# Electrochemical Analytic Diagnosis (eCAD)

## — A Battery Technology for Cell Qualification, Performance Qualification and Design Qualification

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# Address the Gap in the Battery Technology

- **Needs for system-based, integrated failure analysis (FA) + failure mode and effect analysis (FMEA) + diagnostic & prognostic tools**



Serious knowledge gap to address SAFETY

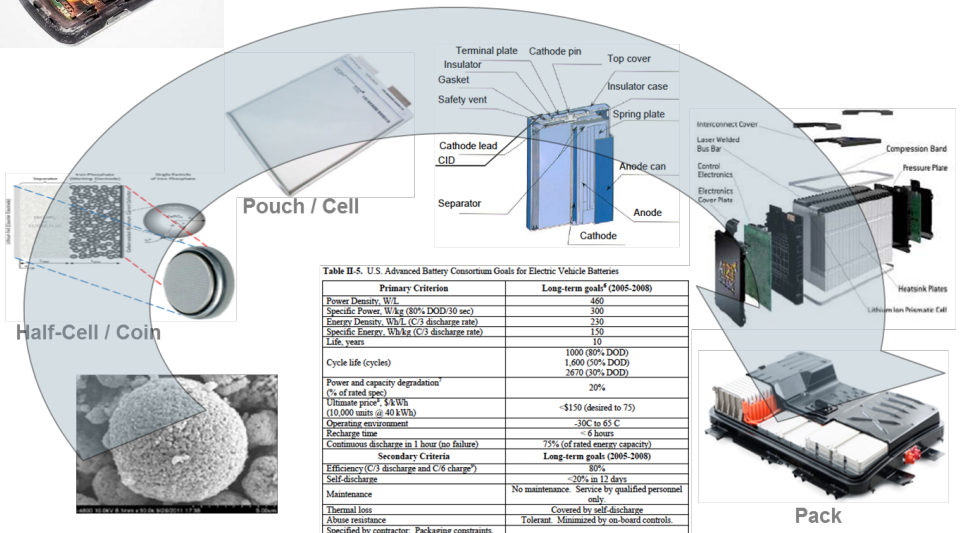
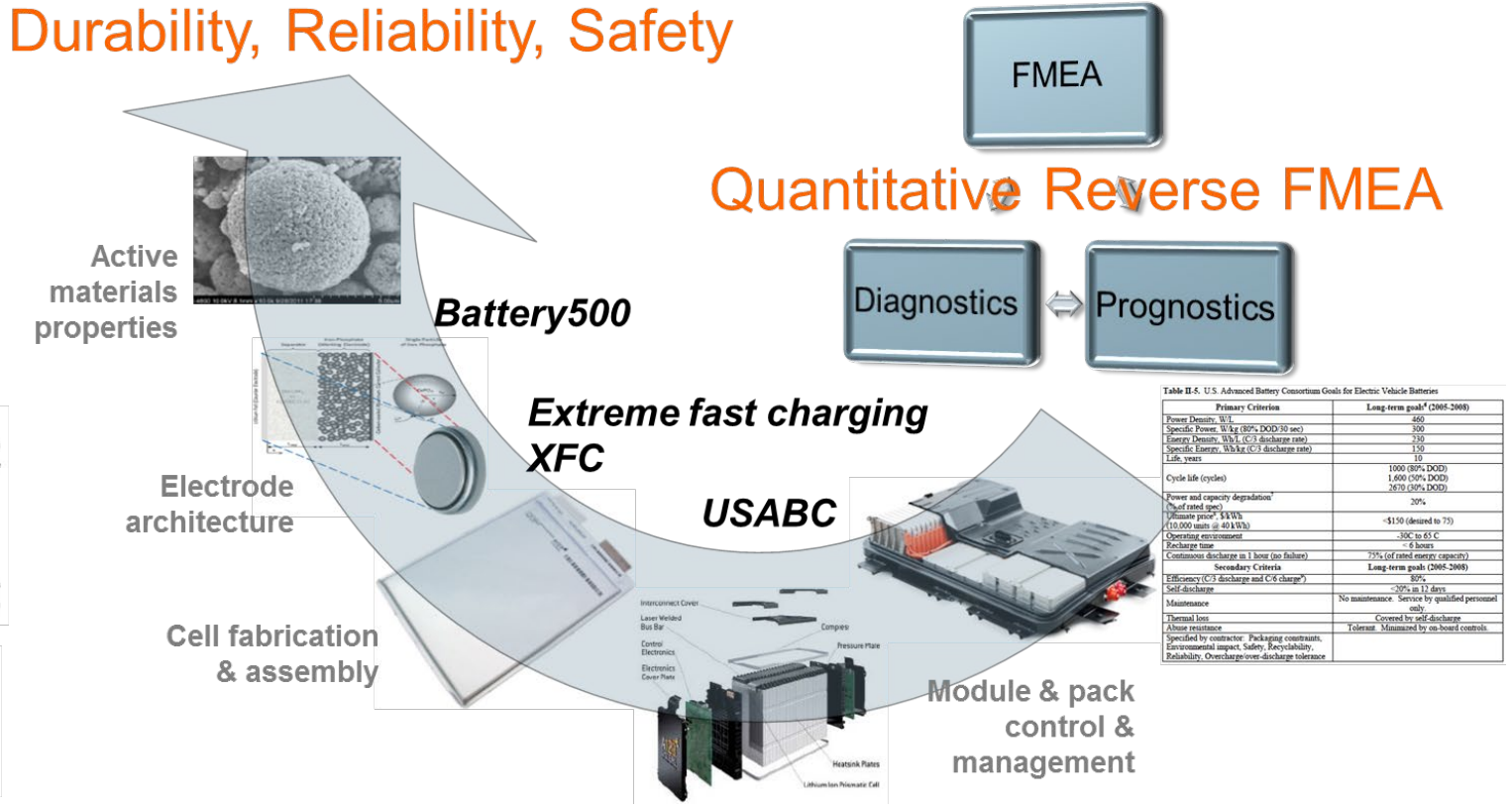



