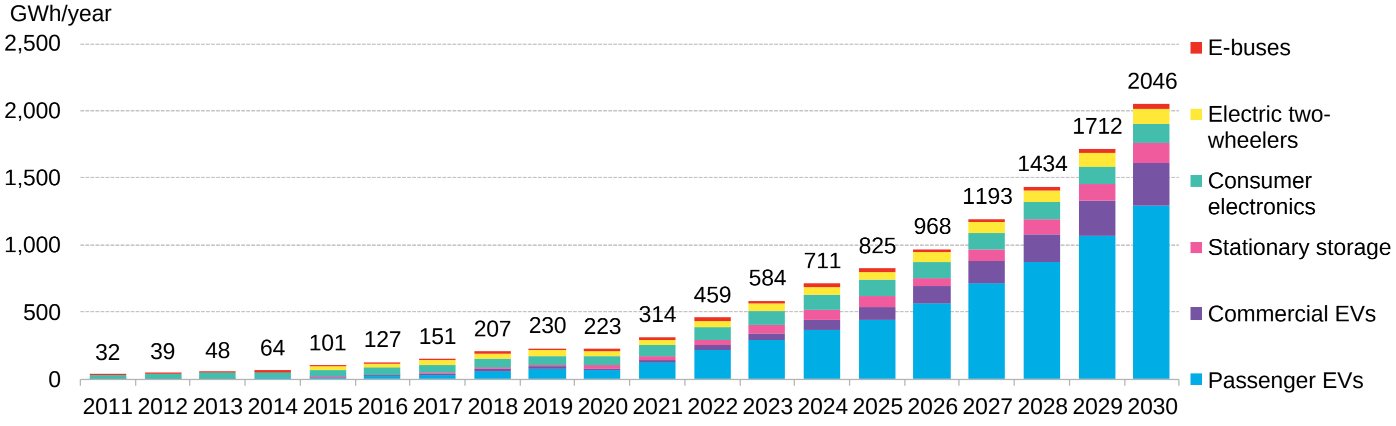
Section 2. Energy Storage

2.1. Primer

Lithium-ion batteries were commercialized in 1991 and have become commonplace in consumer electronics over the last three decades. Since 2010, the lithium-ion battery industry has achieved a remarkable 87% drop in the volume-weighted average battery pack price, and battery pack energy density has doubled. As batteries have improved and become cheaper, their use has expanded into more markets such as transport and power.

By 2030, approximately 2TWh of batteries will be widely used in consumer electronics, electric vehicles and stationary storage systems, BNEF projects. This equates to a nine-fold increase from current deployment levels (Figure 1). Technology advancements and the establishment of a mature supply chain will enable the further battery cost reductions and performance improvements required to enable underpin this growth.

Figure 1: Annual lithium-ion battery demand by application



Source: BloombergNEF

Component materials directly used in the battery production include the cathode, anode, separator, electrolyte and auxiliary materials (Figure 2). Metals contained in the batteries, in particular the lithium, nickel and cobalt, impact both performance and cost of the batteries. This makes the upstream mining and refining of particular interest and importance.

Cells are the direct outputs of battery manufacturing plants. Cell products in the market vary by the format, size and chemistry, depending on the application and performance requirements. Cells used in EV and storage applications tend to be large (usually between 30~250 amp hours (Ah)) and one of three form formats – cylindrical, prismatic and pouch. These cells are integrated into modules and packs before end use in order to meet the high voltage and capacity requirements.

The wide range of potential cathode materials results in multiple cell chemistries. Common cell chemistries include lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium iron phosphate (LFP) and lithium manganese oxide (LMO). The chemistry can determine the characteristics of the cells including the energy density, manufacturing cost,

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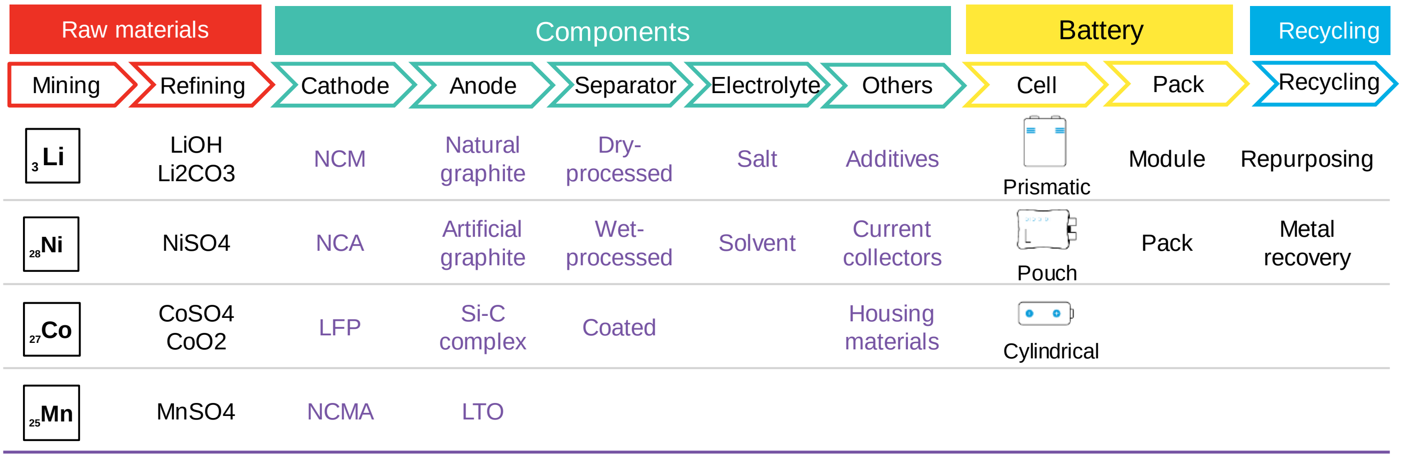
cycle life, safety and the discharge/charge rate. The evolution of the chemistry also impacts the demands of key metals and the production expansion plans of the miners and refineries.

Figure 2: The battery production value chain



Raw materials		Components					Battery		Recycling
Mining	Refining	Cathode	Anode	Separator	Electrolyte	Others	Cell	Pack	Recycling
$_{3}$Li	LiOH Li2CO3	NCM	Natural graphite	Dry-processed	Salt	Additives	Prismatic	Module	Repurposing
$_{28}$Ni	NiSO4	NCA	Artificial graphite	Wet-processed	Solvent	Current collectors	Pouch	Pack	Metal recovery
$_{27}$Co	CoSO4 CoO2	LFP	Si-C complex	Coated		Housing materials	Cylindrical		
$_{25}$Mn	MnSO4	NCMA	LTO						

Source: Source: BloombergNEF. Note: NMC is lithium nickel manganese cobalt oxide. NCA is lithium nickel cobalt aluminum oxide. LFP is lithium iron phosphate. NMCA is lithium nickel manganese cobalt aluminum oxide. LTO is lithium titanium oxide. Si-C complex is silicon-carbide inorganic complex compound.

Table 1: Summary of battery supply chain characteristics

	Number of factories / sites	Largest manufacturer (Country)	Market concentration (Country)	Market concentration (Company)	Adjacent industries	U.S. reliance on imports*	Barrier to entry	Value
Battery cell	215	China	Med	Med	n/a	High	Med	High
Battery pack	65	China	Low	Low	n/a	Med	Low	Low
Cathode	131	China	Med	Med	Metallurgy	High	Med	High
Anode	81	China	High	Med	Graphite	High	Med	Med
Separator	93	China	Med	High	Membrane materials	Med	High	Med
Electrolyte	64	China	Med	High	F chemicals & petrochemical	Med	Med	Med
Lithium mining	19	Chile	Med	High	Metallurgy	Med	High	High
Lithium refining	14	China	High	Med	Metallurgy; Lithium chemicals	Low	Med	Med
Cobalt mining	22	D.R.C	High	High	Metallurgy	Med	High	High
Cobalt refining	21	China	High	High	Metallurgy: Co chemicals	Med	High	High
Nickel mining	22	Indonesia	Med	Med	Stainless steel	Med	High	Med
Nickel refining	18	Indonesia	Med	Med	Stainless steel	Low	Med	Med

*Source: BloombergNEF. Note: The link between the adjacent industries for the components is weaker than the other segments because these components have a number of unique properties tailored for batteries. Number of refers to commissioned plants only. *This is from the perspective of current manufacturing requirements, not resource availability. I.e. U.S. imports are relatively low for many metals because there is relatively little component manufacturing capacity in the country.*

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2.2. Materials

Lithium, cobalt and nickel are three metals crucial to the battery industry. They determine battery performance. Their fluctuating prices influence final battery prices. And there are significant concerns over their availability.

Mines that extract these important metals are obviously located near deposits spread around the world. However, refineries to process these metals are typically found in regions or countries with expertise in chemical processing and large-scale battery production. Australia, Chile, the Democratic Republic of Congo, and Indonesia are home to abundant lithium, cobalt and nickel resources. Meanwhile, China leads refining production across these three battery metals.

In this report, we use nameplate capacity to assess the scale of mining and refining plants. However, in practice, not all plants produce at nameplate capacity. Mines and refineries face multiple types of risk, all of which can affect output. These include technical, geological, political/trade, ESG, financial and fiscal risks. Producers’ operations and inventory strategies are also vulnerable to commodity price fluctuations.

Lithium mining

Lithium is typically extracted from two types of resources – salar brines and spodumene. Australia, Chile, Argentina, Bolivia and China currently account for more than 90% of conventional lithium resources and accompanying operational mining capacity (Figure 3).

- **Salar brines**: Brines are estimated to account for 58% of global lithium resources, the best of which are found in Chile, Argentina and Bolivia. These operations pump brine from underground reservoirs into a series of evaporation ponds to concentrate and isolate lithium. The process takes about 18 months and usually results in lithium carbonate.
- **Spodumene**: Spodumene and other pegmatites account for 26% of lithium resources. Australia is particularly endowed with this high lithium-bearing hard rock. To extract lithium, the ore is mined, ground, roasted, and leached with sulfuric acid. The resulting lithium concentrate is typically shipped to Asia and converted to lithium carbonate or hydroxide.

Ongoing lithium mining additions are concentrated in Australia and Chile, where the world’s best spodumene and brines can be exploited, respectively (Figure 4). In Australia, local companies Pilbara, Altura, Galaxy and international players Albemarle, Tianqi and Ganfeng are actively exploiting the spodumene. In Chile, SQM and Albemarle dominate lithium production. In China, non-Tier 1 producers are piloting small, expensive resource projects.

98% of economically viable lithium reserves in the world are concentrated in Chile, Australia, Argentina and China. Limiting lithium production to a few countries poses a security and supply chain risk. Unconventional lithium resources are key to decentralizing the upstream supply chain. Unconventional resources such as clays (7%), jadarite (3%), geothermal brines (3%) and oilfield brines (3%) can help to diversify lithium production to North America and Europe. Unconventional resources can shorten supply time frames and increase flexibility of lithium-ion battery supply chains. Having raw materials closer to end-use markets can avoid multiple cross-border tariffs, lower transport emissions, and insulate from policy disruptions. However, the estimated capital expenditures for unconventional projects are twice the costs of conventional lithium production.

