Is It Feasible to Use an LFP Auxiliary Battery in a Hybrid Car for Improved Deep-Cycle Performance?

Summary

The use of a $LiFePO_4$ (LFP) 12v battery is only worth considering by a few hybrid car owners: those who drive in mild climates, use power-consuming accessories such as dashcams while parked, and are willing to ensure that battery state of charge remains high enough for safe recharge currents. The capability might be improved by interposing an LFP-optimised charger and return power diode in the 12v circuit, but this would be expensive, and a job for a professional automotive electrician. For most current hybrid car owners, feasibility requires some help from the manufacturer, in the absence of which it is best to stay with the OEM (lead-acid) auxiliary battery. Those who drive at ambient temperatures beyond the 0-40ºC range, and/or do not want deep-cycle ability from a 12v battery, should certainly stay with lead acid.

Background

I have only experimented with a Toyota gen5 rav4 hybrid. The stock 12v battery in this car is a Yuasa 345LN1 or 355LN2. These are small (45-60 Ah depending on model and vintage) flooded-cell, lead(/calcium)-acid, ‘cranking’ batteries. They are “maintenance free” (MF) but not sealed or AGM. They have electrolyte level lines and cell fill caps (under a clear plastic cover). They seem to have been chosen to meet EU regulations, rather than matched to hybrid vehicle use.

This hybrid-electric car does not use the 12v battery to crank the engine, just to boot up the car electronics into ‘READY’ mode. Then the high-voltage NIMH battery pack can start the engine whenever required by the computer system. All the car electricals (except the aircon, traction motors and HV converter) run from the 12v system, and the 12v battery is charged when the vehicle is in ‘READY’ mode, by a step-down from the hybrid car’s high-voltage system. With ongoing slow drain into the car electronics (<0.12-1.2W, depending on ‘sleep’ state) and a dashcam (~2.9W) while parked, the deep-cycle characteristics of LFP may be more suitable as the primary 12v battery for this hybrid car. The potential can be seen in the performance chart:

A rough indicator of discharge (http://www.batteriesinaflash.com/guides, and manufacturers):

	Open circuit (resting) voltage*		**0.125 / 0.5C, 25°C**	**Colour Guide**
State of Charge	**Flooded-cell cranking battery**	**AGM deep cycle battery**	**$LiFePO_4$ battery**	**Expected recharge cycles**
100%	🟩 12.7	🟩 12.8	🟩 13.6 / 13.4	🟩 Green: at least 1000
90%	🟩 12.5	🟩	🟩	🟩 (normal use)
80%	🟨 12.42	🟩	🟩 13.3 / 12.9	
75%	🟨	🟩 12.54	🟩	
70%	🟨 12.32	🟩	🟩	
60%	🟨 12.20	🟩	🟩 13.2 / 12.8	
50%	🟨 12.06	🟨 12.24	🟩	🟨 Yellow: at least 100
40%	🟨 11.9	🟨	🟩 13.1 / 12.75	🟨 (avoid this abuse)
30%	🟥 11.75	🟨	🟩	
25%	🟥	🟨 11.94	🟩	
20%	🟥 11.58	🟨	🟩 12.8 / 12.6	🟥 Red: probably fewer than 100
10%	🟥 11.31	🟥	🟨 12.5 / 12.0	🟥
0	🟥 10.5	🟥 11.64	🟥 10.0 / 8.0	🟥 (never go here)

* Caution: varies with brand, battery age, temperature (and any recent load)

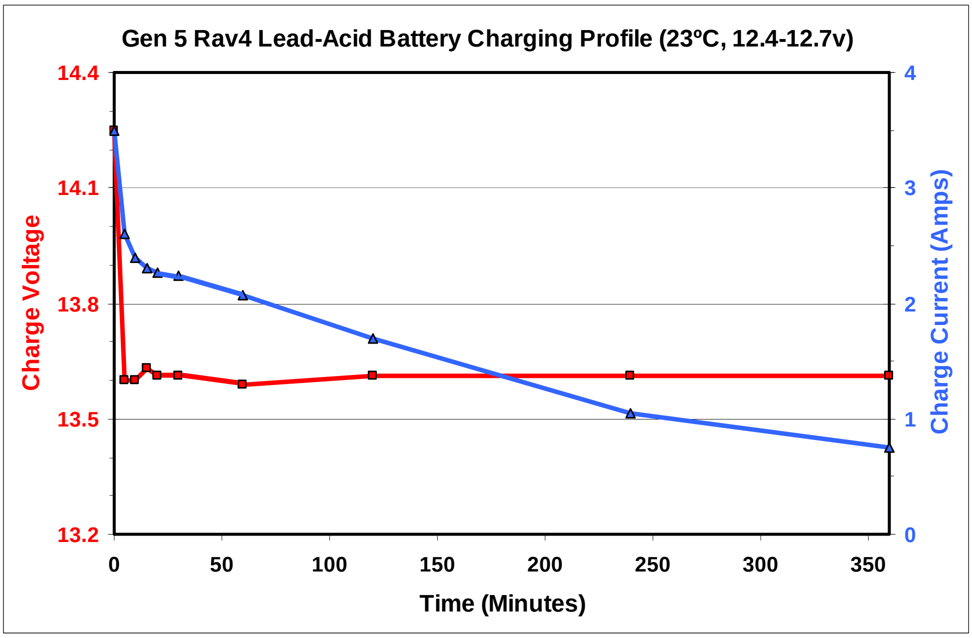
Renogy, Power-Sonic and others supply 50Ah 12v LFP batteries around 197L*166W*171H mm. These fit easily in the rav4 battery holder (LN2 = 242L*175W*190H mm). They weigh only 6.3-6.7kg and are rated at 2000 cycles with 80% discharge (at 0.5C and 25ºC)! The attraction is obvious, but LFP needs a suitable charge profile for safety and performance.