**Table II-5.** U.S. Advanced Battery Consortium Goals for Electric Vehicle Batteries

| Primary Criterion | Long-term goals[a] (2005-2008) |
|---|---|
| Power Density, W/L | 460 |
| Specific Power, W/kg (80% DOD/30 sec) | 300 |
| Energy Density, Wh/L (C/3 discharge rate) | 230 |
| Specific Energy, Wh/kg (C/3 discharge rate) | 150 |
| Life, years | 10 |
| Cycle life (cycles) | 1000 (80% DOD)<br>1,600 (50% DOD)<br>2670 (30% DOD) |
| Power and capacity degradation[f] (% of rated spec) | 20% |
| Ultimate price[g], $/kWh (10,000 units @ 40 kWh) | <$150 (desired to 75) |
| Operating environment | -30C to 65 C |
| Recharge time | ~ 6 hours |
| Continuous discharge in 1 hour (no failure) | 75% (of rated energy capacity) |
| **Secondary Criteria** | **Long-term goals (2005-2008)** |
| Efficiency (C/3 discharge and C/6 charge[e]) | 80% |
| Self-discharge | ~20% in 12 days |
| Maintenance | No maintenance. Service by qualified personnel only. |
| Thermal loss | Covered by self-discharge |
| Abuse resistance | Tolerant. Minimized by on-board controls. |
| Specified by contractor: Packaging constraints, Environmental impact, Safety, Recyclability, Reliability, Overcharge/over-discharge tolerance | |

