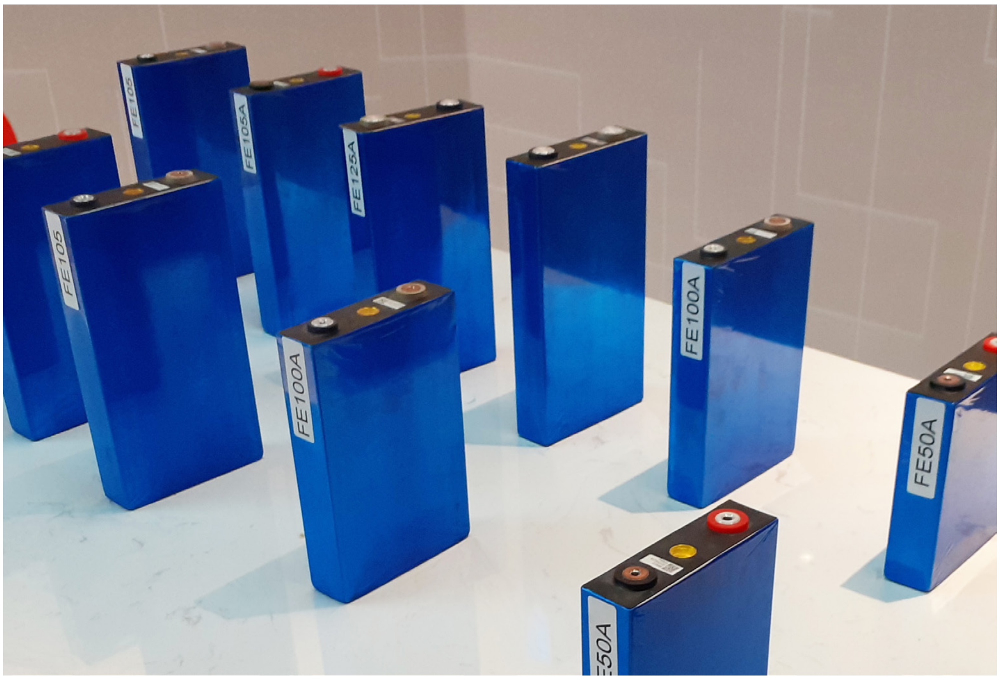
What you should know about manufacturing lithium-ion batteries

Quality | Ensuring high quality levels in the manufacturing of lithium-ion batteries is critical to preventing underperformance and even safety risks. Benjamin Sternkopf, Ian Greory and David Prince of PI Berlin examine the prerequisites for finding the 'sweet spot' between a battery's cost, performance and lifetime



The manufacturing quality of lithium-ion batteries is a key determinant of lifetime performance

The proliferation of rechargeable lithium-ion batteries used in a wide range of applications has moved the technology clearly into the public eye. Debate about various battery types, their properties, cost and performance have become popular topics in private and professional discussions.

However, most of these discussions tend to put an excessive emphasis on the chemistry of the cells in the batteries. For example, whether a lithium iron phosphate battery is safer than a lithium-nickel-manganese-cobalt battery. In truth, battery performance is affected by not just one, but up to five primary factors: cell chemistry, cell geometry, manufacturing quality, matching technology to application, and system integration.

