A Viable Pathway from Durability to Reliability and Safety

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Meeting the Challenge: 2017 ESS Safety Forum

Santa Fe, NM

www.inl.gov

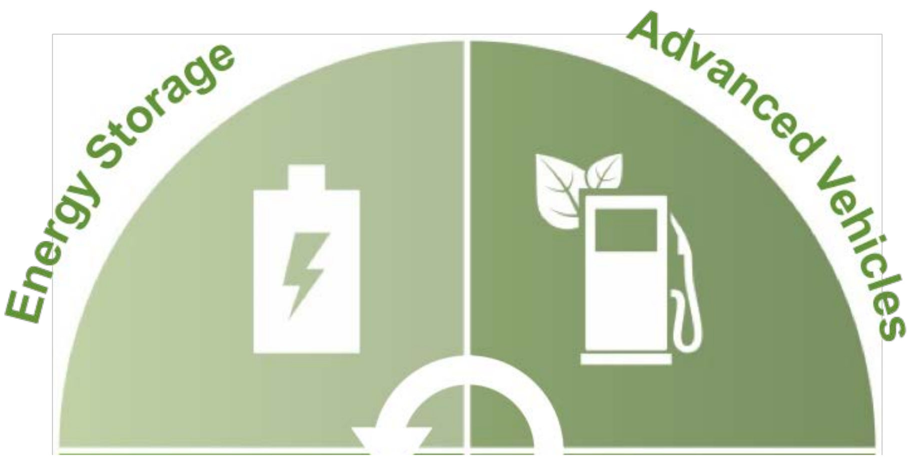
Idaho National Laboratory

Vehicles, Energy Storage & Infrastructure

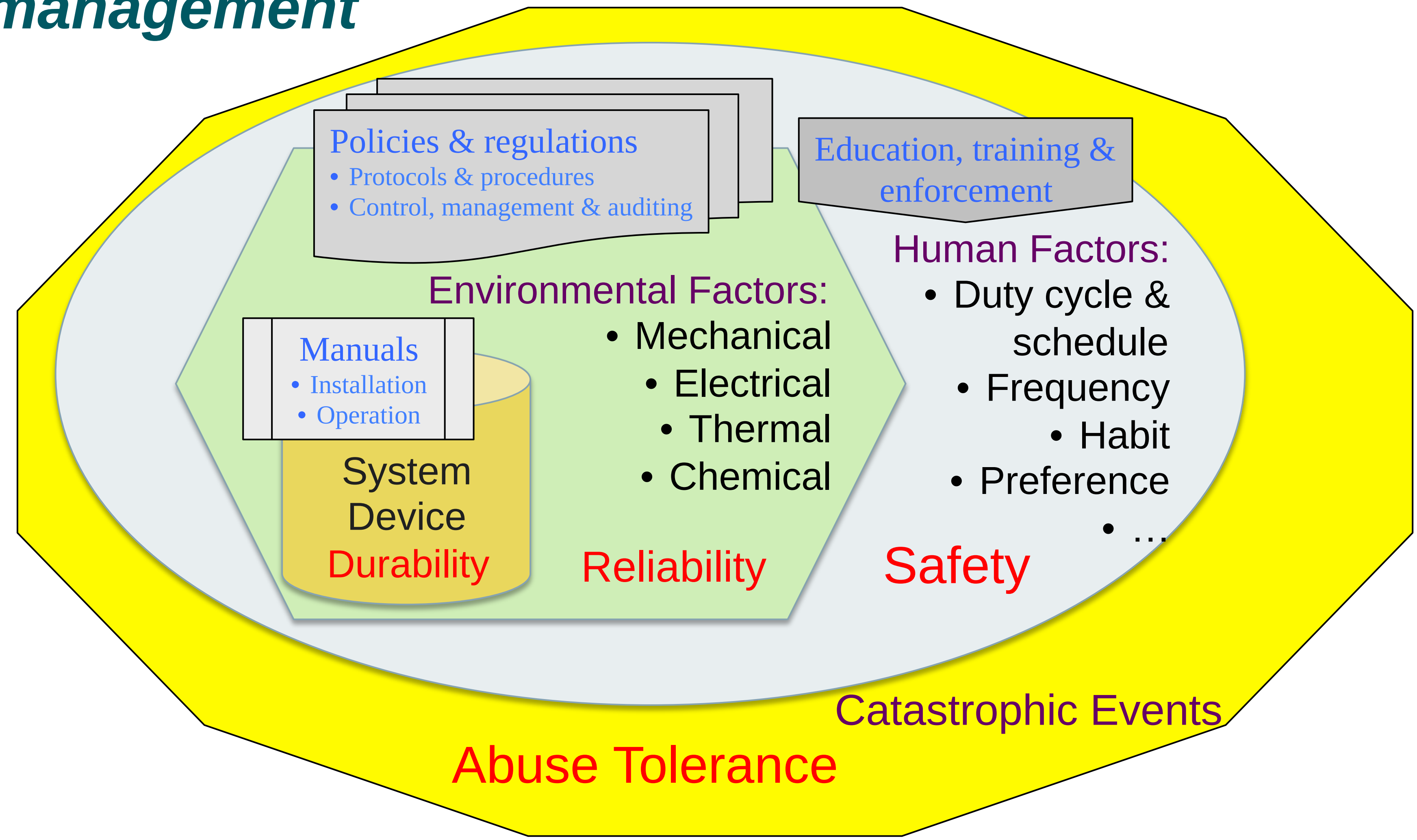
Development of Next-Generation Low Cost / Reliable Batteries:

- Leverage unique INL capabilities to lead Performance Science
- Foundation: Battery Testing Center & Advanced Vehicle Testing
- Growth via strong partnerships with:
  - DOE-EERE (USABC)
  - Automotive OEMs
  - Battery Developers
- Impact: Enabling / accelerating next gen low cost, safe and reliable batteries

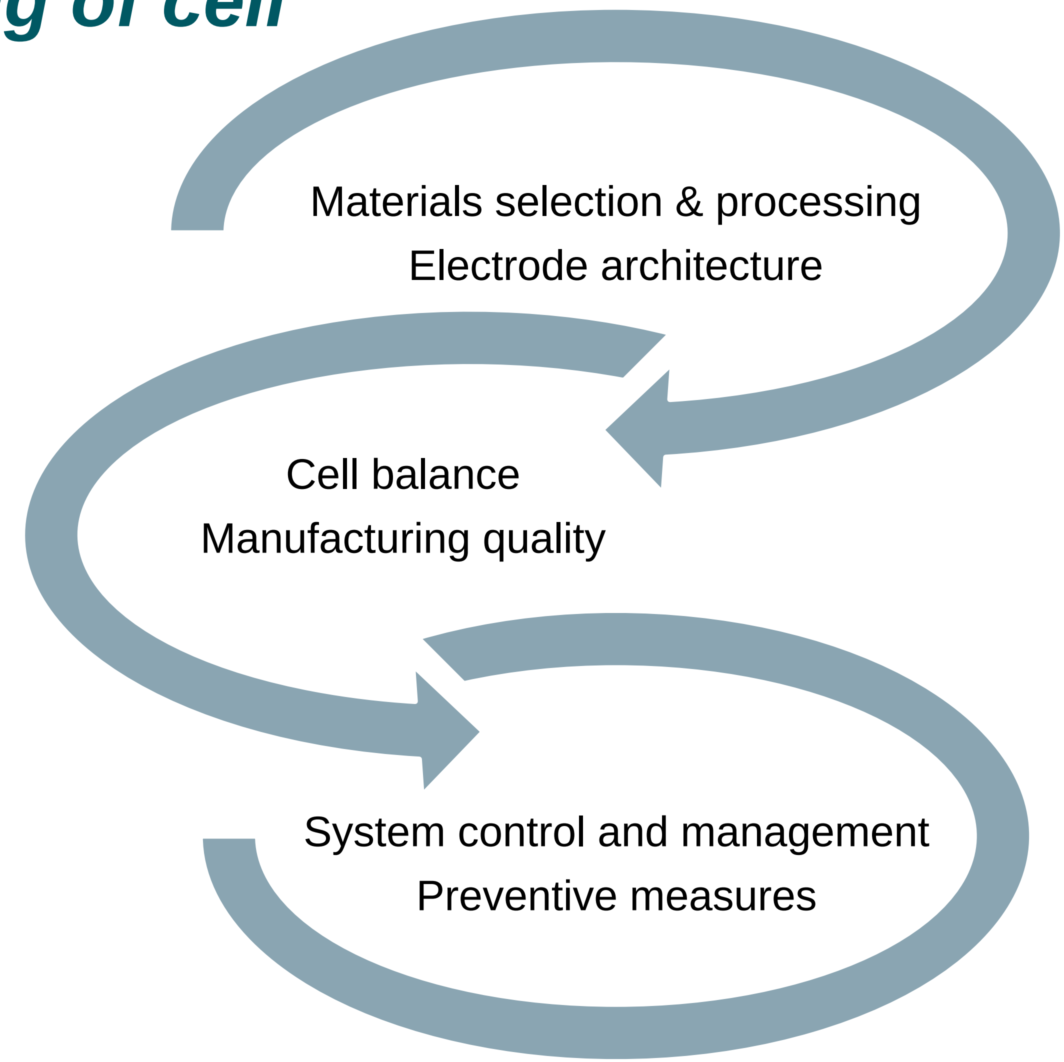
Performance Science:
Half-Cell to Vehicle & Pack



Performance, durability, reliability and safety in a proper perspective – Risk assessment & management

