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# 4 Targets for Optimization in a Battery Cell

## Supported by Covalent Analytical Solutions

Technological breakthroughs have made modern battery cells more efficient, stable, and long-lasting. Better batteries in turn power rapid advancements in other industries, meaning continued innovation in energy storage technologies will be paramount to meeting global climate and sustainability goals. As researchers and engineers seek to further enhance cells' storage capacity, lifetime, and performance, there are 4 commonly identified targets for future optimization. This eBrief summarizes those targets and describes analytical solutions that can supply the data and insight to support advancements in these areas.

## 1. Raw Materials: Structures and Physical Properties

Raw materials can be differentiators for battery cell performance; but are you certain your batteries contain the materials you expect? A variety of chemical, mechanical, and morphological analyses will help you to select, validate, and optimize prime raw materials by investigating their structures and key properties.

- **Particle Size and Morphology**

  The morphology, size, and size distribution of powdered or particulate raw materials have a major influence on their flowability and dispersibility, and furthermore affect the final properties of slurries (including viscosity and sedimentation stability). **PSA** and **DLS** give statistical insight into particle samples, and **electron microscopy** yields nanoscale resolution images that can help you visualize closed porosity, particle coating, and defects that may diminish performance in the final electrode and, consequently, the full battery pack.

- **Microstructural and Mechanical Features of Electrode Particles**

  Careful mapping of the elastic modulus and hardness, together with robust statistical analysis, gives reliable insights into the microstructural and mechanical features of electrode particles. **Mechanical testing** and **nanomechanical analysis** can be correlated to the cell life cycle for a more detailed understanding of the battery's longevity.

- **Crystallographic Properties of the Electrode Materials**

  Graphite is the most-used anode material, owing to its high energy density and low cost. Unfortunately, the long diffusion distance of Lithium ions in graphite crystals results in high diffusion resistance. Graphite suppliers can now impose a variety of modifications to improve electrochemical performance; **XRD** or **Raman spectroscopy** enable you to investigate these modifications.

- **Electrode Powder and Solvent Interactions**

  The wetting behavior between the electrode powder and solvent can be easily analyzed by measuring the contact angle between the particle and solvent, or the slurry and current collector. This can be vital to predicting the interaction of the electrode powder and its solvent at several key battery manufacturing steps.

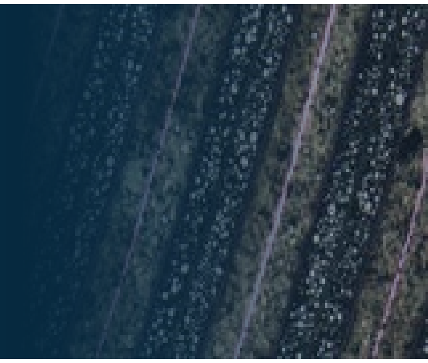
- **Slurry Processing Parameters**

  **Zeta Potential Analysis** via electrophoretic light scattering (**ELS**) can help you optimize processing parameters such as pH and powder concentration, allowing you to better control slurry stability, particle aggregation, and sedimentation behavior (which can be very important to coating and drying processes, as well as slurry storage).

  In addition, **Rheometry** can analyze rheological battery slurry properties (including: sedimentation stability, viscosity vs share rates, and time-dependent viscosity) to provide further guidance on electrode manufacturing optimization.

## 2. Electrodes: Morphology and Defects

Variations in chemical synthesis of electrodes can produce diminished yield of viable particles, inconsistent processibility, and variable solubility in the electrolyte solvent: all of which detract from the cell's electrochemical reactivity. By analyzing the morphology, defects, and performance parameters of the electrode, you can better optimize your synthesis procedure for consistency, yield, and quality.



- **Homogeneity of the Electrode Coating**

  An ideal electrode coating should be continuous and homogeneous without cracks or defects. Using digital **optical microscopy**, you can gauge the estimated uniformity of the dried and calendared electrode. Furthermore, while electrode and interphase materials were historically too sensitive to beam irradiation for **electron microscopy**, both **S/TEM and FIB-SEM** are becoming some of the best and most widely used techniques for studying electrodes. In particular, ***in-situ* S/TEM** is now particularly well-suited for analysis of rechargable battery electrodes and electrolyte materials.

- **Tortuosity Factor of Porous Electrodes**

  The tortuosity factor is a highly important parameter which correlates the electrode microstructures with overall cell performance. To measure tortuosity, **SEM and TEM** (or alternative **high resolution 3D imaging**) techniques can yield spatial resolutions as low as 0.1 nm.