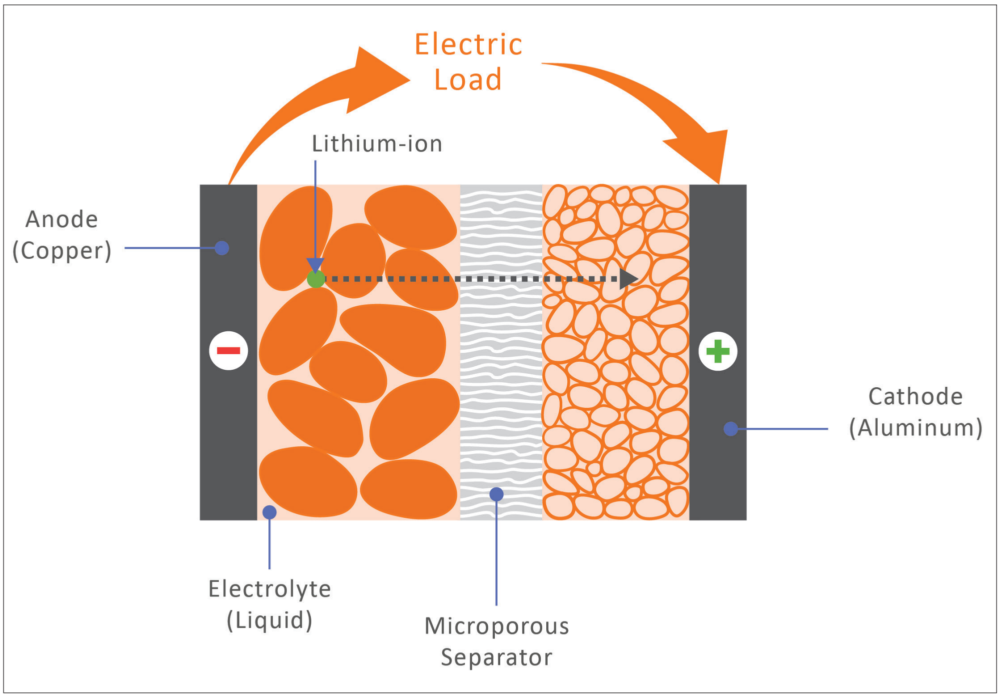
Cell chemistry is considered to be the "tip of the iceberg". It is the most visible characteristic, but the actual performance of battery systems in real-world applications seldom depends to a large degree on the cell chemistry. More often it is one of the other five factors.

Manufacturing quality is one of the most critical factors, but also least discussed. The cause for this is likely that cell chemistry and geometry can easily be discussed based on the multitude of information available in the public domain. Matching of the most suitable battery chemistry to the application is a topic that can be simulated and discussed with modern computing tools. Manufacturing and manufacturing quality, however, is typically an in-house secret of each manufacturer – and often exposes clear differences between manufacturers even when using the same chemistries. There is little incentive for manufacturers to have details about their manufacturing processes published in any form.

What is a "battery energy storage system"?

The term BESS, or battery energy storage system, refers to a system that is more than just a battery. For a battery to function efficiently it needs additional components. A BESS typically includes a power conversion system, otherwise known as an inverter, which includes bi-directional power electronics used to charge and discharge the battery simultaneously. A power control system informs the inverter when to charge and discharge batteries. Additional cooling and fire-fighting systems are installed to prevent and contain any thermal related events. And finally, auxiliary power supplies as well as a storage container are needed to support and house the overall system.

Due to the complexity of a complete BESS, this article focuses on the batteries and their manufacturing only. For real-world projects, it is advised to keep in mind that the battery is only one part of the overall system. The other components and the interactions between them need to be evaluated with the same care to achieve high levels of BESS performance and safety.



Cell manufacturing is a complex process requiring careful quality control

Structure of a battery rack

Before examining how battery cells are manufactured, it is good to understand how a battery rack is organised. Battery cells are similar in design to cell phone or laptop computer batteries, except that they are much larger. Cells are combined into a cell block using either a serial or parallel connection. Cell blocks are assembled into modules with communication ports to measure temperature and voltage. These modules are then connected within a rack, which provides the serial connection for battery modules. The battery rack will also include an upstream control system known as switchgear, which provides current sensors and communication protocols. It is important to note that this arrangement is based on IEC standard terminology and some may use different terminology.

Design of a battery cell

The purpose of a battery is to move electrons from the anode to the cathode while discharging the battery. This is accomplished by having lithium-ions, positively charged particles, moving through a microporous separator that is filled with an electrolyte, which prevents the passage of electrons. This process is sandwiched between a negatively charged copper collector and a positively charged aluminum collector. It is important to have homogenous surfaces to allow the lithium-ions to pass through easily.

Manufacturing of a battery

At first glance, a battery has cells, modules and strings – which makes it similar to a PV panel. However, major differences become obvious when comparing the individual cells. A PV cell operates according to the quantum photovoltaic effect; a battery cell relies on chemical reactions. The operating principle of a battery is more like a chemical process engineering plant, and as a result the manufacturing processes differ significantly.