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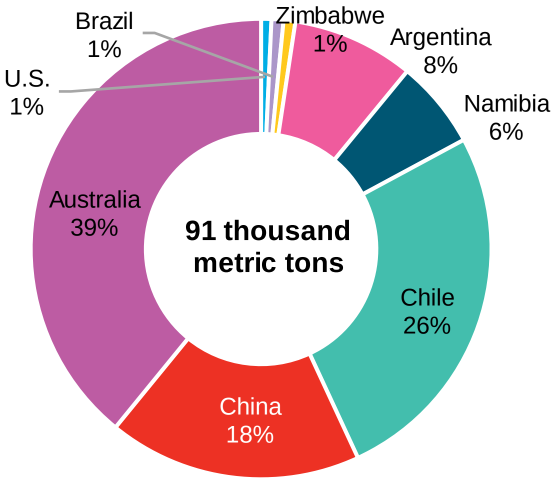
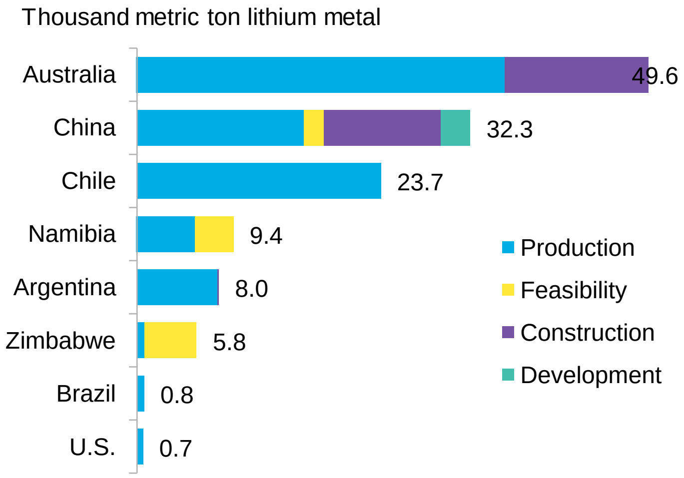
Figure 3: Operational lithium mining nameplate capacity



Source: BloombergNEF. Note: Figure reflect global totals as of October 20, 2020.

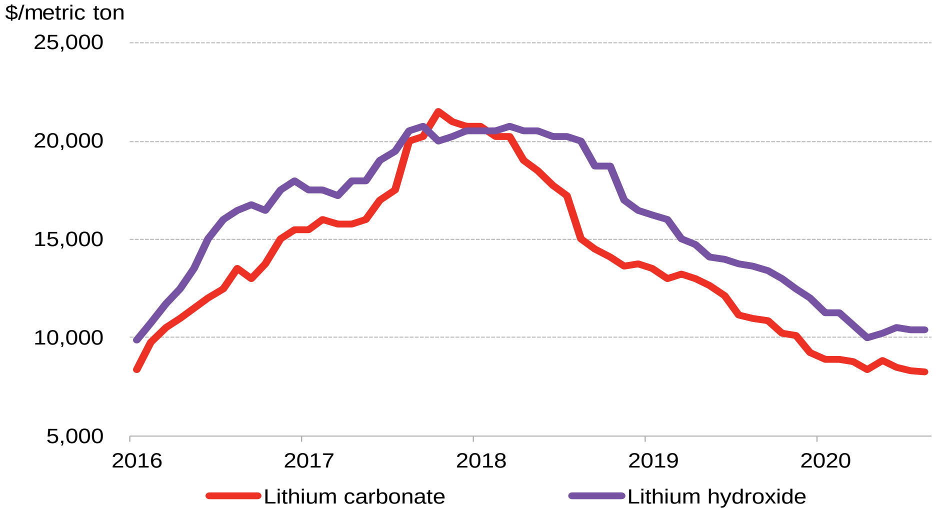
Figure 4: Current and potential lithium mining nameplate capacity



Source: Figures reflect global lithium mining capacity as of 3Q 2020. Note: Production is when the project is operating, feasibility is when it has published a definitive feasibility study, development follows feasibility and is when contracts are issued.

There is significant supply-side flexibility in lithium markets. Producers can accelerate or delay new capacity additions depending on whether global prices for lithium justify plant costs. Lithium prices have halved since 4Q 2017, driven by oversupply in the market (Figure 5). Major producers therefore, have pulled back and re-assessed expansion plans. Since June 2019, Albemarle, Altura, Pilbara, Tianqi, Nemaska and others have announced slowdowns in their expansion phases, or temporarily suspended projects. The majority of scale-backs have occurred in spodumene resource projects in Australia.

Figure 5: Lithium spot prices



Source: BloombergNEF, Benchmark Mineral Intelligence. Data available on the Bloomberg Terminal. Note: Shows Asia lithium carbonate CIF swap and Asia lithium hydroxide CIF swap.

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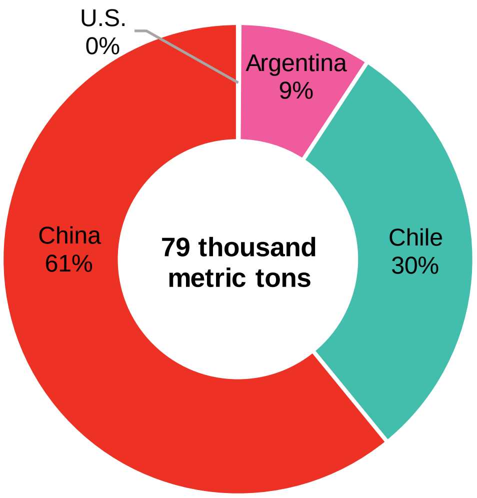
Lithium refining

Lithium mines typically sell their output in the form of intermediate concentrate to refineries for conversion to carbonate or hydroxide. Lithium refining capacity has grown rapidly in recent years to meet rising demand from battery makers. The availability of local expertise is a key consideration when deciding where to site a lithium-refining facility although the distance to downstream demand is also important. There is currently lithium-refining capacity concentrated in China, Chile and Argentina with Australia poised soon to be a major player as well (Figure 6, Figure 7).

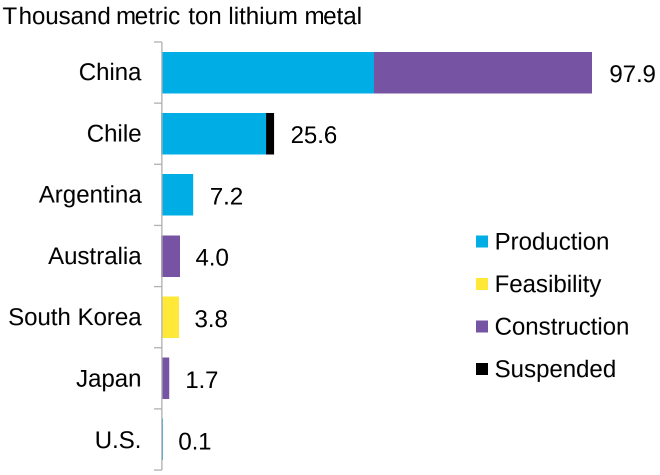
- In **China**, refining plants benefit from local experience in converting these specialized products and from a large downstream market. One of the most common lithium value chains in today's market is one in which spodumene is mined in Australia, processed into lithium concentrate and then shipped to China for chemical conversion, often into hydroxide. Chinese converters are often partially invested into the mining companies as part equity stakeholders.
- In **Chile and Argentina**, producers convert brine to lower quality industrial grade lithium carbonate and ship it to Asia where it is converted to battery-grade hydroxide.
- A number of companies in **Australia** are now seeking to move into refining. Going from ore to hydroxide allows them to take advantage of their high-quality reserves and make a higher value product. The partnership between Australian miners and experienced lithium conversion companies like Albemarle and Tianqi may help jump start this value chain.

Figure 6: Operational lithium refining nameplate capacity



Source: BloombergNEF. Note: Figures refer to global lithium refining capacity as of 3Q 2020.

Figure 7: Current and potential lithium refining nameplate capacity



Source: BloombergNEF. Note: Figures refer to global lithium refining capacity as of 3Q 2020.

Major lithium refining products include lithium carbonates and hydroxides, which can be used to synthesize battery component materials such as cathode active materials and electrolyte salts. The chemistry selection in the battery market greatly impacts the production activities and prices across these two lithium chemicals. Specifically, the synthesis of high-nickel cathode active materials such as NMC (811) and NCA requires lithium hydroxides, while lithium carbonates are mainly used in the processing of LFP and other low and middle nickel chemistries. The increasing adoption of higher-nickel cathode chemistries, particularly in passenger EV batteries, is pushing

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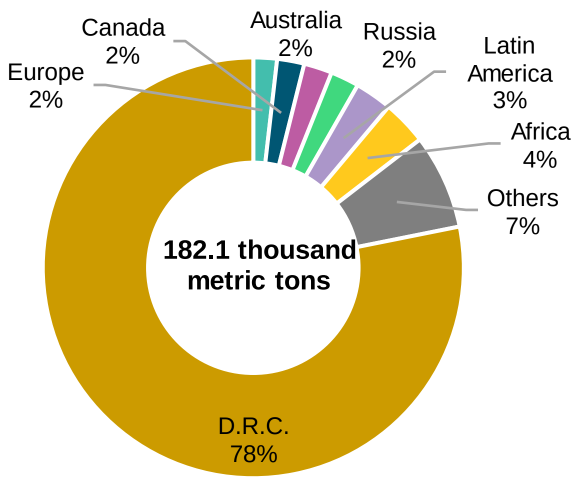
up demand for lithium hydroxide. Hydroxide does not travel well as it has a tendency to absorb moisture. Compared to making carbonates, producing hydroxides requires strong lithium chemical industry experience and needs to be close to battery-manufacturing centers. Most planned additional capacity is planned for China.

Cobalt mining

Over three quarters of global cobalt mining capacity is located in the DRC, which has high-quality deposits and relatively low operational costs (Figure 8, Figure 9). Producers Glencore and China Molybdenum today control a combined 27% of global cobalt capacity through subsidiaries in the D.R.C. Unverified supply from “artisanal” producers in the country has dropped in recent years as human-rights groups have focused on their labor practices and as public and corporate awareness of the issue has grown.

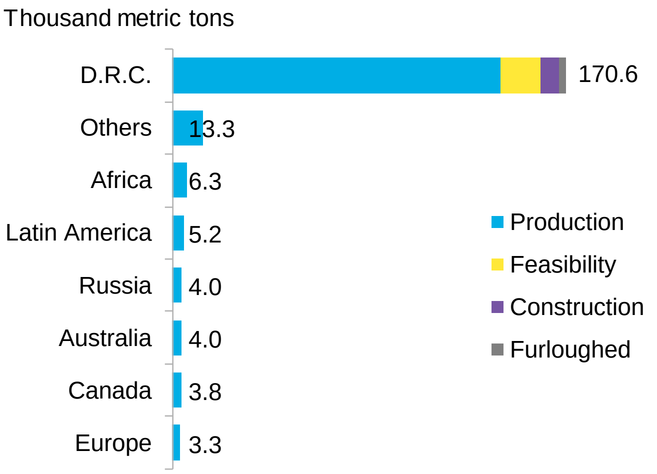
The Bou Azzer mine in Morocco is the only active asset now producing cobalt as its primary product. All others produce cobalt as a byproduct of either copper or nickel. Generally, copper-producing assets can produce cobalt as a secondary product regardless of the selling price of cobalt. They can be relied on to continue producing cobalt in order to reduce their cost of operations. Nickel assets are more expensive in terms of the additional costs needed to process cobalt. They are therefore more reliant on higher cobalt prices to justify the continuing processing of cobalt chemicals.

Figure 8: Operational cobalt mining nameplate capacity



Source: BloombergNEF. Note: The numbers refer to global cobalt mining capacity as of 3Q 2020

Figure 9: Current and potential annual cobalt mining capacity (nameplate)



Source: BloombergNEF. Note: The numbers refer to global cobalt mining capacity as of 3Q 2020. Others includes Indonesia, the Philippines, New Caledonia and other nations.

