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Balancing the positives and negatives – The rise of the battery ecosystem

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Expanding markets such as electric vehicles, renewable energy storage and consumer electronics are driving enormous interest and investment in the battery sector, from both incumbents and new players. Based on a new ADL study, this article explores the drivers, challenges and likely outcomes in the market, providing key lessons to inform future strategies.

The rise of electric vehicles (EVs), energy storage and increasingly power-hungry electronic devices means battery technology is firmly in the spotlight – even if the average consumer is still not satisfied with the experience they receive, whether this is range anxiety in their EV or constantly needing to recharge their smartphone. Demand has grown dramatically, and battery technology is expected to become a $90 billion-plus sector by 2025. All of this means the traditionally conservative battery industry, with its long development times, is seeing the greatest potential disruption in its 150-plus-year history. The key driver is a massive pull effect from end-user markets.

With rechargeable batteries as essential enablers to key trends such as e-mobility and renewable power, new entrants have joined established players in what can seem like an uncontrolled frenzy as companies aim to build leadership positions in key areas and technologies. There has been over $13.7 billion in battery-related investments and acquisitions in the last two years, patent filings have increased exponentially, and ecosystems are becoming more and more complex as companies partner and expand their reaches. Value chains are consequently becoming intertwined – for example, Eaton is reusing Nissan Leaf lithium-ion (Li-ion) batteries in stationary grid power systems.

As well as capacity increases, innovation is essential, in terms of both process transformation and development of new technologies within battery cells and components. Existing technologies and manufacturing processes alone will not be enough to meet future needs – for example, we estimate that to make EVs competitive with vehicles that have internal combustion engines (ICEs) on an unsubsidized basis, EV battery-pack prices need to fall to $100/kWh. Currently, the lowest cost estimates are $190–$250/kWh. The same is true for energy grids – for regions with high renewable penetration, such as Texas (where wind covers roughly 25 percent of demand), battery prices need to drop by 50 percent in order to switch back-up from gas-fired units to battery storage.

Increasingly, achieving market dominance in a wide range of electrifying industries, from automotive to electronic devices, will require companies to build and defend successful battery technology positions together with hosts of larger and smaller partners. If they lose that battle, they may lose the war. Risks are high and not all players will be successful, in terms of both technology choices and partnering strategies. Some parts of the value chain, such as battery cell manufacturing, have repeatedly seen operating margins fall below zero, driven by a need to build strong positions for the future.

In a fast-changing market, how should companies approach battery technology, and what do they need to do to generate and safeguard long-term value for their businesses? Will investors reap rewards in line with the money they have provided? Will innovation lead to increased consumer satisfaction as battery performances improve?

In this article we examine the current state of the market and future scenarios, and outline the strategic questions and approaches that companies need to understand. In particular, we believe the ultimate winners of this game will be companies that orchestrate the best innovation ecosystems in battery technology. (See also our earlier article on ecosystem innovation[1].) Based on a recently published[2] ADL study, we explore the drivers, challenges and likely outcomes in the market, providing companies and investors with key lessons to inform their future strategies.

Charging ahead – the current state of the sector

Driven by its vital importance, the battery market is seeing unprecedented interest and investment. This comes from existing battery manufacturers, vehicle makers, chemical companies, energy suppliers and others, with many businesses moving outside their traditional comfort zones. Significant announcements over the last two years include:

- Tesla/Panasonic: planned a 35 GWh "gigafactory" for 2020 as part of a $5 billion investment.
- CATL of China: announced a $2 billion investment to build two battery plants, one of which would have 24 GWh capacity.
- Asahi Kasei: purchased Polypore to dominate the battery separator market ($2.2 billion).
- Dyson: planned a $1.4 billion investment in the battery market, including the acquisition of start-up solid-state battery manufacturer Sakti3.
- Daimler: plans to invest $1.1 billion in the battery market over the next five years.
- Total: acquired battery manufacturer Saft for $1.1 billion.
- AES/Siemens: created "Fluence", a joint-venture capable of supplying individual companies and enterprises (hospitals, universities), as well as larger arrays incorporated into regional electrical grids.

