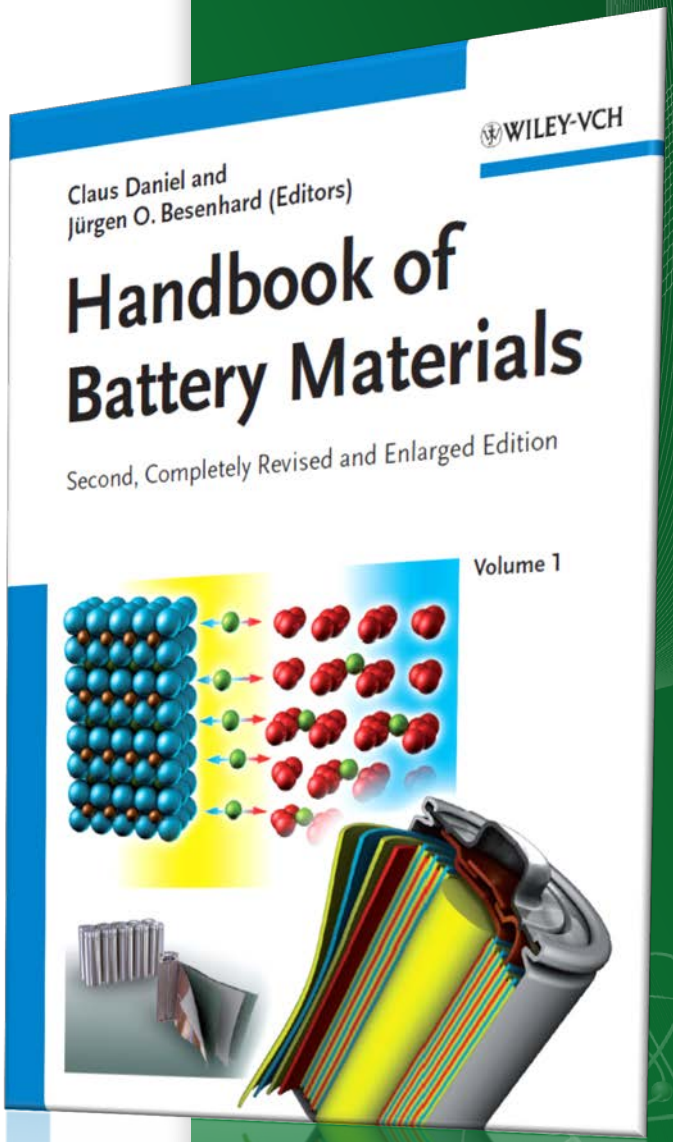
Lithium ion batteries and their manufacturing challenges

Claus Daniel



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U.S. Energy Use

Lawrence Livermore National Laboratory

Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Dual drive train, power electronics, and batteries are too expensive for what you get.

2011 Chevrolet Volt

4D Hatchback
Mileage: City: 35 mpg Hwy: 40 mpg
Fuel Type: P Engine Type: 1.4L

Make/Model: Chevrolet Volt
Segment: Eco
Powert
MSRP: $40,280
Invoice
Depreciation: $27,540.00
Fees & Taxes: $-4,615.00
Insurance: $5,684.00
Interest: $3,687.00
Maintenance: $2,113.00
Opportunity Cost: $276.00
Repairs: $1,406.00
Electricity Price: $0.12
Fuel: $2,692.00
Price of Fuel: $4.00

Five-Year Ownership Cost: $38,783.00

2011 Chevrolet Cruze LTZ

4D Sedan
Mileage: City: 24 mpg Hwy: 36 mpg
Fuel Type: R Engine Type: 1.4L Inline 4-cyl MFI DOHC 16-valve Turbocharged DCVCP ECOTEC VVT (LUJ)

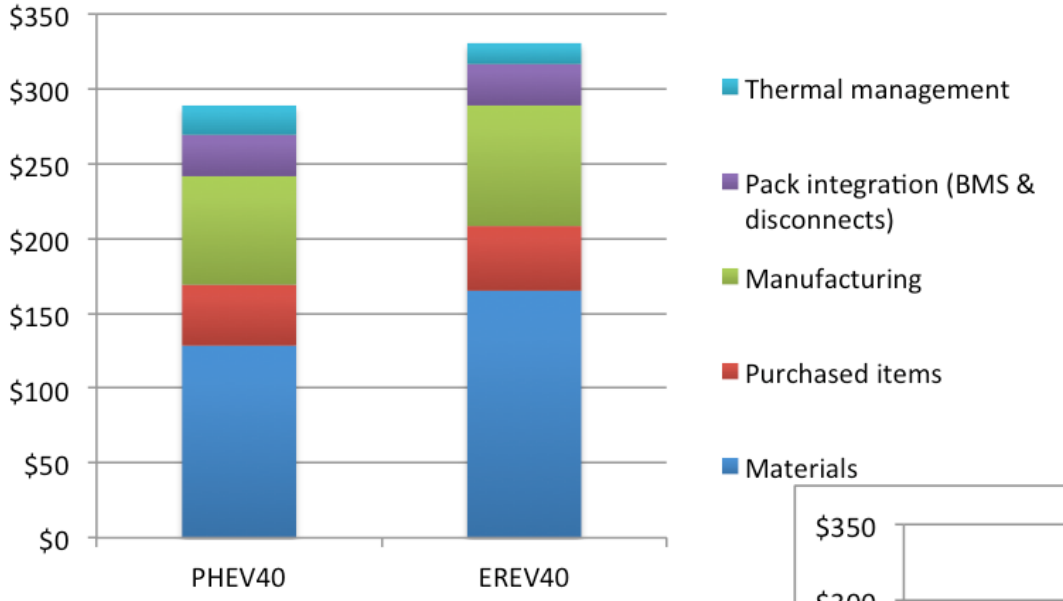
Make/Model: Chevrolet Cruze
Segment: Compact, Sedan
Powert
MSRP: $21,975
Invoice
Depreciation: $14,468.00
Fees & Taxes: $1,661.00
Insurance: $5,529.00
Interest: $1,983.00
Maintenance: $2,465.00
Opportunity Cost: $487.00
Repairs: $1,600.00
Electricity Price: $0.12
Fuel: $11,592.00
Price of Fuel: $4.00

