Batteries for EVs Get a Career-Change

By John Benson

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1. Introduction

Internally, I put each of the papers I write in a specific category, or perhaps two categories, or maybe more. Now that you are confused, I will explain. I started posting papers to Energy Central is 2016, but initially these were few and far between (chronologically). In 2017, I started posting these a bit more often, eventually (in the early 2020s) reaching a pace of one per week. In the last few years, I've been posting two or three per week. Along the way I needed to get future, immediate and past papers organized, and so I developed various file-structures (on my laptop's hard drive) to do this, but not very consistently. This is OK for me, because I can quickly find any paper I need. I also have a leading back-up software application that preserves all of my files on a small hard-drive. Although I occasionally write a special series, I keep the papers for these in special folders, and also in the same "subject" folders as the rest of my papers.

I very, very rarely need to create a totally new folder. I didn't need to do that today, but I did need to clone one of folders from one of my "lists" (my quarterly papers directories) into my primary file-structure. This paper will be the first paper in that folder: "Storage for BESS & Mobility." Somehow in the past I've managed to keep battery energy storage systems (BESS) for utility applications separate from battery energy storage for mobility. However, today I decided that it would be impossible to do this in the future. There is one technology (lithium-ion batteries) that is being used commonly for both of these, and a single Li-Ion chemistry (lithium-ferro-phosphate a.k.a. LFP) is used for both applications. To make sure I checked the Wikipedia article on LFP-chemistry, and this mentions both of these applications, plus others. However, this paper will just focus on BESS & Mobility.

2. Mobility Applications

Lithium iron phosphate (a.k.a. Lithium ferro phosphate or LFP) batteries already power the majority of electric vehicles in the Chinese market, but they are just starting to make inroads in North America. They aren't actually new, having been invented here, but until recently automakers selling EVs here have eschewed them because car buyers wanted more range than they could reasonably deliver. That's all in the process of changing and we'll be seeing a lot more LFP here in the coming years with the performance gap expected to close thanks to companies like Our Next Energy (ONE) and Mitra Chem.[1]

Almost all of the EVs sold in North America use lithium-ion batteries with cathodes comprising some variation of nickel-cobalt chemistry. These batteries have offered the best combination of range, power and size, but that comes at a high price. Nickel and cobalt are currently at more than double the price they were in 2021 following major price spikes in the wake of the Russian invasion of Ukraine and increased demand for EVs. Nickel-cobalt chemistries are also somewhat prone to thermal runaway if they are physically damaged or have manufacturing defects which has led to six different recalls in the last three years including the Chevrolet Bolt.

[1] Sam Abuelsamid, Forbes, "Lithium Iron Phosphate Set To Be The Next Big Thing In EV Batteries," August 16, 2023, https://www.forbes.com/sites/samabuelsamid/2023/08/16/lithium-iron-phosphate-set-to-be-the-next-big-thing-in-ev-batteries/

The thermal runaway is caused by the presence of oxygen in the nickel-cobalt mixtures which gets released when the cell suffers an internal short circuit and heats up. Since fires require fuel, oxygen and an ignition source, robbing the fire of any of these will put it out. Smothering a fire with water or foam is designed to starve the fire of oxygen to extinguish it. However, once a fire starts in a nickel-cobalt battery, it produces its own oxygen which is why these fires are so difficult to extinguish.

LFP batteries contain no oxygen, so while they may vent some gases when shorted, they won't burn like a nickel battery. That makes them much safer and more durable, albeit at the cost of lower energy density. Typically, an LFP battery made with a similar architecture to a nickel battery has about 30-40% lower energy density but it can last for thousands of charge cycles and withstand the abuse of faster charging.

2.1. Our Next Energy

Novi, Michigan-based ONE[2] was founded in 2020 by Mujeeb Ijaz, a former executive at Ford, A123 Systems and Apple. ONE's goal was to make safer, cheaper, more sustainable batteries and they claim to have made significant progress with their latest Aries II battery pack. The original Aries I is already in low volume production and is being used by California-based Motiv Power Systems[3] for its electric commercial vehicles as well as in stationary storage applications.

The Aries II is an upgraded version and Ijaz claims that it is now within 6% of the energy density of the leading nickel-manganese-cobalt battery packs for EVs with 25% lower cost with no nickel or cobalt required. ONE has achieved this in part by using a cell to pack (C2P) architecture that allows significantly more cells to be installed in the same pack enclosure.

