Co-Extrusion (CoEx) for Cost Reduction of Advanced High-Energy-and-Power Battery Electrode Manufacturing

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Project ID # BAT266

Contributors

PARC: Scott Solberg, Kathryn Murphy, Rahul Pandey

ORNL: Kelsey Grady, Marissa Wood, Jianlin Li,, David Wood

Ford: Renata Arsenault, Kent Snyder, Chulheung Bae

Overview

Timeline

- Project start date:
  December 17, 2015
- Project end date:
  Aug 17, 2019
- Percent complete:
  100%

Barriers Addressed

- **Cost**: Current cost of Li-ion batteries is ~$200–$300/kWh, a factor of about two to three times too high on a kWh basis.
- **Performance**: High energy density battery systems to meet both volume and weight targets.

Budget

- Total project funding:
  DOE share: $2,999,115
  PARC share: $787,478
- FY 2019 Funding (DOE): $764,127

Partners

Project Lead

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Project Partners

Oak Ridge National Laboratory

Ford

Collaborations

Navitas Systems

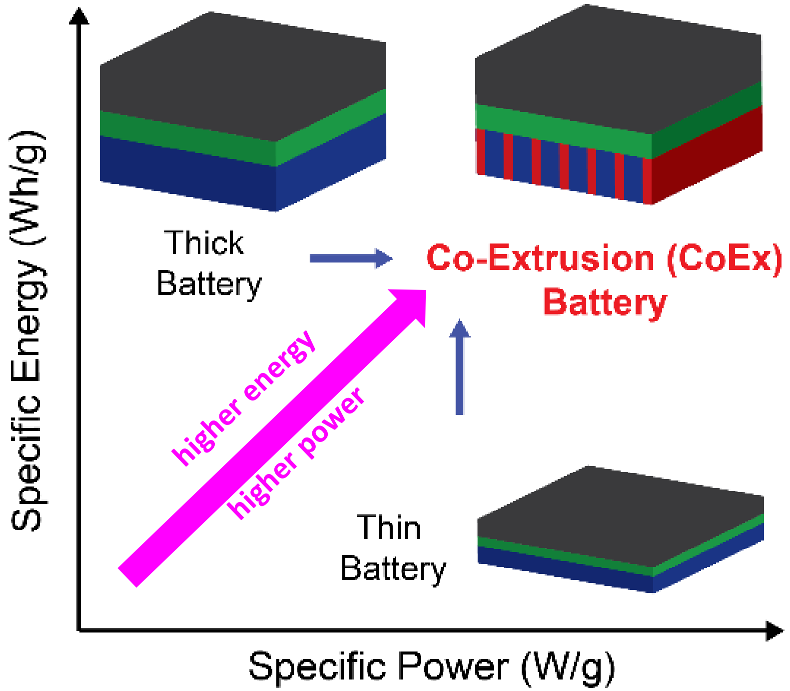
Argonne National Laboratory

SLAC National Accelerator Laboratory

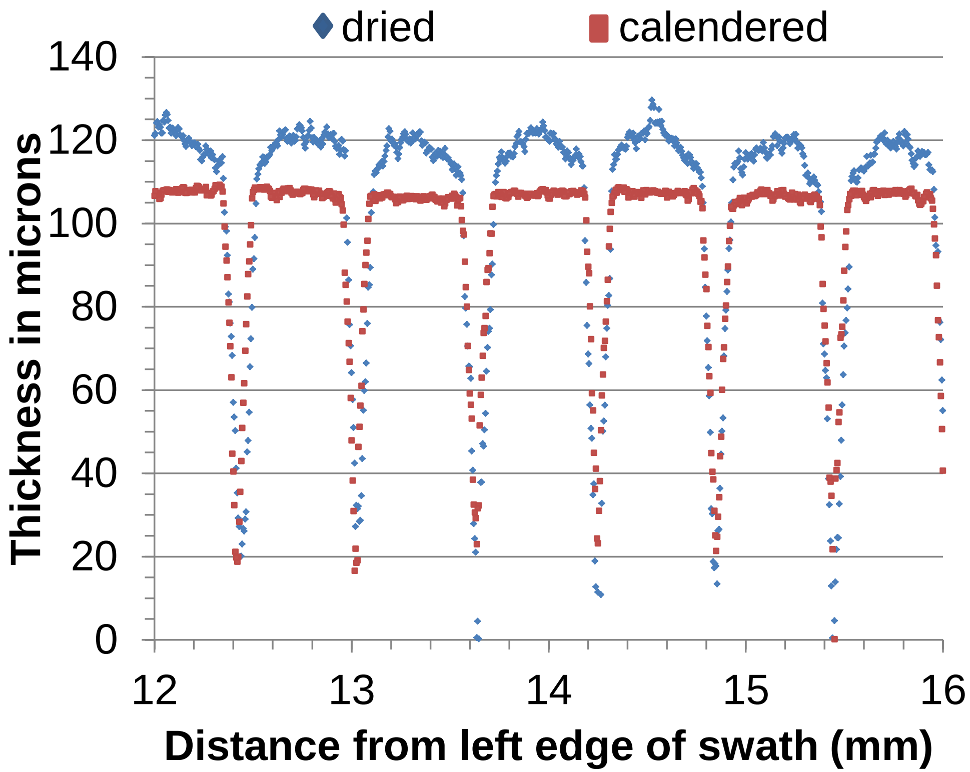
