Q3 2023

rho motion magazine

Exploring the New Energy Matrix

In this issue:

Industrial policy for the energy transition: A step back?

Storage as transmission assets: What, why and how?

China's tariff structure and tariff reforms

Introduction to the magazine

Adam Panayi
Managing Director, Rho Motion

Hello and welcome to the Q3 2023 edition of the Rho Motion Magazine

This quarter we're pleased to bring you another broad range of articles from our Analyst team, who have had free reign to expand on a subject of their choosing. We have also included an extract from our latest whitepaper titled the Rho Motion Energy Matrix which provides both a macro view of our expectations for the overall energy landscape, while leveraging our expertise and unrivalled detail at the industry and technology level. To receive the full whitepaper register here.

In this edition my colleague Shan Tomouk provides an analysis of industrial policy and asks if this new era of onshoring supply chains will end up slowing the energy transition. Second, Research Analyst Xinyi Lin explains China's tariff structure and reforms, and the implications of these for its international partners.

On a related topic Mina Ha outlines the expansion plans of South Korea battery recyclers as all players seek to gain competitive advantage in the early stages of this market. While Ed Keith and Terry Scarrott, who both handle our single client consulting work, discuss the five things you don't (yet) know about the lithium ion battery recycling market. Also on recycling, we're very grateful to Nth Cycle for the excellent article on its Electro-extraction technology.

We then shift focus to energy stationary storage and the grid with an excellent article from my colleague Pete Tillotson on the role of energy storage as a tool for energy management and transmission. On a similar note, Varnika Agarwal provides an analysis of how alternative battery technologies may be employed for long duration storage.

Moving to the vehicle market China Research Lead Yu (Frank) Du outlines the progress towards high voltage EV platforms and the relative advantages of these over current technologies, while Automotive Research Lead William Roberts discusses the role, if any, of solar powered cars.

We also have our usual round-up of the latest public financial transactions from our Energy Transition Capital publication.

I hope you enjoy the magazine,
Adam

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Energy Matrix

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The energy transition is global, multi-sector change drawing in legacy and new technologies as we seek to meet global climate goals. Rho Motion's Energy Matrix provides an insight into the decarbonization efforts across multiple sectors, such as transport, buildings and industry. Within this exclusive whitepaper, we also outline some of our expectations surrounding the development of renewable energy sources such as wind and solar and how we expect energy supply fuel mixes to shift over time.

This is an extract from the whitepaper outlining some of our expectations for the future of energy demand. To receive the full 20 page document register here.

Energy Demand

A key driver in the pursuit for energy efficiency is a shift to electricity in the energy mix.

Global energy demand measured at the end point of use, often called total final consumption (TFC) is typically the most interesting metric when looking at long term trends. It excludes power losses and energy used within the energy sector itself. This is captured within the total primary energy supply (TPES) in the supply section of this report.

Global TFC is primarily comprised of three main sectors: Industry, Buildings and Transport. Global TFC is expected to continue to grow (Figure 1), reaching a peak in 2031-2032 before slowly declining, as efficiency gains begin to materialise and offset demand growth from economic expansion. Though peak TFC is expected in the early 2030s, y-o-y decline will be slow as opposing forces cancel each other out.

By 2030, we expect Industry will continue to be the dominant sector, accounting for approximately 42% of TFC. Buildings consumption is expected to decrease marginally to 27%, with the Transport sector accounting for 25%. This makes sense given efficiency gains in industrial applications are more limited than those in Buildings and Transport.

Improvements in energy efficiency will be the key determinant in the effort to reduce TFC, though doing this at an attractive cost will be vital for incentivising industrialising countries to follow suit.

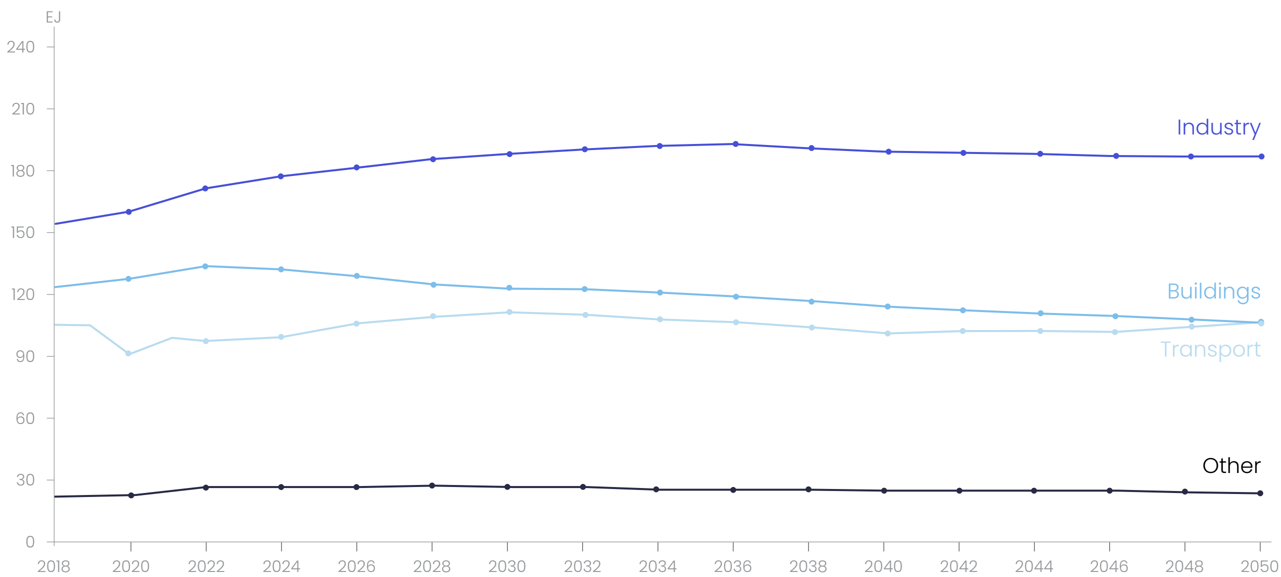
A key driver in the pursuit for energy efficiency is a shift to electricity in the energy mix. Not only is electricity generation a more efficient use of fossil fuels, but also gives rise to low-carbon or renewable alternatives such as solar, wind or nuclear energy. Across the forecast period, oil is expected to rise gradually before peaking in the early 2030s and declining over time. The Transport sector will be the key for reducing end-use oil demand through the electrification of on-road transport. Today, the sector accounts for 66% of end-use oil consumption.

Electricity will also play a major role in reducing energy demand from both the Buildings and Industry sectors in future. The development of new building standards with regards to materials and efficiency savings will help guide both developed and emerging economics globally. The development of electricity grids in lower-income countries will also reduce the burning of traditional biomass fuels, a typically inefficient and high-emissions approach to heating.

Industry will arguably be the most difficult problem to solve and will be the primary user of coal into the future. Although there are new technologies on the horizon, more is needed to incentivise industry players to act to reduce environmental impacts of industrial processes.

Figure 1: Total final consumption by sector

Source: Rho Motion



Industry

Industry comprises of both heavy industry (production of steel, cement, aluminium, chemicals and similar), and light industry (manufacturing of goods, machinery and textiles). The sector has been particularly challenging to abate in the early steps of the energy transition as a result of the high-heat requirements from multiple subsectors.

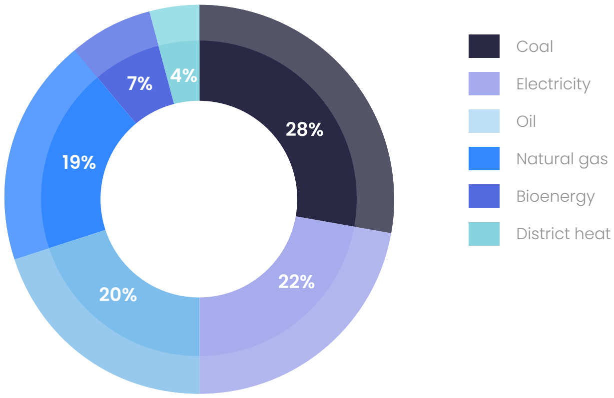
Few alternatives exist to fossil fuels when looking at high-head applications. The development of electric arc furnaces (EAFs) have provided some potential for emissions reductions in steel production. However, limitations with scrap and the high costs of electricity and equipment have slowed growth in this market. Low carbon or green steel are newer entrants to the market which hope to reduce overall emissions by relying upon lower carbon fuels such as hydrogen.

Cement is another market that poses issues for emissions reductions targets. The energy-intensive process of heating limestone to product cement clinker – the primary feedstock for cement – is difficult to substitute currently for multiple reasons. Firstly, lower-carbon techniques or feedstocks are currently costly, with little in the way of subsidisation from governments. Additionally, the stringent regulations for concrete used in buildings mean any change in feedstock or technology is a long-term process.

Currently, carbon capture, utilisation and storage (CCUS) is emerging as the front runner for abatement across multiple industrial markets. Though technological obstacles, in addition to cost, likely mean this will be a long-term reality for much of the industry.

> *In the long-run, the emergence of cheaper hydrogen and renewables will help to reduce total emissions from industry, as efficiency improvements gain momentum.*

Figure 2: Industry TFC by fuel 2023 *Source: Rho Motion*



Despite hitting peak coal demand in 2013, the fuel remains the dominant in Industry at 28% in 2023 (Figure 2). This is forecasted to decline in the coming years to 23% by 2030 and 14% by 2040 as electricity-driven processes become more viable and as industrialising giants such as India and China slow down production expansion.

In the long-run, the emergence of cheaper hydrogen and renewables will help to reduce total emissions from industry, as efficiency improvements gain momentum.

The most significant barrier to emissions reductions in the industrial sector is cost. While high costs remain an issue in all sectors, it is particularly problematic in industry. This is because of the focus on cost-reduction for newly-industrialising countries. Developing countries entering into existing manufacturing industries are typically uncompetitive in the early stages and must rely heavily upon incentives and subsidisation schemes outlined within industrial policies.

With such a focus on reducing costs and protecting infant industries already, it is difficult to see why emerging economies would opt for highly-expensive lower-emissions fuels or processes and potentially inhibit their own economic development. Though some international agreements make accommodations for developing countries, a reduction in costs for new technologies will be vital for future emissions reductions. It is likely that the majority of these costs will come in developed countries and trickle down over time.

We are already seeing the early signs of this in countries such as India, where solar power is at or below the cost of coal, incentivising the country to look at building future industrial growth on renewable energy rather than coal, or imported oil. While the benefit of this is a reduction in emissions, the drivers are cost and greater energy security.

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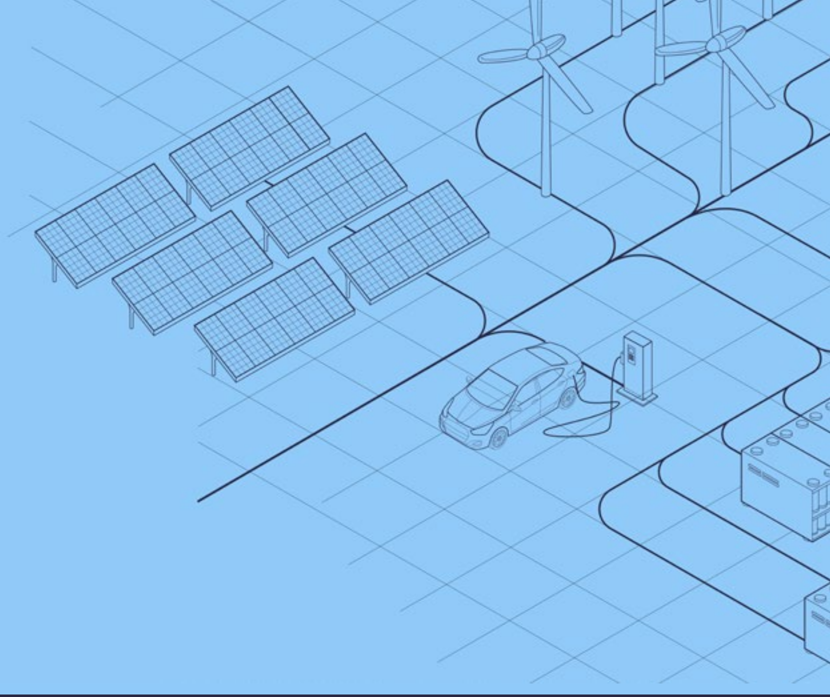
Battery Demand Service



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The Battery Demand Service combines all our battery outlooks and assessments in one place.

	Pro	Plus	Premium
Battery Demand Service: Outlook Excel file • Updated in line with outlook report releases	✓	✓	✓
EV & Battery Quarterly Outlook PDF and Excel File • Quarterly releases	✓	✓	✓
Hybrid EV Quarterly Outlook PDF and Excel File • Quarterly releases	✓	✓	✓
Battery Energy Stationary Storage Outlook PDF and Excel File • Quarterly releases	✓	✓	✓
Fuel Cell Electric Vehicle Outlook PDF and Excel File • Annual releases	✓	✓	✓
Electric 2&3 Wheeler Outlook PDF and Excel File • Annual releases	✓	✓	✓
Electric Micro Mobility Outlook PDF and Excel File • Annual releases	✓	✓	✓
Portables Battery Outlook PDF and Excel File • Annual releases	✓	✓	✓
NRMM Battery Outlook PDF and Excel File • Annual releases	✓	✓	✓
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Industrial policy for the energy transition: A step back?

Shan Tomouk
Senior Reseach Analyst, Rho Motion

Photo: C A/Wirestock

For the past several decades, an age of globalisation and trade liberalisation has swept across the world economy, through the evolution of multilateral and bilateral trade agreements, reduction of cross-border barriers and promotion of private enterprise and capitalism. If asked how the developed countries of today were able to pull ahead in the global rat race of economic growth, you would be forgiven for providing free market trade as the answer. Indeed, several proponents of free market economics have argued this. One example explains how Britain's liberalisation of trade unlocked the country's entrepreneurial spirit, allowing it to rise above competitors at the time and fuel its industrial revolution. However, this does not paint the entire picture.

