U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

High Throughput Solvent-Free Manufacturing of Battery Electrodes| AMMTO

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DE-EE009109| June 30, 2020 – December 31, 2023

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Project Overview

- **Address some of the current gaps in solvent-free electrode processing**
  - Extend the dry electrode fabrication process to lithium-ion battery anode manufacturing
    - State-of-the-art binder systems are not compatible with current cell designs
    - Solvent-free anodes suffer from poor mechanical strength and stability
  - Intensify the process through improved mixing, powder rheology and surface modifications
    - Remove previously used processing additives for improved mechanical and electrochemical performance
  - Enable processing of next-generation electrode materials that are not stable to solvent or ambient air exposure
  - If successful, solvent-free technology can be transferred to small and large-scale lithium-ion manufacturing
- **Final deliverable of a 250 Wh/kg cell with 1000 cycles, in an EV format**
- **A special thanks to all our program partners – Cabot Corporation, Arkema, the University of Tennessee at Knoxville (UTK), and Oak Ridge National Laboratory**

Project Outline

Innovation: High-throughput dry-process electrode manufacturing

Project Lead: Navitas Systems, LLC.

Project Partners: Cabot, Arkema, University of Tennessee at Knoxville, Oak Ridge National Lab

Timeline: June 30, 2020 – December 31, 2023, 80% progress

Budget: Total Project Funding: $5.5M, DOE Share: 80%, Contractor Share: 20%

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$1.6M	$0.93M	$1.87M	$4.4M
Project Cost Share	$0.38M	$0.23M	$0.49M	$1.1M

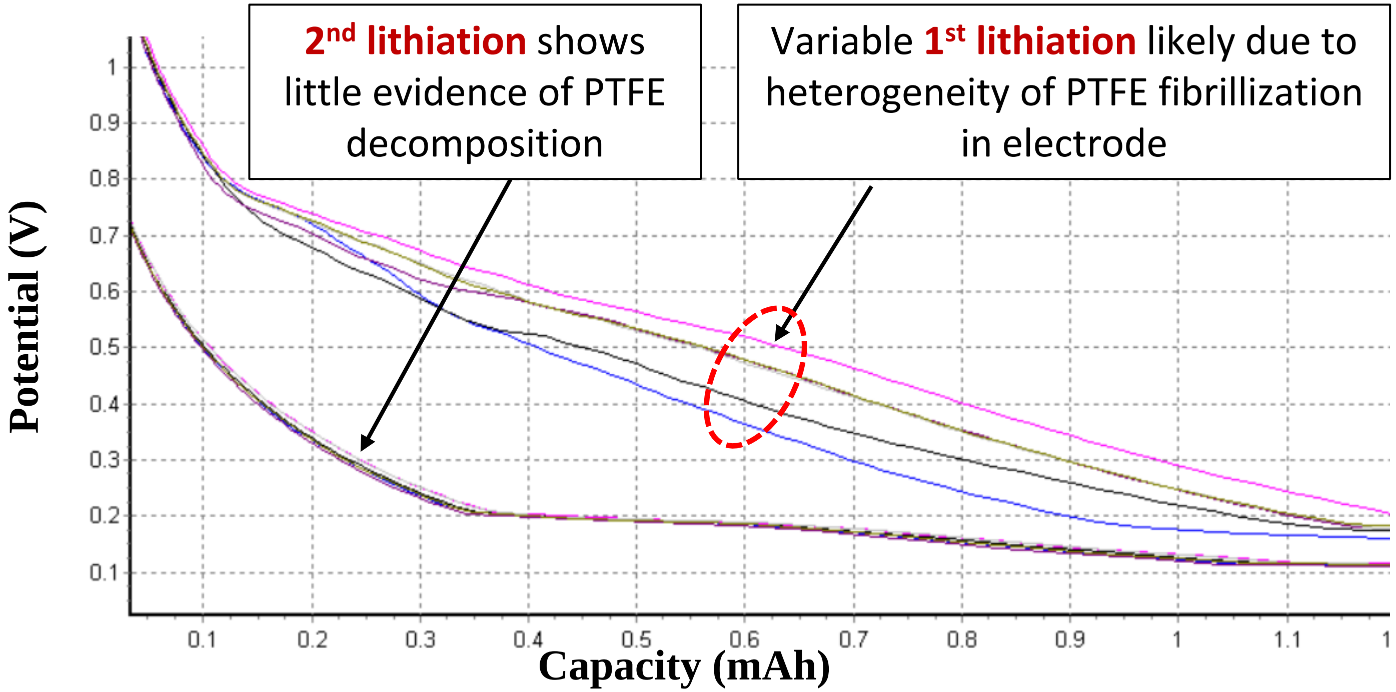
End Project Goal: **demonstrate an EV format cell with a specific energy density of 250 Wh/kg and 1000 cycle capability**

