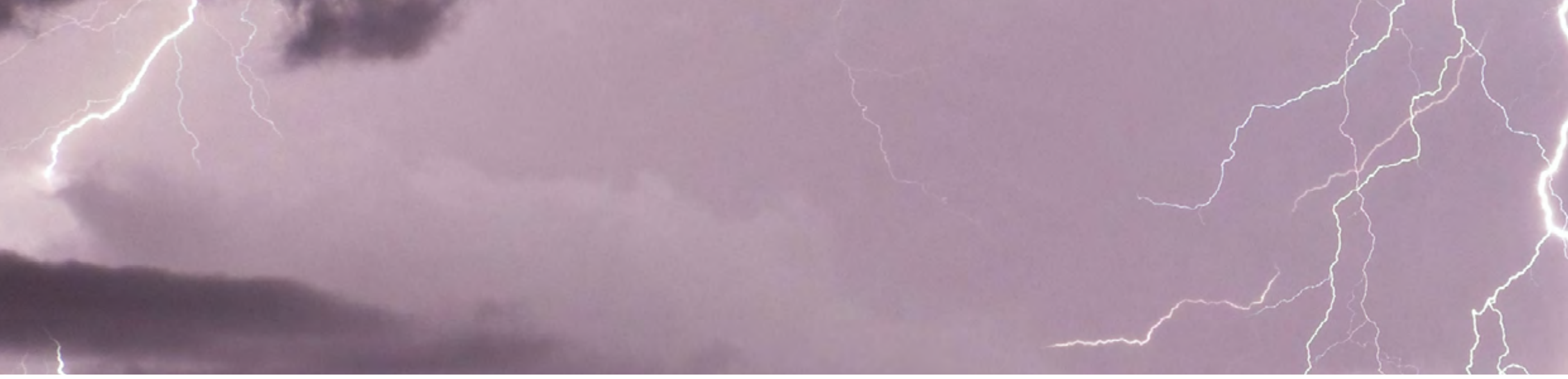
Q4 2022

rho motion magazine

Diversification and sovereignty: the new frontier in the energy transition

In this issue:



Introduction to the magazine

Adam Panayi
Managing Director, Rho Motion

Welcome to the Q4 2022 issue of the Rho Motion Magazine

Each quarter we give our Analysts the opportunity to spend some time thinking about any issue in the market that may have caught their attention. We also thank Aesir Logistics for its insightful contribution to the magazine on the critical issue of shipping of primary and waste battery material. This topic sits well with the overall theme of the magazine around diversification of technology and sovereignty over key materials and production, both of which have been thrown into stark relief by the ongoing energy crisis. As such we have articles on the Inflation Reduction Act and building a domestic value chain, from my colleagues Iola and Ulderico, as well creating a closed loop battery recycling system by Mina. We consider the Energy Stationary Storage market in both the EU and China with articles from Pete and Frank, which examine the differing concerns in each geography, while Charles examines the role of electrification more generally in light of the current energy situation. On the diversification front we have an analysis of both hydrogen and eFuels from Olatomiwa and Will respectively, and new markets in marine and defence from Shan and Ed. We also look at whether China is set to become a truly multi-territorial auto player as it gears up to export more vehicles in the coming year, with this analysis provided by my colleague Jessie. Finally, our new hire Victoria will give a new perspective on development of new battery technologies based on her years working in the lab delivering new technologies.

I hope you enjoy the magazine,
Adam

Photo: Igor Kovalenko

Contents

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The Inflation Reduction Act: Supercharging the US storage market

Photo: malp

Iola Hughes
Research Manager, Rho Motion

August saw the passing of the Inflation Reduction Act (IRA) of 2022 into law. Following months of failed negotiations for the Build Back Better Bill, the IRA was sponsored by Senators Chuck Schumer and Joe Manchin, the latter being the biggest opponent of the Build Back Better Bill. The bill represents the largest investment into addressing climate change in US history, authorising $369 billion in spending on energy security and climate change. Loans and grant programs to the sum of $30 billion have also been made available for states and utilities to "accelerate the transition to clean electricity" and help the US reduce emission by 40 percent or more below 2005 levels in 2030.

The bill provides support for the energy industry through the form of tax credits: the Production Tax Credit (PTC) and the Investment Tax Credit (ITC). The wider battery, automotive, renewables and storage markets are all set to benefit from the bill, with the BESS market expected to see some of the largest benefits, some of which already starting to show their signs in the US market.

Figure 1: Tax credits

Source: US Government Publishing Office

	Production Tax Credit (PTC)	Investment Tax Credit (ITC)
	The PTC is a ten year inflation adjusted US federal income tax credit for each kWh of electricity generated by certain types of renewables or zero carbon emission projects. This is a two-fold tax credit in the form of electricity generation and domestic manufacturing.	The ITC provides a 30% tax credit for clean energy generation, with the potential for extension to 50% when satisfying certain domestic content requirements or located in specific "energy communities"
Renewables manufacturing	Credits for the manufacturing of solar cells, wafers, polysilicon and modules and wind turbine blades.	
Renewable generation	Energy generated from solar, and wind is eligible for up to 2.75c/kWh for 10 years of operations with additional bonus for domestic content requirements.	Now available as an alternate to the PTC for solar projects over 1MW
Battery/BESS manufacturing	Battery cells credits eligible for $35/kWh, with credit for battery modules of $10/kWh	
BESS Projects		Extended to include stand-alone storage projects with a minimum capacity of 5kWh, including certain costs associated with the construction of interconnection equipment installed in connection with other ITC-eligible facilities.

20% extended PTC to $33/MWh
+
$27.50/MWh for 10 years operations

Up to $45/kWh for battery cell and module manufacturing

30% of CAPEX
+
20% extended ITC

A renewable market

The benefits for the stationary storage market are multi-faceted. Firstly, in the form of support for renewables. The bill extends the PTC and ITC for solar and wind through 2024 before transitioning to a technology-neutral tax credit that will remain in place until 2032, or the point at which US electricity sector emissions are 75% below 2022 levels - whichever is later. The PTC reinstated for solar projects under the IRA provides a major boost for solar power producers and manufacturers, who have been suffering a level of uncertainty and expectation for an ITC phasedown between 2020 and 2023. Furthermore, solar projects can now select between the PTC and ITC to maximise profits, whilst large land-based wind projects are eligible for just the PTC.

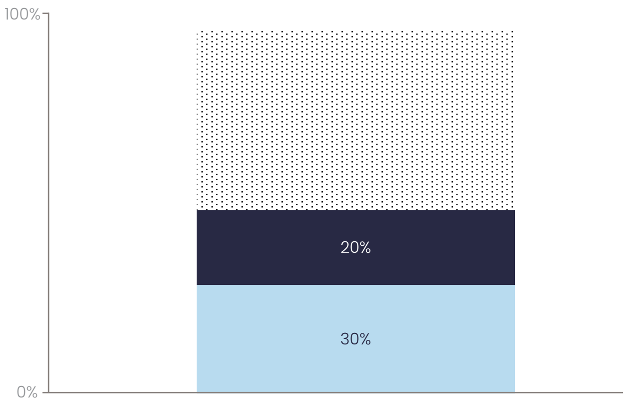
Industry body American Clean Power predicts the tax incentives and investment could add between 525GW and 550GW of new utility scale clean power to the US electricity grid by 2030, to the current 211GW of clean power currently in operation in the US grid. Pre IRA business as usual conditions anticipated closer to 330GW of new clean power for the same period. Renewables translates directly to stationary storage requirements - the higher the level of renewable penetration, the greater the need for grid stability.

Extended ITC and PTC

- The Act also adopts credit adders for eligible ITC and PTC facilities that satisfy certain domestic content requirements or are located in specific "energy communities". Including,
  - Brownfield sites
  - Communities with significant employment related to extraction, processing, transport, or storage of coal, oil or natural gas
  - Communities located in census tracts with closed coal mine or retired coal-fired generating facilities.
- Combined these adders have the potential to increase the ITC to 50% and PTC to 20%

Figure 2: Base & extended ITC and PTC — Base — Extended ITC

Source: US Government Publishing Office



Support for stationary storage

Alongside the support for renewables, the stationary storage market will also be the beneficiary of the PTC and ITC. The production tax credit for battery manufacturing in the US value chain provides long term investment in the battery supply chain leading to increased onshoring of BESS manufacturing. Perhaps more significantly for the US storage market is the introduction of the ITC for standalone storage. The ITC has been available for stationary storage several years, the caveat being the project was only eligible if paired with solar generation. Moves to introduce a standalone tax credit have been long advocated and failed at congress multiple times since as early as 2016. The IRA sets out new eligibility for the ITC and as such now encompasses standalone storage at utility, commercial, industrial, and residential levels.

The Advanced Manufacturing PTC provides $35/kWh for battery cells, and a further $10/kWh for battery modules. Here, the BESS manufacturers (cell manufacturers and integrators) are set to be the largest beneficiaries.

The addition of stand-alone storage to the ITC allows BESS projects to be located in the best position for the grid and to maximise profits. This means BESS can now receive the ITC for positioning in areas of congested high load instead of next to a wind/solar farm and can therefore draw from the grid to provide a wide range of applications from frequency regulation to voltage support rather than just time shift the energy generated from its paired resource. This change opens the opportunity for developers and utilities to effectively invest in new BESS projects, with greater flexibility in terms of operations and contracting, resulting in both a reduced upfront cost and an increase in total potential financial benefit. Additionally, the credits will make moves to counteract some of the issues facing US BESS market has been suffering in the last few years from increasing cost and supply chain disruption.

Figure 3: Operational and Planned US BESS grid projects 2022 & 2023 (size indicates duration hours)

Source: Rho Motion

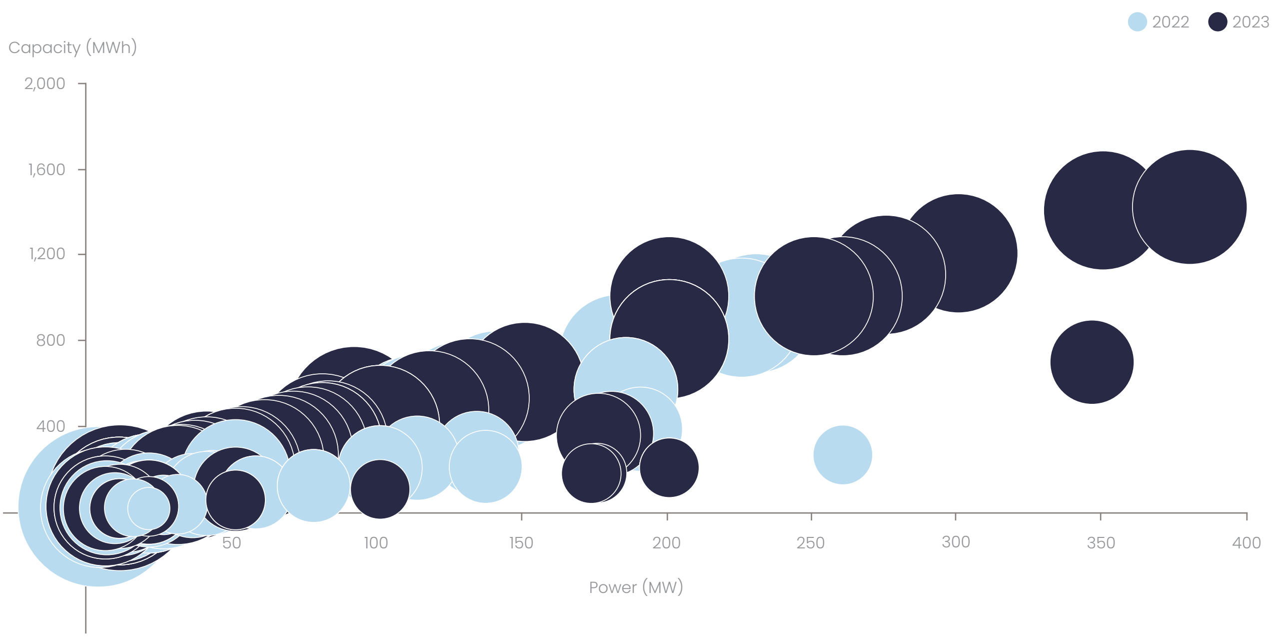
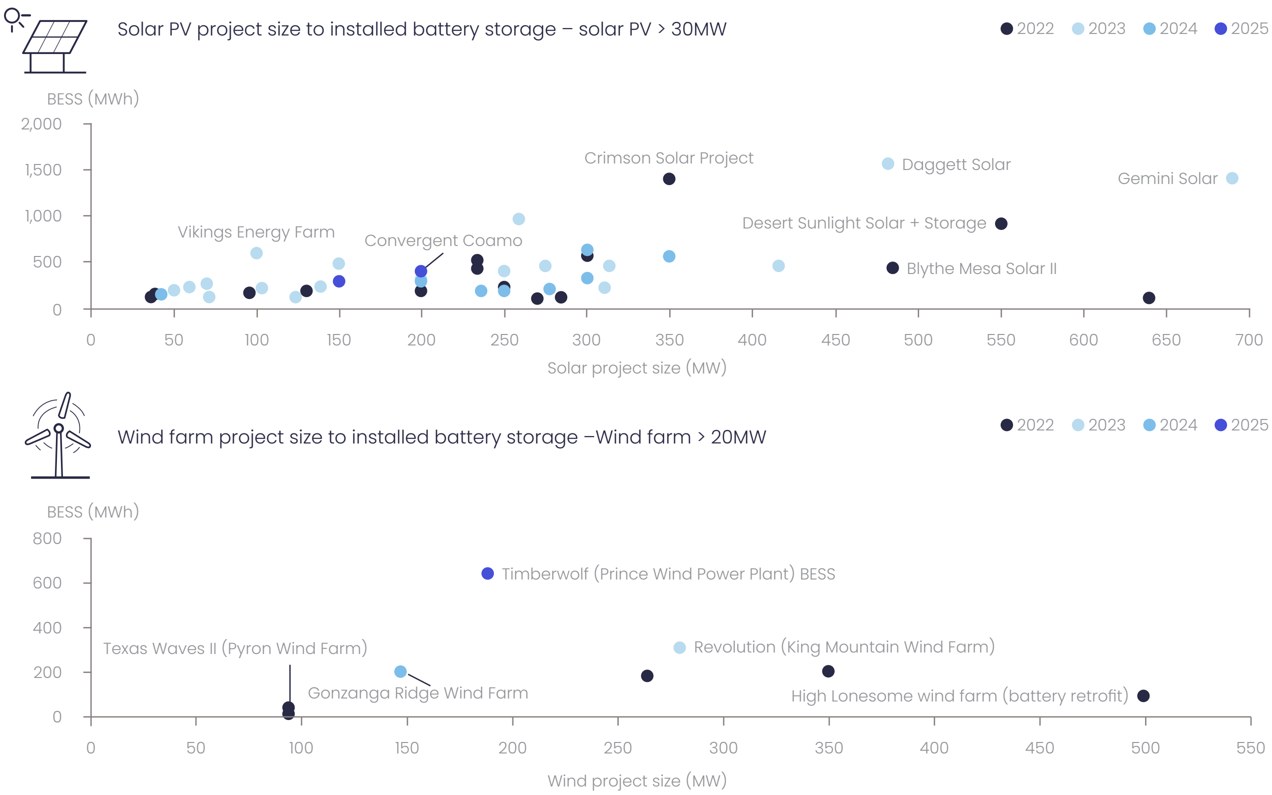


Figure 4: US paired storage projects

Source: Rho Motion



Onshoring of the BESS supply chain

The BESS market will also be the beneficiary of the PTC for battery manufacturing, encouraging the onshoring of a battery supply chain. The Advanced Manufacturing PTC provides $35/kWh for battery cells, and a further $10/kWh for battery modules. Here, the BESS manufacturers (cell manufacturers and integrators) are set to be the largest beneficiaries. If we consider two of the largest BESS manufacturers in the US market, Fluence and Tesla Energy, both companies have brought online US manufacturing facilities in recent months.

In August 2022, Fluence announced it would set up a new contract manufacturing facility in Utah to supply the US market. Fluence's Cube, the building block of the integrator's BESS products, began shipments from September 2022. Fluence purchases cells from a number of battery manufacturers and from these produces BESS units such as the Cube. Production of this system will be eligible for the $10/kWh PTC from 2023. The facility is part of a move from Fluence towards localising its supply chain as it looks to reduce the significant lead times the BESS sector is currently facing.

Similarly, Tesla brought online its Lathrop facility, dedicated to the manufacture of its Megapack product. The 40GWh facility is capable of producing over 10,000 Megapacks a year, and is set to dramatically increase Tesla's energy storage business which in 2021 deployed just under 4GWh being produced solely from Giga-Nevada previously. Similar to Fluence, Tesla purchases cells from battery manufacturer CATL, to then produce it's Megapack and other BESS products, making Tesla eligible for the $10/kWh PTC. Perhaps more interestingly, during Tesla's Q3 2022 investor call, CFO Zachary Kirkhorn stated 'we're pursuing aggressively North American iron cathode supplies', suggesting Tesla's intention to enter the LFP battery manufacturing market going forwards. This would be an obvious move for Tesla as they look to integrate its stationary storage business in a similar move to the OEM's entry into battery manufacturing for its EVs.

Looking to 2023

The US BESS market has experienced significant growth over the last two year, with grid deployments in 2022 more than six times higher than in 2020. Looking to 2023, this market is set to continue to grow at an impressive rate, both in terms of number of projects being deployed and the size of the projects as shown in the chart. The Inflation Reduction Act is set to give the US market a further boost, supercharging deployments across the grid and behind the meter markets for the next decade.

Photo: molotok289

From Zero to Tera

The challenges of creating domestic value chains

Ulderico Ulissi
Battery Research Lead, Rho Motion

Investments in the energy transition are accelerating, with lithium batteries increasingly called "the new oil". Several countries and companies are trying to onshore manufacturing and secure resources to compete with (or lure) Chinese, South Korean and Japanese leaders in the field of energy storage.

Some are facing severe headwinds. One example is the UK. In September, BMW confirmed plans to move Mini EV manufacturing out of the country. It will move production to China to increase plant efficiency, reduce costs and focus domestic production on internal combustion cars.

Start-up Britishvolt, a wannabe battery manufacturer, is reportedly close to entering administration, potentially losing 300 jobs.

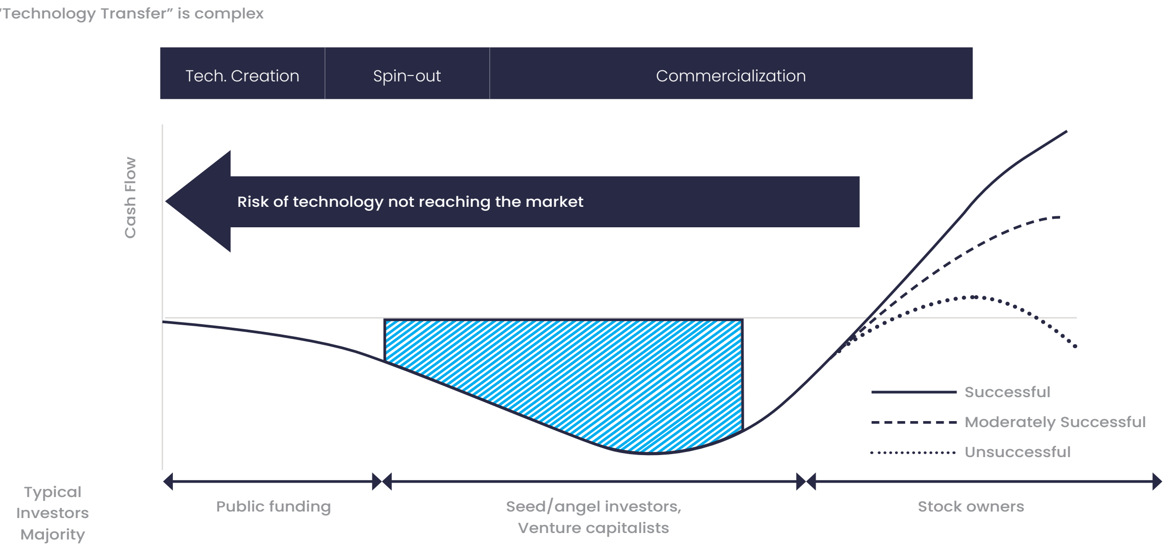
EV start-up Arrival is at risk of being delisted from Nasdaq. It will further cut its workforce in the UK despite successfully building its first van in Bicester.

While these could be seen as significant short-term setbacks to the country's ambition to become a hub for lower-emission vehicle manufacturing, it is crucial to understand that failures are part of the process. On average, according to the US Bureau of Labour Statistics, 20% of new businesses fail during the first year, 50% within five years, and 65% within ten years. The UK has been among the first movers in the emerging energy storage market (see, for example, Nissan/Envision AESC manufacturing plants in Sunderland). There is still time to act and help onshore more manufacturing to secure a greener future for the country.

The real highlight is that established businesses continuously face challenging, unanticipated situations, which can require strategic realignment to continue sustainable growth. Moreover, start-ups are at much greater risk of failing, and sustained public funding past the "Technology Creation" phase (Figure 1) can significantly help reduce the risk of failure. New businesses can face several "Valleys of Death" (Figure 1, evidenced in light blue) when scaling up due to limited cash flow as they rely on investors' money until they generate revenue and become self-sustaining.

