Future EV Batteries

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1. Introduction

This paper started with a very good article in one of my favorite sources (Science), about how consumers are likely to demand EV batteries in the near-term future that can fast-charge at record rates. And further, if manufacturers could not supply these, this would put California's goal of mandating that all light vehicles be mostly electric starting in 2035 at risk.

Contrary to the above argument is the fact that most EV owners in my home state (California) charge in the evenings at home. *Experts noted most EV charging is done in off-peak hours, mostly because of time-of-use rates set by utilities that push drivers to power up overnight. Industry experts said efficient charging technology is just getting started.* [1]

To reinforce this fact, my electric utility (PG&E) and, I assume, other investor-owned utilities in our state, offer special rates for EVs. These rates are three-tiered time-of-use rate, with a very-low off-peak rate (from 11:00 PM until 7:00 AM). For more information, see the rate schedule linked below.

https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_EV%20(Sch).pdf

However, moving to (nearly, see below) 100% light EV sales means that there will be many buyers that do not have reasonable access to home or work chargers, or otherwise need to frequently charge at commercial chargers, which would give the Science article, referenced at the end of this paragraph, more validity.[2]

The escape clause for the 2035 requirement is that it also allows plug-in hybrids if they have an electric-only range of 50 miles. I expect many drivers will choose this option.

Also reference 2 explores options that allow fast-charging much quicker than with current battery designs, and this will be interesting to anyone considering an EV, so I will excerpt part of this article in Section 2 below.

2. Battery Science

California, known for leading the United States in climate regulations, dropped a bombshell last month: By 2035, the state will ban sales of new gasoline powered cars and light trucks. Most new car sales are expected to shift to battery-powered electric vehicles (EVs). But along with high prices and modest range, current EVs have another big drawback: They are slow to recharge. Whereas filling a gas tank only takes a few

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[1] Ashley Zavala, KCRA, Sacramento, "Experts: Electric vehicles could help, not hurt, California's energy grid," Sep 8, 2022, https://www.kcra.com/article/experts-electric-vehicles-can-help-california-grid/41126929

[2] Robert F. Service, Science, "California EV rules jolt battery science," Sep 9, 2022, https://www.science.org/content/article/california-s-move-phase-out-gas-powered-cars-could-spark-battery-innovations Note that access to this article may be limited.

minutes, recharging an EV takes anywhere from the better part of an hour to a day, depending on the charging equipment and the size of the battery.

There will be a pushback [from car buyers] unless there is a faster charging solution" says Sarah Tolbert, a battery expert at the University of California, Los Angeles (UCLA). Yi Cui, a materials scientist at Stanford University, agrees. He predicts the broad adoption of EVs will force a revolution in battery design. The need for fast charging, he says, "will definitely provide opportunities for new battery chemistries to emerge." By using new materials for electrodes or charge-carrying ions, he and others have already come up with promising candidates.

Most EVs today use lithium-ion batteries in which one of the two electrodes, the anode, is made of graphite. Graphite has dominated the market because it's cheap, abundant, and able to store enough lithium ions to give cars a range of about 500 kilometers. During charging, the applied voltage pushes electrons into the graphite, attracting lithium ions from the other electrode, the cathode. As the car drives, the lithium lets go of the electrons and travels back to the cathode, while the electrons are routed through the motor, which converts some of their energy into motion, before returning to the cathode.

But graphite anodes are difficult to charge quickly. Most chargers in the United States today use either a standard household voltage of 120 volts (an L1 charger) or 240 volts (L2). Even L2 chargers can require 10 hours or more to fully charge an EV with a typical 500-kilometer range. Still higher voltage L3 chargers, such as Tesla Superchargers, can charge an EV to 80% capacity within 45 minutes. But these nearly 500-volt chargers can cause lithium ions in the graphite to pile up into metal needles called dendrites that can short out the battery and cause it to catch fire. Even if that doesn't happen, high-voltage charging can cause irreversible structural changes in the graphite that shorten the battery's lifetime…

Author's comments: The preferred charging technology for EV owners charging at home is L2 chargers, and these users rarely let their batteries become (nearly) completely depleted due to range anxiety. Also, all current EVs have charge management software that protects their batteries from over-charge rates that could damage the batteries or shorten their lifetimes. However, EV batteries really need to move beyond graphite anodes, the only good news is that they are inexpensive vs. alternatives described below.

An emerging option is to change the anode material altogether. Fifteen years ago, Cui and others showed anodes made from silicon can increase how much charge a battery can store and enable faster charging. Each silicon atom is able to bind four lithium ions, compared with only one for every six carbon atoms in graphite. But pushing so many lithium atoms into a silicon matrix can cause the anode material to swell up to four times in size. And repeatedly charging and discharging the battery typically pulverizes the silicon, killing the battery.

More recently, Cui and others have shown nanoscale modifications to the structure of the silicon, such as forging it into an array of nanowires, can allow the anode to swell and shrink without fracturing, thereby extending the battery life. Amprius[3], the company Cui spun out to commercialize the technology, reported in February it has developed a silicon-anode lithium-ion battery with a capacity of 450 watt-hours per kilogram, nearly double that of the 280 Wh/kg cells used in current Tesla EVs. What's more, the new cells can charge to 80% of capacity in just 6 minutes. The company now sells the

[3] https://amprius.com/

batteries for drones and other remote aircraft and is working to scale up the technology for EVs.