Sources: various literature documents

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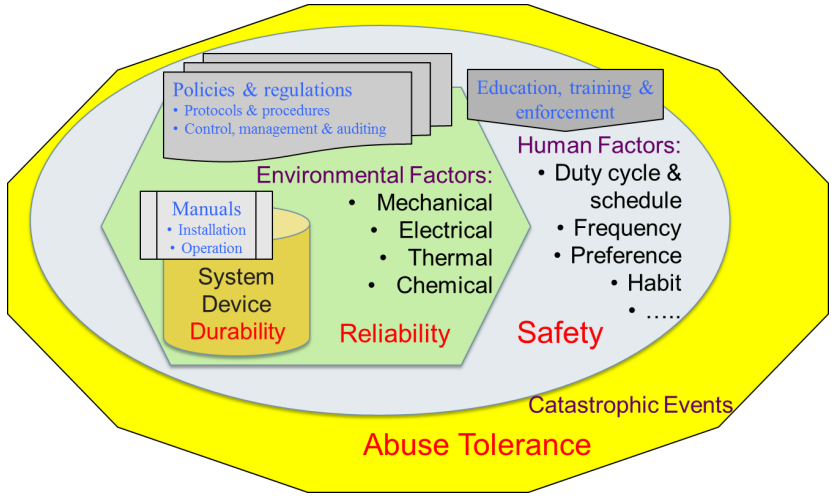
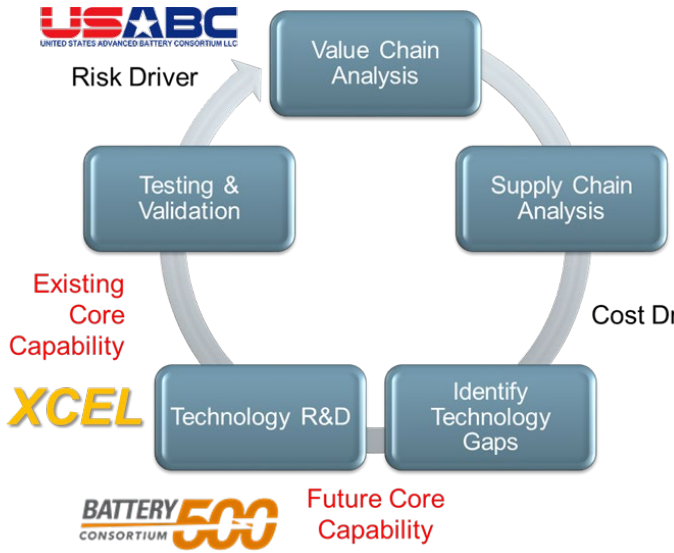
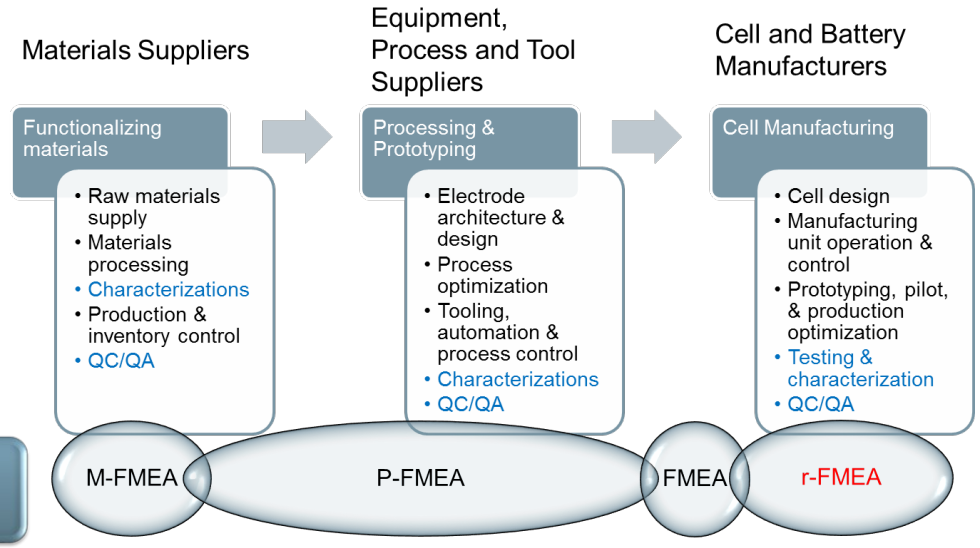
# Solution: Cross-Platform Analyses

