WHITE PAPER

Improving Li-ion Cell Formation Throughput

Time and cost-saving methods for EV battery cell manufacturing

KEYSIGHT

The electric vehicle (EV) battery market is experiencing exponential growth, with news of gigafactories frequently making headlines. The automotive industry expects demand for Lithium-ion (Li-ion) cells to grow by some 33% annually to 4,700 GWh by 2030 (see Figure 1).

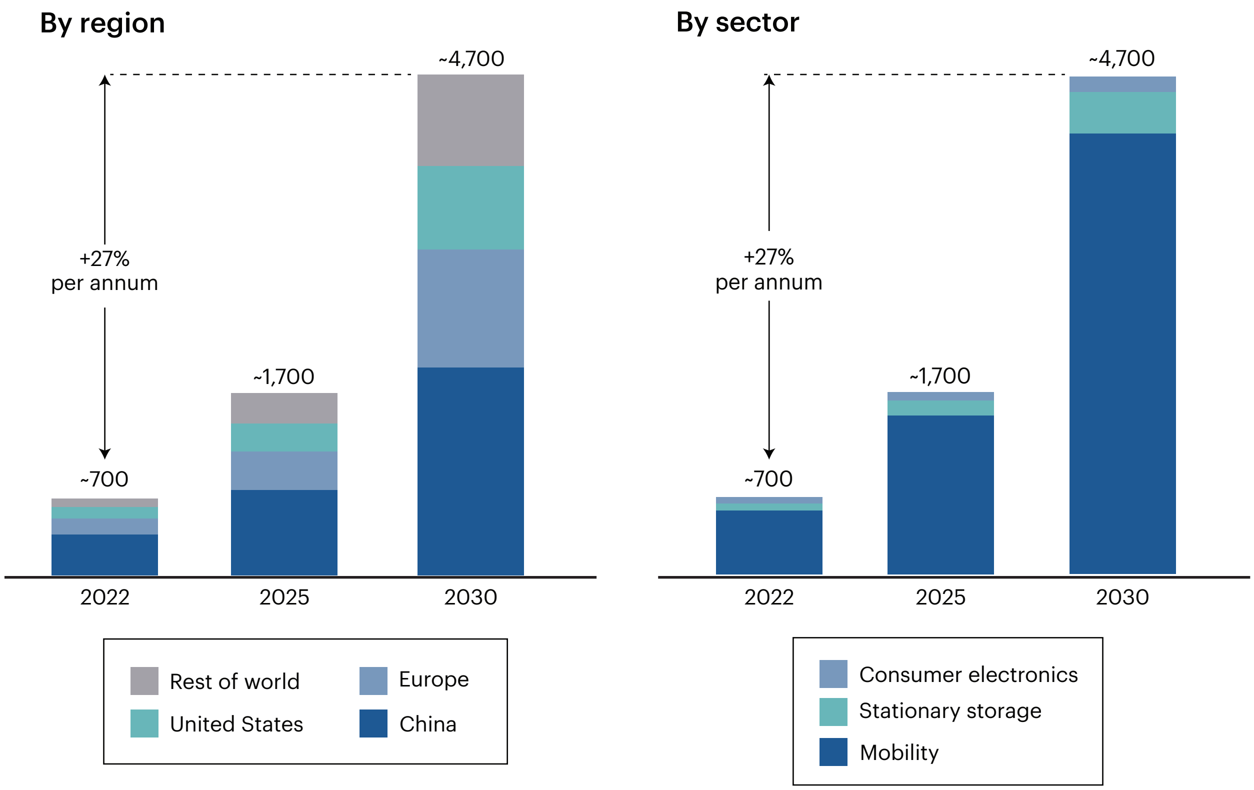


Figure 1. Global Li-ion battery cell demand by region and sector (data source: McKinsey & Company)

The word “gigafactory” did not exist a decade ago, but gigafactories are now a cornerstone of the EV ecosystem. They have helped boost battery production from a capacity of 4 to 10 GWh per year to a capacity of 40 to 80 GWh per year. High-volume production provides cost efficiency, contributing to the 90% plunge in EV battery prices over the past decade.

