NOVONIX

BATTERY TESTING SERVICES

NOVONIX EQUIPMENT FOR HIGH PRECISION COULOMETRY & ELECTROLYTE ANALYSIS

Dr. Chris Burns

March 13, 2019

NattBatt 2019

OUTLINE

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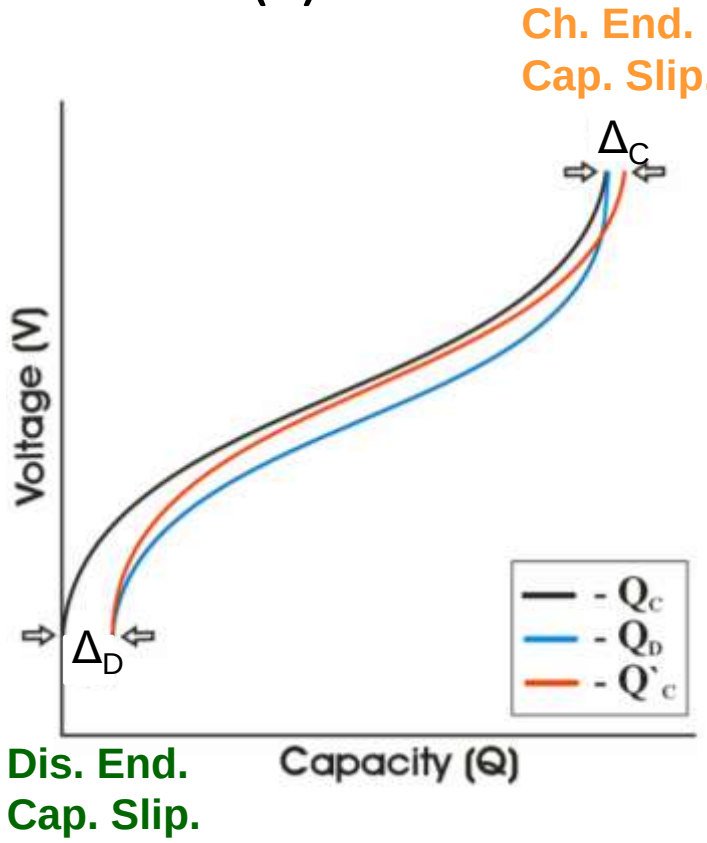
- Introduction to Novonix
- High Precision Coulometry
  - Importance of HPC
  - HPC performance and results
- Electrolyte Analysis
  - Non-destructive technique using differential thermal analysis (DTA)
  - Measuring amount of electrolyte remaining in cell
- Conclusions

INTRODUCTION TO NOVONIX

- Founded in 2013 spun out of Dr. Jeff Dahn's lab at Dalhousie University
- Growing team working on cell testing equipment, materials development and cell design projects
- Flagship High Precision Charger Systems
- New lines of charger and advanced testing equipment solutions
- Systems installed with Tier 1 customers in over 12 countries with distributors in 6 countries
- In-house prototype cell building pilot line, consulting and testing services

WHAT IS HIGH PRECISION COULOMETRY

- Degradation reactions involve transferring charge at or between the electrode(s) and should be quantifies coulometrically



What does HPC measure?

- Capacities ($Q_{C/D}$)
- Coulombic Efficiency ($CE = Q_D/Q_C = 1 - \Delta_D/Q_C$)
- Discharge slippage (Δ_D)
- Charge slippage (Δ_C)
- Capacity loss (Fade = $\Delta_D - \Delta_C$ [positive value is capacity loss])

WHAT IS HIGH PRECISION COULOMETRY

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If the proposed reactions transfer charge they cause the coulombic efficiency to deviate from 1.0000