Typical modular packs have a box-in-a-box arrangement where cells are installed in a module enclosure which is then installed in the larger pack. These enclosures take up space in the pack and require more connections and wiring that add to cost. In a typical modular pack, only about 30-35% of the volume is actually made up of active cell material that stores energy. The Aries II has all of the cells inserted directly into the enclosure and bonded together with heat sinks and the cooling plate, filling more of the space. The fill ratio of active cell material is over 70%. *(See image on the next page.)*

The Aries II pack is expected to enable future EVs to deliver up to 350 miles of driving range on a charge. But ONE has already demonstrated the ability to make a Tesla Model S go over 750 miles with its original prototype Gemini battery. The Gemini uses two chemistries, LFP and an anode-free manganese cell. Since most people only use a portion of the range on a daily basis and only occasionally need the maximum range, the Gemini is designed as a range extender…

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[2] Our Next Energy, https://one.ai/

[3] Motiv Power Systems HQ, and three of their four other facilities are in, or near, the SF Bay Area, https://www.motivtrucks.com/

2.2. Mitra Chem

Ford has already committed to using LFP cells in some of its vehicles beginning this year (2023) with the standard range Mustang Mach-E followed by the F-150 Lightning in 2024. It has also begun construction of a 40 GWh LFP cell plant in Marshall, Mich. GM however, has been a bit quieter on its LFP plans until now. GM has made a $60 million investment in Mitra Chem, a Mountain View, California-based startup to help it develop next-generation LFP chemistries.[4]

Mitra Chem doesn't plan to produce cells or batteries but is instead focusing on developing new material combinations including lithium manganese iron phosphate (LMFP). A key part of what Mitra Chem is doing is leveraging machine learning systems to simulate and test thousands of potential chemistries in order to find the most promising solutions.

The goal is to speed up the design and development process to help overtake the competition and find higher performance cells with better durability at a lower cost. Mitra Chem's R&D facility can simulate and then produce volumes of cathode material from grams to kilograms for testing. Once viable combinations are identified, they will work with GM on scaling to higher volumes for potential vehicle testing.

Cost is a key driving factor in the focus on iron-based chemistries because the reality is that most of the EVs available today are still too expensive for most people to afford. Long term durability and safety are also major concerns.

The addition of manganese to the LFP mix is aimed at improving the cold weather performance of iron-based cells. Like iron and phosphorus, manganese is inexpensive, stable and readily available in most parts of the world…

3. Stationary Energy Storage

The LFP battery uses a lithium-ion-derived chemistry and shares many advantages and disadvantages with other lithium-ion battery chemistries. However, there are significant differences.[5]

[4] https://www.mitrachem.com/, Note that Mountain View is in the SF Bay Area.
[5] Wikipedia article on Lithium iron phosphate battery, https://en.wikipedia.org/wiki/Lithium_iron_phosphate_battery

3.1. Resource availability

Iron and phosphates are very common in the Earth's crust. LFP contains neither nickel nor cobalt, both of which are supply-constrained and expensive. As with lithium, human rights and environmental concerns have been raised concerning the use of cobalt. Environmental concerns have also been raised regarding the extraction of nickel.

3.2. Cost

A 2020 report published by the Department of Energy compared the costs of large-scale energy storage systems built with LFP vs NMC (Lithium nickel manganese cobalt oxides). It found that the cost per kWh of LFP batteries was about 6% less than NMC, and it projected that the LFP cells would last about 67% longer (more cycles). Because of differences between the cell's characteristics, the cost of some other components of the storage system would be somewhat higher for LFP, but in balance it still remains less costly per kWh than NMC.

In 2020, the lowest reported LFP cell prices were $80/kWh with an average price of $137/kWh, while in 2023 the average price had dropped to $100/kWh. By early 2024, VDA-sized LFP cells[6] were available for less than $70/kWh, while Chinese automaker Leapmotor stated it buys LFP cells at RMB 0.4/Wh ($56/kWh) and believe they could drop to RMB 0.32/Wh ($44/kWh). By mid-2024, assembled LFP batteries were available to consumers in the US for around $115/kWh.

3.3. Better aging and cycle-life characteristics

LFP chemistry offers a considerably longer cycle life than other lithium-ion chemistries. Under most conditions it supports more than 3,000 cycles, and under optimal conditions it supports more than 10,000 cycles. NMC batteries support about 1,000 to 2,300 cycles, depending on conditions.

LFP cells experience a slower rate of capacity loss (a.k.a. greater calendar-life) than lithium-ion battery chemistries such as cobalt ($LiCoO_2$), manganese spinel ($LiMn_2O_4$) and lithium-ion polymer (LiPo).

3.4. Safety

$LiFePO_4$ (LFP chemistry) is an intrinsically safer cathode material than $LiCoO_2$ and manganese dioxide spinels through omission of the cobalt, whose negative temperature coefficient of resistance can encourage thermal runaway.

$LiFePO_4$ is highly resilient during oxygen loss, which typically results in an exothermic reaction in other lithium cells. As a result, $LiFePO_4$ cells are harder to ignite in the event of mishandling (especially during charge). The $LiFePO_4$ battery does not decompose at high temperatures.

[6] VDA prismatic cells are based on a standard written by the German automotive industry. VDA stands for Verband der Automobilindustrie (German Association of the Automotive Industry).