When we look at the wealthy nations of today, with the exception of the oil-producing countries in the Middle East, nearly all countries have one thing in common. They all underwent some form of industrialisation to achieve their development. Industrialisation has proved a key step for any country looking to transition from primary industries to a service-based economy typically associated with wealthier nations today. A notable example of a country that tried to circumvent this path was India, which famously tried to transition straight to a service-based economy reliant upon tertiary sectors. While this provided some short-term success, the lack of productivity growth typically enjoyed through manufacturing led to several issues, ultimately forcing the country to opt for a 'reindustrialisation' strategy in later years.

However, successful industrialisation is no easy task. Developing manufacturing industries is an expensive endeavour, particularly in the early stages. Lower-income nations rarely have the skilled labour or technological know-how to compete on a global level with long-established countries that have built competitive advantages over time. Though wealthy countries today enjoy the benefits of low barriers to trade, the vast majority relied heavily on state support in the early days of growth.

For example, the United States, often seen as the global voice of free market economics, had import tariffs as high as 40-50% on industrial goods in the 1870s to help support its manufacturing growth. Even earlier than this, Alexander Hamilton wrote about the importance of protecting infant industries through state intervention.

> *The IRA set a precedent for the global economy, in that when it comes to the energy transition, the status quo no longer applies.*

In Britain, one of the first beacons of free market trade, subsidies and incentives were crucial to the development of the wool manufacturing industry in the mid-18th century, a relatively high-technology industry at the time, dominated by the Netherlands and Belgium. The industry quickly became the country's largest exported good and helped pay for the supplies and raw materials needed to fuel the subsequent industrial revolution.

In more recent history, Japan, Korea, Taiwan and Singapore have all implemented policies of subsidisation and incentivisation to kickstart industrial growth, despite them being seen today as strong adopters of free market trade.

This reality of industrial policy had somewhat faded from global economic discourse, until recently. The Inflation Reduction Act (IRA) passed in the US last year came with a plethora of economic subsidies and incentives to support domestic manufacturing capabilities across multiple industries. Though criticised by some partners as flying in the face of WTO agreements, the introduction of the act highlights an interesting point. The energy transition, in many ways, represents a second industrial revolution for developed nations. In a world where energy security is a primary concern for global superpowers, there has been a marked shift in the desire to bring manufacturing home. This is particularly true for the low-carbon industries expected to fuel long-term GDP growth. Though industrialisation has historically been viewed as a stepping-stone to further development, the energy transition is altering this view. The IRA set a precedent for the global economy, in that when it comes to the energy transition, the status quo no longer applies.

Given China's dominance across multiple supply chains associated with the energy transition, it would be nearly impossible for other countries to rely upon the free market to compete. Much like the physical Great Wall of China, economies of scale, technological expertise and cheaper labour costs have all created a tall barrier for new entrants into these markets. Therefore, it is almost certain that other countries will have to support their domestic industries until they are at a point at which they can support themselves.

With the introduction of the IRA, the US opened the floodgates for other countries to engage in similar interventionist policies to protect their infant industries. Other Asian countries such as Thailand and Indonesia have also implemented subsidy and incentive programmes targeting the battery industry to try and incentivise investors to support domestic production.

For Europe, the IRA came as a disappointing surprise given the long-standing reliance on multilateral agreements that the continent has prospered from in recent decades. The

Photo: Ignacio Ferrándiz

For countries hoping they can circumvent the need for industrial policy entirely, it will be difficult to win a game when everyone else is playing by a different set of rules.

effect of the IRA has also been quickly felt, with a sharp rise in investment in the US compared with Europe. Though the bloc has since responded with its own Net Zero Industry Act, the smaller funding pot and a greater focus on targets over reward is likely to have a less-than-desired effect. For countries hoping they can circumvent the need for industrial policy entirely, it will be difficult to win a game when everyone else is playing by a different set of rules.

Despite the smaller pot of funding in the EU, we have seen initial efforts from member states to support domestic industry. In May, France announced it was reforming its criteria for the allocation of its EV subsidy to only apply to European-made vehicles. Prior to this, approximately 40% of incentives paid in France were for EVs made in China. Not only does a policy like this support demand for European products, but it also allows French tax revenues to be channelled into European suppliers, further helping the domestic industry. French President Emmanual Macron has urged other EU member states to follow suit, highlighting that this is no different from how China and now the United States are operating in the space.

While the desire to achieve domestic energy and supply chain security is currently at the forefront of thinking with this new wave of industrial policy seen in the West, the reality is more complex. Given the intricacy of supply chains across energy transition markets, such as batteries for EVs and semiconductors for solar PV modules, there will always be a need for outsourcing components and materials. Therefore, there will always be a degree of reliance on countries such as China. This is particularly true if countries plan to come anywhere near their emissions reduction targets. Instead, countries should look at it as an opportunity to grab a slice of the low-carbon pie and enjoy some of the associated productivity gains and economic benefits experienced with the growth of manufacturing industries.

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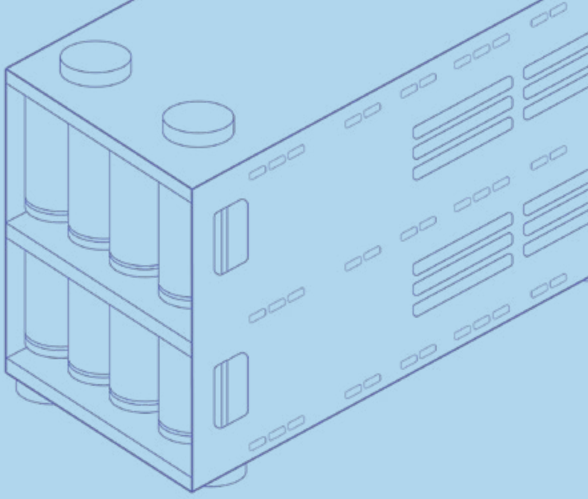

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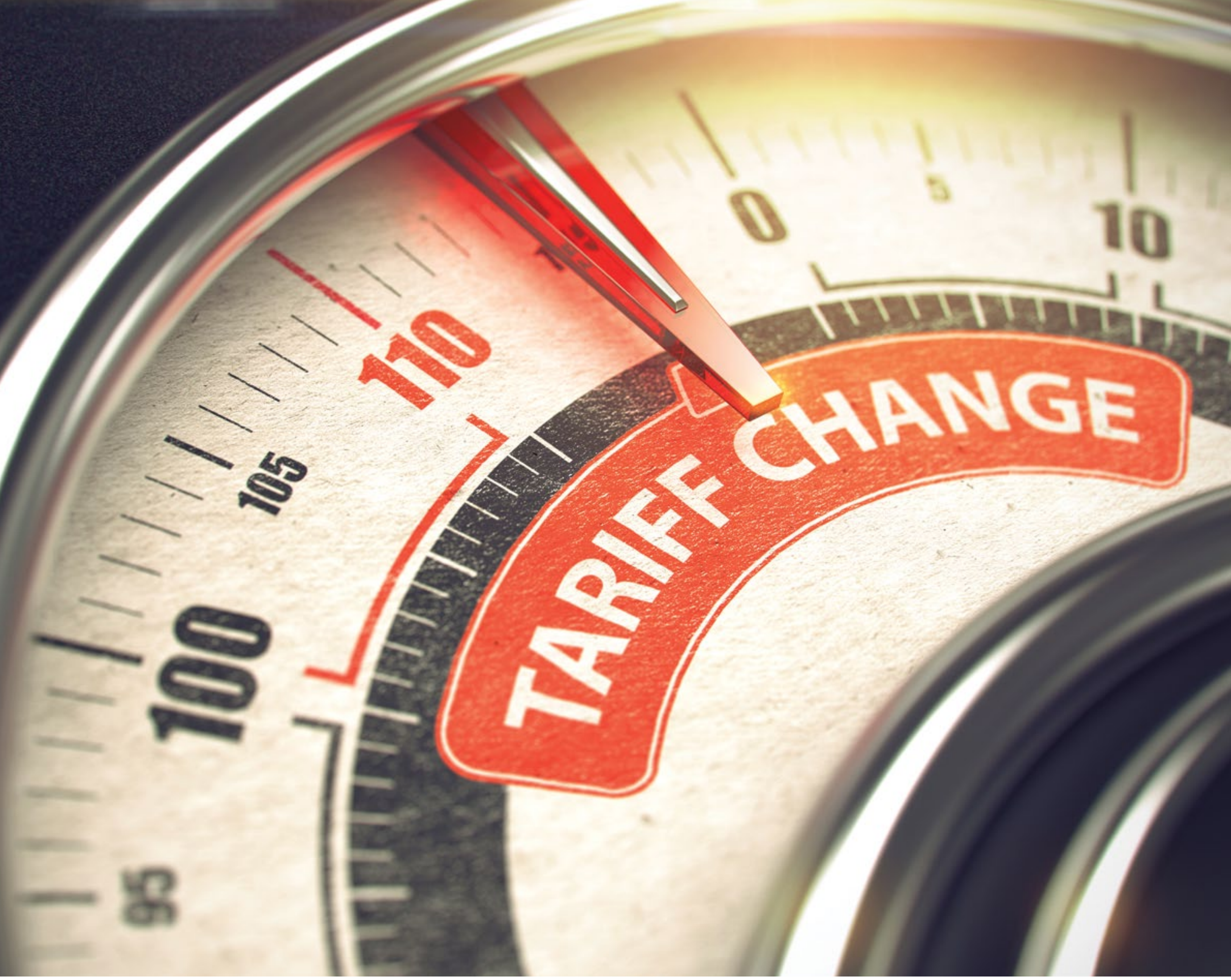


Photo: Tashatuvango

China's tariff structure and tariff reforms

Xinyi Lin
Reseach Analyst, Rho Motion

China's tariff system differs from that of other countries. So far, China has undergone several rounds of market-oriented reforms in its electricity pricing. Being a major supplier of global renewable energy technologies, ensuring the flexibility and stability of the tariff system is vital for China's electricity industry as it undergoes the decarbonisation process. This article will provide insight into China's tariff mechanisms and the progression of its tariff reforms.

Figure 1: China's fundamental tariff structure — *Source: Rho Motion*

On-grid Tariffs: The price at which power producers sell electricity to the grid.

Transmission & Distribution Price: The costs incurred during the process of electricity transmission and distribution, including the loss of energy during transmission.

Government Funds & Additional Charges: Fees used to construction of large-scale water conservancy projects, and relocation of residents in hydroelectric reservoir areas. These fees must be approved by the State Council.

Retail Tariffs: The final price for electricity consumers. According to the category of power users, the retail tariff is mainly divided into four types: large industry; general industry and commerce; residential; and agricultural.

China's fundamental tariff structure

The term 'tariff' refers to the cost associated with electricity usage, also called electricity price. In China, the unit of measurement for tariffs is 'yuan/kWh'. Electricity production involves converting primary energy into electrical energy, which is subsequently distributed to households and enterprises via the grid. The costs associated with producing and transmitting electricity contribute to the tariff. The tariff in different provinces and cities in China vary, and they are formulated by the power organisations in the respective provinces according to policy requirements and their energy use situations. However, the fundamental tariff structure can be outlined in figure 1.

Cross-subsidy policy

In most countries, residential tariffs are generally higher than industrial tariffs. However, in China, the situation is reversed; residential tariffs have remained consistently stable and are considerably lower than commercial and industrial tariffs. This can be attributed to China's unique cross-subsidy policy.

This policy aims to dynamically subsidise various user categories by adjusting the price structure without impacting the overall tariff. It ensures that different types of users bear varying supply costs. For instance, commercial tariffs subsidise residential tariffs, while tariffs in areas with high grid loads subsidise tariffs in rural regions where transmission costs are higher. Consequently, commercial tariffs are higher than residential ones. This also illustrates that China's power grid has a strong coordinating ability. In addition, the supply and demand relationship in China was not marketised then, and all the power industry's core enterprises were state-owned, which facilitated straightforward electricity allocation.

Figure 2: China's tariff reforms — *Source: Rho Motion*

China's tariff reforms can be dived into six stages

1. 1949–1985 — Government monopoly
2. 1985–1997 — Capital & interest tariff
3. 1997–2022 — Operation period tariff
4. 2002–2015 — Benchmark tariff period
5. 1997–2021 — Transmission & Distribution tariff reform
6. 2021–2015 — Time-of-use pricing system

Electricity tariff reforms

From 1949 to 1985, the Chinese government centrally managed tariffs, maintaining stability. During this period, the government attempted to introduce a two-part tariff system and implement a mechanism linking coal and electricity prices.

From 1985 to 1997, under the government's monopoly, China's electricity industry was lackadaisical, and numerous regions experienced severe power shortages, negatively impacting the Chinese economy. To address this, the government encouraged social investment and introduced a 'Capital & Interest tariff'. It mandated that the on-grid tariff include the power generation unit's costs, taxes, and profits.

The Asian financial crisis broke out in 1997, and the supply and demand relationship of electricity in China had improved. To expand demand and prevent the price of electricity from rising too quickly, China changed the 'Capital & Interest tariff' to the 'Operational period tariff'. The operational period tariff factored in operational costs, taxes, and reasonable profits over the operational period. On the other hand, it unified the management of retail tariffs; incorporated fuel transportation surcharge standards into catalogue electricity prices; and fully implemented peak-valley electricity pricing methods. During this time, reforms in rural electricity pricing were also implemented, sharing the rural electricity grid operating costs among urban and rural users, greatly enhancing the level of safe, reliable, and economical electricity use in rural areas.

In 2002, China's State Council issued the 'Electricity System Reform Plan,' marking the beginning of China's benchmark tariff period. During this stage, the electricity pricing policy separated the prices of power plants and the power grid, introducing a 'Benchmark tariff' based on the operational period tariff policy. The policy began to steer the electricity industry toward market-oriented practices. However, this mechanism at the time still had lagging issues and lacked flexibility.

To promote the growth of renewable energy generation, China also applied the benchmark tariff to renewable energy fields such as wind power, photovoltaics, and biomass power generation.