Experiments

OEM Lead Acid Battery Charging

Using the method described in https://www.rav4world.com/posts/2846974/, I measured 12v battery charging voltage and current provided by the gen5 rav4 while it is in 'READY' mode.
My model has parking lights that stay on in this mode (in my garage), but I think this (along with the dash display and other electronic drain) should not affect the 12v battery charging, which is well below the system's rated current flow. No doubt it increases the frequency with which the ICE automatically starts to recharge the NiMh battery bank. In my case, this was for about 3min every 50min (during which 12v battery charging was unaffected).

When I started the test (at 23ºC) the 345LN1 12v battery measured 12.4v with the usual <10mA 'deep sleep' drain. Some people call this 'parasitic' drain, but it is useful for the vehicle; so to a biologist it is better called 'commensal'; but I digress. The 12v battery was below full capacity of 12.7v, so I expected it to activate recharging from the NIMH bank in 'READY' mode.
Here is the result: the initial charge at 14.25v and 3.5A (CC / bulk mode?) quickly dropped to 13.6v at 2.6A, then the current dropped to below 1A (CV / absorption or float mode?) over 6 hours (when I terminated the test, and the battery showed 12.7v). Bulk mode may be longer with lower initial state of charge.



The results comply partly with the Yuasa guidelines (in Japanese, for the 50Ah 3<u>5</u>5LN1: https://gyb.gs-yuasa.com/assets/data/manual_enj-3.pdf) of a normal charging current of 2.5A for 5-10 hrs, to terminate when gas is produced in any cell. No charging voltage is specified by Yuasa.

On these numbers, there seems to be no danger of damage to an LFP battery through over-voltage charging from the vehicle, but it would not exploit either the fast-charging nor the high-capacity of LFP chemistry; and an external charger would be needed to bring the LFP battery to full capacity. The possibilities of vehicle error codes, failure to charge through excess sensed voltage, and/or altered charging into a lower-resistance LFP battery were still open questions.

LFP Battery Charging at High State of Charge

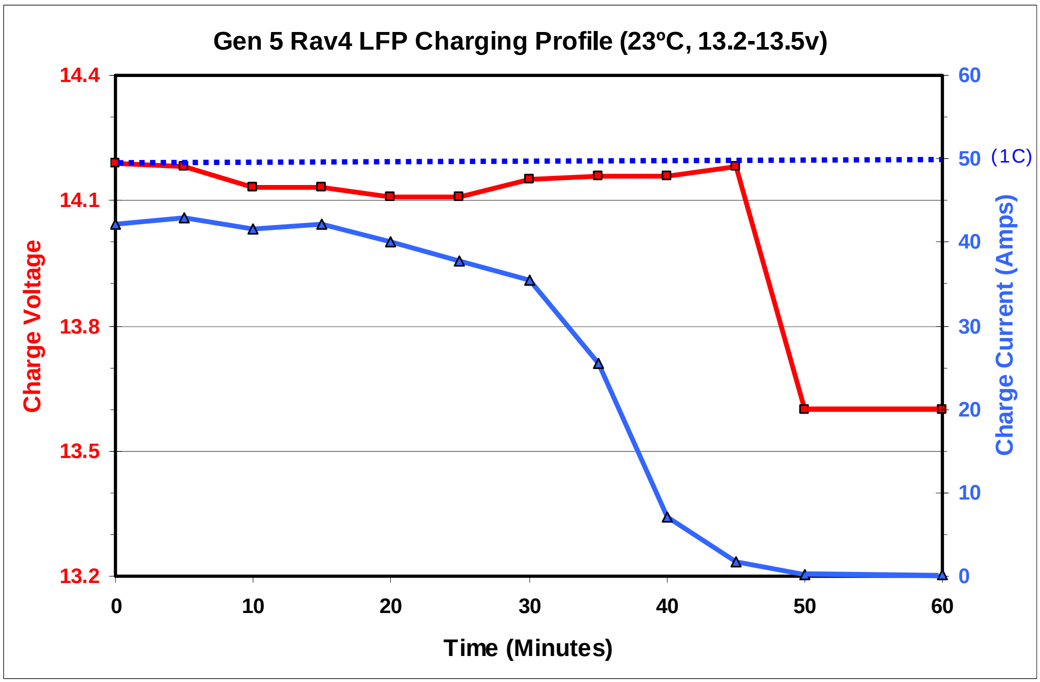
I experimented with a Renogy 12v 50Ah LFP battery (which I bought on sale for less than either a 45Ah 345LN1 lead-acid battery or a 6.4Ah Cellink Neo LFP dashcam battery). There may be room for dual batteries in a larger 'truck', but not in a rav4. Therefore I replaced the 345LN1 (using a jump starter to retain ECU settings, after the vehicle had been off and the battery ventilated for a long while, being very careful to avoid sparks or short circuits during the whole process). The 50Ah LFP battery is a bit smaller than LN1, so I used some of the polystyrene packing from the Renogy shipment for a snug fit. Toyota also uses polystyrene to make the rav4 holder fit LN1. I used M8-SAE post adapters from Fullriver (which fit the Toyota battery post clamps and also provide M8 threads into the brass SAE posts). Sealed LFP batteries do not vent hydrogen or toxic fumes (https://gwl-power.tumblr.com/post/141674260966/), so they do not need the rav4 vent tube, which I secured aside using a cable tie. I live in a mild climate, so the LFP temperature constraints (0~45ºC for charge; -20~60ºC for discharge), and the usual temperature compensations in lead acid (LA)-optimised chargers (-16 to -32mv/ºC), are fine for me.