- **Materials (coin cells) — Electrodes (pouch cells) — Cell (performance evaluations) — Modules & packs (control and functionality)**
- **None-empirical, principle-based correlations**
- **Supply chain and value chain integration**

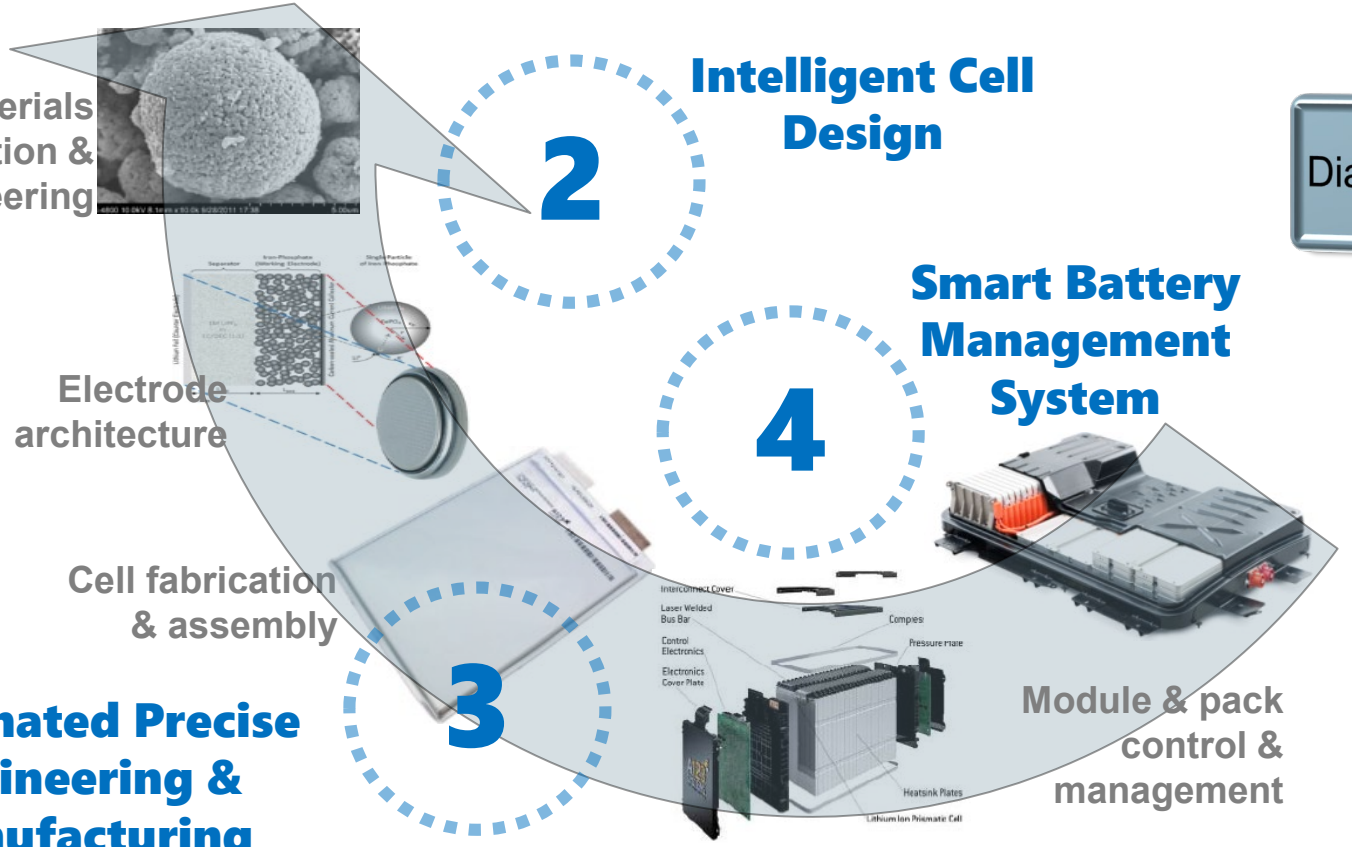


# Intelligent Materials-to-System Integration for Advanced Battery Technology

Durability, Reliability, Safety



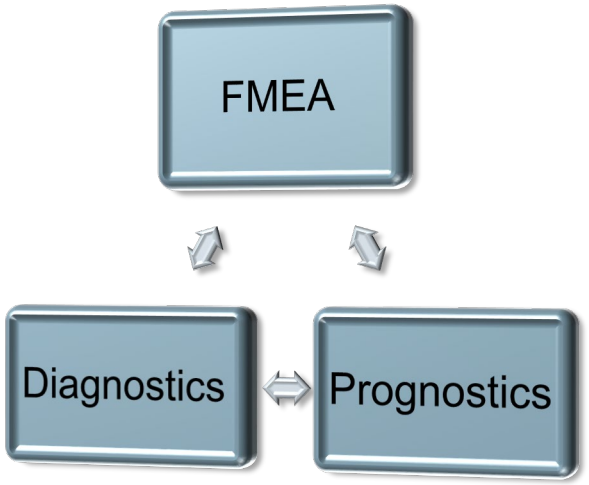




**Table II-5.** U.S. Advanced Battery Consortium Goals for Electric Vehicle Batteries

| Primary Criterion | Long-term goals[6] (2005-2008) |
|---|---|
| Power Density, W/L | 460 |
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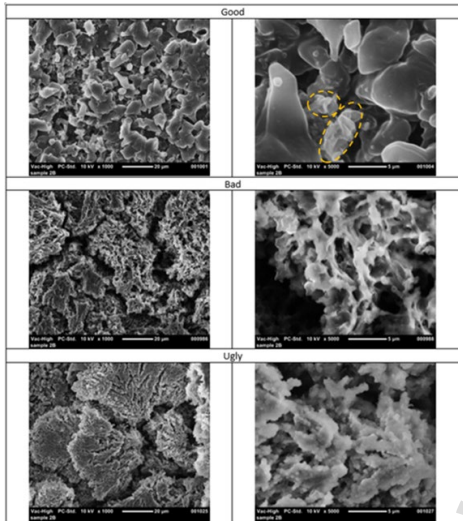
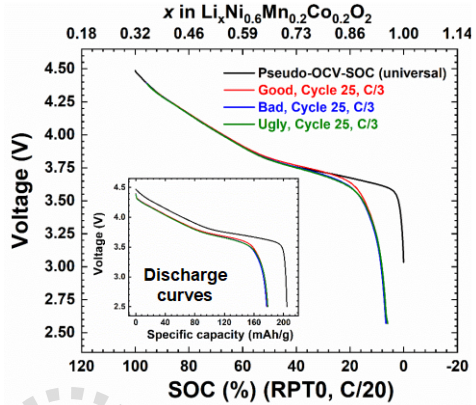
| Energy Density, Wh/L (C/3 discharge rate) | 230 |
| Specific Energy, Wh/kg (C/3 discharge rate) | 150 |
| Life, years | 10 |
| Cycle life (cycles) | 1000 (80% DOD)<br>1,600 (50% DOD)<br>2670 (30% DOD) |
| Power and capacity degradation[7] (% of rated spec) | 20% |
| Ultimate price[8], $/kWh (10,000 units @ 40 kWh) | <$150 (desired to 75) |
| Operating environment | -30C to 65 C |
| Recharge time | < 6 hours |
| Continuous discharge in 1 hour (no failure) | 75% (of rated energy capacity) |
| **Secondary Criteria** | **Long-term goals (2005-2008)** |
| Efficiency (C/3 discharge and C/6 charge[9]) | 80% |
| Self-discharge | <20% in 12 days |
| Maintenance | No maintenance. Service by qualified personnel only. |
| Thermal loss | Covered by self-discharge |
| Abuse resistance | Tolerant. Minimized by on-board controls. |
| Specified by contractor: Packaging constraints, Environmental impact, Safety, Recyclability, Reliability, Overcharge/over-discharge tolerance | |