Background & Strategic Approach (1)

- **Material development to address anode formulation and electrochemical challenges**

PTFE reacts at Li^+ at low potential (~0.7V)[1]

$$(C_2F_4)_n + 4nLi^+ + 4ne^- \rightarrow 2nC + 4nLiF$$

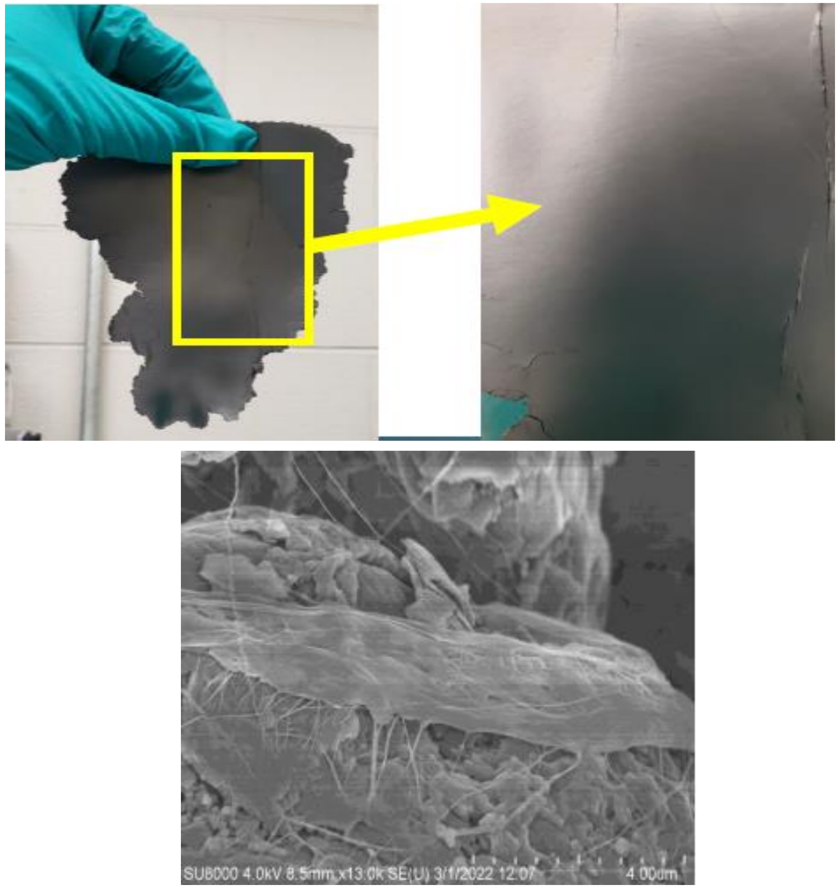


Voltage profiles of ADEP anodes containing PTFE

Need to reduce the amount of PTFE in anodes as much as possible for improved full cell capacity