However, keeping tabs on battery costs is a constant challenge because of rising raw materials, supply chain, and energy costs. Cell manufacturing is energy intensive.

This paper looks at how disruptive technology in the cell formation and quality management process can contribute to time and cost savings in battery cell manufacturing.

Critical Stages in Gigafactory EV Battery Cell Production

The keys to cost-effective manufacturing of high-quality products are speed, precision, and a high degree of reliability and repeatability. Figure 2 provides a simplified overview of the complex automated processes behind high-volume battery cell manufacturing.

Throughput is a vital manufacturing cost parameter in the gigafactory. It quantifies the rate at which a cell goes through the manufacturing process. For Li-ion cell manufacturing, the cell formation and aging phases are the most time-consuming. The following sections discuss the causes of these bottlenecks and ways to alleviate the time pressures.

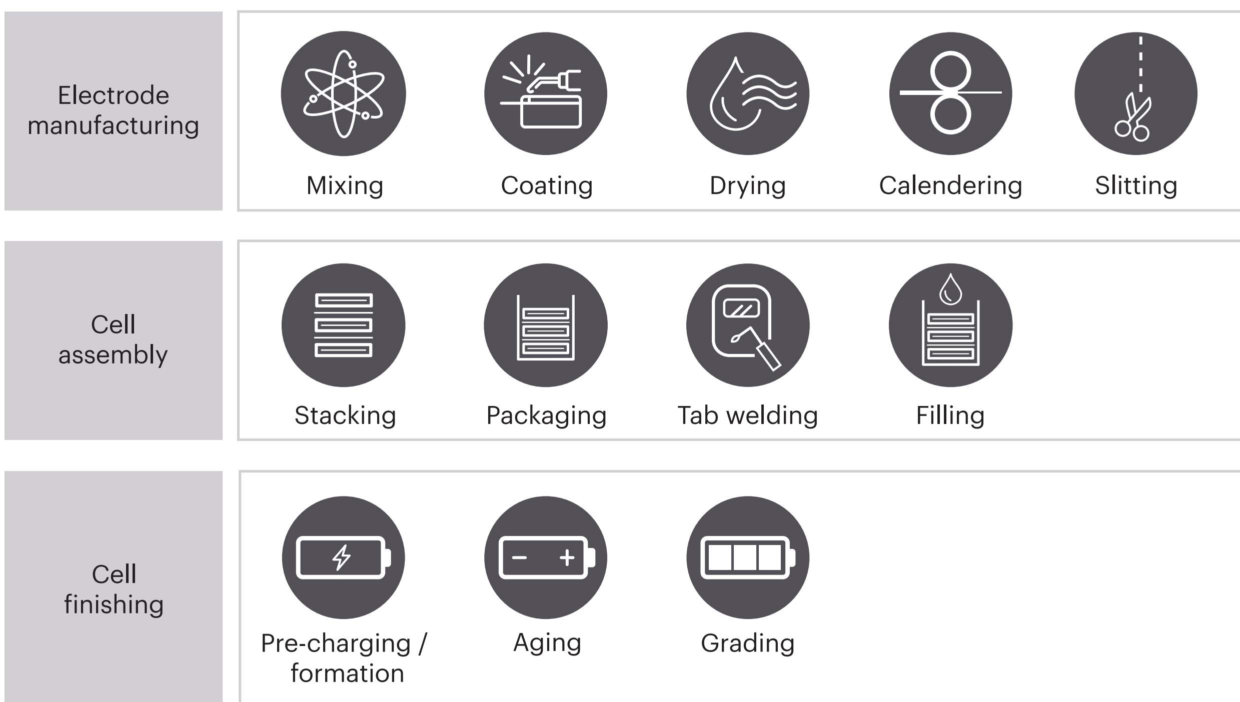


Figure 2. Critical stages in the battery cell manufacturing process

Electrode fabrication and cell assembly are highly automated processes with relatively fast throughput compared with the cell formation and aging stages.

