**How to make Batteries more Reliable and Longer Lasting**

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Isidor Buchmann, CEO & founder of Cadex Electronics Inc.
 [www.BatteryUniversity.com](http://www.BatteryUniversity.com); answers@cadex.com

Knowing the health of a battery is important, but no quick method exists to test them with certainty. State-of-health (SoH) cannot be measured per se, only estimated to various degrees of accuracies based on available symptoms. A battery behaves much like a living organism that is swayed by conditions such as state-of-charge (SoC), charge and discharge events, rest periods, environmental conditions and aging. A battery with low charge behaves similarly to a pack that exhibits capacity loss and these two symptoms become a blur. Battery test methods must look beyond mood swings and capture characteristics that only relate to SoH.

The leading health indicator of a battery is *capacity*; a unit that represents the ability to store energy. A new battery delivers (should deliver) 100 percent of the rated Ah capacity. Lead acid starts at about 85 percent and the capacity will increase with use before the long and gradual decrease begins. Lithium-ion enters service at peak capacity and starts its decline with use and aging, albeit very slowly. Nickel-based batteries need priming to reach full capacity and also follow the gradual decline with use.

To reduce stress, charge Li-ion with a moderate two to three-hour charge rather than an ultra-fast charge lasting less than one hour. Prevent harsh and erratic dischargers. It is better not to drain a battery fully but charge it more often. As the author of [www.BatteryUniversity.com](http://www.BatteryUniversity.com) I am citing these recommendations; they are the most commonly asked questions of this popular educational website on batteries.

Device manufacturers base the performance specification on a new battery, but this is only a snapshot at the beginning of a career. Like a sports athlete, the performance will drop with time and the loss will only become visible after the shine of a new device has worn off and daily routines are taken for granted. As the runtime shortens, battery-related breakdowns begin to occur more often and the battery becomes a nuisance. An analogy is an aging man whose decreased endurance begins to show after the most productive years draw to an end. Figure 1 demonstrates such an aging process.

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|   | **Figure 1: Battery aging in comparison of a man growing old**.Few people know when to replace a battery; some are replaced too early but most are kept too long. |

When asking battery users: “At what capacity do you replace the battery?” most reply in confusion: *“I beg your pardon?”* Capacity as a measure of storage capability and runtime is poorly understood. Nor is capacity used as a threshold to retire a battery unless they are serviced with a [battery analyzer](file:///C%3A%5CCadex%20Files%5CDocuments%5CWEB%5CBatteryU%5C2011%5CBU-909%20Battery%20Test%20Equipment1.doc).

Battery retirement depends on the application. Healthcare, defense and public safety organizations with battery analyzers set the replacement threshold typically to 80 percent. There are applications where the battery can be kept longer and there is a balance between cost and risk, also known as economics and “what if.” Some scanning devices in warehouses can go as low as 60 percent and still provide a full day’s work. A starter battery in a car still cranks well at 40 percent. Engine-starting requires only a short discharge burst that is replenished while driving, but letting the capacity go much lower than the 40-percent threshold may get the driver stranded without warning.

A reliable indicator to assure sufficient runtime is checking the spare capacity on return of a mission or a day’s shift. The [Cadex battery analyzers](http://www.cadex.com/en/products/battery-analyzers) do this by applying a discharge before charge. A battery should always have 10–20 percent spare capacity at the end of the shift to cover unknowns and emergencies. If the weakest battery in the fleet returns with 30 percent remaining capacity, then the target may be lowered from, say, 80 to 70 percent. Such fine-tuning maximizes battery life without added risk, resulting is cost savings. Figure 2 illustrates a battery analyzer that provides this service.

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|  | **Figure 2: Cadex C7400ER Battery Analyzer**Services four batteries from 1.2 to 36V and up to 6A per station. Batteries connect by custom adapters and programmable cables. The device operates in stand-alone mode or with a PC. |

The importance of checking the battery regularly is illustrated on a battery-powered drone. The drone in our example is specified to fly for 60 minutes with a good battery. Unknown to mission control, the capacity may have dropped from 100 percent to 75 percent, reducing the flying time from 60 to 45 minutes. Not aware of the capacity fade, the shorter runtime could crash a $50,000 vehicle when forced to navigate a second landing approach.

The analyzer’s [print option](file:///E%3A%5CWEB%5CBatteryU%5C2011%5CBU-810c%20How%20to%20Maintain%20Fleet%20Batteries.doc) makes capacity, internal battery resistance and service dates visible on a label that is attached to each battery. Figure 3 illustrates such a label. With this information available on each pack, batteries delivering close to 100 percent can be assigned for long hauls while older packs would fly shorter errands. Another label method is identifying each battery with a bar code number. Scanning the code fetches historical battery information, configures the analyzer to the correct battery setting and adds the new service information.