[1]J. Power Sources 67, 1997, 344-347

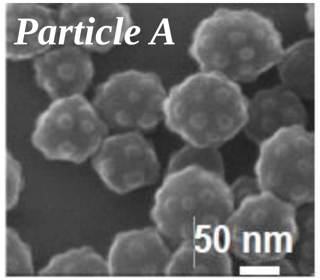
Develop a new hybrid binder formulation to reduce PTFE while maintaining film strength

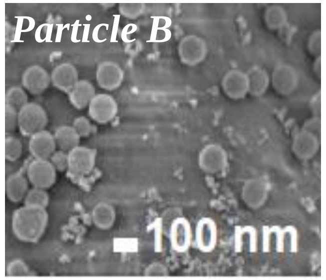


(Top) newly formulated hybrid binder anode and (bottom) SEM of fibrillization in hybrid binder anodes

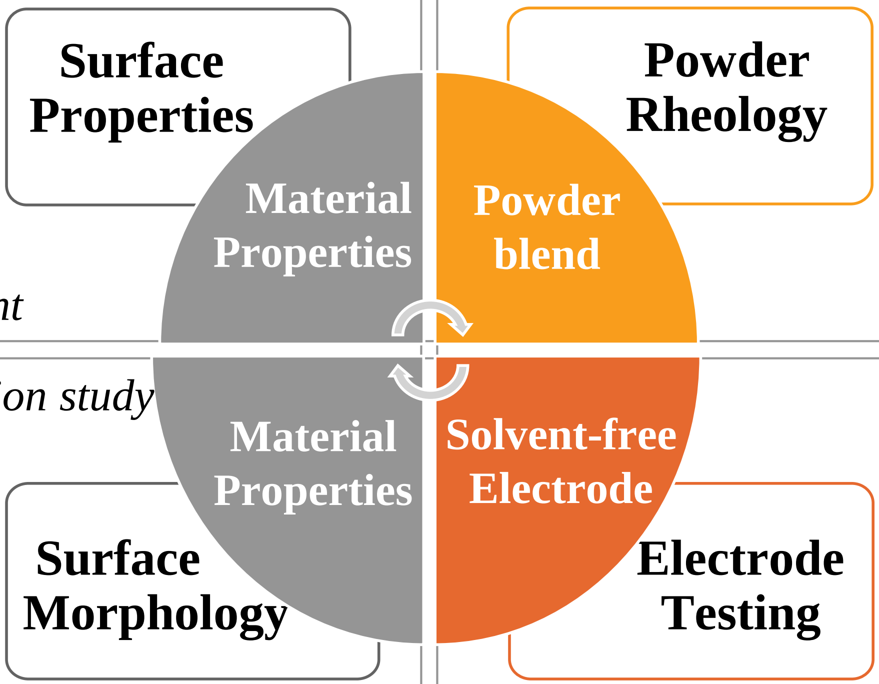
Background & Strategic Approach (2)

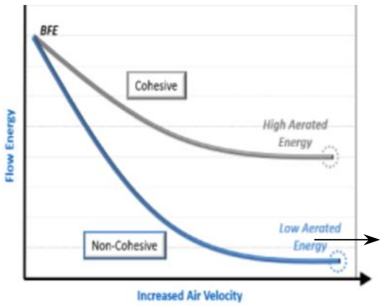
- **Develop innovative processing materials for solvent-free electrode processing**
  - Development of multifunctional carbon to eliminate prior processing additives (i.e. activated carbon)