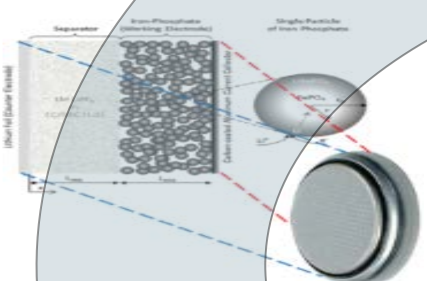


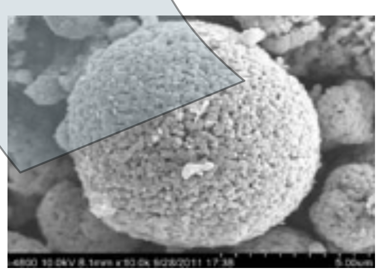
Safety relies on proper cell design and deep understanding of cell performance



Design-Build-Test Paradigm

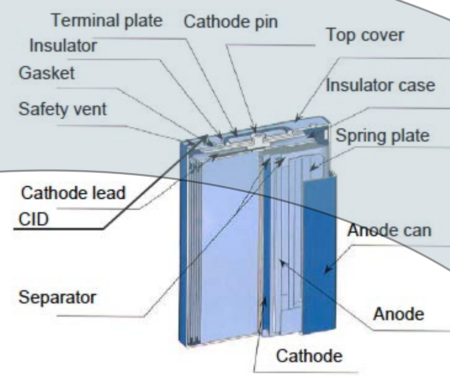
- Forward-looking design principles – Insufficient to enable failure mode and effect analysis (FMEA)

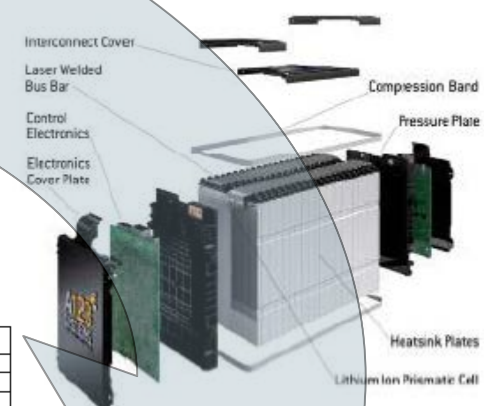


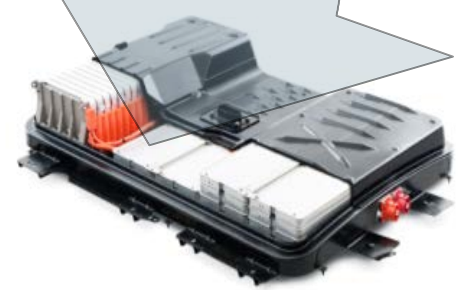


Half-Cell / Coin

Pouch / Cell







Pack

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
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) 1,600 (50% DOD) 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	

Sources: various literature documents

Engineering approach

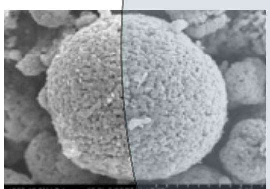
Durability
Reliability
Safety

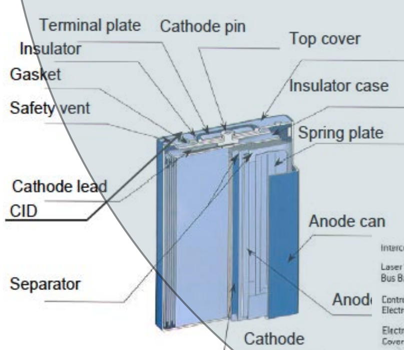
FMEA

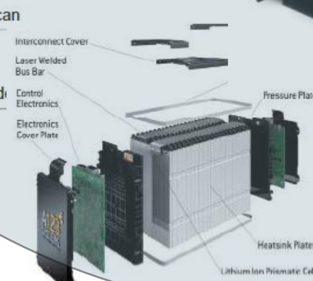
Quantitative Analysis

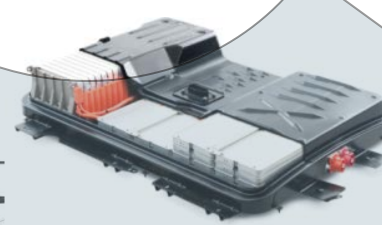
Diagnostics

Prognostics









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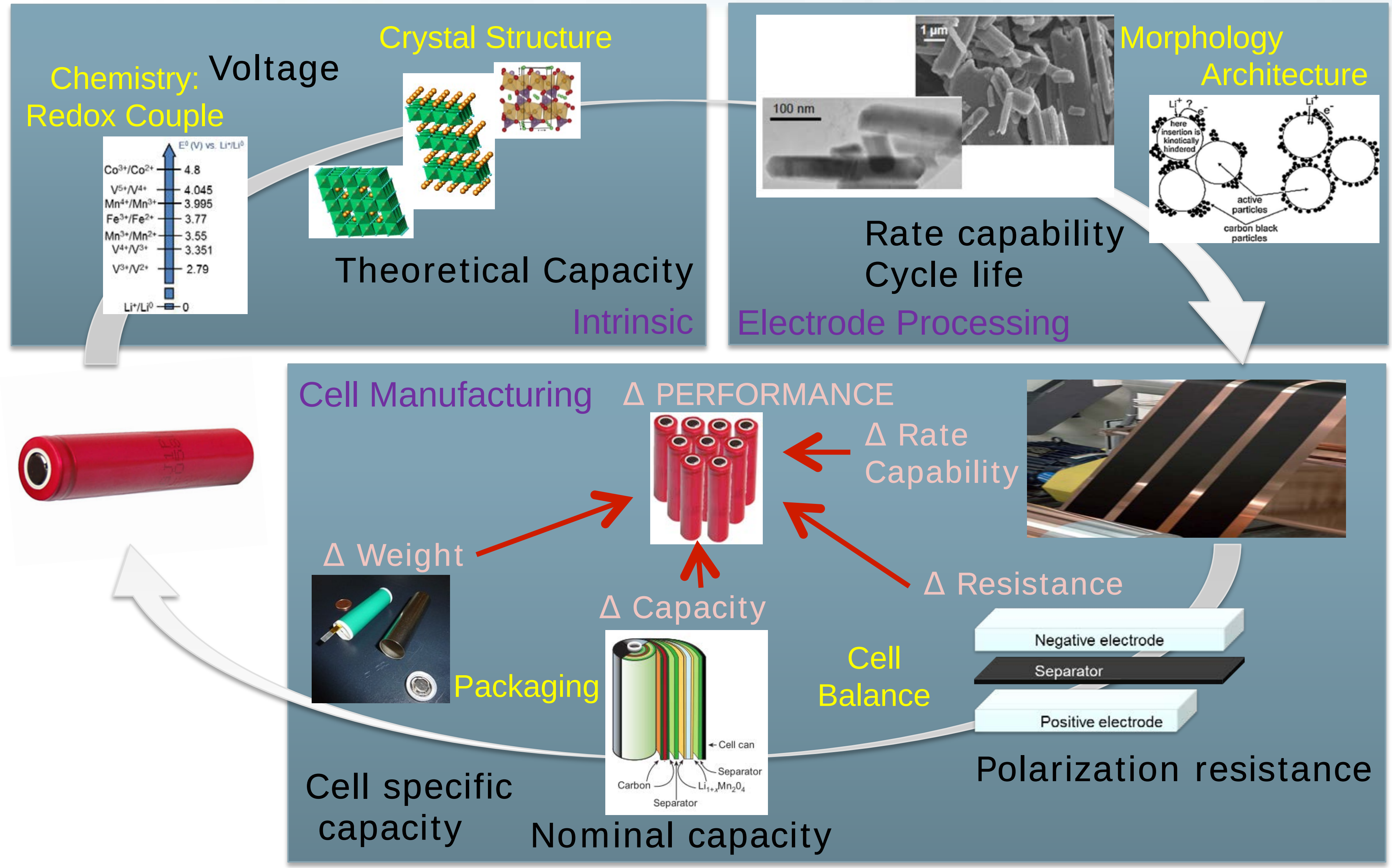
Cell Variability – Origins



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Origins and accommodation of cell variations in Li-ion battery pack modeling

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SUMMARY

Rechargeable battery industry will see significant growth in the use of battery systems for portable devices and power electronics, renewable energy storage, power systems for transportation, and telecom backup power applications. Despite such promising market sentiment, the battery system management remains as a challenging issue to be resolved in order to provide a safe and reliable power and energy storage system. Here we report advancement in the battery management approach by providing a solution to analyze battery performance variations in a lot of batteries produced from the same manufacturing process. A lot of 100 Li-ion cells were analyzed in order to quantify the inherent cell variations associated with cell manufacturing process and test protocol. Both statistical and electrochemical analyses were used to characterize and quantify the capacity variations among the cells along with other parameters that can be readily derived from the test results. Information extracted from a minimal testing of the cells in the lot and more intensive characterizations on a few cells including one as the nominal sample cell allows the establishment of a single cell model (SCM), based on a generic equivalent circuit, with high accuracy in predicting cell performance. The analyses also permit a carefully crafted logic development of how to separate the origins that cause the cell variations in performance. Such separation of the attributes enable a proper tuning of the cell parameters in the model, which allows the accommodation of cell variations in a battery pack model to handle most of the imbalance issues. A careful validation of the SCM to predict performance of any arbitrary cell in the lot with high accuracy was demonstrated.