Unlike PV cells, lithium-ion battery cells need to be monitored individually for voltage, current and temperature for safety and performance reasons. The quality and accuracy of the battery management system plays an equally important role in the performance and safety of the overall battery system. That means all processes related to the manufacturing of the corresponding electronics need to be managed similarly to the production of a PV inverter.

Making a high performance, safe battery system is not rocket science, but it does require extensive diligence. The main challenge is in creating a three-dimensional structure (a round or prismatic cell) out of a largely two-dimensional structure (layers of foil).

As an example, a common 50MWh BESS will have a surface area in the magnitude of 500,000 square meters (i.e. approximately 5,000,000 square feet) of electrode pairs. That's equivalent to the area of 70 soccer fields. If the BESS were coupled to a 50MWp PV power plant, the surface area of the battery cells would be larger than the surface area of the PV panels charging them.

To manufacture these cells, it is critical to create this surface with extreme precision. A common benchmark is that the maximum deviation of surface thickness should not exceed 1% to 2%. If a manufacturer exceeds this, the battery runs a higher risk of becoming a safety hazard and suffering accelerated performance degradation.

The manufacturing of a battery can generally be separated into four major steps:

1. Initial quality control and electrode production
2. Cell stack assembly
3. Drying, electrolyte filling, formatting, ageing, and sorting
4. Assembling cells into a battery

Step 1: Initial quality control and electrode production

As with any manufacturing process, it is crucial to verify that the materials and processes meet product quality requirements, such as:

- Are the raw materials of the required purity?
- Does the residual humidity within the electrolyte meet the set limits?
- Are the critical operations and process checks fully automated or do they depend on the attention and qualification of individual personnel?
- Is the machinery calibrated and cleaned in order to avoid cross-contamination between different production processes?

To manufacture cells, there are two required electrodes: the anode and the cathode. There needs to be an aluminum foil associated with the cathode material, and a copper foil plated with the anode material.

Step one is to produce active materials through mixing. Dry materials are added into the mix for the storage of lithium ions, but also for electrical conductivity. Then a solvent is added to the mix for the application of the active material onto the foils. The goal is to coat the foil with larger particles of the active material and smaller particles for the electrical conductivity. A binder is also added to help the material stick to the foil.

The mixture, also referred to as "slurry", needs to be evenly distributed so that it will lead to good conductivity both electrically for electrons to reach the foil and ionically for the lithium ions to pass through the material itself. This is one of the most critical parts of the cell manufacturing process.

The mixture needs to be homogenous, which can be very tricky because large and small particles don't like to mix together, nor stay that way. An example would be adding large and small stones to a box. When shaking the box, the different stone sizes will have a tendency to separate from one another. In order to achieve a homogenous mixture it is critical that this step be managed carefully.

Once the homogenous active materials are created, they need to be coated onto the substrate foils. Coating foils is a critical step. It's important that the foils be coated in a consistent way and with minimal defects. This process requires creating a continuous, defect-free foil. If one section of the foil is defective, the entire length is discarded. This is a step where a manufacturer can decide to cut corners and allow defective rolls to be used, otherwise they would be throwing away valuable material. The continuous nature of some of these processes makes it very important that they are monitored closely by appropriate sensors and qualified personnel.

Once the foil has been coated it is checked for thickness. If the coated foil meets the specifications, it is processed through a drying machine because the foil itself is wet. There is solvent in the foil, which needs to evaporate to ensure a solid coating on the surface. Running the next batch of foil is critical at this time because as foils are stacked there needs to be coating on both sides.

Calendering is the compression stage for the active materials on the foil. The foil coating will have shrunk slightly during the drying process. Without compression the ions will pass easily but will have difficulty passing electrons due to internal resistance. Furthermore, calendering increases the energy density of the coating. After calendering there is a cutting process for the foils. The result will be stacks of anode and cathode sheets that can now be used for the production of the actual cells.