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1. Ecosystem innovation – The growth of hyper-collaboration in a fast-moving world, Prism 2017
2. See: "Future of Batteries: Winner takes all?", 2018

These investments are accompanied by the rise of a complex series of ecosystems (see Figure 1), which is also demonstrated by a threefold increase in patent filings – up from 35,000 in 2010 to nearly 93,000 in 2016. A growing number of these are joint filings between research institutions, companies developing battery technology, and businesses using battery technology within applications, such as automotive, electronic devices and utilities.

Co-owning of patents between sectors

Relevant patents
n = 25,567

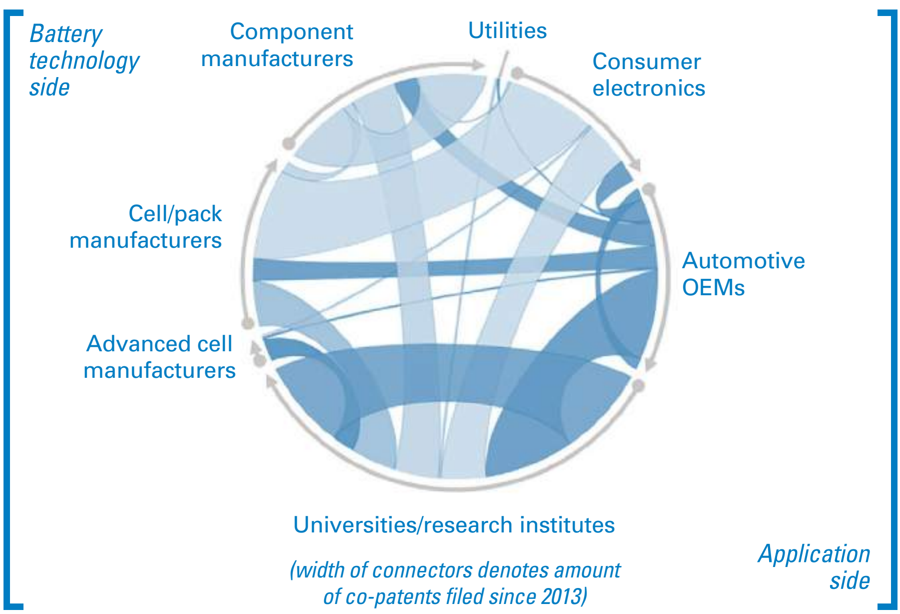

Figure 1: **Co-owning of patents between sectors (filed 2013–2017)**
Source: European Patent Office, Arthur D. Little analysis

Understanding and mitigating risk

Amid all the positive announcements, return on investment has so far been slight. Companies, whether new entrants or existing businesses, face significant risks if they are to successfully carve out market positions. While these risks vary depending on the companies' positions in the value chain, victorious players will need to manage their way through complex ecosystems, pick the right technologies to back, secure necessary knowledge and intellectual property, and ensure that they can operate at scale in their chosen areas. This must all be done within a traditionally conservative and risk-averse industry. How can this be achieved?

When creating a battery strategy, the first point that is vital to understand is that the market is made up of multiple applications, each with different and very specific needs. (See Figure 2.) Factors impacting technology suitability for each application include power density, capacity, cycle lifetime, energy density, capital cost, charging time, reliability and safety. That means, in our view, that no single technology is likely to ultimately dominate the industry at large – and there is no "God battery", as some pundits have asserted.