Figure 1: From technology creation to commercialization, cash flow (y-axis) versus time (x-axis). The area in light blue is informally defined as the "Valley of Death". Picture adapted from "Bridging the Valley of Death: Transitioning from Public to Private Sector Financing, NREL/MP-720-34036".

Source: Rho Motion



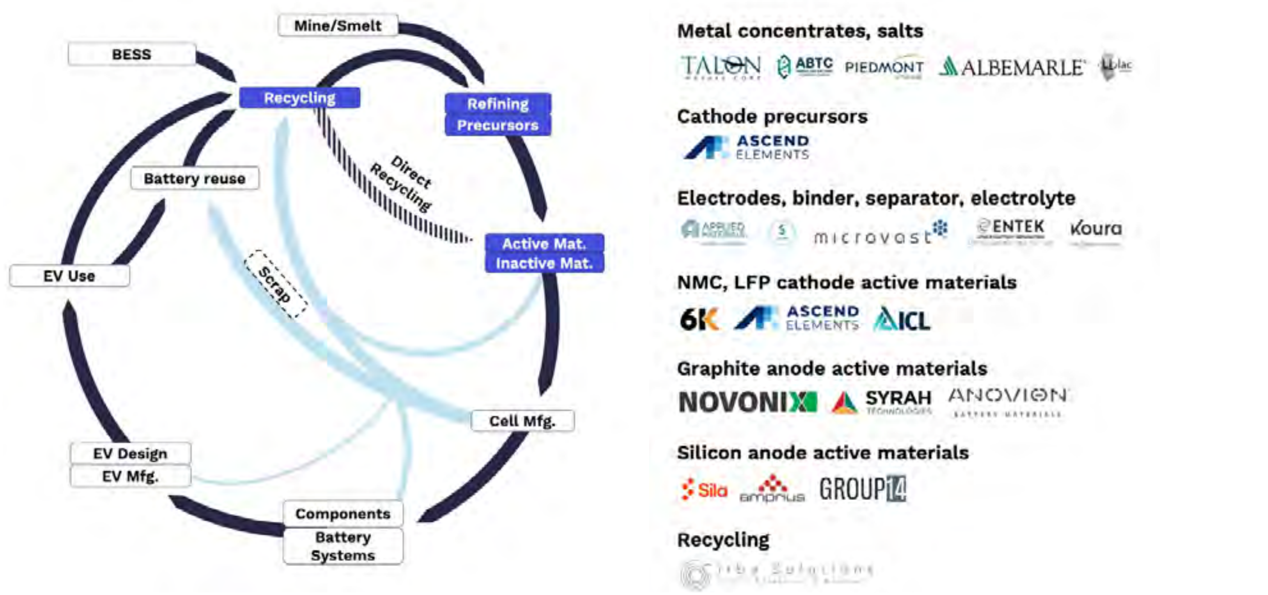
The role of Public Investment. The Bipartisan Infrastructure Law as a bridge over troubled valleys of death?

Looking overseas, in the United States, the Department of Energy (DOE) announced the recipients of a USD2.8 billion funding grant to develop a domestic energy storage value chain, the first part of a USD7.0 billion investment aimed at building up a domestic battery value chain (Bipartisan Infrastructure Law). The money will be split between 20 companies involved in 21 projects and matched by the recipients to USD9.0 billion. These initial projects focus on battery material processing, the extraction and processing of lithium, graphite and other battery materials, and the manufacturing of inactive components, including the use of recycled materials. An overview of the recipients is given in Figure 2.

According to the DOE, the funding for the selected projects will support, in numbers, the production of the following critical battery-grade commodities:

- Lithium to supply 2 million EVs annually
- Graphite to supply approximately 1.2 million EVs annually

Figure 2: On the left, the EV Battery Value chain is shown, with steps relevant to the 21 funded projects highlighted in blue. On the right is a more granular overview of the companies involved, as well as the products or processes being developed. Source: US Department of Energy, Bipartisan Infrastructure Law: Battery Materials Processing and Battery Manufacturing, Factsheets, DE-FOA-0002678. *Source: Rho Motion*



- Nickel to supply about 400,000 EVs annually
- The first large-scale, commercial lithium electrolyte salt ($LiPF_6$) domestic production facility
- An electrode binder facility capable of supplying 45% of the anticipated domestic demand for binders for EV batteries in 2030
- Domestic silicon oxide production facilities supply an estimated 600,000 EV batteries annually
- The first lithium iron phosphate (LFP) domestic manufacturing plant

These targets are vital milestones for the US ambition to be at the forefront of the energy transition. Virtually all lithium, graphite, battery-grade nickel, electrolyte salt, electrode binder, and iron phosphate cathode material are produced abroad, with manufacturing primarily located in China.

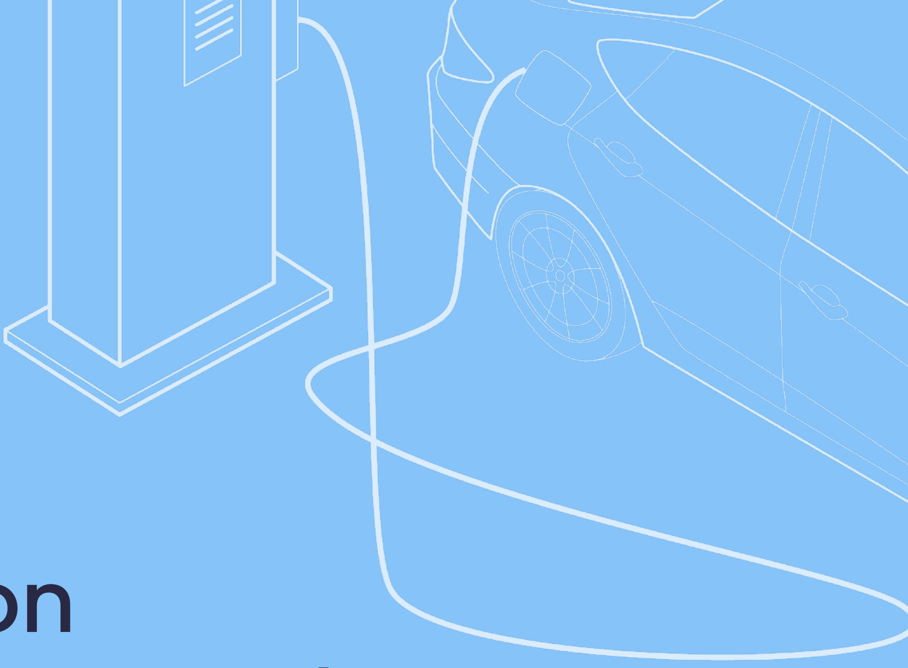
Looming challenges, and lessons learned from the old continent

It is likely that all these projects and future grantees will face several issues before reaching mass manufacturing and commercial success. Some will fail, and this will be part of the process. Asian countries have established ecosystems, and Europe has been facing several crunches, with the UK only being an example. Senior experts, such as Bob Galyen, the former CTO of CATL, described a set of headwinds for the US very similar to those faced in Europe. The energy storage markets are new for most decision-makers in governments and corporate executive boards. Companies that want to stay competitive will need to establish manufacturing hubs across the country and effective corporate structures to support the creation of competitive value chains. To this end, automotive OEMs like General Motors and Ford have been revising their strategies and diversifying their product portfolio. They are looking at ways to build the required infrastructure and fruitful partnerships, such as joint ventures and investments in companies upstream.

Sourcing raw materials will not be straightforward, as we can forecast deficits in critical minerals to manufacture battery-grade active materials. These will require access to large volumes of lithium, nickel, cobalt, manganese and graphite, both as mined and refined commodities. If history teaches us something, raw materials won't be the only supply crunch. Access to low-carbon emissions, low-cost energy sources, high quality manufacturing equipment, and a well-trained workforce will determine success.

These are only some of the looming obstacles that will be faced by the participants in this rapidly growing and evolving market. Preparing and planning can play a significant role in avoiding a "Valley of Death".

Having advised a range of OEMs, leading suppliers and investors, Rho Motion is in an excellent position to provide informed insights into the energy transition. Get in touch if you are interested in this topic or want to discuss it with us. The analyst team is always available to discuss ideas and perspectives in the open Chatham House rule environment.



Rho Motion Consultancy and Advisory Services

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Rho Motion provides bespoke consultancy and advisory services, based on our clients' needs covering the EV and battery supply chains in the following areas:

- Competitor analysis
- Market entry strategy
- Business appraisal and strategy
- Battery chemistry and technology evaluation
- Techno-economic modelling
- Technology strategy
- ESG circular economy
- PFS/DFS

Our clients are diverse, global players and our research is relied upon in bankable feasibility studies, preliminary economic assessments and public finance raising including IPOs and debt issues.

Photo: Adobe Stock

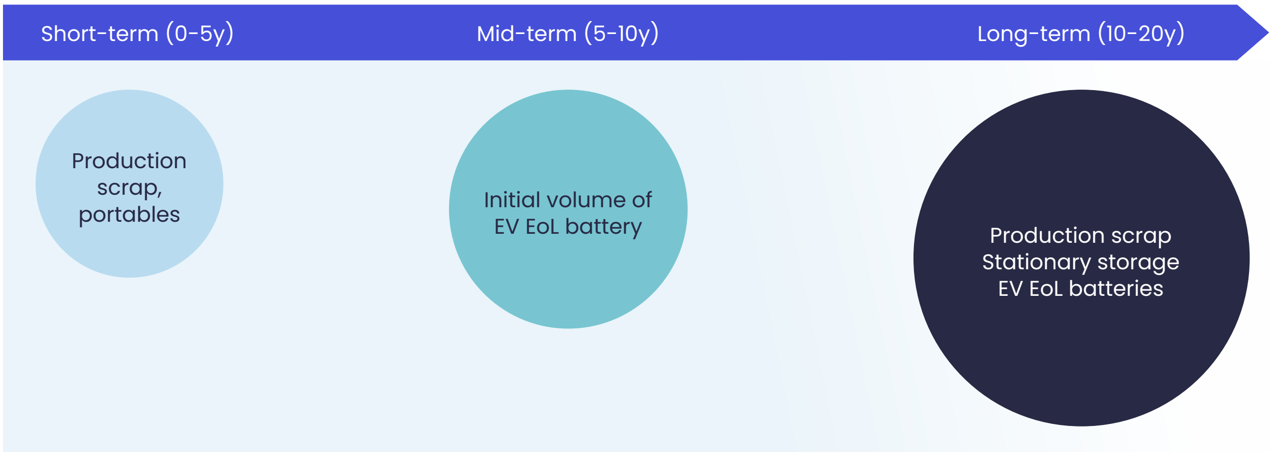
Reaching toward a closed-loop EV battery recycling system

Mina Ha
Senior Research Analyst, Rho Motion

As the battery recycling market expands, there have been increasing investments in establishing battery closed-loop supply chains. Furthermore, the Inflation Reduction Act of 2022 (IRA) announced by the US government in August is likely to act as a catalyst for building the battery closed-loop supply chains. China begins to expand to other regions while challenges remain with the new legislation.

Global battery recycling capacities are scaling rapidly; the global battery recycling pre-treatment capacity reached around 1.3 million tonnes of batteries per year as of October 2022, with China accounting for 79% of the total capacity. As the battery recycling market expands, there have been increasing investments in establishing battery closed-loop supply chains through acquisitions, joint ventures or partnerships on the back of the various advantages it brings in the long term; 1) the closed-loop supply chain provides certainty in the process of selling recovered materials, 2) mitigates financial instability especially when economies of scale are yet to be achieved and 3) lowers costs in cathode material production by using recycled battery-grade materials.

Figure 1: End-of-Life EV is expected to become the majority of feedstock towards 2030 as vehicles start coming off the road *Source: Rho Motion*



Battery recycling feedstock primarily comes from production scrap at present and initial volumes of EV end-of-life batteries are expected near the end of the decade as vehicles start coming off the road. It means that in the short and medium term, battery-grade materials recovered are unlikely to cover the insufficient supply of raw materials fully. However, in the long term, reliance on battery-grade materials recovered is expected to increase. The closed-loop supply chains will play an important role in raw material supply and establishing them now will provide higher possibilities of partnering with existing players with advanced technology, networks and large-scale operations.

Furthermore, the Inflation Reduction Act of 2022 (IRA) announced by the US government in August is likely to act as a catalyst for building the country's battery closed-loop supply chains. The new bill will invest USD369 billion in Energy Security and Climate Change programs over the next 10 years and is projected to have a significant impact on helping the US meet its climate goals with wide-ranging support for several clean technologies. The IRA also includes the requirements on minimum percentages of the value of critical materials sourced domestically (or any country that the US has a free trade agreement with) that will accelerate the US battery recycling market growth.

Some of the large-scale recycling companies in China are already operating in the closed-loop system. For example, Chinese battery producer CATL has established its battery supply chains; its subsidiary Brunp Recycling currently operates two battery recycling facilities with an annual capacity of 120,000 tonnes of batteries and large-scale CAM production in China. Another top-tier battery recycling company in China, GEM currently recycles 10% of the total electronic waste and 10% of the total end-of-life

Figure 2: Inflation Reduction Act *Source: Rho Motion*

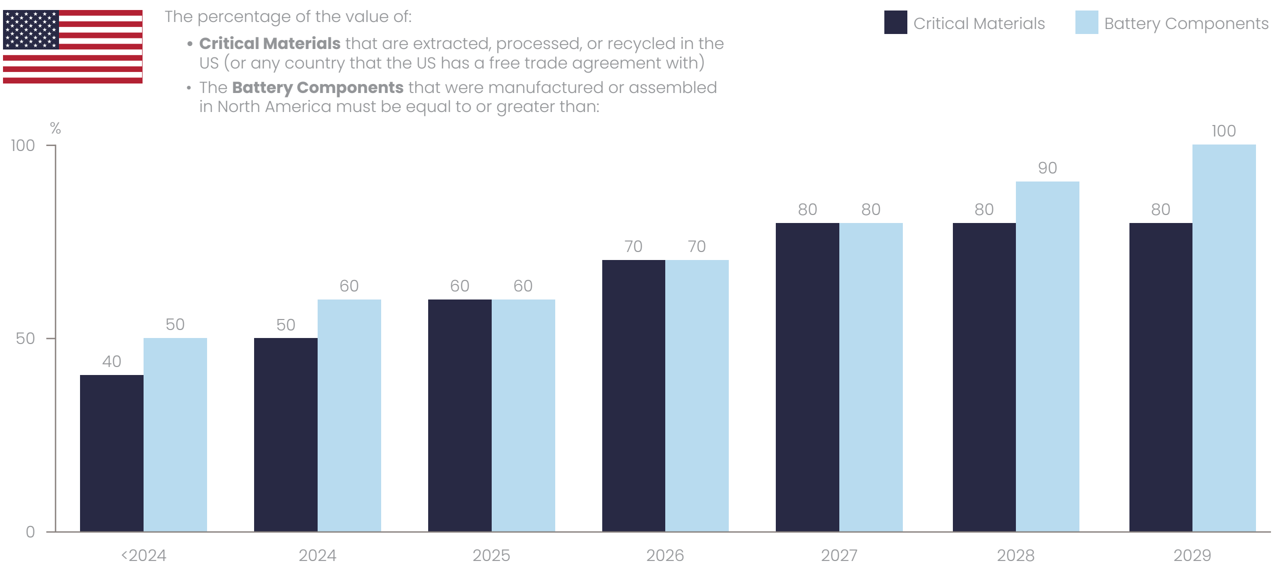
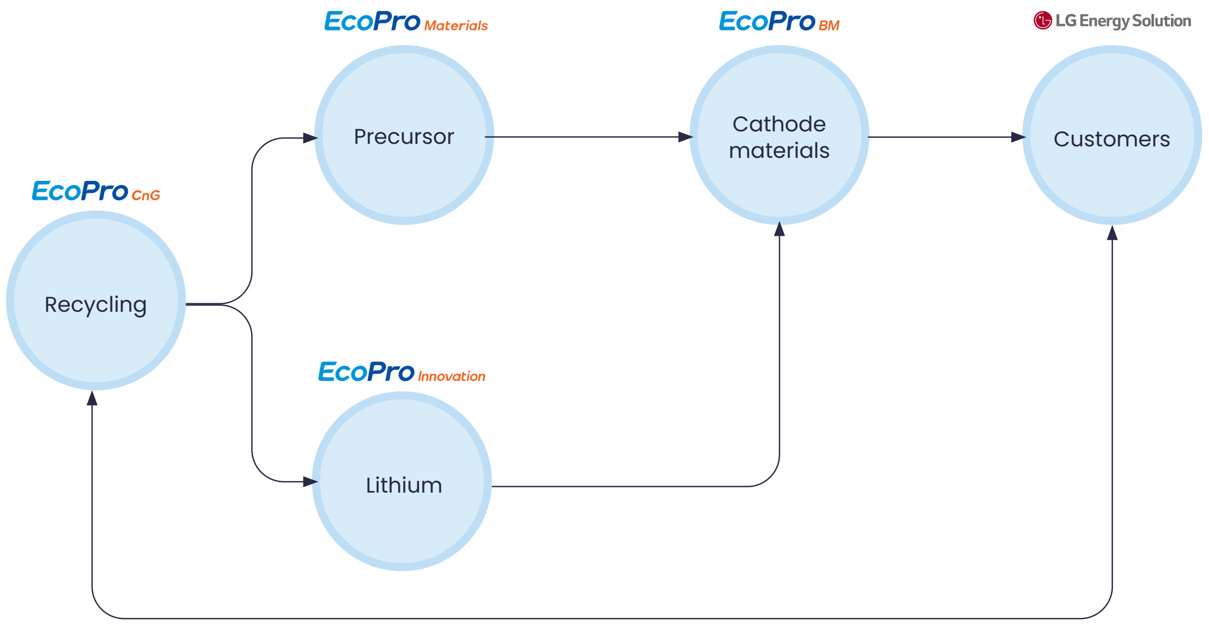


Figure 3: EcoPro's closed-loop supply chains

Source: Rho Motion



batteries (excluding lead-acid batteries) in the country. It follows a 2+N+2 business model: two main recycling plants + N online & offline collection platforms + two raw material re-production plants.

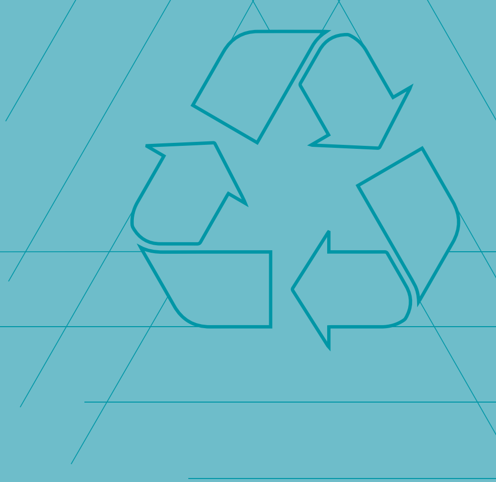
In the US, Cirba Solutions and 6K agreed to form a joint venture to produce recycled cathode materials, thereby creating a closed-loop value chain for lithium-ion battery production in the country. In Europe, Umicore and Volkswagen's subsidiary PowerCo agreed to form a joint venture in Brussels, Belgium, establishing closed-loop battery materials value chains. The joint venture will produce pCAM and CAM for PowerCo's battery plant in Europe. It will also develop battery recycling based on Umicore's technology.

In South Korea, raw material producer EcoPro has established its closed-loop supply chains from precursor and cathode material production to battery recycling. Its main feedstock for battery recycling comes from LG Energy Solution's plants in South Korea and Poland. Cathode and anode material producer Posco has been investing aggressively in building closed-loop battery supply chains and scaling battery recycling capacity.

Posco in partnership with SungEel HiTech completed constructing its battery recycling plant in Lower Silesia, Poland in August this year. The plant is capable of processing 7,000 tonnes of batteries annually, sourcing its feedstock mainly from LG Energy Solution. Black mass produced at the plant will be shipped to its joint venture with Huayou Cobalt, the Posco Hy Clean Metal, in South Korea for the post-treatment process. In October this year, Posco signed a joint venture agreement with GS Energy, a subsidiary of the South Korean conglomerate GS Group, for the battery recycling joint venture, Posco-GS Eco Materials.

The wave of establishing closed-loop supply chains is going to continue as the battery recycling market expands. As for China, its closed-loop supply chain remains largely within the country as Chinese battery recyclers are currently focused on domestic expansions. With the IRA, expansions to the US seem limited.

Although the challenges remain, overseas expansions are likely. Companies like CNGR Advanced Material and Huayou Cobalt are expanding in partnership with Korean companies (SK Ecoplant, LG Energy Solutions and Posco) as a way to enter other regions. CATL's investment in battery projects in Indonesia is expected to cover a whole battery supply chain including battery recycling.



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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.

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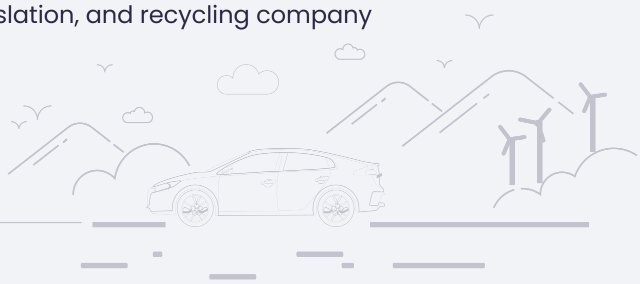
Our forecast provides long-term outlooks for the following:

- 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.