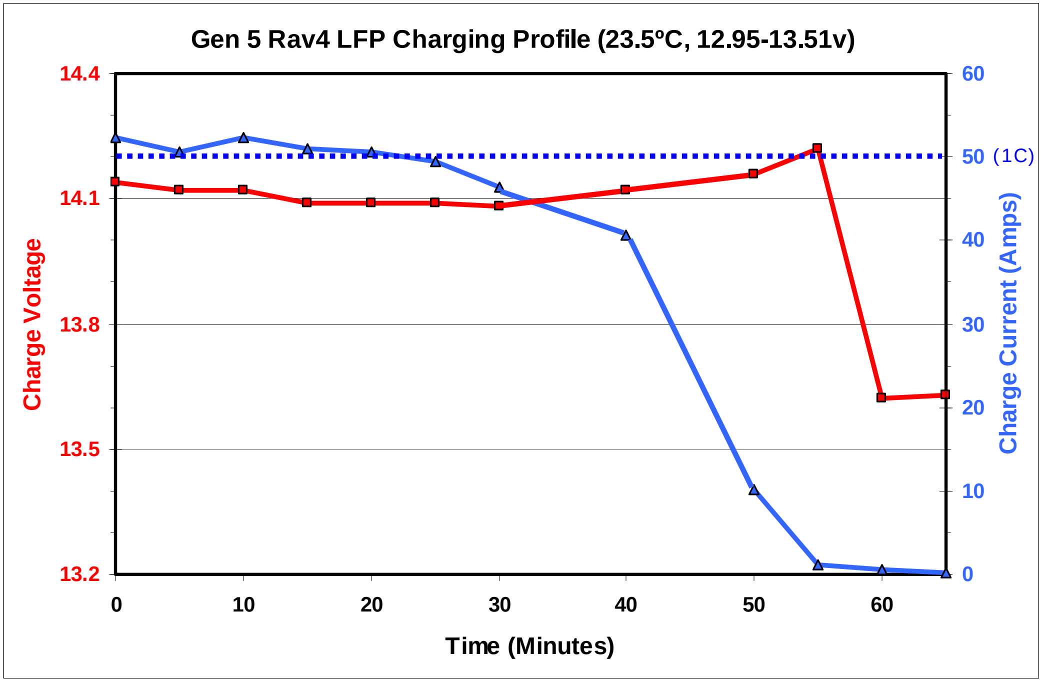
To 70% discharge (about 13v at 25ºC with the expected low current drain) this battery should power my A129 plus duo in 1fps time-lapse parking mode (2.9W) for more than 6d. My 256 Gb SanDisk Max Endurance micro-SD card will hold about 18d of 1fps parking-mode recordings before overwriting. (Viofo claims that this unit does not overwrite any recording that includes an event that triggers its impact monitor, but that is not my experience in time-lapse parking mode). The "sweet spot" may be 2fps. The remaining 30% battery charge should hold the rav4 (at up to 120mW average commensal drain) for several months without jump starting. I have not tested these calculated times. They will vary with the efficiency of voltage converters, cut-offs etc. Cigarette lighter-USB converters that I tested varied from 2.8-20mA current draw (36-260mW) with no load, and 72-95 % efficiency with loads of 0.4-1.8 A. My one test with dashcam load gave battery voltage drop from 13.20v to 12.95v (~35% of battery charge at 23ºC) at 2fps parking mode (with lots of door opening = higher vehicle commensal drain) over 48hr.

I decided against the Viofo HK3 after reading about its poor efficiency and voltage regulation at https://dashcamtalk.com/forum/threads/hk3-hard-wire-kit-terrible-voltage-regulation.44244/. With no load, HK3 draws 86mW before and 35mW after cut-off. It does not have suitable voltage options for LFP, I prefer thicker wires, and I don't want to stand on my head to find the right fuse sockets then leave the fuse box cover off because of piggy-back fuse connectors. So I decided on a Victron Smart BatteryProtect, which has the advantage of more adjustable cut-off and restore voltages. It is wired after a 10A fuse near the battery, then double-insulated 1.5mm^2 (AWG16) wires run to a cigarette lighter-USB converter in the console box. My dascham will not draw more than 1A through this 7m circuit, so there should be no problem with voltage drop or heating of the cable. BatteryProtect power use is very low (16mW before and 9mW after cut-off, plus 3mW if Bluetooth is enabled). Cheaper units using continuous monitoring and a non-latching relay, instead of periodic sampling and a MOSFET, have much higher drain. However, MOSFETS can be stressed by voltage spikes from inductive loads, and if they fail (which may be silent) they normally keep power to the controlled circuit.