After electrolyte filling, the cell has no energy stored inside. Determining the voltage on the cell at that moment depends on many factors, the primary one being the materials used to construct the cell. Typically, you see low voltages immediately after electrolyte filling, ranging from 50 to 100 mV, but even small negative voltages of −100 to −200 mV are possible.

Pre-Charging: The First Step in Electrical Cell Finishing

It is critical to quickly move to the pre-charge stage once the cell is filled with electrolyte. To stop the corrosion process, pre-charging takes a cell with a very low voltage (typically from −100 mV to 100 mV) to about 2 V, a 0% state of charge (SoC), and a safe, stable voltage. The cell can then move on to formation without concerns about delays that could cause additional corrosion.

What are OCV and SoC?

A battery cell's open circuit voltage (OCV) represents the potential difference between the positive and negative electrodes when no current flows and the electrode potentials are at equilibrium.

The state of charge (SoC) measures the amount of energy available in a battery at a specific point in time, expressed as a percentage of the full charge.

With pre-charging, the cells enter the formation process at 2 V. As a result, formation equipment can operate over a minimal range, from 2 V to the maximum open circuit voltage (OCV) at 100% SoC, which can be 3.6 V to 4.2 V, depending on the cell chemistry.

The minimum 2 V operating voltage on formation equipment contrasts with a typical cell test system or power supply / charger that operates down to 0 V. The greater operating range of cell test equipment typically increases costs. Thus, EV battery cell manufacturers prefer narrower-range, lower-cost, and more specialized formation equipment for pre-charging purposes.

Time and Cost of Cell Formation and Aging

Cell formation is a time-consuming but critical step in the cell finishing process. During formation, a current passes through the cell, charging it for the first time while forming the solid electrolyte-interphase layer. Once the solid electrolyte-interphase forms, you have a working cell that can charge, retain energy, and discharge.

A published study[1] on current and future Li-ion battery manufacturing showed that the cell formation and aging process incurs the highest cost, almost a third of the total manufacturing process cost (see Table 1 and Figure 3).

Most of the total aging time comes from the process of determining whether the cell's self-discharge behavior falls within acceptable limits. It takes time in aging to observe the change in the cell's OCV due to the effects of self-discharge. Reducing the time cells spend in the aging step provides savings that flow directly to the gigafactory's bottom line. We will discuss this in detail later and delve a little deeper into cell formation here.

1 Liu, Yangtao, Ruihan Zhang, Jun Wang, and Yan Wang. "Current and future lithium-ion battery manufacturing." iScience 24, no. 4 (2021), 102332. doi:10.1016/j.isci.2021.102332. https://www.sciencedirect.com/science/article/pii/S258900422100300X.

Table 1. Cost, throughput, and energy consumption of Li-ion battery manufacturing processes

Manufacturing processes	Cost per year / $* (Nelson et al., 2019)	Throughput (Heimes et al., 2019a)	Cost percentage %
Slurry mixing	7,396,000	30 min – 5 h	7.91%
Coating / drying	13,984,000	35 – 80 m / min	14.96%
Solvent recovery	4,296,000	NA	4.60%
Calendering	4,849,000	60 – 100 m / min	5.19%
Slitting	2,891,000	80 – 150 m / min	3.09%
Vacuum drying	2,990,000	12 – 30 h	3.20%
Stacking	8,086,000	NA	8.65%
Welding	6,864,000	NA	7.34%
Enclosing	11,636,000	Depending on the cell design	12.45%
Formation / aging	**30,482,750**	**Up to 3 weeks**	**32.61%**

Source: “Current and Future Lithium-ion Battery Manufacturing” [1]