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|  | **Figure 3: Sample of removable battery label**The label shows pertinent battery information at a glance. Showing service and due dates help in battery maintenance.  |

Many batteries and portable devices include fuel gauges. While these show the remaining charge, capacity estimation is not possible. The state-of-charge will always show 100 percent after a full charge whether the battery is new or faded. This creates a false sense of security by assuming that a fully charged battery will faithfully deliver the anticipated runtime.

Not only does the battery capacity drop with use and time, the fuel gauge also loses accuracy and the battery needs calibration. The instruction manual of an Apple iPad says: “For proper reporting of SoC, be sure to go through at least one full charge/discharge cycle per month.” Engineers call this “digital memory.”

The industry is aware of deficiencies and since the mid-1990s has added “smarts” to mission-critical batteries. The SMBus is a widely used format that measures voltage and current during charge and discharge. While this provides valuable battery information such as SoC, cycle count and error diagnostics, true capacity estimation is not possible. The *digital battery,* which the SMBus manages, is exclusively based on the peripherals of the *chemical battery,* information that is assumed and drifts with time. Calibration is done by a full discharge/charge cycle in the device or with a battery analyzer.

In the absence of regular battery maintenance, some device manufacturers mandate battery replacement according to a date-stamping or cycle count. A pack may fail before the appointed time has expired but most last far longer, prompting perfectly good batteries to be discarded prematurely. Dr. Imre Gyuk, manager of the Energy Storage Research Program at DOE, says that “every year roughly one million usable lithium-ion batteries are sent in for recycling with most having a capacity of up to 80 percent.”

Battery problems also affect healthcare. An FDA survey says that “up to 50% of service calls in hospitals surveyed relate to battery issues.” Healthcare professionals at the Association for the Advancement of Medical Instruments (AAMI) say that “battery management emerged as a top 10 medical device challenge.”

**When Rubber-stamping is not enough**

Simply choosing the best battery from the lot to get a device rubber-stamped by the approval agencies is not enough. Equally or more important is assuring that the device provides continued performance to the planned retirement. While the approval process can be overly detailed and painstakingly slow, few rules apply to assure continued reliability once approved and released,. The agencies have done their job; they wash their hands and pass the responsibility on to the user.

Rubber-stamping appears simpler than enforcing standards to ensure continued field reliability. Device manufacturers are an easy target and authorities can shut them down for trivial infractions. Placing too much importance on the “cradle-to-graduation” can overshadow the vital phase of “deployment-to-retirement.” It is the battery that gets exhausted first and needs replacement. A host device may see several batteries during its service life and the health-check procedure must be made more effective.

Small to mid-sized batteries should be checked with a full discharge/charge cycle on a battery analyzer. This measures the battery capacity and calibrates the smart circuit. Rapid-testing would be desirable but the developments are not sufficiently mature for all applications, nor does rapid-testing calibrate the battery. However, it is better to rapid-test with a less reliable method than to disregard the test altogether.

Larger battery systems that cannot be removed from service or are impractical to cycle are equipped with a battery management system (BMS). Research is continuing to include capacity estimation by applying [electrochemical impedance spectroscopy](http://batteryuniversity.com/learn/article/recognizing_battery_capacity_as_the_missing_link) (EIS). This technology is being developed to rapid-test a broad range of batteries, including starter batteries on vehicles.

**Summary**

It appears as if little has changed since the invention of the lead acid battery by Gaston Planté in 1859. We don’t even have a reliable method to measure state-of-charge; not to mention attaining accurate capacity assessments as part of rapid-testing. Simply measuring voltage and internal resistance, as was done in the past, is no longer sufficient to estimate state-of-charge and capacity. Batteries have improved and keep low resistance throughout life. The research team of Cadex is working on several developments that will make battery performance more transparent and accountable to the user.

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**About the Author**

Isidor Buchmann is the founder and CEO of Cadex Electronics Inc. For three decades, Buchmann has studied the behavior of rechargeable batteries in practical, everyday applications, has written award-winning articles including the best-selling book “Batteries in a Portable World,” now in its third edition. Cadex specializes in the design and manufacturing of battery chargers, analyzers and monitoring devices. For more information on batteries, visit [www.batteryuniversity.com](http://www.batteryuniversity.com); product information is on [www.cadex.com](http://www.cadex.com).

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