Wires were fairly easily routed under the trim: forward from the auxiliary battery to the side of the NiMH traction battery, along the front base of the NiMH battery to the centre, under the carpet and felt beside the tunnel, and under the console trim to enter the console box with the dashcam cable. (Pop off the rear seat and a few trim panels, but there are no screws or bolts to undo. The tunnel was trickiest because of cross-braces, but no big deal. I used a packing strap from the Renogy battery to find the route. An electrician's plastic guide would also work, just twist and push gently to get past any obstructions). This allowed me to use a USB Y cable for automatic parking mode as described in a companion article.

After the battery change, I conducted tests like the one described above, at several starting voltages:





Starting at 12.95v battery voltage (estimated 25% SOC), it was a bit scary to watch 52.3A at 14.14v flow into the battery. While many LFP batteries (including the Renogy 50Ah) are specified for charging up to 1C (50A in this case), and the battery got barely warm to touch at the side after 30min, I would not like the charging current to go any higher. I assume the fast charge is simply a result of the low resistance presented by the LFP battery. The rav4 does have a current sensor on the battery, but how this is used does not seem to be made public.

Some car alternators might struggle with 50A continuously for 30 min (https://www.victronenergy.com/blog/2019/10/07/careful-alternator-charging-lithium/), but the rav4 hybrid DC-DC converter seems fine with it. Toyota hybrid car DC-DC converters are typically ≥100A (https://priuschat.com/threads/please-explain-12v-system-to-me.183008/), and the rav4 12v circuit fusible link is 120-140A (https://www.rav4world.com/threads/pure-sinewave-inverter-for-ac-power.298553), so there should be enough headroom for all other current draws. The ICE ran more frequently while the current into the auxiliary battery was high (for about 3min every 15min while current was 40-50A).

The charge voltage dropped quite suddenly to 13.6v when the current was below 1A (at 50-60min in the charts above). I do not understand why the drop from 14.2v to 13.6v occurred at a charging current >2.6A with LA, but ~1A with LFP. Could it be Coulomb counting with an algorithm tailored to the inefficient charging of LA? Why does Toyota not make such details public?

In any case, almost no charge is expected to flow into an LFP battery at 13.6v (and 1A is the recommended current for termination of charge to 50mAh LFP), so I turned off the vehicle at 60-65min, at which time the LFP battery voltage was 13.5v.

LFP Battery Discharging

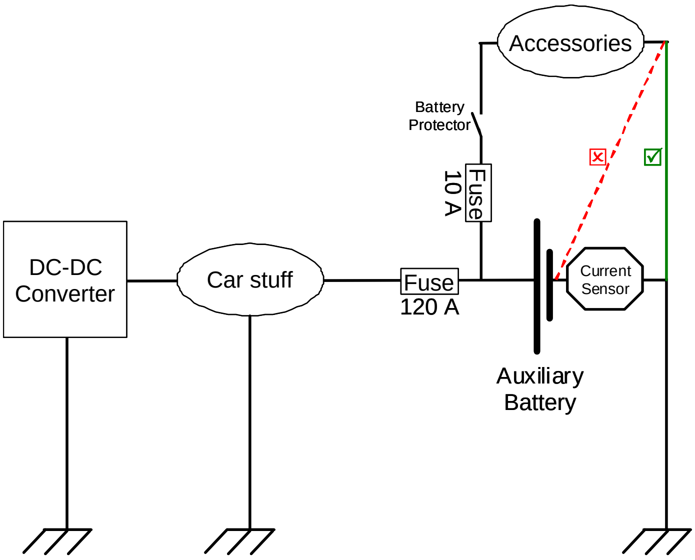
Then I kept watching battery voltage and current flow. In the first experiment, the commensal current draw by the rav4 dropped to about 100mA within 10min, about 15mA within 20min, and below my measurement limit of 5-10mA within 3hr (when battery voltage was 13.34v). In the second experiment, the commensal current draw by the rav4 was about 450mA after 10min, about 100mA after 20min, and below my measurement limit of 5-10mA within 30min (when battery voltage was 13.38v). The times to reduced commensal drain varied somewhat between experiments, for reasons I do not understand. But the stepped levels of commensal drain from the LFP battery were the same as those from the OEM LA battery, within my measurement errors. In essence, commensal drain takes the top off the fully-charged battery voltage when the car is stopped, then drops to a very low level until a door is opened.

So Far, So Good (with Some Niggling Doubts)

On these results, the rav4 is fine with an LFP battery that is kept above 25% SOC. At 14.2v and ≤1C during the bulk/CC phase, there is no danger of damage to a properly top-balanced battery through overcharging, and the vehicle does exploit the fast-charging capability of LFP chemistry. I might be happier at 0.2C for longest cycle life (by reducing the possibility of irreversible plating of lithium metal onto the anode), but dascham users who need to recharge the battery during short drives will appreciate the faster charge near 1C (if allowed by the battery manufacturer).

The ‘automatic’ drop in charging voltage at 50-60min (and 0.02C) in both experiments with LFP was reassuring. But to understand if it might vary in a way harmful to an LFP battery, we need to know how it is triggered. (Charging current? Coulomb counting? Does it count when the car is off? Does it correct for charging efficiency? Is it adaptive? Can it be programmed? If so, which parameters are programmable?)