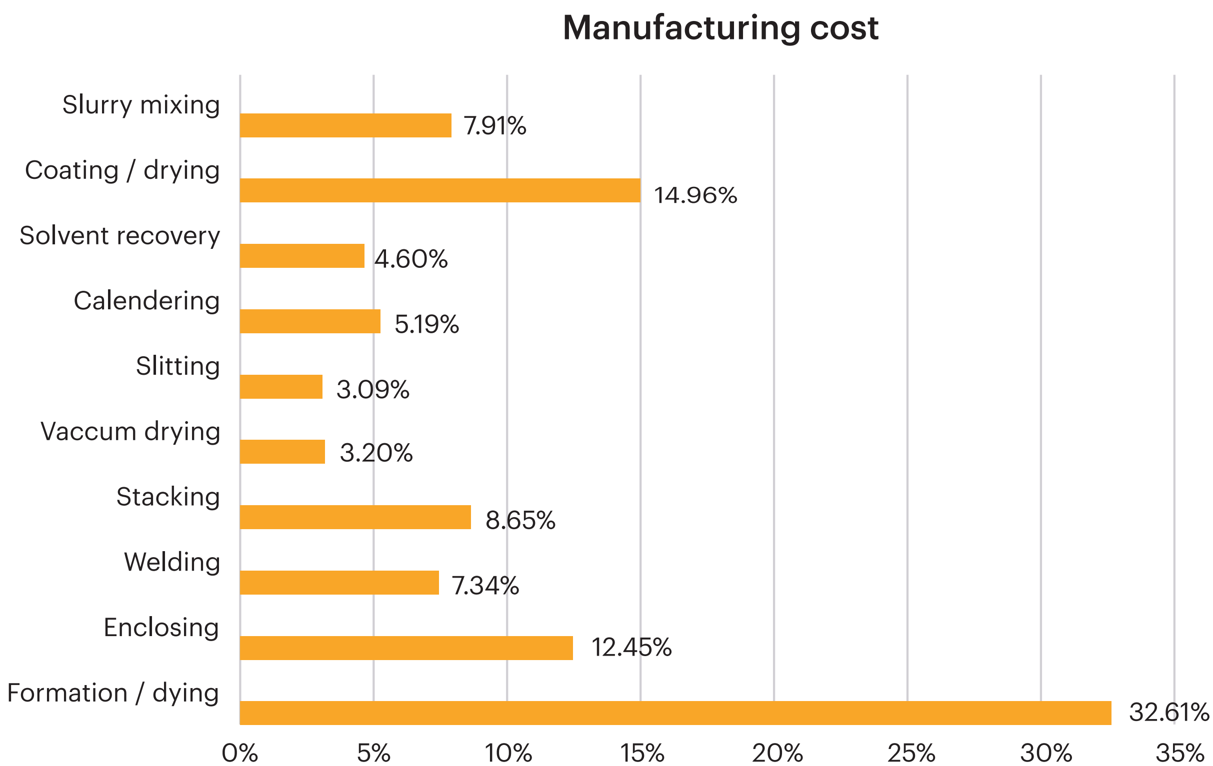


Figure 3. Graphical representation of Table 1 showing cost contributors of Li-ion battery manufacturing processes

Most cell manufacturers hold formation process information (for example, what current and for how long) as company-confidential data. Optimized formation equipment minimizes capital expenses.