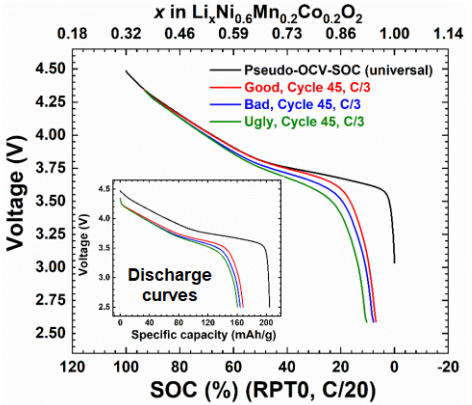
# Novel Electrochemical Analytic Diagnosis (eCAD)

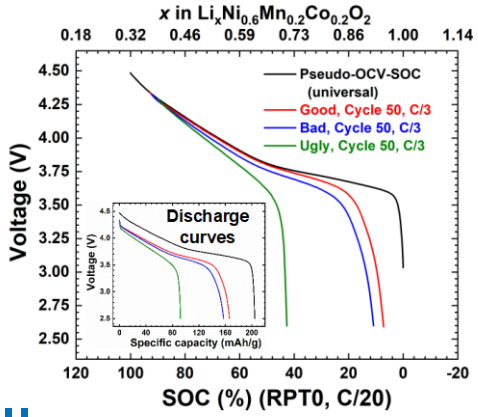
Failure analysis (FA) and Failure mode and effect analysis (FMEA)