KEY WORDS: intrinsic cell imbalance; battery pack management; equivalent circuit model; statistical analysis; battery pack

Experimental

Int. J. Energy Res. 2010; 34:216–231

- 100 commercial AAA size 300 mAh Gr/$LiCoO_2$ cells.
- Charging regime: CC @C/2 + CV @4.2V and 0.5 hrs cutoff
- Discharge regime: C/5, C/2 (RPT: C/25, C/3, 1C and 2C)
  - High rate: Solartron 1470
  - Low rate: Bio-logic VMP3
- Rest: 3 hrs ➔ relaxed cell voltage (RCV)
- SOC = Q/Q_{25} ➔ pseudo-OCV vs. SOC curve
- SOC determination by RCV

Speciation in cell metrics to performance variations

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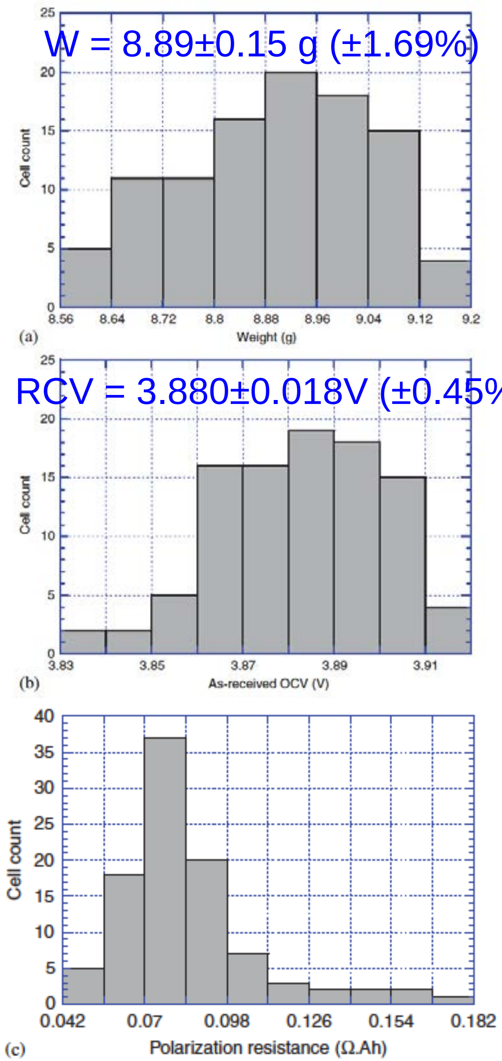

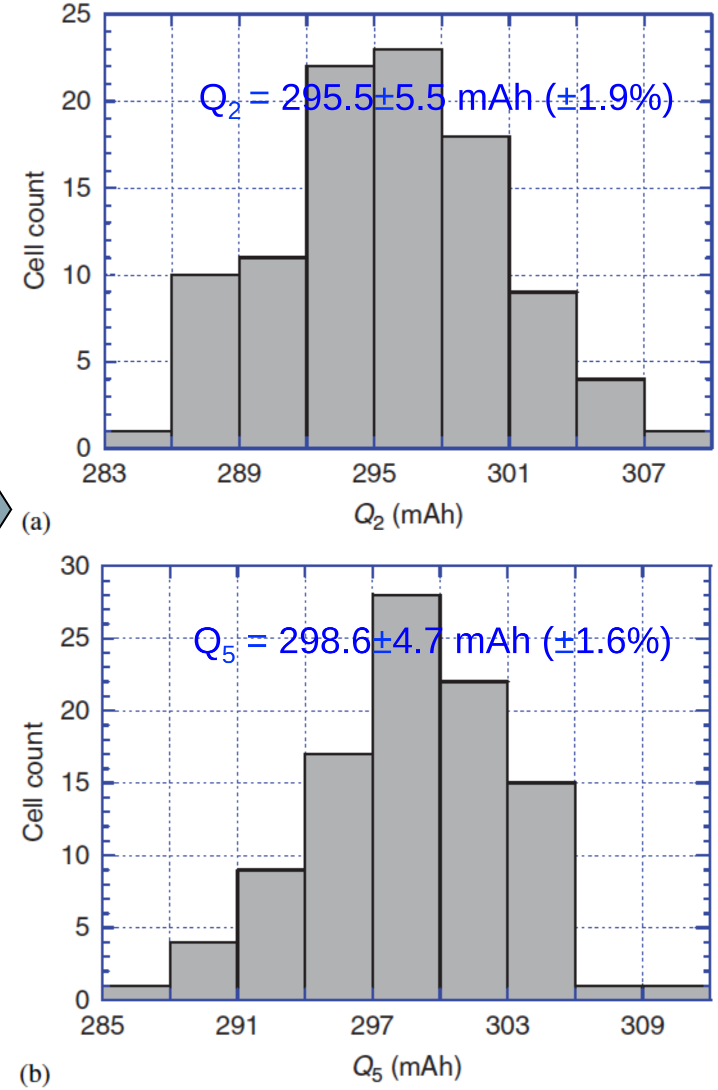

EOC to BOD

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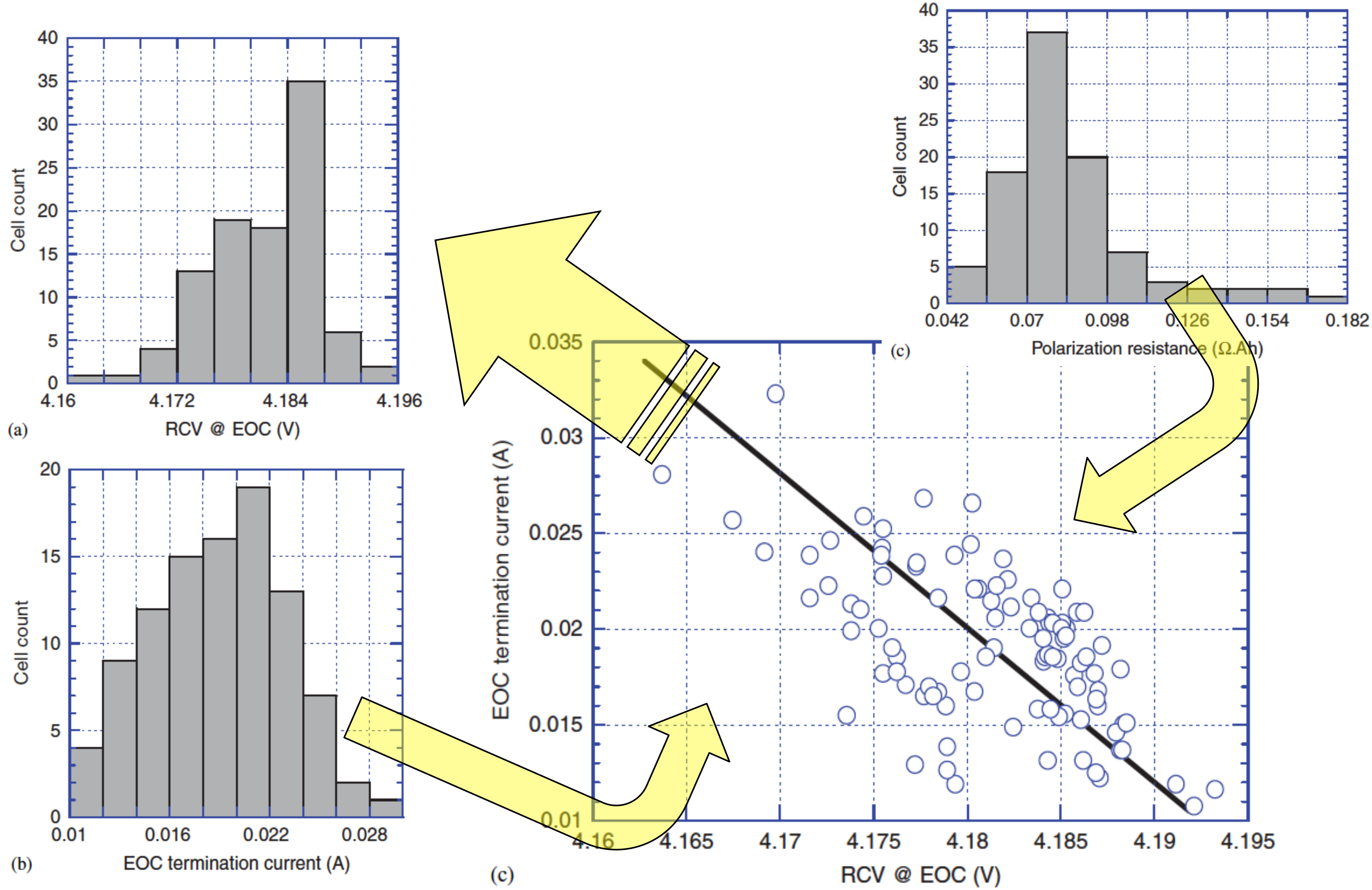

BOD to EOD

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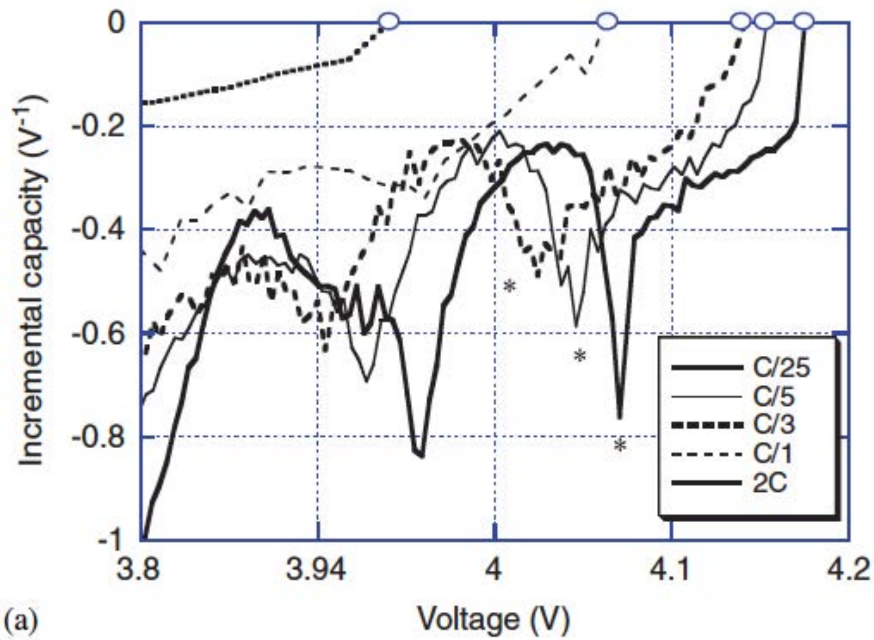