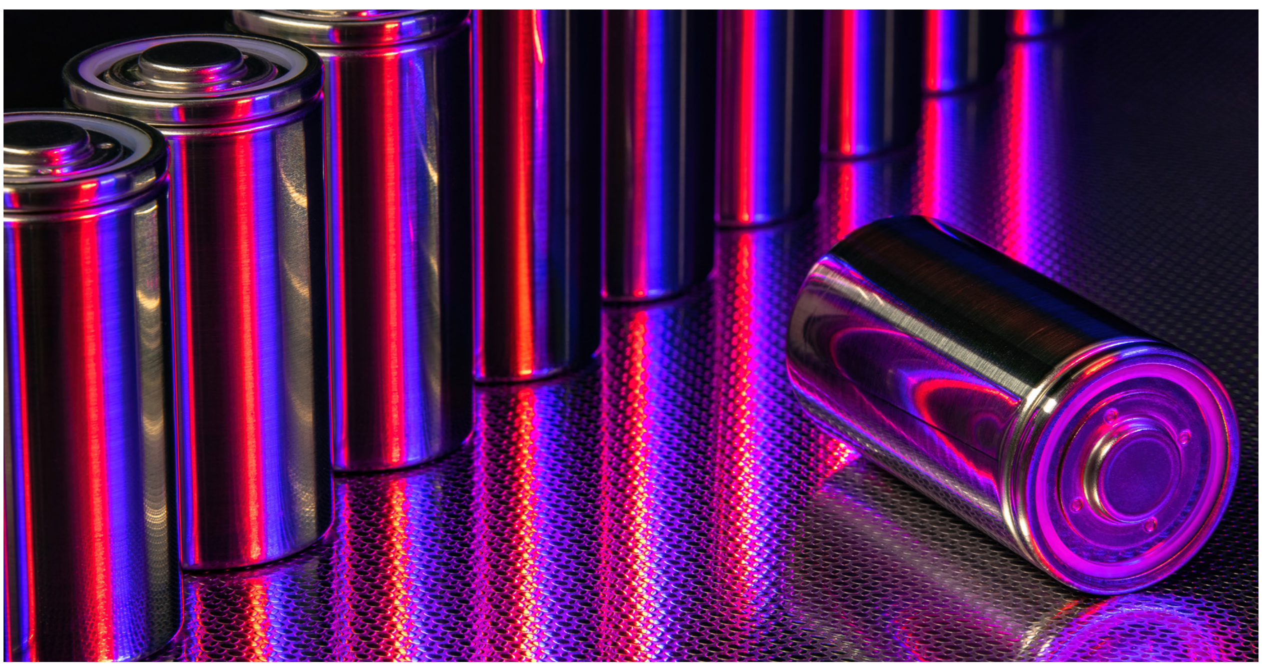
Differences in Cell Pre-charging and Cell Formation Requirements

Using the right tools is essential for optimizing the manufacturing process. The charging equipment requirements for pre-charge differ from those used for formation.

During pre-charge, the cell goes from a very low voltage, possibly even negative, and quickly rises to 2 V by adding a quick charge. Unlike formation, where low-voltage operation is undesirable and potentially dangerous, pre-charge requires low-voltage operation. Standard formation equipment for pre-charging is inadequate because it may not tolerate the pre-charge operating range with small negative voltages.

Hence, it is essential to consider the following key points when weighing the process and equipment requirements of Li-ion cell formation versus pre-charge:

- Formation equipment can operate at 2 V and higher to save on capital equipment expenses. This is important in large-scale manufacturing, which uses many formation channels because of long formation times.
- Pre-charge equipment needs to operate from a small negative voltage to 2 V, meaning standard formation equipment may not be able to perform the pre-charge step.
- While the 2 V range specification may slightly increase pre-charge equipment costs, fewer channels are necessary because the pre-charge step is much shorter than the formation step.



Cell Self-Discharge Measurement

Li-ion cells lose electrical charge even when they are not in use. This phenomenon is known as cell self-discharge.

A cell's capacity loss is 1% to 2% per month. The challenge for cell manufacturers is to quickly discern whether newly formed cells exhibit abnormal self-discharge behavior because of latent manufacturing defects.

Manufacturers must screen out cells with excessive self-discharge from the main population of cells. Screening prevents the faulty cells from flowing downstream and ending up in EV battery modules and packs.

As mentioned in Table 1, determining if a cell's self-discharge behavior is within acceptable limits uses the bulk of the total formation / aging time because of the lengthy change-in-OCV (ΔOCV) measurement period. Any method to reduce the time a cell spends in the aging step provides savings.