Step 2: Cell stack assembly

With the cathode and anode sheets separated, the next step is to stack the copper foils and aluminum foils with a separator in between. The separator serves to keep an electrical separation between the active materials, but to allow lithium ions to pass through the electrolyte. When stacked they become battery cell stacks. There are several different methods to create the stacks, such as rolling, stacking or z-folding. The possibilities are constrained by the desired cell geometry.

The completed stacks are inserted into a case and the external terminals are connected. The cell is then sealed shut through vacuum sealing or welding.

Step 3: Drying, electrolyte filling, formatting, ageing and sorting

Residual humidity inside the lithium-ion cells is a critical factor that affects the ageing and degradation characteristics of the cell. To reduce it, the assembled cells are left in a drying oven for hours to days. Longer drying periods improve the durability but increase production cost.

The separator foil between the cathode and the anode is not conductive to the lithium ions. For the cell to function, an electrolyte needs to be introduced into the dried cell. An opening in the case allows humidity to evaporate and provides the manufacturer an access point for adding electrolyte filling. The electrolyte is usually a lithium salt mixed into a solvent. This step is followed by the final sealing of the cell.

Lithium ion cells have one important chemical difference to other cells – they come in a discharged state. To make the cells operational they must first be charged and discharged through a series of cycles. During the first charging something very important happens. The formatting creates a protective layer on one of the electrodes, which is excellent for the lifespan of the battery cell. For this to be effective it must be produced correctly, or the cell will quickly degrade. Similar to the drying process, slow formatting improves the durability of the cell, but increases the production cost.

Ultimately, the cells are inserted into a hot ageing chamber for several days to identify any defective cells. Afterwards, they are graded and sorted into different qualities in accordance with the customer's requirements.

Step 4: Assembling cells into a battery

Cells need to be assembled to make a complete battery. There may be the option of adding a cooling system before the module is sealed. Voltage sensor wires and temperature sensors are added to the module. Other options include installing fuses, fans or sealant depending on the application. The battery is run through a series of tests including high voltage testing, internal resistance testing, load testing and capacity testing.

Adding a cooling system is an option before cells are assembled into a module

Managing manufacturing quality

Battery manufacturing is a complex production process featuring over 170 individual steps between quality control and production. Some of the most critical quality parameters include residual humidity and surface homogeneity. The impact of poor manufacturing can cause the cell to degrade very quickly. Cell capacity can be reduced after only a few cycles, or if cells remain inactive, they will be more prone to self-discharge. If the production process is managed poorly safety hazards can also be produced. For example, poor surface homogeneity can generate small spikes that can punch through the separator and generate a short circuit inside the cell.

Making good quality batteries is complex and needs high levels of control and precision. Quality management in manufacturing is therefore key to delivering a performing and safe battery. Quality management often comes down to practical and financial questions – specifically:

1. Making the "perfect" battery is expensive. The main cost factors are production time and raw material costs. It is possible to make batteries that last 15,000 cycles and 20 years. However, the cost would be prohibitive and, in reality, 3,500 to 4,000 cycles and 10 years are good enough for most applications. The recipe for making such a battery is not about making a "perfect" battery, but about finding the sweet spot between cost, performance and lifetime.
2. Mistakes happen. Just as in any other production facility, quality management depends a lot on the culture and processes in a company. The question is not if errors happen in the factory, but whether the manufacturer has the right processes and skilled personnel in place to identify and rectify them promptly and appropriately.
3. Being a critical customer. Most cell manufacturers provide cells of the same type at different quality levels. By default, it's likely that buyers will be sold the most basic grade that only just pass the quality requirements. To get a consistent, high-quality battery, buyers need know how to specify what they want and are able to check during and after production.

It is not always possible to check the most important qualities of a battery when you have the final product in your hand. So as a buyer, what are the practical options to manage quality and safety?