Relevance and Project Objectives

- Overall Project Objectives:
  - Demonstrate pilot scale, electric vehicle (EV)–relevant 14 Ampere hours (Ah) pouch cells using Co-extrusion (CoEx), addressing:
    - <u>Cost Barrier</u>: ≥30% reduction in $/kWh costs through thick structured high energy and power electrodes
    - <u>Performance Barrier</u>: Gravimetric energy density improvement of ≥ 20% relative to conventional electrodes of the same chemistry

- March 2019–September 2019 Objectives:
  - Install large CoEx printhead and associated print hardware on web coater in Battery Manufacturing Facility at ORNL
  - Print multiple meters of CoEx cathode, baseline cathode, and matching anodes
  - Prepare electrode materials for assembly into large pouch cells and subsequent electrochemical testing

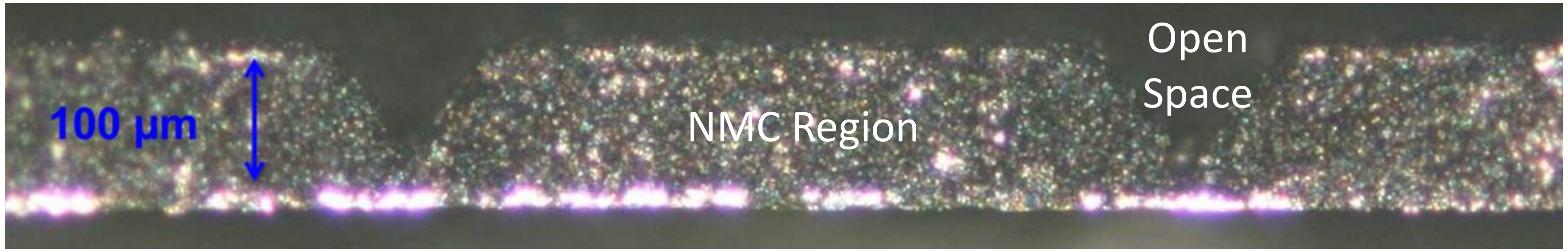


Approach: CoEx Structured Cathodes



CoEx printheads and slurry formulations can be used to create corrugated electrode structures, with periodic grooves that fill with electrolyte and provide fast ionic transport

These grooves form during drying and maintain their shape during calendering process