The battery industry is moving toward high-nickel chemistries in an effort to achieve higher energy densities for batteries. This has the potential to reduce future cobalt demand and slow mine expansion momentum. Changing expectations around demand are reflected in spot price fluctuations, which in turn directly impact cobalt miners’ strategies (Figure 10). Some stockpile run-of-mine (ROM) production when prices dip while others blend high and low grade ore to attain consistency in saleable feedstock. Offtake agreements often require companies to sell ore at a fixed grade or quality. The quality or grade produced at the mine can vary so companies stockpile

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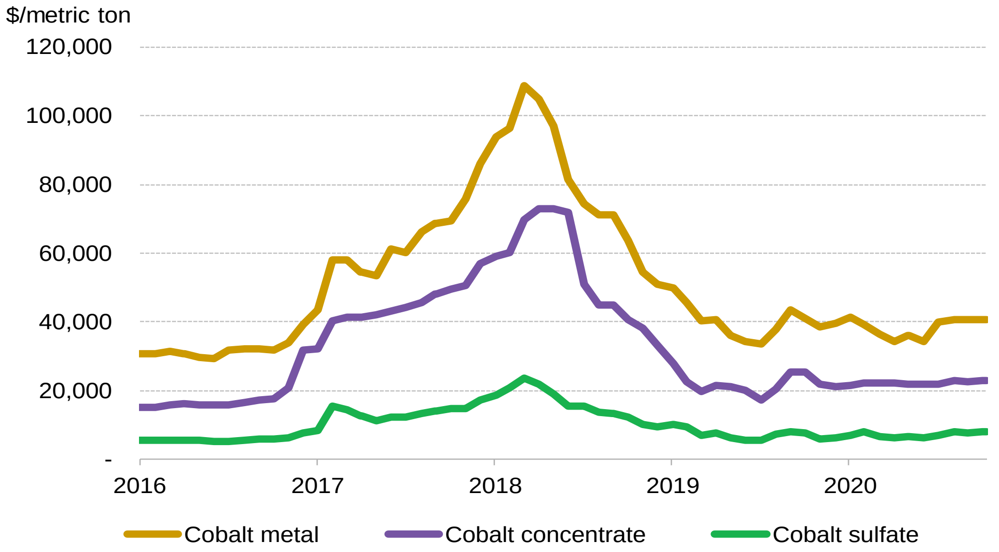
high and low grades ore in order to blend them to obtain the required grade to meet the demands of their offtake partners. This results in some cobalt reaching refineries months or even years after it is extracted.

Figure 10: Cobalt spot prices



Source: BloombergNEF, Benchmark Mineral Intelligence. Data available on the Bloomberg Terminal. Note: Series shows China Shanghai Changjiang cobalt spot price, China cobalt concentrate 6-8% CIF and China cobalt sulfate 20.5% DEL.

Cobalt refining

BloombergNEF classifies refined cobalt as the final stage of processing before consumption. Refineries in the cobalt market produce cobalt metal, powder or chemicals. Cobalt chemicals, like sulfate and oxides, are the main feedstock used in making cathodes for batteries.

Cobalt refining is predominantly controlled by Chinese companies, despite the fact that the vast majority of cobalt is mined half a world away in the D.R.C (Figure 11, Figure 12). In China, Jinchuan Group, Zhejiang Huayou Cobalt, and Shenzhen GEM are the largest refining players. Their dominance is likely to stretch well into 2025 due to the strategic upstream investments they have made in mines in the D.R.C and Zambia.

Examples of refining operations outside of China are few. Umicore owns the Kokkola refinery in Finland and Eramet has a small facility in France. Glencore has also invested in First Cobalt, which could result in cobalt sulfate refining operations in Canada in the future. Sconi could also seek to expand cobalt sulfate production at a plant in Australia.

With the formation of the European Battery Alliance, manufacturers there are seeking to expand capacity on EU soil, as the region seeks to reduce reliance on China for raw materials. Meanwhile the Canadian, Australian and U.S. governments have allied to promote cobalt refining for the same reason.

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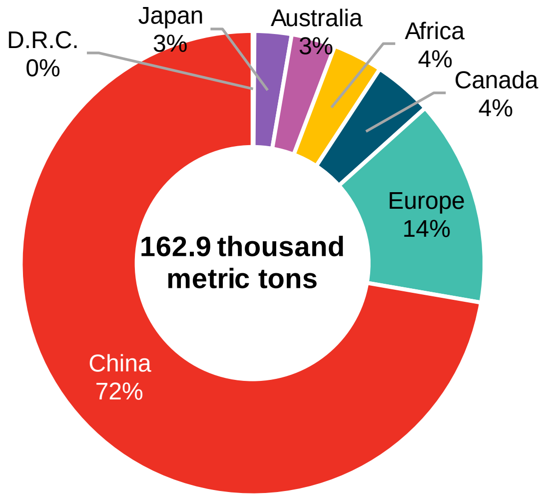
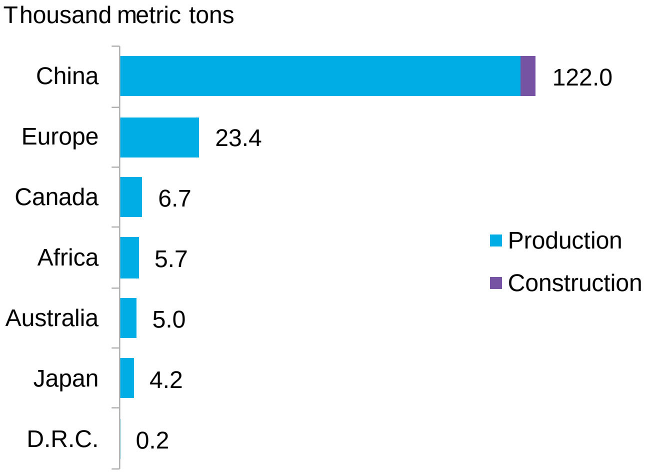
Figure 11: Operational cobalt refining nameplate capacity



Source: BloombergNEF. Note: Figures refer to global cobalt refining capacity as of 3Q 2020.

Figure 12: Current and potential cobalt refining capacity (nameplate)



Source: BloombergNEF. Note: Figures refer to global cobalt refining capacity as of 3Q 2020.

Class 1 nickel mining

Combined trackable nickel mining capacity in operation is roughly 1.23 million tons and is fairly widely spread across the world (Figure 13). Mined supply ranges from nickel production from raw ore mining to production of intermediates. Major nickel deposits can be classified into two types: sulfides and laterites. Sulfides often produce higher-purity nickel products at a relatively lower processing cost. These sulfides are found in Russia, Australia, and Canada. In Indonesia, Philippines and New Caledonia, nickel metals occur in laterites.

Over the last two decades, nickel mining has shifted from traditional leading markets Russia, Australia and Canada to Southeast Asian countries. Today, Indonesia, the Philippines, and New Caledonia have become significant players with significant capacity online (Figure 14). Technology has played a key role in this shift. At the peak of the nickel boom, Chinese companies discovered new methods, typically the High Pressure Acid Leaching (HPAL) technology, which enable using low-grade nickel ore to produce nickel pig iron, a low-cost raw material, for steel production at an industrial scale. This technology led to a rapid capacity expansion of nickel produced from laterite-bearing orebodies found in Indonesia and the Philippines that were previously economically unviable.

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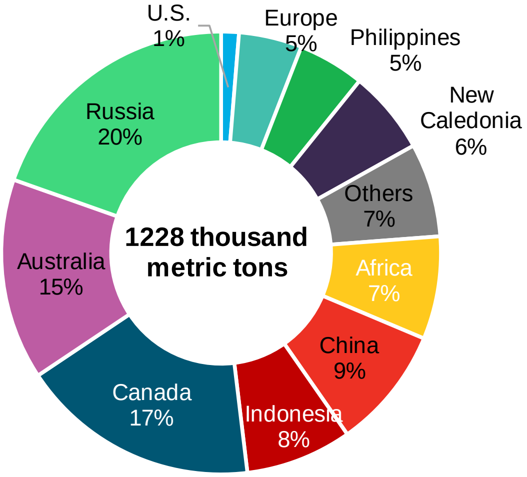
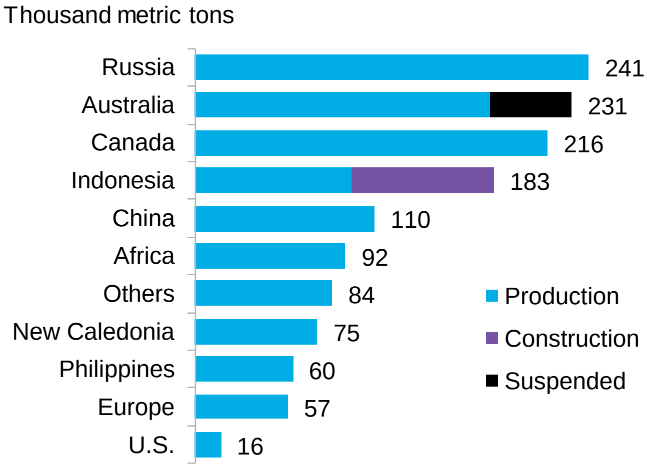
Figure 13: Operational Class 1 nickel mining nameplate capacity



Source: BloombergNEF. Note: Figures refer to global class 1 nickel mining capacity as of 3Q 2020.

Figure 14: Current and potential Class 1 nickel mining capacity (nameplate)



Source: BloombergNEF. Note: Figures refer to global class 1 nickel mining capacity as of 3Q 2020.

Class 1 nickel refining

Total global Class 1 nickel production tracked by BNEF today stands at 1.17 million metric tons per year (Figure 15, Figure 16). Most of locations where Class 1 nickel is refined are established sulfide production centers.

The growing stainless steel industry has created greater demand for nickel. EV batteries are the fastest-growing consumer for Class 1 nickel, which is converted to nickel sulfate for the production of cathodes in batteries. In the near-term future, most Class 1 capacity additions are expected from HPAL projects in Indonesia and Australia, which are in fully integrated complexes and aim to produce nickel sulfate for lithium-ion batteries. Chinese companies such as Tsingshan, GEM and Jinchuan dominate investments in nickel production capacity in Indonesia, partly driven by the ore export ban in the country.

Definition of different categories of nickel

Mined nickel – nickel contained in products that will be used as feed for further processing and refining. This includes raw nickel ore and nickel intermediates.

Nickel intermediates – mined nickel ore milled in processing facilities, to be further processed in smelters and/or refineries. Intermediates include nickel concentrate, nickel matte, mixed hydroxide products (MHP), mixed sulphide precipitates (MSP).

Finished nickel – nickel contained in smelter and refinery output in forms which can be readily utilized by end-users. Divided into Class 1 and Class 2 nickel, depending on nickel content.

Class 1 nickel – also called refined nickel. Includes products with nickel content greater than 99%. Includes briquettes, pellets, electrolytic nickel, powders. Nickel chemical products, including nickel sulfate used in lithium-ion batteries are derived from synthesizing Class 1 nickel.

Class 2 nickel - also called charge nickel, products with less than 99% of nickel content. Includes ferronickel (FeNi) and nickel pig iron (NPI).