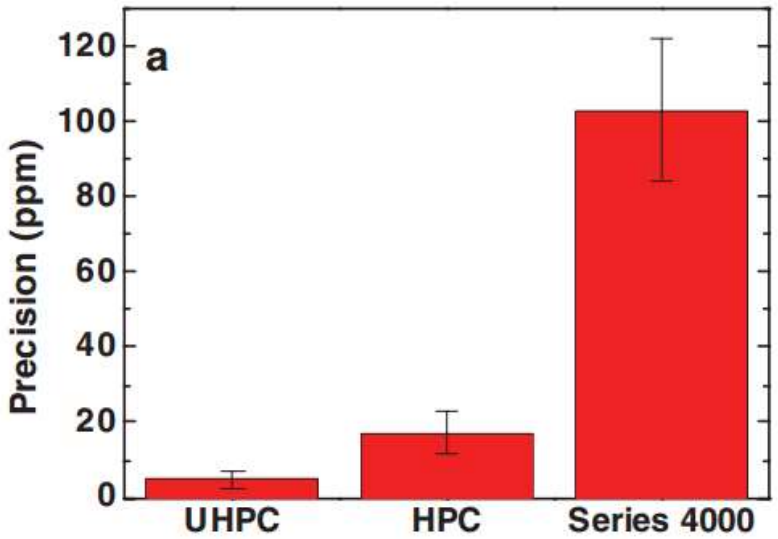
If CE = 1.00000….., the cell should last forever!

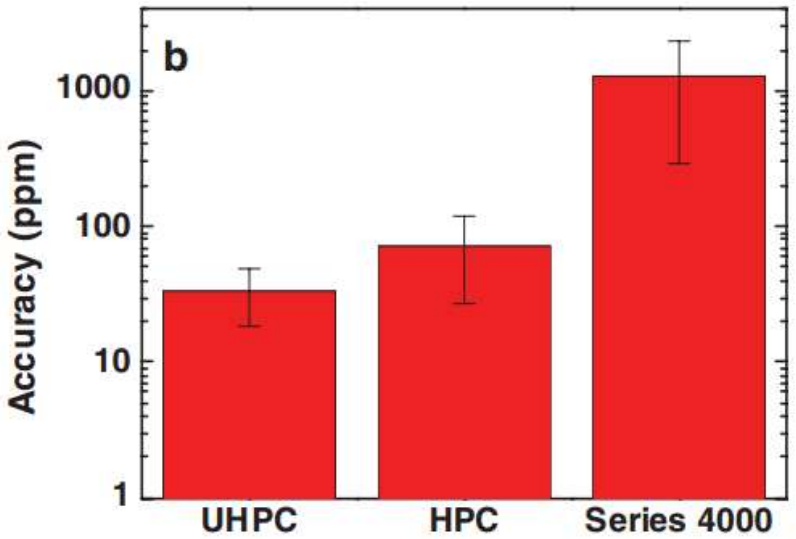
Need to measure CE with accuracy better than 100 ppm (noise better than 10 ppm)

Errors in CE can come from current inaccuracy, voltage sense inaccuracy, variations in cell temperature and timing resolution of measurements

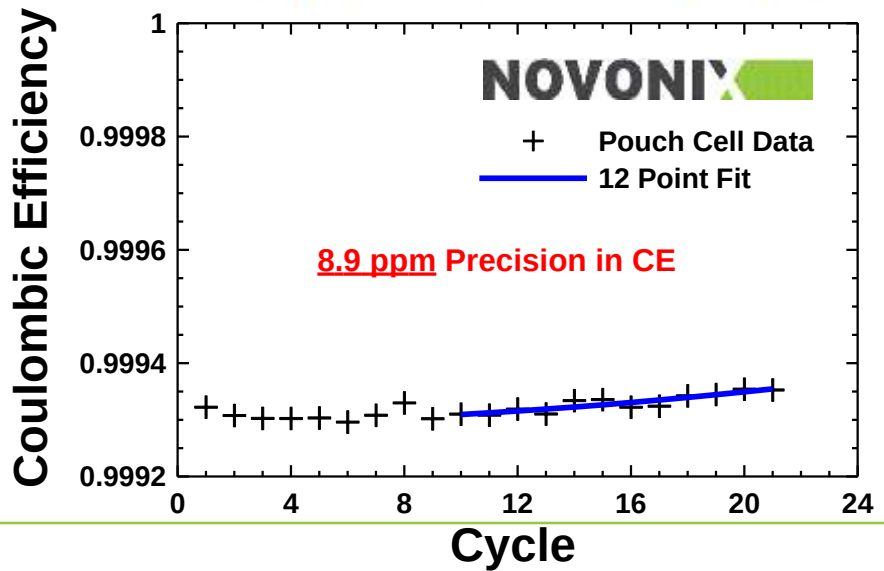
Need High Precision Charger systems that are able to minimize these sources of error