Current Collector

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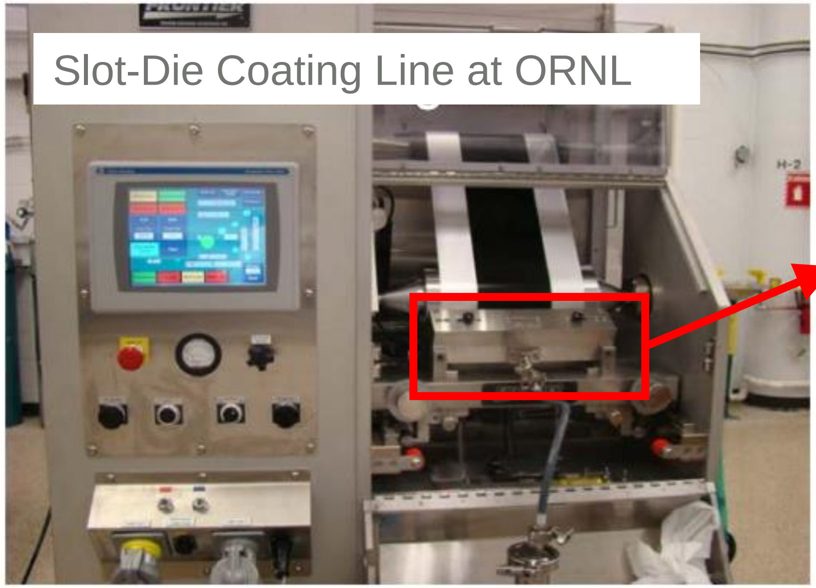
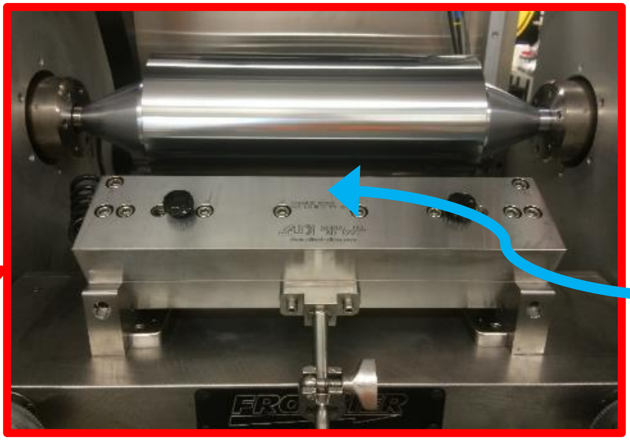
Approach and Strategy: ORNL BMF

End of Project Goals

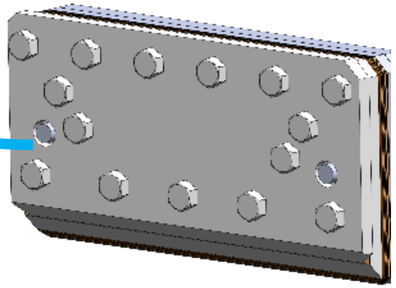
- Integration of pouch cell scale CoEx printhead equipment at ORNL Battery Manufacturing Facility (BMF) and production of large format CoEx Cathodes
- Development of thick matching anodes by ORNL using slot-die coating
- Production and characterization of 14 Ah pouch cells
- Develop a plan for commercialization of the CoEx technology with potential end-users and suppliers