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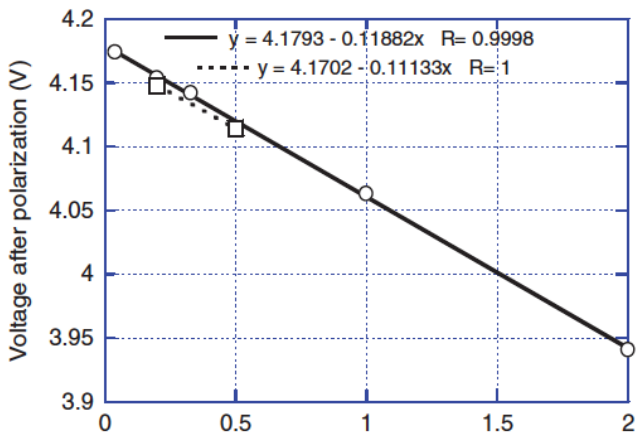

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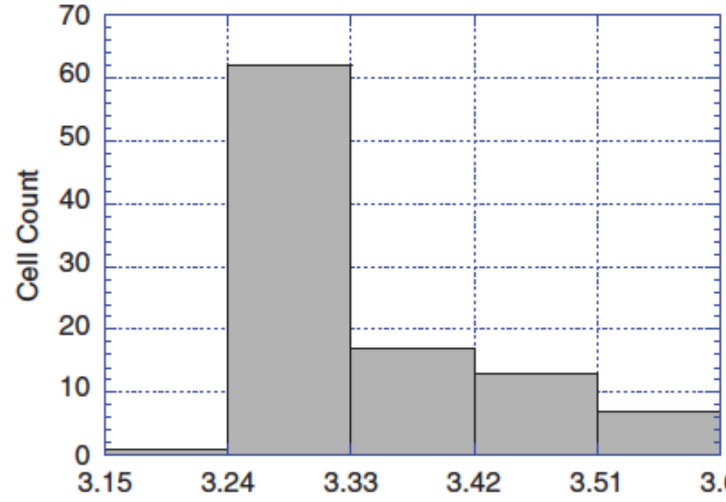

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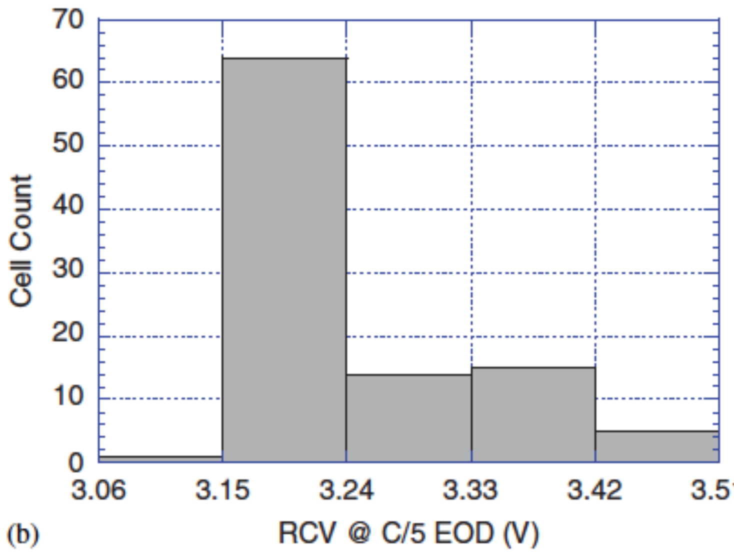

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EOD to Capacity

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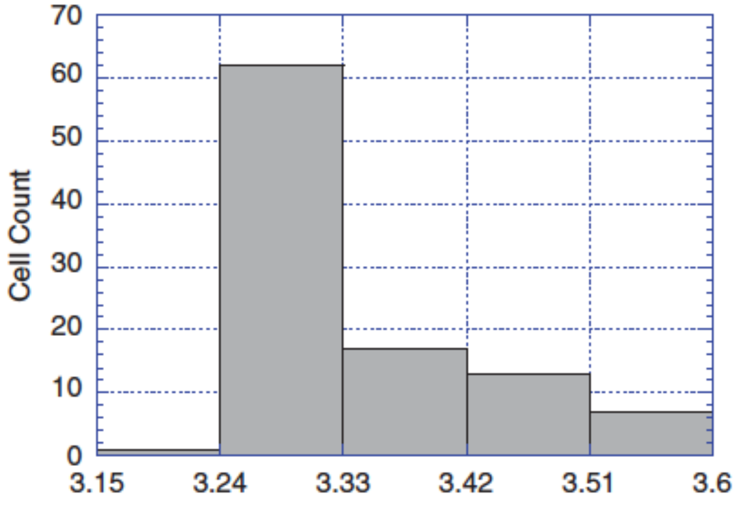

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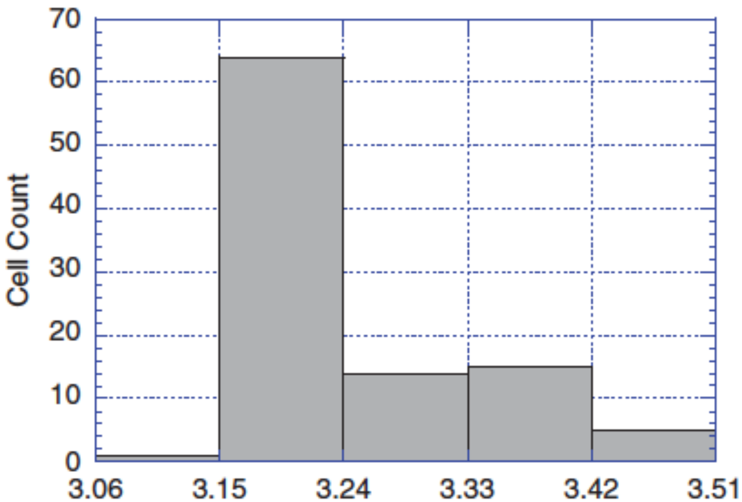

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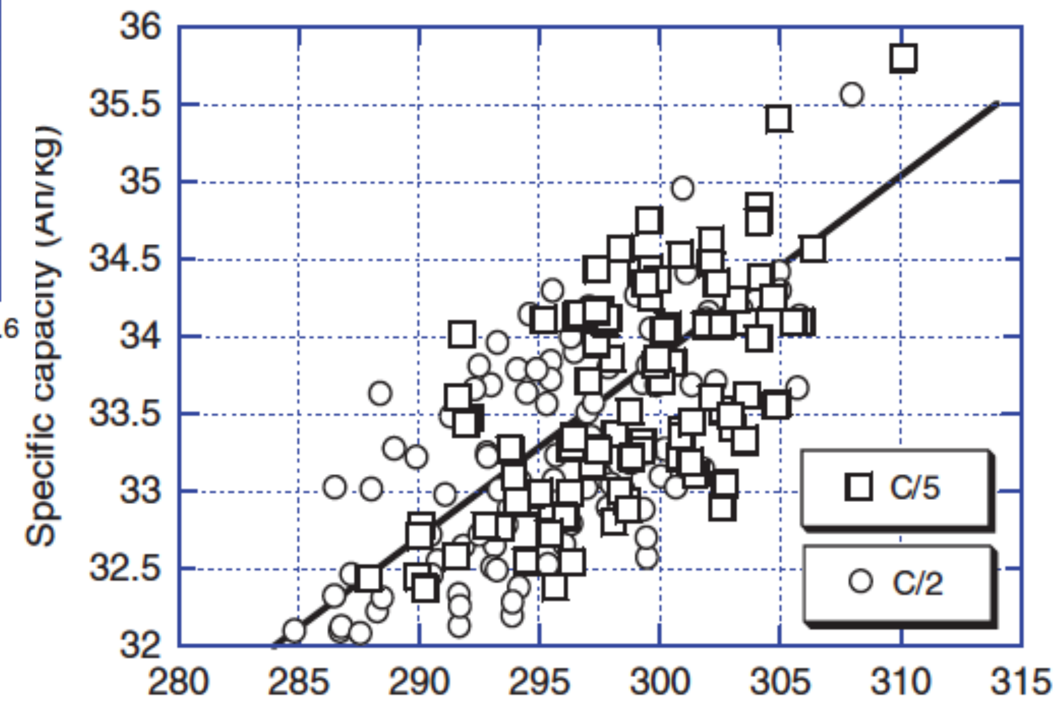

(d)