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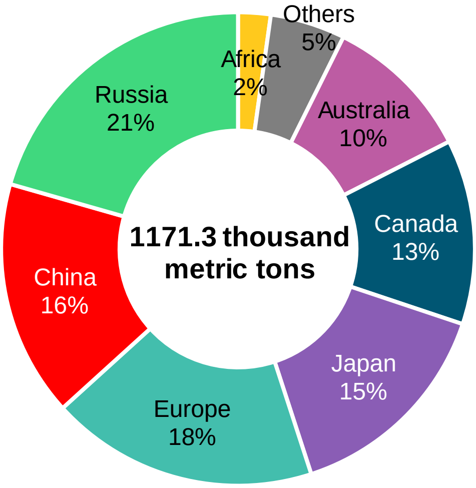
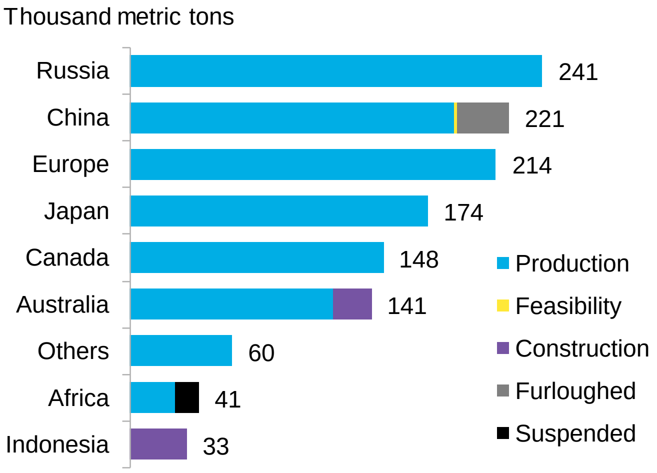
In order to ensure sufficient nickel is available in the future, battery makers are working with their upstream partners to speed up investments into nickel resources, particularly in Southeast Asia. Sumitomo Metal Mining (SMM), Panasonic's long-standing upstream partner, has invested in nickel mining capacity in the Philippines and refining capacity in Japan. This gives it access to a cost-competitive and high-quality supply of the high nickel NCA cathode materials. CATL's holding subsidiary Brunp Recycling, Tsingshan Group and GEM have signed an agreement to invest in a nickel refining plant in Indonesia's Morowali Industrial Park. The plant will produce 50,000 metric tons of nickel hydroxide intermediates and 150,000 metric tons of battery-grade nickel sulfate crystals annually.

Figure 15: Operational class 1 nickel refining nameplate capacity



Source: BloombergNEF. Note: The numbers refer to global class 1 nickel refining capacity as of 3Q 2020

Figure 16: Current and potential class 1 nickel refining capacity (nameplate)



Source: BloombergNEF. Note: The numbers refer to global class 1 nickel refining capacity as of 3Q 2020

2.3. Manufacturing

This section starts with a review of battery cells since cell manufacturing is the most important segment of the battery value chain. The location and scale of cell manufacturing plants affect the upstream supply chain. Produced cells get integrated into packs or racks for use in transport or stationary storage applications. Cell characteristics determine the production technology in the pack assembly segment.

Batteries

The huge increase in expected battery demand has prompted a surge in investment in battery manufacturing capacity. The location of each new plant is determined by a combination of factors including the size of the local market, local know-how and sector experience, and policy support.

The geographic distribution of cell manufacturing strongly influences the upstream supply chain. To ensure supply chain alignment, remain competitive and avoid bottlenecks, component producers tend to follow battery makers when selecting sites for new capacity. Major processing capacities across the four key components remain concentrated in China, South Korea and

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Japan. This is thanks to the established upstream supply chain and the long history of battery manufacturing in these countries, which began in the advent of the consumer battery era.

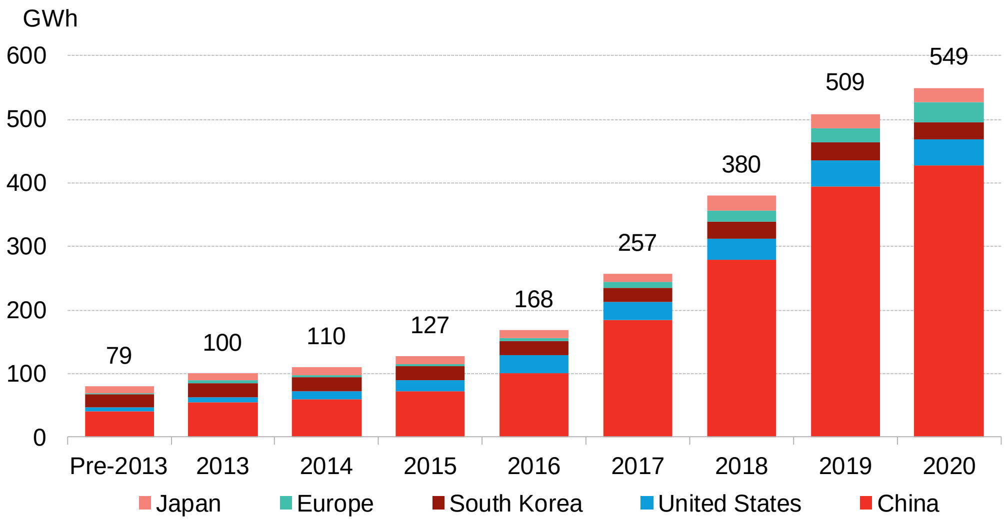
Battery cells

Global commissioned cell manufacturing capacity quintupled between 2013 and October 2020, reaching 549GWh/year[1] (Figure 17). Some 78% of current global commissioned cell manufacturing capacity is located in China. The country was a prominent manufacturer of consumer batteries and the government has supported the domestic electric vehicle industry for a number of years.

Cell manufacturing in the Europe is set to boom in the near term, thanks to stringent emissions policies and an accompanying surge in EV demand and production. Many of the manufacturers setting up operations in Europe are from outside the trade bloc, from countries such as Japan, South Korea and China.

Most cell manufacturing capacity in the U.S. is owned by Tesla. Its Nevada Gigafactory, operated in a joint-venture with Panasonic, has a capacity of 35GWh. Other battery makers such as LG Chem and SK Innovation are rapidly increasing their presences in the U.S. to better supply automakers in the country.

Figure 17: Cumulative battery manufacturing capacity



Source: BloombergNEF. Note: Excludes consumer batteries. The 2020 capacity refers to cumulative global commissioned cell manufacturing capacity as of October 20, 2020.

Drivers of capacity additions

Cell manufacturing capacity additions tend to follow market demand. Any increase in electric vehicle sales and stationary storage deployments necessitate an increase in available lithium-ion battery supply. BNEF expects annual lithium-ion battery demand to serve these two markets to pass 1,900GWh per year by 2025 (Figure 18).

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[1] Only include plants producing large-format cells for electric vehicle and stationary storage applications. Consumer battery plants are excluded from this production capacity counting.

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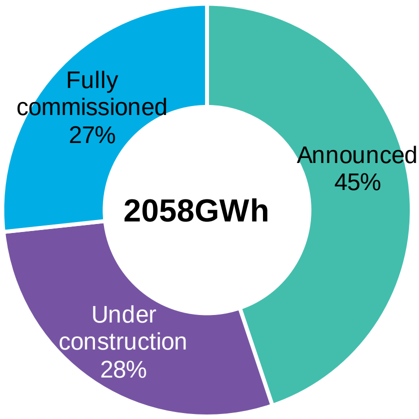
Improvements to battery technology, especially energy density and production automation, will facilitate this unprecedented increase. Manufacturing capacity is measured on a GWh basis while the production speed determines the amount of cells that can be produced in a given time. Over the last decade, battery energy density has increase 109%. The increase of energy density means cells of the same size can store more energy, resulting in larger capacity. The increase of production speed means that a plant can produce more cells in the same time, for the same investment.

Regional distribution

We expect new capacity additions to be located close to the demand centers, i.e. to major electric vehicle markets. This is because battery manufacturers need to work closely with automakers on EV models through prototype design, testing, mass production and delivery. Proximity for battery-makers also allows for greater certainty of shipments and lower logistical costs. With demand from the automotive sector dwarfing other segments of the market, we anticipate EV makers will continue to dictate where battery plants are located.

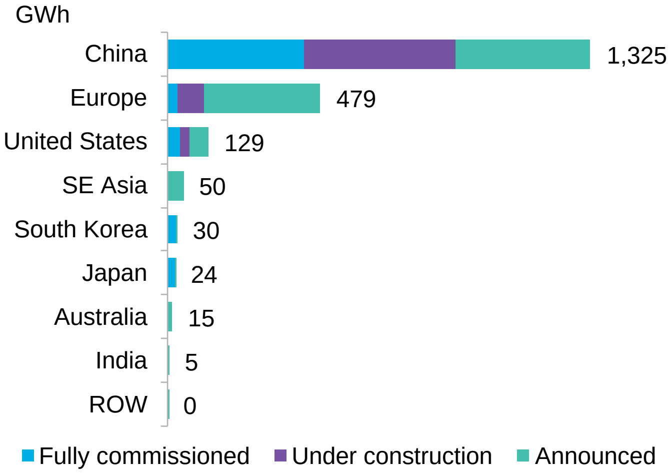
China and Europe are on course to account for the largest share of EV sales over the next decade, given policies on the books. As a result, most new battery cell manufacturing capacity is likely to be located there (Figure 19). Other regions could catch up, particularly if they nurture domestic EV industries. In the U.S., much depends on the extent to which the incoming president, Joe Biden, can implement his clean energy policies, including more stringent corporate average fuel efficiency standards on cars and trucks. Other countries and regions such as India, Australia and Southeast Asia aim to leverage local resources such as cheap land and labor, and access to key battery metal resources to play catch-up to market leaders. They remain a good deal off the pace at the moment now, however.

Figure 18: **Global battery cell manufacturing capacity**



Source: BloombergNEF. Note: Excludes consumer batteries. Capacity current as of October 20, 2020.

Figure 19: **Leading nations' and regions' battery cell manufacturing**



Source: BloombergNEF. Note: Excludes consumer batteries. Figures reflect capacity as of October 20, 2020. All announced and under construction capacity listed due online by 2025.

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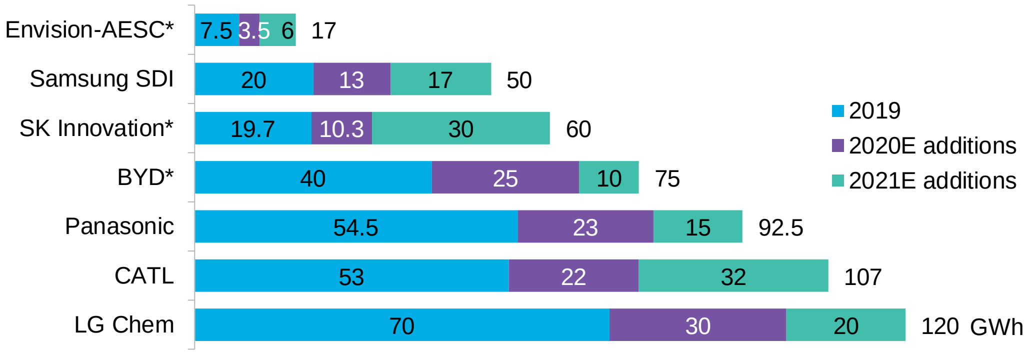
Leading companies

A small number of battery manufacturers supply the leading automakers and stationary storage developers. Most are headquartered in Asia. Combined cell manufacturing capacity in 2019 for the global top seven battery makers reached 268GWh, accounting for nearly half of global cumulative commissioned cell manufacturing capacity (Figure 20). Tesla aims to have 3TWh of manufacturing capacity by 2030 on its own.