> *China must rapidly transition to renewable energy generation. The reforms of generation system are the cornerstones of this transformation.*

From 2015 to 2021, China underwent reforms in the transmission and distribution of electricity prices, forming a complete system applicable to all types of market-oriented electricity transactions. Meanwhile, the State Council decided to cancel the coal-electricity price linkage mechanism from 2020 onwards, transforming the benchmark on-grid tariff mechanism into a market-based "base price + fluctuation" system. Subsequently, electricity prices for general industry and commerce notably decreased, and cross-subsidisation improved, albeit persisting.

Starting in 2021, China began to gradually implement time-of-use pricing, scientifically dividing the periods into peak, valley, and normal times, determining the price differences between peak and off-peak periods. By widening the scope of price fluctuations in market transactions, the electricity industry managed to allocate a greater portion of the actual costs to end-users.

Looking back at the entire path of China's tariff reform, China's electricity market is gradually transitioning towards complete marketisation. Recently, China has actively promoted spot market trading in electricity, resulting in market-based transaction volumes of 5,250TWh in 2022. Nevertheless, due to centralised

Photo: Nilima

management and cross-subsidies that still exist, China's residential tariffs remain relatively low, and the cost of industrial and commercial electricity is still quite high. In 2022, the National Development and Reform Commission indicated that the corporate cross-subsidies would be reduced in the upcoming reforms. Certainly, the direction of future reforms will continue to drive tariffs towards complete marketisation through full competition.

The outlook for power system transformation under the carbon peaking and carbon neutrality goals

China's electricity generation is primarily reliant on coal-fired power, accounting for 14% of global carbon dioxide emissions. Therefore, to achieve the goals of achieving the targets of peak carbon emissions by 2030 and attaining carbon neutrality by 2060 as planned, China must rapidly transition to renewable energy generation. The reforms of generation system are the cornerstones of this transformation.

Newly constructed photovoltaic and onshore wind projects can establish on-grid prices through participation in market transactions. The central government no longer provides subsidies to the projects, implementing grid parity. On-grid prices for photovoltaic power generation have dropped from around Wind generation on-grid tariffs have also significantly decreased. The drawback of higher renewable energy generation costs has been somewhat alleviated.

From the user's perspective, the current time-of-use pricing system is not yet perfected, including challenges such as imprecise time segmentation and limited dynamic adjustment capabilities. In the future, besides adjusting for these flexibilities, time-of-use pricing may also be set according to different user types and places. This is because electric vehicle charging and swapping facilities, new energy storage, and other emerging entities on the user side have substantial potential for time-of-use regulation.

According to data released by the National Energy Administration up to June 2023, renewable energy generators in China contributed to 48.8% of the country's total installed capacity. It is foreseeable that non-clean energy will gradually phase out of China's power system. However, the fluctuating nature of renewable energy introduces significant challenges to power system flexibility, making it a pivotal aspect of future power system transformation.

Photo: Didiksaputra

South Korean battery recyclers continue their domestic and overseas expansion

Mina Ha
Senior Reseach Analyst, Rho Motion

In South Korea, there have been an increasing number of new entrants in the battery recycling market this year, which, together with existing battery recycling companies, are expected to contribute to the country's battery recycling capacity expansion in the coming years. However, whether all the capacities announced will come online will also depend on various factors such as investment, relevant business experience, and overcoming market competition.

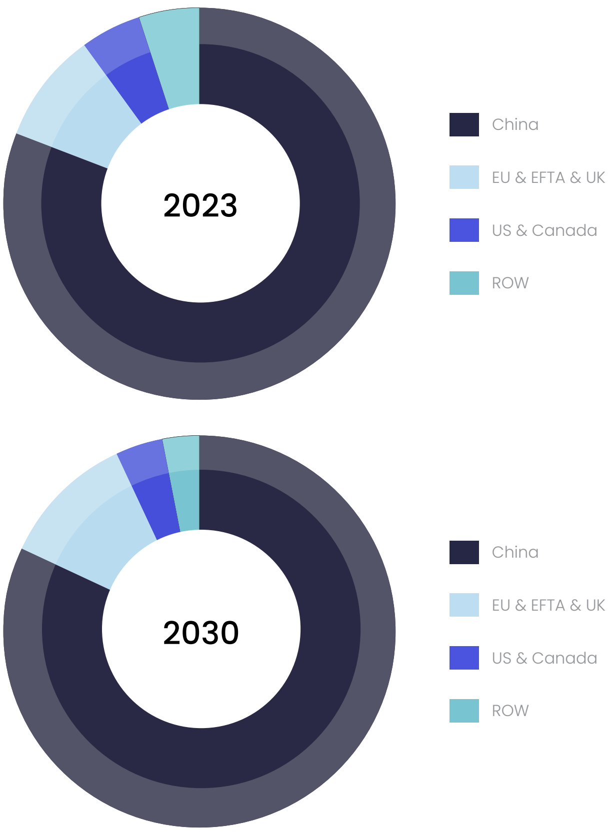
Global battery recycling capacity has reached around 1.6 million tonnes of recycling inputs as of July 2023 with China accounting for 81% of the total. Capacity is expected to continue growing around the major regions - North America, Europe, and China - where large-scale recycling plants are planned or currently under construction. Going forward, the regional capacity share is expected to stay similar with China dominating. However, recent announcements also indicate potential future capacity, not necessarily all on a large scale, in countries with relatively lower battery recycling capacities at present such as Taiwan, Italy and Romania.

New entrants are increasing in South Korea

In Asia, South Korea appears to have the second-largest recycling capacity in place after China, led by existing players such as SungEel HiTech, Posco and more. This year, new entrants from various sectors including smelting and non-EV battery players are emerging, with plans to build battery recycling plants over the next few years. Market entry strategies generally vary depending on whether a company possesses in-house recycling technology, feedstock supply channels and capital. In South Korea, new entrants often enter through acquisitions, which could be a quick way of gaining market share.

Figure 1: Regional battery recycling pre-treatment capacity share

Source: Rho Motion



Below demonstrates some of the new entrants' strategies and their expansion plans.

IS Dongseo expanded its battery recycling business through acquisitions in recent years: INSUN Motors for waste battery collection and dismantling, ISBM Solution for black mass production and IS TMC for recovering materials including lithium carbonate and NCM solution. In May 2023, IS Dongseo announced that its subsidiary ISBM Solution started the construction of its pre-treatment plant in Hwaseong, Korea. The plant is expected to have an annual capacity of over 6,000 tonnes of recycling inputs, comprising primarily of end-of-life EVs.

Korean chemical producer Kolon Industries plans to invest KRW4.5 billion (USD3.45 million) in Korean battery recycling startup RD Solution. The companies aim to construct a battery recycling plant that recovers lithium carbonate, copper and more by the end of 2023, with an economic feasibility assessment to follow.

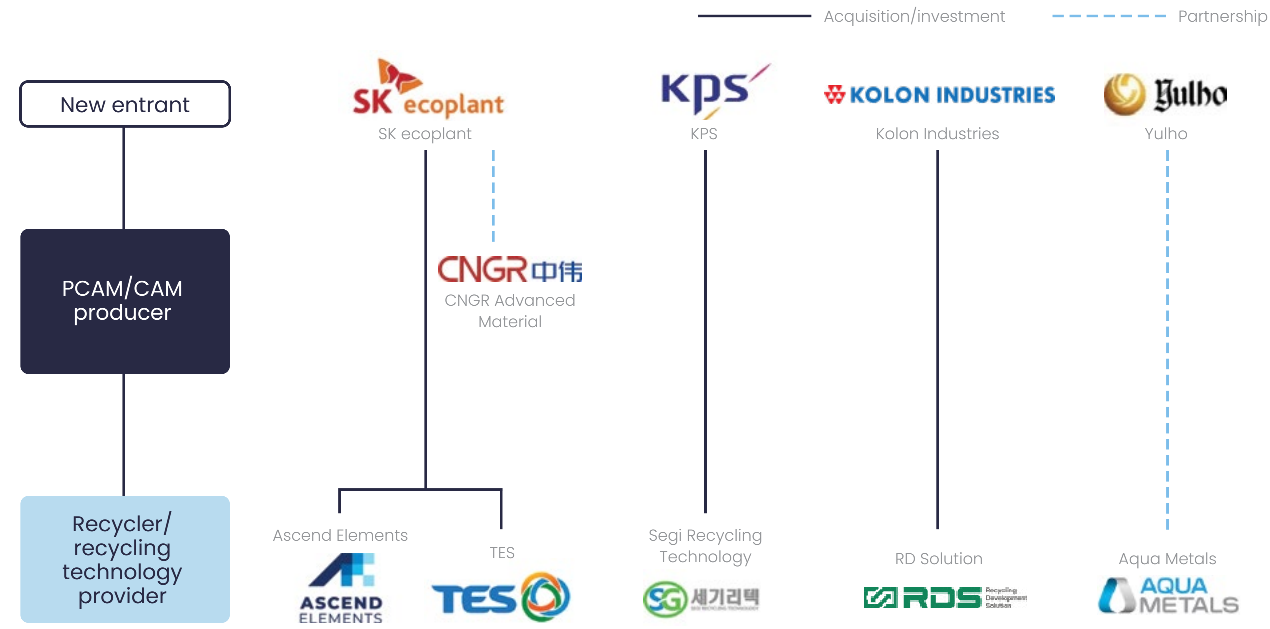
Korea-based Yulho entered the battery recycling market by setting up its subsidiary, Yulho Materials, in June 2023. Yulho Materials plans to build a black mass production plant with an annual capacity of 8,000 tonnes in Hwaseong, South Korea by the end of 2023, ramping up to 24,000 tonnes depending on the market conditions. It also plans to run refining processes by using Aqua Metals' electro-hydrometallurgical technology.

In May 2023, Korean biodiesel producer Dansuk Industrial announced it started the construction of its battery recycling plant in Gunsan, South Korea. The plant aims to start operation in 2024 with an annual capacity of 8,000 tonnes of batteries. It is also planning an IPO later this year.

Korean OLED equipment manufacturer KPS entered the market through an acquisition of Segi Recycling Technology in May 2023. Korean lead-acid battery recycler Segi Recycling Technology plans to build an LFP recycling plant in South Korea by 2024.

Figure 2: New entrants' market entry strategies

Source: Rho Motion



Expansion into Europe

Some of the new entrants are also planning to enter the European market. SungEel HiTech and Posco are currently operating in Europe and planning for further expansion. SungEel HiTech and Samsung C&T, in partnership with BeePlanet Factory and other Spanish companies, plan to build a black mass production plant with an annual capacity of 10,000 tonnes in Navarra, Spain by 2025. Posco currently has its black mass production plant, Poland Legnica Sourcing Centre, in Poland and plans to build its black mass refining plant in Europe. SK Ecoplant, a subsidiary of SK Group, entered the battery recycling market by acquiring TES in early 2022. In September 2022, it partnered with CNGR Advanced Material, a Chinese PCAM producer and battery recycler, to enter the European battery recycling market, potentially forming a joint venture in the future.

Challenges also remain

The European recycling market, which is built more on black mass production, is gaining interest from companies with post-treatment processing technologies in particular. South Korean recyclers are keen to enter the EU market through partnerships with local companies to secure both feedstock and plant permits, which companies often cite as one of the main challenges along with complying with environmental requirements. Another challenge would be that market competition in Europe is likely to get intense especially if and when Chinese recyclers, particularly large-scale operators such as

> *The European recycling market, which is built more on black mass production, is gaining interest from companies with post-treatment processing technologies in particular.*

Brunp and GEM, enter. CATL, Brunp's parent organisation, has already announced its plan to build several battery recycling plants in Europe and US. Potential candidates for its first European battery recycling site include Germany and Hungary where CATL plans to expand its battery production. GEM is also considering plant locations in Europe.

In short, new South Korean entrants, together with existing players, are expected to contribute to an increase in the country's battery recycling capacity and potentially in Europe's too. However, whether all these announced capacities will come online will also depend on various factors such as raising capital, relevant business experience, and overcoming market competition.

rho motion

Battery Recycling Outlook

Our Battery Recycling Outlook provides a long-term outlook for global scrap material available for battery recycling. The outlook is presented by region, battery chemistry and feedstock and covers end-of-life EVs, battery manufacturing scrap and end-of-life energy stationary storage.

EV & BATTERY • CHARGING • INFRASTRUCTURE

Our forecast provides long-term outlooks for the following:

GWh of BEV and PHEV scrap material available for battery recycling by feedstock, battery chemistry and region to 2040

Tonnes of black mass available for battery recycling by feedstock, battery chemistry and region to 2040

Battery recycling technologies

Battery recycling OEM profiles

Battery recycling legislation

The battery recycling market is gaining traction as EV value chains evolve toward long-term sustainability goals amid future raw material shortages and environmental, social, and governance (ESG) concerns.

The outlook provides an in-depth analysis of the current and future battery recycling market in aspects of the market dynamics, technologies, and key drivers. The report can be used as a tool to understand how the market grows at global, regional, and country levels on the back of EV demand, legislation, and recycling company strategies.

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Photo: Markobe

The five key things you don't know about the lithium-ion battery recycling market

Terry Scarrott
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Ed Keith
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Battery recycling is widely expected to provide the lithium-ion battery (LiB) industry with a long-term solution to some of its greatest challenges, including the scarcity of supply of battery-grade active materials, and finding ways to close the loop on the supply chain to improve ESG credentials. By 2030, the pool of global metals recovered (primarily nickel, cobalt, lithium, and manganese) via LiB recycling is expected to be close to 2 million tonnes per annum, rising to nearly 8 million tonnes by 2040 at a compound annual growth of 16% between 2030 to 2040 (source: Rho Motion, 2023).

At this early stage of development in the LiB recycling industry, multiple actors in the value chain are taking proactive steps to build capability and capacity to recycle second-life production and battery scraps, however, at present, no single LiB recycling player outside of China has comprehensively resolved the challenge to convert second-life scrap materials to battery-grade materials as a viable business at scale.

Unsurprisingly, there is little transparency and consistency when it comes to reporting of key performance indicators in the LiB recycling space; cost structures, payables, feedstock inputs, recycling throughputs, process flows, and recovery rates are all closely guarded as emerging players strive to create viable scalable business models whilst protecting their IP. This, of course, makes it incredibly challenging to produce meaningful comparisons from recycling operation-to-operation, which, accordingly, deters investors from making key investments that are needed to stimulate growth in the sector. In the absence of definitive harmonisations, Rho Motion presents some of its key observations for those considering position in the sector.