Five-Year Ownership Cost: $39,785.00

Source: GM-Volt.com, LLC

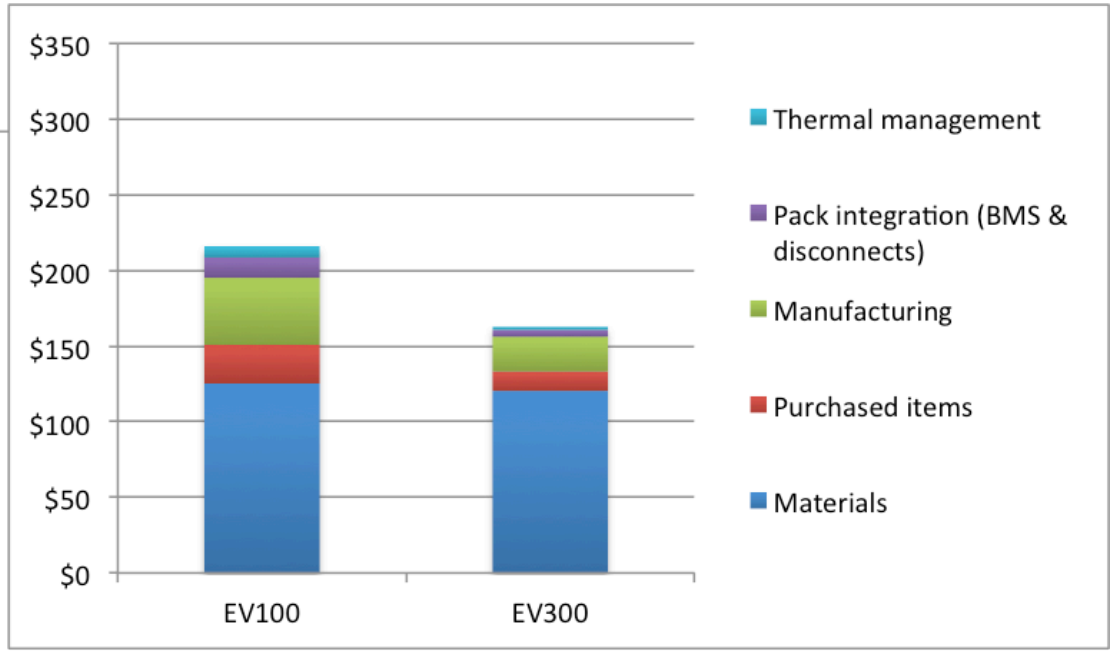
PHEV and EV Cost Estimates, $/kWh

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



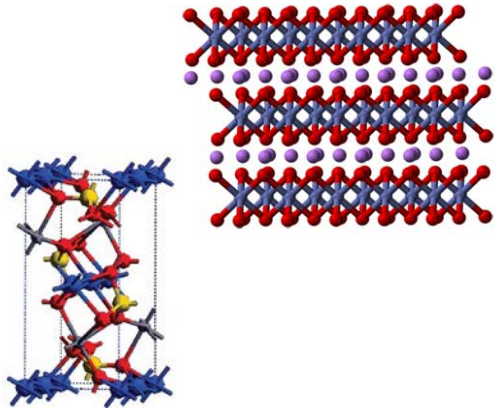
- Estimates from ANL's BatPaC model.
- Based on 2020 production year and annual battery production of 100,000
- Chemistry is graphite anode, NMC441 cathode, EC-EMC-$LiPF_6$ electrolyte
- All batteries have liquid cooling

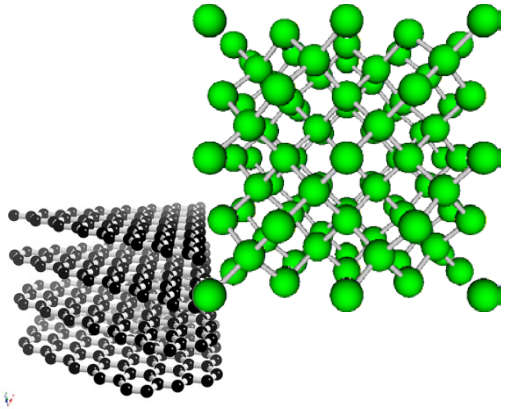
- Manufacturing = electrode processing, cell assembly, formation, module and battery assembly
- Purchased items = cell terminals and packaging. module and pack jackets

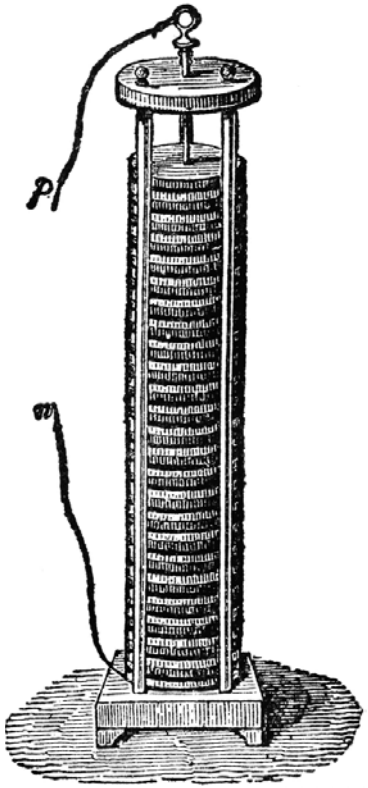


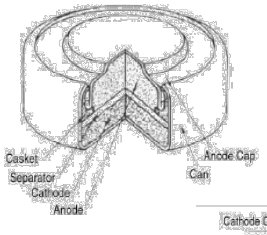
From DOE, David Howell

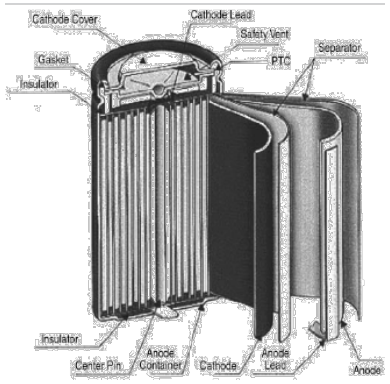
There is no single one “lithium ion battery”

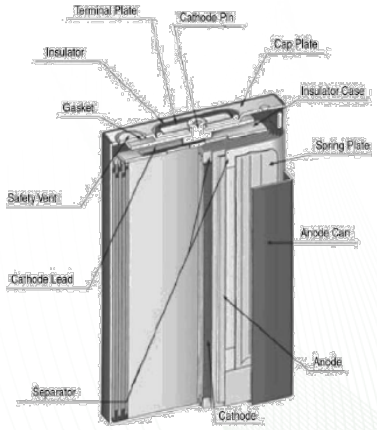












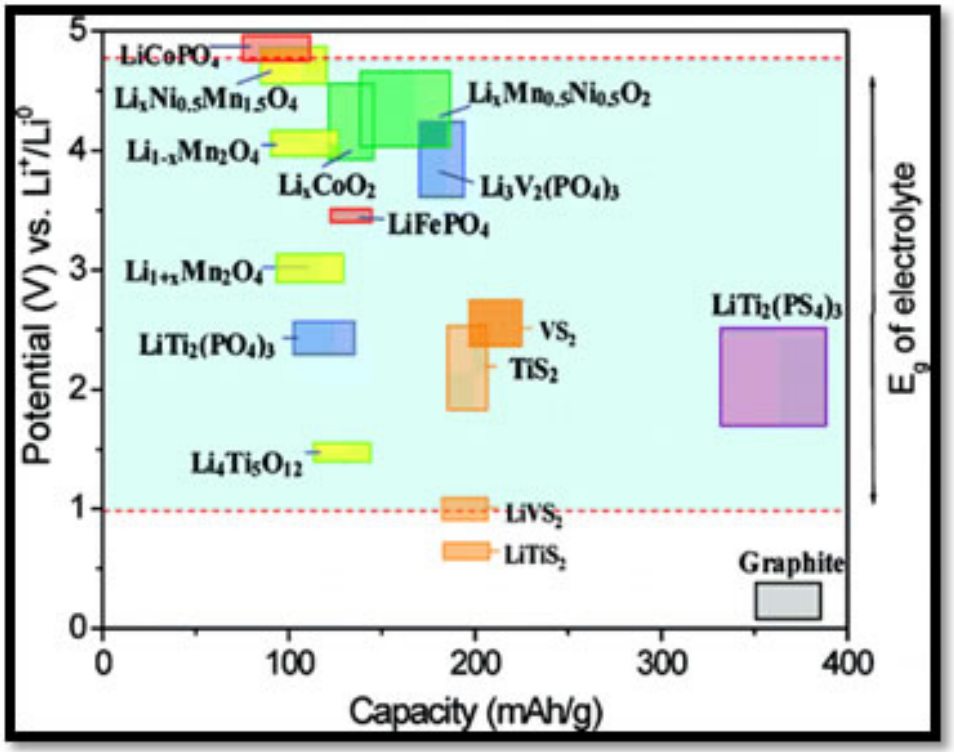
Overview

- Materials pairings
  - Variety of electrode materials
  - Balancing of materials in a real cell
- Manufacturing challenges
  - One example of cost reduction via water based processing
- Thoughts on the future

Selection of materials and manufacturing strategies depend on needs and application

Variety of electrode materials

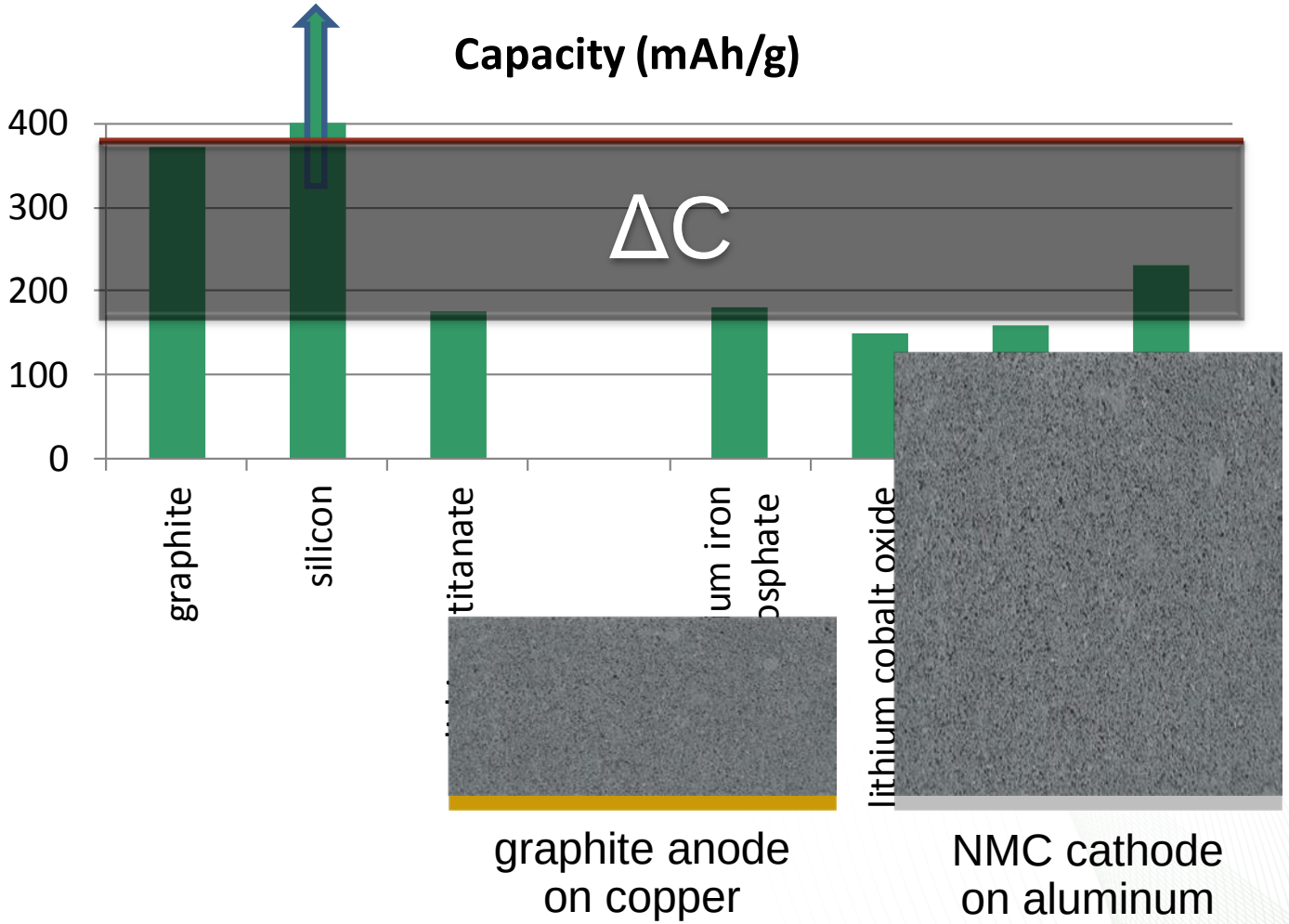
Energy per charge transfer



http://www.engr.iupui.edu/~yk35/img/r3-1.jpg

Number of charges available

Balancing of materials in a real cell

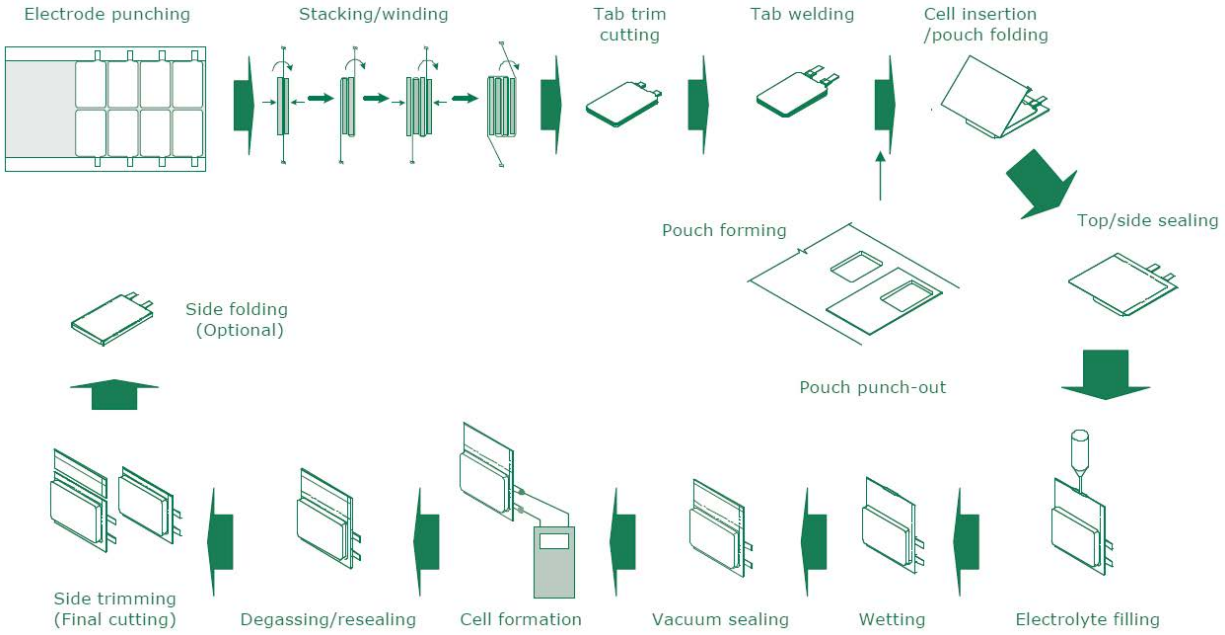


Manufacturing challenges

Electrode processing

Raw materials → Slurry processing and mixing → Coating → Drying

Cell assembly



Post processing

Formation

Example: Electrode manufacturing – Solvent usage

US 20130108776A1

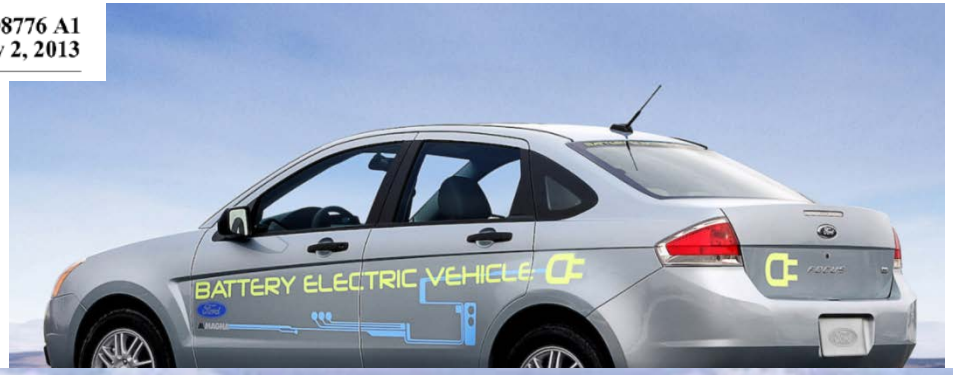
(19) **United States**

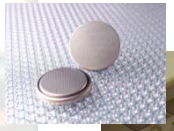
(12) **Patent Application Publication**
Li et al.

(10) **Pub. No.: US 2013/0108776 A1**

(43) **Pub. Date: May 2, 2013**

- **Why?**

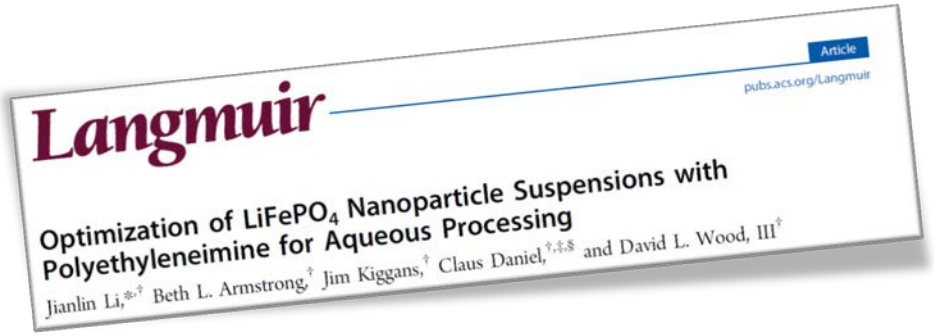


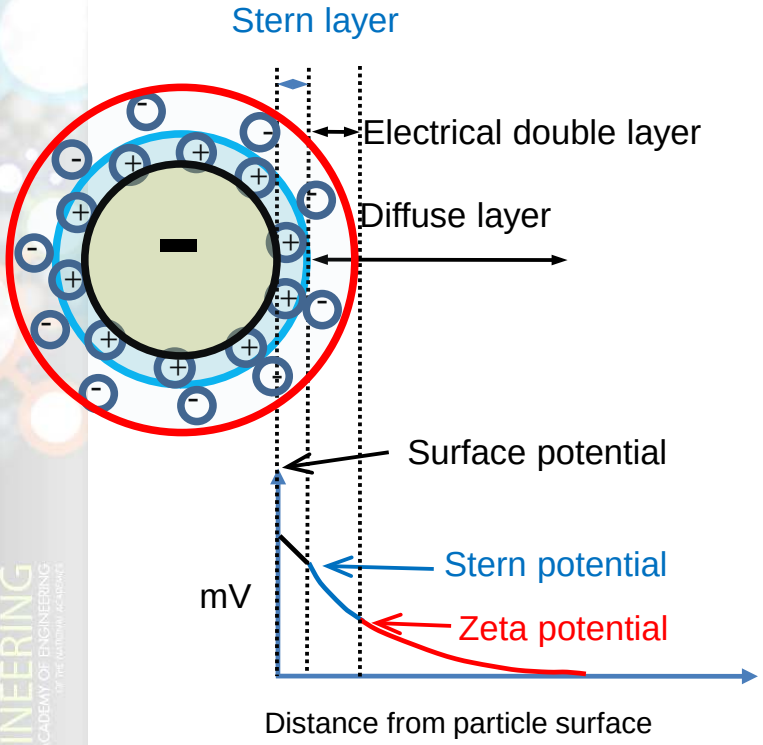


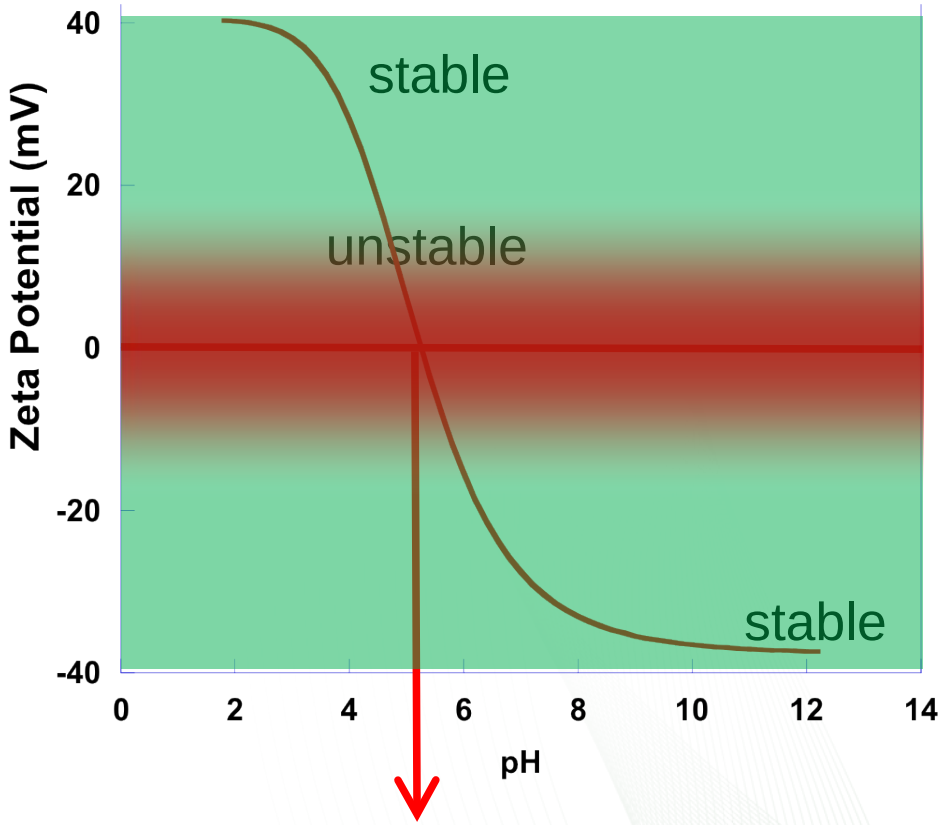
Can we replace n-methyl pyrrolidone as a solvent?

- **Why?**
  - **Solvent cost**
  - **Flammable vapors**
  - **Toxicity**
- **Why not water?**
  - **Agglomeration**
  - **Adhesion**
  - **Life issues**

Zeta potential is a way to characterize surface charge



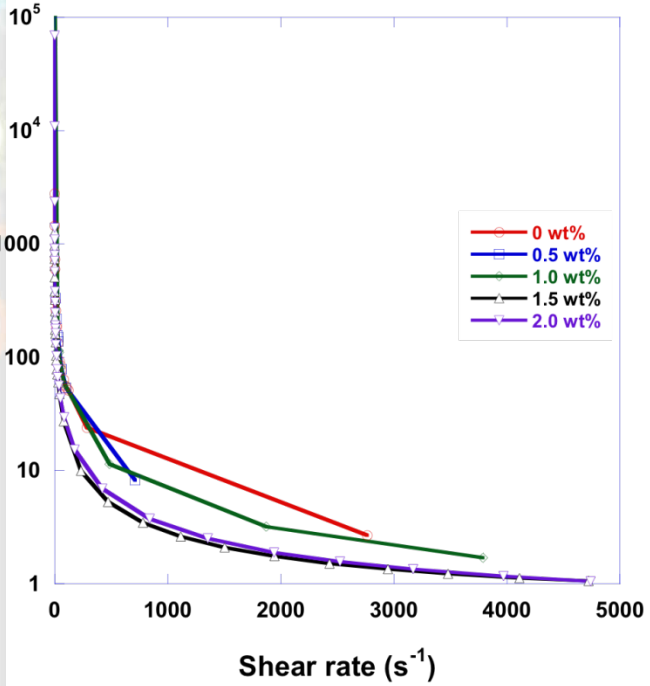


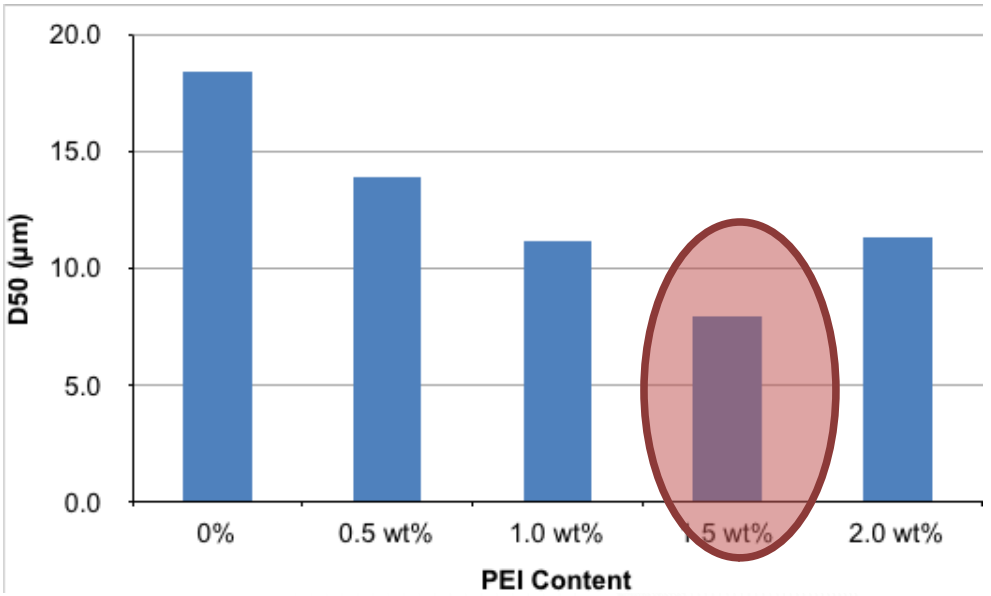


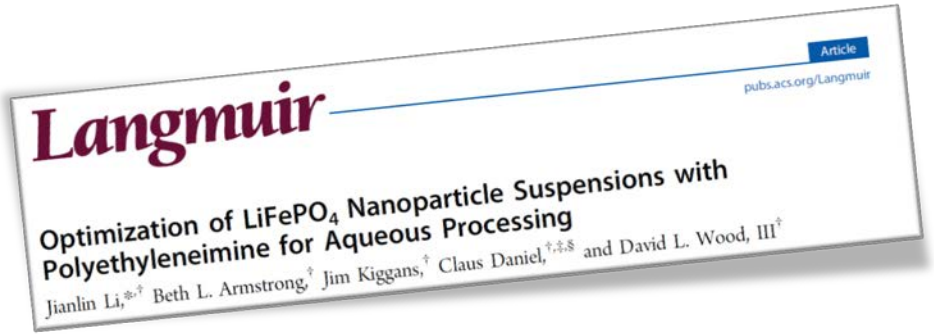
Isoelectric point (IEP): least stable

Composite electrode dispersion control in water

$LiFePO_4$ / C45 / Xanthan Gum / PEI / H_2O =100 / 10 / 2.5 / 0-2 / 250 wt%






Langmuir

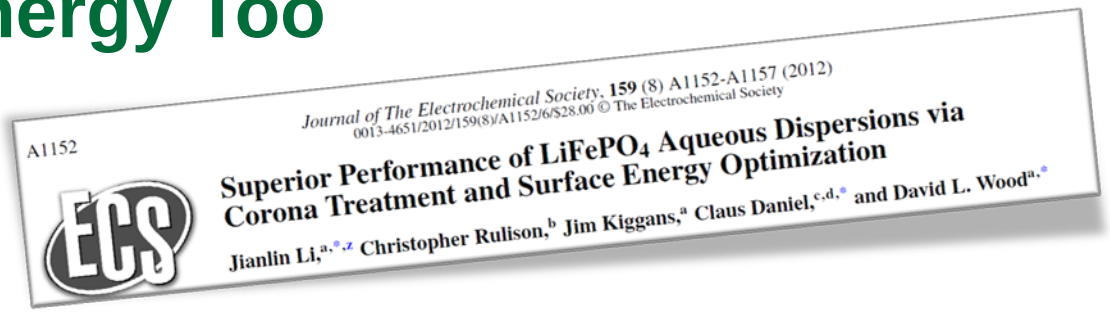
Article

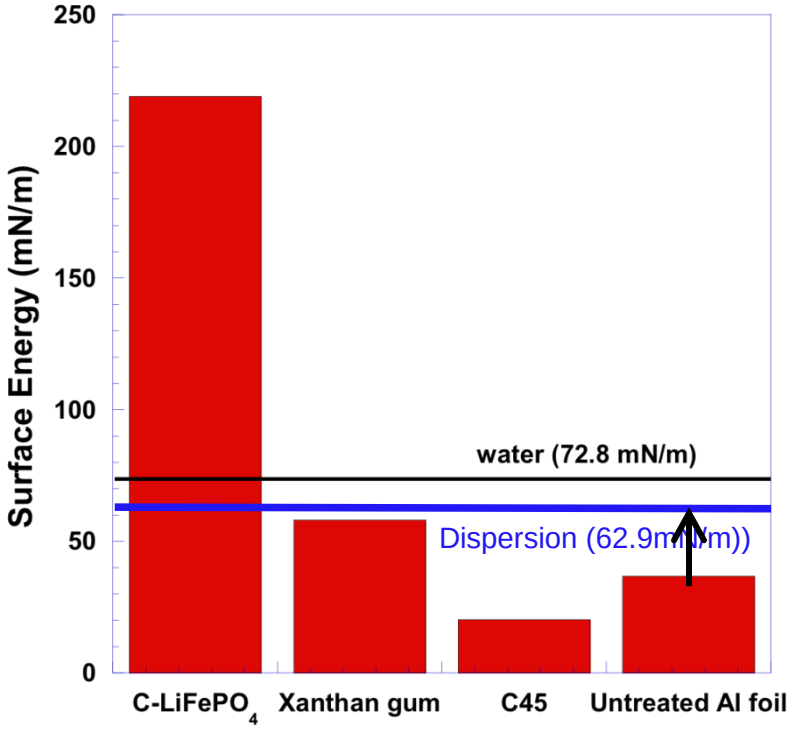
pubs.acs.org/Langmuir

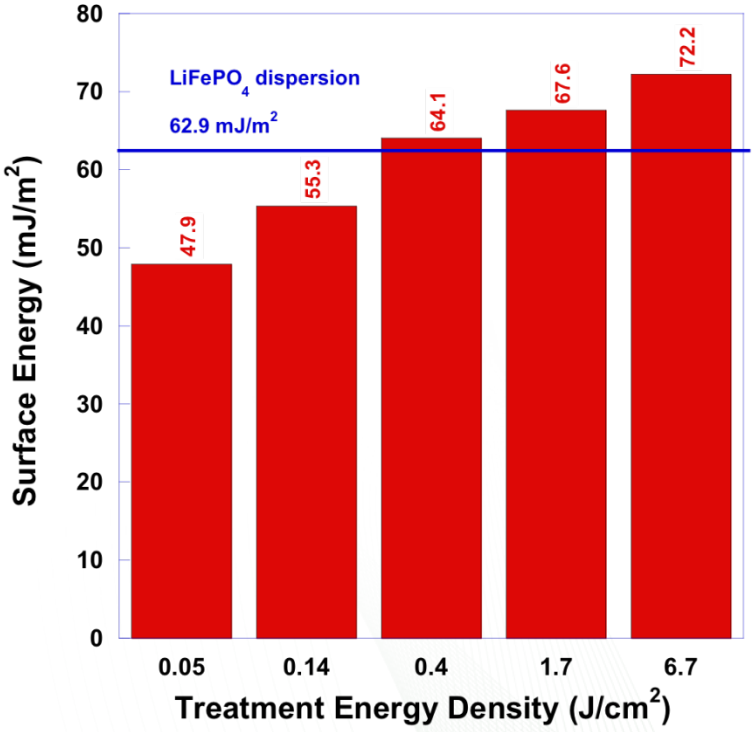
Optimization of $LiFePO_4$ Nanoparticle Suspensions with Polyethyleneimine for Aqueous Processing

Jianlin Li,*[†] Beth L. Armstrong,[†] Jim Kiggans,[†] Claus Daniel,[†,‡,§] and David L. Wood, III[†]

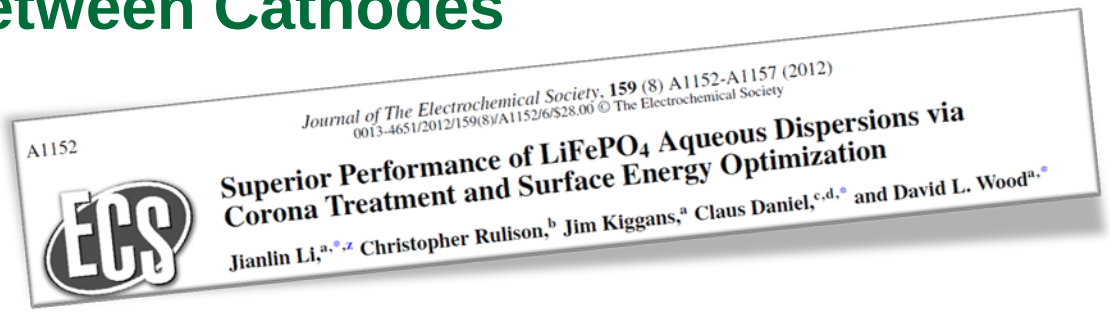
Slurry Surface Energy Too High for Coating

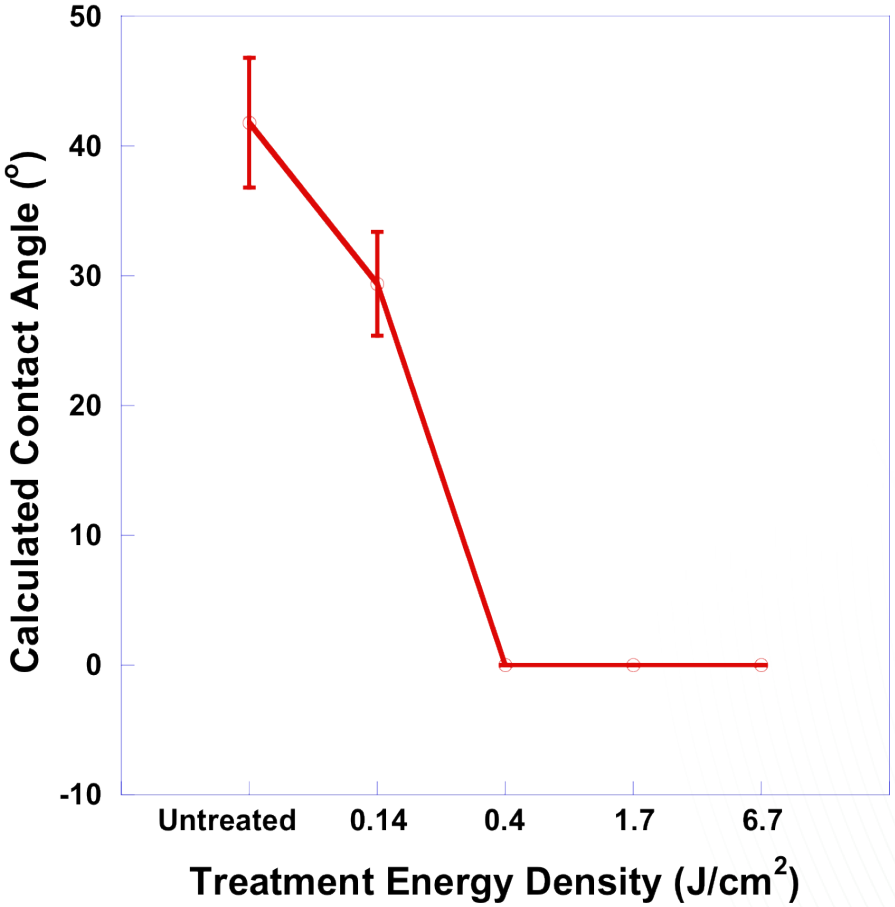






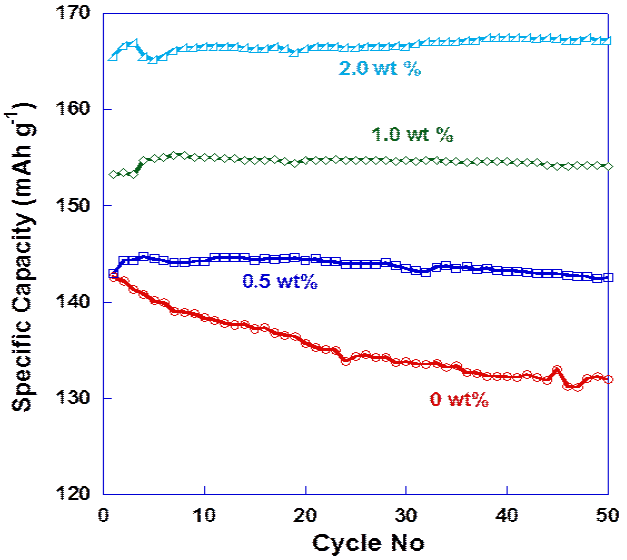
Better Wettability Between Cathodes and Treated Al Foil

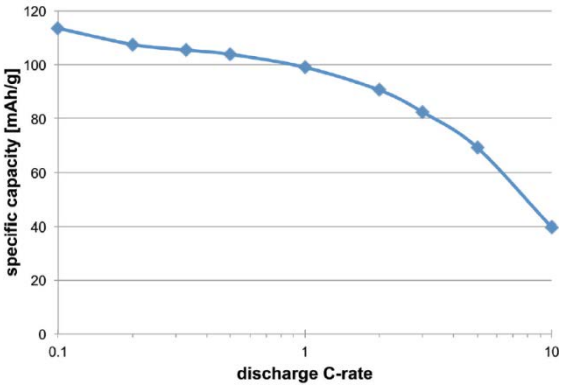


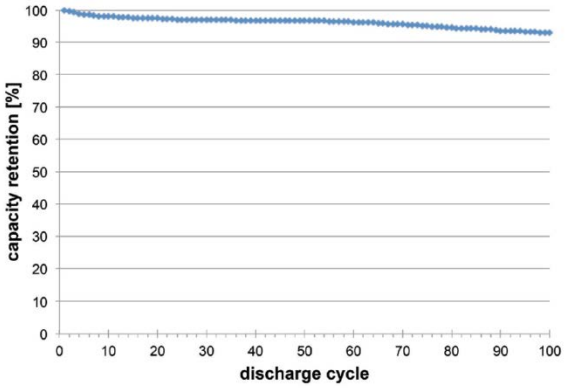


Aqueous electrode processing for lithium ion batteries

- **Elimination of toxic organic solvents**
  - **Organic solvent free processing**
  - **Near theoretical capacity cycling**
  - **Extended cycle life**
- **Reduction of processing cost for electrodes**
  - **Aqueous processing via slot-die coating could reduce electrode coating cost by up to 75% and eliminate expensive, toxic NMP solvent.**
  - **Estimated >15% pack cost reduction.**







US Patent pending US 2013/0108776 A1, pub. May 2, 2013; J Power Sources, 196, 2452–2460 (2011); J Electrochem Soc, 159, A1152–A1157 (2012); Langmuir, 28, 3783–3790 (2012); J Electrochem Soc, 160, A201–A206 (2013); J Colloid Interf Sci, Under Review, 2013