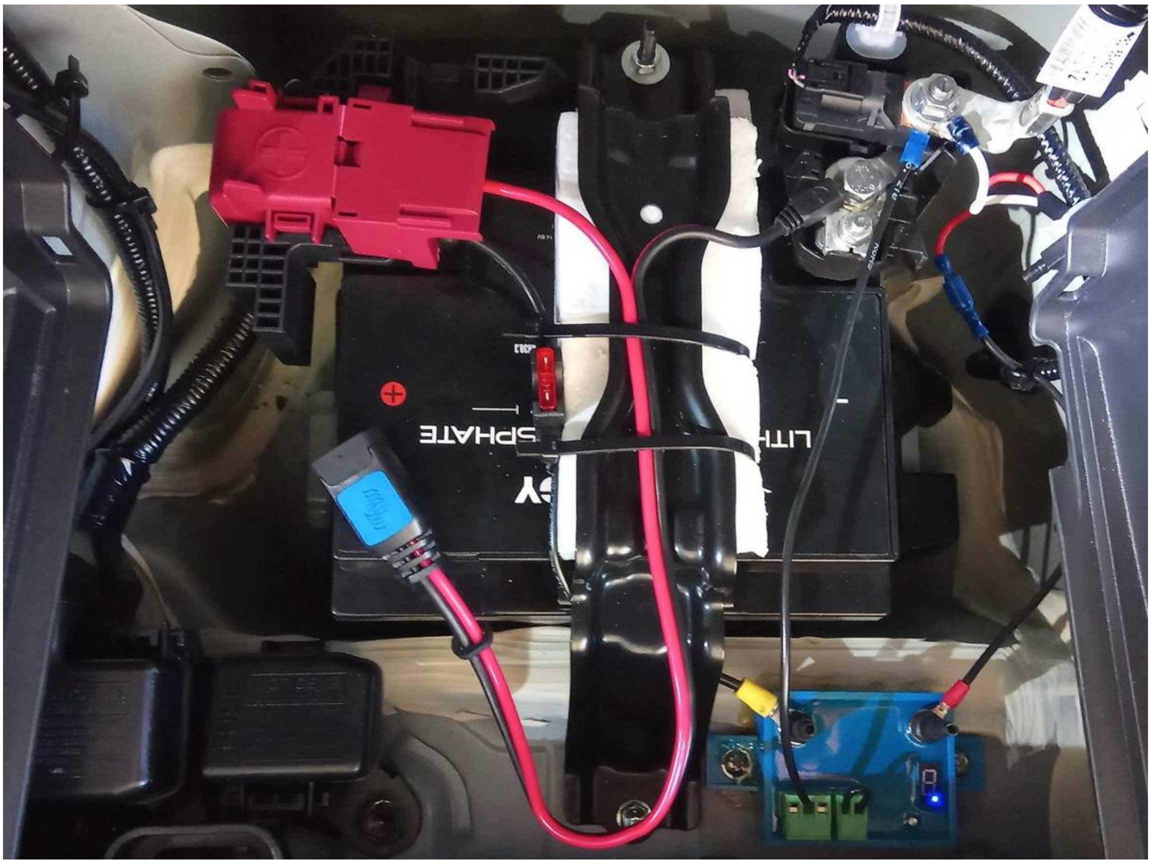
Any accessories that drain current while the vehicle is running should be wired with return/ground connection downstream of the current sensor, so as not to interfere with it.



Trickle charging of LFP batteries should be avoided, but the rav4 ‘float/trickle’ voltage of 13.6v does not raise any concerns for durations of a few hours. For long drives, a lower float voltage (≤13.2v), or no charge, would be better for LFP life. There were no problems with fusible links, sensors, relays or fuses. No errors have been displayed. The vehicle entered ‘READY’ mode as usual from the LFP battery at 25-95% SOC. If anything, fuel economy should improve due to the light weight and efficient charging of LFP, but this may be hard to see among other driving variations. The rav4 at 14.2v charged LFP to an estimated 90-95% SOC at 23ºC, which is fine for most purposes and good for battery life. Those who want 100% SOC (or more ‘absorption/CV’ time at >14v for cell balancing or erasing any memory effects) will have to use something supplementary, like a good LFP wall charger.

I have a Victron Blue-Smart IP65 12v/10A wall charger that can be programmed for the optimal charging specs from Renogy, except that it lacks the ability to set absorption charge termination based on charge current (try Enerdrive chargers for this feature). For charge termination based on current, a Victron user would need to watch charge current by Bluetooth (reported to 0.1A), and turn off the charger at the wall when it reached the desired level (1A = 0.02C for 50Ah). Charge termination based on cell current additionally requires a BMS with this output (which is not in the Renogy 50Ah) and an interface to the charger, which is lacking in everything I own. The Victron charger has split leads that can permanently attach to the LFP battery (as in the photo) and it includes the ability to report charging status and history via a smartphone. If the rav4 counts Coulombs when off, the charger (and all accessories) should be connected after the current sensor.

In default Lithium mode (14.2v charge, 2h absorption) the Blue-Smart IP65 added only 0.2+0.4 = 0.6Ah to the charge from the rav4. At 14.6v (with 1 hr absorption for full charging and cell balancing) it added 10.3+0.2 = 10.5Ah (much more than I expected). It can also maintain an LA battery (now my spare 345LN1, which at 14.4v charge it reported as 3.7+11.1 = 14.8Ah ie 33% undercharged by the rav4, perhaps a reflection of the low charging efficiency of LA chemistry). At the 14.7v charge recommended for lead-calcium batteries, it added another 0.0+0.2 = 0.2Ah.