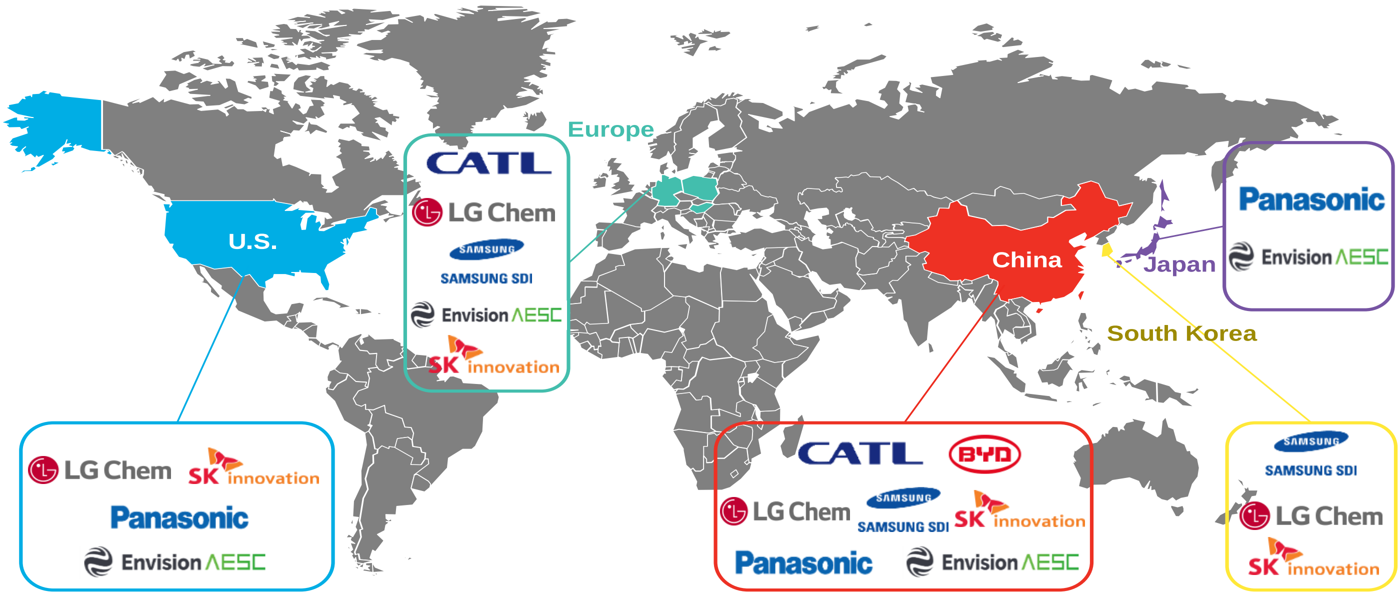
Figure 20: Battery cell-making capacity of the world's top battery producers



*Source: BloombergNEF. Note: Excludes consumer batteries. Includes the cell manufacturing capacity of JV plants between battery vendors and automakers. Tesla's Gigafactory is reflected in Panasonic today. * Indicates that the number comes from a company statement.*

Even as the list of countries hosting battery manufacturing facilities grows, the roster of leading battery makers remains largely the same. LG Chem, Panasonic, Samsung SDI and SK Innovation are all investing in greater production capacity located outside their home markets than within (Figure 21).

Figure 21: Cell manufacturing plant locations for the world's seven largest battery makers



Source: BloombergNEF. Note: This map is based on cell manufacturing plants commissioned and under construction as of 1H 2020. Battery vendors' fully-owned plants as well as joint ventures with automakers are included. Pack assembly plants excluded.

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Battery packs

Battery pack producers encompass three distinct company types: battery cell makers, automakers and standalone pack manufacturers. The distribution of pack plants geographically relates to the split between these companies (Figure 22, Figure 23). Pack assembly capacity is relatively flexible: production does not tend to be fully automated and the output highly depends on the shifts and working hours of local labor.

- **Automakers**: Automakers are increasingly investing in in-house pack assembly plants. This helps them better integrate with the powertrain system and other proprietary technologies. These pack capacities are usually co-located with EV factories. For automakers with in-house pack supply strategies, they have built up pack capacity in line with their near-term EV production expectations. This can be flexible to supply both BEV and PHEV models.
- **Battery makers**: Battery makers usually have some pack assembly capacity integrated into their cell-manufacturing plants to cut logistics costs and boost margins. Battery makers' pack assembly capacity is usually much smaller than their cell-making capacity. From their perspective, the packs are just an extended type of battery product. Delivered products depend on client requirements, which in most cases are cells and modules. There is less transparency around total pack manufacturing capacity since cell makers often do not disclose this information.
- **Standalone pack manufacturers**: The capacity and plant distribution of third-party pack manufacturers are typically dictated by their partnerships with automakers. These companies usually locate pack plants near EV production centers. In some cases, automakers are also shareholders in some pack plants. Joint-ventures between battery makers and automakers are becoming more commonplace, and we expect a similar setup to materialize for pack assembly. These companies supply other clients as well.

Figure 22: Number of commissioned battery pack manufacturing plants

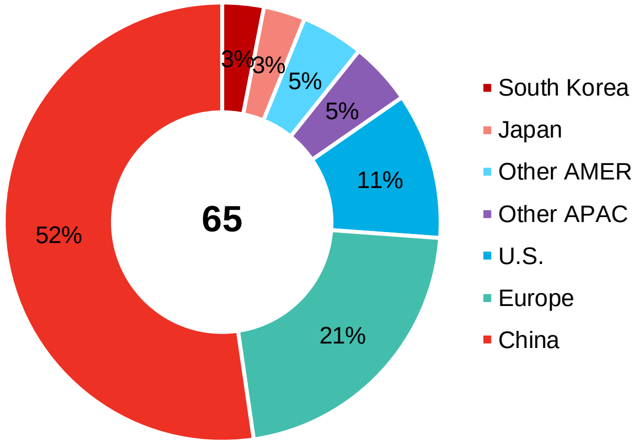
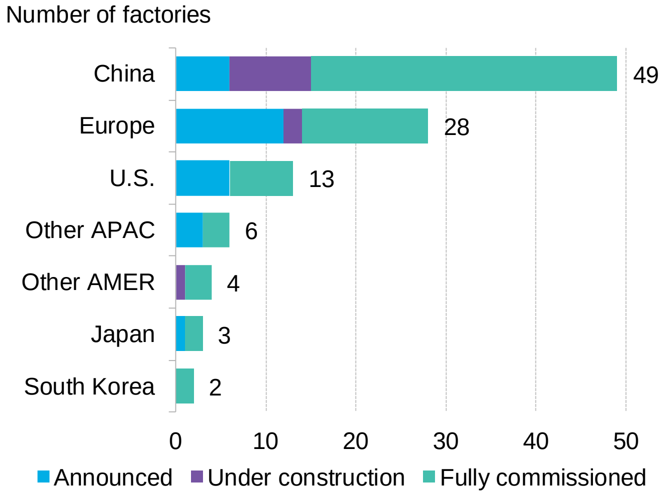


Figure 23: Geographic location of battery pack plants



Source: BloombergNEF. Note: Includes pack plants owned by automakers, third-party pack manufacturers and JVs between automakers and battery makers. Excludes battery makers' in-house pack production capacity.

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Components

Processing capacities for four key battery components – cathodes, anodes, separators and electrolytes – remain highly concentrated in three nations: China, Japan and Korea. Well-established battery industries in these countries have fostered robust upstream production of these major components. Even as battery makers add cell-manufacturing capacity in new markets such as Europe, they still rely on component-processing capacities back in these more mature markets.

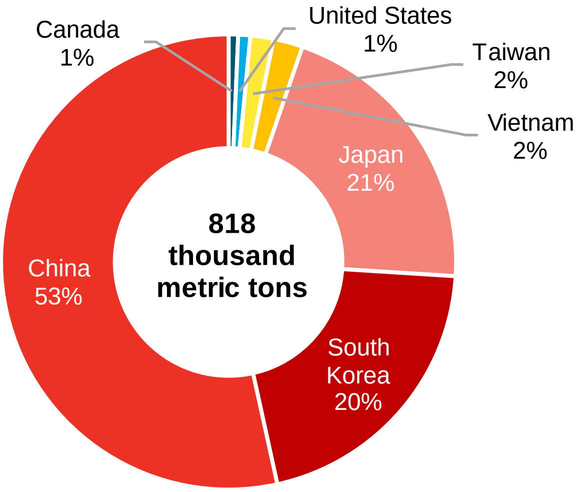
The scaling up of component plants typically comes only after the establishment of cell-manufacturing bases. Component makers' strategies are often dependent on the plans of their cell-making clients. Separator and electrolyte companies, in particular, tend to be most active in staying close to their customers to ensure the best cooperation and lowest logistics costs.

Cathodes

As of October 2020, global commissioned annual cathode processing capacity totalled 818,000 metric tons with another 397,000 metric tons under construction and 1,201,000 metric tons planned but not yet being built. China, Japan and South Korea jointly hold nearly 94% of current processing capacity (Figure 24) with a huge pipeline of announced and under-construction projects in China. These are expected to supply the country's growing cell-making base (Figure 25).

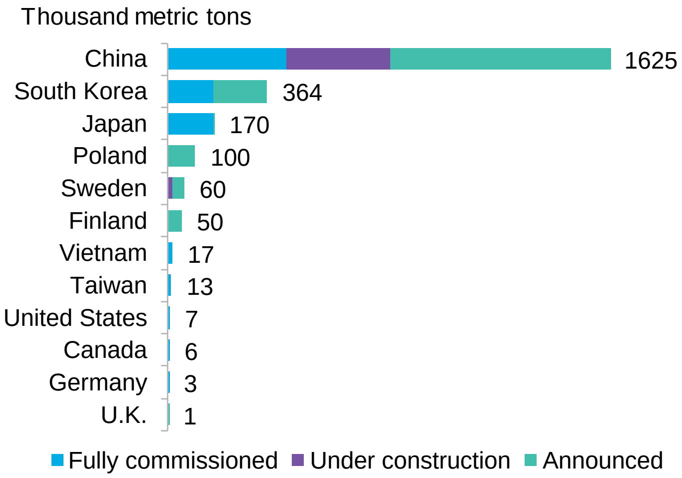
Cathodes are critical in determining battery performance and on their own account for roughly half of typical cell-manufacturing costs. Their importance is driving cell-makers to expand in-house cathode-production capacity, either via JVs or internal investments. Leading battery makers LG Chem, CATL, Samsung SDI all have cathode-production capabilities in their home countries and aim to scale up there in the near term. This, to some extent, explains the inconsistent regional distribution of planned cathode-processing capacity compared with cell-making growth. Despite this, we do expect these companies will eventually expand cathode-production on a more localized basis once they ramp production of other components in these new markets.

Figure 24: Commissioned cathode-processing capacity



Source: BloombergNEF. Note: The numbers refer to global cathode processing capacity as of October 20 2020.

Figure 25: Current and future cathode-processing capacity



Source: BloombergNEF. Note: The numbers refer to global cathode processing capacity as of October 20 2020.

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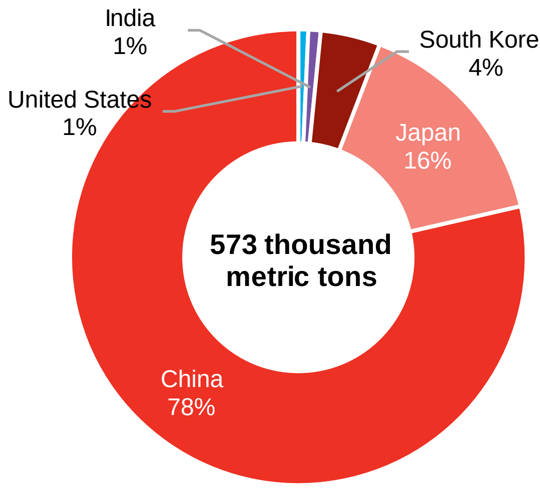
U.S. cathode manufacturing capacity is virtually non-existent. This is expected to change as companies scale up cell manufacturing capacity in the country. Tesla for instance plans to produce its own cathode materials using new processes that it claims will slash processing costs by 76%.