RESULTING ACCURACY & PRECISION





Dahn's UHPC is equivalent to Novonix's High Precision Charger systems

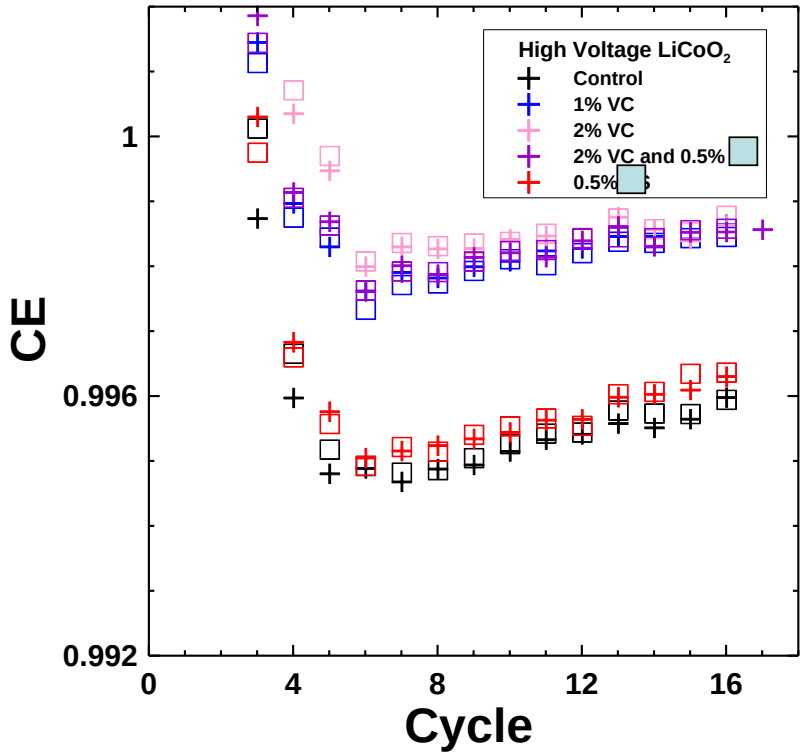


Bond *et al.* shows precision of between 4.8 – 10 ppm on LCO/LTO cells.

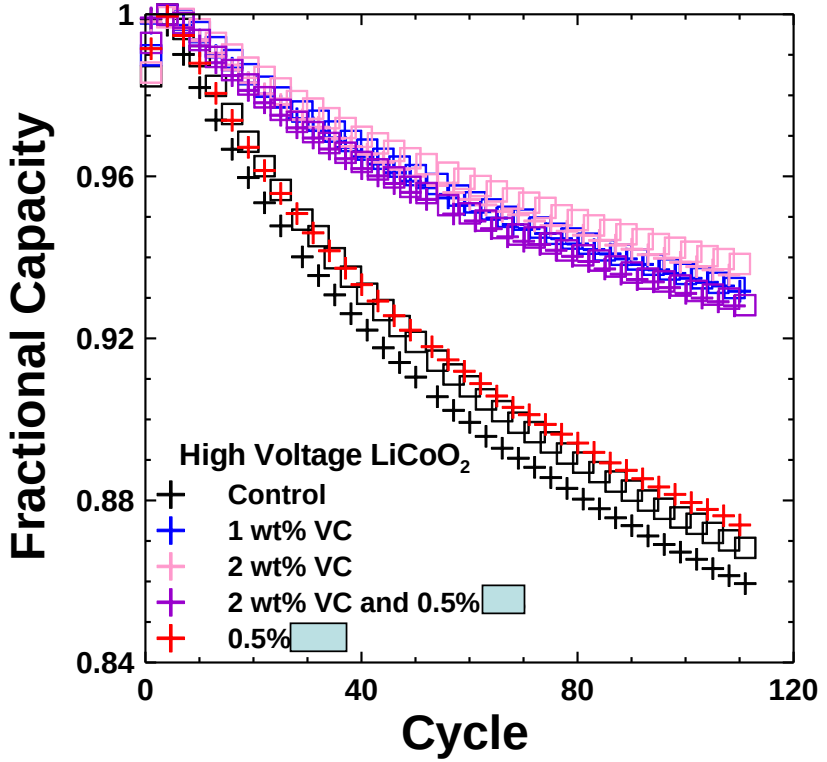
Novonix HPC has been measured in the same range on NMC/graphite cells.