Setting sail: EV & battery waste shipping

Aesir Logistics

Steven Scecchitano
President, Aesir Logistics

Photo: Adobe Stock

There isn't much chatter in the logistics industry when it comes to moving EV and battery waste – at least not yet. The shipping industry has experienced rough seas with the ebb and flow of COVID, increasing regulation, fuel costs, and war to name a few. Remarkably, the global cargo shipping market is still projected to grow from 11.09 billion tons in 2021 to 13.19 billion tons in 2028 at a CAGR of 2.5% during the 2021-2028 period. Capacity, congestion, and increasing regulation are on the top of the industry's chatter list, but not batteries.

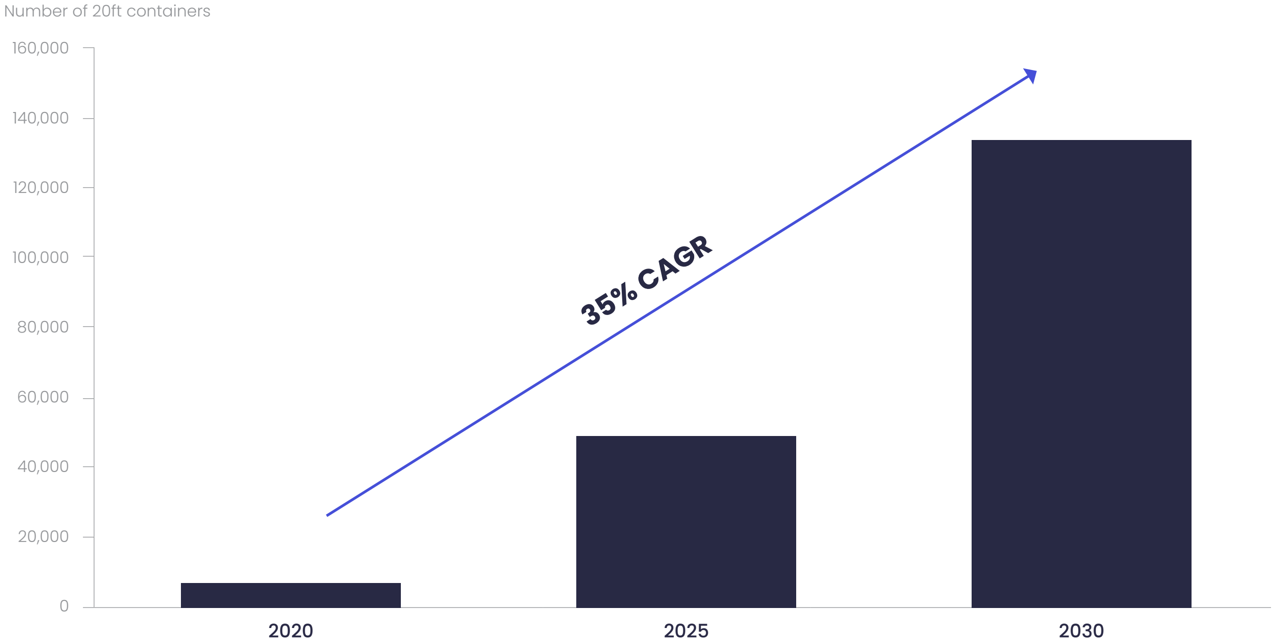
On the other side of the spectrum, the EV and battery waste industries have plenty to talk about, but are not talking enough about one topic in particular – logistics. Transporting batteries and battery waste both internationally and domestically requires additional levels of regulatory compliance and expertise.

Step into any one of the EV and battery conferences taking place globally (there are many) and one thing is for sure; ask all the participants in the room what the biggest pain point is and watch all of their hands rush toward the ceiling as they shout out, -"logistics". It is astonishing to see the EV and battery recycling industry boom overnight. With billions getting invested into the industry it is even more mind blowing to witness the lack of focus and direction where it matters most. All of the new technology and recycling plants sound great, but not a single one will start up without feedstock. Which, by the way, will need to get moved by a truck, train, boat, or in some cases all three.

The dirty truth that many do not want to face is that moving batteries and especially battery scrap and waste is extremely difficult, and to add salt to the wound, the difficulty is increasing. Already highly regulated, lithium ion batteries are essentially restricted to moving by sea and truck. That is, if one can find an ocean carrier or trucker willing to take the material onboard.

Figure 1: The global annual black mass is forecast to grow at 35% CAGR by the end of the decade *Source: Rho Motion*

Global annual black mass by market in 2020-2030



Note: The number of 20ft containers is calculated based on 18.1473 tonnes of black mass per 20ft container

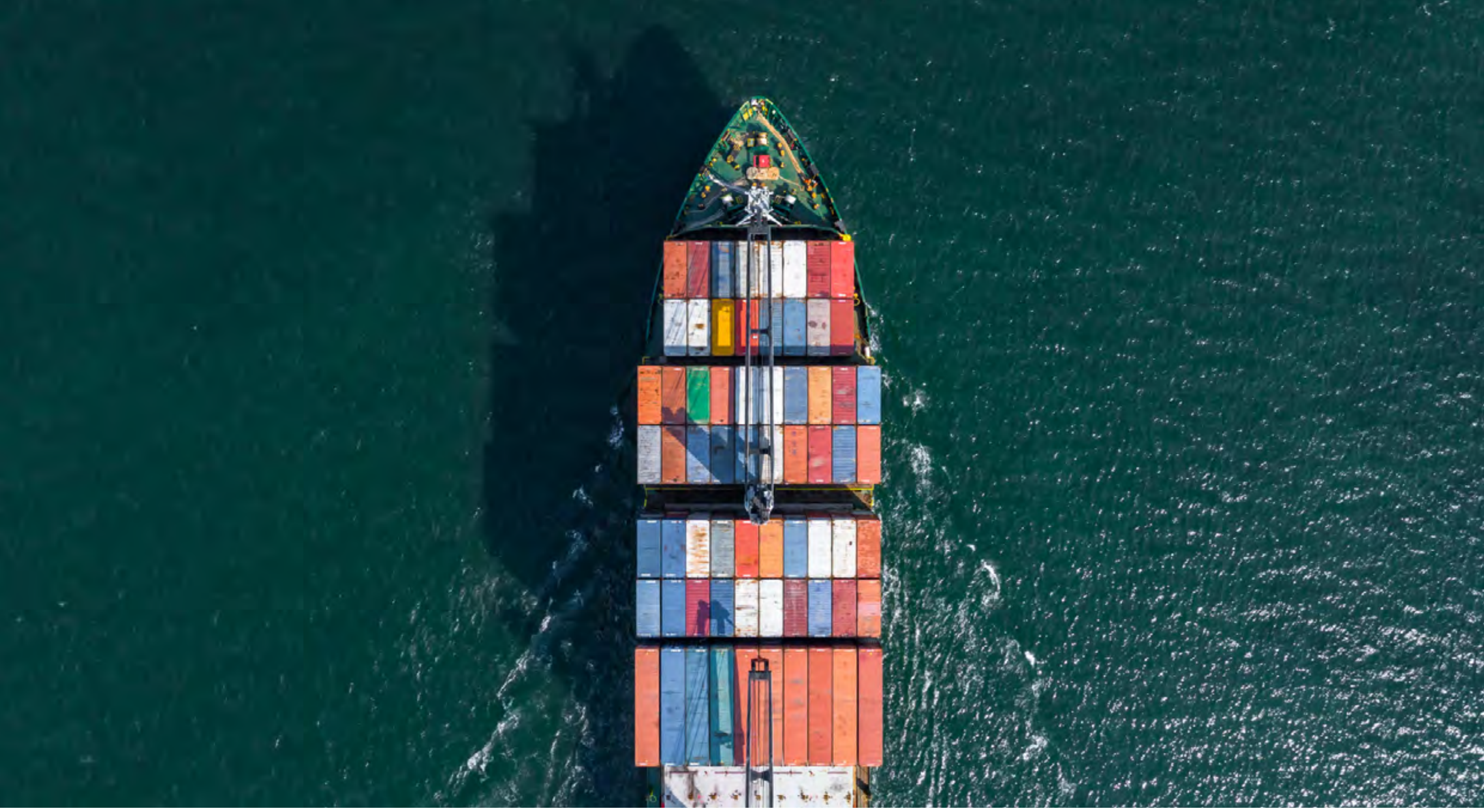


Photo: Adobe Stock

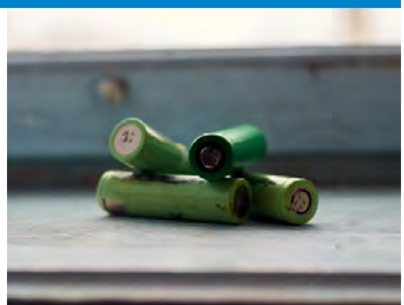
Many carriers have flat out refused this cargo by developing internal policies that prohibit its transportation onboard their vessels. This reluctancy and prohibition has stemmed from an industry plagued with safety concerns over safe packaging and handling, which in several cases has led to catastrophic fires onboard vessels and vehicles. Also, let's not forget the vessels and trucks of the world are already over capacity, so moving a cargo that is already stigmatized with safety and regulatory concerns will require a fair amount convincing.

The global annual black mass forecasted to grow at 35% CAGR by the end of the decade. This equates to over 120,000 TEU's. A TEU (twenty-foot equivalent unit) is a measure of volume in units of twenty-foot long containers. With the average ocean vessel carrying 15,000 TEU's, by 2030 it is projected there will be enough black mass to charter more than eight ocean vessels in one year. That is eight, massive ships, entirely filled with 15,000 containers of black mass – get ready to set sail.

As if convincing the world's largest ocean carriers to accept batteries and battery waste wasn't challenging enough, players in this industry are also faced with the ever evolving international waste regulations. Some startups in the recycling industry have suggested the spoke & hub model to eliminate the need for international transportation, but the reality is markets will change along with the geopolitical landscape. Any leading organization knows, mostly through trial and error, supply chains must be adaptable. Navigating local waste regulations as well as the international agreements such as the Basel Convention and the OECD Membership can be mind-numbing.

Don't let all of this chatter about logistics and regulatory challenges take the wind out of your sails. Battery scrap and waste, including black mass, is currently moved via ocean, rail, and truck. It's not for the faint of heart, but with the right logistics partner it becomes a methodical and sustainable process on repeat. The first step is ensuring your logistics partner has the in-house expertise to correctly classify the cargo. From there, creating the required documentation, and in some cases permits, is the precursor for a physical booking from the carrier. One must remember, the major network of carriers need be convinced and assured the cargo is properly labeled, safety packaged, secured, and all international waste regulations have been met. Only a freight forwarder with a close working relationship with the carriers can put their concerns at ease.

Aesir Logistics is just that partner. As a tried and trusted international freight forwarder in this exciting and upcoming industry, Aesir has been moving batteries, battery waste, and black mass for five years all around the globe. Aesir works closely with the major ocean carriers to ensure our client's cargo is safe and compliant. With in-house expertise in packaging, labeling, documentation, and international waste agreements, Aesir will focus on your logistics so you don't lose sight of what's most important – growing your business. Trust us, it's smooth sailing from here.



Aesir Logistics is the preferred logistics partner for transporting batteries for recycling both domestically and internationally. With expertise in multi-modal dangerous goods regulations as well as international waste agreements, Aesir can manage entire supply chains or parts thereof. Depending on the mode of transport, battery shipments are subject to strict regulations which are constantly evolving. Not to mention, shipping batteries as waste requires additional measures including permitting with the EPA and origin or destination countries. Aesir works closely with the major ocean carriers to ensure our client's cargo is safe and compliant. From proper labeling, documentation, and permitting; Aesir Logistics will manage your battery shipments to ensure your supply chain keeps moving both safely and on time.

Services:

OCEAN CARGO
AIR CARGO
TRUCKING
WAREHOUSING
DANGEROUS GOODS (HAZMAT)
CUSTOMS CLEARANCE
CARGO INSURANCE

Why Choose Us?

OVER 15 YEARS OF EXPERIENCE
SINGLE POINT OF CONTACT
END-TO-END SOLUTIONS
IN-HOUSE COMPLIANCE & HAZMAT EXPERTISE
OUR OWN WAREHOUSE OPERATIONS
ASSET BASED FORWARDER
FAST RESPONSE TIME

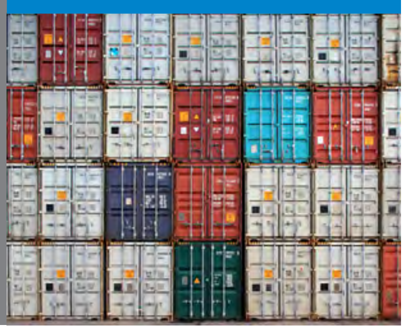


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Photo: JF Martin

The future of maritime electrification

Shan Tomouk
Senior Research Manager, Rho Motion

As the passenger EV market continues to grow in strength, hitting the one million monthly sales milestone in September, increased attention is being directed towards ancillary transport industries. One such area gaining momentum is that of the maritime industry. As countries strive to reduce emissions in line with international targets, the electrification of marine crafts may play a vital role in the future success of such targets.

The environmental importance of the maritime industry should not be overlooked. It is currently estimated that shipping accounts for approximately 90% of global trade, according to the International Maritime Organization (IMO). The industry as a whole contributed 2.89% to global anthropogenic GHG emissions in the year 2018, representing both an absolute and relative increase on 2012 figures.

Small Focus

Despite the impressive technological developments deployed thus far in BEV vehicle markets, significant limitations remain for the marine sector. As ships increase in size and weight, so does the technological mountain to climb. For example, the size of the battery pack that would be required to power a large container ship would introduce both significant cost barriers and safety issues that would place pressure on an already tight raw materials market. Additionally, the long distances typically travelled by freight ships across oceans would test even the most advanced battery technologies today.

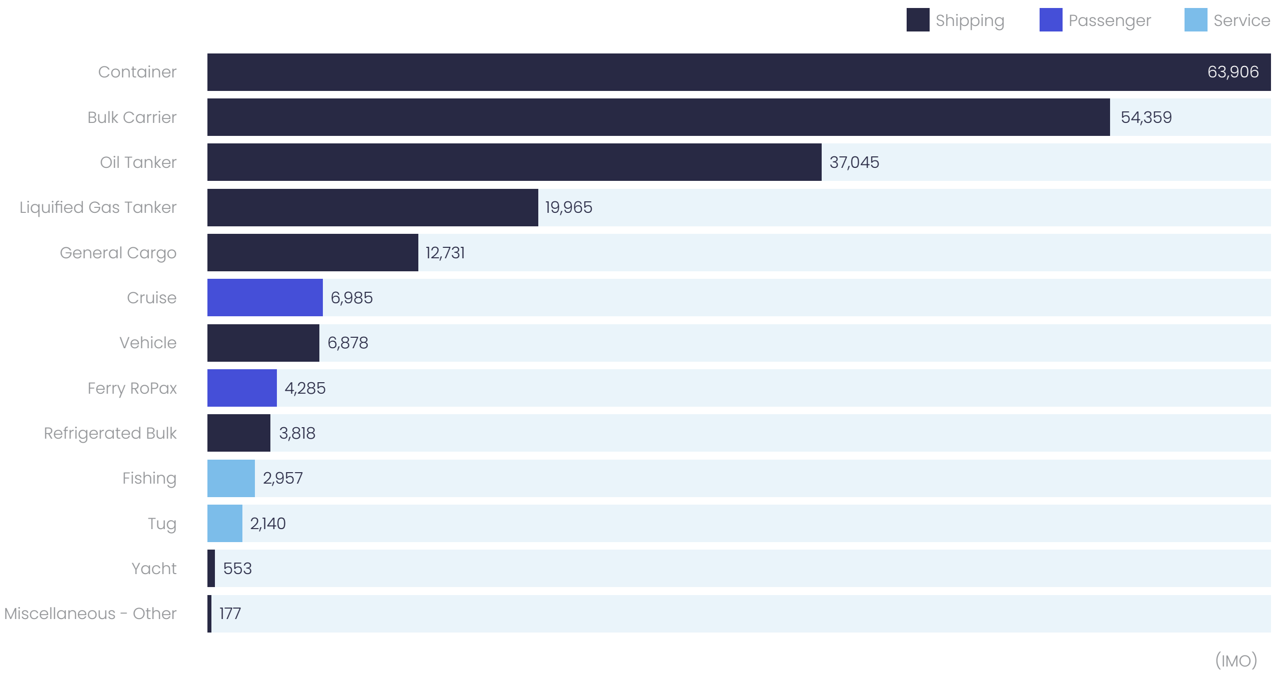
It makes sense then that we have seen a strong focus on smaller, short-range craft for electrification in the near term. In the leisure sector, we have seen several smaller crafts come to the market, with yet more models in development. Swedish-based Candela has developed hydrofoil boats powered by 40kWh NCM battery packs from the BMW i3, with agreements with Polestar to develop purpose-built battery packs for future models. Elsewhere, X Shore has brought two light-duty leisure boats to market with the larger of the two, the Eelex 8000, capable of 115 miles using its 126kWh battery.

On the commercial side, Dutch shipbuilder Damen has developed a range of electrified ferries and tug boats designed for short-range local tasks. Multiple contracts with municipalities in Canada, Denmark and New Zealand have demonstrated a viable alternative to diesel-generated offerings for short-range use cases. Other prototype offerings, such as Scandlines' upcoming PR24 RoPax ferry, which will rely upon an onboard 10MWh stationary storage system provided by Leclanché, are paving the way for further growth.

An interesting consideration for leisure boat owners is the idea of battery management. In the US, approximately 11.9% of US households owned or co-owned a boat of some kind in 2020 (US Coast Guard). Approximately half of these experience fewer than 50 days of use in the year. For owners who keep their boat idled for several months or years at a time, adequate battery management will be crucial.

One potential for marine craft in this respect is the development of vehicle-to-grid charging, in which owners can plug in their boats during the off-season to buy and

Figure 1: Global HFO-equivalent fuel consumption by ship – '000 tonnes *Source: Rho Motion*



sell electricity to the grid while managing battery health. As charging technology develops over time, we will likely begin to see vehicle-to-grid or boat-to-grid charging gain traction in the market.

Despite the promising developments outlined above, there is still a question as to whether maritime electrification can make a significant difference to overall GHG emissions. As can be seen from Figure 1, the shipping industry accounts for a large majority of fuel consumption in ships. A focus on smaller, short-range fleets may be beneficial for local pollution within in-land waterways and cities, however, large-scale GHG emissions reduction will require more effort and technological development.

Legislation: a new mountain to climb?

In November 2022, the European Parliament announced drafted legislation regarding emissions in the maritime sector. Within the draft, the EU plans to target an 80% reduction in GHG emissions from shipping by 2050 (compared to 2020 levels), with a 20% target by 2035. The legislation would apply to all ships with a gross tonnage of 5,000 tonnes or more, operating within or between EU ports, and 50% of the energy used on voyages entering into or departing from regions outside the EU.

The introduction of legislation will certainly aid in the further development of electrified offerings in the shipping industry. The potential for fines for those who fail to reach targets further increases the viability of battery-powered offerings.

However, the reality of reaching these goals is different. For long-range, heavy-duty shipping uses, electrified offerings will struggle to compete. It is more likely that a combination of sustainable fuels and efficiency gains will be the key to achieving these targets on a large scale. Another interesting development comes from onboard carbon capture and storage (CCS) technologies to reduce escaped emissions. UK-based Seabound are in the process of developing CCS technology for ships, which the company claims could help to reduce up to 95% of CO_2 emissions from the ship.

There is also a question concerning enforceability in the industry. Without similar legislation from other regions, it is easy to see shipping companies choosing to shift focus

"The development of an entirely new charging infrastructure in marine bays and ports will also require significant investment and likely some legislation to incentivise such projects.

to non-EU markets to avoid the stringent requirements, particularly given the high costs of electrification or emissions reduction.

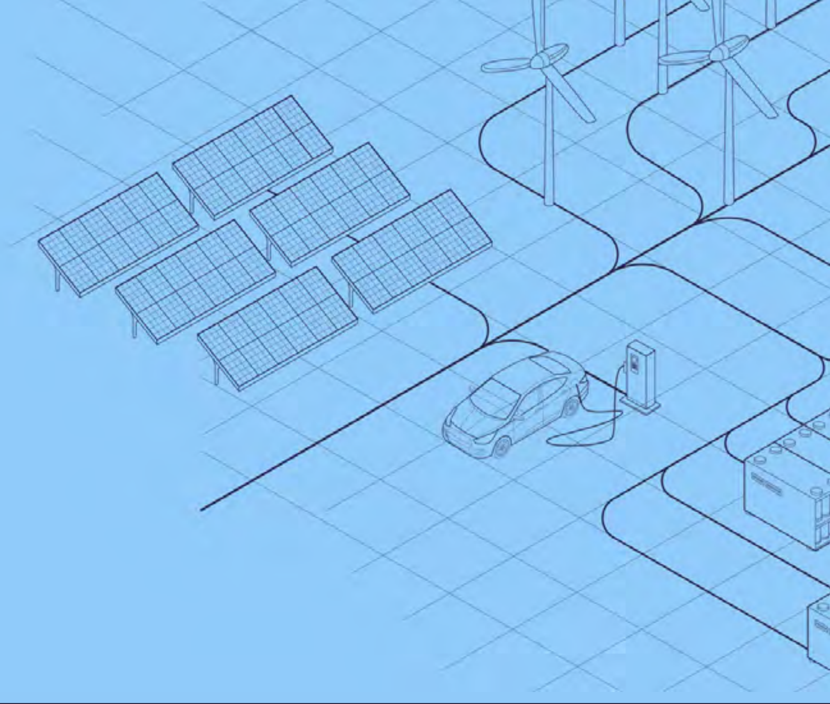
One step at a time

Despite the glaring obstacles faced regarding the large-vessel shipping industry, the electrification of the small-scale maritime sector provides a promising opportunity for emissions reduction in local areas. As technology advances and OEMs push the boundaries of what is possible, we can expect to see larger and longer-range ships follow suit.