There is no consistent mechanism for payables

Recycling players wish to model their profitability and tolerance to market and future supply chain dynamics through an understanding of payables, whether those are for black mass, battery-grade active materials or intermediates. The choice of business model is likely to be strongly determined by the profitability, for example, the type of tolling or buy/sell arrangement.

At present, the price mechanism for black mass payables is developing but not robust, while those involved in post-treatment hydrometallurgical processing are not always sure as to whether recycling should command a processing or 'green' price premium, cost pass-through or another pricing mechanism. The difference in composition and purity of recycling outputs, particularly black mass, from operation-to-operation means there is always likely to be ambiguity in the pricing of those materials, and therefore should be treated as speciality materials with unique price points, agreed between buyer and seller, rather than a market price.

The mechanism for pricing of payables is likely to evolve as current recycling players recycle greater volumes of production scrap than battery scrap; the former commanding a higher recovery price because of the higher purity inherited from the feedstock. The evolution of pricing is also likely to change as end-of-life battery volumes, especially from electric vehicles, become the dominant feedstock in the early 2030s. Recyclers will be faced with the prospect of deciding whether they are comfortable taking on a tolling arrangement if it minimises risk of securing access to increasingly greater volumes of feedstock material.

Current evidence collated by Rho Motion suggests that tolling arrangements don't really exist as a 'gate' fee but are more incorporated into revenue models based on the metal payable (based on purity and recovery rate), essentially a concept of an implied tolling charge. Payables are expected to be around 60-70%, like those achieved in chemical refining. Equally, recovery rates for any given operation must be scrutinised before definitive conclusions can be made regarding the potential payable. Fundamentally, the questions that should be asked are: what is the recovery rate being reported and for what material?

Profitability delta is likely to be wide from operation-to-operation; treat financial comparisons with caution!

Recycling process flows are often a closely guarded secret, and therefore it's virtually impossible to understand the true cost structure of all recycling operations. For hydrometallurgical players, the differential on the opex can be incredibly wide, determined by multiple variables such as the type of reagents used, maintenance, and utilities; owed to the unique requirements of the operation, including feedstock inputs, processing steps, type of reagents, quality of the output and yield, and level of vertical integration from the point of disassembly through battery-grade chemical recovery. Furthermore, both capex and opex will be determined by the degree of vertical integration within the process, for example those that can perform pre-treatment (e.g., black mass refining) and post-treatment (e.g., hydrometallurgical extraction) are likely to find a clearer path to cost optimisation than, say, those who only undertake post-treatment by inheriting black mass from third-party suppliers. Fundamentally, profitability is sensitive to the cost structure, payable and the recovery rate.

The current landscape from battery collection to black mass refining is a Wild West

At present, most of the world's black mass produced is either transported to South Korea or China because it is logistically easier and cheaper than transporting batteries for disassembly and shredding. Modern processes include local collection hubs, with initial comminution and separation of materials to obtain black mass. Currently, the industry is the Wild West for collection and sale of EoL batteries, with "middle-men" acting within and setting unique price points based on their capability and output, some of whom are merely brokers with little experience.

Greater regulatory control would, in theory, harmonise this part of the supply chain, but requires a universally agreed global policy to remove the disparities associated with handling, processing, transporting, storage, and disposal of batteries and black mass material. Furthermore, the fact there is likely to be multiple battery technologies available for EOL in the next decade means that recyclers and investors should get comfortable with the idea that it will be difficult to harmonise the composition of black mass content, and therefore more pertinent to pivot according to the availability of EOL battery feedstocks that are available.

Emerging recycling operations will likely require heavy subsidising to be competitive with scaled Chinese players

In recent months, the European and North American markets have both set legislative targets to stimulate the LiB recycling sector; the US Inflation Reduction Act has introduced specific critical minerals requirements as part of its Clean Vehicle Credit to incentivise recyclers, while the European Commission has set stringent minimum thresholds to encourage recyclers to localise supply chains and remain tariff-free.

The current reality is that Chinese recyclers are likely to be more competitive because of the heavy subsidisation that has taken place in the LiB recycling sector. Emerging recyclers outside of China will require greater support mechanisms to be competitive, especially in Europe where there is an evident lack of financial support at the European Commission level. Therefore, it is likely to fall on governments at a national level to provide the necessary

Photo: Usmanify

support to grow their respective LiB recycling markets, treating it as both a problem that needs to be addressed and a business opportunity.

Recycling capacities are often mis-reported or mis-represented

In recent months, Rho Motion has discovered that many players within the recycling sector have made unsubstantiated claims about their recycling capabilities, potentially as a way of attracting interest and investment. For example, few European and North American hydrometallurgical players have post-treatment capacity at scale or remain undisclosed, while reported values are often reflective of pre-treatment black mass capability rather than post-treatment recovery of metal salts or battery-grade chemical forms. In Europe, only a couple of players have reliably committed to a specific hydrometallurgical post-treatment capacity of black mass, while all other players remain undisclosed.

> *The type of recycling business model will be determined by the economics, and therefore will likely be unique to the specific operation.*

It should also be noted that no two recycling processes are the same, and therefore any comparisons taken, say, between different hydrometallurgical refiners should be treated as indicative. As the LiB recycling industry scales across the globe, however, so is the expected quality of reporting and transparency of recycling capacities and capabilities.

Conclusions

The LiB recycling industry is still in its early stage of development, however multiple players are taking an early position to build capability and capacity to address the tremendous opportunity on the horizon, especially when a significant volume of EOL batteries from electric vehicles becomes available for recycling post-2030. And, they will require investment to scale.

Those involved in the LiB recycling sector are trying to gain a better understanding of the cost structures and payables to determine profitability, however this is currently challenging when most of the operations are at pilot-scale or conceptual. For recyclers, payables will be key to determine profitability, driven through evolving contractual arrangements, both with suppliers and offtakers. The type of business model will be determined by the economics, and therefore will likely be unique to the specific operation. For vendor due diligence, understanding the unique commercial and technical challenges for battery recyclers will be key to determine the level of risk and, ultimately, the potential financial rewards for any given asset.

To discuss opportunities regarding commercial due diligence or market entry, please contract us... facilities, new energy storage, and other emerging entities on the user side have substantial potential for time-of-use regulation.

Photo: Nth Cycle

Electro-extraction: Solving the demand for critical metals

Chad D. Vecitis, PhD.
Co-Founder & Chief Scientist, Nth Cycle

In 2012, the National Renewable Energy Laboratory (NREL) released the Renewable Electricity Futures Study ("RE Futures"), which predicted renewable energy resources could technologically and economically supply 80% of U.S. electricity in 2050, while balancing supply and demand every hour of every day in every region. The analysis included shifting to predominantly end-use electricity demand in the building, transportation, and industrial sectors.

Electrification is inevitable

Eleven years later, we have a commonly-used word for this energy evolution: "electrification." Following their initial study, NREL specifically investigated the prospects for, and challenges to, electrification in a six-part, multi-year study. NREL concluded that; popular - and policy-driven demand for electrification is driving the sustained deployment of renewable energy, and that the U.S. has abundant cost-effective resources to meet electrification-driven renewable growth. However, the cost impact of electrification on the entire energy sector depends on advancements in reducing capital cost, scaling output and increasing efficiency of electric vs. fossil fuel technologies.

Batteries are foundational

First and ultimately, among these "electric end-use technologies" are batteries. After all, batteries are the foundation—literally—of electric vehicles (EVs), and the transition from internal combustion-powered vehicles to EV's is vital since the transportation sector is now the largest source of greenhouse gas emissions and pollutants including SOx, NOx, and particulates, far outstripping the power sector. And we are not talking just passenger EVs here: transit buses, heavy-haul truck fleets, aircraft and trains, and even support equipment such as forklifts and airport TUGs are being manufactured or prototyped as EVs. Of course, many other devices including smartphones, laptops, computer peripherals, tablets, smartwatches, and game controllers also depend on Li-ion batteries.

Critical minerals have a perilous supply chain

US-based companies only manufacture about 10% of all batteries produced, and more importantly, a principal Li-ion battery chemistry relies on the use of five critical minerals: nickel, cobalt, manganese, graphite, and lithium. Domestically, we are at the far end of a brittle and unreliable critical mineral supply chain, as we are exceedingly dependent on materials originating in countries fraught with geopolitical challenges, sometimes contentious trade agreements and tariffs, periodic shipping interruptions, and commercial uncertainty. For example, 30% of global lithium reserves sit in Chile, a country struggling with low economic growth, income inequality, and a constitutional crossroads. Similarly, 70% of cobalt is mined in the Democratic Republic of Congo (DRC), a nation rich in natural resources yet politically corrupt and unstable, with mining often conducted by children working alongside adults under extremely hazardous conditions. At any moment, precipitous developments in an unstable country could shut down mining indefinitely, resulting in the U.S. being cut-off from these critical minerals and negatively affecting our national energy security. Concurrently, most of the critical mineral supply chain requires an immense amount of energy and has a large environmental impact. And we are talking considerable numbers here; for example, Reuters estimated late last year that EV leader Tesla Inc. will need about 139,000 metric tons of nickel in 2030. Fulfilling that projected requirement using Nth Cycle's current technology would avoid releasing 1,820,900 tons of CO_2 to the atmosphere, the equivalent to driving 405,205 gasoline-powered cars for a year.

30% of global lithium reserves sit in Chile, a country struggling with low economic growth, income inequality, and a constitutional crossroads.

Photo: Nth Cycle

Moreover, the U.S. faces a significantly insufficient capacity to reuse and recycle spent batteries, a process referred to as "the domestic circular economy." Exacerbating the problem are uncertain waste recovery regulations, unmonitored decentralized collection, lack of reprocessing infrastructure, and a lack of uniform purity standards. The combination of these uncertainties results in minimal domestic Li-ion critical mineral recovery, and significantly less than technologically possible. Consequently, U.S. Li-ion battery collection facilities send the vast majority of 'recycled' batteries overseas to be reprocessed and remanufactured into next generation batteries that will be sold back to us. Thus, we are essentially giving away critical minerals needed for domestic electrification along with potential profit to be made from a domestic battery manufacturing supply chain.

Electro-extraction: an exceptional advancement

Nth Cycle, a company I co-founded in 2017 along with Megan O'Connor, PhD., and Desirée Plata, has developed and patented the rapid, effective, and efficient Electro-Extraction process, enabled by nanotechnology, for (re) processing critical mineral feedstocks into high-quality products, typically over 95% in purity. The process can reliably recover over 95% of the targeted critical metals, ensuring that every bit of usable material is recovered. Among Electro-Extraction's innovations is its small footprint and modular format that enables the ability to co-locate at customer sites where Nth Cycle can source feedstock and return the upgraded material to OEMs, or at battery recycling facilities to environmentally and economically recover critical minerals from mechanically-processed waste streams. Nth Cycle's solution can also be deployed at existing mining or refining sites to enhance critical metal recoveries from low-grade ores or waste-streams.

Electro-Extraction hybridizes traditional unit-processing techniques including electrochemistry, precipitation, and filtration into a single, compact, and modular unit providing a sustainable solution for recyclers, miners, and OEMs. The technology utilizes a unique, porous electrode material that; increases the effective electrode surface area; allows for flow-through electrochemistry that significantly increases production rates; and can selectively dissolve and/or precipitate metals based on electrochemical flow regime tuning of aqueous conditions. As compared to traditional centralized pyrometallurgic and hydrometallurgic methods, Nth Cycle's Electro-Extraction solution is markedly different; modular for decentralized applications, relatively low-cost at small-scale, and deployable in a matter of months, not years.

Nanotechnology is king

The Electro-Extraction process is enabled by nanomaterial-based electrochemical filters with sub-micron pore diameters that have numerous advantages over traditional electrodes, yielding a remarkable increase in critical metal Electro-Extraction rates. Nanomaterial-based electrified filters have many advantages over traditional porous electrodes such as carbon or metal mesh, felts, and cloths. For example, Nth's electroextraction electrodes have significantly smaller pore diameters, greater surface areas, and can be made into thinner electrodes allowing for a large electrode surface area to be packed into a small volume. Nth Cycle's proprietary Electro-Extraction technology is the base of "the Oyster" device and process, and similar to an oyster, Nth Cycle's technology can take in low value waste battery materials or ores and output high value nickel and cobalt mixed hydroxide precipitates.

Environmental, cost, and operational advantages

Nth Cycle's patented process will markedly contribute to the U.S. domestic critical mineral supply chain in the near future, supporting the aims of both the Inflation Reduction Act (IRA - 2022) and the Infrastructure Investment and Jobs Act (IIJA – 2021). The Electro-Extraction process is also a big step environmentally forward as models predict it will emit 30-40% less CO2 equivalents than traditional metallurgic recycling processes and has potential to emit 70-90% less CO2 equivalents than traditional metallurgic virgin ore concentrate refining processes. A single onsite Electro-Extraction unit will be able to produce 400-600 tons of high-purity metal such as cobalt or nickel annually on a footprint of only 2000 square feet. Thus, Nth Cycle's Electro-Extraction technology can be a rapid add-on to existing mechanical recycling facilities, providing low capital and operating costs, and a cleaner alternative to traditional centralized metallurgic facilities. Last month, Nth Cycle announced it would be opening a 21,000 square foot facility outside of Cincinnati, Ohio which would help us dramatically scale operations and be the first company in the country to offer a domestic source of MHP, or Mixed Hydroxide Precipitate. In doing so, we will also be the first in the nation to help EV makers meet the qualifications of the Inflation Reduction Act.

Ultimately, it will be essential to achieve a net-zero-carbon economy in the most rapid time frame possible to blunt the negative effects of global warming and natural disasters associated with climate change. Access to critical metals will be a critical element in achieving this objective for humanity. Nth Cycle will enable critical metal accessibility by providing an electrified path to an electrified future.


Photo: Nth Cycle

Storage as transmission assets: What, why and how?