Author's Comment: I decided to use some graphics from Amprius as my main image. In order to get some good quality images, I dug out an Amprius Presentation that was given to NASA. It was good that I did this, as I found out that even though Amprius is only at a pilot production stage they have already chalked up some impressive accomplishments, albeit at scales smaller than EVs. Rather than describing these, I will send you to the presentation, linked below.

https://www1.grc.nasa.gov/wp-content/uploads/5.-Amprius.pdf

Also, Amprius has identified a partner for full production. Go through the press release linked below.

https://amprius.com/corporate-announcements/amprius-technologies-inc-announces-purchase-agreement-with-centrotherm-for-silicon-nanowire-anode-production

Other anode materials are also in the works. In 2013, Tolbert, along with UC Los Angeles colleague Bruce Dunn and others, reported that anodes made from the light, gray metal niobium would also enable higher capacity and faster charging than graphite. They processed niobium oxide into a sponge-like form, made up of nanoscale tendrils shot through with micron-size pores. This material's very high surface area enables it to hold lots of lithium, and the larger channels enable lithium ions to race through, resulting in faster charging. And unlike silicon, the structure of the niobium-oxide does not change when it grabs and releases lithium ions. Lithium ions nestle close to niobium atoms during charging and simply drift away during discharge, causing less damage to the battery as it goes through repeated charge/discharge cycles.

Author's comment: niobium is relatively inexpensive (US$45 per kilogram) and has reasonable supplies. However, as pointed out previously and below graphite is **<u>really</u>** inexpensive.

Also, just to be fair, I dug out a presentation from Battery Streak and it is linked below.

https://assets.niobium.tech/-/media/niobiumtech/documentos/2019-formula-e---berlin/nt_battery-streak-charge-lightning-fast.pdf

In 2017, UC Los Angeles licensed its technology to a California startup called Battery Streak.[4] Last month, the company reported it has made palm-size "pouch" cells capable of charging to 80% of capacity in just 10 minutes. (Current EVs use thousands of similar-size cells.) During that fast charging, Battery Streak's cells warm up by just 8°C, compared with graphite-based lithium-ion batteries, which heat by as much as 50°C during high-voltage charging. That should slow battery degradation and extend the life of Battery Streak cells more than 10-fold over current graphite-anode lithium batteries, says Dan Alpern, Battery Streak's vice president of marketing. That increased battery life should offset niobium's price, which is typically more than 30 times that of graphite. Like Amprius, Battery Streak is working to scale up its batteries for EVs…

Not excerpted from the above article are some other suggested chemistries.

[4] https://batterystreak.com/

3. Additional Resources

I write frequently on EVs and their components, including EV batteries. The following are descriptions of and links to recent posts on new EV Battery technologies. I checked on each of the firms identified below, and any comments or additional links from these investigations are also below.

3.1. Lyten Lithium Sulfur Battery

The Perfect Rechargeable Battery? *(Dec 2021) From a chemical standpoint one battery chemistry, lithium-sulfur appears to be perfect, except for several major issues that made it totally non-viable in the past.*

Now a Company has designed a fix for all of these problems, by designing a completely new cathode material, and they will begin limited production of these batteries by the end of the this year.

This post is about this development, how it as the potential to be a game-changer for a number of industries, and how this development is different than every other "battery of the future."

https://energycentral.com/c/ec/perfect-rechargeable-battery

Lyten appears to be growing (go through link below), but I didn't see any indications that they had actually sold any batteries in significant numbers.

https://www.msn.com/en-us/travel/article/san-jose-company-s-battery-tech-propels-hiring-big-expansion-in-alviso/ar-AA114T54

3.2. Additional Design

Only one of the technologies mentioned in the post described and linked below is still viable, and it may, or may not survive.

New Battery Technology: *(March 2021): In this post we will look at two more lithium-ion battery designs that include solid electrolytes and metallic lithium anodes. Both of these designs have progressed enough to where they should be in EVs that are on the road by 2025, but it has been a long road to these new designs.*

https://energycentral.com/c/ec/new-battery-technology

The two firms reviewed in the above post are:

3.2.1. EC Power Group

The web site is still in existence, but just barely. Note that there is another "EC Power" that sells LiIon batteries and related products, but this is not "EC Power Group".

3.2.2. QuantumScape

The QuantumScape Battery has been under development for well over a decade, first at Stanford, and since 2010 as a private company. In 2018, they were considered a Silicon Valley Unicorn (a startup with a valuation of more than a billion dollars). Thus, they are very well funded.

They also continue to make progress, but there are some recent signs that their investors are becoming impatient. See the article through the link below.

https://www.msn.com/en-us/money/other/why-quantumscape-shares-dropped-today/ar-AA123svX

As of my final edit of this post, the shares of QuantumScape continue to be volatile. It will be years before they start producing batteries in volume, and only time will tell if their design will be competitive with existing or other emerging designs.

4. Final Comment

A majority of EV Owners charge at night, and percentage of those that don't charge at night will gain better access to chargers (either at work or at their apartment, etc.) as time goes on.

Battery-electric vehicles (BEVs) have many intrinsic design simplifications. As the price of BEV batteries comes down over time, via better designs and larger manufacturing economy of scale, so will the price of new (and eventually used) BEVs.

I would guess that after 2035 the remaining vehicle-owners that don't want BEVs will either keep their then-current internal combustion (IC) powered vehicle, buy a used IC-powered vehicle or buy a plug-in hybrid (these transactions will be allowed in California).

I would also guess that when my state really needs to get rid of residual IC-powered vehicles (at some point well after 2035), they will use a combination of incentives, like buy-out programs, and disincentives, like really expensive clean gasoline and diesel-fuel substitutes. The latter fuels exist today, and will probably offer better pricing (up to a point) and improved performance over time. There will be a market for clean fuels for classic or other collector cars for the foreseeable future, albeit in very low quantities and very, very expensive prices per gallon.