Let's look at traditional OCV versus a new potentiostatic method that can significantly reduce measurement time.

Traditional ΔOCV method

Traditionally, discerning self-discharge does not require complicated measurement. Measuring how the OCV of cells changes over time is relatively straightforward.

However, this ΔOCV method is a time-consuming process, typically taking many days. The long aging period negatively affects work-in-progress inventory metrics for the gigafactory. The massive inventory of cells undergoing OCV measurements consumes expensive floor space in temperature-controlled environments, incurring operational overhead.

Potentiostatic or direct measurement method

An alternative approach to the ΔOCV method is using a potentiostatic method to directly measure the cell's internal self-discharge current. A high-performance DC source that precisely matches the cell's OCV connects to the cell using a microammeter. The DC source holds the cell at a constant SoC, externally furnishing all the cell's self-discharge current.

This method typically takes hours or less for the measurement to settle out and even less time to discern those cells with excess self-discharge from the good ones. In manufacturing, this can significantly reduce work in process with its associated costs by eliminating or drastically reducing aging time.

To measure the cell's self-discharge quickly, the potentiostatic analyzer must have these essential characteristics:

- The analyzer must accurately measure low-level self-discharge currents in the range of tens or hundreds of microamperes.
- The analyzer should not disturb the cell. The voltage the analyzer applies to the cell must precisely equal the cell voltage. It must also quickly match the cell voltage. Otherwise, the applied mis-matched external voltage will charge or discharge the cell, resulting in unwanted charge redistribution, which causes currents that mask the self-discharge current you are measuring.
- The equipment must apply a very stable voltage to the cell. Any instability or noise in the applied voltage causes the cell to continually charge and discharge, producing noise currents on the self-discharge current measurement.