Pete Tilloston
Reseach Analyst, Rho Motion

In the realm of modern energy management, the integration of storage as transmission assets (SATA) stands as a transformative concept, redefining the role of energy storage systems within electrical grids. SATA represents a strategic departure from conventional grid paradigms, advocating for the seamless integration of energy storage technologies directly into transmission infrastructure. Progress is now being made in real-world applications to demonstrate how BESS can enable more efficient transmission of energy around the grid, in turn easing grid congestion and avoiding management costs to the tune of multi-billion dollars per year. SATA has the potential to contribute even more potential use cases for energy storage in the context of decarbonisation and the energy transition, but how does it work?

Photo: Negro Elkha

A typical BESS system will be connected either to a renewable generation asset or the grid through a substation grid connection. The battery will participate in a wide range of potential markets depending on its intended use case and energy market landscape. Crucially, these BESS systems help move electricity through time, i.e. shifting loads of renewable energy to times of high demand. SATA, however, has the specific capability and purpose of easing congestion on the transmission grid, forming part of the transmission infrastructure that moves electricity spatially as well as performing load shifting services. What does this mean? Put simply, a transmission line can only accommodate so much electricity before overheating and damaging the internal components of the line. As a grid connects increasing amounts of renewable energy, the pre-existing transmission network can become overloaded with energy at the point of generation, and likewise at the point of distribution with increasing energy demand.

To avoid this breach of system constraints, a system operator has the option to direct generators to adjust their dispatch levels to reduce the amount of electricity in the system, paying them to do so. This limits the amount of cheap electricity in the system and frequently increases the cost of energy consumption for the consumer. Reporting estimates have shown that grid-congestion costs in the US have more than doubled since 2016, costing consumers billions of dollars per year. Such curtailment is a major inefficiency in grid-management, and requires extensions and upgrades to the transmission grid as well as utilisation of reserve power lines to be recitifed. However, these upgrades are costly and require lengthy planning and stakeholder consultation processes, as well as causing significant land disruption in the affected area.

SATA involves strategically placing energy storage systems along the transmission network to facilitate power flows using the existing infrastructure. When a transmission line is nearing maximum load capacity, an energy storage system can be used to soak up the surge in energy to keep the transmission line operating within safety margins (in Germany, for example, this is around 70% operating capacity). The grid battery near the load centre simultaneously charges/discharges in accordance with network needs to mimic a power line, crucially helping to level out electricity supply in the context of increasing demand driven by the growth of EVs and related charging infrastructure, among other sources. This dual-application avoids curtailment, minimises grid-congestion costs, and simultaneously increases grid utilisation efficiency. As a result, land disruption can be reduced by up to 80% when compared to the construction of additional power lines and grid infrastructure that would otherwise be required to achieve similar results.

Figure 1: Traditional transmission grid

Source: Rho Motion

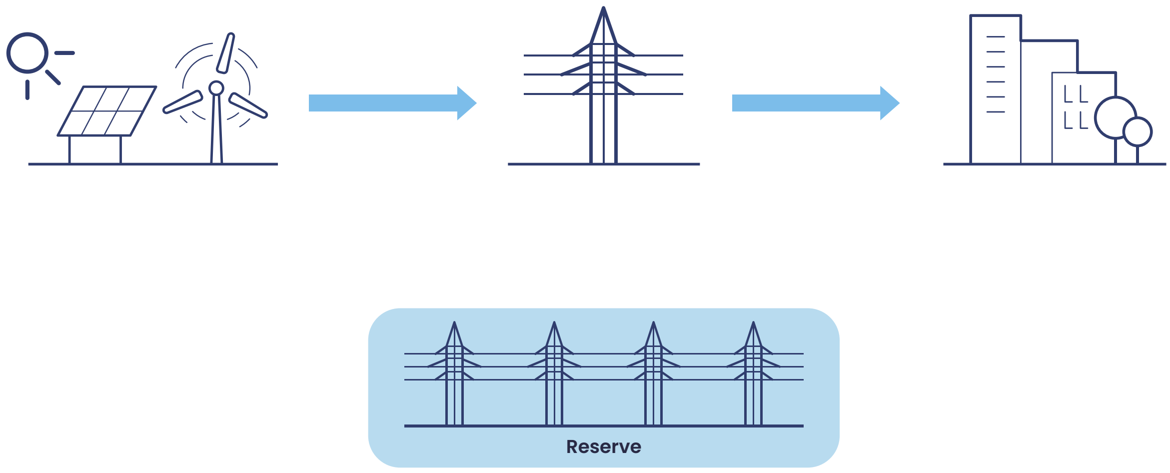


Figure 2: Congested transmission line

Source: Rho Motion

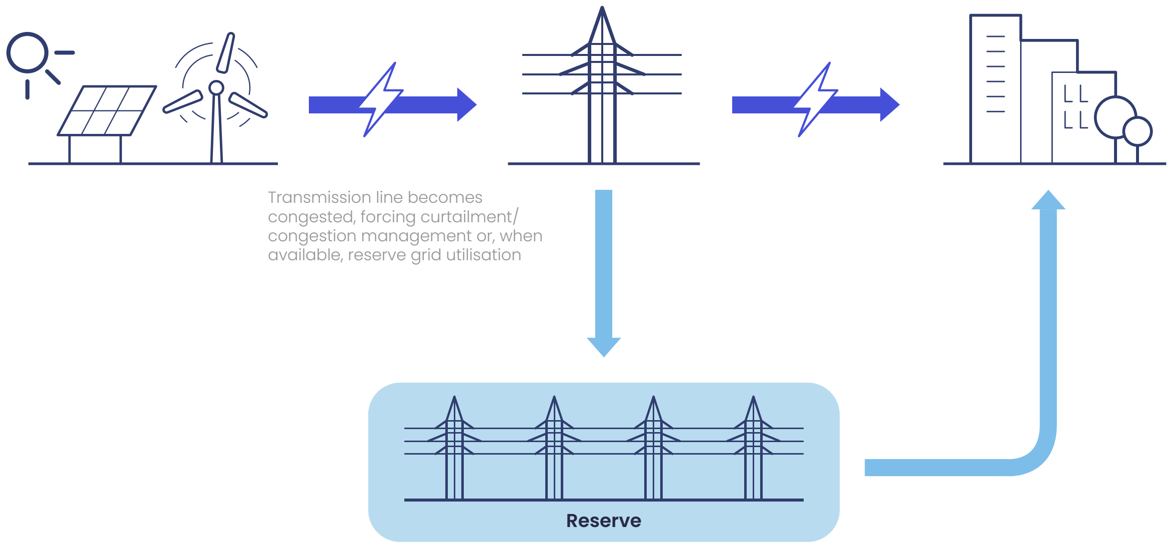
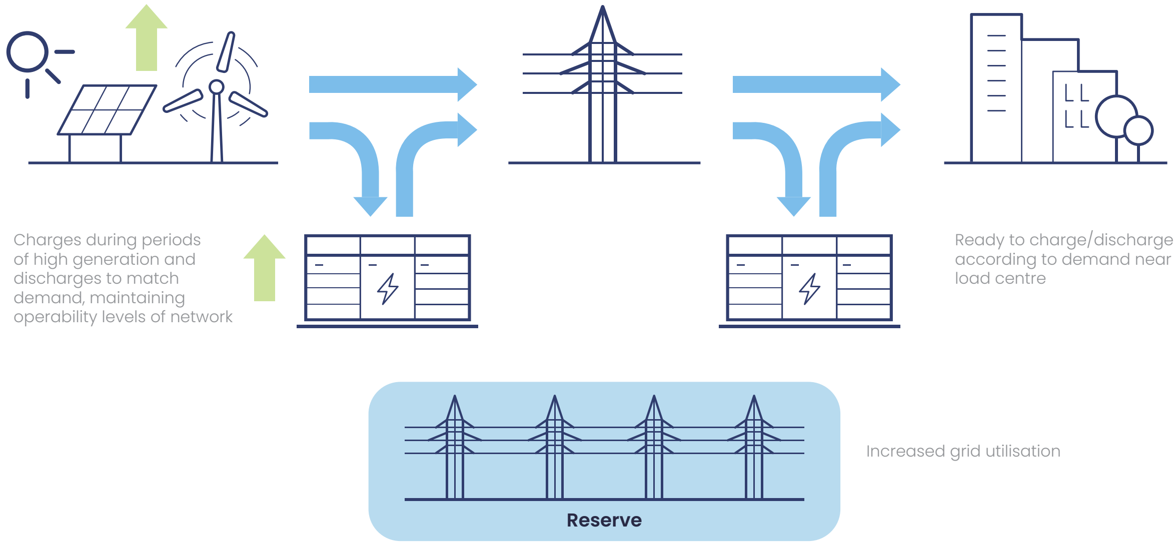


Figure 3: SATA easing transmission congestion

Source: Rho Motion



One of the key challenges lies in the intricate regulatory landscape, which often fails to provide clear frameworks for the deployment, operation, and compensation of energy storage systems integrated into transmission infrastructure.

While the concept of SATA offers promising solutions to numerous grid challenges, its implementation is not without hurdles. One of the key challenges lies in the intricate regulatory landscape, which often fails to provide clear frameworks for the deployment, operation, and compensation of energy storage systems integrated into transmission infrastructure. Some grid operators, such as the New England ISO, are considering altering regulation to allow storage systems to be operated as transmission-only assets (SATOA). Rather than allowing value-stacking mechanisms available to more typical BESS systems and SATA projects as mentioned earlier, SATOA costs are recovered through the same mechanisms as traditional transmission and under the remit of the transmission owner. Preventing storage assets from performing these multi-purpose roles in SATOA use-cases hinders grid operators and asset owners from capturing the full benefits of energy storage assets, which in turn reduces their effectiveness in enabling the energy transition. This difficult regulatory environment only adds to the more common challenge of securing adequate funding and investment for the installation and maintenance of large-scale SATA projects, which can prove to be a daunting task especially as stakeholders navigate these uncertainties in cost-recovery mechanisms. Addressing these multifaceted challenges is imperative to harness the full potential of SATA and ensure its seamless integration into the evolving energy landscape.

Multiple announcements of SATA projects have been made and are expected to come online in the coming years. System integrator Fluence is deploying two separate "Gridbooster" projects in Germany. Two 100MWh/100MW BESS systems are being deployed on the Tennet grid, deployed to transmit largely wind energy concentrated in the north of the country, along congestion-susceptible transmission corridors to the demand centres in the south. Another 250MWh/250MW project is being deployed on TansNetBW's grid. Fluence is also pursuing similar projects in Lithuania to assist grid management in the country. It will not be long until we see more integrators and developers entering this space as grids integrate ever-increasing capacities of renewable generation and grid-congestion management becomes increasingly important.

Another interesting case study is in Australia. Due to the rapid rate at which renewables are coming online, the regulatory framework has not been able to keep up with the transmission requirements of the grid and therefore energy storage projects are still technically restricted from participating in transmission services. However, in New South Wales (NSW) and Victoria, extra-regulatory Renewable Energy Zones (REZs) have been established. A REZ is an area in which significant upgrades in transmission infrastructure and exceptional renewable energy generation is deployed. Multiple parties cooperate to co-locate and share costs of a single grid connection, as well as possible network upgrades required to enable the new load and use. In Australia's case, these Zones are being used to displace Australia's extensive coal generation capacity which is being rapidly decommissioned. Within these zones, energy storage project developers have been able to bypass regulatory restrictions to participate in transmission related services. Specifically, the Waratah Super Battery (1680MWh/850MW) and Victoria Big Battery (450MWh/300MW).

Although grid management is of critical importance to facilitate the energy transition, and SATA poses a potential solution, it does not negate the need for further grid upgrades and extensions. Rather than a direct replacement, SATA is to be an enabler of a more efficient grid management system alongside inevitable grid expansions. That said, the potential upsides of SATA and SATOA provide an enticing avenue for grid operators amidst the rapid in-boarding of renewable generation to the grid and ever-increasing demand.

Photo: Malp

Pioneering the future:

Exploring alternative technologies for long duration energy storage (LDES)

Varnika Agarwal
Reseach Analyst, Rho Motion

In the Net Zero Emissions by 2050 Scenario, the vision involves a dual approach: widespread adoption of variable renewables like solar PV and wind power, coupled with a substantial rise in electricity consumption due to the electrification of various sectors. To effectively handle the challenges posed by fluctuations in the renewable energy generation, the use of batteries becomes crucial. These storage solutions will play a pivotal role in managing the impact on the power grid, storing excess renewable energy during high-generation periods, and releasing it when demand surges or renewable output declines.