For most manufacturers, NCM has been the battery chemistry of choice given the higher associated energy density and thus, higher range capabilities. In some larger models, we have seen the emergence of other battery chemistries, such as lithium-titanate (LTO), which is featured in Damen Shipyards' electric ferry line-up. This is reflective of the industry's focus on increased safety, as mid-journey battery faults or fires would be costlier for large passenger marine vehicles than would be expected for a passenger electric car on the road.

The development of an entirely new charging infrastructure in marine bays and ports will also require significant investment and likely some legislation to incentivise such projects. Nevertheless, the current pilot schemes in operation across the globe shine a light of optimism on the short-range maritime market and will help to build momentum for future electrification in the space.

rho motion



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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	✓	✓	✓
EV Battery Chemistry Monthly Assessment PDF and Excel File • Monthly releases		✓	✓
Battery ESS Monthly Assessment PDF and Excel File • Monthly releases		✓	✓
EV & Battery Monthly Database Excel File • Monthly releases			✓
Battery ESS Monthly Database Excel File • Monthly releases			✓

Hydrogen in civil aviation: A rusty silver bullet?

Photo: Jens Kreuter

Olatomiwa Olajide
Research Analyst, Rho Motion

One industry that has received much flak for its supposed reluctance to decarbonisation is the aerospace industry, specifically civil aviation. One might argue this is undeserved, as the perceived reluctance is not due to a lack of trying. Experimentation with hydrogen as an aviation fuel began as far back as 1937, and in 1988 the Soviet Union became the first country to experiment with hydrogen fuel in a passenger aircraft. However, almost three decades later, hydrogen is still thought of as a 'fuel of the future'.

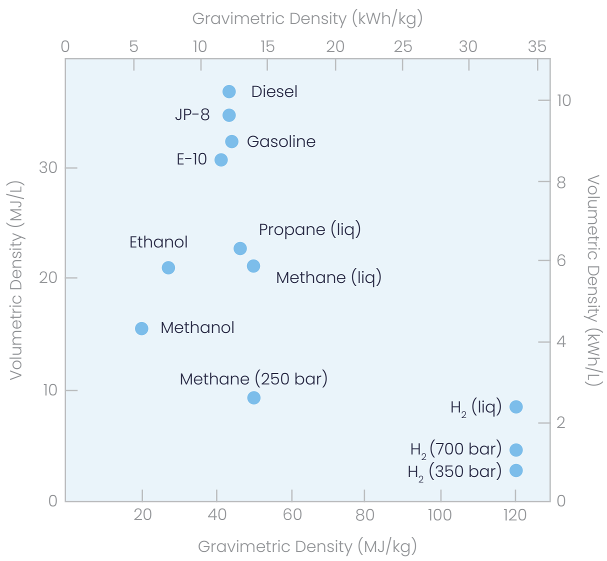
Figure 1: Hydrogen Timeline (Non Exhaustive) Data *Source: Rho Motion*

Year	Event
1937	He-S-2 experimental turbojet engine on hydrogen
1957	US Air Force B57 bomber flight tests
1970s	Studies by NASA Ames; Institute of Gas Technology; Linde; Lockheed, and others
1988	First flight of TU-155 proves viability of commercial aircraft flying on liquid hydrogen and LNG
2000	Cryoplane project launch: development of safe, environmentally friendly concept aircraft to investigate medium/long term transition scenarios from kerosene to hydrogen
2007	Clean Sky programme launch: development of environmentally-friendly aviation technologies
2014	Clean Sky 2 programme launch: design of Innovative Aircraft Demonstrator Platforms (IADPs) for large passenger aircraft, regional aircraft, and fast rotorcraft
2020	Airbus reveals ZEROe concept aircraft

Hydrogen to the rescue

At first glance hydrogen is near perfect. It is ubiquitous, more energy dense (figure 2) than aviation kerosene and batteries (33kWh/kg vs 12kWh/kg vs 0.175kWh/kg) and is the lightest element in the periodic table. This is especially important. At full capacity, a 747-8's fuel load is nearly 50% of its maximum take-off weight – about 200 tonnes. In addition, hydrogen combustion produces *only* water as a byproduct. On the surface, hydrogen appears to be a panacea for all of civil aviation's emissions problem – that is until you read the fine print.

Figure 2: Hydrogen Energy Density Chart *Source: U.S. Department of Energy*



https://www.energy.gov/eere/fuelcells/hydrogen-storage

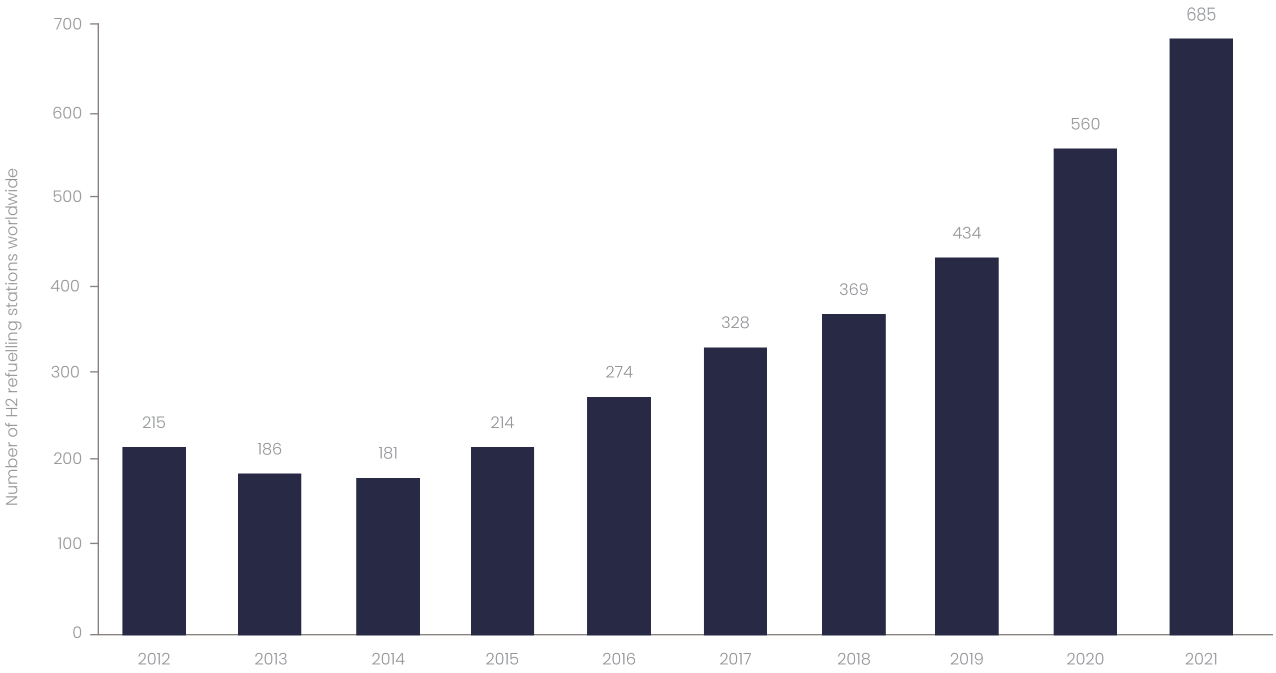
Setbacks in the implementation of hydrogen

For starters, hydrogen is truly abundant on our planet. The problem is it is often bonded with carbon, forming hydrocarbons, the very fuel type that the world wants to move away from. Secondly, while hydrogen has a high energy density, it has a poor volumetric density (figure 2). That is, for example, 1 kg of hydrogen will produce three to four times as much energy as 1 kg of aviation kerosene but would require four times as much storage space.

As mentioned, hydrogen combustion produces water as a byproduct. But for water to be the only byproduct, hydrogen would have to be burned in pure oxygen. Hydrogen combustion in air produces water vapour and oxides of nitrogen, colloquially referred to as NOx, as byproducts; even if it is burned in a lean air mix. NOx causes damage to the human respiratory tract, and the exhaust water vapour causes a greenhouse effect like CO2 although the extent to which it does is still disputed.

Additionally, there is still the problem of cost and infrastructure. Hydrogen can be produced using several different methods, with the most eco-friendly option being electrolysis of water. This is where water molecules are split into their constituent hydrogen and oxygen atoms. This process is currently expensive. As of October 2022, global price of jet A1 fuel is about $1.14 per kg, while hydrogen produced through electrolysis of water costs between $3 - $8 per kg. Hydrogen infrastructure on the other hand has significantly improved over the last decade (figure 3). There has been nearly 250% increase

Figure 3: Hydrogen refuelling stations *Source: H2Stations.org*



in the number of refueling stations, which currently stands at about 730 globally. Provided there is continued government support, we expect this upward trend to continue.

Solution outlook

To put it candidly, the biggest barriers to adoption of hydrogen in civil aviation have largely been technological. Several companies and projects have set out to solve these problems and overall, three major solution pathways have evolved – ***propulsion, storage***, and ***airframe design***. Admittedly, these approaches are all interconnected.

On the propulsion front, hydrogen-electric (fuel cell) propulsion is currently in the lead, with companies such as ZeroAvia, Overair, and GKN Aerospace developing their own propulsion systems often times in partnership with other OEMs. A specific advantage of a hydrogen fuel cell system over hydrogen combustion is that a fuel cell reverses the electrolysis process, combining hydrogen and oxygen to produce electricity and water only. No NOx is produced. This, however, still leaves the exhaust water vapour and the associated problems. To counter this, some companies have developed conceptual designs aimed at either recycling the water produced within the fuel cells or collecting them to be used for other on-board purposes – flushing maybe?

As previously mentioned, under normal conditions, hydrogen exists in a gaseous state. It must be cryogenically cooled at high pressure to become liquefied. Hence, hydrogen is stored in tanks with enough durability to withstand the high pressure and low temperature requirements. Consequently, these tanks are often heavy and bulky, which is undesirable. As a result, tank materials have had to evolve over the years – from steel and aluminium to composites (figure 4). There are currently several ongoing projects aimed at designing and manufacturing the next generation of hydrogen tanks. One of such projects is Project OVERLEAF, which aims

> *The airframe route is perhaps the most radical of the three as designing a commercial aircraft from the ground up requires significant investment.*

at developing materials, capable of reducing current tank masses by 50%. Airbus is also working on new tank designs as part of its ZEROe project.

The airframe route is perhaps the most radical of the three as designing a commercial aircraft from the ground up requires significant investment. Hence, it is unsurprising that only a handful of companies, most notably Airbus, are working on such projects and oftentimes in partnership with governments and other OEMs. Airbus currently has three design considerations for its ZEROe project – turboprop, turbofan, and blended-wing body (BWB). Although the company is yet to make a selection, the turboprop variant is the most likely of the three. It has a traditional airframe and will not cannibalise any of Airbus' current offerings. Nevertheless, Airbus' ZEROe project is only expected to come online in 2035. But the market is eager to decarbonize, and this has led to the creation of a possible fourth solution pathway – *retrofitting*.

Rather than designing airframes from scratch, companies such as Fokker, ZeroAvia and Universal Hydrogen are retrofitting existing aircraft with hybrid-electric propulsion systems and providing liquid hydrogen storage solutions. Universal Hydrogen currently for example has a retrofit kit suited to the ATR72 and De Havilland Canada Dash-8. This consists of a fuel cell propulsion system and patented modular hydrogen storage tanks which are loaded unto the aircraft's cargo bay. The company hopes to, in the future, retrofit transcontinental narrowbody aircraft in the A320 and 737 families.

Retrofitting these aircraft will undoubtedly come with new challenges – specifically weight and structural problems. Airplanes store fuel in their wings, giving them added rigidity, reducing flutter. If hydrogen cannot be stored in the wings, then aircraft wings must be structurally reinforced to increase their rigidity. In addition, if hydrogen tanks are to be stored in the aft (rear) section of the fuselage, as most companies currently propose, then

Figure 4: Hydrogen Tank Evolution

Source: 2022 FCEV Outlook slide 15

Tank Type	Description	Material Tank	Liner/Windingz	Pressure (bar)
Type I	Metal (Steel/Aluminum)	Aluminum	-	175
		Steel	-	200
Type II	Metal tank with filament windings around the metal cylinder	Aluminum	Glass	263
		Steel	Carbon or Aramide	299
Type III	Tanks made from fiberglass, aramid, or carbon fibre with aluminum or steel liner	Glass	Aluminum	305
		Aramide	Aluminum	438
		Carbon	Aluminum	700
Type IV	Carbon fibre tanks with thermoplastic polymer liners	Carbon fibre	Polymer	700
Type V	All-composite, liner-less tank	Composite (prototype)		1,000

existing aircraft will have to be elongated in an effort not to reduce passenger capacity. This will likely lead to a shift in the aircraft's centre of gravity and therefore impact its longitudinal stability.

Hope on the horizon

To conclude, it is apparent many technological breakthroughs will be required for hydrogen to become a truly viable and mainstream fuel in civil aviation. Companies like Airbus have been involved in hydrogen aircraft research for more than two decades and it is encouraging that a major industry player is backing the fuel. Noteworthy progress has been made in the short haul and regional aircraft range, and these will likely be the first set of aircraft to run on hydrogen (2030s), with long range aircraft coming further down the line. Despite current challenges, hydrogen it seems is here to stay.

Electrification in defence

Edward Keith
Associate Consultant, Rho Motion

After a seismic shift in the geopolitical landscape in 2022, electrification of propulsion mechanisms in the UK's defence sector has an unlikely opportunity to accelerate.

At the first glance, it may appear that electrification doesn't have anything to do with defending the UK's shores. Dig a little deeper however, and you'll find the contrary; it has a critical role. The UK defence sector used 666 million litres of fuel in 2018-19. In June 2019, the UK Government signed the net zero emissions commitment, requiring the UK to bring all greenhouse gas (GHG) emissions to a net zero by 2050. Like many other large organisations, the defence sector, with legislation as the only driver, has been largely asleep at the wheel with respect to cutting emissions. Simply, battleships, fighter jets and tanks are not simple or cheap, to electrify. Even with defence accounting for half of the total UK Government's GHG emissions (according to the MoD's CCSA document), a combination of an inability to assign liability, expense, and focus on short-term internal goals, means there is no real incentive to change. This article will discuss options for the propulsion systems for the tactical components in the UK's defence sector for warfare on land, sea and in the air. The operational and strategic components are better aligned with the electrification of the UK's wider infrastructure.

Figure 1: A guide to the domains of war

Source: Rho Motion

Domain of war	Description	Capacity for electrification
Strategic (*e.g. Gary Oldman in Darkest Hour*)	The high-level decision making that occurs in government headquarters	Small: Does not consume significant energy
Operational (*e.g. Nicholas Cage in Lord of War*)	The means by which Strategic and Tactical connect. i.e the supply of war material.	Large: Provides the greatest elements for electrification
Tactical (*e.g. Tom Hanks in Saving Private Ryan*) The focus of this article	The service personnel facing the enemy, be it on the land, sea, or air.	Medium: Provides some bespoke electrification opportunities.

SITREP

In February 2022 the situation changed, Putin invaded Ukraine. The invasion returned war to Europe for the first time since the 1990s Balkan conflict. Immediately, the price of brent crude rose above USD100 per barrel and the cost of energy has subsequently spiralled, causing economic unease. Over and above the expense of fuel, the war bought into sharp focus the UK's (and NATO's) reliance on imported energy. More than ever, the status quo for providing troops with a guaranteed energy supply is a strategic vulnerability.

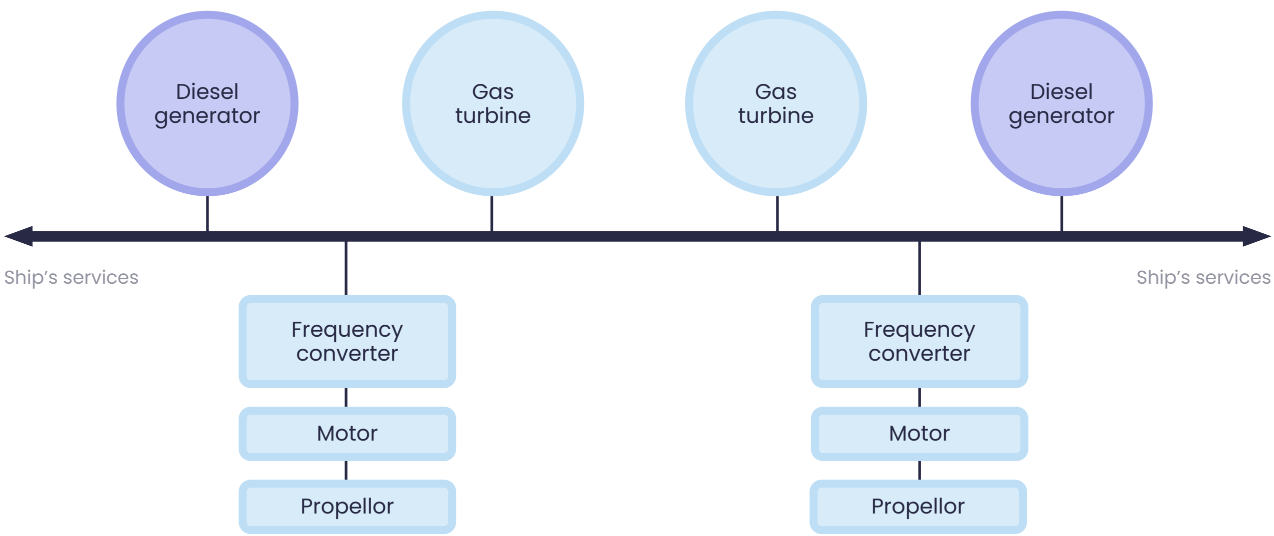
The result is that defence, more than any other sector, must look for alternate power sources. Two well-known phrases that, when considered in a modern context, demonstrate why: 'An army marches on its stomach' and 'War is the mother of invention.' The first means that front line units, regardless of domain, are only as effective as the supply lines providing them support. The second conveys the imperative, that to increase fighting power, innovation must be resourced sufficiently to develop weapons faster than an opponent. Conservation and efficient consumption of energy, whichever form it is in, and domestic control of energy production are therefore two key reasons for electrification. In contrast, the case against electrification is simple, cost: The military has faced notorious issues with equipment procurement in recent history, a quick search of 'AJAX' or 'Type 45 destroyer' should be enough to reassure you that defence procurement is still toward the top in ways to waste taxpayer money, so large scale spending is always contested.

The Marine Domain (The Royal Navy)

The Navy has perhaps the greatest potential benefit from electrification. Electrification and marine vessels have an interwoven history, there are countless World

Figure 2: The core components of Integrated Electric Propulsion (IEP)

Source: Rho Motion



War Two submarine films that involve a U-boat charging its batteries on the surface with diesel engines, before diving and switching to electric power to attack. The tactical benefits of electrification in a naval context are clear: stealth and reliability. Naval warfare has a large focus on deception and tactics. Adversaries are seldom constrained by the lay of the land and therefore must rely on superior tactics, misdirection, and the element of surprise for victory. Silent propulsion has been a key requirement of naval vessels in the modern age. The ability to locate an opponent through sonar was so advantageous that during the height of the cold war, the US Navy placed microphones across the entire Atlantic to listen for Soviet submarines, in a system known as SOSUS. The Royal Navy already runs hybrid diesel and gas electric systems. Integrated electric propulsion (IEP) systems are becoming more prevalent, with the UK introducing an IEP in its new aircraft carriers, as well as in its new destroyers (both of which have created media attention for reliability.) The diagram below shows the system, the essence of the design being vessel develops its own microgrid from with which to run its motors.

The current IEP systems are complex and fragile. The frustrating reality is that further progress to a pure electric system seems unlikely to be anytime soon, as the levels of energy required are staggering. Modern electric storage and generation (with the notable exception of nuclear) are unable to meet the demand. Even covering the 16,000 m^2 of HMS Queen Elizabeth's deck with solar panels does little to plug the 109 MW power requirement filled by the

The frustrating reality is that further progress to a pure electric system seems unlikely to be anytime soon.

gas turbine and diesel generator combination. (On a sunny day it could make ~3.5 MW.) Additionally, near-future weaponry like rail guns and drone swarms are only likely to add to the power demand. The best option available immediately for powering large war ships and reducing GHG are carbon neutral fuels or nuclear.