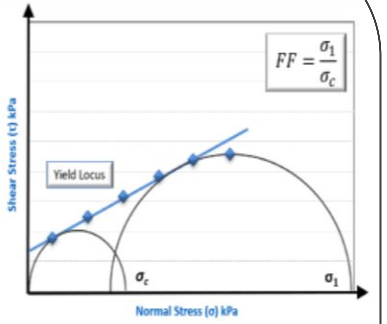




Material compatibility assessment

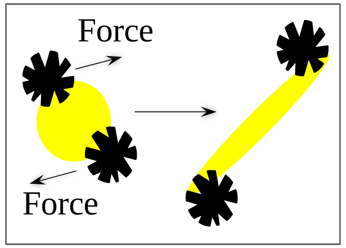


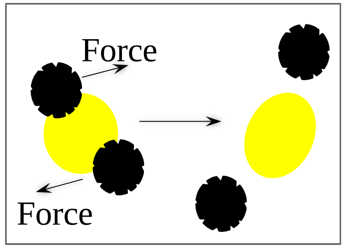




Processability screening

Carbon morphology vs binder fibrilization study





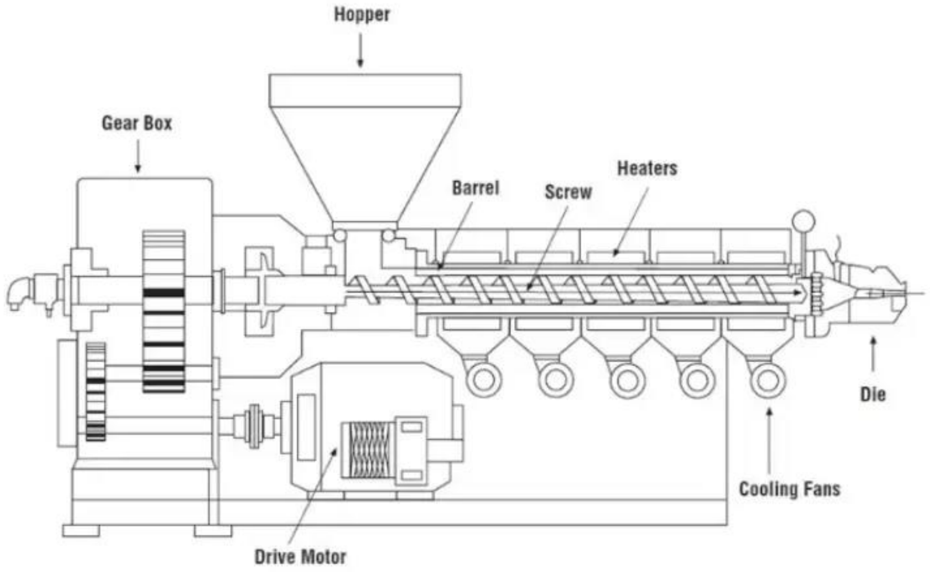
Application testing

- **Free-standing dry film:**
  - Tensile strength & elasticity
  - CCA dispersibility & binder fibrillization
- **Laminated dry-process electrode:**
  - Adhesion
  - Electrode porosity
  - Resistivity
- **Electrochemical performance testing**

Multifunctional carbon development approach

Background & Strategic Approach (3)

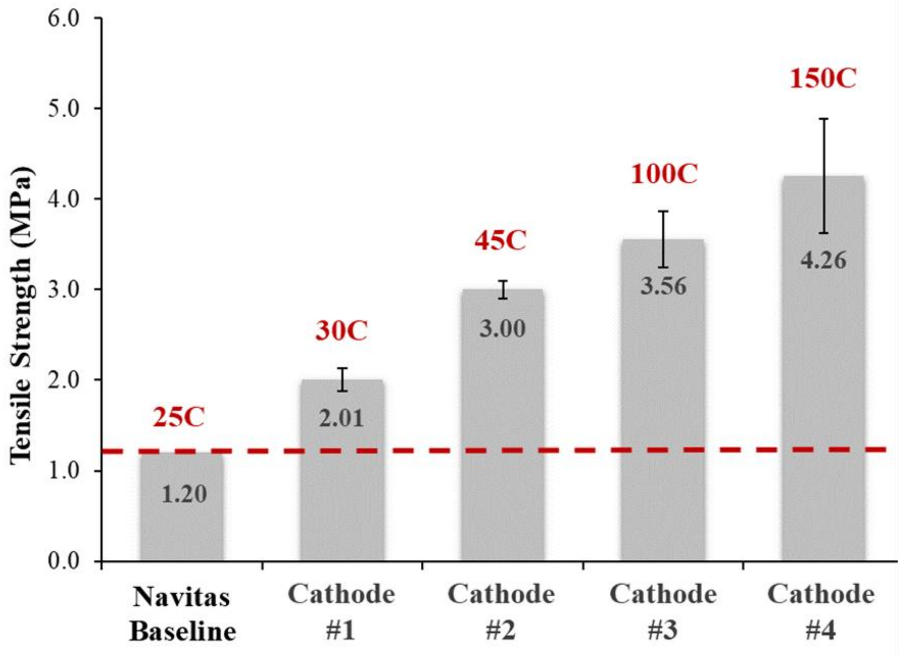
- **Utilize innovative and commercialized machinery for high-throughput processing**
  - Adaptation of twin-screw extrusion to develop laboratory/small-pilot-scale production of dry-process