- **Electrode Topography and Solute Distribution**

  Adjusting the electrode topography and its distribution of dissolved components (e.g. active materials, additives, and binders) has been proven effective to extend cell life cycle. Atomic Force Microscopy (**AFM**) can give not only surface properties, but also localized analysis of electrochemical processes at a nanoscale.

- **Electrode Porosity**

  Electrodes are calendered in order to improve cells' total available active surface area; however, if your calendering process yields too low a porosity in the electrode, both the cell's energy density and overall performance will be compromised. Pore analysis via **porometry**, **porosimetry**, and **pycnometry** can provide straightforward, non-destructive measurement of pores and total surface area, allowing you to tune the cell's impedance, capacity, and charge/discharge behavior.

- **Evolution of Mechanical Properties During Cycling**

  Over many rounds of cycling, the porosity and irreversible thickness changes in the electrode correlate to the evolution of key mechanical properties of the material (in particular, the mechanical properties of the binders). **Dynamic Mechanical Analysis (DMA)** and **Nanoindentation** can precisely identify and measure these properties in the electrodes and separator. In addition, peel and scratch **Nanomechanical Tests** can qualitatively measure the coating's adhesion strength.

## 3. Electrolyte Performance

The rate of redox reactions in the electrolyte governs how quickly energy can flow in the cell. Characterization of the electrolyte's electrochemical and rheological properties is fundamental to optimizing cell performance. Furthermore, chemical analysis of the electrolyte can identify and quantify degradation by-products, allowing experts to reduce reactions responsible for battery aging.

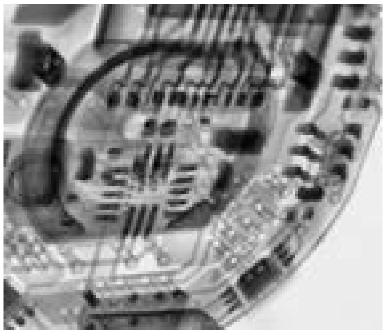
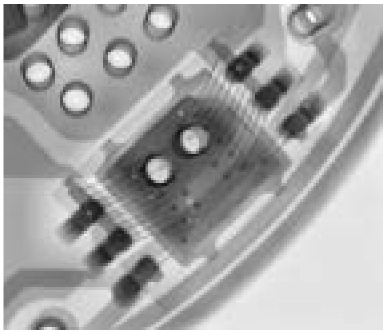
- **Electrolyte Extraction & Deformulation**

  Proper electrolyte extraction and comprehensive chemical analysis allow for precise electrolyte deformulation. Various additives used to enhance electrochemical and thermal stability, or to promote low viscosity, can be easily identified using spectroscopy methods such as **NMR**, **GCMS**, and **ICPMS**.

- **Electrolyte Rheology**

  The viscosity of the electrolyte has an outsized influence on key transport properties, such as electrical conductivity and ion diffusivity. Temperature-dependent viscosity measurements via **Rheometry**/**Rheology** are therefore used for quality control and to predict electrolyte performance.



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- **Electrolyte Conductivity**

  Ideal electrolytes should be good ionic conductors, electronic insulators, and must be thermally stable. Electrochemical Impedance Spectroscopy (EIS) gives electroconductivity measurements spanning a wide temperature range, correlating electrical performance with thermal stability to assess performance of novel or modified electrolyte compositions.

## 4. Longevity of the Battery Cell & Battery Pack

The constant flux of chemical and electrical transformations within a cell leads the materials inside to degrade over the course of many use cycles. Robust analysis of the physical and electrical characteristics of reactive surfaces in the cell can illuminate degradation patterns so you can strategize ways to extend the battery lifetime.

- **Cell and Battery Pack Teardown**

  Expert teardown of the battery pack and cell, followed by robust component characterization, yields holistic insight into the failure mechanisms and vulnerabilities affecting performance and battery life. This includes the identification of battery degradation mechanisms upon cycling, or under accelerated charging conditions.

- **Defect Analysis**

  Undesirable flaws in the battery cell (including foreign object debris, non-uniformities or structural anomalies in the components, or other manufacturing defects) can lead to increased self-discharge, internal shorts, and poor cell performance. X-ray radiography techniques allow analysts to non-destructively image internal components and contacts. Using Micro-CT, experts can take this analysis a step further to provide full 3D reconstructions of battery cells.

- **Full-suite Battery Failure Analysis**

  Costly research and production delays can result when you encounter unexpected failures in your battery cells. Covalent's expert failure analysts have over 100 years of combined analytical experience and can accelerate your troubleshooting with efficient characterization and actionable results. In addition to a full report, they'll lend insight on how to extend battery life and mitigate future cell failures or performance deficits.

# Battery Analysis at Covalent Methodology

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