Capacity normalization to SOC

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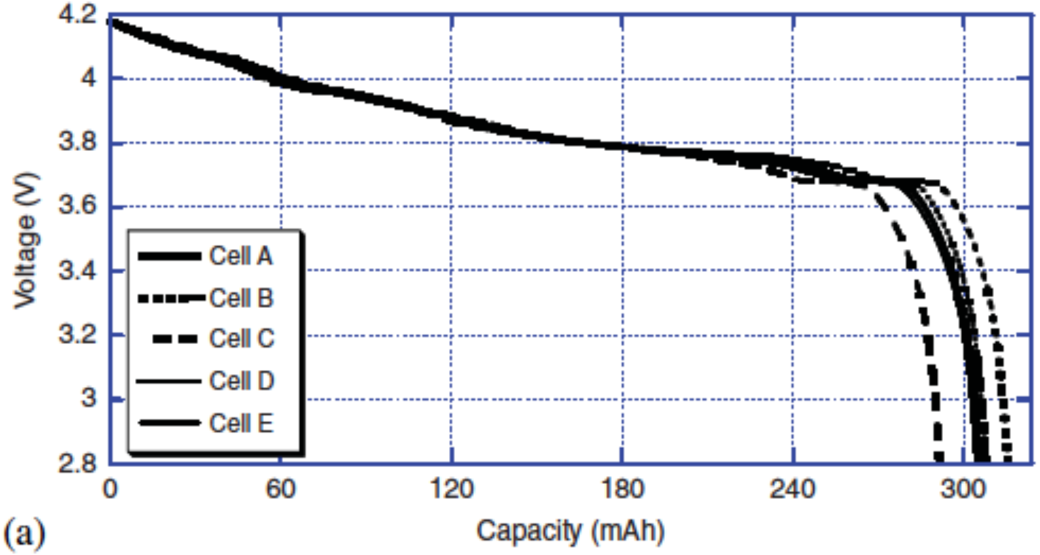

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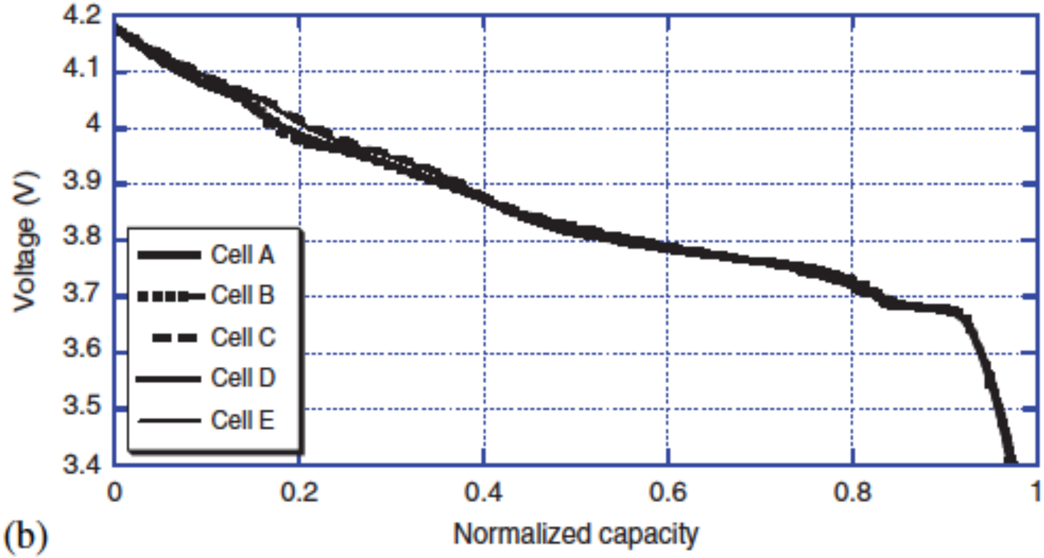

(b)

Cell variability in SOC during testing

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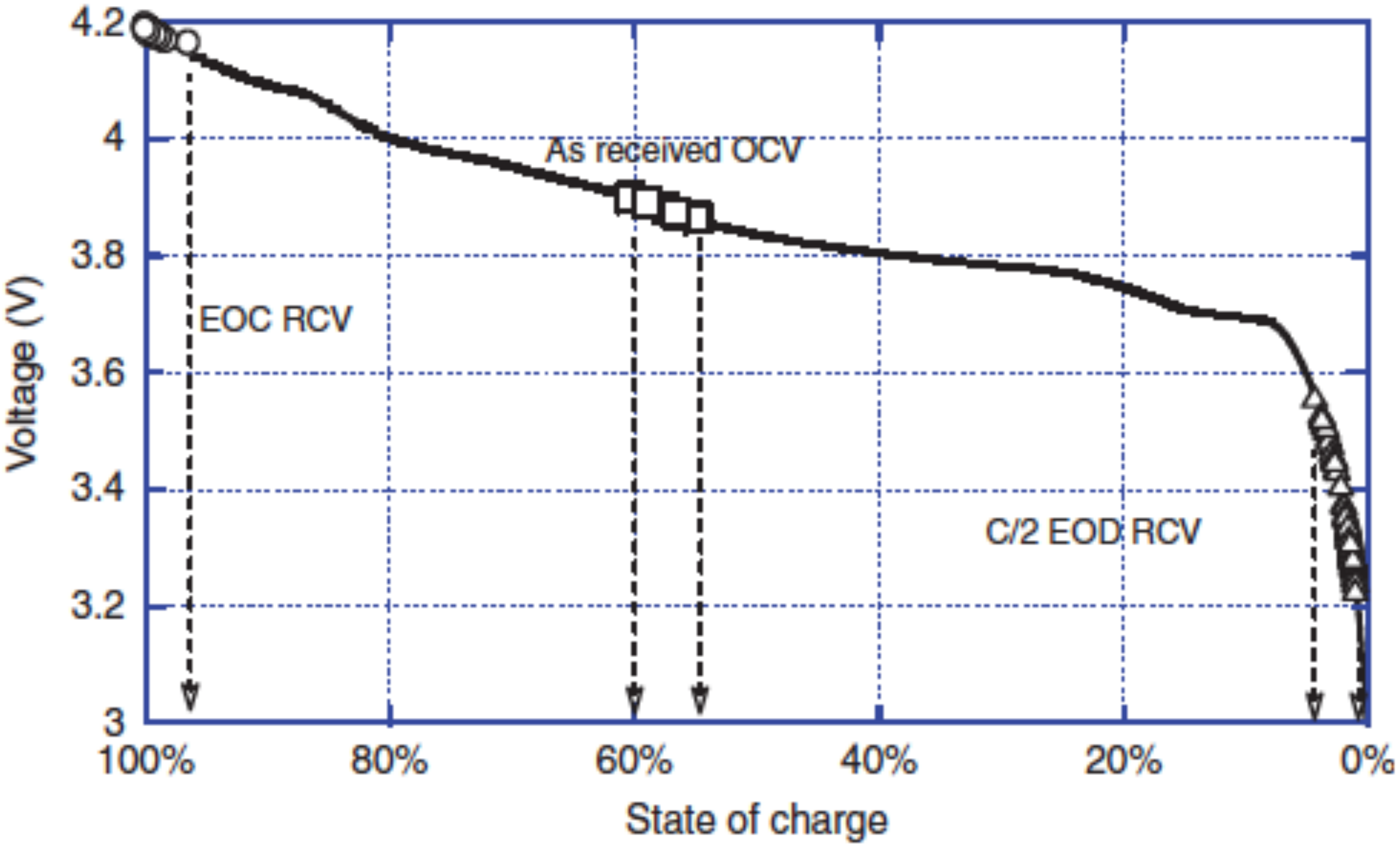

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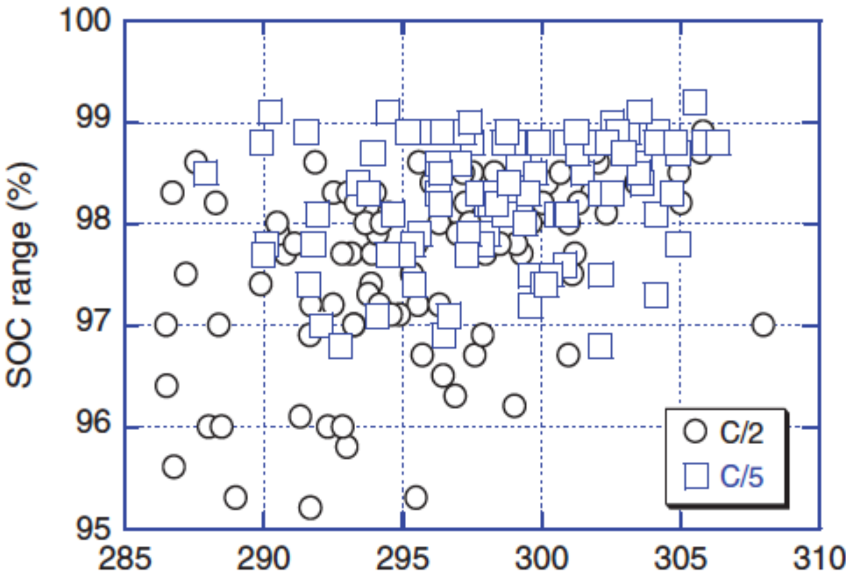
Capacity ration (mAh/%SOC)



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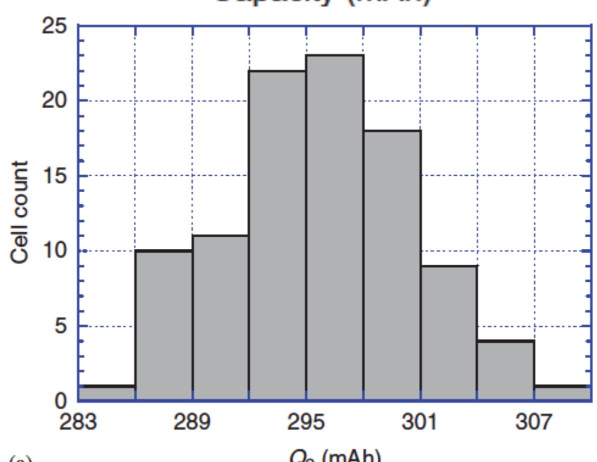