Long duration energy storage (LDES) will play a crucial role in addressing the challenges associated with intermittent renewable energy sources. This will require technologies capable of durations >10h, including multi-day and seasonal energy storage. As of 2023, there is no consensus on what defines LDES - Table 1 shows the definitions used by various governments and associated initiatives. At COP27, held in Egypt, the Grid Storage Launchpad displayed a video featuring its crucial role in supporting the Department of Energy's (DOE's) Long-Duration Energy Shot initiative. The US DOE announced USD30 million to advance energy storage solutions to show support for LDES. In California, Governor Newsom announced USD380 million to support LDES projects as part of the State's 2022-2023 budget. Out of the total amount, USD140 million will be provided in fiscal year 2022-23, while the remaining USD240 million will be disbursed in 2023-24. In the realm of battery energy stationary storage, there is not one universal solution

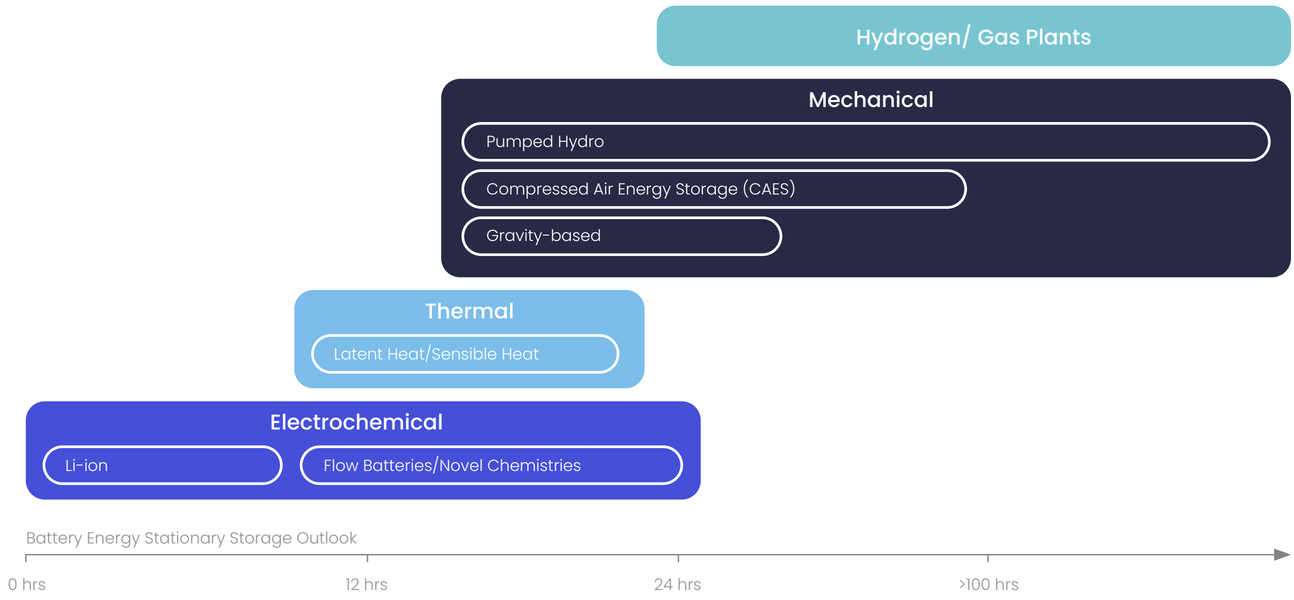
> *In the realm of battery energy stationary storage, there isn't a single universal solution that perfectly fits all applications.*

Table 1: Long duration enegy storage intiatives

Source: Rho Motion

Organisation	Full Form	Duration defined	Aim/Role
DOE storage shot	Department of Energy	> 10h	Aims to accelerate grid-scale energy storage development by achieving 10 hours of storage within the next 10 years. The funding allocated for this initiative is $1.16 billion
CPUC IRP	California Public Utilities Commission	8-12h	Require regulated utilities to create integrated resource plans to meet a reduced greenhouse gas emission target for the electric sector.
CEC	California Energy Commission	> 10h	Initiated a Grant Funding Opportunity (GFO) in 2020 to investigate the role of long duration energy storage (10 hours or greater) in California's grid and its optimal durations and locations for various applications.
ARPA-E days program	Advanced Research Projects Agency-Energy	10-100h	Focuses on long duration energy storage technologies with durations ranging from 10 to 100 hours. The goal is to achieve a cost of $0.05 per kWh of output.
LDES council	Long Duration Energy Storage	8-24h	Consisting of technology providers, energy providers, and end users, aims to replace fossil fuels with zero carbon energy storage to meet peak demand.
PJM	Pennsylvania-New Jersey-Maryland Interconnection	4, 6, 8, 10h	A transmission organization with electricity sales across multiple states.

Figure 1: Overview and comparison of non-battery technologies *Source: Rho Motion*



that perfectly fits all applications. The dominance of lithium-ion in the storage market can be attributed to its extensive development, driven by the electric vehicle (EV) sector. Recently, there has been commercial progress in non-lithium-ion battery technologies with companies like Redflow, a Brisbane-based manufacturer of redox-flow batteries, securing USD12 million in funding from the California Energy Commission (CEC) to supply a 20MWh battery system for a clean energy storage project in northern California.

Similarly, non-battery technology has been gaining attention. Recently, Corre Energy acquired a 280MW compressed-air energy storage project in Texas, US. In this article, we will explore some of these innovative alternative battery and non-battery technologies that have the potential to revolutionize the field of energy storage as shown in Table 2 and Figure 1.

Non-lithium-ion battery technologies

1. Flow Batteries
Flow batteries store energy in liquid electrolytes. These electrolytes, known as the anolyte and catholyte, are stored in external tanks, making it possible to easily replace them and potentially extend the battery system's lifespan indefinitely.

This technology works by pumping the liquid electrolytes into a central stack, where they are separated by a thin membrane that facilitates the movement of charge. This separation enables reversible redox reactions to occur at the electrode surface, resulting in the flow of current.

Figure 2a) shows the status of flow battery projects and Figure 2b) shows the current capacity in MWh in different regions. Currently, China is dominating the flow battery

Figure 2a: Status of flow battery projects *Source: Rho Motion*

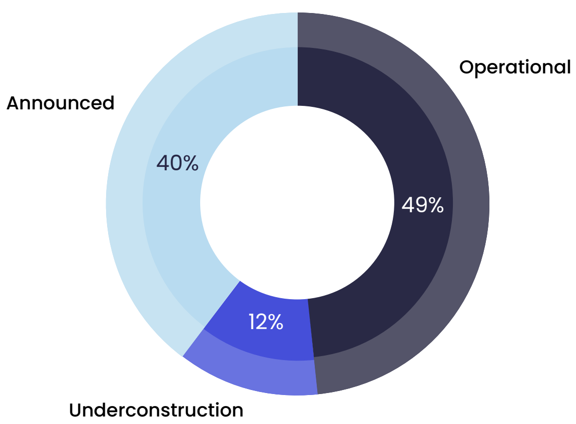


Figure 2b: Operational capacity in MWh by region for flow batteries *Source: Rho Motion*

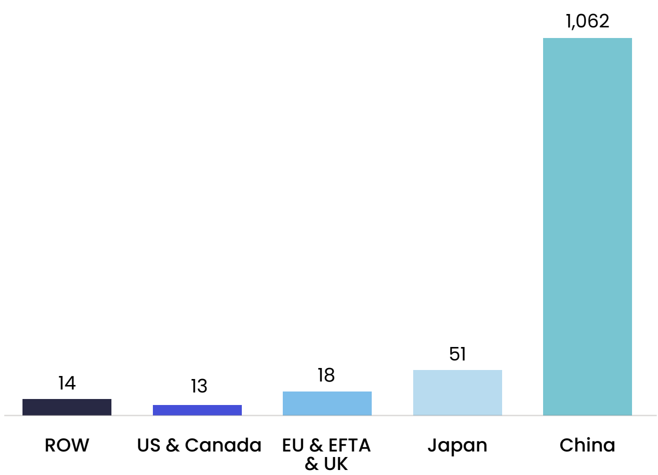


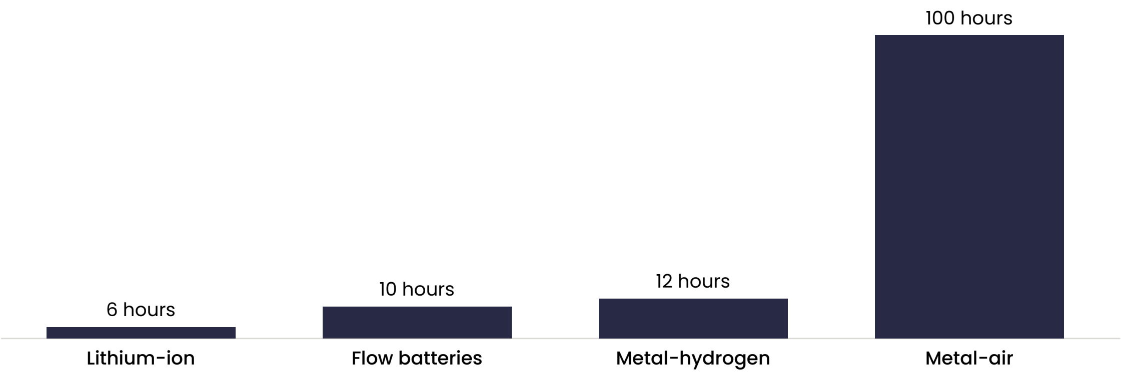
Table 2a: Overview and comparison of alternative battery technologies with Lithium-ion for LDES

Source: Rho Motion

Technology	Average cell energy density (Wh/kg)	Duration	Cycle life (ESS)	Key attributes
Lithium-ion	150-270	1-6 hours	6000	Short to medium duration, fast response and daily cycling
Flow batteries	10-50	4-10 hours	> 10,000	Medium to long duration, slower response and daily cycling
Metal-hydrogen	50-70	2-12 hours	> 20,000	Flexible duration, daily cycling and long cycle life
Metal-air	60-500	up to 100 hours	> 10,000	Extreme long duration, slow response and long cycle life

Table 2b: Graph depicting the duration stored:

Source: Rho Motion



technology space with 28 operational plants with a combined capacity of 1,062MWh, compared to only four operational plants in US & Canada with 13MWh capacity. As of August 2023, 32 new projects have been announced around the world.

2. Metal-hydrogen

The fundamental operation of a metal hydrogen battery centres on storing hydrogen within a metal hydride compound. Charging the battery involves the absorption of hydrogen gas into the metal hydride, resulting in the formation of a stable chemical bond.

During the cycling process of a nickel-hydrogen cell, hydrogen gas is generated when the cell is charging, while it is consumed when the cell is discharging. The distinctive feature of the nickel-hydrogen battery lies in its utilisation of hydrogen in gaseous form, which is stored under high pressure, reaching up to 1200 psi (82.7 bar), within a specially designed cell.

EnerVenue, the pioneering company introducing metal-hydrogen batteries, are to supply 25MWh of Energy Storage Vessels to a major energy firm in the Southeastern US. These vessels, set to be delivered by Q4 2024, will bolster a significant Florida-based energy storage initiative benefiting local residents.

3. Metal-air

Metal-air batteries consist of a positive electrode primarily composed of carbon and infused with precious metals, facilitating the oxygen reaction. The negative electrode, responsible for the metal-air battery's power generation, is constructed from metals like zinc, iron, aluminium, magnesium, or lithium.

Iron-air

Iron-air batteries work on the principle of the reversible rusting of iron, where during discharge the iron electrode reacts with oxygen from the air to form rust and release energy.

Form Energy, a US-based startup, claims to have rechargeable iron-air technology utilising this rusting process to store energy with 100 hours of storage. In May 2023, Form Energy broke ground on its first large-scale manufacturing facility Form Factory 1 in Weirton, West Virginia. The plant is scheduled to reach mass production in mid-to-late 2024 with a fully operational annual production capacity of 500MW.

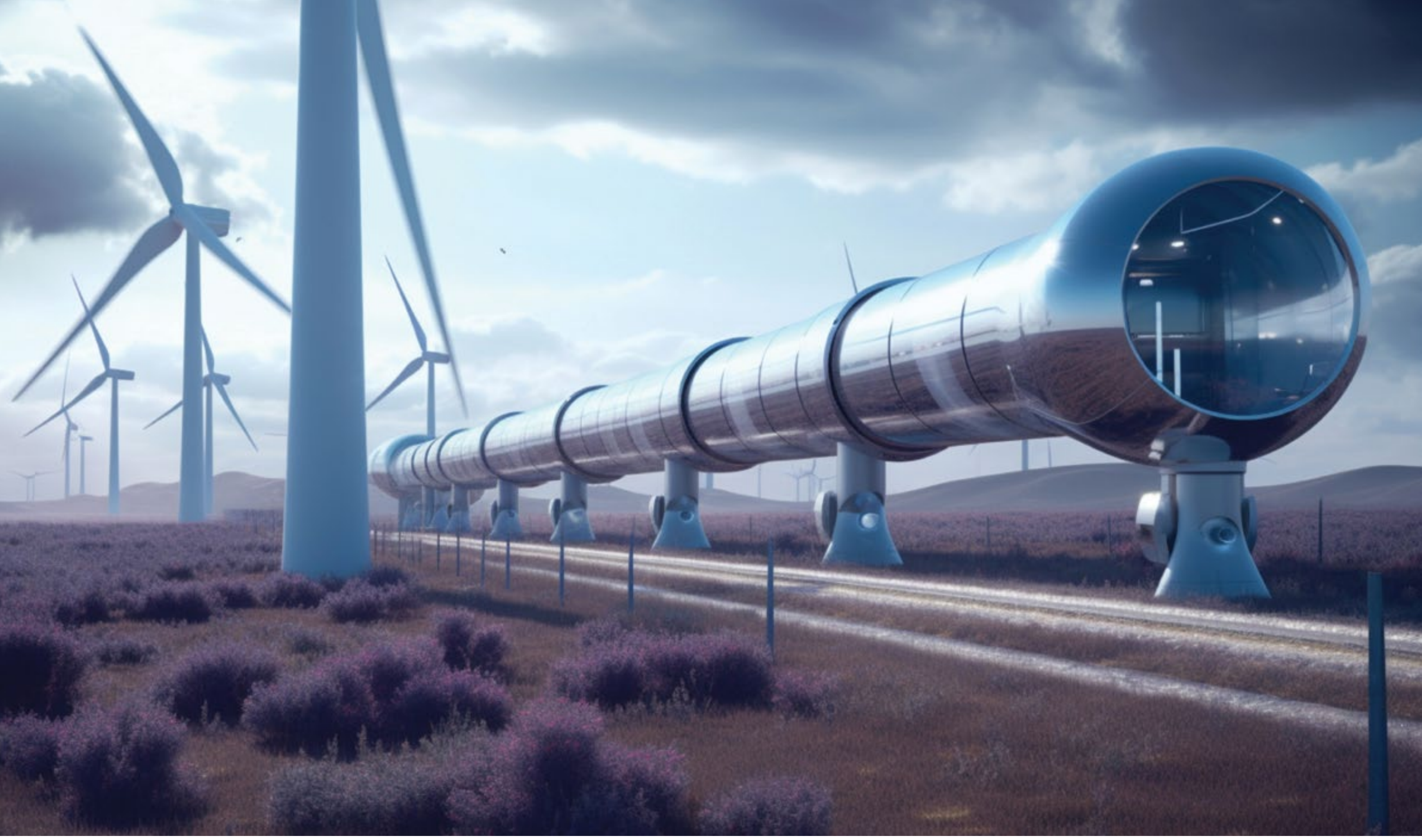


Photo: TheRainstep

Non-battery technologies

Energy can also be stored as potential or kinetic energy. One approach is compressing gas to capture its expanding energy or raising and lowering weights to harness gravitational energy. Innovators are refining these concepts for greater efficiency.