1



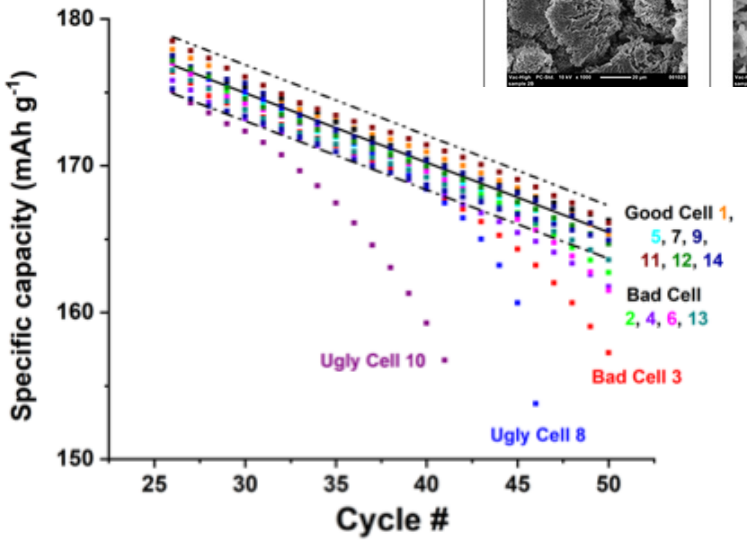



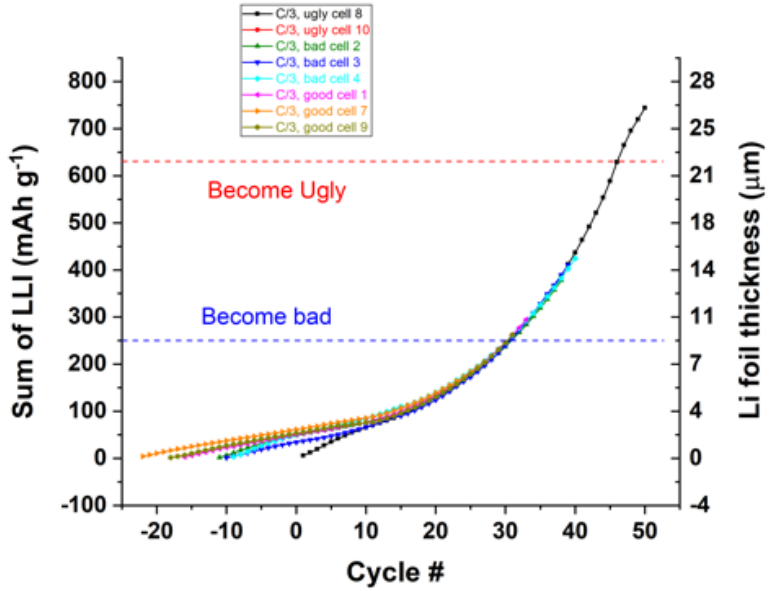

2

Predictive models for cell performance, battery life, and early fault detection



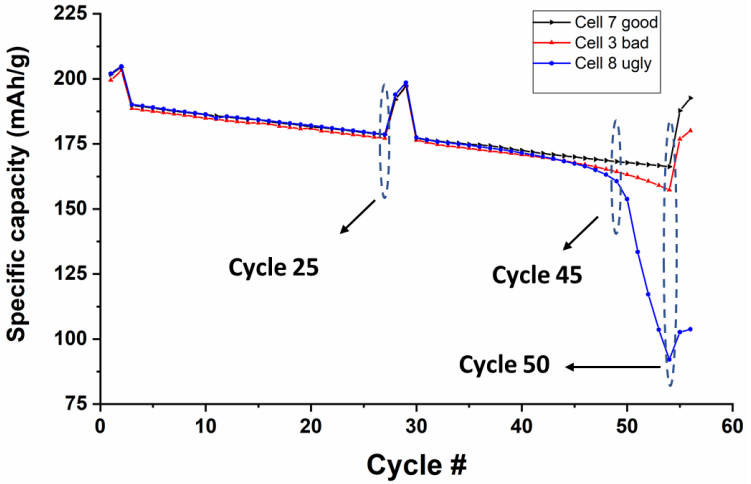

3

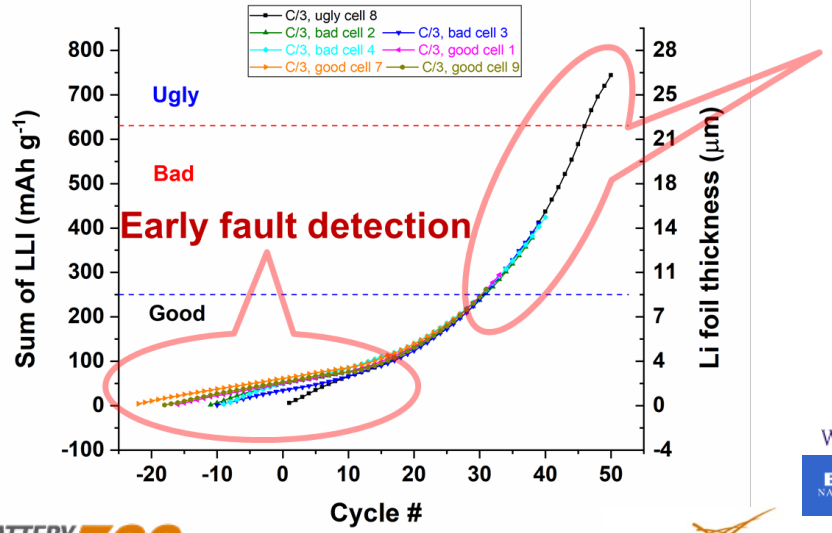
Battery & cell, performance, and design qualification (QC/QA)



# Failure Diagnostics to Identify Cell Design & Performance Gaps

- **Quantify capacity fade attributes between Li and NMC electrodes, cell-to-cell, cycle-by-cycle, in a complete life cycle analysis to help identify gaps in materials, electrodes, and cell level for specific energy and cycle life improvements.**
- **Integrate three keystone efforts into a consistent platform for cell qualification and performance quantification**




## Life prediction

**Remaining Useful Life for each cell:**

**Bad cell 2**: 8 cycles
**Bad cell 3**: 7 cycles
**Bad cell 4**: 6 cycles
**Good cell 1**: 13 cycles
**Good cell 7**: 19 cycles
**Good cell 9**: 15 cycles

Zhang Y. et al. *J. Electrochem. Soc.* (under review); *Several manuscripts* (in prep).