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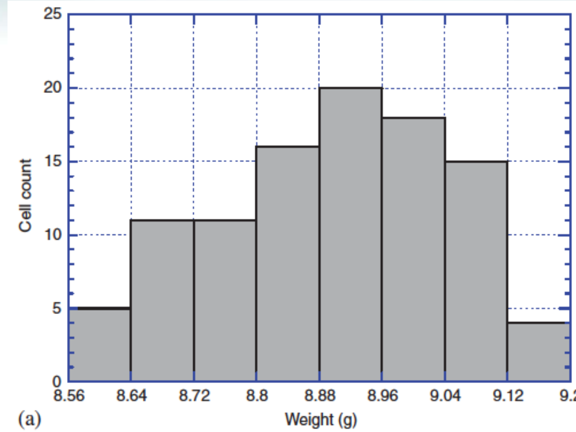

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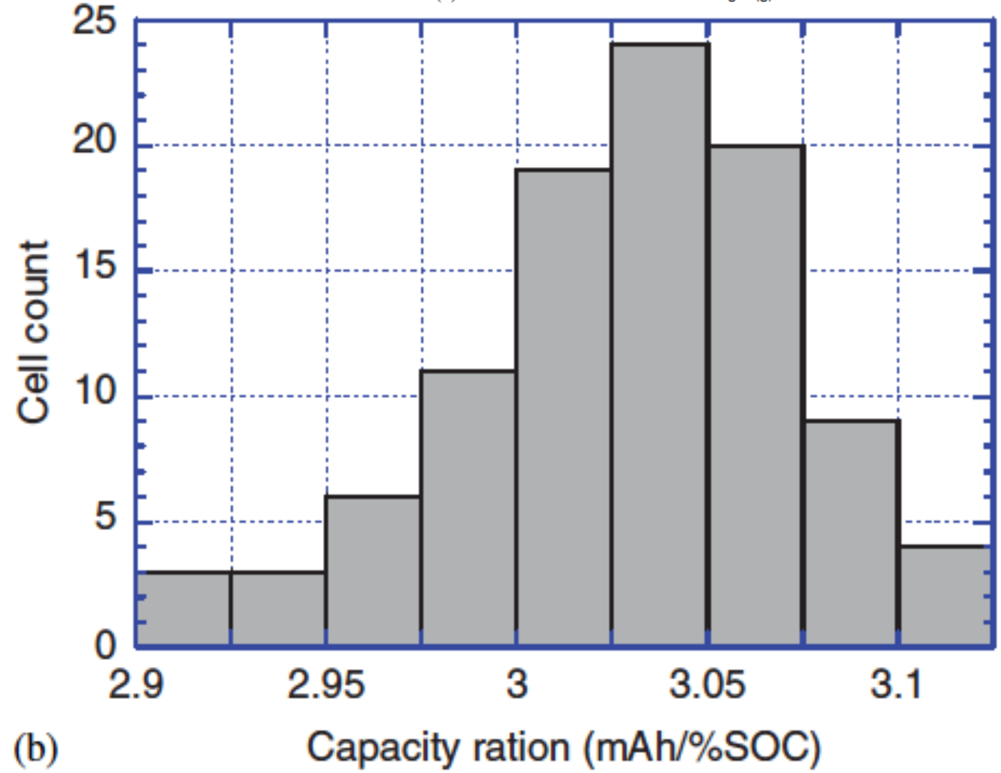

(b)

Impacts from DCR on SOC

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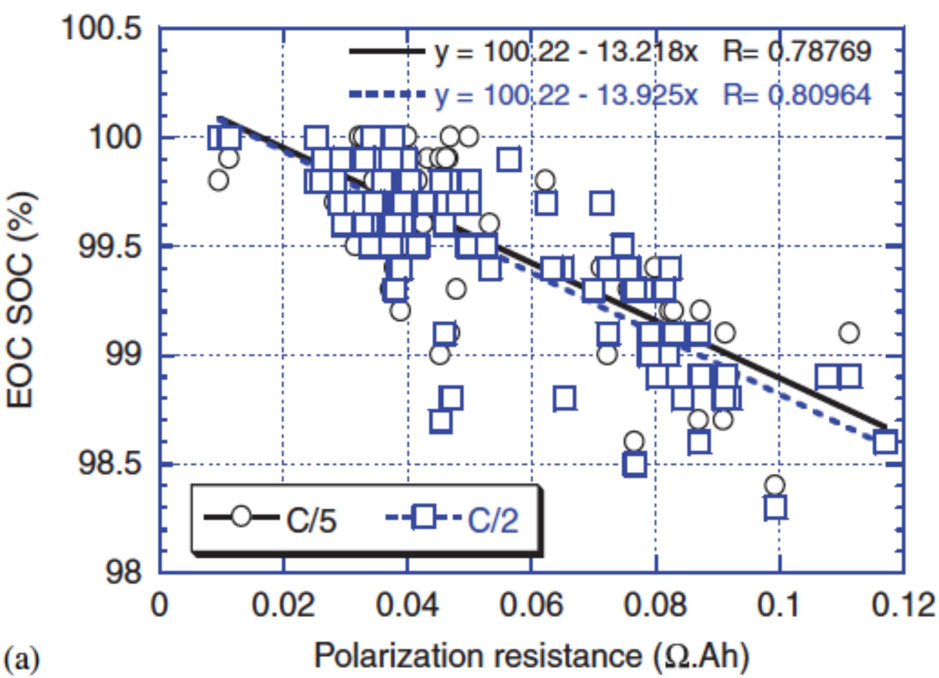

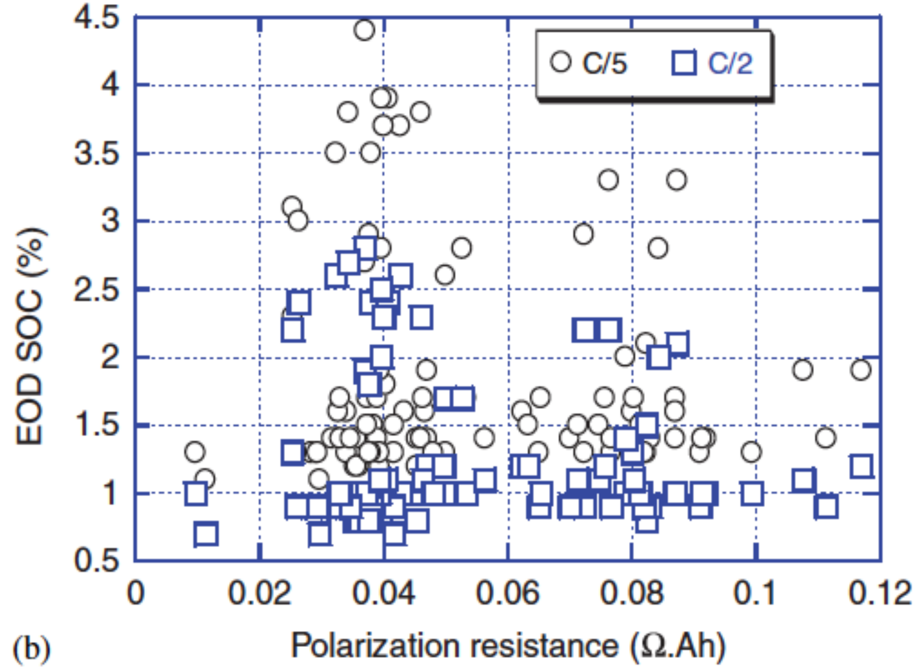

Impacts from DCR on capacity

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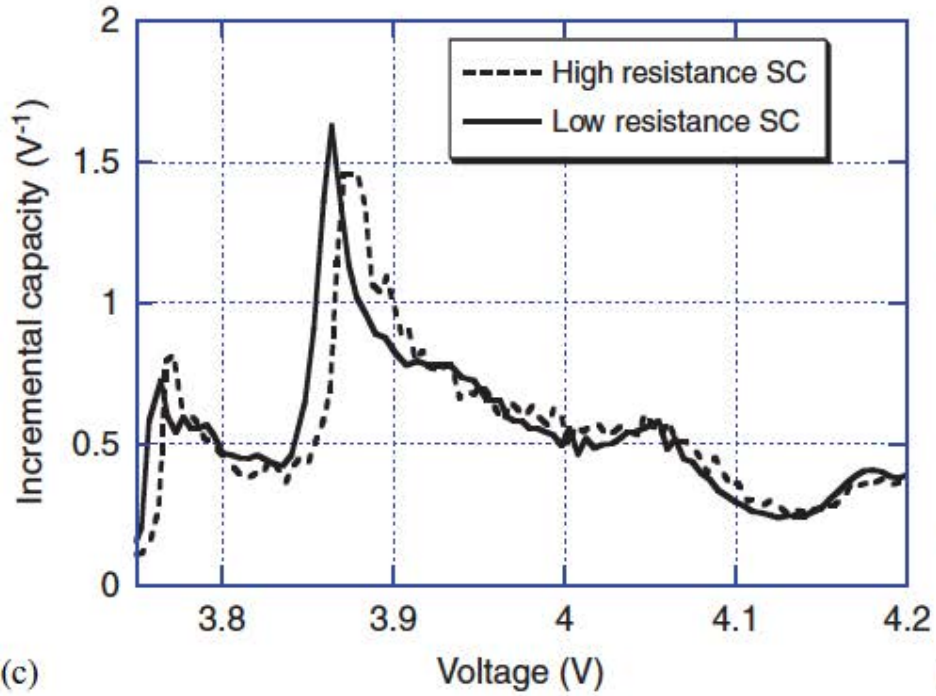