1. Compressed Air
Energy is utilised to compress air, which is stored in an underground cavern. It is later heated for expansion through a turbine to generate power.

2. Gravity-based
Lifting a weight stores energy, which is released to spin a turbine upon dropping.

3. Pumped Hydropower
Water moved between reservoirs generates power, with pumping for recharge. Some variations involve high-pressure subsurface water storage.
These technologies are being developed by various innovators like Hydrostar, Green-Y, Innovatium, EnergyDome, Energy Vault and Quidnet for durations ranging from hours to over a thousand hours.

Energy can also be stored as heat.

Heat is stored in diverse materials like water, molten salt, and minerals. Electricity is converted to heat, charging the thermal medium. This heat is either utilised directly or used to power turbines by boiling water, facilitating discharge. While converting electricity to heat and back has losses, efficiency improves when working with heat-based inputs or outputs.

1. Latent Heat
Energy triggers phase transition of storage medium, releasing heat.

2. Sensible Heat
Energy heats storage medium, usable directly or for various processes upon discharge.

Innovators like StorWorks, Azelio, KraftBlock, Kyoto Group, Hyme, EnergyNest, 1414 Degrees, SaltX, and Malta are working on durations of 8-24 hours.

Overall, LDES technologies offer a diverse set of solutions for different timeframes, contributing to a more stable and sustainable energy grid. While batteries may dominate the shorter duration range, novel solutions are emerging for the 12–24-hour period. Beyond this other non-battery technologies excel at storing energy over weeks or even months, providing balance to the grid during storms or between seasons, as shown in Figure 1. By effectively managing energy storage across these durations, LDES technologies play a crucial role in integrating renewable energy sources and enhancing the reliability and efficiency of the grid.

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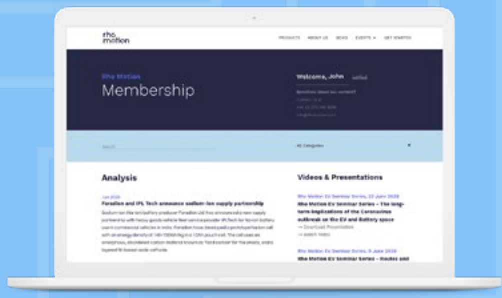

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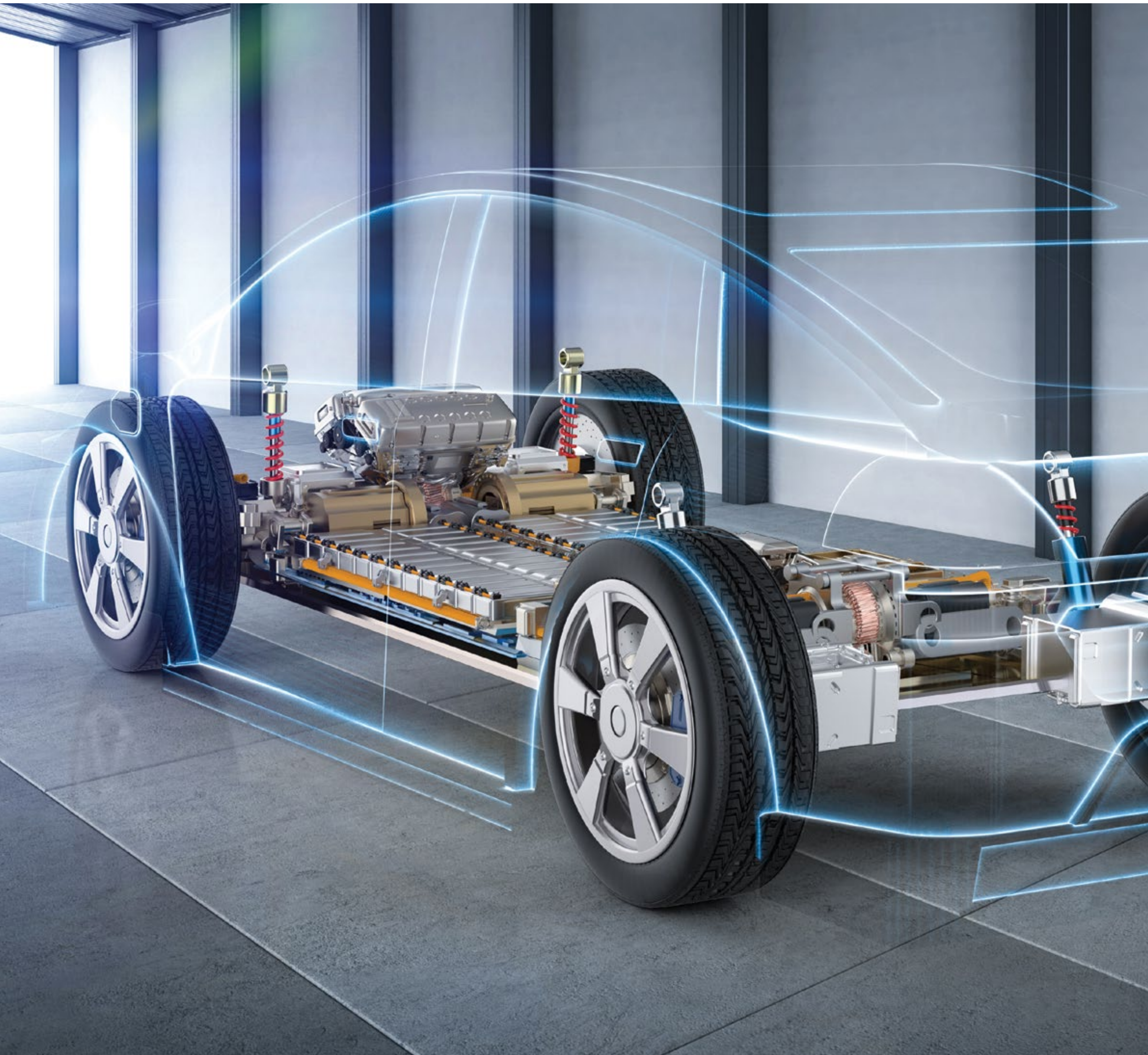
Progress towards high-voltage EV platforms

Frank Du
China Research Lead, Rho Motion

Photo: Phonlamaiphoto

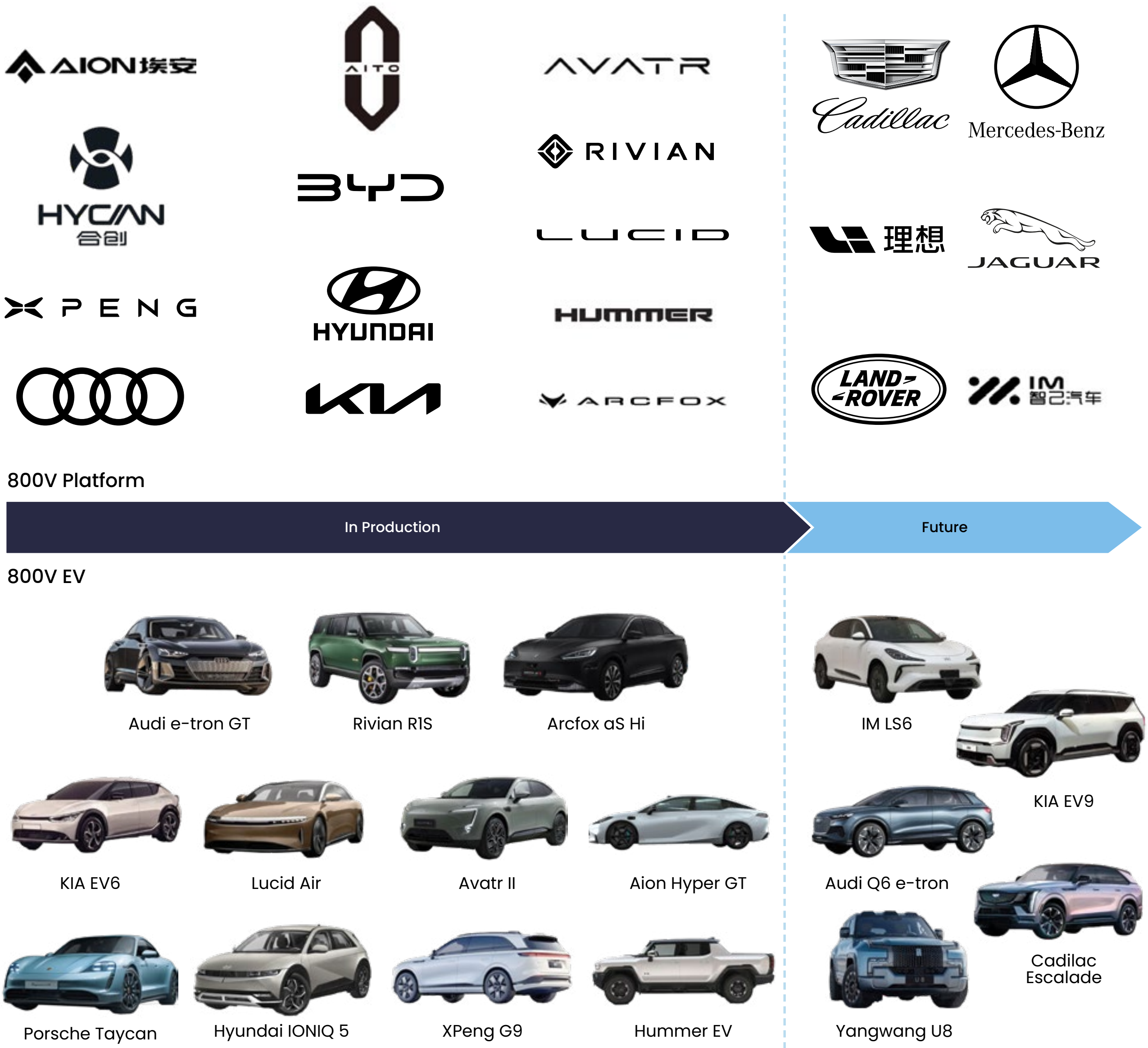


Four years ago, Porsche launched the Taycan, the world's first EV that was developed on an 800-Volt platform. Since then, all major OEMs around the world consider the high-voltage platform as the next generation technology and have invested heavily in research and development of the technology. Several leading players, such as Audi, Rivian and BYD, have already delivered their mass-produced 800V EV models to their clients.

The automotive industry is undergoing a significant transformation as the world shifts towards more sustainable transportation solutions. According to Rho Motion's EV database, over 10 million EVs were sold in 2022, a 59% increase from 2021. Within the realm of EV technology, the 800-volt (800V) EV platform has gained significant attention for its potential to revolutionise the way we perceive and utilise electric vehicles. It has been 4 years since Porsche launched the Taycan, the world's first 800V EV. The OEMs shown in Figure 1 have all invested lots of resources and time in 800V architecture.

Figure 1: Progress of 800V EV Architecture

Source: Rho Motion



One of the most compelling advantages of the 800V platform is its ability to significantly reduce charging times.

Traditional electric vehicles commonly use a 400-volt electrical architecture, which has been effective for powering EVs and cost-saving. However, as EVs becomes more popular, many shortcomings of 400-volt EVs begin to emerge, such as long charging time. So, engineers began to explore the next generation of EV architectures and developed the 800-volt platform. The 800V platform operates by doubling the voltage of the electrical system, enabling several key benefits that are poised to transform the EV landscape:

1. Faster charging times:

One of the most compelling advantages of the 800V platform is its ability to significantly reduce charging times. Previously with the 400-volt architecture, extremely high current is required for ultra-fast charging. For example, if the EV is charged at 350kW (Tesla's V4 Supercharger), the current required to the car will be 875 amperes. This high current can over time damage battery cells and generate tremendous amounts of heat.
As a result, the charging power for 400-volt platform is limited for large portions of the charging cycle, leading to a longer charging time.

With double the voltage, the current required to achieve a specific power output is halved. This means that EVs equipped with an 800V platform can handle higher charging rates without overheating, allowing drivers to recharge their vehicles to 80% capacity in remarkably shorter durations. The 350kW charging in the last example now only generates a current of 437.5 amperes, which is much more manageable. OEMs can easily achieve ultra-fast charging without adding heavy and expensive cooling systems to the battery pack.

2. Improved performance:

Higher voltage levels in the 800V platform translate to increased power delivery to the electric motor, resulting in enhanced acceleration and overall performance. Improved efficiency and power utilisation further contribute to extended driving ranges, as the electric motor can operate at its optimal efficiency over a wider range of speeds. In addition, with lower current requirements, the electrical components experience reduced energy losses and generate less heat. Ultimately, this more sustainable and longer-lasting electrical system will contribute to the longevity of the vehicle.

3. Innovative design opportunities:

In an 800-volt architecture, smaller and lighter electrical components can be used without compromising performance, freeing up space within the vehicle for other purposes, such as safety features and additional battery storage. For instance, by moving to 800V, the current in the Taycan is halved, and the required cross-sectional area of the high-voltage wiring harness is only one-half that of the 400V architecture, resulting in a weight reduction of 4Kg in the wiring harness alone.

4. Enhanced energy recuperation:

When an EV brakes or decelerates, energy can be recovered and fed back into the battery, extending driving

Photo: Uliachupina

While the 800V EV platform holds tremendous potential, it's important to acknowledge that the adoption of high-voltage platform requires advancements in charging infrastructure, battery technology, and manufacturing processes.

range. The 800V platform allows for more efficient energy recuperation during regenerative braking, leading to a longer drive range.

While the 800V EV platform holds tremendous potential, it's important to acknowledge that the adoption of high-voltage platform requires advancements in charging infrastructure, battery technology, and manufacturing processes. All components, including battery system and motor, have to be replaced to tolerate the high voltage. Charging infrastructure must be upgraded to ultra-fast chargers to provide high power for 800V EVs. Additionally, safety issues must be addressed thoroughly before high voltage system becomes popular.