In contrast, there is increased scoped for further electrification of smaller vessels. They form the bulk of the Royal Navy's fleet (50m or less in length). They carry the duty of training sailors as well as protecting strategic coastal areas. These vessels have smaller endurance requirements and regularly dock. There are numerous examples battery electric ships in the commercial sector, but mainly these vessels travel known routes with large infrastructure requirements at their ports. Due to the variety of workload required for Royal Navy vessels, the current flexibility is not yet a suitable replacement. They are, however, ideal candidates for battery replacement as soon as technology allows. In October, the Royal Navy participated in a NATO exercise off the coast of Portugal, experimenting with unmanned vessels, piloted from HMS Lancaster. These unmanned vessels may be the first wave of battery power naval vessels, although information on the technology is understandably limited.

Land Electrification (The British Army)

History is littered with examples of powerful armies failing, due to under resourced troops: The French invasion of Russia, Operation Barbarossa, Operation Market Garden to name a few. Commanders and their staff will spend days planning the deployment of resources needed for their troops, to ensure they have the means required to fight, but even the most robust plans still carry risk. Land based units are particularly vulnerable to attack during resupply, due to topographical constraints associated with resupply (large, usually wheel based, vehicles are often used). The perfect solution is to have troops that are self-sufficient but in practice, this doesn't exist. Regardless, there are still gains to be made from reducing the frequency of resupply.

The benefits are therefore twofold: increased logistical freedom from reduction in the burden on supply chains (less fuel, lubricants, parts and electric vehicles are more efficient) and, like the Navy, reduced emissions signatures (both thermal and acoustic). Unfortunately, there are some clear barriers to prevent widespread adaptation. Again, technological limitations feature, the below table illustrates this by selecting three of the UK's main fighting vehicles and assess their current consumption, giving a theoretical battery requirement in kWh. Currently, it is possible to retrofit these vehicles with batteries, but with batteries costing around USD130 per kWh, it becomes expensive quickly. Using Jackal as an example, the cost of the batteries alone is at USD66,520 per vehicle and would be USD28.6 million for the fleet.

Despite the expense, the British Army has begun to experiment with hybrid vehicles, creating a USD10.15 million programme. Unsurprisingly, it is Jackal that has received a hybrid drive system. Paired 30kWh batteries, in conjunction with the incumbent diesel engine, it allows for silent

Figure 3: An indication of the energy requirements for BEV conversions of some British Army fighting vehicles *Source: army.mod.uk, Rho Motion*

Vehicle	Weight	Engine	Listed fuel capacity *(theoretical energy MJ)*	Range *(current fuel economy)*	Theoretical kWh required for same range per unit (MWh for fleet conversion)
Main Battle Tank *(Challenger 2)* *UK Units: 227*	64,000 kg	Perkins 26.6 litre V12	1,592 litres 60846 (MJ)	550 km (~0.8 mpg)	5,633.8 kWh per unit 1278.9 MWh for fleet
Light Reconnaissance Vehicle *(Jackal)* *UK Units: 431*	6,650 kg	Cummins 5.9 litre I6	147 litres 5518 (MJ)	800 km (~12.8 mpg)	510.9 kWh per unit 220.2 MWh for fleet
Mechanised Infantry *(Boxer)* *UK Units: 523 (ordered, expected in service for 2024)*	33,000 kg	MTU 15.9 litre V8	562 litres 21480 (MJ)	1,100 km (~4.6 mpg)	1988.9 kWh per unit 1040.2 MWh for fleet

Conversion factors and assumptions:
Efficiency factor: Diesel Engines 30%, Electric Motors 90%
At 15 °C, 1 litre of diesel weights 0.84 kg, having a calorific value of 38.22 MJ
1 MJ is 0.27· kWh

running and increased operational range. Some small steps in a longer electrification journey.

The Air Component (The Royal Air Force)

Electrification of aircraft in general present one of the most technologically challenging obstacles to net zero emissions. Weight and energy densities of current batteries are not at the sufficient level to compete with existing combustion powered jet aircraft. Theoretically, replacement of a jet engine is possible, with an electric equivalent. Simply powering a compressors fan and forcing the air through a nozzle using electric energy, strictly speaking this is not a jet engine, rather a ducted fan, but it could produce the same effect. The problem exists around the thermodynamic benefits created through the combustion. In a jet engine, the value of thrust is amplified by thermodynamics, with addition of afterburners also enhancing thrust, something not possible without a combustible fuel. To create this effect through electricity is not practical. The bulk of the RAFs aircraft are jet powered so the direct replacement RAFs aeroplane with electric engines is currently limited.

The most intriguing option for electrification available to the RAF lies in elaborate evolution of its current tactical practice- continued removal of humans from aircraft. Unmanned aerial vehicles (UAV) reduce the risk to life and exposure to political leverage on operations. Two examples: In 2012, two Tornados collided in Scotland with fatal consequences and in January 1991, John Peters and John Nichol were shot down during the invasion of Iraq. Both events resulted in a media storm and the RAF sustained reputational damage. Additionally, headline aircraft like the F-35B, Typhoon and Voyager are complex and expensive to fly. An F-35B costs USD145 million to purchase and USD35 thousand per hour of flight. Due to the operating complexity, effective piloting requires hundreds of hours of training, all of which contribute to GHG output.

Conversely, unmanned aircraft lend themselves to simulator training more than conventional aircraft. The RAF already has a squadron of MQ-9 Reaper drones and has a USD108 million project to develop this space through replacing the Reaper with the MQ-9 Protector. The MQ-9 platform uses a turbo-prop engine, which is better suited to possible future electrification, through replacement of the jet turbine, which spins the propellor, with an electric motor. The aircraft performance capabilities required are not as intense and so lower the energy density development delta between current jet and electric aircraft. Still, the current technological limitations present the biggest barrier to electrification

> *Electrification of the tactical elements of defence has some way to go, with many obstacles yet to be overcome. The early signs show promise and the potential for development is rich.*

Electrification of the tactical elements of defence has some way to go, with many obstacles yet to be overcome. The early signs show promise and the potential for development is rich. The benefits of electrification are clear, and imperative, should the UK take seriously its commitment to zero GHG by 2050, aggressive development is needed. Not just to meet this target, but equally to ensure the future fighting components remain competent with greater self-sufficiency, even if acting as a deterrent. The counter is that in a time of austerity, the military doesn’t have the funds (or at least the history of good fund management) required to truly invest in tactical electrification.

Whatever the requirement, energy is needed to fight. It must be managed and utilised in a safe, reliable, and domestically controlled manner. Electrification is the answer.

rho motion

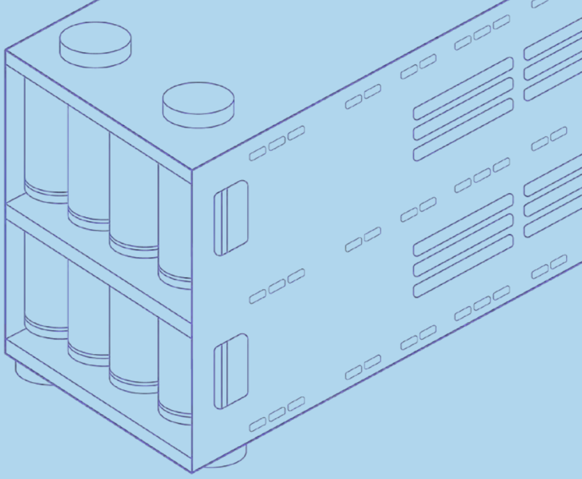


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Photo: Casey Horner

BESS in Europe

Playing catch-up

Pete Tillotson
Research Analyst, Rho Motion

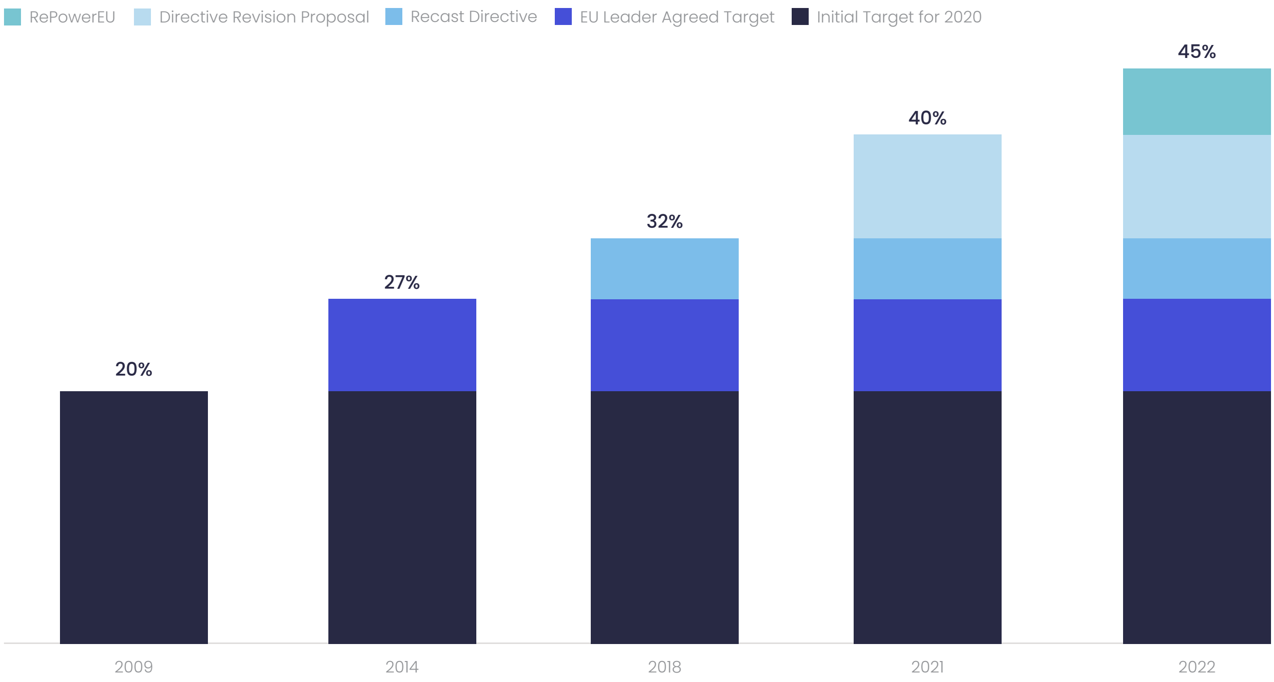
Russia's invasion of Ukraine and the subsequent energy crisis have highlighted the urgent need for a ramp-up of Europe's grid-scale battery energy stationary storage (BESS). Within the past year, rising energy costs and the need for independence from Russian oil imports has driven Europe's renewable energy deployment strategy as the continent simultaneously pursues energy security and the decarbonisation of its energy system.

Renewable energy generation has unsurprisingly been the focal point of this strategy and as a result has received a multitude of capacity targets and policy support mechanisms. Yet energy storage, a crucial enabler of renewable energy integration, has been comparatively neglected from a policy support perspective.

Grid-scale Storage

In May, the European Commission set out its action plan to address these concerns in the "RePower EU" publication which called for a nearly doubling of annual renewable deployment (predominantly solar and wind) from 42GW to 78GW by 2030. This would bring the total renewable energy generation capacity up from 1,067GW to 1,236GW by 2030. No such targets were set for energy storage within the document, either in absolute terms or as a percentage to be paired with new renewable deployment. The document acknowledged the need for energy storage but lacked detailed plans and concrete policy support mechanisms through which the storage market can grow. Greater attention was awarded to debatably more nascent technologies such as green hydrogen and carbon capture and storage.

Figure 1: EU Legislation for Percentage of Renewables in 2030 Energy Mix *Source: Rho Motion*



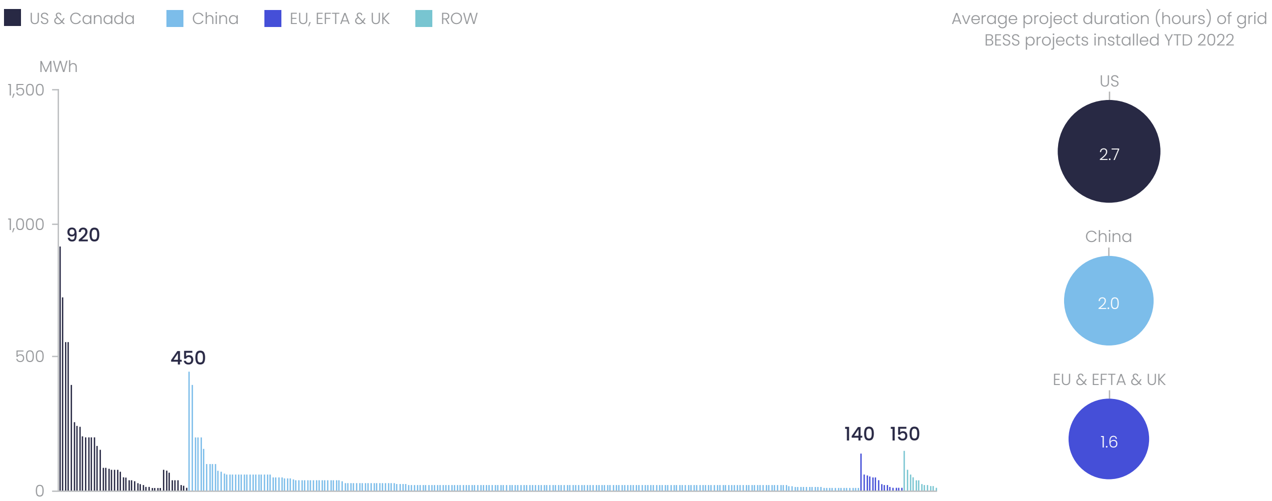
Legislative and regulatory ambiguity continue to hinder BESS investment and deployment in Europe, and further progress is needed to cultivate an environment in which storage projects can be planned with a greater degree of certainty over revenue streams, regulatory requirements, and market structure. Lack of government support and streamlined legislation are significant contributors to Europe's BESS market being so far behind that of the US and China, who have clearly defined roles for storage systems in legislation with direct subsidy support and, as a result, have a more developed and cohesive market. Indeed, Rho Motion forecasts predict Europe will be overtaken in total grid BESS MWh deployed by Australia alone as soon as 2023.

European BTM Market

Conversely, the behind the meter (BTM) market is performing well in Europe as a direct consequence of government support policies. Germany now has over 40% of rooftop solar applications paired with BTM storage as a result of various subsidy schemes implemented since 2013. It is now by far the leading European market for BTM storage, with roughly 4GWh of installed residential storage as of October 2022. As part of the COVID-19 national recovery plan in 2020, Italy introduced a subsidy whereby consumers could potentially receive 110% tax credit for grid-connected solar-paired residential energy storage systems installations. Along with Germany and Italy, the UK and Austria are also driving Europe's strong BTM demand. The European BTM market will show higher annual growth rates than that of the grid market , in part due to legislative support as well as less complex planning and implementation processes. The energy crisis is also likely to have its most visible effect on BTM storage as opposed to grid-scale in the short-term as individuals look to shield themselves from rising energy costs. Yet the policy, regulation and subsidy support demonstrated in the BTM market demonstrate the importance of government intervention in storage deployment and highlights the potential for growth in the BESS market under the right conditions.

Figure 2: Grid scale projects over 10MWh installed YTD 2022 by project capacity and region

Source: Rho Motion



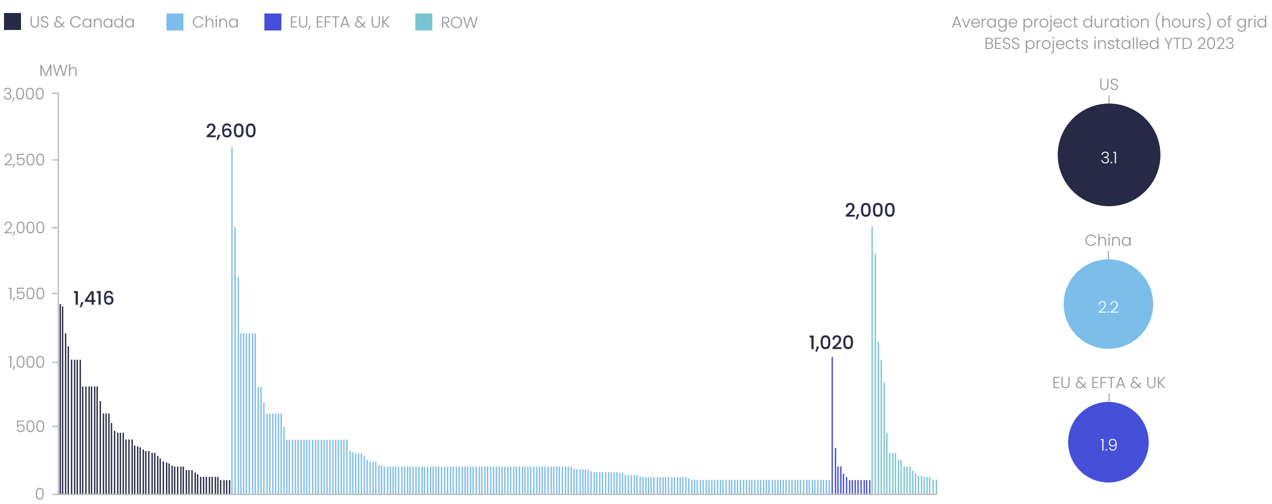
Signs of progress

Some recent progress has been made within EU member-state national policy to provide legislative clarity over the role of energy storage in future energy systems. In 2022, Greece doubled its energy storage target in 2022 to 3GW by 2020, and the Spanish government approved an energy storage roadmap forecasting the need for 20GW of storage by 2030 and 50GW by 2050. Germany has passed legislation which allocates energy storage an explicit definition in law and, although market development in the country still faces significant hurdles, this update is welcome progress for market players seeking less convoluted regulation and planning processes. In January, the Dutch national government legislated to remove double taxation of energy storage assets as both a consumer and a distributor of electricity. However, still being classified as an end-consumer, energy storage assets are liable to grid-access fees.

The issue of double taxation is a significant barrier to attracting investment and generating revenue streams, and is therefore restricting energy storage deployment. Proposed revisions to the European Energy Tax Directive (ETD) will reclassify energy storage as redistributors from 2023, resulting in a single application of tax for either drawing or supplying power from the grid. Combined with the recently announced European Investment Bank's funding boost of €30bn for transition technologies, including grid upgrades and storage deployment, gradual progress is being demonstrated by Europe's supranational institutions to encourage investment in energy storage.

Figure 3: Grid scale projects over 100MWh planned 2023 by project capacity and region

Source: Rho Motion



Proposed Solutions

However, major structural obstacles remain. Since the release of RePowerEU, major European energy storage players have highlighted several areas in which policymakers could provide support for BESS deployment and, in turn, increase the likelihood of achieving the renewable targets set out within the strategy. For example, Europe's current peaking capacity strategy relies heavily on gas assets that could be relatively quickly replaced, in-line with renewables deployment, by low-carbon energy storage assets. Long lead times on storage projects as well as revenue uncertainty dissuade potential investment that could both remove polluting assets from Europe's energy mix and enhance the continent's energy security. Policy suggestions also include establishing mandatory paired renewable and storage auctions, Contracts for Difference (CfDs) for flexibility and curtailment prevention and establishing longer contracts for new-build low-carbon assets. These measures target market-based incentives and revenue predictability for the BESS market. If combined with regulatory clarity on the role of storage in a renewable-dominated energy system and sufficient government support mechanisms, the European BESS market has a far better chance of meetings its own targets set out in the RePowerEU plan.

In October 2022, Wartsila completed the commissioning of the Netherlands' largest energy storage project to date. The GIGA Buffalo facility, a 25MW/48MWh energy storage system, is paired with wind and solar generation assets at the Wageningen University and Research test centre in Leylstad. The project utilises Wartsila's Gridsolv Quantum battery system and GEMS Digital Energy Platform energy management software, and will be Europe's first large-scale grid storage project to use LFP battery technology.

Giga Buffalo	
Power	25MW
Capacity	48MWh
Duration	2
Battery	LFP
Paired resource	Wind + Solar
Commission date	2022

Pillswood	
Power	25MW
Capacity	48MWh
Duration	2
Battery	LFP
Paired resource	Wind + Solar
Commission date	2022

Harmony Energy is close to completing the construction of the Pillswood BESS project in Cottingham, UK.
The site will use Tesla megapacks to provide grid-stabilising services to the National Grid as well as integration of renewable energy generation assets. The commissioning dates for both phases of the project were brought forward from December 2022 and March 2023 to November 2022. At the date of commissioning, it will be the UK's largest energy storage project. The UK-based company has a project portfolio of six 2-hour duration battery projects totaling 312.5MW.

Fluence Energy has announced it will deploy the world's largest battery-based storage-as-transmission asset in the world with TransnetBW, the German transmission operator for the state of Baden-Wurttemberg. The project will be located at the major grid hub Kupferzell and will act as a virtual transmission line on the existing transmission infrastructure to reduce congestion and maintain grid stability. It has been noted that deploying storage capacity is cheaper and faster than installing further transmission infrastructure lines. Fluence has a similar project operating for LitGrid, the Lithuanian national transmission operator, utilising 200MW of 1-hour duration energy storage.

Netzbooster	
Power	250MW
Capacity	250MWh
Duration	1
Battery	LFP
Paired resource	Grid
Commission date	2025

Updates on alternative battery technologies for BESS applications in China

Yu (Frank) Du
China Research Lead, Rho Motion

When it comes to battery energy storage systems (BESS), Lithium iron phosphate (LFP) battery is dominating the China market with a market share of over 95%. And it is very clear that LFP batteries will continue to be the most popular technology in the ESS sector in this decade. However, ever since BESS became one of the key pillars of the national 14th Five Year Plan in 2021, the development of potential alternative energy storage technologies is accelerating.