Twin Screw Extruder Diagram – Illustration Only

- **Power requirement:** 0.05-0.50 kWh/kg
  → @$0.15/kWh means <$0.01-$0.08/kg
- **Throughput:** 0.5-10 kg/h
- **Screw Speed:** 200-1000 RPM

- **TSE screws have 3 different types of elements**
  - *Conveying*: move material forward
  - *Kneading*: mixing elements that produce PTFE fibrils
  - *Cutting*: breaks up larger flakes into smaller ones

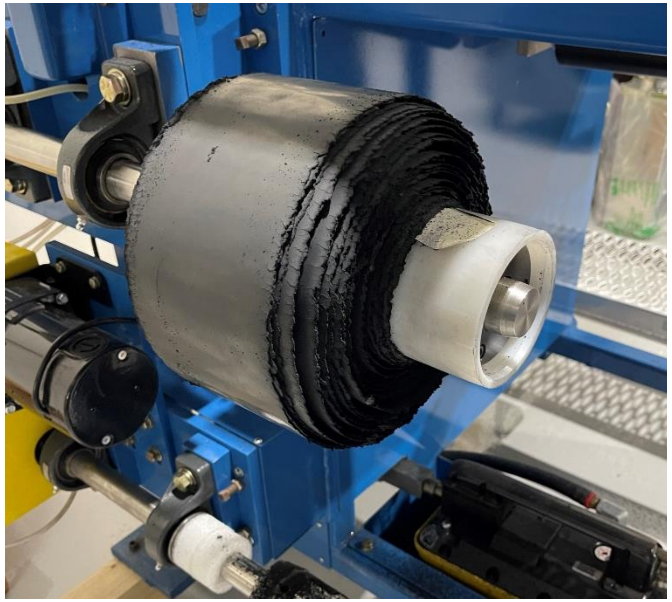


Improvement in ultimate tensile strength of NMC622 cathodes using twin-screw extrusion at various processing temperatures

Results and Achievements (1)

- **R2R Demonstration of Free-Standing Electrodes from Twin-Screw Extrusion Powders**