***A Very Important Caution*: Excessive Charging Current at Lower State of Charge**

BUT, the initial charging current in the rav4 rose to over 73A when the LFP battery was discharged further, to around 12.7v (~20% SOC at 23ºC). The unmodified rav4 is not suited for this task, as the applied current at >1C is above the level that will quickly damage the battery. This high current might also damage the rav4 DC-DC converter and/or 12v circuit.

Toyota implies that using other power-consuming parts of the vehicle (headlights, aircon and blower, rear window defogger, radio) can reduce charging current to the battery (http://toyota.custhelp.com/app/answers/detail/a_id/7692/~/). In my experience the maximum effect is a few Amps, which is not enough to avoid battery damage in this situation.

Could the Manufacturer Help?

As the rav4 has a current sensor on the auxiliary battery, it would be ideal if Toyota could program the vehicle for a maximum auxiliary battery charging current (10-50A for 0.2-1C charging of a 50Ah LFP battery), and at 1A either terminate charging or 'float' at 13.2v (which will stop any current flow into the LFP battery). Maintaining supply to the vehicle 12v system; while accurately sensing, controlling and terminating 12v battery charge current; may require separation of 12v battery charging and load circuits. This is simple enough to design, and already at least partly implemented, but the available circuit diagrams are somewhat ambiguous (https://priuschat.com/threads/.183008/page-2#post-2622517). It would not be trivial to implement after manufacture. The "float" approach seems easiest, as it only requires appropriate programming, and 13.2v is fine for both the LFP battery and the remainder of the nominal 12v electrical system. But it leaves the challenge of providing an optimal LFP charge current below the potential demand of other 12v electrical components while the vehicle is running.

The rav4 current sensor is also said to include a temperature sensor, but I can not establish how it is used in the hybrid model. Charge voltage to an LFP battery should not be altered according to temperature, but at the usual compensation of ~-27mv/ºC for a 12v battery it is not a big deal at normal cabin temperatures. Most 'smart' battery chargers simply disable this feature for LFP charging. Maybe LFP compatibility will be included by design in future rav4s?

Some modern vehicles seem too smart (or dumb) when their mechanisms are kept secret. An owner can set all the relevant parameters is a quality (Victron) 'smart' battery charger costing $150. Yet the same owner is not permitted to know (let alone adjust) the same parameters in a rav4 hybrid costing $40,000. Amazingly, a Toyota car owner is required to pay a fee just to view their own *Car Features* (https://techinfo.snapon.com/TIS/Register.aspx) and this document is not even listed in Australia (https://toyotamanuals.com.au/). Surely having paid $40,000 an owner is entitled to know the technical features of the car they have purchased. Toyota, it is time to lift your game!

Toyota (USA) responded: "Toyota does not recommend or assist with modifying our vehicles from the original factory specifications." Fair enough, though I asked about my rav4 not theirs; and such advice ignores the millions of Toyotas out there with non-OEM modifications such as dual-battery systems, or even dual dashcams or battery chargers. Perhaps compatibility with LFP auxiliary batteries will feature in original factory specifications of Toyota hybrids in the future.

Is it Feasible to DIY?

Anyone thinking about DIY installation of an LFP battery should read https://marinehowto.com/lifepo4-batteries-on-boats/ (vehicle use shares many potential pitfalls). An important point from this article is that if the BMS cuts off during charging (even if this is from a single faulty cell), it may cause a voltage spike through the circuit that risks damage to other vehicle electrical components. Such spikes can arise from a charging alternator or from any inductive load (anything with a coil, such as a motor or solenoid; especially with high current). The same applies to cut-off through a battery isolation switch, circuit breaker or fusible link while charging.

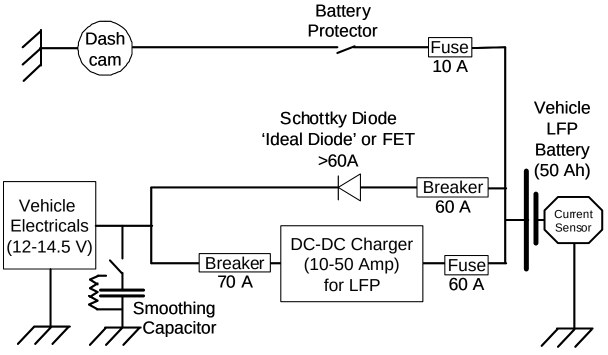
The rav4 hybrid does not have an alternator, and the 12v DC circuit is effectively isolated through the DC-DC converter from major inductive sources like the high-voltage generators. If the BMS cuts off the battery during charging, any inductive loads should continue to receive power from the DC-DC converter. But a connected car battery acts as a buffer (capacitive load) for the vehicle electrical system. Although the 12v output in a hybrid with DC converter may be more stable than a conventional vehicle with an alternator, the interactions between control circuits for the 12v and high-voltage (traction) systems are unknown (to me). So it is preferable not to run any vehicle without a connected battery. With these things in mind, we wish to ensure that the LFP is never charged above 1C, but we do not want to disconnect an LFP battery at a low SOC after the vehicle (and thus the charger) is on.

Also remember the doubt expressed above: if the rav4 is using a (dumb) LA-adjusted Coulomb-counting algorithm instead of current-based charging control, it could overcharge and damage an LFP battery at some time, even if it seems OK initially. In the absence of a meaningful response from Toyota, identification of any other risks requires analysis of the entire vehicle 12v system by a qualified electrical engineer familiar with LFP batteries. This is yet to be published.