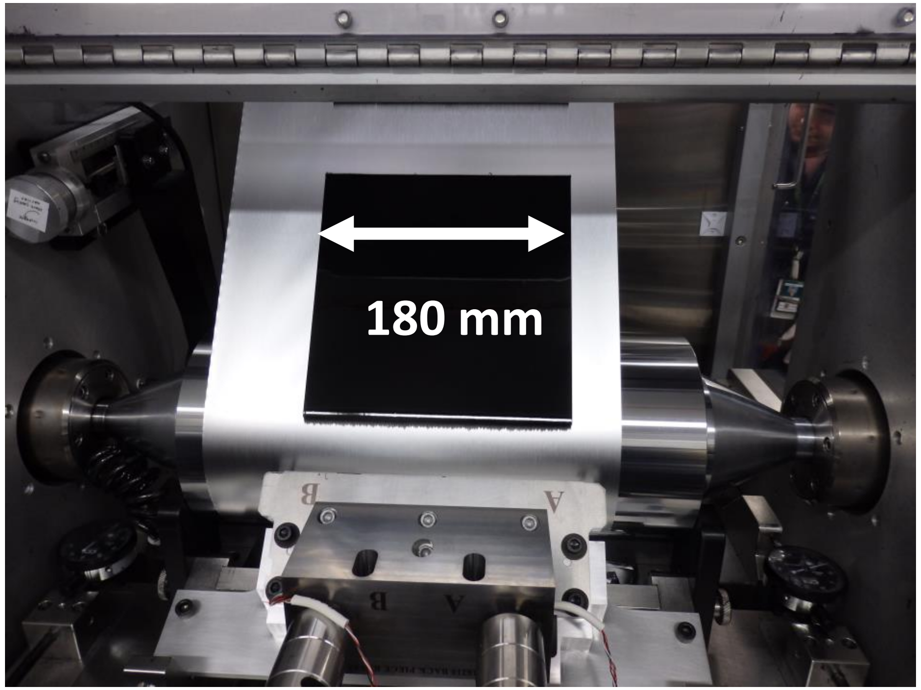


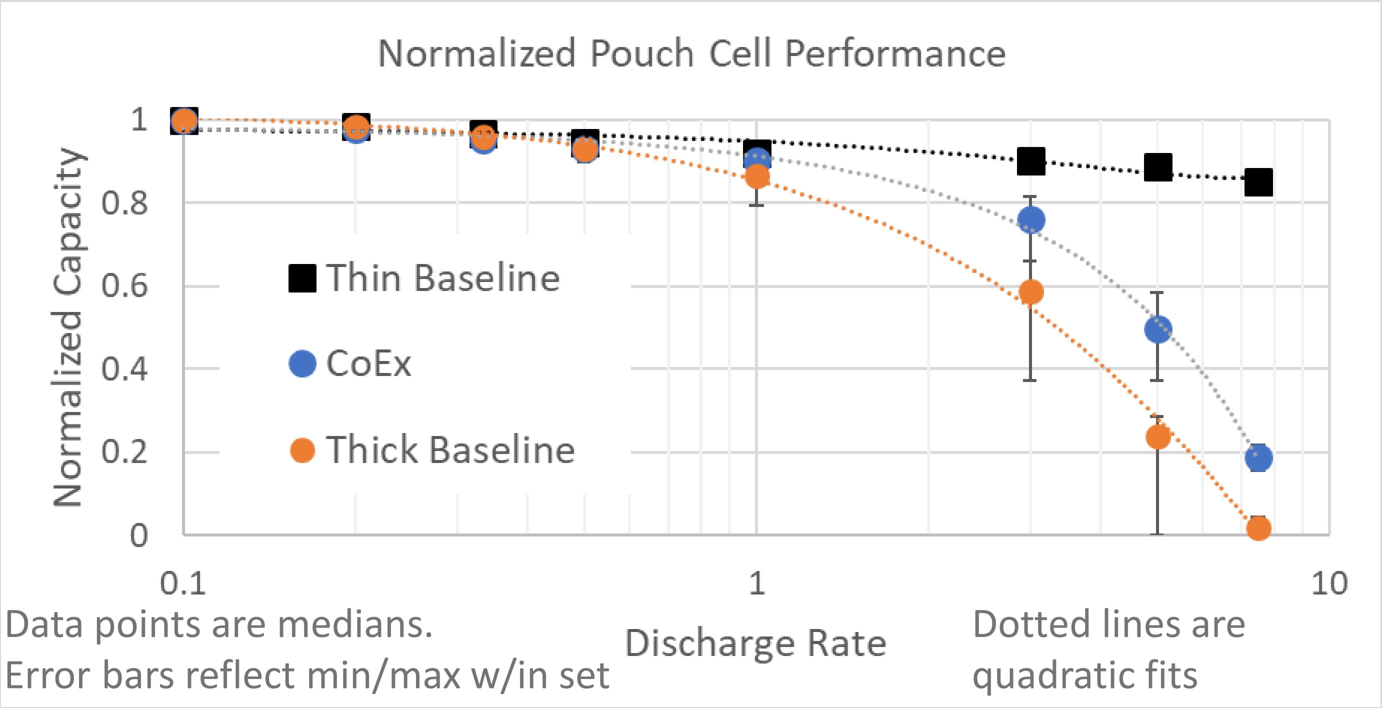
Slot-Die will be replaced with CoEx printhead & high pressure slurry dispensers