J. Electrochem. Soc., 160, A521-A527 (2013).

SHORT TERM HPC VS. LONG TERM CYCLING

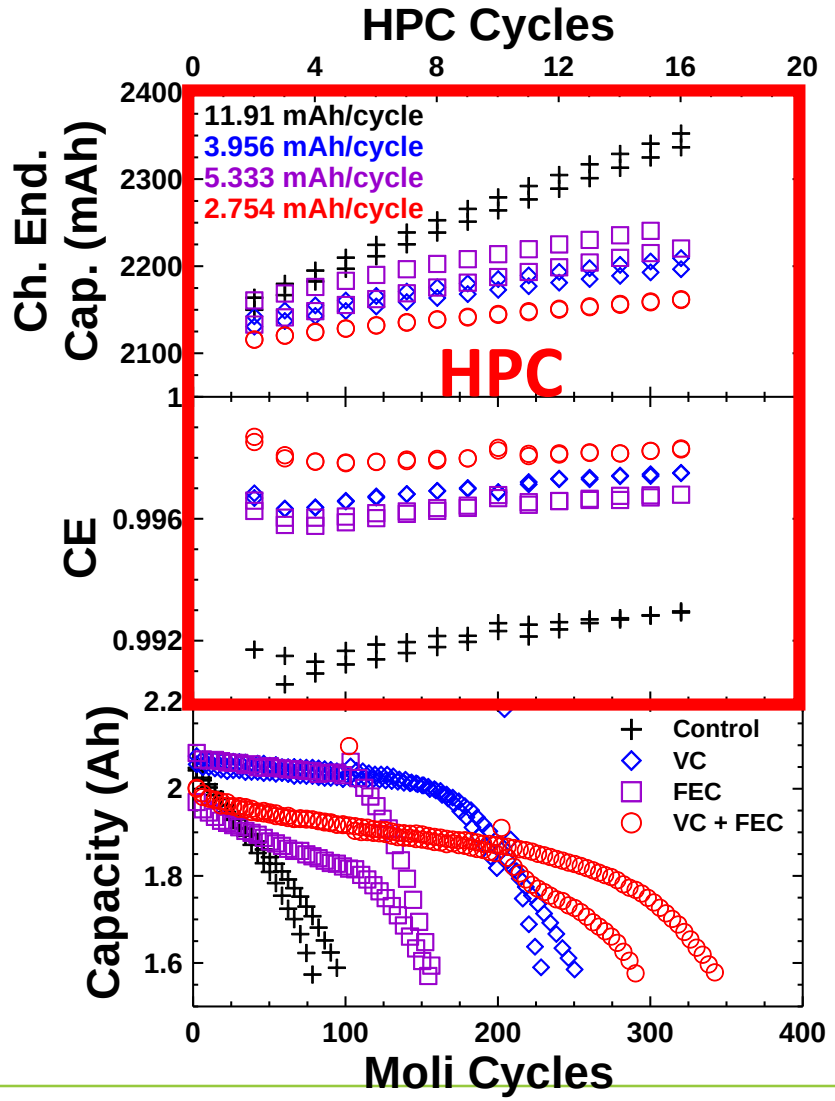


Short term CE measurements on $LiCoO_2$/graphite prismatic cells at 40°C C/20 using the HPC.



Long term cycling measurements of capacity on the same cells at 55°C C/10 on Maccor 2000.

SHORT TERM HPC VS. LONG TERM CYCLING



- HPC at C/20 and 30°C to measure CE and Slippage (2.8 – 4.2 V)
- Cells returned for long term cycling at 1C (CC-CV charge) at 23°C
- Cells "fail" (defined at 80% of nominal 2Ah) in the order expected from HPC measurements

J. Electrochem. Soc., 160, A1451-A1456 (2013).

ELECTROLYTE CHANGES DURING CYCLING

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- SEI growth, electrolyte oxidation and other side reactions lead to degradation of the electrolyte.

- Post mortem analysis can show these changes in electrolyte solvent ratios and salt content.

- How can electrolyte analysis be done in-situ without disassembling the cell and ending the tests?

