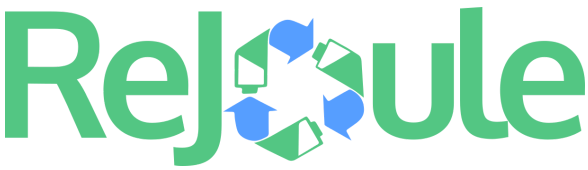

Fast Diagnostics to Maximize the Value of Every Battery

September 2022

What to do with all those batteries?

We are seeing an inevitable trend that Electric Vehicles (EVs) will continue to grow their market share. EVAdoption forecasts EV sales share will reach 29.5% versus less than 5.37% in 2022 by 2030 & cumulative EVs to reach around 25 million by 2030 versus 3 million in 2022 in the US (Figures 1 & 2).

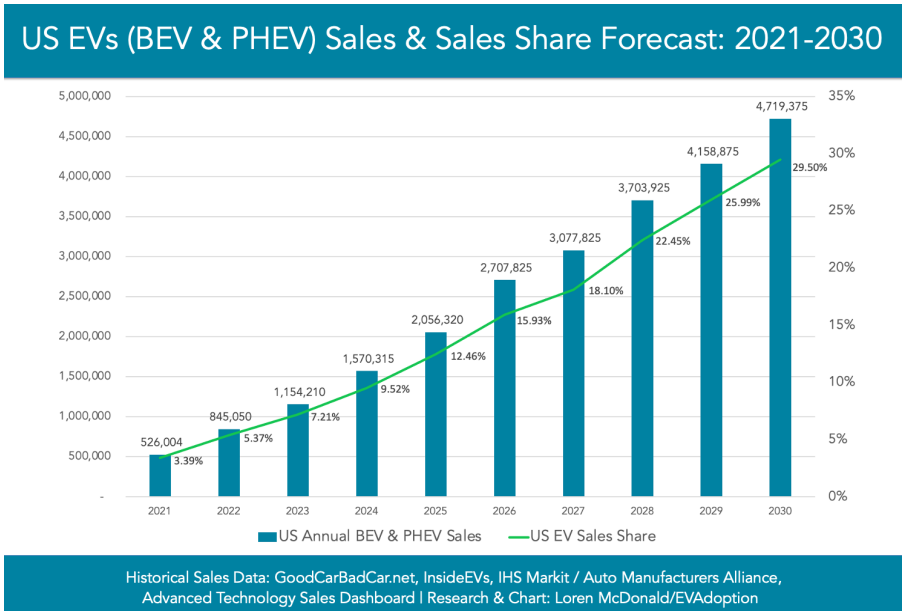

Figure 1: US EVs Sales & Sales Share Forecast by EVAdoption

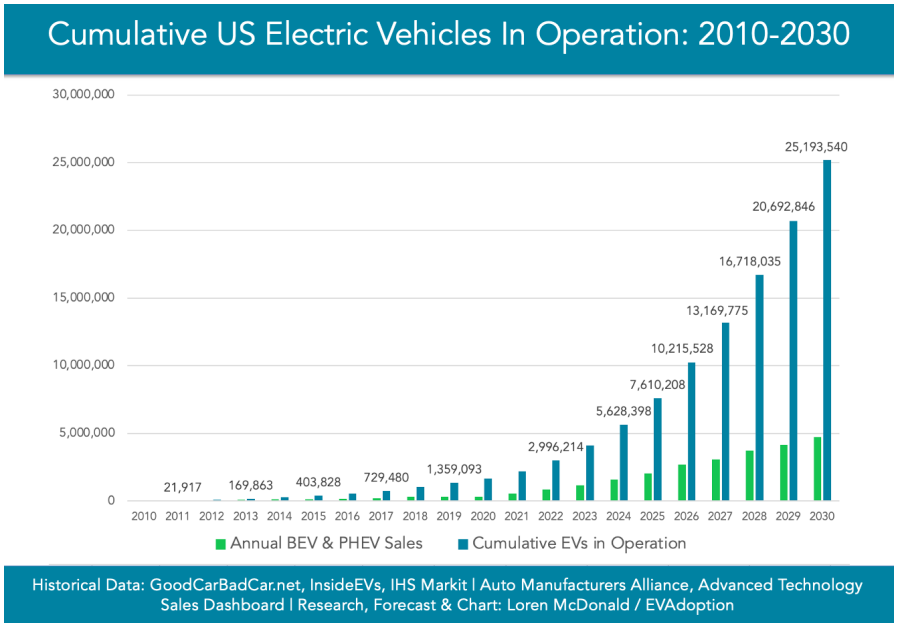

Figure 2: Cumulative US EVs Forecast by EVAdoption

Millions of these EV batteries will be decommissioned in the coming years, threatening a deluge of toxic battery waste, as projected by Circular Energy Storage, a UK-based consulting company (Figure 3). However, just because a battery is no longer suitable in a vehicle, does not mean that the battery is dead. It can still be used in a less demanding application for several years. Fortunately, even when no longer able to provide the range or acceleration needed on the road, these batteries typically retain as much as 90% of their initial capacity. At that point they can be repurposed to store renewable energy for stationary applications (see more in our blog Born Again Batteries).