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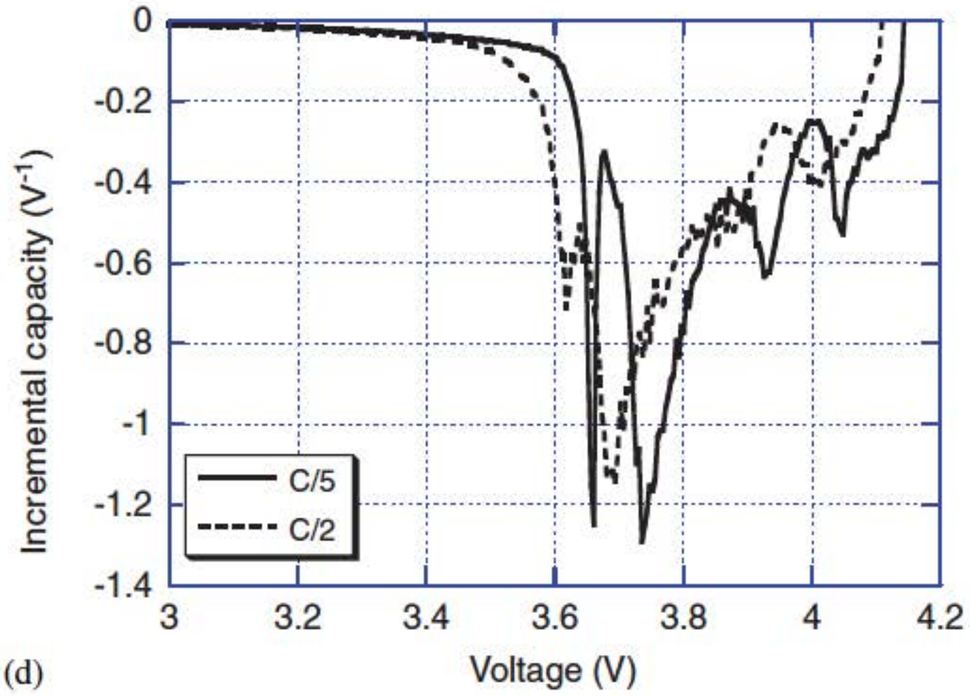
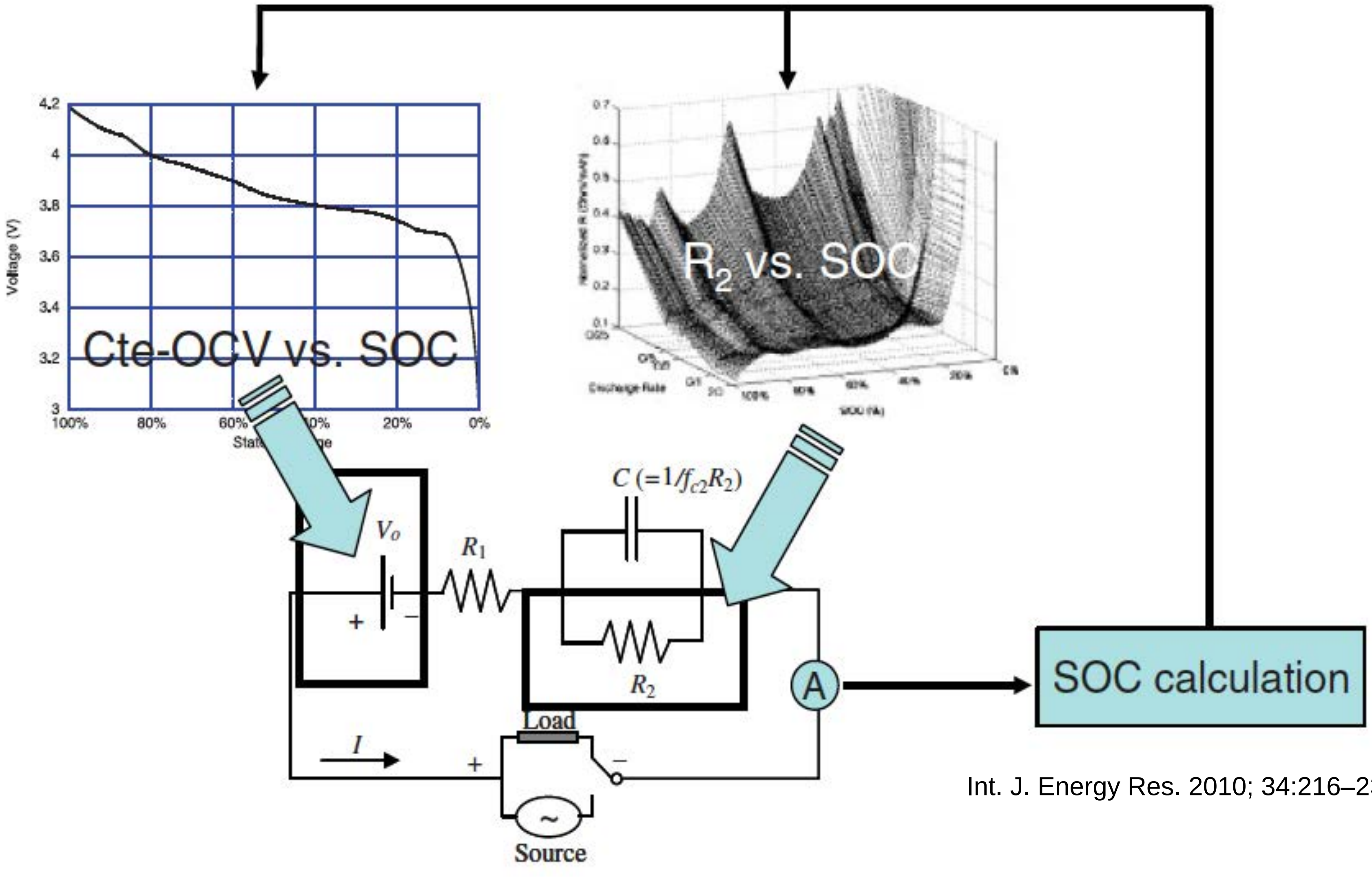


(d)

High fidelity of cell model and simulation



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Every cell in the pack can be modeled precisely

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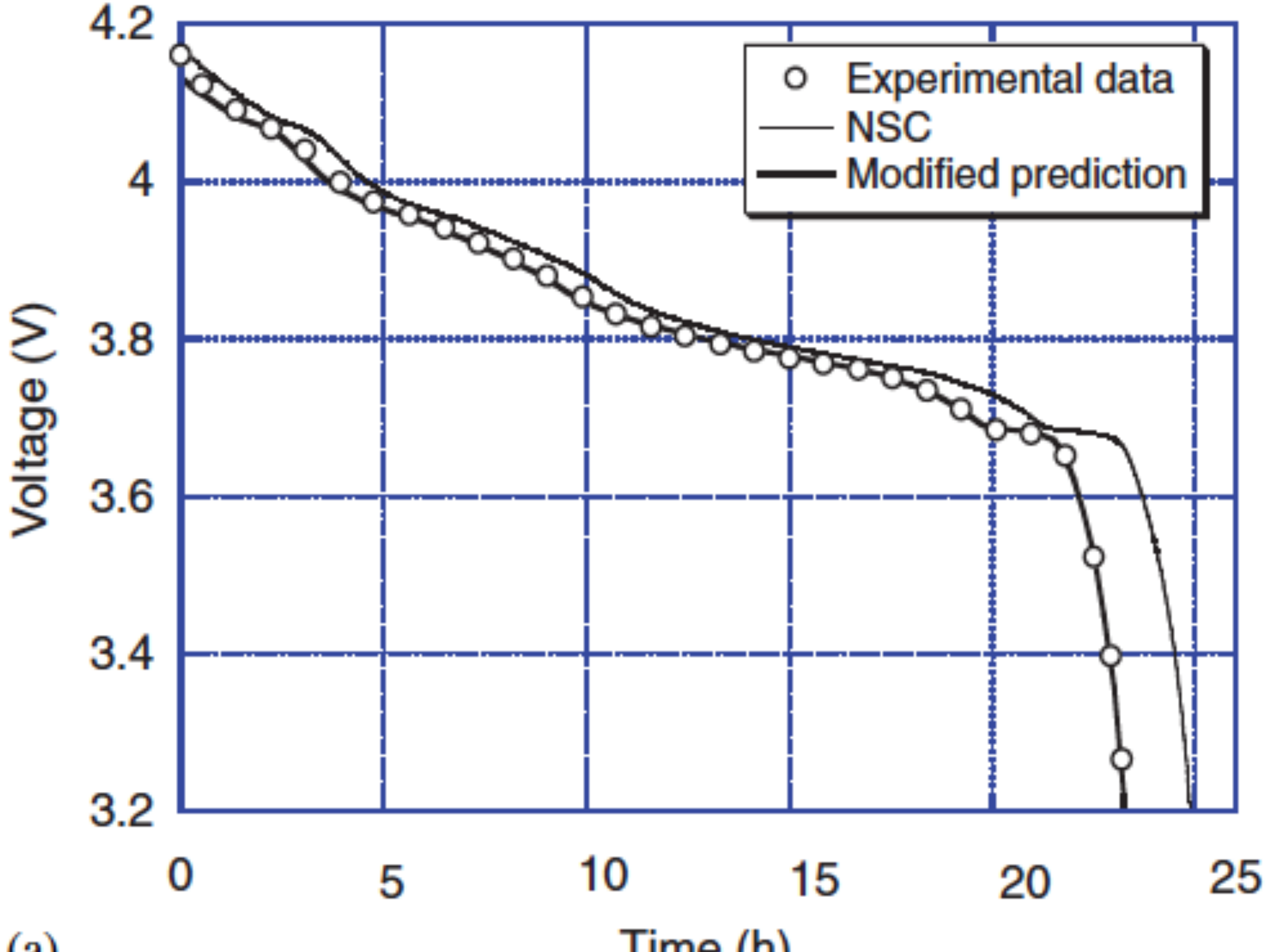
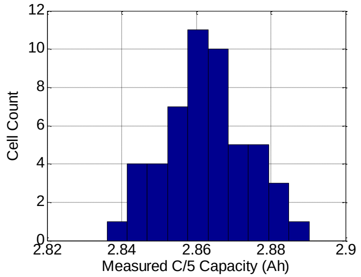