PARC CoEx printhead



Technical Accomplishments and Achievements – Web Coating and Pouch Cell Testing





- Baseline (nominal active material loading of 16 mg/cm^2), thick baseline (25 mg/cm^2), and CoEx (25 mg/cm^2) cathodes were manufactured on the web coater in the BMF
- These electrodes were used to prepare ~ 16 Ah pouch cells and test them electrochemically
- The CoEx pouch cells performed better than the thick baseline (unstructured) cathodes, even though both sets of cells had similar loading and porosity

Technical Accomplishments and Achievements – Energy Density Summary

Median Volumetric E-Density Values (Wh/L)			
	Thin Baseline	Thick Baseline	CoEx
D/10	412.7	440.0	441.4
D/2	387.7	403.2	400.7
1D	374.3	361.2	378.8
2D	360.1	233.9	306.8
5D	319.9	6.7	74.5

Median Gravimetric E-Density Values (Wh/kg)			
	Thin Baseline	Thick Baseline	CoEx
D/10	177.4	192.8	197.3
D/2	166.9	176.8	179.7
1D	160.8	158.4	169.9
2D	154.8	102.6	134.8
5D	138.0	3.0	31.9

% Difference in Energy Density				
	CoEx Vs Thin Baseline		CoEx vs Thick Baseline	
	Wh/L	Wh/kg	Wh/L	Wh/kg
D/10	7.0	**11.2**	0.3	2.3
D/2	3.4	7.7	-0.6	1.6
1D	1.2	5.7	4.9	7.2
2D	-14.8	-12.9	**31.2**	**31.4**
5D	**-76.7**	**-76.9**	**1007**	**983**

- Above, we compare the median volumetric and gravimetric energy densities for the tested pouch cells, which shows how CoEx cells have high energy density at low discharge rates and suffer less degradation at higher discharge rates compared to the thick baseline cells
- Left, we compare the CoEx cells to the thin and thick baseline in terms of percentage difference in energy density at the different discharge rates

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Collaboration and Coordination

Palo Alto Research Center (Prime)
Developing CoEx printhead hardware and print development. (Key Contributors: Ranjeet Rao (PI), Scott Solberg, Corie Cobb (now at UW), Kathryn Murphy, Rahul Pandey

Oak Ridge National Lab (Project Partner)
Developing the matching high capacity anode, providing materials guidance, 1-6 Ah pouch cell assembly, and BMF integration assistance for CoEx hardware (Key Contributors: Marissa Wood, Jianlin Li, Kelsey Grady, David Wood)

Ford Motor Company (Project Partner)
Providing guidance and recommendations on baseline electrode design, testing and cycling protocols, and market evaluation of CoEx technology (Key Contributors: Kent Snyder, Renata Arsenault, and Chulheung Bae

Navitas Systems (Collaboration)
Providing use of pouch cell assembly equipment for 14 Ah pouch cells in FY 2019 (Special Thanks to Chris Silkowski & Michael Wixom)

Argonne National Labs (Collaboration)
Providing guidance on best practices for coin cell assembly and half cell testing protocols (Special Thanks to Bryant Polzin & Daniel Abraham)

SLAC National Accelerator Laboratory (Collaboration)
Using synchrotron radiation source to perform microstructural analysis of CoEx electrodes (Special Thanks to Johanna Nelson Weker)