Value of an energy capacity warranty

A practical measure is to obtain a warranty covering the energy capacity of the BESS or battery system being purchased. The warranty may also be called a battery performance warranty. It is a robust legal tool to secure against improper sizing or accelerated degradation. However, this warranty has some limitations similar to those of any product warranty:

- A warranty is reactive, not proactive. It only becomes active once the energy capacity of the battery system has been proven to be insufficient. It does not address the problem of manufacturing quality at its root cause, nor does it prevent failures or underperformance from occurring in the first place.
- The bankability of a warranty depends on the warrantor. If relying on an energy capacity warranty, the warrantor must still exist at the time a case of warranty is identified.
- A warranty claim always bears additional costs for the buyer or owner. For a BESS, these are typically legal costs and any costs for balance of plant extensions required to fit the additional battery systems that the warrantor provides to remedy the lack of energy capacity. There may also be other costs incurred by the BESS owner during the process of making and establishing a claim for which there will be no reimbursement from the manufacturer.

Therefore, it is good business practice to accompany the energy capacity warranty by the following proactive measures to manage quality.

Type testing

Cells and the battery system can be type tested. This type testing can cover both safety and performance characteristics. Type testing usually provides a good insight about the general quality of a battery system. However, it also has the following limitations:

- Cells for type testing are usually manually selected by the manufacture. This bears the risk of "cherry picking" the best cells for testing.
- As mentioned above, most manufacturers have different grades of the same cell. There is no certainty that the sample cells provided will be manufactured using the same raw materials, production line and grading criteria as will production cells.
- Performance type testing is time consuming. When testing whether the cyclic ageing of a cell is in compliance with the requirements, a test for 4,000 cycles takes approximately one year. That amount of lead time is usually not available in real-world projects and the products being manufactured could well have changed during that time.

Therefore, type testing addresses some of the concerns about proactively managing battery quality, but it needs to be accompanied by other processes.

Manufacturer auditing

Let's assume a battery manufacturer has the right product at the right price, with a sound energy capacity warranty and a battery type that has passed all the performance and safety tests an advisor or engineer has recommended – what quality

Warranties offer some protection against underperformance but do not prevent this happening in the first place

related risks should still be considered and how should they be managed?

The first is to review the factory of the manufacturer in person and in detail. The best time to do this is before closing the supply contract. This review is called manufacturer (factory) auditing and usually covers the following:

- Are the incoming materials used for production checked appropriately?
- Is the battery production process managed and supervised appropriately?
- Does the manufacturer comply with an appropriate level of production care to meet the economical "sweet spot" or does the manufacturer take impermissible shortcuts?
- Are the required and appropriate quality checks carried out after each step to verify the product is suitable for the next steps?
- How are errors and rejected materials handled? Are the conclusions fed back into the production process?
- How is the final product checked, tested and graded?
- Does the manufacturer respect the compliance requirements of the customer? Does the manufacturer comply with the applicable environmental and occupational hazard requirements?

The manufacturer audit provides insights on these questions and gives a much higher degree of confidence that not only is the battery design sound, but that the manufacturing process to build it is also of a high, consistent quality.

Production witnessing

Ultimately, once the supply contract is signed and the battery for a project is in production, it is imperative to verify that the manufacturer maintains a high level of quality during the actual build of batteries that will be installed – especially if corrective action was undertaken to address weaknesses after the manufacturer audit was conducted. This method of 'live' quality assurance is called production witnessing and typically consists of a third party supervising all the key process, testing and inspection steps in making the finished batteries. After production witnessing has given the green light, the battery is ready for integration and shipping to site – to hopefully enjoy a long reliable, safe life delivering dependable, electric power. ■

Authors

Benjamin Sternkopf has the degree of Dipl.-Ing. (German equivalent to MSc) in electrical power engineering from RWTH Aachen University, Germany. He has worked exclusively in energy storage with a strong focus on battery energy storage systems since 2011. His track record includes milestone projects such as the first commercial large-scale BESS in Europe (WEMAG Schwerin, 10 MW / 10 MWh, 2012), the first multi-purpose BESS in the UK (Leighton Buzzard, 6 MW / 10 MWh, 2014) and the first large-scale BESS in Mexico (Aura Solar, 10 MW / 5 MWh, 2018).

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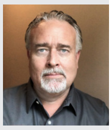

An accomplished digital content producer and marketing professional, David Prince has long been interested in contributing to environmental sustainability. He has an extensive background in cable television, information storage and higher education. As a content producer, he has served small enterprises to large corporations. David holds degrees from the University of Rhode Island and Fairfield University.