Anodes

Global commissioned anode annual processing capacity today stands at 573,000 metric tons, with 182,000 and 421,000 metric tons of capacity under construction and announced, respectively (Figure 26, Figure 27). Most anode-processing plants can produce equipment for use in either consumer or EV batteries. Only five countries have anode-processing capacity on line today: China, Japan, South Korea, the U.S. and India. China accounts for 78% of annual anode-processing capacity.

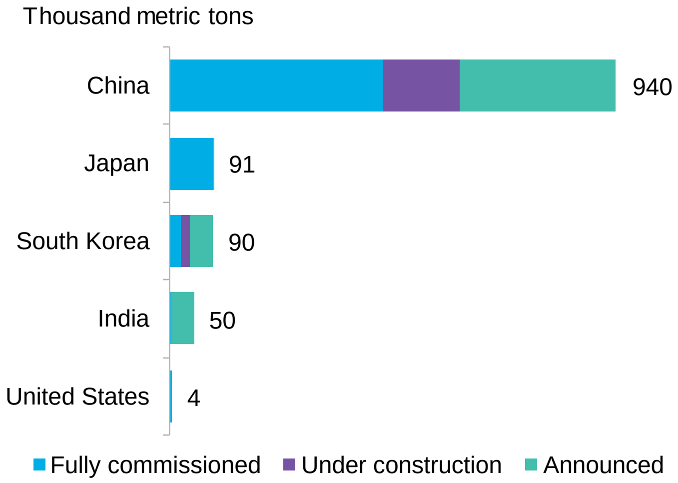
Commercially-available anode active materials include natural graphite, artificial graphite and carbon-silicon complex. Natural graphite can be used in EV batteries but is primarily employed in consumer batteries. Artificial graphite is increasingly popular for use in EV batteries since it enhances the rate capability and active capacity. Because artificial graphite processing is expensive, companies are increasingly bringing it in-house. In fact, graphitization accounts for almost half of total artificial graphite processing costs. Companies are trying to use in-house production to ensure a stable and cost-competitive supply. The adoption of silicon-based anodes is expected to take place in the near term in order to improve the battery energy density.

Figure 26: Commissioned anode-processing capacity



Source: BloombergNEF. Note: Figures reflect global total as of October 20, 2020.

Figure 27: Current and future anode-processing capacity



Source: BloombergNEF. Note: Figures reflect global totals as of October 20, 2020.

Separators

Global commissioned capacity for separator technologies today totals 7.1 billion square meters per annum, with 3.8 and 3.7 billion square meters of annual capacity under construction and announced, respectively (Figure 28, Figure 29). In the U.S., Celgard is the major separator producer. The company is a subsidiary of Japanese firm Asahi Kasei.

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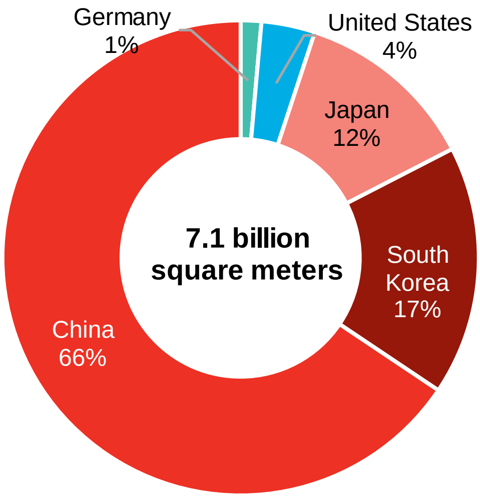
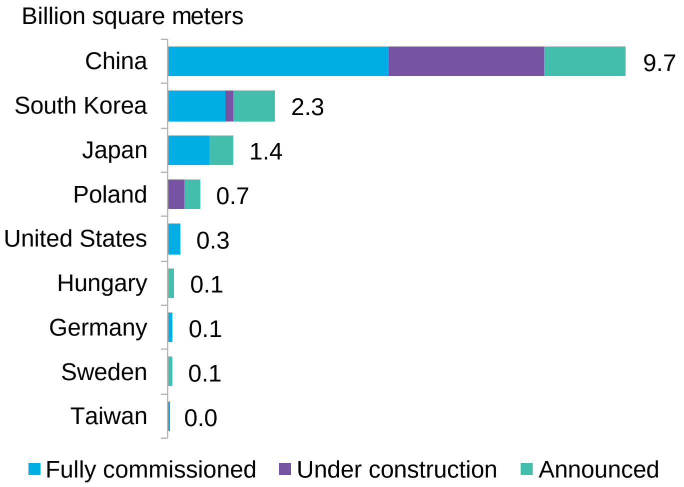
Given the specialized nature of separators, separator suppliers typically work very closely with their battery cell-manufacturer clients. Separator makers also typically make decisions on where to build new plants based on where their customers are building new capacity.

Figure 28: Commissioned separator processing capacity



Source: BloombergNEF. Note: Figures reflect global total as of October 20, 2020.

Figure 29: Current and potential separator-processing capacity



Source: BloombergNEF. Note: Figures reflect global totals as of October 20, 2020.

Electrolyte

Electrolyte in battery cells is a solution consisting of the salts and solvents. Lithium hexafluorophosphate (LiPF6) is the most widely used electrolyte salt while organic liquids such as ethylene carbonate (EC), dimethyl carbonate (DMC) and diethyl carbonate (DEC) act as the solvents. When talking about electrolyte-processing capacity, we are referring to the production scale of the electrolyte solution.

There are 466,000 tons of commissioned annual electrolyte-processing capacity globally as of October 2020, with a further 506,000 tons more annual capacity potentially on the way (Figure 30, Figure 31). Roughly 62% of existing capacity is located in China. Leading companies with capacity in the U.S. include Japan's Mitsubishi Chemical, South Korea's Enchem and Soulbrain and Germany's BASF.

Electrolyte suppliers tend to have in-house electrolyte salt production capacity and source a large portion of the solvents from the market. This is because the property of the LiPF6, the ratio and composition of salt and solvent determines the performance of the electrolyte. Organic solvents meanwhile are relatively common in the petrochemical industry. Given the liquid state of the electrolyte solution and the difficulty in the logistics, electrolyte plants need to be geographically close to their battery maker clients. This explains why processers are investing in new capacity in countries such as Poland, to meet demands from cell manufacturers such as LG Chem, Samsung SDI and SK Innovation (Figure 31).

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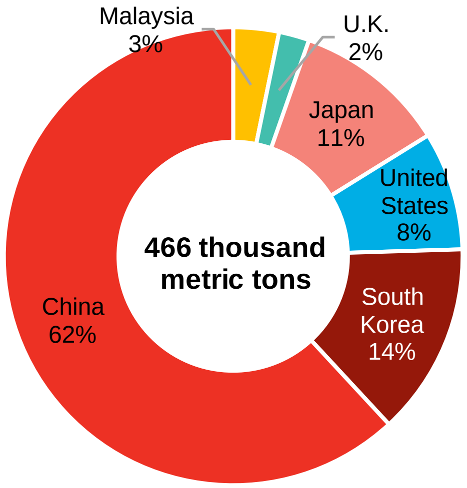
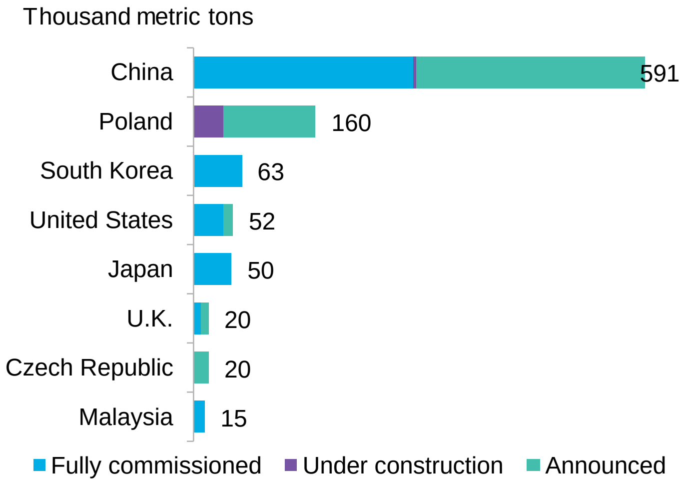
Figure 30: Commissioned electrolyte processing capacity



Source: BloombergNEF. Note: Figures reflect global total as of October 20, 2020.

Figure 31: Total electrolyte processing capacity



Source: BloombergNEF. Note: Figures reflect global totals as of October 20, 2020.

2.4. Trade flows

International trade of battery equipment takes place primarily in the form of assembled batteries moving across borders. Recorded trade volumes of battery components tend to be small and mostly occur from countries with significant battery production scale, such as China, Japan and Korea. This is because batteries can be shipped either for direct integration into products such as electric vehicles or to end consumers for immediate use. By contrast, components have only one purpose: to serve the battery supply chain.

International customs database registries generally do not track each component of the battery value chain with great specificity. Battery trade flows are typically counted as a combination of cells, modules and packs. In some cases, component materials are simply lumped into the battery category. Batteries used in consumer electronics, electric tools, transportation and stationary storage systems are all included under a single “lithium-ion battery” header.

There is one further complication: in the course of the assembly process, a battery cell can cross borders multiple times. For instance, cells may first be shipped to a country for pack assembly and then exported again to a third country for EV production. When directly adding up the reported deals disclosed in the customs systems, these cells could generate trade values multiple times.

As a result of these many issues, recorded international trade values do not easily match with the production capacity data and analysis presented in the previous sections of this report, which only focus on batteries manufactured for EV and stationary storage applications.

Batteries

From the start of 2017 through 2020, U.S. gross imports of batteries have been rising month by month and hit $400 million in July 2020. By contrast, gross exports have remained relatively flat over that time at $100 million per month (Figure 32). The U.S. imported batteries mainly from

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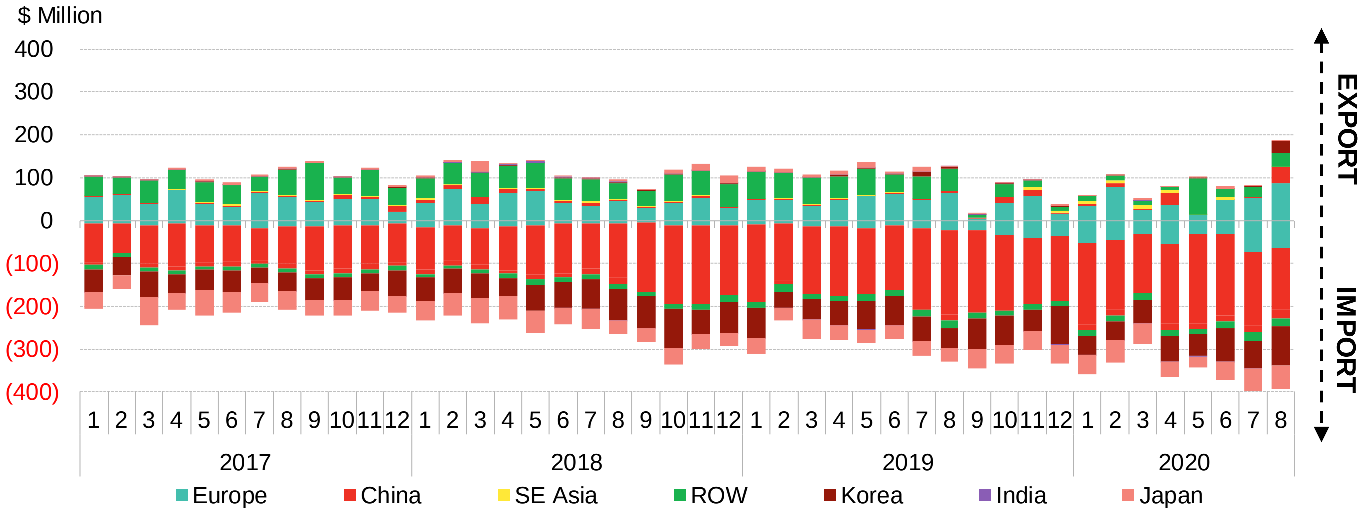
China, South Korea and Japan. Its exports have gone primarily to Europe and to a variety of other markets.