DIFFERENTIAL THERMAL ANALYSIS

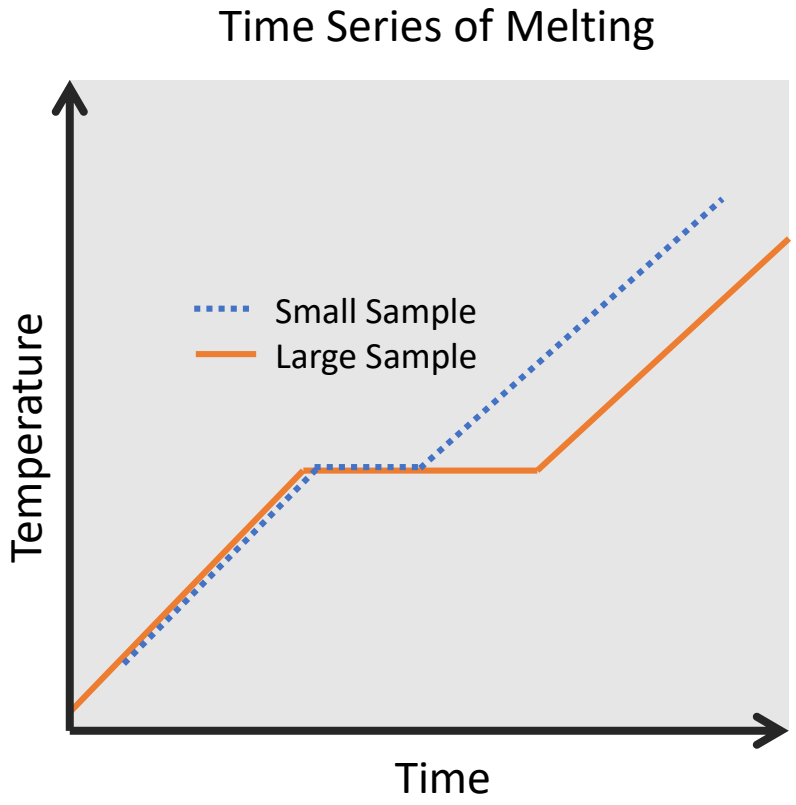
Li-ion cells degrade due to reactions, which can cause sudden cell failure after seemingly stable performance

Need to quantify these reactions in a non-destructive manner to understand battery failure

Example: elementary thermodynamics

- Size of temperature plateau during phase transition is proportional to mount of substance melted

Use Differential Thermal Analysis (DTA) system to monitor how liquid electrolyte evolves during the lifetime of a battery



DIFFERENTIAL THERMAL ANALYSIS

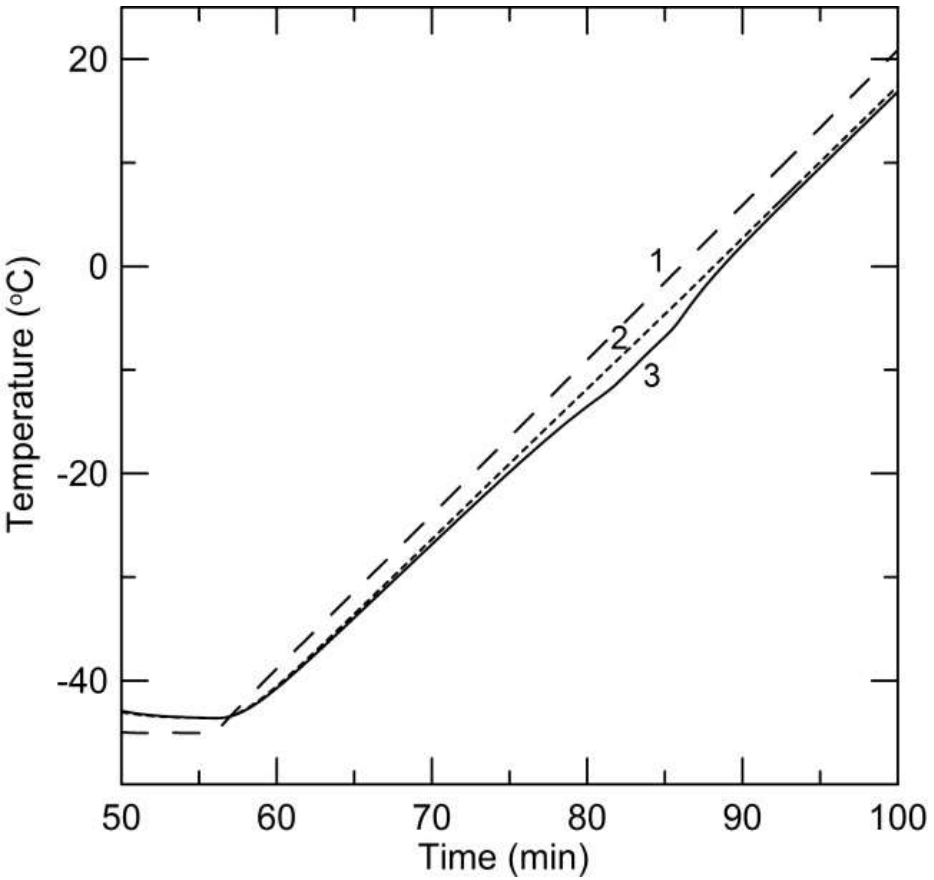
Analyze amount, content, and composition of liquid electrolyte