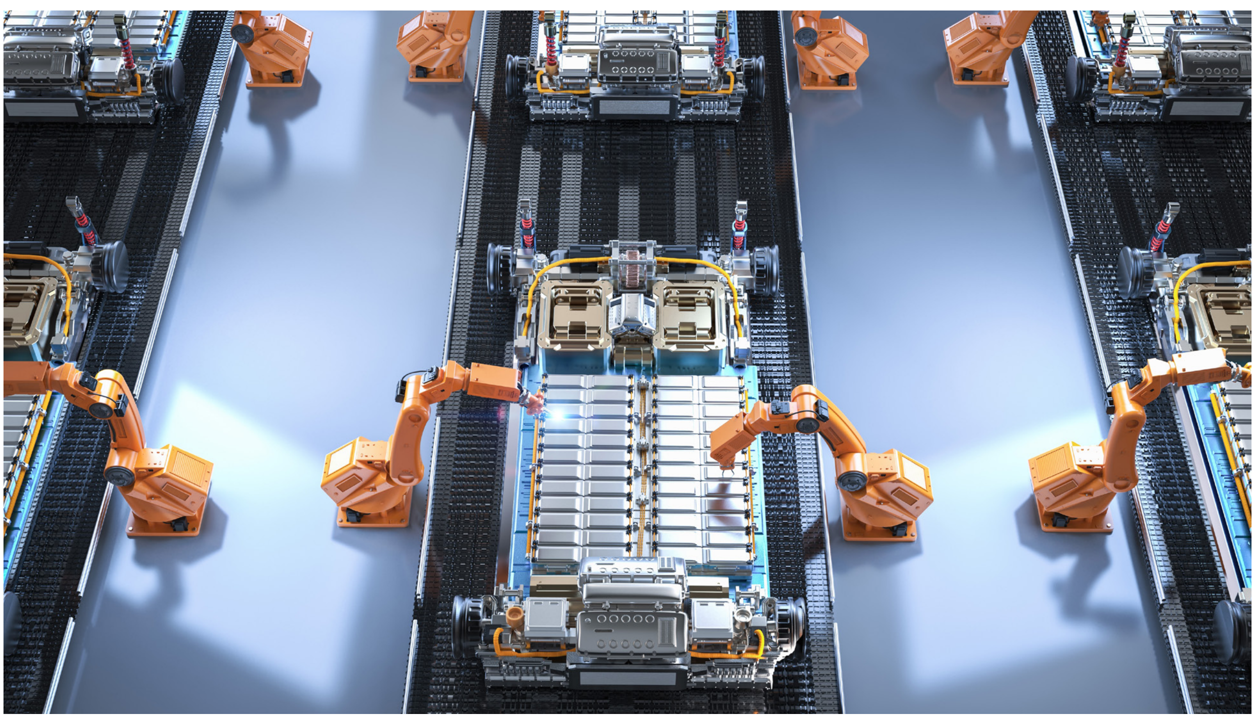


Figure 4 shows an example of a potentiostatic measurement on several cells using the Keysight BT2152B self-discharge analyzer. The BT2152B meets the requirements mentioned above for potentiostatic measurement:

- It can accurately measure low-level self-discharge currents with an uncertainty of ± (0.30% + 250 nA).
- It quickly matches the voltage applied to the cell (± 1.25 μV), minimizing new charge or discharge and unwanted settling currents that could otherwise mask the self-discharge current you are measuring.
- It applies a stable voltage to the cell (± 3 μVpk) to minimize continuing charge / discharge and other current noise on the self-discharge current measurement.