For a long time, the development of battery technology has revolved around electric vehicles. High-voltage lithium-ion batteries, commonly referred to as Power Batteries in China, were developed for electric vehicles (EV) but are used for both EV and energy storage systems (ESS). However, in reality, the requirements of BESS batteries and EV batteries are very different. Figure 1 demonstrates the major difference between BESS batteries and EV batteries. As you may see, EV batteries focus on performance and energy density while BESS batteries require lower cost and longer life cycle.

Researchers have been developing alternative battery technologies tailored for BESS application in the laboratory and have identified many promising ones, such as zinc batteries and solid-state batteries. But of all the alternative technologies, redox flow batteries (especially the vanadium flow batteries) and sodium-ion batteries are the most advanced and are in the process of commercialization at the moment. This article will provide some updates on the current status of these two technologies in China.

Redox Flow Battery (RFB)

Flow Battery technology has been available for decades. However, it never gained popularity until renewable energy came online in large scale and the energy storage is in high demand in China. Especially after the price surge of all lithium-ion battery materials in the past two years, the market is fiercely seeking for cheaper alternatives because the BESS business is very cost sensitive. Naturally, flow battery technology became one of the most promising candidates and is one of the key technology initiatives in China. You may find out more details about redox flow battery in Rho Motion's BESS Quarterly Outlook.

In China, there has been some progress in four RFB technologies - vanadium flow battery, iron-chromium flow battery, zinc-iron flow battery, and zinc-bromine flow battery, of which vanadium flow battery is the most developed. Earlier this year, China's largest vanadium flow battery (400MWh/100MW) BESS project came online. Some key players such as V-Liquid and Rongke Power have started the construction of their large-scale production lines. China National Nuclear Power, a state-affiliated energy company, has started the bidding process to procure 1GW vanadium flow battery energy storage system through its subsidiary. It is expected that the technology will be mature and accepted by more developers in the near future.

As for the other three technologies, they are still at early development/verification stage with some demonstrational projects of about 1MWh capacity.

Figure 1: Battery Requirements for Different Applications *Source: Rho Motion*

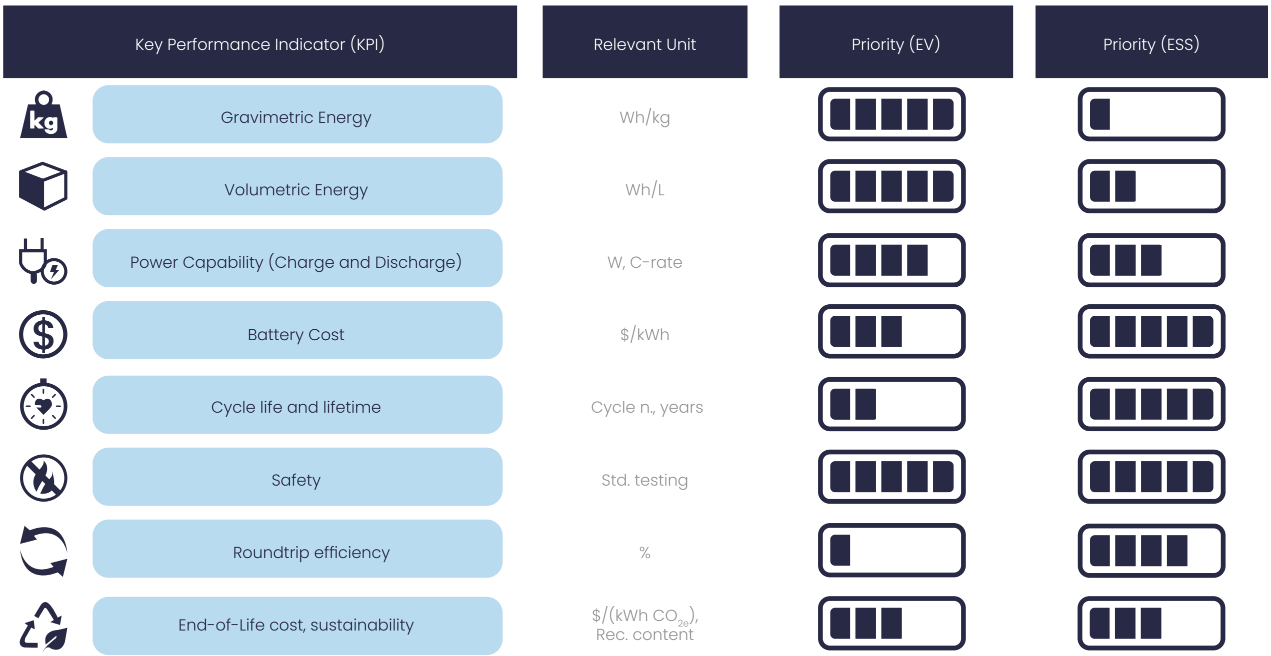


Figure 2: Sodium-ion Battery Supply Chain Update (China) *Source: Rho Motion*

Other Keynotes from the Industry		
Energy Density	BoM (China)	Latest Application
140~160Wh/kg (cell)	~USD40/kWh	HiNa Battery supply Na-ion battery to a 30MW/60MWh BESS in Anhui. (Commission in June 2023)

*Including small-scale/trial production. HiNa Battery is the only company that can produce at commercial scale.

SPIC, one of China's largest renewable energy and BESS developers, chose Iron-chromium flow battery as the key alternative energy storage technology. Its trial production plant is under construction. On the other hand, Weijing Energy Storage, a zinc-iron flow battery start-up, announced two GW level factories in China. However, zinc-iron flow battery does not have any commercial BESS project available. So, it is still too early to say how successful Jingwei will be in the energy storage market. Similarly, zinc-bromine flow battery technology has been pursued by two start-ups – HAES and ZbestPower. HAES has even started the trial production at its 4.5GW (planned) Gigafactory. Same as zinc-iron, the market is not familiar with the technology and the future of zinc-bromine is still unclear.

Sodium-ion Battery

Sodium-ion battery has got lots of attention after CATL's announcement about its 2023 roll-out plan for sodium-ion battery. According to CATL, the sodium-ion battery will be ready for commercialization when the supply chain is established in 2023. As the time approaching, there has been some development in the supply chain. Figure 2 listed some major players in the sodium-ion battery supply chain. At this stage, some sodium-ion battery manufacturers, such as HiNa Battery and Hanxing New Energy, also produce their own battery cathode materials. On the other hand, mature battery materials suppliers, such as Shanshan and Tinci, are preparing for the sodium-ion battery market to pick up the demand.

Backed by a strong R&D team from Chinese Academy of Engineering and Chinese Academy of Science, HiNa Technology is leading the game at the moment. It supplied the battery system to China's first MW level sodium-ion battery energy storage project in Taiyuan, which has been running for over one year by now. HiNa Battery is also building a 5GWh production plant in Shanxi, of which 1GWh capacity has been put into operation in Q3 2022. According to HiNa Battery, this project will reach 30GWh annual capacity in the future.

Other than HiNa Battery, Lifun New Energy and Hanxing both have gigafactories under construction. It is expected that small-scale commercialized production of sodium-ion batteries will be operational in 2023. If the batteries are verified and accepted by the market, a wave of large expansion will come soon after.

Both sodium-ion batteries and redox flow batteries are very suitable for large-scale energy storage applications. However, because of the limitation of those battery technologies, they are not very suitable for EVs. As a result, it will be difficult for sodium-ion battery and flow battery to achieve the same level of economy of scale as lithium-ion battery. In other words, lithium-ion battery will remain its dominant position in the EV and ESS market while alternative battery technologies will expand rapidly and take slightly more market share.

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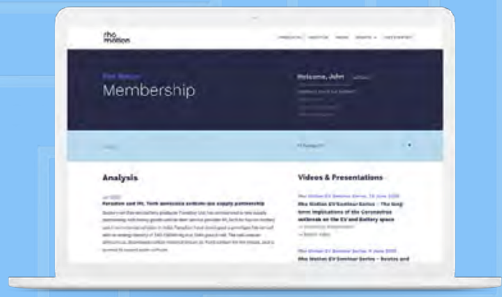

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Photo: Denys Nevozhai

Will eFuels be part of the road transportation solution?

William Roberts
Senior Research Analyst, Rho Motion

eFuels are currently one technology that hold an extraordinary level of potential to decarbonise industries and sectors which otherwise meet the question of net zero with blank faces and muffled silence. On the other hand, eFuels also hold great potential in being a distraction and a wasteful use of precious renewable electricity if not deployed in the right way and at the right time. We'll take a look at both sides of this intriguing solution.

What are eFuels?

eFuels, or Synthetic Fuels, are a direct replacement for the fossil fuels used today, from jet fuel to petrol and diesel. As the name suggests they are man-made, this is done by combining CO_2 and Hydrogen (H_2) to create the hydrocarbons found petroleum products, most commonly via the Fischer-Tropsch process.

With just hydrogen and carbon dioxide as the feedstock necessary to produce eFuels we can start to see the potential of eFuels. Hydrogen can be made in a 100% renewable fashion using electrolysis of water, with the electricity provided by power from renewable sources such as wind, solar or hydropower. Carbon dioxide is also a resource we have in plenty, most projects are planning to turn to carbon capture technology removing carbon dioxide from the atmosphere to produce the eFuel. This then creates the potential for a *carbon neutral* fuel as the carbon removed from the atmosphere will be released back to the atmosphere when burned in the vehicle it finds it way back to.

What can eFuels potentially do

The lowest hanging fruit in many ways for eFuels is in cars and trucks. The vast distribution network of petrol stations and tankers already exists and even with the transition to electric vehicles continuing at a blistering pace there will continue to be fossil fuelled powered cars on the roads for many decades to come. The current worldwide fleet of cars is still around 2% EV. Even if the last ICE car was sold in 2040, it would likely stay on the road until 2060.

Shipping is facing a tough challenge to reduce emissions, Maersk, one of the world's largest shipping companies, has committed to net zero by 2040 and is looking to methanol as a fuel to do it. Methanol can operate as a near drop-in with current diesel engines, needing only minor modifications, though Maersk will be starting with new dedicated methanol ships to begin with. Maersk hopes to operate the first ship using a green methanol eFuel from 2023 but is struggling to find enough supply already to help this first boat get afloat.

Current directives for aviation are the most prominent for using eFuels via the ReFuelEU Aviation regulation. This requires 2% SAFs (Sustainable Air Fuels) in 2025 – this incorporates advanced biofuels from waste. However, in 2030 the quota for SAFs rises to 5%, with 0.7% coming from eFuels. The quota rises to 63% SAFs, with a minimum of 28% eFuels in 2050. Aviation is also the most likely to be able to overcome the economic barriers of eFuels, flying will become more expensive but the leeway is probably greater than in the shipping industry which has historically used some of the cheapest available fossil fuel on the planet.

Figure 1: The steps to producing eFuels *Source: Rho Motion*

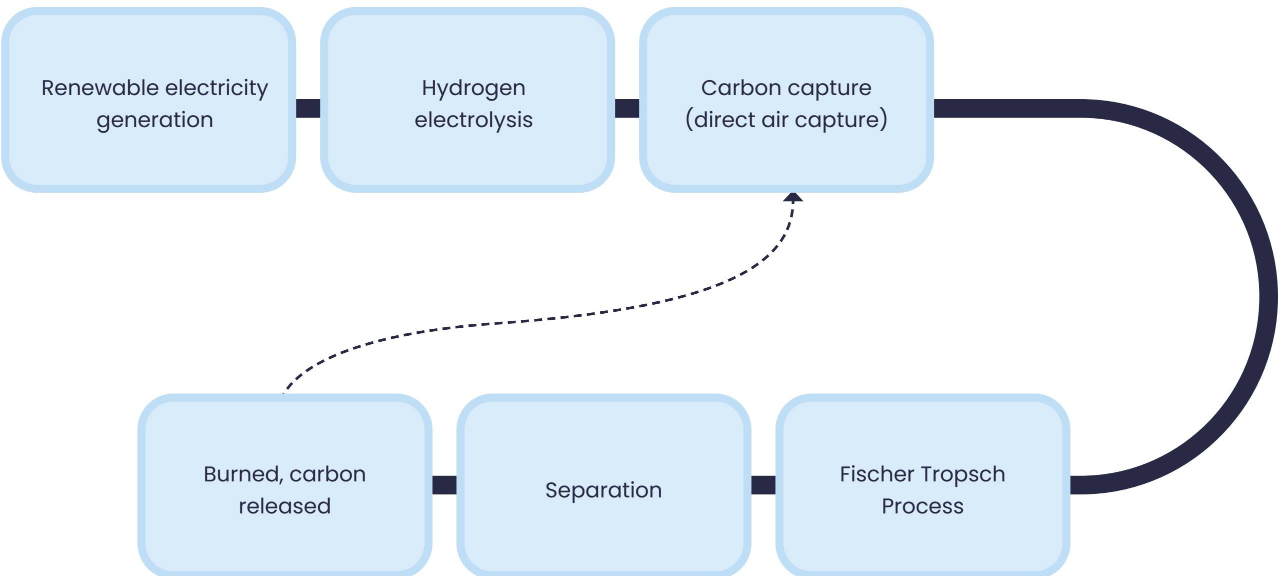
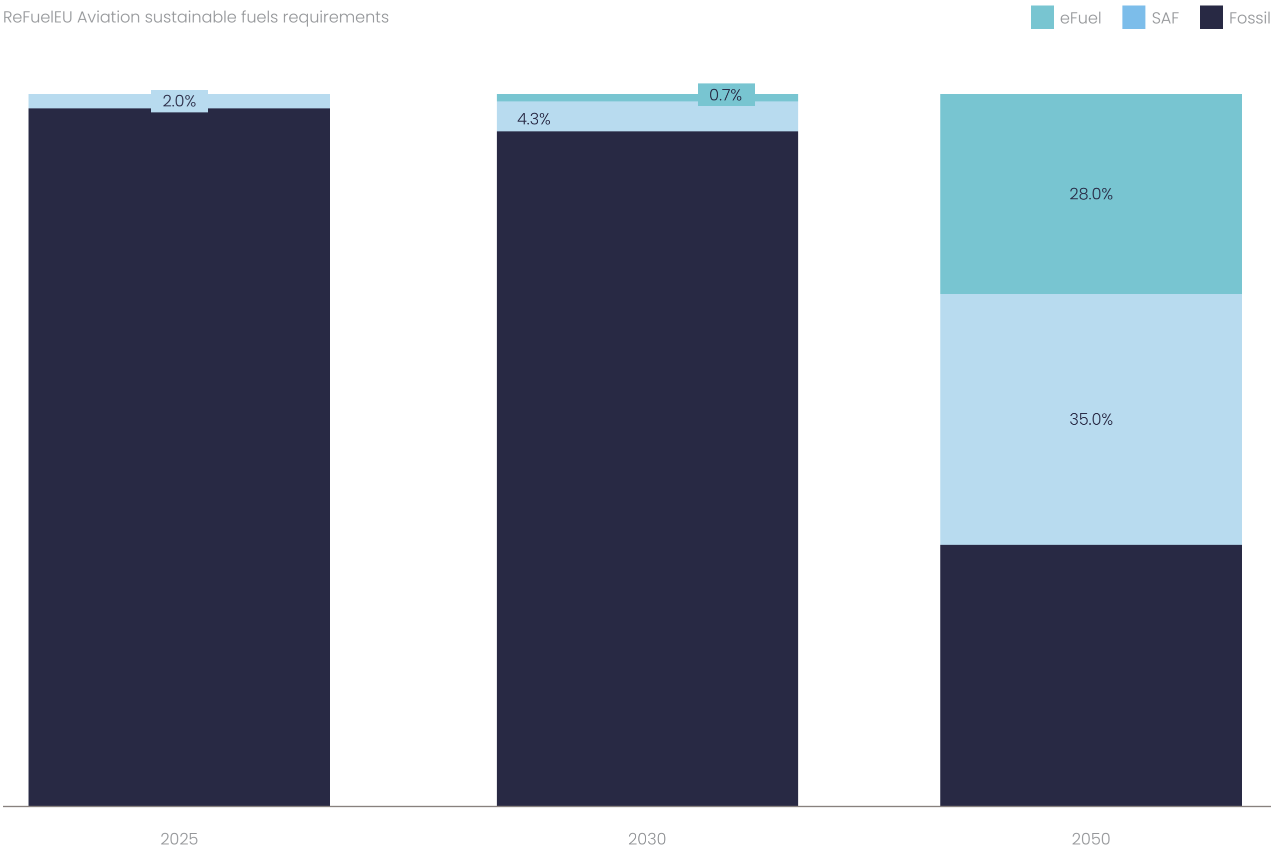


Figure 2: Sustainable Air Fuel (SAF) and eFuel requirements under the ReFuelEU Aviation legislation *Source: Rho Motion*



Capacity to produce eFuels

The key here is the first three steps in this process, every one of these steps is well recognised as being crucial to our energy transition. Renewable electricity will decarbonise our grids, hydrogen is often touted as the fuel of the future with the applications it is needed for seemingly endless, and the median amount of Carbon Capture and Storage (CCS) needed by the IPCC's 97 scenarios to keep warming below 1.5 C is 665 billion tonnes by the year 2100.

It would therefore seem that eFuels could be already well on their way with the underlying technology well understood. Contrary to this viewpoint, the required technology is already oversubscribed, each of these resources cannot simultaneously be promised to solve a multitude of problems.

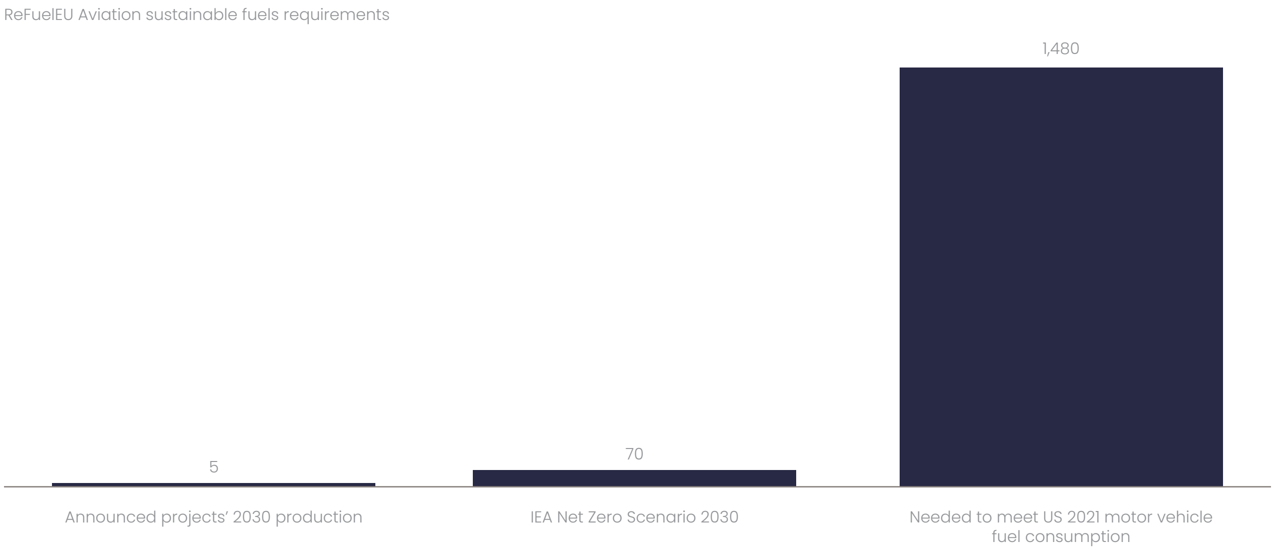
Starting with the carbon capture necessary to provide CO_2 for eFuel production. This technology is in its infancy and would likely be the bottleneck to the process. Around 35 CCUS (Carbon Capture Utilisation and Storage) facilities are in operation today with a capacity of 45 Mt CO_2 each year. This includes capture capacity from industrial sites and power generation, the direct air capture portion of this which is the focus of most eFuel projects. The IEA World Energy Outlook puts the role of DAC (Direct Air Capture) at around 70Mt CO_2 in 2030 and 600Mt CO_2 in 2050 for a net zero scenario. Furthermore 85% of that captured will need to be stored, leaving 15% available for use in areas such as synthetic fuels. Currently the announced projects put us on a path to capture 5Mt CO_2 by 2030.

The amount of CO_2 required to produce 1L of eFuel is 2.9-3.6 kg, according to a study by Shell. Using the low end of this range, our 5Mt of CO_2 captured in 2030 will be enough to create around 1.7 billion litres of eFuels. This would be enough to satisfy just the US consumption of gasoline by motor vehicles for a little over one day.

This is before we consider the other source material needed, hydrogen. 0.41 - 0.5 kg of hydrogen is needed to be combined with the CO_2 to create 1L of eFuel. Therefore, we would need around 0.7 Mt H_2 to match the 5 Mt CO_2 gathered from direct air capture. This would need to happen using renewable electricity, via electrolysis. Creating 0.7 Mt of H_2 via electrolysis at an efficiency of 80% would take 34.8 TWh of renewable electricity. That's

Figure 3: Figure: a comparison of the amount of direct air capture capacity expected in 2030 with the amount that would be needed to convert the US motor vehicle consumption to eFuels

Source: IEA, eia



the same as California's Solar and Wind generation in 2021. Remembering this level of production would satisfy around 1 day of driving for the whole country.