Learn about salt consumption and solvent reactions

Accommodates cylindrical cells and small-format pouch cells

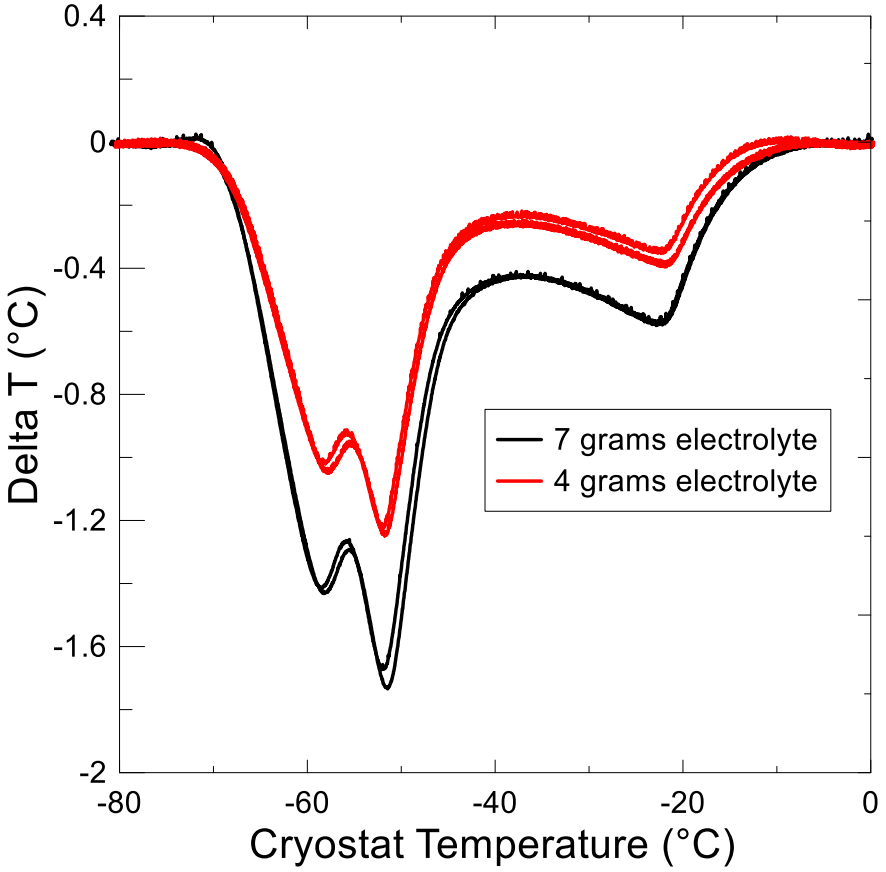
Temperature range: -150°C to +50°C

DIFFERENTIAL THERMAL ANALYSIS



Thermal signature obtained for two cells containing 4 g of electrolyte and two cells containing 7 g of electrolyte

Can detect volume or composition changes over cycling without disassembling the cell!



CONCLUSIONS

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- Novonix's High Precision Charger systems allow industry leading accuracy in cell testing leading to faster analysis of cell performance.
  - Screen new materials/chemistries
  - Evaluate different supplier cells under application conditions

- Novonix continues to innovate new products for advanced diagnostics of lithium-ion cells.

- With in-house cell making capability and state of the art test equipment, Novonix can help customers work through a variety of material, cell design and testing challenges.