If any technically-adept owner goes ahead with an LFP battery at their own risk, it seems best to use a high-quality ‘battery protector’ and set the cut-off voltage for any added circuit (such as dashcam power) to 13v (~30% SOC at 25ºC?) so that subsequent charging current should not go above 50A (1C). It would be wise to check battery voltage before charging from the vehicle, any time substantial battery discharge is suspected. This is simple with a cigarette lighter-USB converter that incorporates a voltage readout (which is also useful to confirm the drop from 14.2v to 13.6v after an appropriate period). If the LFP battery is below 12.95v at 25ºC, it should be disconnected from the vehicle charging system before starting, to avoid excessive charging current. That would leave problems of how to start and run the vehicle, if the situation ever arose.

To ensure that this could never arise, it would be necessary to seek professional advice. An interposed DC-DC charger (as in the diagram below) would effectively isolate the battery from the car’s charging circuit, which may be unwise. A large smoothing capacitor (as used in the hybrid rav4 HV circuit) may help, but how the car programming would react to altered signals from the current sensor is untested. Also, DC-DC chargers are one-way devices, so they cannot provide power from the battery through the charging cable to the vehicle electrical system, as in the OEM rav4 wiring. At least an added power diode would be needed; or two DC-DC converters wired master and slave (https://community.victronenergy.com/questions/5277/bidirectional-charging-with-2-buck-boost.html). This will need input from an automotive electrician. On preliminary advice, it may be feasible but expensive. There is limited space near the rav4 auxiliary battery to mount additional electrical components. If this approach is feasible, charger current could be chosen based on preferred balance between LFP battery cycle life and charge speed. One could also choose a device with current-based charge termination and adjustable recharge voltage threshold, as desired for optimal life of LFP batteries. Also check the standby current drain.

Without these features in the charging system, life of an LFP battery kept above 25% SOC in a rav4 hybrid will be less than 2000 cycles (specified under ideal conditions at 0.2C charge, no float and no delay before discharge). But if there is substantial cycling, LFP life should be far greater than any LA battery of similar capacity, if a well-installed and high-quality LFP battery is used at moderate temperatures.



LFP Considerations

An informative site about LFP battery technology is http://nordkyndesign.com/category/marine-engineering/electrical/lithium-battery-systems/. A good academic review is http://hdl.handle.net/10125/101139. At 1 cycle/day with a 2000 cycle life there may be a better technology before a well-installed LFP battery needs replacement. Reported calendar life for properly managed LFP batteries is >10y. Although I have been convinced about the benefits of LFP auxiliary batteries for hybrid vehicles, anyone considering a change should note:

- LA is a more robust technology; because it is more temperature-tolerant, and because lead is more stable than lithium. But the strong acid electrolyte and hydrogen gas production from LA batteries are dangerous. Experts disagree on which battery technology is safer overall (and both require careful use for safety).
- LFP is more stable than Lithium-Cobalt (used in most Li-ion and Li-Po powerbanks), but it still needs at least a dedicated battery controller (called a PCM or BMS) for safety. This may be built into the battery or wired in. It must connect to each cell within the bank that forms the battery. It is essential as the ‘protection of last resort’ to avoid over-charging and over-heating (which can be dangerous as well as damaging to the battery) and over-discharge (which can quickly destroy the battery).
- For safety, no lithium battery chemistry other than LFP should currently be considered for in-vehicle use. Although unlikely with properly installed LFP batteries, thermal runaway followed by a lithium fire is such a dangerous scenario that redundant protections should be used against it. Protections should be redundant in the battery and charger, in case either fails in a way that keeps the circuit active.
- Most external battery (charging) management systems use some form of battery voltage sensing. LFP batteries present higher charged voltage (~13.5v) so they have used at least 50% of capacity (>80% at low discharge rates) by the time they drop to the LA maximum around 12.7v. At 0.1-0.3C current and 20-30ºC, voltage drops steadily to 12.5v at 80-90% discharge, then rapidly to 100% discharge (typically defined by the internal BMS as 10v). See the charts below. True ‘resting voltages’ (with no commensal drain) would be a little higher. The slope is small from 5% to 80% discharge (and the relationship depends on both temperature and discharge rate). So a small error in specified or measured voltage, or estimation at an incorrect temperature or discharge rate, can give a large error in estimated battery state of charge (SOC). Some experts recommend Amp-hour or Coulomb counting or more complicated algorithms to estimate SOC; others find them unreliable.
- A dumb bulk charger for LA (or even a Li-Po charger) may push out more than 14.6v and dangerously overcharge LFP. A smart (multi-stage) charger for LA may not provide any current at LFP battery voltage. Or it may work just fine if it uses suitable voltage and current cut-offs. As a conservative charger setting for LFP, a regulated 13.8-14.4v at 0.2-0.5C should be fine for the bulk/CC stage (but check your battery specifications). As battery resistance rises with state of charge, current at this regulated charging voltage will drop (absorption/CV stage). Even ‘ripple’ above the regulated voltage can be damaging if it goes over the safe voltage limit for LFP charging. Below 13.4v there will be no charging (or very slow charging and greater risk of memory effects from partial charging).
- Some experts recommend charging well-matched cells to only 13.8v to avoid challenges of balancing at higher voltages. Others use at least 14v and absorption to 0.05C to avoid memory effects. Some BMS units only commence cell balancing above 14v. In any case, a prolonged absorption phase (> 4 hr) should be avoided.
- Absorption/CV charging should stop before charging current drops to 0.02C (1A for a 50Ah battery); but not all chargers (even those with ‘lithium’ profiles) have this feature, and it is complicated by any substantial ‘parasitic load’. Some chargers use a higher cut-