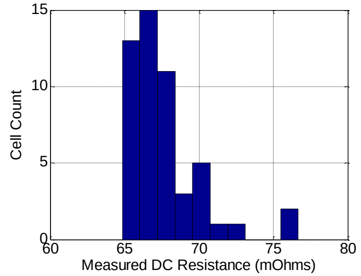
(a)

Cell variability in aging & capacity fading

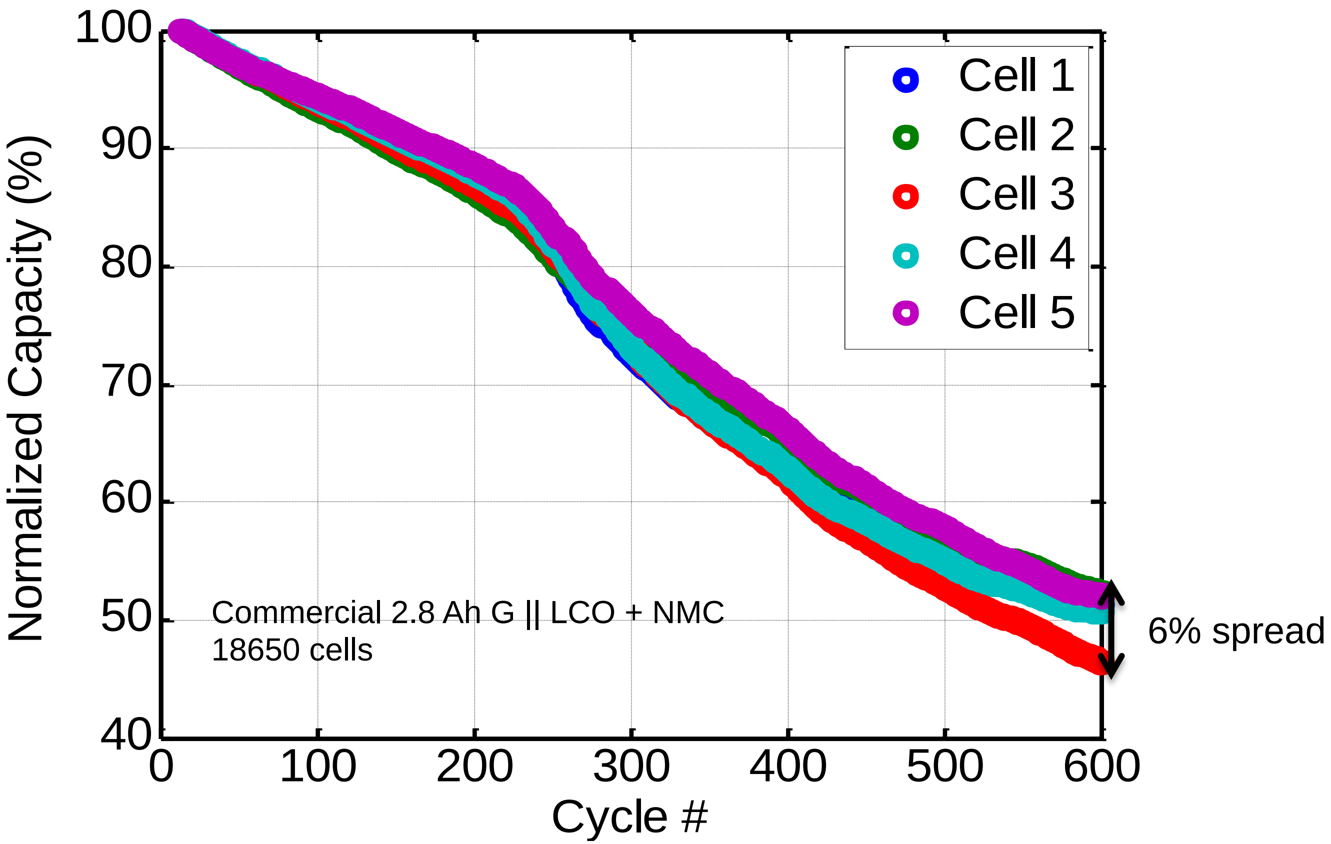
- Even with the best state-of-the-art cell design and manufacturing, variability in endurance remains as an issue that impacts durability, reliability and safety



2863.09 ± 11.35 mAh
(± 0.40%)

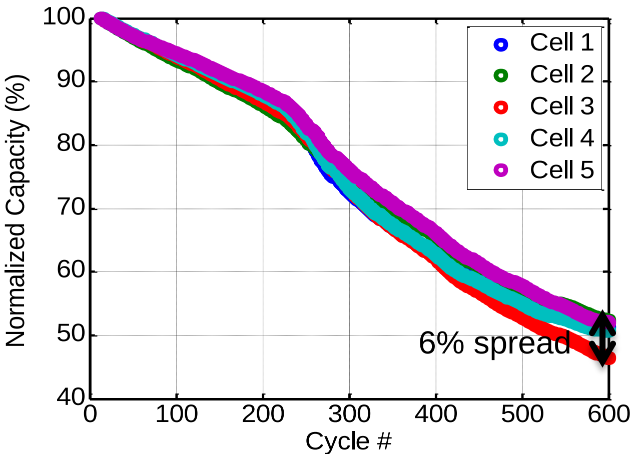


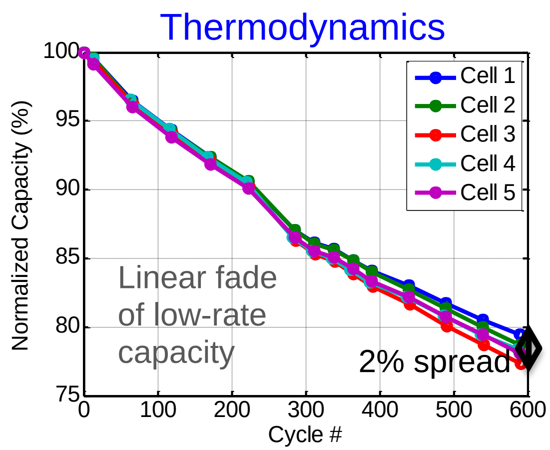
66.30 ± 2.45 mΩ
(± 3.7%)

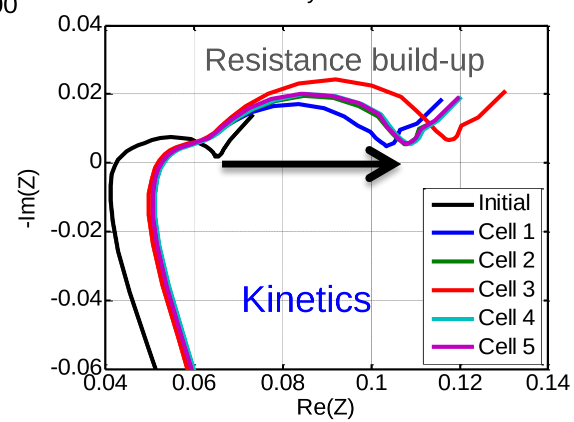


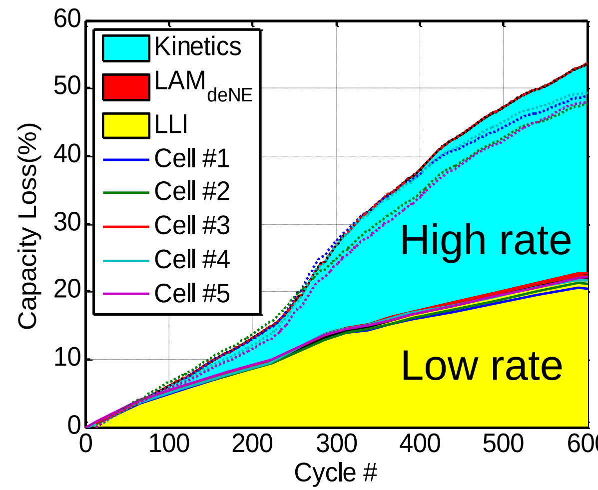
Quantify Cell Variability over Aging

- 51 commercial G || LCO + NMC 2.8 Ah 18650 cells









Performance	LLI (%)	LAM_{deNE} (%)
Base	22.5	14
Under	25.5 (↗)	16 (↗)
Over	20.5 (↘)	13 (↘)
Batch	*22.5^{+3}_{-2}*	*14^{+2}_{-1}*
Avg ratio	*1.6*	*1*

$LAM_{deNE}=f(LLI)$

Dubarry and Liaw, “Assessing Cell-To-Cell Variations in Commercial Batteries”, 218th ECS, Las Vegas, B2- #326: Battery Safety and Abuse Tolerance, 2010

M. Dubarry et al. *Internat. J. Energy Res.* 34 (2010) 216-231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