Proposed Future Research

- This project’s funding period has ended

Summary Slide

- **Relevance**
  - Demonstrate pilot scale, electric vehicle (EV)–relevant, 14 Ampere hours (Ah) pouch cells via Co-Extrusion (CoEx), with goals of 30% reduction in cost and gravimetric energy density improvement of ≥ 20%
- **Approach**
  - Develop thick structured electrodes with CoEx to mitigate power and energy trade-offs in cathodes
  - Use advanced slot coating capabilities to develop a matching, thick, high capacity anode
  - Leverage ORNL's BMF to scale up CoEx production to produce 14 Ah pouch cells
- **Technical Accomplishments**
  - We have demonstrated that the CoEx printhead technology is compatible with web coating, and multiple meters of defect free coatings were used to create ~ 16 Ah pouch cells
  - Two different baseline pouch cells, comprised of conventional, unstructured cathodes at low and high loading were also created to compare against the CoEx cells
  - Electrochemical testing shows that the CoEx cells have similar energy density to the highly loaded baseline cells at low (D/10) discharge rates, but substantially higher energy density at > 1D discharge rates
  - At low discharge rates, CoEx cells showed energy density gains of 7 and 11% (volumetric and gravimetric, respectively) compared to the thin baseline

- **Technical Back Up**

Technical Backup – Electrochemical Testing

- Testing Instruction: To summarize the test, all charge steps were conducted with a CCCV charge at 0.33C with current cut-off of 0.07C. The sequence of discharge rates was D/10, D/5, D/3, D/2, 1D, 2D, 3D, 5D, 7.25D & D/5. Cells were allowed 20 minutes to rest after each charge and 30 minutes after each discharge. All testing was conducted at room temperature.
- It's 7.25D instead of 10D because the cells were higher capacity than initially estimated and 10D would exceed the current capabilities of the testing equipment

	Thin Baseline - Capacity (Ah)				Thick Baseline - Capacity (Ah)				CoEx - Capacity (Ah)				
Nominal Discharge Rate	Cell 1	Cell 2	Cell 3	Cell 4	Cell 1	Cell 2	Cell 3	Cell 4	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
D/10	15.6	16.0	15.4	16.1	17.1	17.2	17.6	15.4	16.6	10.2	17.9	17.4	16.2
D/5	15.4	15.8	15.2	15.8	16.9	17.0	17.3	15.0	16.2	10.0	17.5	17.0	15.8
D/3	15.2	15.4	15.0	15.4	16.7	16.7	16.8	14.5	15.7	9.7	17.1	16.6	15.5
D/2	15.0	15.0	14.8	15.0	16.3	16.2	16.3	13.9	15.3	9.5	16.7	16.2	15.2
1D	14.5	14.6	14.3	14.7	15.4	15.0	15.2	12.3	14.7	9.2	16.3	15.7	14.6
2D	14.1	14.5	13.9	14.5	11.3	10.4	10.1	5.7	12.6	7.8	14.5	10.0	12.0
3D	13.9	14.3	13.6	14.3	4.9	4.1	4.1	0.0	8.5	5.0	10.5	6.4	6.9
5D	13.3	13.7	13.2	13.5	0.7	0.4	0.3	0.0	3.2	1.9	3.8	2.7	2.3
7.5D	11.5	11.7	10.9	10.1	0.0	0.0	0.0	0.0	1.5	0.9	1.6	0.9	1.3
D/5	15.4	15.6	15.3	15.6	17.0	17.2	17.3	15.1	15.8	10.0	17.4	16.9	15.9

- Due to an oversight in testing, we only have electrode weights for 2 of these 13 pouch cells, and as such the only real way to compare them is to normalize these cells to their D/10 capacity
- <u>Note: One of the CoEx cells is only 18 cathode layers (9 double-sided cathodes) and that's why the capacity is lower</u>

Pouch Cell Construction

	Thin Baseline	Thick Baseline	CoEx
Cathode Loading (mg/cm^2) active material	16	25	25
Number of cathode layers in pouch cell	44	28	28

Each layer's cathode area is 162 cm^2