Figure 32: U.S. battery trade flow



Source: BloombergNEF, Bloomberg Terminal function: US BOL <AHOY>. Note: Hong Kong figures are included in China data.

U.S. imports

U.S. battery imports consist of a few different types:

- **Consumer batteries**: These make up the largest portion of imported batteries. They usually include pouch-type polymer lithium-ion batteries, coin cells and cylindrical cells, which can be widely used in consumer electronic devices, cell phones and computers, electric tools and scooters. Apple, Amazon, Bosch, Sony are typical buyers for these batteries. LG Chem, Samsung SDI, Panasonic and a number of Chinese consumer battery manufacturers are the major exporters. These batteries mostly come from China, where all of above battery makers have located large-scale manufacturing bases.
- **EV battery packs**: Automaker demand for modules and packs account for the lion's share of this category. Overseas-headquartered carmakers Volkswagen, BMW, Toyota all import from their global pack production bases in their headquarter nations rather than build local pack plants. Such strategies have generally been sensible and cost competitive as U.S. EV demand today is relatively low. However, that could soon change. U.S.-headquartered carmakers also import batteries from leading battery makers worldwide.
- **Batteries used for stationary storage system integration:** The boom of the utility-scale storage deployments and residential storage markets has led to an increase in imports of racks and containerized battery systems. System integrators such as Fluence or GE may for instance import batteries from LG Chem's China factory while Doosan may source from Samsung SDI's plant in South Korea.
- **Cells and components for further local productions:** Some battery makers and independent pack assemblers with U.S. presences also import cells, components and auxiliary materials from their major production bases. Samsung SDI for instance, imports cells from its plants in Europe, South Korea and China to the U.S., where it only has a pack plant. LG Chem's cell plant in Michigan uses cathodes and electrolytes imported from South Korea and China.

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U.S. exports

U.S. gross exports of battery equipment totals approximately $100 million each month – roughly one third to one quarter the volume of gross exports. Tesla has made up the largest portion of batteries exported in the past two years. Tesla's EV packs have shipped to its newly commissioned Shanghai plant. The company has also sold its Powerwall, Powerpack and Megapack batteries for use at homes or on the grid in Germany and Australia. Apart from minor EV packs and storage battery systems, the exports to other regional markets are mostly consumer batteries.

China

China's gross monthly battery exports have almost tripled on average over last three years. In July 2020, the country hit a new high with $1.49 billion in gross exports, thanks in part to the country's quick recovery from the Covid-19 pandemic. Batteries made in China today are shipped widely to more than 200 countries. In addition to China-headquartered firms that export, overseas firms with operations in the country also send their products from plants they operate in China. Panasonic, LG Chem and Samsung SDI all have facilities in mainland China. Trade volumes and products vary by company and by export destinations.

- Batteries that are shipped to regions without significant EV production are most likely to be used in consumer devices. This includes Southeast Asia, India and the rest of the world (Figure 33).
- China-Europe and China-U.S. battery trade is rising in volume and scope. Most batteries are still for consumer electronics but this is changing. Automakers in these regions mostly have established in-depth partnerships with leading battery makers in light of the increasing EV demand. Battery makers are likely to use their established capacities in China to ensure stable supply before establishing operations overseas. Chinese firms unwilling for the moment to establish major manufacturing capacity at the top of the value chain are exporting such components.
- China-Japan and China-Korea trade tends to be more complex, as leading battery makers from these countries also have strong presences in China. They have built cross-national supply chains for the components and equipment used in battery manufacturing. For instance, it is common for a Korean battery maker to import precursors and lithium chemicals from China for local cathode processing in Korea. The firm then ships the cathodes back to its Chinese factory for cell manufacturing.

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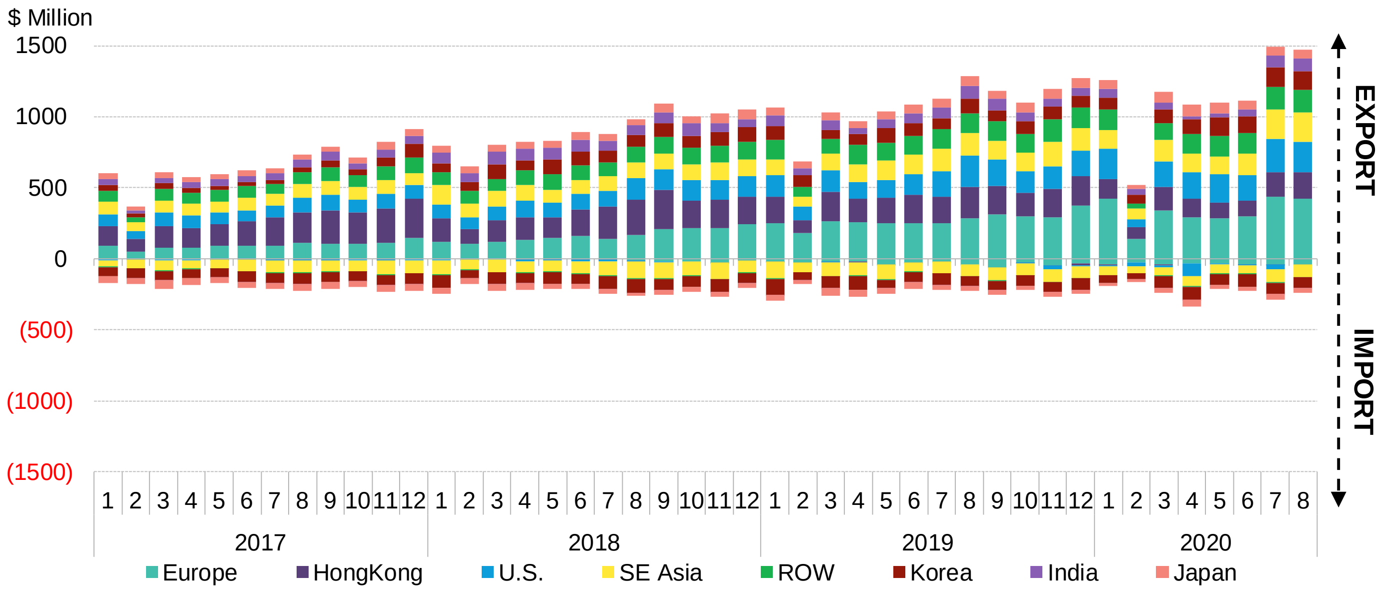
Figure 33: China battery trade flow

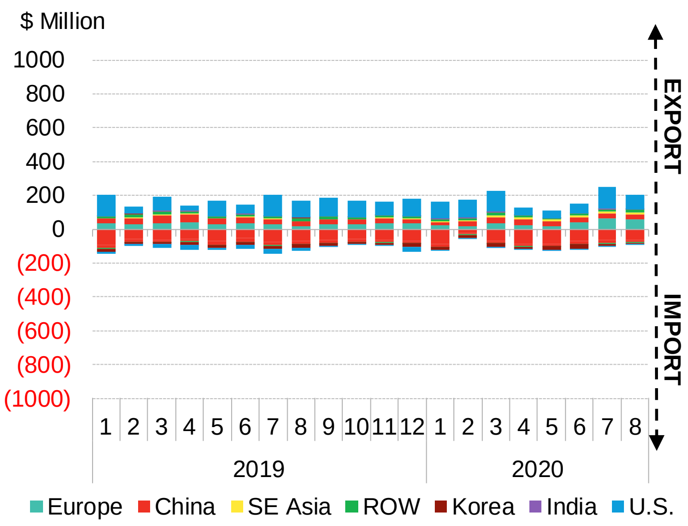


Source: BloombergNEF. China Customs.

Japan and South Korea

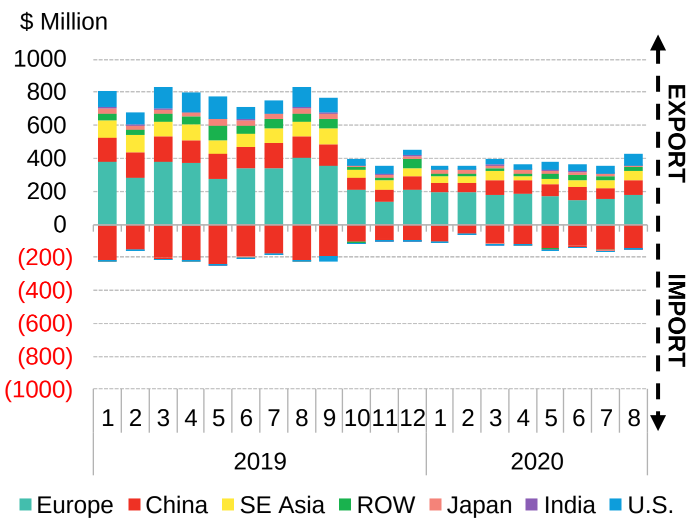
As longstanding battery manufacturing nations, Japan and Korea are also net exporters. Trade volumes from Japan however are largely dwarfed by Korea (Figure 34, Figure 35). A large portion of batteries exported from Japan go to the U.S. while Korea has a more extensive list of exporting partners. The fall in Korean exports post-3Q 2019 might be due to LG Chem, SK Innovation and Samsung SDI commissioning new plants in Europe and China, which cut their reliance on domestic manufacturing. Both Japan and Korea import large volumes from China, largely because of the plants Japanese and Korean firms own in China.

Figure 34: Japan battery trade flow



Source: Source: BloombergNEF, Japan Customs

Figure 35: South Korea battery trade flow



Source: BloombergNEF, South Korea Customs

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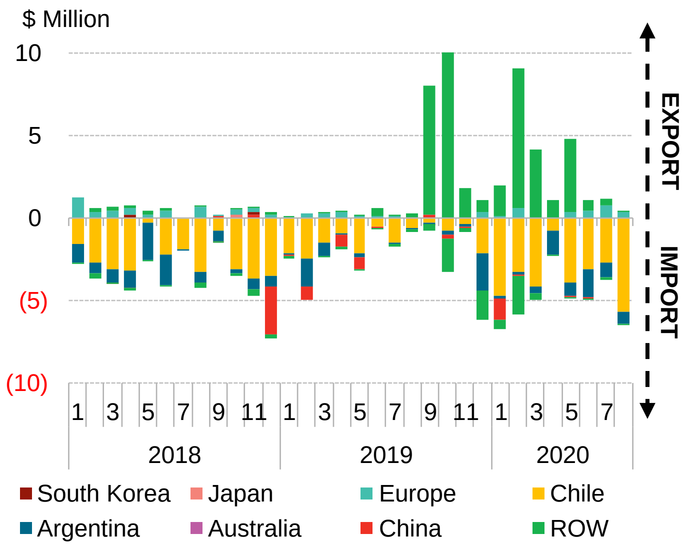
Metals

Lithium

Trade of lithium chemicals reported by the U.S. varies greatly between carbonates and hydroxides (Figure 36, Figure 37). Lithium giants Albemarle and FMC Lithium (operated by Livent) account for major portions of trade of both chemicals. The carbonates imported into the U.S. mostly come from Chile, where both companies own deposits and operate refineries. Monthly exports of carbonates vary month to month by volume and destination, spanning a range of countries in Latin America and Europe. Along with serving the battery market, lithium carbonates are used the production of pharmaceuticals. By contrast, hydroxides go mainly to Japan for use in battery manufacturing.