As the automotive industry continues to evolve, the 800V EV platform represents a significant step forward in the development of electric vehicles. Its ability to deliver faster charging, improved performance, efficient power distribution, and design flexibility makes it a game-changer in the pursuit of more sustainable transportation solutions. With ongoing advancements in technology and increased collaboration among manufacturers, the widespread integration of the 800V platform could enhance EV performance, leading to a higher adoption rate of electric vehicles.

Solar powered passenger cars: An obvious solution or a wasteful expense?

William Roberts
Automotive Research Lead, Rho Motion

Photo: Scharfsinn86

While listening to a recent popular radio phone-in, a show in the UK where the public can ask questions to be answered by other more qualified listeners, one such listener rang in to ask with bewilderment – "why don't electric cars have solar panels". To this particular gentleman it seemed a clear and obvious solution – you have a car, parked outside much of the time with a non-zero amount of available real estate for solar panels to sit converting photons into useful driveable kilometres! It might seem easy to some to dismiss the idea as not viable due to conversion efficiencies, cost, the energy required to move a vehicle and a host of other factors. However, despite this there are still a handful of start-ups who have given the technology a first go in production cars – is there any chance it is still a good idea?

Currently there have been two types of solar power integration for electric vehicles hoping to make it to mass production, the first is simply an add-on, providing a notional number of additional Watt-hours but never intending to be a replacement for plug-in charging in any realistic driving conditions or drive cycles. The second, more challenging task to overcome has been those attempting to make the solar power an integral part of the vehicle, providing enough electricity to make a significant difference to the way the car can be used, potentially replacing charging for part of the year.

10 years ago, in 2013 a team formed of Engineering students from the University of Eindhoven entered the World Solar Challenge. This competition, held every other year since 1987, sees teams compete to cover a 3,000km course from Darwin to Adelaide – bisecting Australia from top to bottom. As the name suggests, the cars used to cover this distance are solar powered, with the original 'Challenger' class completing the distance in one single stage without charging. The team from Eindhoven competed in the inaugural 'Cruiser Class' using their vehicle named Stella. This class is split into 3 stages of 1,200 km where teams are allowed to recharge in between stages but the vehicle must have two or more seats, with additional points for more passengers carried.

The Stella vehicle would carry three passengers across Australia in 40 hours 14 minutes, winning the race. Solar Team Eindhoven contained four of the five founders of Lightyear, so far, the only company to successfully deliver to customers a vehicle with a significant solar array. Just one year ago, the outlook for solar vehicles was the most positive it had ever been. The Lightyear 0 had been delivered, had a waitlist of 40,000 and work was continuing with the development of a second model which aimed to follow the tried and tested Tesla business plan of increasing scale and reducing cost. Another start-up in Europe, Sono Motors was also getting closer and closer to the production of its entry-level solar vehicle, the Sion. Furthermore, companies like Aptera had around 25,000 reservations for its three-wheeled solar car.

Just one year ago, the outlook for solar vehicles was the most positive it had ever been... However, since then the landscape has changed significantly.

However, since then the landscape has changed significantly. In January of this year, Lightyear ceased production of the 0 after approximately six months. The subsidiary responsible for the production of the vehicle

> *High end applications can begin to penetrate the market, help introduce the technology, provide some benefit and lend a hand to future cost reduction.*

was allowed to enter administration, and only a handful of the intended 946 Lightyear 0s were ever made.
Just a month before the news from Lightyear we witnessed the beginning of the end for another promising solar vehicle. In December 2022 Sono Motors launched its #SaveSion campaign. The company found the economic conditions after the pandemic made raising equity to continue the development of a new car too difficult. Furthermore, it was starting to see a more positive route in its B2B solar business focusing on commercial vehicles so feared the additional investment in the Sion car needed could impede progress there.

To attempt to still give reservation holders a chance to see the vehicle make it to production the #SaveSion campaign aimed to get 3,500 of the 21,000 private reservation holders to make a firm financial commitment and give a downpayment for their vehicle to help raise the cash to get it over the line.

This proposition ultimately didn't attract the support needed for Sono to continue with the Sion. The original campaign made it clear that the amount they hoped to raise via downpayments was still not planned to cover the entire cost, and additional funding would still need to be found to pay for machinery, tooling and manufacturing setup for production to begin in Q1 2024 at the earliest. It appears this combination of timeline and further risks did not inspire the confidence of enough reservation holders.

Two start-ups failed to produce passenger cars, but was this the solar technology's fault?

The challenges of solar vehicles in comparison to a more typical use case – for example a house – is broadly that the amount of space available to create electricity is far smaller for something that can use far more electricity. Ofgem estimate the average UK household uses just under 8kWh of electricity per day (2,900 kWh per year). With around 10 solar panels covering 20m^2 of roof space this demand can be very nearly met in most of the country, this kind of area is also very achievable for almost all homes with a roof – even when halving the available roof area to optimise for facing south.

For EVs, the ratio of electricity consumption to available space is not as straightforward. Lightyear managed to squeeze five square metres of solar cells onto the vehicle, but even with that the problem has to be attacked from both angles due to energy consumption. It also created a vehicle with the lowest drag coefficient of any production car on the market at 0.175, only slightly higher than Mercedes-Benz's EQXX concept which achieved 0.17. This resulted in a vehicle with exceptional efficiency.

Using Lightyear's WLTP figures of 388 miles of range from 60 kWh of battery we can estimate the 0 would still need 1,144 kWh per year to travel the UK average mileage of 7,400 miles (2019). Lightyear presented two case studies from its own testing and found based on an average commute of 35km per day you could drive for two months in summer in cloudy climates such as the Netherlands without ever plugging in. In optimal conditions and a sunnier climate such as southern Spain, this could be extended to as much as seven months of the year.

Sono went even further, adding 7.5m^2 of solar cells to the car, even if that meant using less-than-optimal positions such as the door panels or the boot with a very shallow angle to the sun. Sono created multiple pre-production prototypes of the Sion, which it said could charge itself 70 miles on an average week, and up to 150 miles in a sunny week. This is based on the climate of Munich, Germany. While Lightyear were targeting the top of the market with the 0 costing north of a quarter of a million GBP, Sono were attempting to build their vehicle far more affordably, targeting a MSRP of GBP21,300. Furthermore, Lightyear's hopes of a production solar passenger car are not over, a new slimmed-down version of the company with just 100 employees compared to the 600 previously are still pursuing the Lightyear 2, the mass-market model. The waitlist has already gone live, and the price is currently listed as "< £40,000".

Are solar EVs just around the corner or on the distant horizon?

Those looking at the more scaled back solar additions of a high-specification addition have also started to

Photo: Molostock

appear. When launching the Ioniq 5 in 2019, Hyundai promised a solar roof option for its high spec models – though this did not appear to make it to widespread production, Toyota has also included the option in the bz4x for some selected markets.

Fisker has recently launched the Ocean, which as a base specification is reasonably priced starting at GBP35,970. However, only the highest spec 'Ultimate' version comes with 'SolarSky', and this currently starts at GBP59,900. Fisker say the solar roof can add as much as 2,400 km of range per year in optimal conditions.

The cost and the technology integration are clearly two major barriers as we stand, however if high end applications can begin to penetrate the market, help introduce the technology, provide some benefit and lend a hand to future cost reduction then perhaps in the future the predictions of Lightyear's lead solar engineer will become true when he said cars like this will be "normal within 20 years". Unfortunately, the Lightyear 0 wasn't meant to be as the trailblazer they wanted but 20 years is a long time for two technologies witnessing the fastest pace of development of almost any industry in the world, Solar and EVs.

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Energy Transition Tracker

Q3 2023

In June 2023, both CSI Solar and Prulde Electric Appliance Co., Ltd. successfully listed on Shanghai Stock Exchange and Shenzhen Stock Exchange, respectively. It is also confirmed that SVOLT's IPO progress has recovered after the company updated all required documents with the authority this month. Outside of the China region, the global equity market still suffers from the higher interest rate in the US. Investors have little motivation to invest in riskier assets when the return on treasury bond is so high. However, as the expectation of interest raise ends, the equity market is believed to recover to certain degree in H2 2023. In addition, in June 2023, two companies indicated that they would start the IPO process. INTILION, an energy storage system integrator, plans to hit the Frankfurt stock market in Q3 2023. Dansuk Industrial Co., a South Korean enterprise, plans to start its IPO process to fund the expansion in waste battery recycling business.

Nine companies went public in July 2023, in the busiest month since H2 2022. Surf Air Mobility went public through direct listing on New York Stock Exchange. Metals One got listed on the AIM (Alternative Investment Market) of the London Stock Exchange. Jinyang, Mingyang Electric, and Hi-Tech Spring went public on the Shenzhen Stock Exchange. VMAX New Energy, Utimes, Scenergy, and CHEMSPEC was listed on the Shanghai Stock Exchange. In July 2023, Kunlun New Energy filed its prospectus to the Shanghai Stock Exchange.

In August 2023, three companies went public successfully. Defu Technology (SZSE:301511) and MGL New Materials (SZSE:301487) both went public on the Shenzhen Stock Exchange and VinFast (NASDAQ:VFS) got listed on the NASDAQ. Meanwhile, battery recycling company CN Technology terminated its IPO process and withdrew its application last month. In August 2023, three companies indicated that they would soon go public. WeLion New Energy, NIO's semi-solid-state battery supplier, has confirmed that it plans to go public in 2025. SinglePoint (OTCQB:SING), an energy company, plans to uplist its stocks on the NASDAQ Exchange. Baowu's IPO is going well, and the registration will start soon.

Company	Company Area	Transaction type	SPAC	Date
June 2023				
INTILION	Batteries	IPO	-	H2 2023
Dansuk Industrial Co.	Recycling	IPO	-	2024
LS Materials	Batteries	IPO	-	2024
Honeycomb Battery Company	Batteries	SPAC	Nubia Brand International Corp.	Q4 2023
Ji Rui Keji	Recycling	IPO	-	2024
DESRI	ESS	IPO	-	Q4 2023
AION	EV	IPO	-	2025
Vinfast	EV	SPAC	Black Spade Acquisition Co.	Q4 2023
Charge Amps	Charging	IPO	-	2024
Lotus	EV	SPAC	L Catterton Asia Acquisition Corp	Q4 2023
ECOPRO BM	Battery Materials	IPO	-	2024
CSI Solar	Energy	IPO	-	09/06/2023
Prulde Electric Appliance	Portables	IPO	-	01/06/2023
July 2023				
Kunlun New Energy Materials	Battery Materials	IPO	-	H2 2023
Vinfast	EV	SPAC	Black Spade Acquisition Co.	Q4 2023
Lishen Battery	Batteries	IPO	-	2025
SVOLT	Batteries	IPO	-	2024
Surf Air Mobility	EV	IPO	-	28/07/2023
Metals One	Battery Materials	IPO	-	01/07/2023
Jinyang	Battery Materials	IPO	-	01/07/2023
Mingyang Electric	Energy	SPAC	-	31/07/2023
Hi-Tech Spring	Battery Materials	IPO	-	07/07/2023
VMAX New Energy	EV	SPAC	-	26/07/2023
UTimes	Battery Materials	IPO	-	12/07/2023
Scenergy	Energy	IPO	-	29/06/2023
CHEMSPEC	Battery Materials	IPO	-	20/07/2023
August 2023				
SinglePoint	Energy	IPO	-	Q4 2023
WeLion New Energy	Batteries	IPO	-	2025
Baowu	Battery Materials	IPO	-	Q4 2023
Kunlun New Energy Materials	Battery Materials	IPO	-	H2 2023
ProLogium	Batteries	IPO	-	2026
SolarMax Technology	ESS	IPO	-	Q4 2023
MN8 Energy	ESS	IPO	-	Q4 2023
Sondors	EV	IPO	-	Q4 2023
Hi-Tech Spring	Battery Materials	SPAC	L Catterton Asia Acquisition Corp	Q1 2024
REV Renewables	ESS	IPO	-	Q4 2023
Defu Technology	Battery Materials	IPO	-	17/08/2023
MGL New Materials	Battery Materials	IPO	-	09/08/2023
VinFast	EV	SPAC	Black Spade Acquisition Co	15/08/2023

Rho Motion's Energy Transition Capital tracker tracks companies going public through an Initial Public Offering (IPO) or special purchase acquisition companies (SPAC), SPACs are blank cheque companies designed to bypass the traditional IPO process.

Pre Merger/IPO
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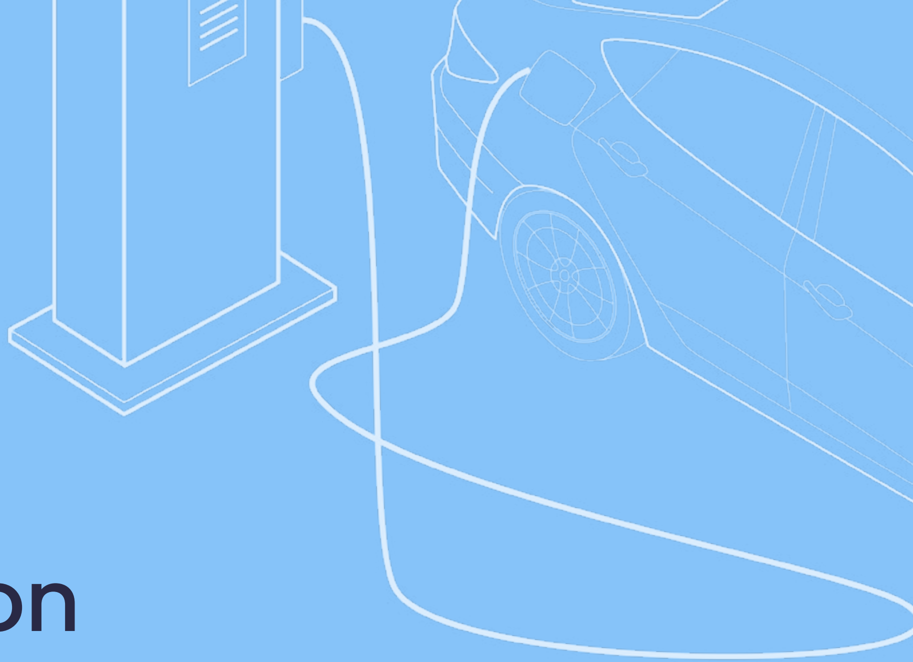

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