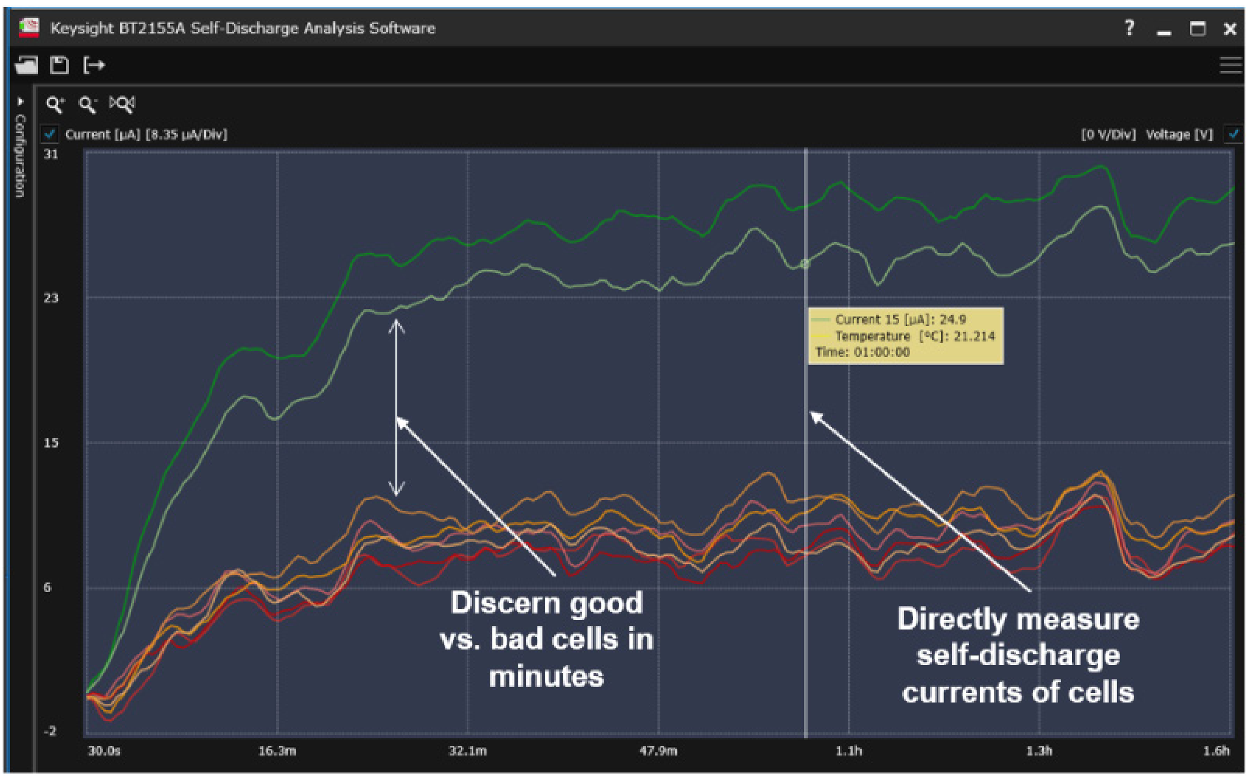


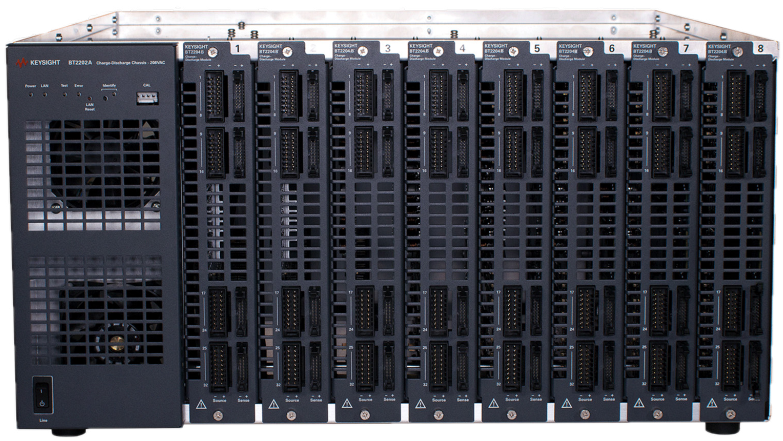
Figure 4. Self-discharge current measurements of multiple Li-ion cells using the Keysight BT2152B

Keysight Cell Manufacturing Solutions

Keysight offers the following solutions to reduce cell manufacturing time and achieve lower cell manufacturing costs:

Keysight BT2200 charge-discharge system

The Keysight BT2200 charge-discharge system is suitable for both cell pre-charge and formation. The BT2202A or BT2203B mainframe and eight BT2204B modules provide 256 6 A channels. Depending on the cell size, you can connect these channels in parallel for higher power and current as required for cell formation. Individual channels are well suited for applying the lower voltage and current typically required for pre-charge, including operation down to or below 0 V.



Keysight BT2152B self-discharge analyzer

The BT2152B self-discharge analyzer measures the self-discharge current of Li-ion cells using a potentiostatic measurement technique that reduces the time required to discern good versus bad cell self-discharge performance. It also dramatically reduces the number of work-in-process cells on the manufacturing floor, saving space and energy.

Quality and Productivity Solutions Key to Meeting EV Battery Demand

Figure 5. Automotive original equipment manufacturers and cell manufacturers use Keysight's battery test solutions to develop cells, modules, and packs for new EV battery models

Producing high-performing EV battery cells at the gigafactory level requires research and development in the laboratory to formulate a tried, tested, and fine-tuned blueprint that meets precise performance specifications. This process requires high-precision and reliable battery test solutions, from formulating cell chemistries with high density and capacity to testing how these cells will work in situ when assembled into battery modules and packs. These batteries also need to undergo stringent tests to ensure that they deliver on performance and safety in the harsh operating environment of a vehicle on the road.

Keysight's expertise in power supply, analysis, and power emulation hardware and software helps automakers and their battery manufacturing partners design, validate, and produce better batteries. Explore our solutions today:

- Characterizing Self-Discharge Current
- Flexible Cell Formation and Lifetime Cycling Solution
- EV Battery Cell Test
- Validate EV Battery Module Design
- High-Power EV Battery Pack Test

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