It is also common to hear 'excess renewable' electricity will be used to generate this hydrogen, though this also comes with its own set of issues. Excess, or curtailed renewable energy is intermittent by nature and so operating a commercially viable production operation on intermittent supply will be difficult. Additionally, that intermittent electricity could still be more directly put to good use with the addition of a battery storage system integrated with the renewable source, as is becoming far more common with installations already.

> *Of the 94.3 Mt of Hydrogen produced in 2021, low emission hydrogen accounted for 1%. The hydrogen market as it stands today is the obvious place to start for green hydrogen production*

California did curtail 1.4 TWh of renewable electricity last year, and there is no doubt that could be put to good use. Of the 94.3 Mt of Hydrogen produced in 2021, low emission hydrogen accounted for 1%. The hydrogen market as it stands today is the obvious place to start for green hydrogen production before we add additional demand. Currently, hydrogen production accounts for 900Mt of CO_2 emissions each year. California's curtailments could have increased green hydrogen production to 1.03%.

The production of eFuels is easy to state as a great answer, a drop in solution that doesn't require any mining or fossil fuels. Simply pulling carbon from the air and hydrogen from the water and your 6 litre v8 can continue to run forever more! However, on closer inspection of the numbers involved it is difficult to see how it can add up to anything close to a silver bullet solution for an issue as large as on road transportation. At each step along the way we introduce further inefficiencies and use up valuable capacity of crucial technologies for the energy transition. While it might be argued that this is still worthwhile as ICE vehicles remain on our roads, it could also delay the pace of transition in other areas which are far more achievable such as hydrogen production for the fertiliser industry, or carbon storage.

It is still clear that eFuels, particularly methanol for ships and synthetic jet fuel are going to be needed, and this is where the focus should lie for this industry. Rather than extending the life of combustion engine vehicle where viable alternatives exist.

Is China ready to go overseas?

Jie (Jessie) Xu
Research Analyst, Rho Motion

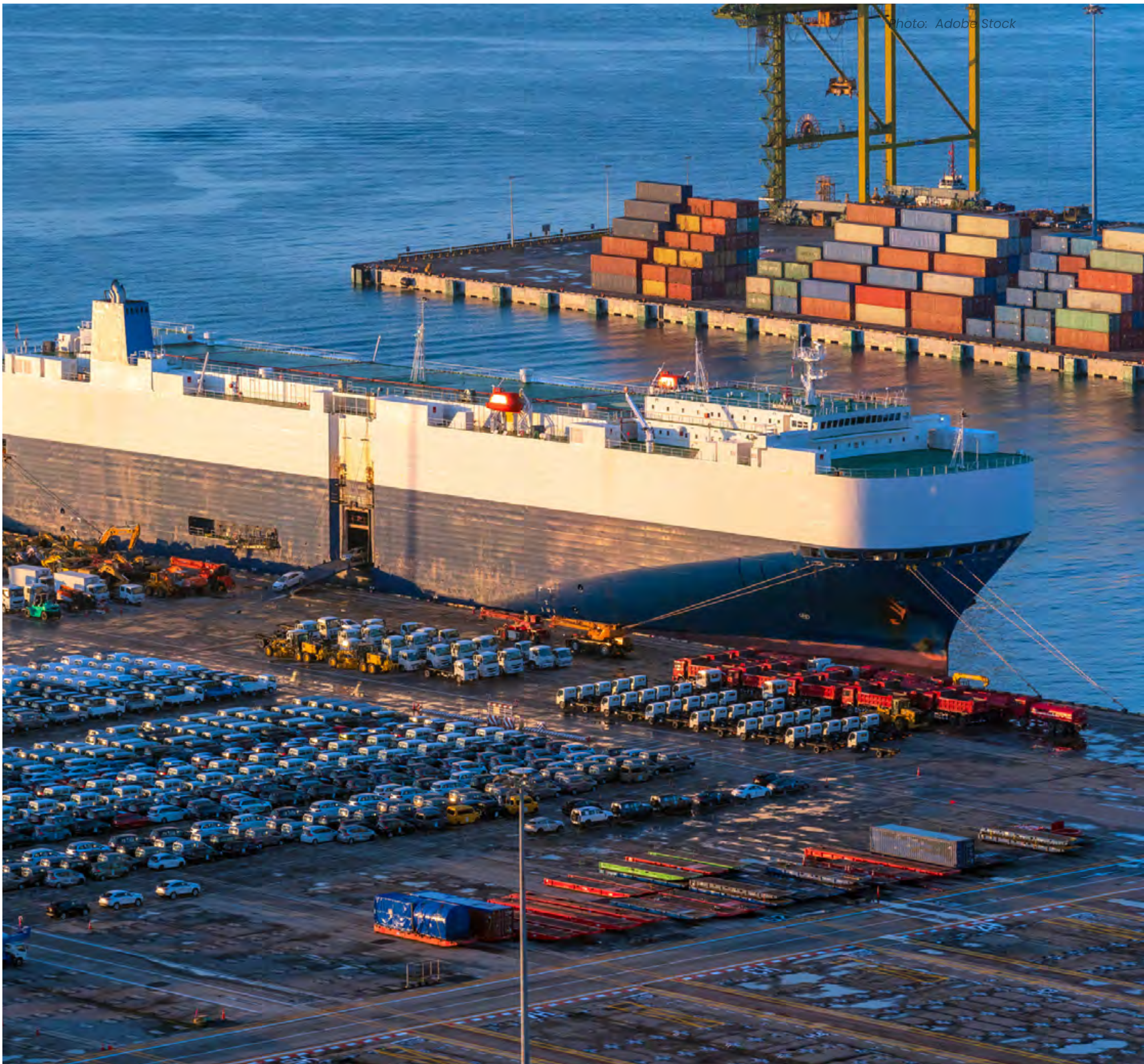
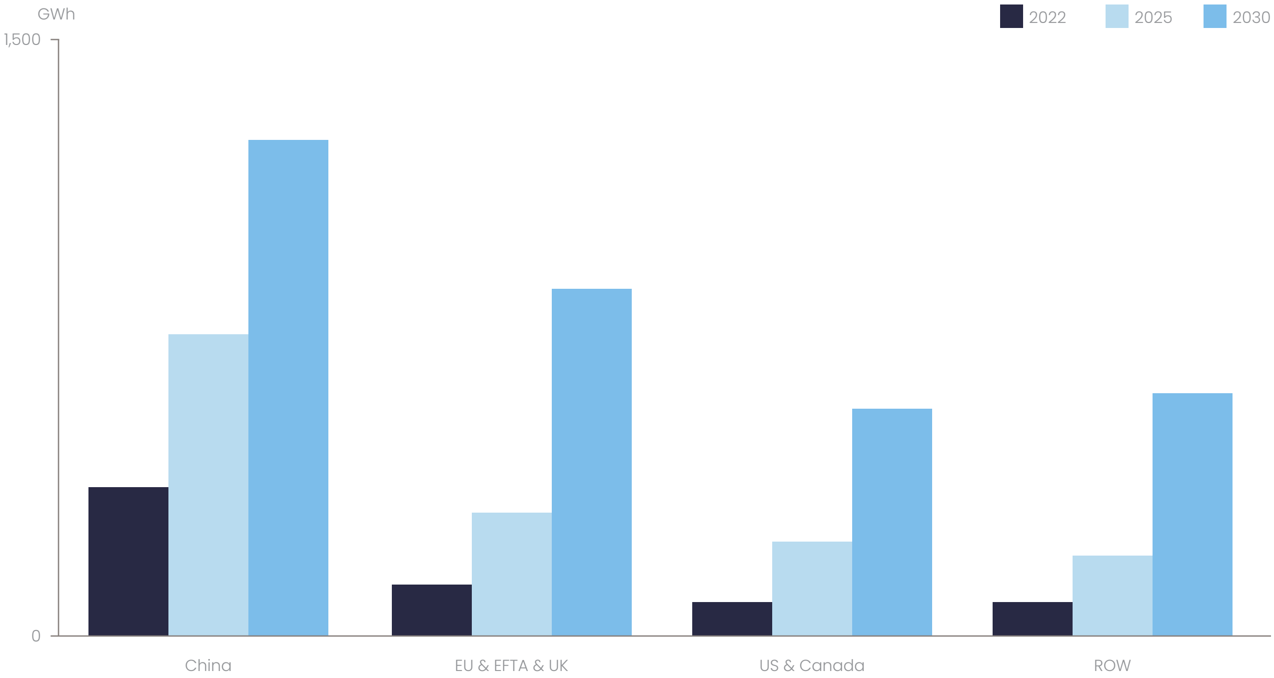


Figure 1: Global battery demand by region *Source: Rho Motion*



According to the China Association of Automobile Manufacturers (CAAM), 389,000 NEVs were sold overseas YTD September 2022, almost double from last year. Europe is the largest overseas destination for China-made vehicles, including international brands that are made in China. More and more Chinese OEMs are looking for opportunities to start their global expansion.

As most countries have set their carbon neutrality target by 2050, the demand for EVs is rising significantly. In Q3 2022, we forecasted global EV sales to reach 36 million units by 2030 and over 86 million units by 2040 for all classes of EVs. The EV penetration rates also continue to increase in most regions, even though the overall automobile market has been weaker. Global EV battery demand is expected to reach over 300GWh in 2030, where China, Europe, and North America market will take up over 80% of the market share, as shown in Figure 1.

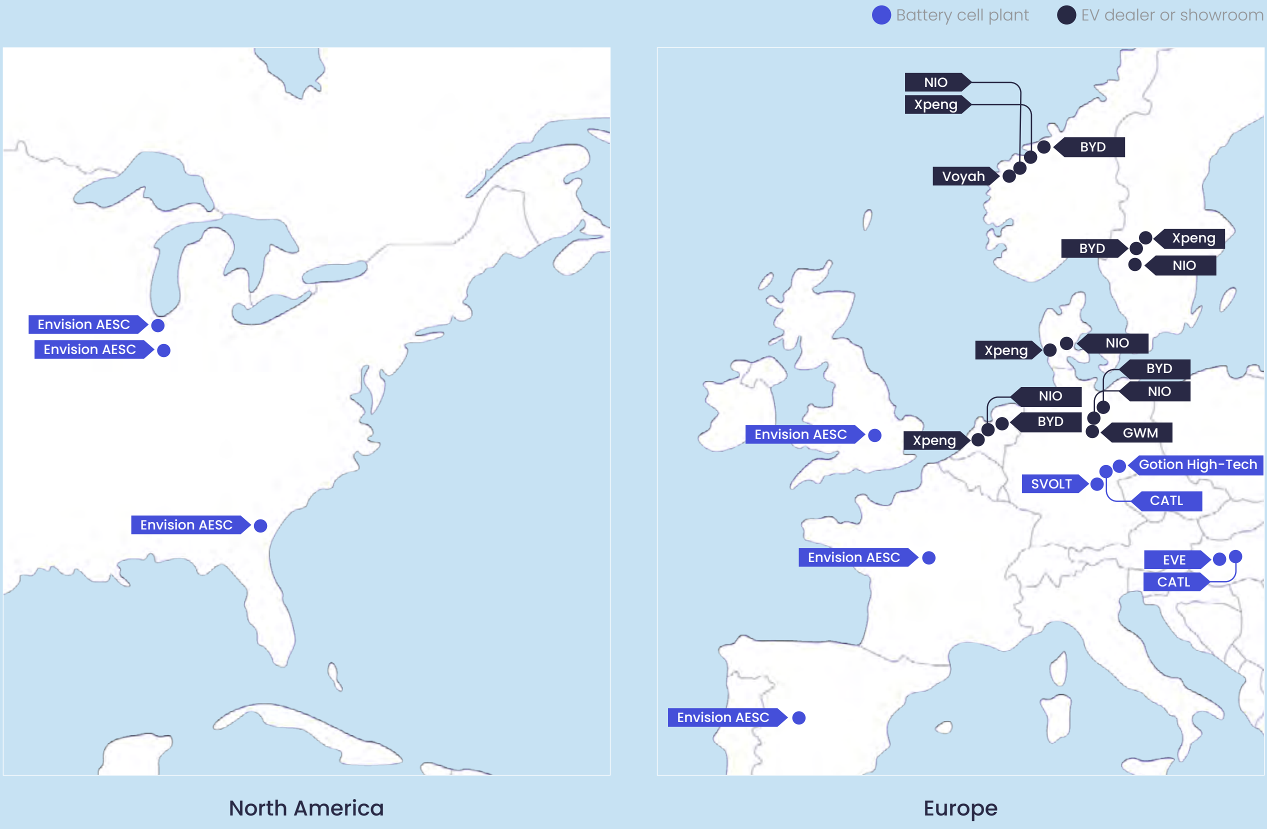
The high demand will bring more potential opportunities for Chinese companies to go overseas, especially in Europe and the US. As shown in the map below, some Chinese OEMs and battery suppliers are accelerating their global expansions this year. In general, Chinese companies favour the European market and normally take West Europe as the first entry market.

Localisation of the battery supply chain

In terms of battery manufacturing, Chinese manufacturers are seeking opportunities to team up with local OEMs and localise the supply chain. As demonstrated in the table below, Chinese battery suppliers have announced a total of over 200GWh in Europe and over 60GWh in the US. In Europe, Hungary and Germany are the most popular regions for Chinese companies to build plants. Battery Giants such as CATL, SVOLT, and Gotion High-Tech have all unveiled their plans of building battery plants in Germany. In Hungary, CATL announced their largest-ever investment of EUR7.48 billion (USD7.49 billion) in a new battery plant with a designed capacity of 100GWh in August 2022. Earlier in July, BMW announced that it will build four battery plants in China and Europe under a partnership with EVE and CATL (two plants for each partnership).

Figure 2: Chinese companies' expansion in Europe and North America

Source: Rho Motion



In the US, Envision AESC is the first Chinese battery manufacturer to enter the US market. It has announced three plants in Tennessee, Kentucky, and South Carolina. The South Carolina plant will supply batteries to BMW. The total planned capacity of 63GWh will be put into operation by 2026.

Overseas market entry of EVs through local distributors

It is very difficult for new OEMs to enter a mature automobile market, such as Europe or US. Due to the complicated geopolitical issue between China and US, there is no Chinese OEM that tries to enter the US market. In Europe, Chinese OEMs form a partnership with local distributors to enter the market.

Norway is a prime location for Chinese OEMs to pick as their first European country to enter due to its high penetration rate as a developed market, which is where NIO first entered the market. In July 2022, BYD launched three EV models (Han sedan, Tang SUV, and ATTO 3 SUV) in Sweden, Netherlands, and Germany under a partnership with distributors such as Hedin Mobility and RSA. BYD has also confirmed to enter the UK by the end of 2022. Compared to other Chinese OEMs, BYD has more experience in entering overseas markets because of the successful global expansion of its CV business.
NIO launched its leasing service which has been tailored for European customers in Germany, Netherlands, Denmark, and Sweden. Also, NIO is expanding the battery swapping service network in Europe to promote EV sales.

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Figure 3: Current capacity announced by Chinese companies

Source: Rho Motion

Company	Plant Location	Planned Capacity (GWh)
CATL	Germany	14
Gotion High-Tech	Germany	18
SVOLT	Germany	16
CATL	Hungary	100
EVE	Hungary	Undisclosed
Envision AESC	UK	1.9
Envision AESC	France	43
Envision AESC	Spain	30
Envision AESC	US	63

It aims to build 120 swapping stations in Europe by the end of 2023.

In August 2022, Great Wall Motor (GWM) announced its entry into the EV market in Germany. The first two models to be launched are WEY Coffee 01 and Ora Good Cat. Earlier in March 2022, Xpeng introduced the P5 model to Netherlands, Sweden, Denmark, and Norway for the first time as part of its global expansion strategy.

Besides Europe and US, Chinese OEMs are also exploring other regions such as Japan, Australia, and India. In July 2022, BYD introduced ATTO 3, Dolphin, and Seal in Japan. In October 2022, BYD announced that it will enter the passenger EV market in India.

When it comes to EV exporting, it is also vital to consider the challenges of international freight services. Because it costs more to manufacture in Europe and US, Chinese OEMs are likely to maintain EV production in China and export to the target markets by rail or ship. To secure future global supply, some Chinese OEMs are actively investing in global logistics.

SAIC, one of the biggest OEMs in China, established its vehicle shipping subsidiary, Anji Logistics in 2000. In 2020, Anji Logistics added one new route to Europe. In addition, SAIC has invested in COSCO Shipping to enhance its global logistics network. On 18th August 2022, several other OEMs, including Changan, Geely, and GWM, also signed an agreement with COSCO shipping to secure future NEV shipping.

There have also been rumors saying that BYD is investing RMB5 billion (USD690 million) in purchasing up to six cargo ships to secure global logistics for its NEVs.

Chinese OEMs also leverage China-Europe Railway Express as an alternative freight service. China-Europe Railway Express is a freight rail service that connects China with 23 European countries. According to the China-Europe Railway Express development report 2021, compared with shipping, railway express can reduce the cost by 8-20% and reduce the time to only 15-18 days. On 14th October, NIO became the first Chinese OEM to use this express service to deliver NEVs to Germany.

Nevertheless, the global expansion of Chinese OEMs has just begun. It is unclear how successful the expansion will be due to several factors such as geopolitical tensions, the energy crisis in Europe, and supply chain challenges. Ultimately, it is the quality of EVs and value for money that will win over customers.

Electrification and the energy crisis

Charles Lester
Data Manager, Rho Motion

Photo: Precious Madubuike

Post-pandemic pent-up demand followed by Russia's invasion of Ukraine and the resulting sanctions put pressure on European energy. Europe was paying over the odds after Russia demanded to be paid in roubles and stopped Nord Stream gas supplies after the leaks. This resulted in wholesale electricity prices soaring, combined with high inflation, eating into one of the key benefits of owning an EV; cheap running cost. We investigate these issues and the role governments will have in doubling down on the energy transition as they reduce dependence on fossil fuels.

Firstly, we look at the direct impact of rising electricity prices on the consumer. For this analysis, we are comparing the cost of driving a BEV versus the cost of driving an ICE, with a focus on the markets in the UK, Germany, and France. We used a pool of the top 20 BEV vehicles sold in Europe in September 2022 YTD, including all versions (standard range, medium range, long range) to determine the average number of miles driven per kWh, which was 4.3. In addition, we used an average miles per gallon (mpg) of 54 for ICE vehicles. This comes from a weighted average of ICE vehicles sold over the past 10 years in Europe, for both gasoline/petrol and diesel. We also assume 8,000 miles are driven per year.

For energy prices, we used average household electricity prices (inc. taxes and levies) from 2020 against the first six months of 2022. Likewise, national energy statistics for petrol prices in each country. Then we used a pool of public charging providers in each country to gain an understanding of the average price for DC fast charging in 2020 and 2022.

Finally, we look at three different scenarios. One scenario with 100% of EV charging taking place at home, the second with 80% of charging taking place at home, and the third scenario with 100% of charging taking place in public.

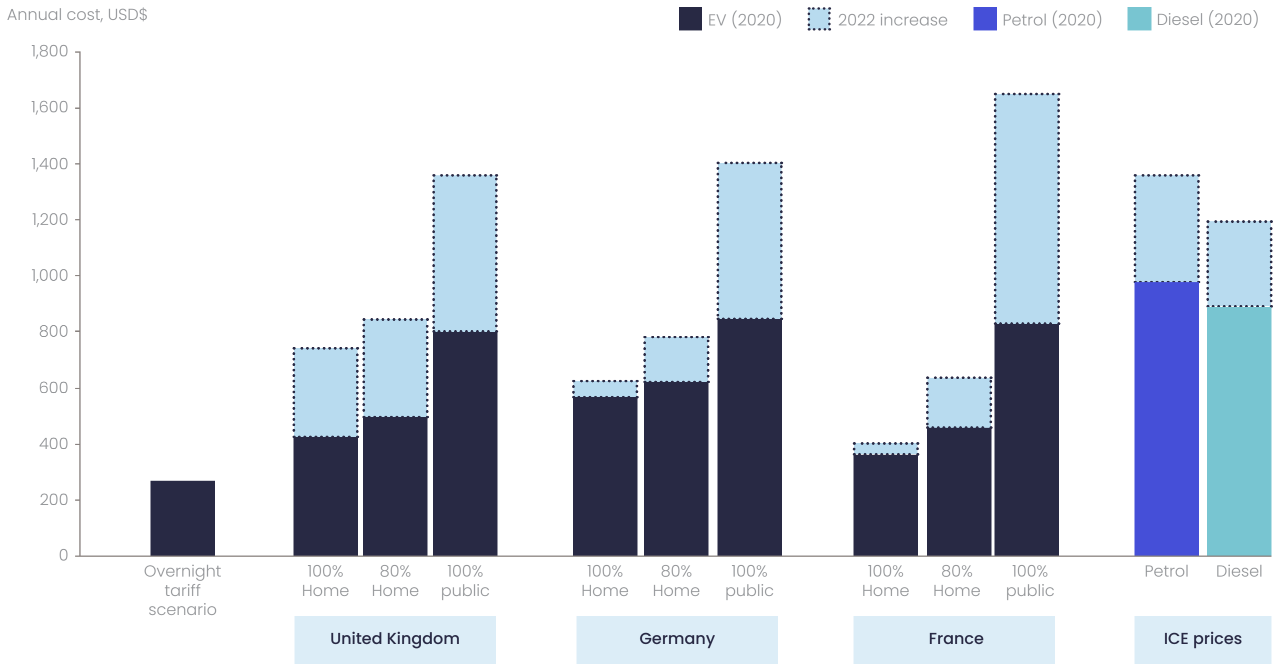
Overall, the average annual cost of charging an EV at home in 2020 was around USD450. Since the rise in energy prices, some of which has been passed onto the consumer, the average annual price for charging an EV has risen by USD130 to $580. Despite this rise, consumers in these regions have been somewhat shielded from a steeper rise. There are many ways governments are looking for short-term fixes to help benefit consumers. In the UK, from October 1 2022, there has been an energy price cap, at £0.34/kWh, as well as a GBP400

Table 1: EV charging scenarios *Source: Rho Motion*

Scenario	Charging Strategy	Example
1	100% of EV charging takes place at home for average residential electricity price.	Those that have access to private charging and are able to fully charge their EV overnight
2	80% of EV charging taking place at home, 20% at public chargers.	Those that mostly charge their EV at home but travel long distances regularly and therefor need to publicly fast charge as well.
3	100% of charging taking place at public chargers.	Those that do not have access to private charging as they live in an apartment and therefore must publicly charge.