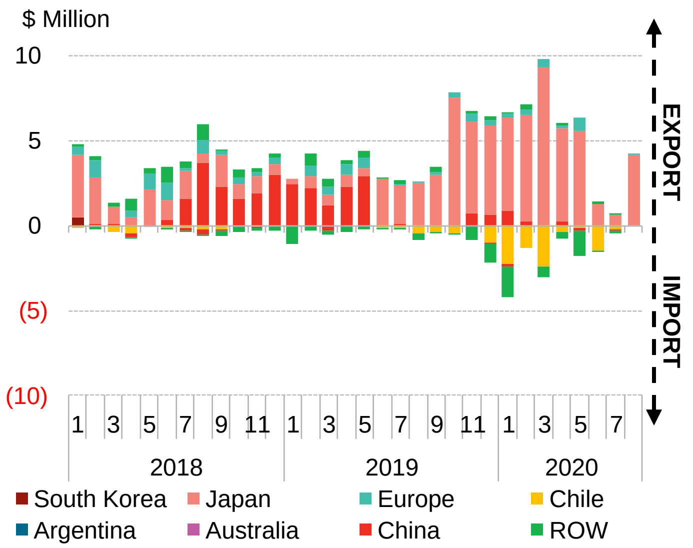
Compared to carbonates, monthly imports of hydroxides are relatively small. One potential reason: the major lithium firms convert carbonates into hydroxides in their plants in the U.S. Hydroxide is also hard to transport.

Figure 36: U.S. lithium carbonates trade flow



Source: BloombergNEF, Bloomberg Terminal command US BOL <AHOY>. Note: Includes Hong Kong in China figures.

Figure 37: U.S. lithium hydroxide trade flow



Source: BloombergNEF, Bloomberg Terminal command US BOL <AHOY>. Note: Includes Hong Kong in China figures.

Cobalt

U.S. imports and exports of cobalt were largely balanced until 4Q 2019 (Figure 38) when the market was largely put on pause due to investigations into worker conditions in the Democratic Republic of Congo. Traded cobalt compounds are a mix of cobalt oxides, cobalt sulfates and lithium nickel manganese cobalt oxide – the NMC cathodes. Monthly trade volumes have dropped from roughly $10 million to just $1 million as investigations into “artisanal” cobalt sourced from the DRC have proceeded. Companies have since pledged to take greater responsibility for sourcing more ethically produced cobalt.

The U.S. imports most cobalt compounds from Belgium, where the refining giant Umicore is headquartered. Chinese cobalt chemical company Zhejiang Huayou Cobalt, Finland-based cobalt products provider Freeport and chemical giant BASF are also major participants in the cobalt trade with the U.S.

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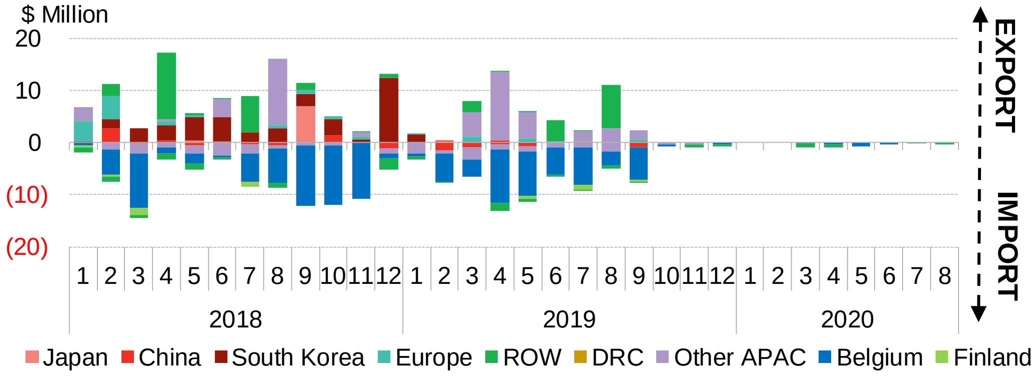
Cobalt chemicals exported from the U.S. go to a range of countries, including Vietnam, India, Singapore, Saudi Arabia and South Korea. Apart from the exports to Korea and Japan, U.S. cobalt compounds do not directly go into the battery supply chain. Rather, they are likely to be further processed or shipped to other markets.

Figure 38: U.S. trade flow for cobalt ore, concentrates and chemicals in total



Source: BloombergNEF, US BOL <AHOY>. Note: Include Hong Kong into China.

Nickel

U.S. trade of nickel is a good deal smaller than that of lithium or cobalt. Just $1 million of trade occurs in a typical month, although larger deals occasionally take place. Nickel sulfate is the primary product that moves. Apart from sulfate, other nickel products are mostly mined nickel, which contributed to significant imports in December 2019, January 2020 and April 2020. For nickel sulfates, imports largely dwarf exports. Average monthly imports are roughly $1 million and mostly come from Belgium and Taiwan. There is relatively little local production of precursors and cathodes in the U.S., so most imported nickel chemicals are expected to be used in other industries such as stainless steel production.

Figure 39: U.S. trade flow for nickel ore, concentrates and chemicals in total

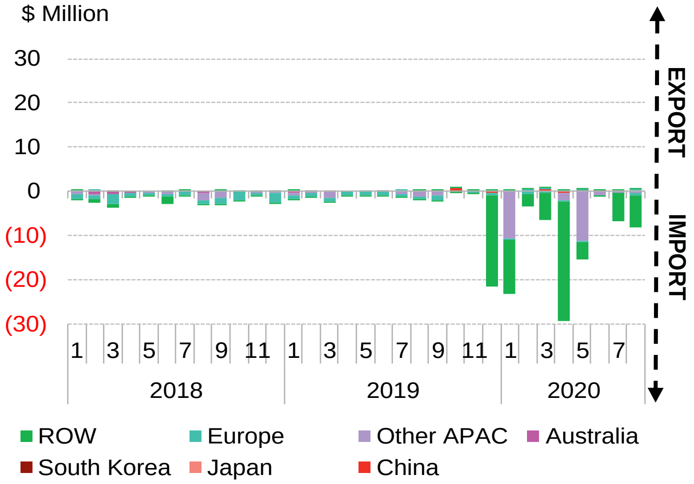
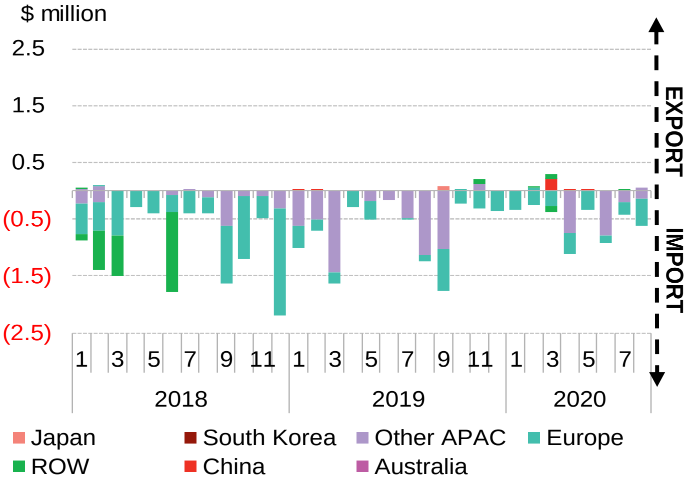


Figure 40: U.S. trade flow for nickel sulfate



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Source: BloombergNEF, US BOL <AHOY>. Note: Include Hong Kong into China.

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Table 2: U.S. cumulative EV market share, 2011-3Q 2020

Tesla	41%
General Motors	15%
Nissan Motor	9%
Toyota	8%
Ford	8%

Source: BloombergNEF

Value break-down

The supply chain strategies for the leading suppliers of li-ion batteries in the U.S. battery companies vary so considerably that it is impossible to display a single, representative value break-out for a finished li-ion battery assembled in the U.S. Instead, we offer here illustrative examples of a typical Tesla/Panasonic battery and one made by a major Korean manufacturer with cell manufacturing capacity in the U.S.

Tesla, which sold 41% of all EVs in the U.S. from 2011 through 3Q 2020 (Table 2), has considerable and increasingly integrated manufacturing capacity located on U.S. soil, which explains the relatively high value that accrues to the U.S. through the production of one of its batteries (Figure 41). Its partnership with Panasonic ensures Japan is a close second. Much of the value associated with the cathode, anode, electrolyte and separator accrues to Japan, whereas pack assembly is located in the U.S.

By contrast, a Korean manufacturer such as LG Chem, Samsung SDI or SK Innovation has a markedly different supply chain (Figure 42). The share of product made in the U.S. is lower, and most of the pack is made in Korea, meaning the value accrues there. We assume some cathode material is sourced from Europe as well due to ease of supply lines between the countries.

The picture is similar in Europe at the moment although this will change as the region's battery supply chain scales. By contrast, in China 100% of the value of a finished battery tends to accrue locally.

Figure 41: Estimated value break-out of a typical Tesla/Panasonic battery assembled on U.S. soil

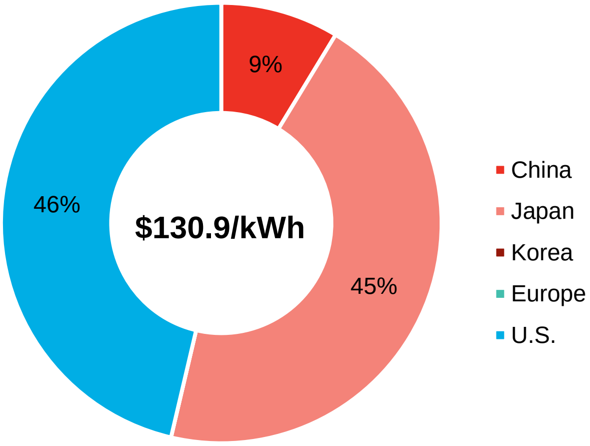
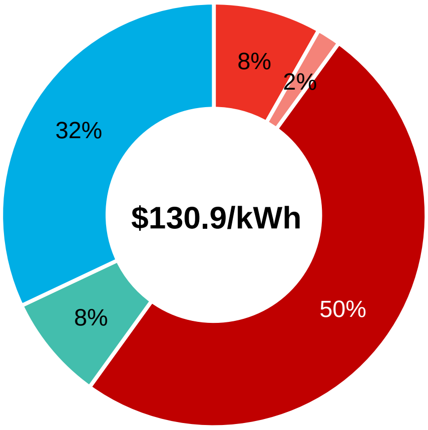


Figure 42: Estimated value of a typical battery assembled on U.S. soil in a plant owned by a Korean manufacturer



Source: BloombergNEF. Note: Both cost calculations are based on a 60Ah prismatic cell using NMC (622) chemistry. The cells are assumed to be produced at a 10GWh plant, which operates 330 days/year, 24 hours/day. Cell costs include cathode, anode, separator, electrolyte, labor, manufacturing and depreciation.

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