off current, some use timed cut-off of the absorption phase, and others go on until stopped manually. If you are happy with 90% SOC (and longer cycle life) you do not need any absorption/CV charging; just a bulk/CC stage to 14.4v. To get 100% capacity (and possibly for cell balancing and avoidance of memory effects), you will have to check specifications and/or measure your particular systems (vehicle and external chargers and battery). Most likely, battery specifications will call for absorption charging to terminate at some fraction of C, in the absence of any 'parasitic load'. The fraction may vary with charge voltage: some would say 0.03C (1.6 A for a 50Ah battery) when charged to 14.2v. It is sometimes recommended to terminate charging based on BMS readings from individual cells, which are unavailable in many LFP batteries.

- Memory effects occur in LFP after partial charge combined with partial discharge, and become more difficult to erase after multiple partial charge cycles to the same level. In practice, to clear memory effects it is usually only necessary to charge fully (terminating by absorption current) a few times a year.
- LFP batteries are safest, and show highest capacity and cycle life, at moderate temperatures (around 23ºC). They must never be charged at freezing temperatures, or discharged at elevated (engine bay) temperatures. Vehicle cabin temperatures are generally OK (humans function best in the same range), but can reach unacceptable levels if parked outdoors in hot or freezing conditions. Temperatures over 40ºC can greatly shorten the life of LFP batteries.
- LFP batteries are generally not designed to be cranking batteries. If you want to be able to jumpstart another (non-hybrid) vehicle, you should use a battery designed for cranking.
- High-quality LFP batteries can be recharged quickly (0.2-1C at a charge voltage up to 14.6v, depending on the brand and model). There are compromises between highest charge rate and capacity vs highest cycle life. For safety they should never receive a higher-voltage 'desulfation' or 'equalisation' charge, and for long life they should not be trickle/float charged for a long period. Short-term float at 13.8v or below should not be damaging. Unlike LA, their stored life is longest with a partial charge, ~50% SOC (and at < 25ºC). When fully discharged, they should be recharged (at least partially) as soon as possible. Algorithms for LFP batteries in active use typically trigger 'recharge' at a battery voltage of 13.1-13.2v (aimed to keep >50% SOC).
- The vehicle charging system must be checked for safety with LFP. It may be necessary to modify the vehicle system for safety, and/or use a smart wall charger and/or manual intervention for highest capacity and cycle life. You may also need to consider whether your typical and extended drive durations would replace used battery capacity, though LFP will typically charge much faster than lead acid (if the vehicle provides sufficient current, at charging voltages of 14.0-14.6v). Cycle life will be greater with 0.2C than with 1C charging; and with current-based charge termination.
- Ideally, the charging system should ensure that the LFP battery has discharged substantially before initiating a current-limited and current-terminated recharge. Vehicle 12v battery charging systems are not yet designed this way.
- LFP batteries vary in quality. There are important differences in BMS features (temperature sensing, cell balancing, communication), wire size, vibration resistance, electrolyte composition, cell type, cell matching, true capacity, life-span, warranty and recommended charge or discharge profiles. It may not be possible for a buyer to check these features, so it is safest to use a reputable brand. Fortunately, prices are dropping.
- Vehicle warranty may be affected if a case can be made that use of a non-OEM LFP battery was relevant to damage to the vehicle. Insurance is a potential minefield.

Although widely used as light, fast-charging, deep-cycle batteries in hybrid vehicle traction systems and recreational vehicles (where they may have separate cooling and charge/discharge management systems), they are not necessarily the best choice for all hybrid vehicle owners as replacements for the vehicle 12v auxiliary battery. LFP batteries work best for regular cycling. LA batteries are better for prolonged standby at full capacity. Most current mobile systems with LFP use it in parallel with at least one LA battery. There is no such thing as a simple LFP 'drop-in' replacement for an LA vehicle battery. It is at least essential to consider the extremes of cabin temperature in your location, and to check the suitability of the vehicle battery charging system, especially looking for excessive charging current at low battery SOC. If in doubt, stay with the OEM-supplied battery. Before thinking about DIY installation, read https://marinehowto.com/lifepo4-batteries-on-boats/ and look at http://nordkyndesign.com/category/marine-engineering/electrical/lithium-battery-systems/. Marine and land-vehicle uses share many potential pitfalls.

Ideal Settings for an LFP Auxiliary Battery (kept in a cabin around 25°C)

Stage	**Voltage**	**Current into battery**
Charge (Bulk)	14.2v charge	≤0.2C (needs to be limited)
Charge Termination	--na-- (>90% SOC)	0.02C
Float	13.2v or 0v charge	0 (none will flow at this voltage)
Recharge threshold	13.1v battery (~50% SOC)	--na--
BatteryProtect (non-essential circuits)	12.8v battery (~ 20% SOC) IF charge current is limited	--na--

Charts clarified from Power-Sonic https://www.power-sonic.com/wp-content/uploads/2020/07/PSL-12500-Technical-Document.pdf: