Cell Manufacturing for EV Lithium-ion Batteries

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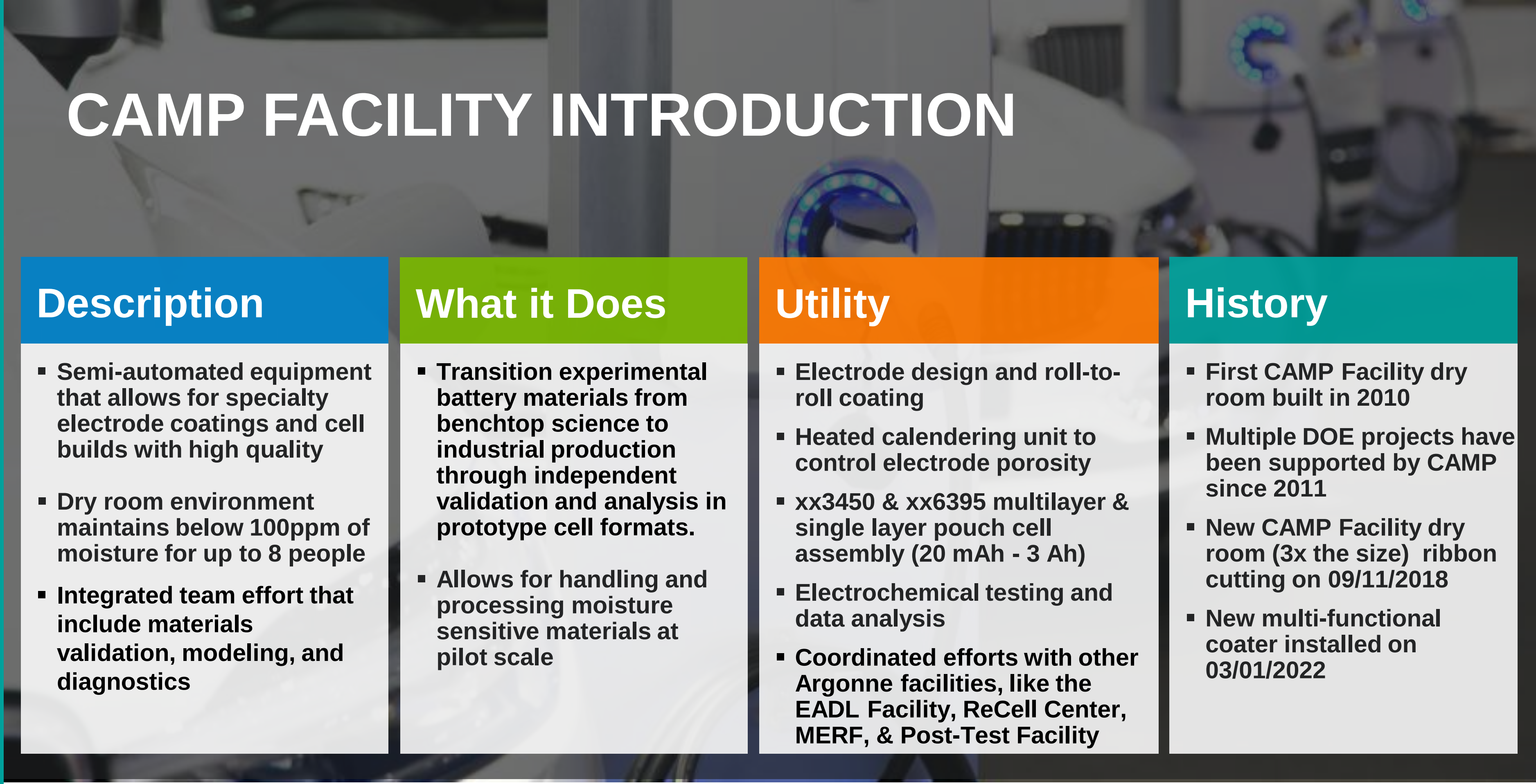
CAMP FACILITY INTRODUCTION



Description

- Semi-automated equipment that allows for specialty electrode coatings and cell builds with high quality
- Dry room environment maintains below 100ppm of moisture for up to 8 people
- **Integrated team effort that include materials validation, modeling, and diagnostics**

What it Does

- **Transition experimental battery materials from benchtop science to industrial production through independent validation and analysis in prototype cell formats.**
- Allows for handling and processing moisture sensitive materials at pilot scale

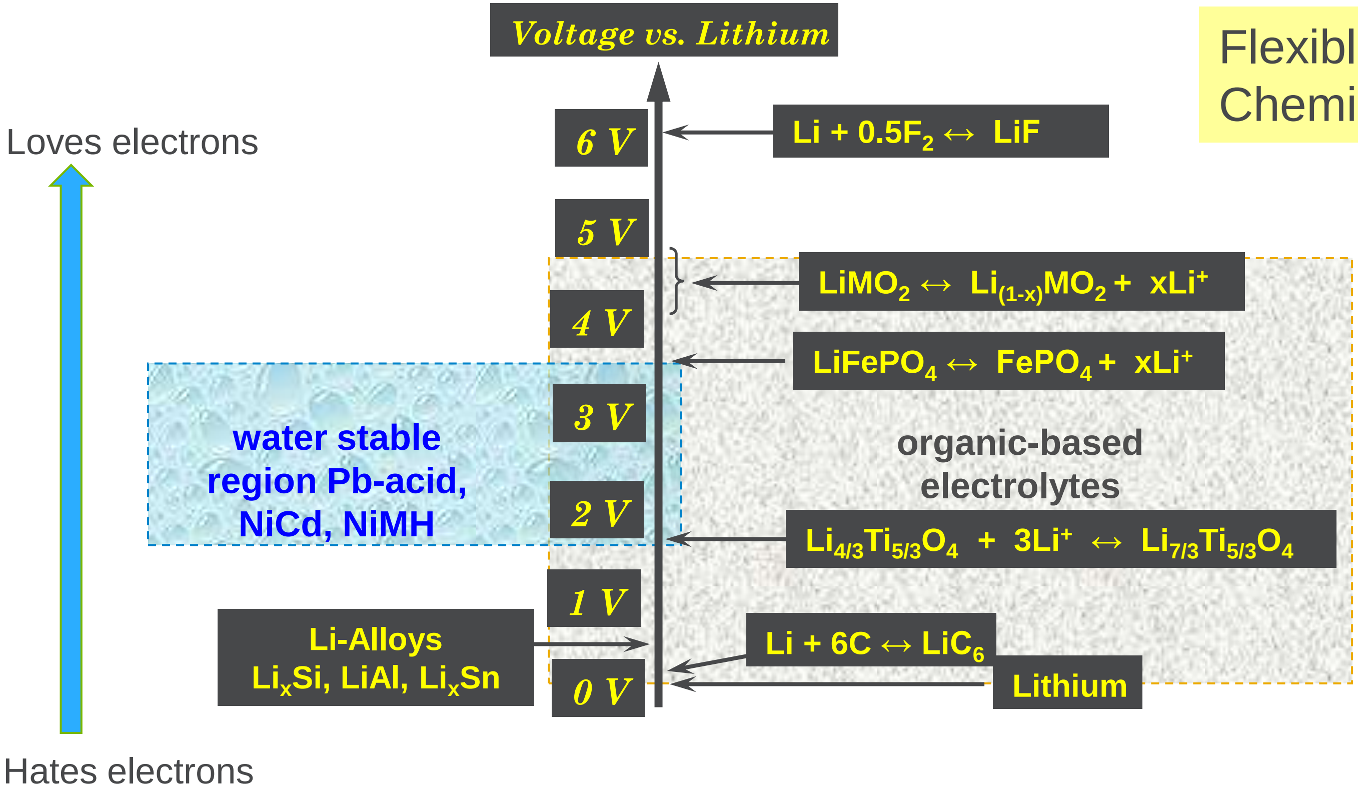
Utility

- Electrode design and roll-to-roll coating
- Heated calendering unit to control electrode porosity
- xx3450 & xx6395 multilayer & single layer pouch cell assembly (20 mAh - 3 Ah)
- Electrochemical testing and data analysis
- **Coordinated efforts with other Argonne facilities, like the EADL Facility, ReCell Center, MERF, & Post-Test Facility**

History

- First CAMP Facility dry room built in 2010
- Multiple DOE projects have been supported by CAMP since 2011
- New CAMP Facility dry room (3x the size) ribbon cutting on 09/11/2018
- New multi-functional coater installed on 03/01/2022

CELL VOLTAGES AND ENERGY/POWER DEPEND ON CATHODE-ANODE COMBINATION



Voltage vs. Lithium

Flexible Chemistry

Loves electrons

Hates electrons

6 V

5 V

4 V

3 V

2 V

1 V

0 V

$Li + 0.5F_2 \leftrightarrow LiF$

$LiMO_2 \leftrightarrow Li_{(1-x)}MO_2 + xLi^+$

$LiFePO_4 \leftrightarrow FePO_4 + xLi^+$

organic-based electrolytes

$Li_{4/3}Ti_{5/3}O_4 + 3Li^+ \leftrightarrow Li_{7/3}Ti_{5/3}O_4$

$Li + 6C \leftrightarrow LiC_6$

Lithium

water stable region Pb-acid, NiCd, NiMH

Li-Alloys
Li_xSi, LiAl, Li_xSn

WHAT HAPPENS IN A Li-ION CELL?

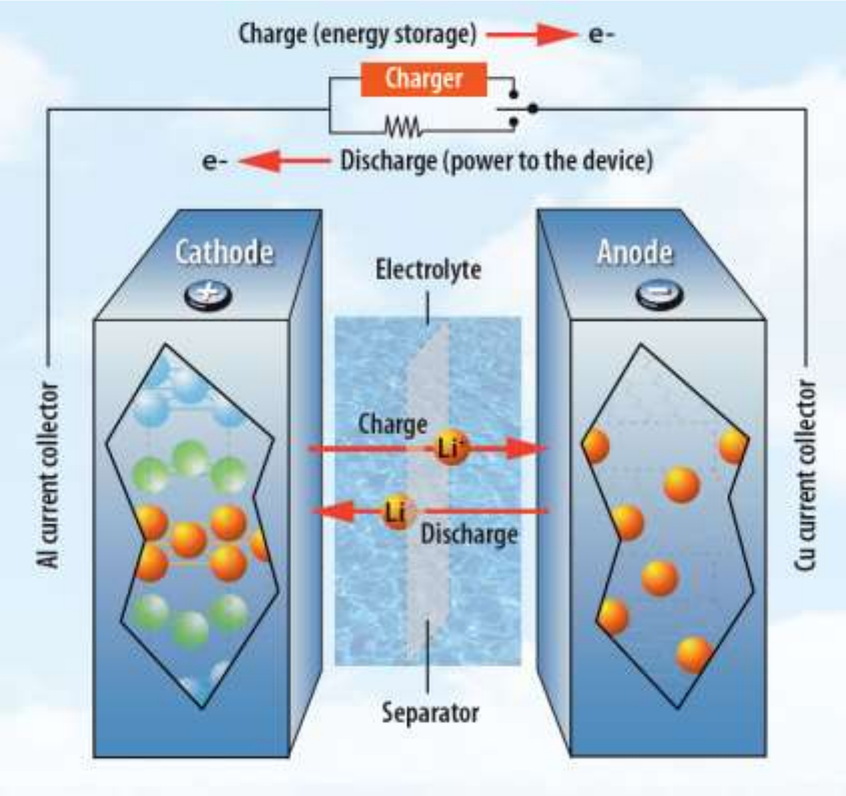
$LiCoO_2$

$Li(NiMnCo)O_2$

$Li(NiCoAl)O_2$

$LiFePO_4$

$LiMn_2O_4$



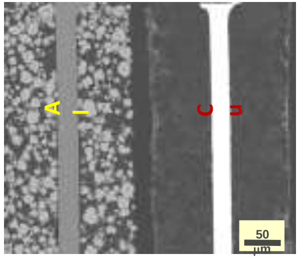
Graphite

$Li_4Ti_5O_{12}$

Li_xSi_y

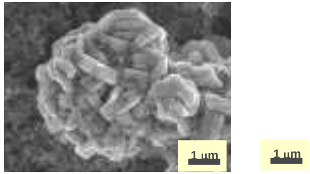
EC:EMC (3:7) + 1.2M $LiPF_6$

MULTISCALE APPROACH TO IMPROVE BATTERIES



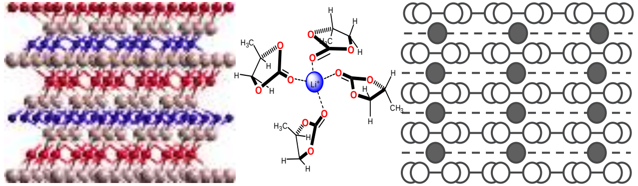
Electrode/Cell scale

Coupled chemical , mechanical, and thermal aging mechanisms alter electrode makeup and affect cell performance



Meso scale

Aging can alter particle morphology through cracking & through surface film formation



Atomic/molecular scale

Aging often induces irreversible and detrimental changes in electrode and electrolyte structures

Identifying sources of performance degradation is the first step to designing long-life cells

ELEMENTS (KG) IN A 100 KWH EV BATTERY

Assuming graphite anode; from BatPaC Version 4, 2022

Element	NMC333	NMC532	NMC622	NMC811	NCA	LFP	LMO
Lithium	14	14	12	**10**	10	9	11
Nickel	35	51	53	**60**	67	0	0
Cobalt	35	20	18	**7**	13	0	0
Manganese	33	28	16	**7**	0	0	139
Iron	0	0	0	**0**	0	61	0
Fluorine	7	6	6	**5**	5	8	8
Aluminum	119	117	109	**101**	106	152	145
Graphite	87	87	85	**85**	87	97	80
Copper	106	103	92	**81**	85	151	144
Steel	2	2	2	**2**	2	3	3

WHERE ARE THE MINERALS FOUND?

90% of cobalt is produced as a by-product of Ni and Cu

Element	Global Producers	Mineral Sources
Lithium	Chile (44%) China (39%) Argentina (13%)	Brine water Spodumene
Natural Graphite	China (69%) India (12%) Brazil (8%)	Natural graphite
Cobalt	Congo DR (59%) China (7%) Canada (5%)	Copper & nickel by-product (Cobaltite, erythrite, glaucodot, skutterudite)
Nickel	Indonesia (30%) Philippines (16%) Russia (10%) New Caledonia (8%) Australia (7%) Canada (7%)	Laterite Pentlandite

Notes from ”2021 European Federation for Transport and Environment”

ELECTRODE MAKING STEPS – DRY ROOM HELPS

Slurry Making

Powders with binder plus carrier (NMP, water)

Coating

Drive off carrier (NMP, water); control loading

Calendering

Reduce porosity to ~30%

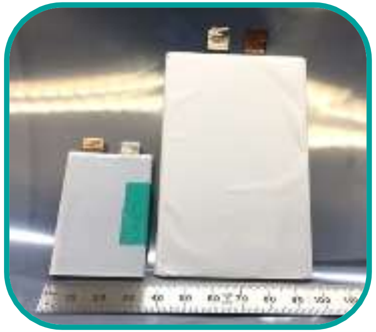
Punching/Slitting

Cut electrode to size
Dry before assembly

CELL MAKING STEPS – MUST BE DONE IN DRY ROOM

Stacking/Winding

Separator between electrodes



Tab Welding

Ultrasonic or laser

Sealing

Heat sealing for pouch, laser or crimping for prismatic or cylindrical

Electrolyte fill

Before final weld

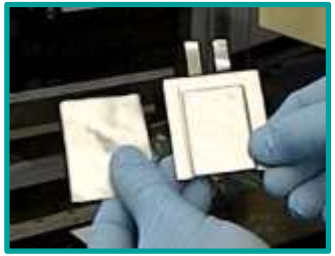
Vacuum sealed

Electrolyte reacts with moisture to make HF

Formation

Cycle for 1-3 weeks to form passivation layers

Degas and reseal



Quality Control is critical!

MULTI-FUNCTIONAL COATER MADE IN TOWANDA, PA

- **State-of-the-art features:**
  - Interchangeable coating heads (Gravure & Slot Die, can get others)
  - Progressive cavity pump
  - Corona treatment
  - IR drying system
- **Coating system greatly enhances adaptability for coating various materials:**
  - Hybrid ceramic polymer electrolyte composite membrane
  - Promising next-gen anodes & cathodes
  - Polymer electrolyte material
  - Thin to thick coatings
  - Structured layered coatings
  - Traditional energy storage materials

Advanced interchangeable coating head system designed for utilization flexibility

FRONTIER
A Delta ModTech Company

Uniform thin coatings were achieved using the gravure coating head.

Al_2O_3 w/ PVDF on substrate

PPG ACTIVITY IN CATHODE COATING TECHNOLOGY

PPG, Cellforce Group to Develop Sustainable Battery Solutions

January 13, 2022

PITTSBURGH--(BUSINESS WIRE)-- PPG (NYSE:PPG) today announced that it has partnered with Cellforce Group, which is a joint venture between Porsche and CUSTOMCELLS, to develop exclusive sustainable battery cell solutions to better serve the electric vehicle and mobility segment.

PPG will supply cathode binder systems, which are free of N-Methylpyrrolidone (NMP) solvent, to the Cellforce Group. The collaboration would eliminate the use of NMP in producing the conductive-carbon slurry that forms cathodes for Li-ion batteries. NMP, which is widely used in electrode manufacturing, has been identified as a reproductive hazard by several global regulatory agencies and was recently identified by the U.S. Environmental Protection Agency (EPA) as an “unreasonable risk” to workers in certain conditions.

“PPG is eager to partner with the Cellforce Group to build the next generation of battery cell technology that will define a new level of sustainability for the electro-mobility segment,” said Markus Vogt, PPG general manager of mobility. “Additionally, the partnership enables collaboration to provide critical technology development to increase cell performance and safety.”

PPG is helping vehicle, battery and component manufacturers accelerate the development of tomorrow’s automotive energy storage solutions. The company’s broad-based materials expertise covers virtually every area of Li-ion battery design and construction, helping customers boost energy density, extend service life, improve safety, increase manufacturing throughput and reduce cost per kilowatt hour.

PPG’s dedicated team of mobility professionals provides differentiated solutions for automotive electro-mobility, such as sustainable binder solutions for the battery cell and coating solutions for the battery pack that include battery fire protection, anti-corrosion coatings for battery packs/trays, dielectric shielding and thermally conductive materials.

ARGONNE’S RECENT BATTERY EXPERIENCE:

SOME DOE PROJECTS CAMP IS INVOLVED IN:

- **ReCell:** Focus on Recycling
  - Validating methods of material recovery & rejuvenating harvested cathodes
  - Recycling Impurity Studies
- **XCEL:** Focus on Fast Charging
  - Improve fast charging through electrode structural changes & system optimization
- **SCP:** Focus on Silicon in Anodes
  - Prelithiation & annealing studies
  - Binder, Si particle size, & low-to-no graphite studies
- **RNGC:** Focus on Earth Abundant Materials (EAM) for Cathodes
  - Experimental low-to-no cobalt / EAM cathode coatings & validation
- **BTMS:** Focus on Battery Storage in Commercial Buildings
  - LTO | LMO & LTO | LFP Builds (lower energy, long life, EAM goal)
  - Electrolyte, separator wetting, & n:p ratio studies

ADDITIONAL EXPERIENCE

- **Solid Polymer Electrolyte (SPE) preparation & characterization**
- **Imaging Analysis**
  - Cell optimization *via* X-ray imaging at the APS
  - Visualizing “breathing” in NMC811/li coin cells

CHEMISTRIES CAMP HAS WORKED WITH

- **Cathodes**: NMCs, LFP, LMO, LCO, LMR-NM, LNO, HE5050, NCA, NMA, spinels, single-wall carbon nanotubes, & other low-to-no cobalt cathodes
- **Anodes:** natural & artificial graphite systems, silicon systems of varying particle sizes, LTO
- **Separators:** PP, PE, PP:PE:PP, ceramic coated polymers, PVDF, polyester fiber, *etc*
- **Binders:** PVDF, CMC, SBR, LiPAA, PAA, Polyimide, *etc*
- **Solid State Systems**
- **Various Electrolytes & Additives**

CAMP FACILITY COLLABORATIONS:

Majority of these collaborations over the past several years are centered on the CAMP Facility providing electrodes, cells, and data

Universities

- Michigan Technological University
- BYU
- Berkeley University of California
- WPI
- UC San Diego
- University of Maryland
- University of Delaware
- Virginia Tech
- Michigan
- Stanford University
- Northeastern University
- UK Kentucky
- Western Michigan University
- UIC University of Illinois at Chicago
- University of Cambridge
- Northwestern University
- The University of Akron
- Ohio Polytechnic University
- RIT
- Oregon State University
- RICE
- Boise State University

Industry

- TODA AMERICA
- Superior Graphite
- Wildcat Discovery Technologies
- CUBERG
- Silatronix
- PARACLETE ENERGY
- NEI Corporation
- 24M
- SEPION Technologies
- 6K Energy
- TARGRAY
- RAYOVAC
- FORGE NANO
- PPG
- Navitas Systems
- SOLVAY
- BOSCH
- CELGARD
- JSR Micro
- BTR power your life
- BASF The Chemical Company
- parc
- Physical Sciences Inc.
- pH Matter LLC
- ARKEMA
- DRAPER
- ECELLIX

National Laboratories

- ARL
- Oak Ridge National Laboratory
- CEES
- Berkeley Lab
- INL Idaho National Laboratory
- arpa-e
- JPL Jet Propulsion Laboratory
- Sandia National Laboratories
- NREL
- CSIRO
- Pacific Northwest National Laboratory
- Brookhaven National Laboratory
- WMG Innovative Solutions
- CATAPULT High Value Manufacturing
- JCESR Joint Center for Energy Storage Research

Support from Haiyan Croft, Peter Faguy, Steven Boyd, and David Howell of the Department of Energy's Vehicle Technologies Office is gratefully acknowledged.

Thank you!
Any Questions?

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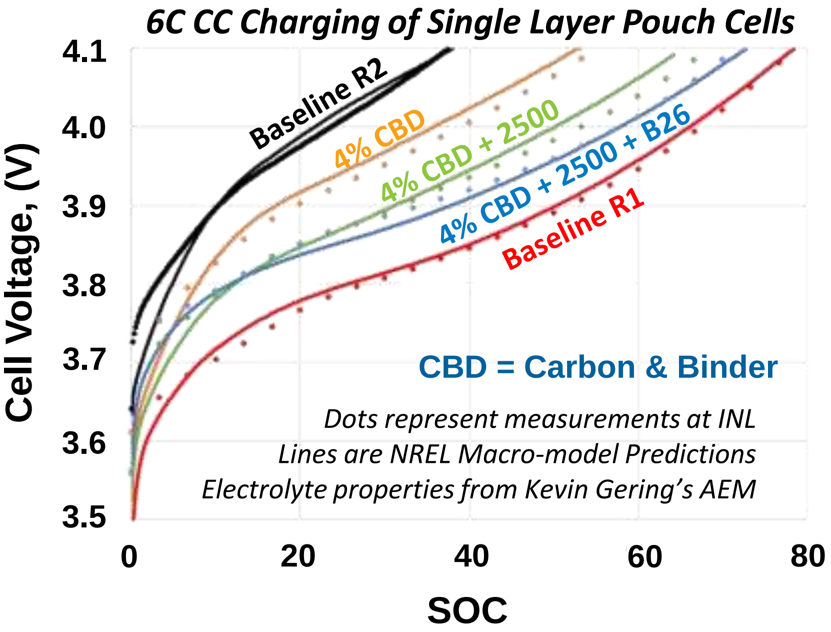
Steve Trask, Alison Dunlop, Marco Rodrigues, Daniel Abraham, Wenquan Lu

COMBINED APPROACH TO IMPROVE FAST CHARGING

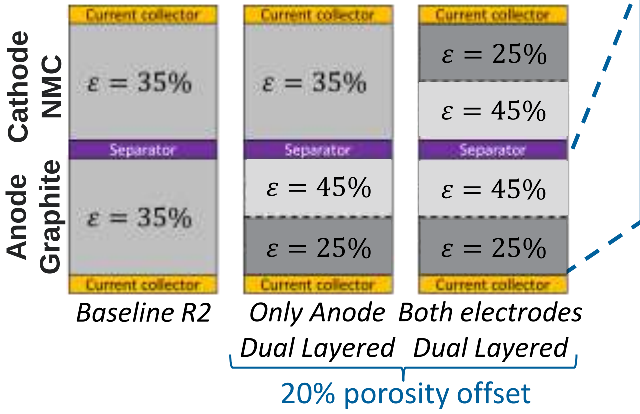


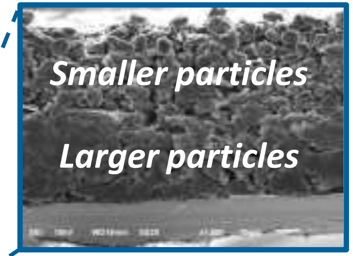
6C CC Charging of Single Layer Pouch Cells

CBD = Carbon & Binder

Dots represent measurements at INL
Lines are NREL Macro-model Predictions
Electrolyte properties from Kevin Gering's AEM

NMC | Gr Case	6C CC/ 10 min predicted capacity
Baseline R2 (~2.6 mAh/cm²)	38% / 77%
4% CBD (~2.7 mAh/cm²) + 2500 + B26	73% / 91%
Baseline R1 (~1.6 mAh/cm²)	79% / 93%



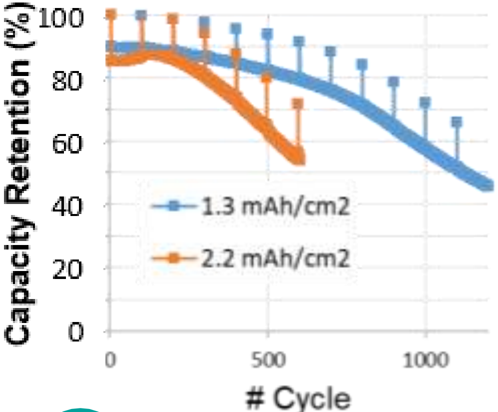


SLC1520P/SLC1506T

- Reduced CBD loading (10% baseline → 4%)+ high porosity separator (2500) + enhanced electrolyte (B26)
- Bilayer architecture for improving fast charging
- Optimized front of electrode for transport (~power cell) & optimized back of electrode for storage (~energy cell)

POUCH CELLS USING SiO$_x$-RICH ELECTRODES:

Initial experiments using commercial SiO$_x$ material provided information on anticipated challenges when processing high-loading electrodes and fabricating prototype cells



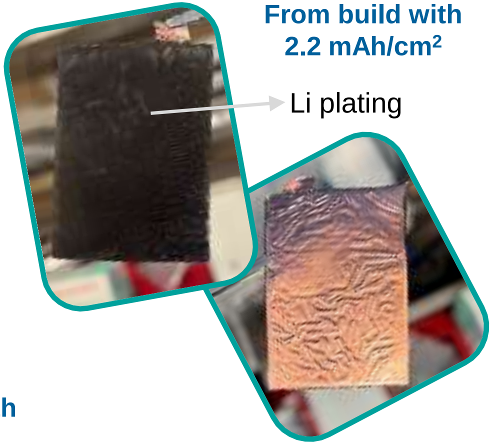
70% SiOx, 10% C45, 20% P84 binder

vs. NMC811
Gen2 + 3% FEC

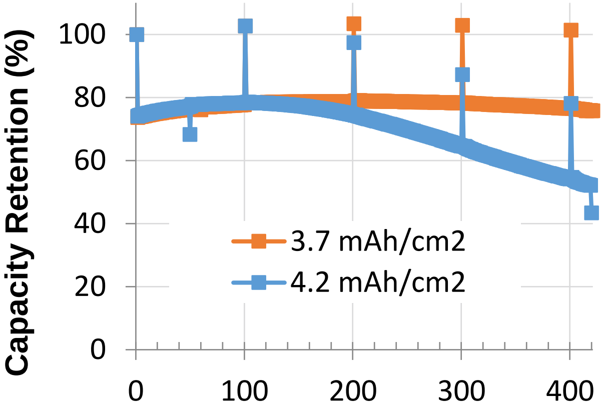
Thin: 3 - 4.15 V, prelith. to 850 mV
Thick: 3 - 4.06 V, prelith. to 600 mV
1x C/10, HPPC, 99x 1C, loop

~950 mAh/g$_{SiOx+C}$ utilization

From build with 1.3 mAh/cm²



From build with 2.2 mAh/cm²



vs. NMC811
Gen2 + 3% FEC

3 - 4.15 V, prelith to 600 mV
1x C/10, HPPC, 99x 1C, loop
same anode, varying cathodes

640 / 715 mAh/g$_{SiOx+C}$ utilization

60% SiOx, 17% graphite, 10% C45, 20% P84 binder