The five main application areas are:

1. Starter, lighting & ignition (SLI), for vehicles with internal combustion engines
2. Electric vehicles (EVs), including hybrids, plug-in hybrids and full electric
3. Electronic devices, in particular consumer electronics
4. Stationary battery energy storage (BES)
5. Other (aviation, drones, power tools)

Amid all the talk of new technology and new applications such as EVs, the current biggest application remains SLI – the battery used within every vehicle with an internal combustion engine (ICE). And this broadly relies on the same lead-acid technology used within the first rechargeable battery, which was invented in 1859.

Innovation in Li-ion batteries is much more dynamic, but most capacity, by far, is in fairly well-established technology. Entering existing markets at this stage is certain to be expensive, and probably unattractive.

The opportunities for next-generation technology

The positive news for innovators is that there are important needs in many of these applications that are currently not properly addressed, including:

- Cost, reliability and charging time for EVs
- Cycle lifetime and cost for high-frequency battery energy storage
- Safety across multiple applications

Figure 2: **Met and unmet needs in key applications**

Source: Arthur D. Little analysis

For those that can deliver on these opportunities, there is a promise of large and lucrative potential markets. Even though existing technologies, such as Li-ion, have seen rapid improvements in performance and cost, these are not sufficient to meet the requirements of the market. That means next-generation innovative technologies are required to deliver the step-change in performance such applications need. These may take considerable time and investment to cross the "valley of death" (the time between the R&D stage and becoming commercially cost-competitive with current technologies). Therefore, organizations will need to take a long-term view of which innovations to back, payback times, and with whom to partner.

Innovative technologies – the advent of solid-state?

A lot is happening in next-generation technologies – far more than can be covered here. Our recent analyses of hundreds of battery-related start-ups have revealed that a host of technologies using alternative materials are being developed. However, there is increasing innovation within the Li-ion space, primarily focused on three areas: silica anodes, advanced cathodes and solid-state electrolytes.

Box out – battery chemistry

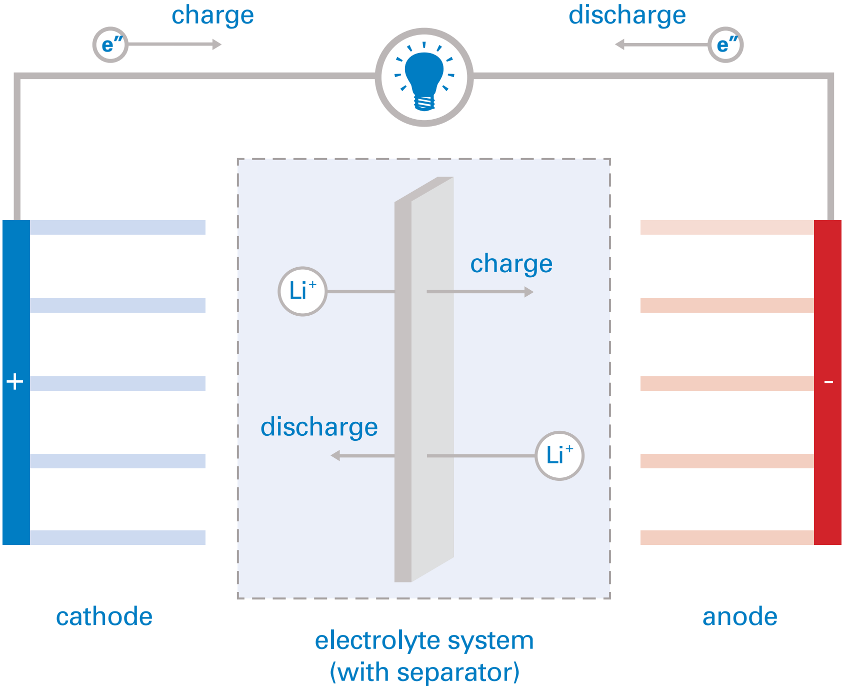

Figure 3: **Simple schematic of a lithium-ion battery. On discharge, lithium-ions move from the anode to the cathode through the electrolyte system (and the separator), while electrons flow out from the anode through the electric circuit. On charge, the flows reverse.**

- Graphite is the normal material for battery anodes, but silica provides higher energy capacity, which leads to it being blended into current graphite anodes. The long-term aim of full silica anodes offers theoretical increases in energy density of up to 40 percent, but to realize this, issues in cycle lifetime have to be overcome. Ongoing innovations use only minor silica concentrations, limiting potential density increases to 10–20 percent.

