THEME 01

What to expect from battery development

batteries | technological innovation | renewable technology

The rise of electric vehicles and the energy system's growing need for energy storage solutions have us craving ever-better and cheaper batteries. Currently, our smartphones, vehicles and home batteries make use of li-ion batteries and these have improved immensely over the past decades, but further gains in production costs and performance are more than welcome. There are, however, boundaries to what can be achieved with li-ion technology and a range of alternative chemistries are being developed. The question really is how far li-ion can take us and what we can expect from next-generation batteries.

Our observations

- According to BloombergNEF, lithium ion battery costs have fallen by 87% from $1,100 per kilowatt-hour in 2010 to $156/kWh today. This is mostly due to upscaling and automating production. By 2023, costs may be as low as $100/kWh, but at some point, raw material costs will limit further reductions and, growing demand for these materials (e.g. lithium, nickel, cobalt) is likely to result in supply problems and volatile material costs.

- According to the U.S. Department of Energy, a price of $125 per kWh is needed for electric vehicles to compete with gasoline or Diesel vehicles and estimates this threshold can be reached by 2022. The DOE and others (e.g. McKinsey) are somewhat more skeptical as to when the $100/kWh can be achieved.

- Cost, however, is far from the only criterion. Important characteristics of batteries obviously include energy density (i.e. by weight and by volume), but also power density (i.e. the power they can deliver at any moment), lifetime and safety. Ideally, abundant, low-cost and non-toxic raw materials would combine all these properties. Unfortunately, there are many trade-offs between these characteristics.

- Current and future supply problems have made reducing the cobalt content of batteries a key priority. By 2030, EV production is expected to have outgrown current cobalt mining and processing capacity by far and today automakers are scrambling to secure long-term supply of (responsibly sourced) raw materials. Tesla has pledged to eliminate the mineral in its next-gen battery.

- More radical changes in chemistries (e.g. lithium metal, solid state, sodium ion, multivalent-based, and lithium sulfur and metal-air) are in various stages of development, but even when they are (technologically) "ready" for commercial use, they will have to go through (more or less) the same process of upscaling and learning.

- Last month, (fuel cell) electric truck startup Nikola announced it is working on a revolutionary, but undisclosed, type of battery that will hold four times the energy of a li-ion battery, while costing only half as much. In recent history, we have seen a number of battery startups making similar claims, but they have never delivered on their promise. These included Sakti3, which was acquired, and ditched, by Dyson, Envia, linked to General Motors and Belenos, a subsidiary of watchmaker Swatch. These companies seem to have in common that they made overly bold promises on the basis of lab-scale achievements that proved too difficult to scale up in terms of performance and costs.

- Beyond transportation, the energy system is in dire need of low-cost, high-capacity energy storage solutions. Along with pumped hydro (which has been used for decades already) and new solutions such as compressed air or hydrogen, batteries will likely play a big role as well. BloombergNEF expects the storage market for batteries to grow from 17GWh today to 2,850GWh in 2040. This is a 122-fold increase and would require an estimated $662 billion in investment.

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Connecting the dots

Any battery consists of two electrodes, an anode and a cathode, that contain electrochemically active materials. As the battery is used (i.e. discharged) particles (i.e. ions) move from the one electrode through the other and, in doing so, force an electron to go through an external electric circuit and power a device. In rechargeable batteries, the reverse process takes place when the battery is charged. The two electrodes are separated by an insulating material through which the ions can pass, in most li-ion batteries this is a separator film drenched in a liquid (the electrolyte). The composition of both electrodes and the separator material determines the characteristics of the battery and some combinations could, in theory, yield a superb battery. In practice, however, there are many challenges to actually making those batteries work for hundreds, or thousands, of charge and discharge cycles without substantial degradation or safety issues. And, when those requirements are met, the battery has to be manufactured at mass scale and against low costs, which, among other factors, rules out all too exotic and expensive materials.

One challenge is finding the optimal combination of materials is that all materials add specific characteristics and there are several trade-offs between them. To illustrate, an important group of li-ion batteries uses so-called NMC cathodes which are made from a mixture of nickel, manganese and cobalt in varying compositions. Roughly speaking, nickel adds capacity, manganese brings safety, and the amount of cobalt determines how fast a battery can charge and discharge. This, however, means that increasing capacity (i.e. more nickel, less of the others) necessarily comes at the expense of safety and charging speed. Other types of li-ion batteries include lithium iron phosphate batteries, which are relatively cheap and long-lasting, but low in energy density, and nickel cobalt aluminum oxide batteries (used by Panasonic/Tesla), which can hold a lot of energy, but are costly and less safe.

Decades of fundamental research and engineering have led to dramatic improvements in common li-ion designs. To illustrate, the first Nissan Leaf in 2011 was equipped with a li-ion battery with a capacity of 24 kWh. Increasing energy density has enabled Nissan to fit a 40 kWh battery in its similar-sized 2018 model. Yet, for this generation of batteries, the end is in sight as far as storage capacity goes. What's left is reducing costs through further upscaling and automation of production. This will result in cheaper electric vehicles, but not necessarily in vehicles that can drive much farther on a single charge; any vehicle can only carry a battery of a certain weight and volume.

For genuine breakthroughs we have to look to other types of batteries that use different materials and principles. Some of these promise far greater storage capacities than li-ion (in terms of kWh/kg), but all of them still face considerable hurdles towards practical applicability and readiness for mass production. Among this new generation of batteries, solid-state batteries appear most promising from a mass-market perspective. These use a solid electrolyte instead of flammable liquids, which makes for a safer battery and because a solid layer takes up less space than a fluid one, it can also increase energy density. For these reasons, solid-state batteries are already in use in pacemakers and other critical applications, but as of yet they are too expensive for EVs. One of the challenges is to find a means of applying an ultra-thin layer of solid electrolyte to the electrodes that that stays in place even when the electrolytes swell and contract during charging and discharging (which they do as ion shuttle back and forth). Depositing such a layer, atom by atom is technologically feasible, but extremely time-consuming and thus difficult to scale up. Solid-state and other next-gen batteries have been in development for decades and progress is slow and fundamentally uncertain. In other words, no "miracle battery" is on the horizon yet and in any case, it will take at least another decade for any of these batteries to come to the market and move beyond specific niche markets where certain trade-offs are acceptable (e.g. with space applications, costs are less of an issue than with automotive uses). In the meantime, (likely) cost reductions will be key to mass scale adoption of electric vehicles and the use of (li-ion) batteries for stationary, grid-scale, energy storage. In terms of vehicle range, progress is most likely to come from further optimization of powertrains and overall weight reduction.

Implications

- **As far as transportation goes, vehicle ranges, on a single charge, are not likely to improve dramatically in the coming decade. For heavier vehicles (e.g. trucks and buses), other strategies may be needed to cover longer distances (e.g. fast-charging en-route, possibly while driving along specific stretches of road with overhead wires or induction chargers in the road surface). Limitations to battery capacity (and longer-term cost reductions) open up a window of opportunity for hydrogen (fuel cell) technology.**

- **As we noted before, a lot of renewable technology relies on relatively scarce resources and there will be a scramble for metals such as cobalt and nickel. Ethical sourcing will also be increasingly important in this sector and this will further limit availability of raw (and processed) minerals. Potential beneficiaries include mining companies in politically stable and well-governed regions and battery recycling facilities.**

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