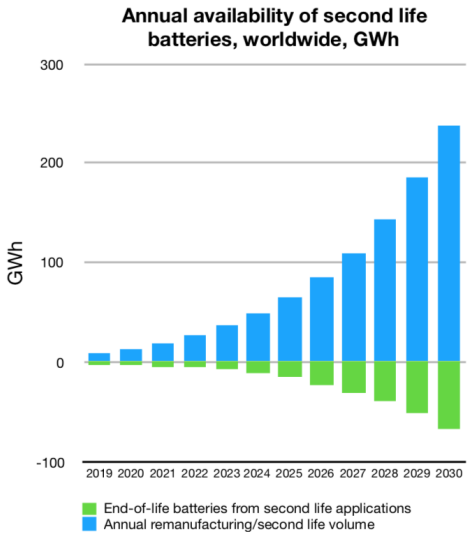

Figure 3: Annual Availability of Second Life Batteries Worldwide (Source: Circular Energy Storage)

Reusing/Repurposing EV batteries can reduce their carbon footprint by up to 17%, as reported by Cornell University researchers, funded by US National Science Foundation. Pairing used batteries with solar and wind generation can help us get to 100% renewables more quickly with less wasted resources and draw out the useful value of aging energy storage assets. Finally, repurposing EV batteries for stationary storage applications can have the added benefit of reducing the complexity of battery collection efforts when it finally becomes time to recycle the battery materials.

How do you measure the value of a battery?

Batteries are still one of the most expensive components in an EV. It is increasingly important for automakers to understand the battery's performance, especially as it ages. This knowledge of battery performance and health is not only important for automotive manufacturers, but also for auto dealers, service centers, and fleet operators, for the purpose of battery warranty, repair, and understanding residual value of the battery and the vehicle. Knowing the health and value of the battery at the end of its life in an EV is important also from the perspective of using it in a second-life application.

The performance of a battery at any point of its life can be represented by its State of Health (SOH). The traditional definition of SOH is the ratio of current capacity (kWh or Ah) over the original rated capacity when it was still new. However, the capacity at any time also varies depending on the charge or discharge current, the impedance (the effective resistance to an

Alternating Current) changes over its lifetime, and the temperature it experiences. Hence, it is imperative to monitor and track these parameters over the lifetime of the battery to properly diagnose it.

A big challenge for the battery industry is that with increasing size and complexity of battery design, there is a need for measuring SOH at every level of the battery design hierarchy - cells (smallest form), modules (collection of 2 or more cells) and packs (multiple modules and largest form factor) (Figures 4 & 5) . There is a growing demand to measure the SOH at module and pack level because disassembling them to the cell level means additional labor cost, and then assembling them for another application adds even further costs. These additional costs can sometimes lead to the counterintuitive result of second-life battery products costing more than new battery products.

Figure 4: A battery module at ReJoule facility consisting of multiple cells

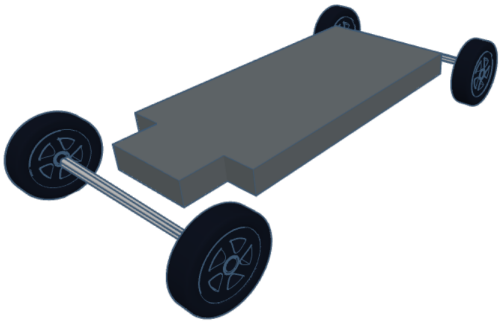

Figure 5: A rendering of an EV battery pack consisting of several modules

The prevailing diagnostic methods are inefficient and cost prohibitive. To grade used batteries today, they must be shipped to a central location and then cycled (charged and discharged) for up to 10 hours on expensive machinery to measure battery SOH and ensure safety. Relying on existing commercially available equipment and test methods virtually ensures that retired EV batteries will never be repurposed at scale.

There are several technologies that are trying to achieve better battery diagnostics than traditional cycling - ultrasound, statistical data analysis (usually pure software), and conventional Electrochemical Impedance Spectroscopy (EIS). However, all of these have their own challenges with accuracy, scalability to different form factors of batteries, ability to test high voltage, and fast test time. For example, ultrasound can perform fast testing with high accuracy but requires more work to test different battery form factors and doesn't scale up to higher voltages (like modules). Similarly, software based solutions are more scalable but their accuracy is low and they require thousands if not tens of thousands of data points.

ReJoule's fast diagnostics is the solution

Figure 6: ReJoule's BattScan050V device for grading battery modules

Our vision is to set a standard for measuring battery SOH by making the test quick, accurate and easy to use, so our customers can maximize the value of their batteries. ReJoule's fast grading product uses a trusted method called Electrochemical Impedance Spectroscopy (EIS). EIS is typically performed for cell level measurements up to 5V, and ReJoule's patent pending technology makes EIS possible for larger, higher voltage batteries of any form factor and chemistry. ReJoule has already commercialized this product for batteries up to 50V (Figure 6), and is currently developing a solution for batteries up to 400V. ReJoule pairs this unique measurement with a machine learning algorithm that combines electrochemical battery modeling techniques and statistical modeling techniques to predict the SOH of batteries. Our 5 to 10 minute test achieves an accuracy of 95 - 98% (see case study) compared to cycling which takes up to 10 hours. This allows us to accurately, quickly, and conveniently measure battery SOH at the source, without having to ship a battery to a centralized test facility, and in some cases, without needing to remove the battery from the car. ReJoule's technology will reduce the overall process of readying even the largest battery pack for repurposing from several days to a matter of minutes.

ReJoule has several success stories working with the government as well as industry clients. We are in the process of installing solar with storage using second-life batteries for two commercial buildings under a grant from the California Energy Commission (CEC). The goal is to prove the technical and economic benefits of second-life batteries. We are about to start a federal grant project which involves working with a company creating a used battery marketplace. ReJoule's value is helping them grade their batteries, so buyers will have a better sense of the residual value. Apart from these grant projects, ReJoule has also shipped its BattScan (download spec sheet) grading device to customers on two continents for used battery grading, enabling our customers to maximize the value of their batteries.

Want to learn more about how we can help improve your battery testing operations? Email us at info@rejouleenergy.com, and tell us about your needs!