- Advanced cathode chemistries exist that have higher energy capacities and voltages, such as lithium nickel manganese oxide (LNMO). However, to be successful, these effectively need to overcome issues with the liquid electrolyte used in common battery systems, which breaks down at voltages above 4.5 V.

- The solid-state electrolyte is the strongest contender for innovation. It replaces the current electrolyte system, which is made of organic solvents, dissolved lithium salts and polyolefin separators with one thin, ion-conducting membrane. In turn, this unlocks the use of new cell components and delivers four benefits:

1. A solid-state electrolyte makes the safe use of pure lithium anodes possible, readily increasing the energy density of a cell by 40 percent.
2. It unlocks new types of cathodes. Inorganic oxide-based, solid-state electrolytes do not break down at 4.5 V, allowing the use of 5 V cathodes and increasing the energy density by 10 percent.
3. It enables a new class of conversion cathodes, such as sulfur and oxygen, facilitating even larger potential increases in energy density.
4. It improves battery safety. By using a solid material instead of a flammable liquid electrolyte, the formation of dendrites (lithium slivers living in the electrolyte that can cause internal battery short circuits, which lead to meltdowns) is prevented and the risk of electrolyte ignition is made impossible. Increased cell simplicity might potentially also lead to decreased costs. With safety one of the primary priorities of virtually all big players, even a slightly higher initial cost for this new technology might be worth their investment.

Thanks to these advantages, solid-state electrolytes are of increasing interest to battery manufacturers and users, as shown by the large number of well-funded start-ups, investment activity, M&A, and increased research work/patent filings. Examples include:

- Recent ~$100m acquisitions of the start-ups Seeo and Sakti3 by Bosch and Dyson, respectively.
- News from companies including Samsung, Toyota and Bosch, which claim they will be able to produce solid-state batteries before 2020.

- Several ~$100m start-ups active in solid-state with prominent VC and CVC investors, including Khosla Ventures (into QuantumScape, Sakti3, Seeo), Kleiner Perkins Caufield & Byers (into Quantumscape, Ionic Materials), General Motors and Volkswagen.
- Increased research activity and patent filing by large corporates (880 in 2015 alone).

Three scenarios for the mid-term battery market

While there is extremely large potential demand for battery technology in markets such as EV and BES, the over-riding driver for success is currently cost. This means activity in the battery industry is concentrated in two areas:

- Research and development into a diverse range of new technologies.
- Bringing down the costs of existing Li-ion battery technology, such as by scaling up manufacturing.

Lowering Li-ion prices is a double-edged sword. It helps meet existing demand, but lengthens the commercialization time for new technologies, as these have to have their costs reduced further in order to cross the valley of death and become economically viable. In turn, Li-ion focus potentially holds back the longer-term innovation that battery-driven markets require.

All of this means there will inevitably be winners and losers, both in terms of next-generation technology choices and among existing players that cannot improve their processes and scale to meet cost pressures. Due to these factors we predict that one of these three scenarios will dominate the mid-term battery technology industry:

1. Current-generation Li-ion technology dominates (medium likelihood)

This scenario assumes the industry becomes dominated by one single technology, as has happened with solar panels. Here, massive investment in huge manufacturing facilities will further lower the costs of current-generation Li-ion technologies. This means other existing battery technologies will struggle to compete, while new innovations will be unable to cross the technological valley of death and fail to reach viable price points. Current-generation Li-ion therefore becomes the technology of choice due to its good balance of technical properties and price.