Manufacturing challenges

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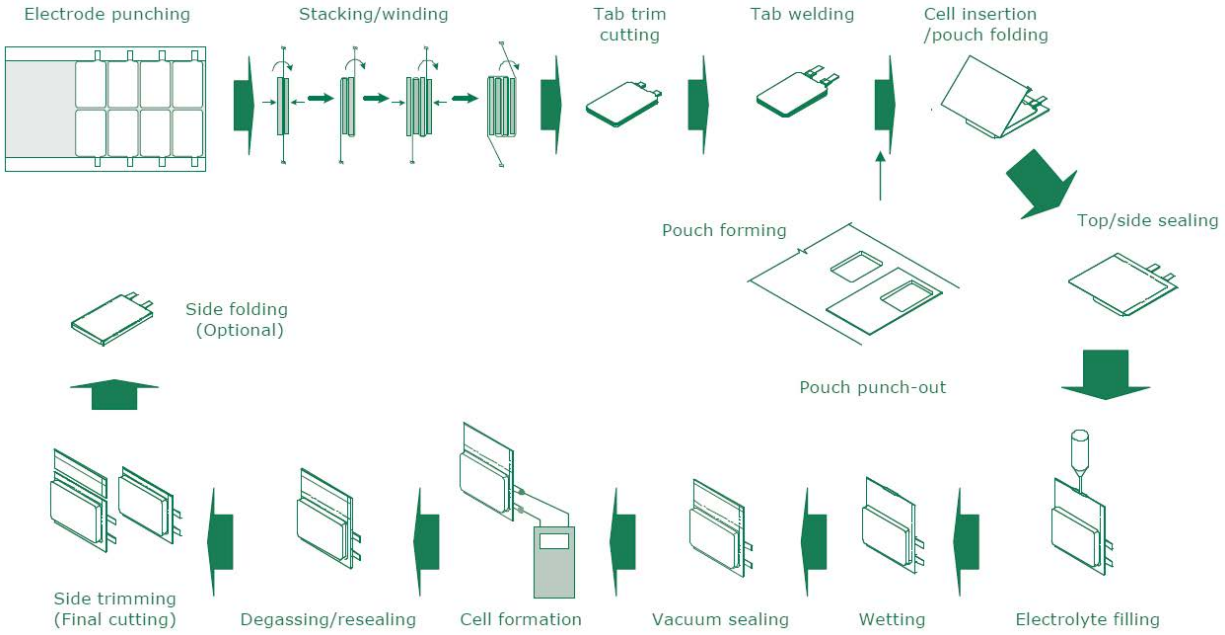
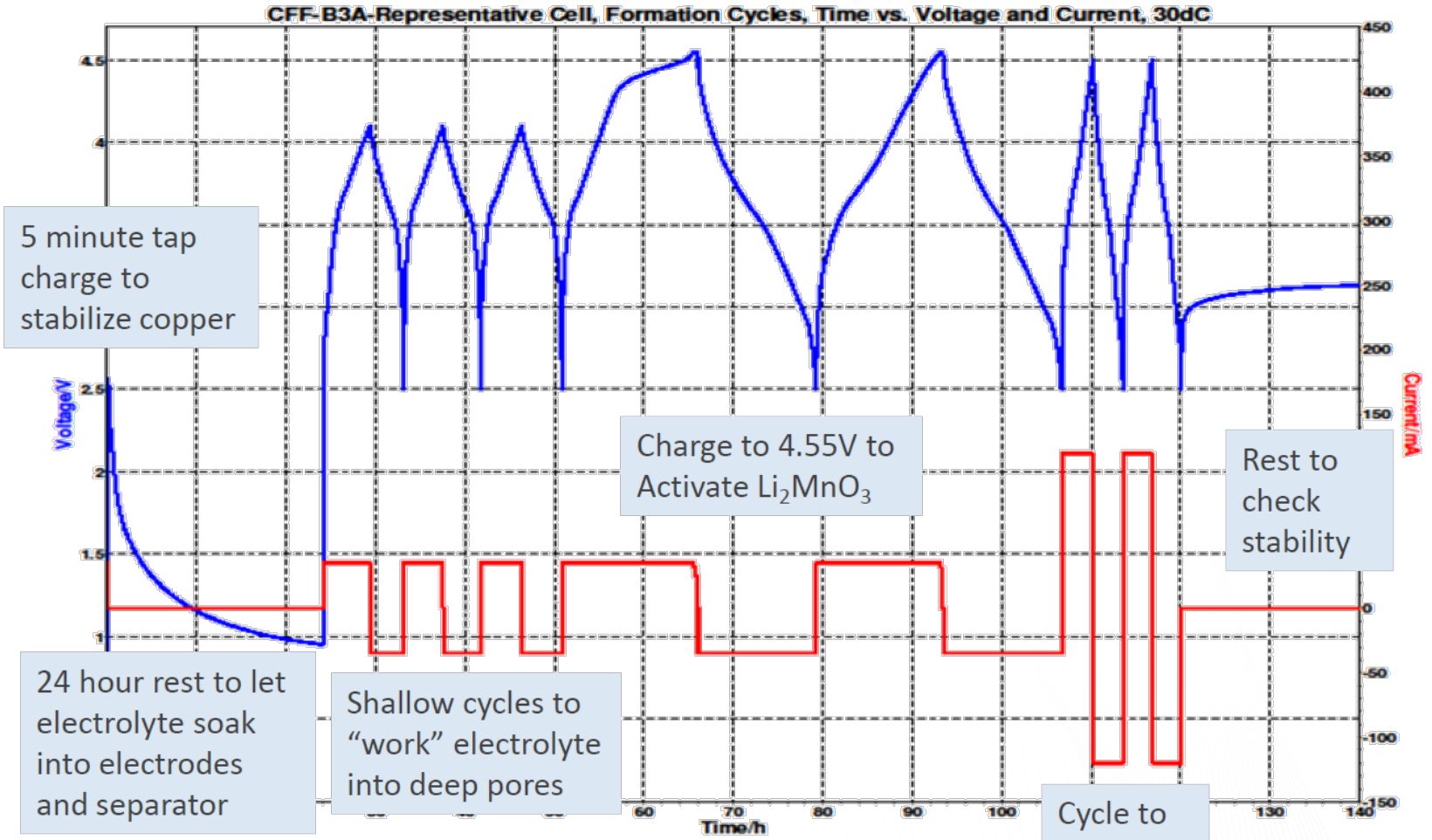
Cell assembly



Post processing

Formation

Formation cycling



From Andrew Jansen, ANL, 2012 AMR, DOE

Thoughts for the future

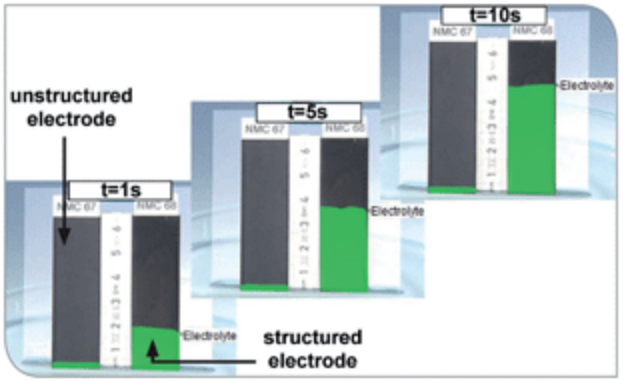
Corrosion science

Manufacturing Science

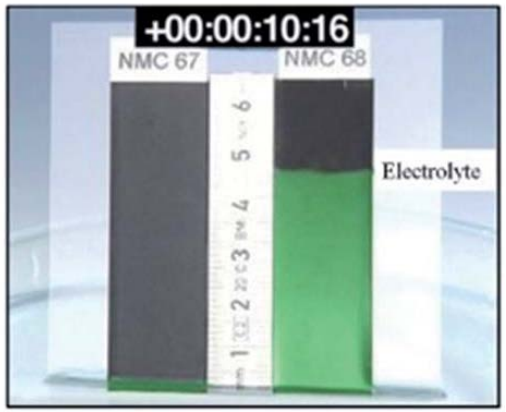
Tribology

Electrochemistry

Process Optimization



Pfleging et al. Mater. Chem. A, 2014,**2**, 14918-14926



Unstructured Laser-structured

Chemical Engineering

Process Engineering

Environmental science

Mechanical Engineering

Physics

New Materials

Chemical and electrochemical stability

Surface science

Mechanical Degradation

Thank you

- Contributors
  - David Wood, Jianlin Li, Debasish Mohanty, Sergiy Kalnaus, Nancy Dudney, Beth Armstrong, Jim Kiggans, Robby Meisner

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