Figure 1: Average annual fuel costs, EV & ICE scenarios

Source: Rho Motion



grant to each household. This figure has been used in the analysis. In Germany, a €200 billion energy relief package was approved by the German parliament at the end of October which will likely feature residential relief. It is expected to include a private price cap of €0.40/kWh starting in January 2023. In France, price caps were discussed earlier in 2022. In January 2022, the French government forced state-owned energy provider EDF to cap price rises at 4% for the year. Further to this, France will also cap 2023 power and gas increases for households at 15%.

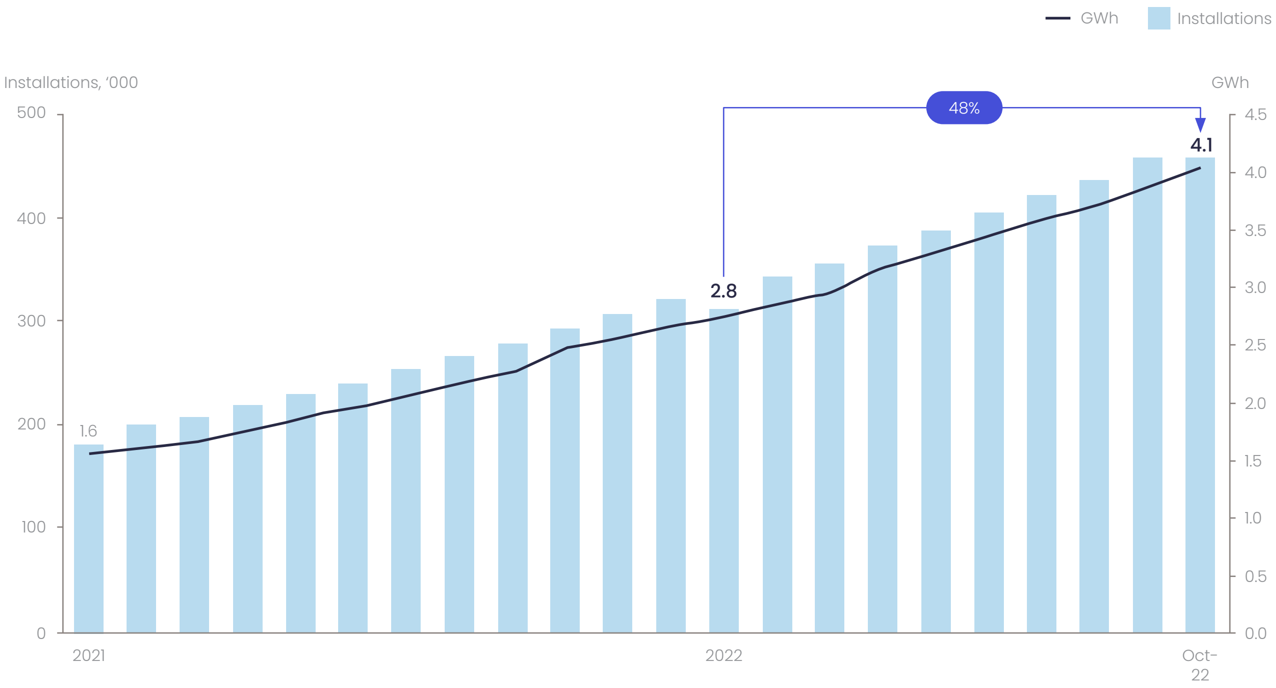
However, this is not the case for public charging. To remain economically viable, public EV charging stations have been increasing in price. In some cases, DC fast charging has been approaching one dollar with Charge Point Operators (CPOs) regularly rising prices. Despite this, in Scenario 2 with 80% home charging and 20% public charging, annual operating costs are still lower than running an ICE vehicle in both 2020 and 2022.

The challenge appears when comparing running ICE costs against 100% public charging. For public charging, we have assumed DC fast charging at current 2022 prices. Consumers that use 100% public charging will include those that do not have access to a private charger or a workplace charger, and as a result, will have to rely on the rollout of public charging infrastructure. Those that do not have access to private charging in Europe will be skewed toward those that are less wealthy. Therefore, there is less incentive to move over from an ICE vehicle to an EV for both convenience and cost. In the long term, there will have to be a solution for those who do not have access to private charging but must pay higher to publicly charge their EV.

Consumers that use 100% public charging will include those that do not have access to a private charger or a workplace charger, and as a result, will have to rely on the rollout of public charging infrastructure.

Figure 2: Germany home battery storage installations

Source: Rho Motion



Is overnight charging the solution?

The final scenario on the left of the graph is the Overnight Tariff Scenario. Many electricity providers offer tariffs that benefit EV drivers. For instance, Octopus Energy in the UK offers overnight charging between £0.10-0.12, which if you exclusively charge during the period would cost around USD250 per year. Likewise, depending on the region you live in the UK, EDF Energy will also offer off-peak rates between £0.07-0.17.

One step towards this solution is the introduction of smart charging and the ability to choose when your vehicle charges, allowing consumers to take advantage of this off-peak cheaper EV charging tariff. For example, in the UK from 30 June 2022, all EV chargers sold for home or workplace purposes must support smart charging functionality. This is a step toward other integrating technologies, such as vehicle-to-home (V2H) or vehicle-to-grid applications. This is where your car battery can act as an energy storage system, allowing for greater independence from the grid by creating a home energy ecosystem, especially when paired with solar.

Will the energy crisis spur an increase in renewable energy?

Following on from COP27 in Egypt in November 2022, many political leaders have urged the world to move faster on renewable energy. Due to the rise in energy prices and greater uncertainty consumers face, there has been a push toward more independent energy in the household. In Germany, home battery storage has increased by 48% YTD October 22 to a total of 4.1GWh of Behind-the-Meter (BTM) home battery storage. This is almost half a million homes in Germany that now have an energy storage system, furthermore, most installations are paired with solar.
On top of this, there are also added benefits of grid stability and blackout prevention, especially in those areas that are susceptible to natural disasters.

The EU received 40% of its imports of natural gas from Russia in 2021 and this has decreased to 23% in Q2 2022. As a result, more gas has been imported from other countries, such as the USA. The rising electricity prices have been curbed by national fiscal support in the form of grants and price caps in the short term, and the solution in the long term is the move to more renewable energy.

Dedicated EV charging tariffs will help reduce consumer costs, with additional benefits possible from solar-to-storage and V2G applications. The real challenge will be the costs that arise for those who do not have access to private charging. Despite whichever direction future energy prices head, renewable energy is the future.

rho motion

Energy Transition Tracker

Q4 2022

In August, due to the volatility of the equity market and the uncertainty of the global economy, there have been several delays to the IPO process of several companies. CALB's IPO, potentially the largest by far in 2022 in the Hong Kong market, was slightly delayed due to the postponed listing hearing. Plentitude Energy, a spin-off IPO from Italian energy giant DEO, and Vinfast, the first Vietnamese EV OEM, have both confirmed that their IPO will be postponed. Recently less companies than usual have announced plans for an IPO, with the exception in the China market.

Despite the overall market concern, most companies under our watch have not made further announcements. In August, two companies closed their IPO deals – Forza X1 and NeoVolta.

September was a very busy month. In September 2022, seven companies went public successfully. Livewire and Amprius closed their SPAC deals while the other five companies were listed through the traditional IPO method.

In October 2022, three companies went public successfully. CALB's IPO made it the first power battery manufacturer to be listed on Hong Kong Stock Exchange. Atlis Motor Vehicles and Dragonfly Energy Holdings both started trading on NASDAQ this month. In October, Sondors, an e-bike producer, filed an application to go public on NASDAQ.

Company	Company Area	Transaction type	SPAC	Date
August 2022				
Senior Material	Battery Materials	IPO	-	Q3 2022
SinoHytec	Hydrogen & Fuel Cells	IPO	-	Q1 2023
High Power Technology	EV	IPO	-	Q4 2022
Power New Energy	ESS	IPO	-	Q1 2023
Leap Motor	EV	IPO	-	Q4 2022
Vinfast	EV	IPO	-	2023
Charge Amps	Charging	IPO	-	2023
CALB	Batteries	IPO	-	Q4 2022
Dragonfly	Battery Materials	IPO	-	2023
Livewire	EV	SPAC	AEA-Bridges	2023
Next.e.GO Mobile	EV	SPAC	Athena Consumer Acquisition Corp.	Q4 2022
NeoVolta	ESS	IPO	-	30/07/2022
Forza X1	EV	IPO	-	12/08/2022
September 2022				
MN8 Energy	ESS	IPO	-	2023
AION	EV	IPO	-	2023
		IPO	-	Q4 2022
CALB	Batteries	IPO	-	October 2022
Novusterra	Battery Materials	IPO	-	Q1 2023
Vinfast	EV	IPO	-	2023
Power New Energy	Battery Materials	IPO	-	19/09/2022
High Power Technology	Batteries	IPO	-	05/09/2022
Wanrun New Energy	Battery Materials	IPO	-	29/09/2022
Livewire	EV	SPAC	AEA-Bridges	27/09/2022
Porsche	OEM	IPO	-	29/09/2022
Leap Motor	EV	IPO	-	29/09/2022
Amprius	Batteries	SPAC	Kensington Capital Acquisition Corp IV	15/09/2022
October 2022				
MN8 Energy	ESS	IPO	-	2023
Sondors	EV	IPO	-	Q3 2023
AION	EV	IPO	-	2023
Sunwoda	Batteries	IPO	-	Q4 2022
Novusterra	Battery Materials	IPO	-	2023
Vinfast	EV	IPO	-	2023
Next.e.GO Mobile	EV	SPAC	Athena Consumer Acquisition Corp.	Q1 2023
ABB	Charging	IPO	-	2023
DESRI	ESS	IPO	-	Q1 2023
Charge Amps	Charging	IPO	-	2023
CALB	Batteries	IPO	-	06/10/2022
Dragonfly Energy	ESS	SPAC	Chardan NexTech Acquisition 2 Corp	10/10/2022
Atlis Motor Vehicles	Batteries	IPO	-	27/09/2022

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
Post Merger/IPO

Lessons from the Lab

Victoria Hugill
Battery Research Analyst, Rho Motion

With the world careering towards net-zero, the race for more powerful, cheaper, and more sustainable energy solutions is vital. The lithium-ion rat race is taking the world by storm, a monopoly of companies trying to develop the next state-of-the-art technology. But all this innovation must start somewhere. Generally, in the basement lab at a university, where a research group might just invent something with potential commercial applications. From this an academic spin off is formed and from there the life of a start-up begins.

Working for a technology start-up is challenging enough but when you are faced with defying the innate nature of your product, you're in for a wild ride. This is exactly the reality facing companies trying to solve the 'silicon problem'. Silicon is believed by many to be the anode of the future for lithium-ion batteries, with its theoretical capacity topping 3600mAh/g, ten times that of the current industry standard of graphite. Unfortunately, this comes alongside >300% expansion upon the formation of fully lithiated silicon ($Li_{15}Si_4$). There have been many theories on how to prevent or mitigate this to make silicon a viable option for commercial batteries, from pure nanostructured silicon to composite materials that encapsulate the silicon. Researchers have been very creative with these solutions and proven them effective – at lab scale. Now to make these technologies commercially scalable is another major hill-climb.

Data on a dime

On this point, I am going to draw from some personal experience. Prior to joining Rho Motion, I was 1/4 of the electrochemical testing team at a silicon-anode materials manufacturer, part of this group of companies trying to bring silicon anodes to the commercial market. When I first started, as a fresh-faced graduate, my work was primarily proof-of-concept material validation for its next-generation product. At this stage you're working with sub five grams of material, as the manufacturing process is still lab-scale and low-yield. And for the battery scientist this means one thing – coin cells. Whilst not a particularly commercially relevant cell format, coin cell testing is necessary when you need rapid feedback with limited resources. Any scientist will tell you that the most crucial part of any lab study is to get good replicates to ensure your data is reliable. Unfortunately, due to their size, coin cell data isn't the most reproducible, with comparatively high failure rates compared to other cell formats. This can be a serious issue, especially knowing you don't have enough raw material to repeat the experiment. One way or another you learn to be both accurate and efficient.

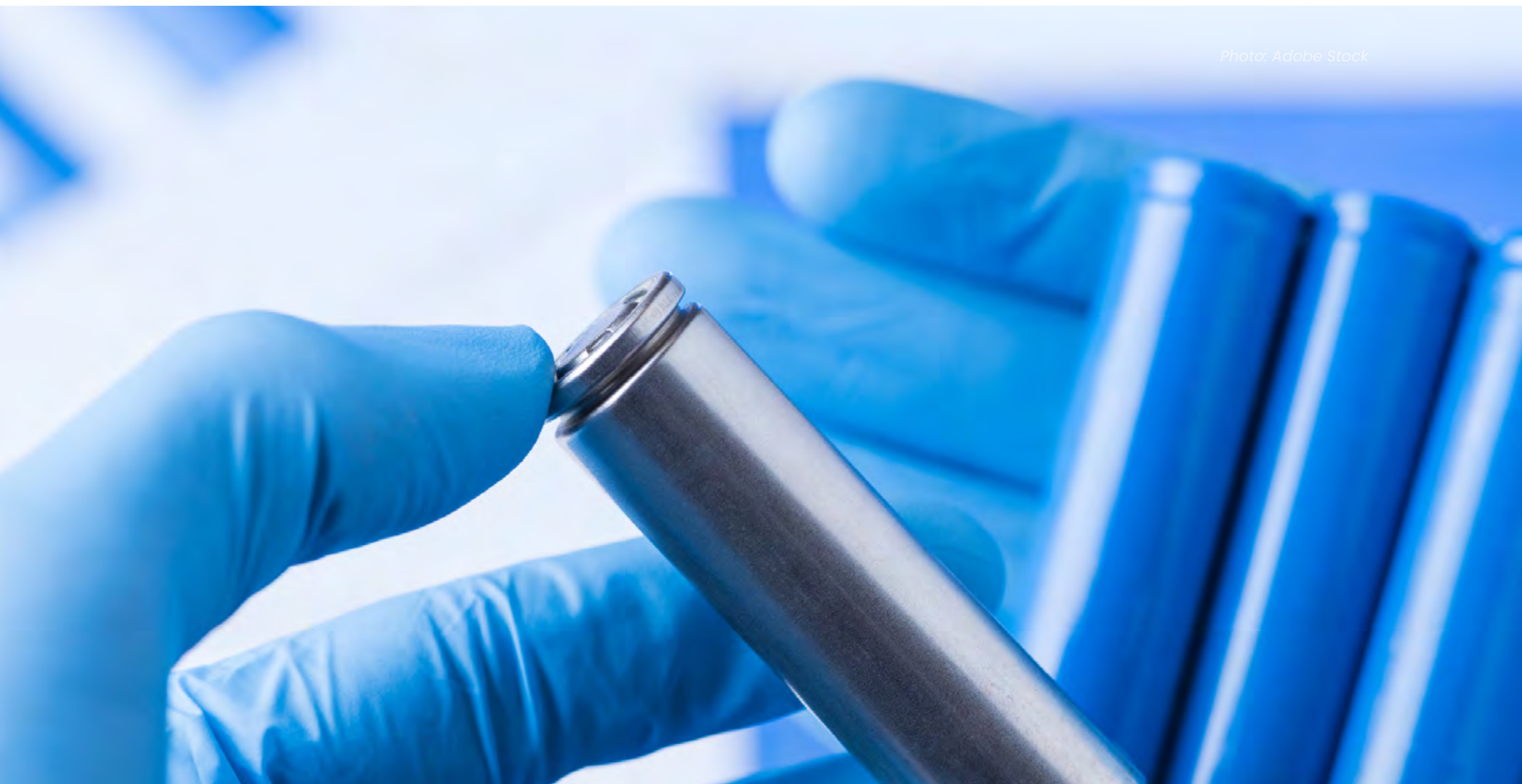
Verifying that the material is fit for its designated purpose must be done early on before major time and resources are utilized. As part of this material validation the correlations between process parameters and material properties/performance must be identified. This feedback loop to the material scientists and process engineers is the key to producing truly great material. It is vital to be systematic in the changes made in order to pinpoint correlations with the electrochemical results. This seems obvious, right? In theory. But like in any business the ideal scenario is not always the reality. Time constraints, customer requirements and resource restrictions can often get in the way of this ideal.

Scale-up struggles

Now, let's say you have passed this initial material validation process and you're ready to start scale-up. You've just taken yourself out of the frying pan and straight into the fire. Possibly the single greatest challenge in the industry is taking this material you can make perfectly at the five-gram scale and having it work on the tons per annum scale. Oftentimes a complete re-think of process and reactor design is required, thus you somewhat end up taking two steps back in terms of material development. Trying to both scale-up and fine-tune materials simultaneously is a very challenging position to find yourself in.

Formulation, formulation, formulation

At this point the sampling size available to the battery scientists starts to increase and we can get a bit more creative, to optimise material performance. The first hurdle is the anode formulation itself. The major variables here are: how much active material to use; combine with graphite or use pure silicon; conducting additives (which ones? how much?) and what binder matrix to employ.



Now, of course you want to give your material the best chance possible, with plenty of conducting additive to counteract the higher resistivity of silicon and the most advanced binder matrix to help contain the expansion.

However, you should also consider from a customer point of view, how they will realistically use your material. Depending on application, customer requirements will of course vary but the common denominator will always be the bottom line. There is little purpose in showing a customer electrochemical data that you have obtained using the most expensive components on the market in order to boost your material performances.

Once that golden recipe of your anode formulation is finalised you can move forward with electrode fabrication and a major consideration here is the energy density. For example, with cylindrical cells the more electrode you can wind into your coil pack, in keeping the same final dimensions, the higher capacity of your final cell. This is a complicated balance with silicon because the 3D structure of the silicon or silicon composite has been carefully designed to contain or mitigate expansion. Now imagine you compress this to increase energy density you will essentially pulverise all your hard work. So, optimising this step can involve much trial and error.

Test it 'til you make it

When selecting cell format, the primary considerations are intended end-use by the customer and the stage of qualification you are in. It is much easier to design and manufacture a pouch cell than a cylindrical and requires significantly less material. Additionally, when generating the cell design, you must look at the electrolyte.

There is much debate regarding electrolyte formulations, which additives to use and at what levels. For example, the function of the electrolyte additive FEC (fluoroethylene carbonate). The purpose of this additive is to increase the stability of the SEI (solid electrolyte interface). SEI stability is key for silicon-containing anodes to protect the cell from excessive electrolyte consumption caused by the cycle-by-cycle expansion of silicon exposing ever more surface for electrolyte to deposit on. However, the drawback here is that the formation of this SEI causes irreversible capacity loss, as well as increasing the overall resistivity of the electrode. Cathode selection is another key choice, not only regarding which chemistry to use but also the cathode to anode ratio (C:A). To see the benefits

> *Whilst the journey of internal validation has been completed, this is only the beginning of the journey for your new technology.*

of silicon's high energy density you need a suitably high-capacity cathode. However, in order to preserve cycle life, you may want to limit the strain caused by full lithiation by having an excess of anode.

Once the cell has been made, there is then the choice testing protocols. The cells first cycle, or formation cycle, is key for the cells life as you are essentially conditioning the cell for the next potentially 1000+ cycles. High C-rate testing can be informative for fast charging applications. Additionally, you can use extreme temperature testing to assess the viability of your material in different climates and from a safety perspective.

Post-mortem analysis is another valuable technique. To see the condition of your electrodes after cycling can be informative of the failure mechanisms. For example, delamination of your active material from the current collector, formation of dendrites and lithium plating. It is also possible to deduce which component of the cell likely caused the failure – anode or cathode. After disassembly, each electrode can be washed and re-assembled into separate cells with pure lithium metal counter electrode to assess how much capacity is recoverable from each.

Leaving the lab

Whilst the journey of internal validation has been completed, this is only the beginning of the journey for your new technology. When sampling to customers, they will inevitably run your material through their own use-specific testing that may find weak spots you never would have thought of.

The hope is you've done enough work to give your now product a fighting chance to hold its own in a competitive market, at least until the next great innovation comes along and the whole cycle begins again.

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