Despite the huge increases in production capacity of current Li-ion technology, we do not believe this scenario is very likely, for two reasons:

- Batteries have a highly diverse application range (more than solar panels, for instance). Certain niche applications with high willingness to pay for increased performance (such as consumer electronics) will drive new technological innovations which established Li-ion cannot naturally provide. This can later spill over into mass-market applications.
- Further cost reduction needs to surpass mere manufacturing synergies and be achieved through product performance characteristics to make batteries cheaper on a cost/kWh basis. This cannot come from incremental developments, but requires a step change.

2. New-generation Li-ion emerges (highest probability)

In this scenario, the current generation of lithium-ion technology keeps its dominant position, supplemented by next-generation Li-ion technology, which eventually attracts sufficient investment to make it a viable alternative. We believe this scenario is the most likely for three reasons:

- Current-generation Li-ion technology is reaching its theoretical performance limits.
- The development of EVs and consumer electronics is creating further "pull" for better solutions, which could be potentially addressed by new Li-ion technologies early in the development pipeline.
- Applications such as high-end consumer electronics provide attractive markets with willingness to pay for higher performance, which enables next-generation Li-ion to establish itself before targeting mass-market applications.

The hottest candidate, the solid-state electrolyte Li-ion battery, will need to surpass multiple challenges, as well as find a safe pathway through the cost valley of death. This means that even when solid-state batteries enter the market in niche applications such as high-end consumer electronics, current lithium-ion batteries will probably be produced to cater for the bulk of applications for another 10–15 years.

From consumer electronics the technology will gradually spread to the majority of other applications, such as EVs, for which development cycles are typically much longer due to stricter requirements around cycle and shelf lifetime. Alternative technologies, such as flow and zinc-air batteries, will occupy certain niche applications with very specific functional or technical requirements. In the energy sector, a range of other technologies will coexist, depending on the application and driven by the less strict requirements on size and space for stationary systems.

3. Unforeseen technology steals the show (low likelihood)

This scenario sees a completely new technology developed (outside lithium-based batteries) that has such promising potential that it attracts sufficient capital to become a dominant alternative to existing Li-ion technologies.

As of now, there is no truly viable battery technology with sufficient potential to replace the currently dominant Li-ion batteries across all applications. Lithium is the lightest metal around, with the lowest electrochemical reduction potential, which makes it clearly the most suitable charge carrier for high-performance batteries. Only in energy grid storage applications do low-performance and low-cost technologies have specific potential applications. In EVs, no other battery type stands a chance currently, which makes only hydrogen fuel cells a minor threat.

Insight for the executive

While the future of the battery space is shrouded in uncertainty, some things are clear:

- Demand will continue to grow aggressively across a wide variety of markets and applications.
- Being able to respond to current unmet needs (such as cost, charging time, cycle time) can bring enormous opportunities for both established players and new entrants.
- For fundamental reasons of chemistry, unlike, for instance, computer CPUs, performance improvements in the battery industry will not be exponential, as many have assumed or hoped for in the past.
- Nevertheless, new investment, new entrants and innovation will lead to improvements that will see markets and applications reach tipping points. Improved battery technology performance and declining price points will therefore make batteries suitable for mainstream applications such as EVs.
- A wide range of promising next-generation technologies are currently being developed, with a very active scene of new patents, research, collaborations and M&A. Not all of these new technologies will succeed, and many partnerships will fail.

Overall, the future battery industry is likely to be much more complex than the one of the past. No single company will be able to come out on top without the support of an intricate and dynamic innovation ecosystem made up of partners, start-ups, institutes, etc. These bring complementary technologies, application know-how, and access to captive markets. Master the critical parts of the ecosystems you play in – or lose.

Batteries are at the heart of key trends such as e-mobility and renewables. This makes understanding the impact of changing technology vital to executives and investors involved in battery technology and applications across many sectors, if they are to safeguard their interests and potential rewards.

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