Free-standing electrode fabrication



20m R2R free-standing cathode

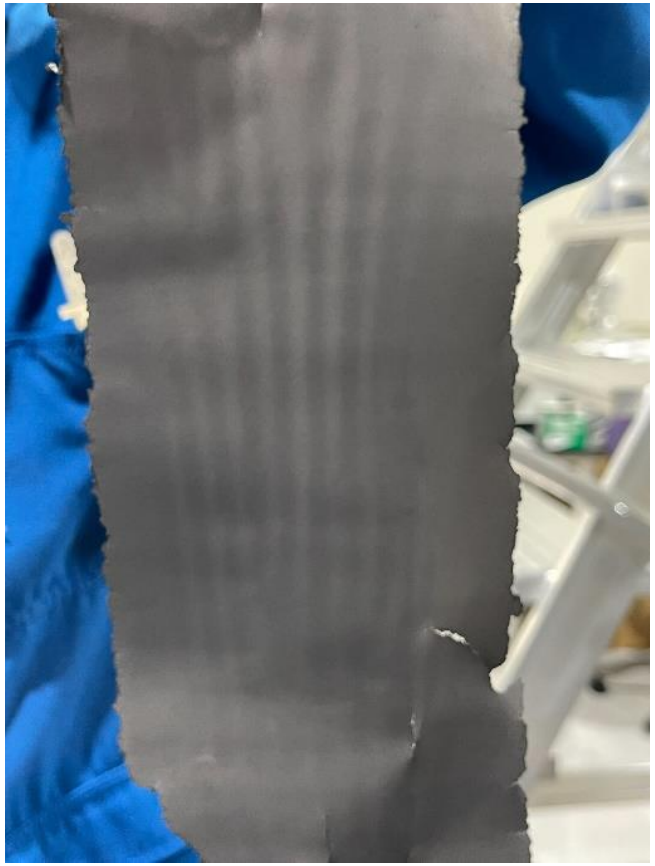
~2m free-standing anode

- **Able to demonstrate R2R production of both free-standing electrodes**
  - Elevated calendaring temperature (120°C) and roll speed of ~1 m/min
  - Initial NMC622 cathode R2R demonstration was ~150 mg/cm^2; now down to ~30-40 mg/cm^2 (5-6.5 mAh/cm^2)
  - Moderately thick free-standing graphite anode produced (~20 mg/cm^2, 6.5-7 mAh/cm^2)

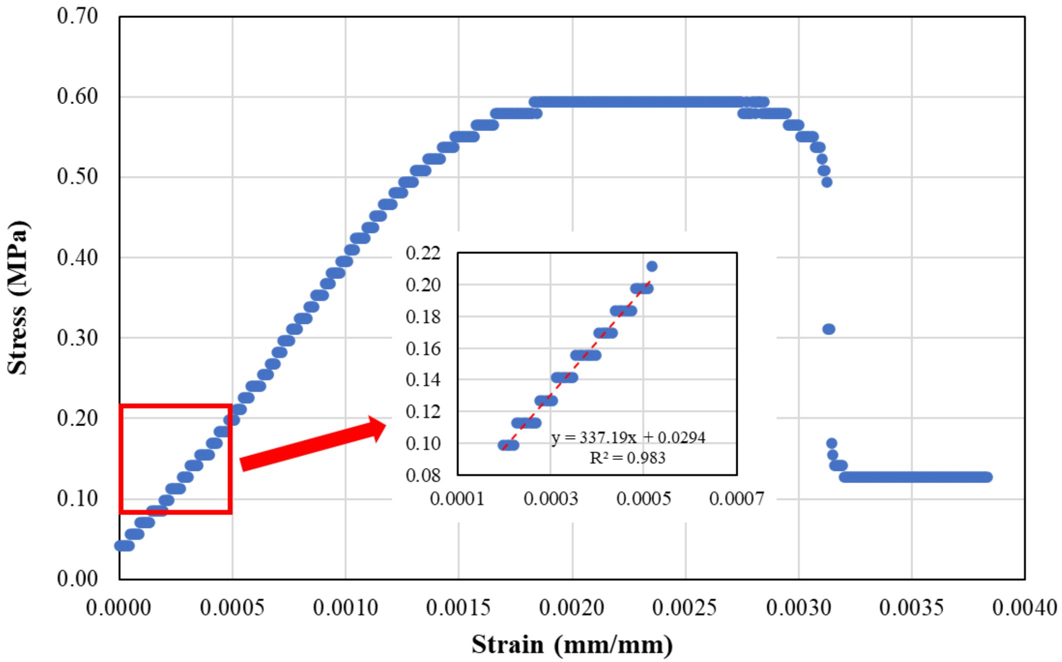
Results and Achievements (2)

- **Hybrid Binder Dry-Process Anode with Multifunctional Carbons**
  - Arkema hybrid binder was combined with Cabot's multifunctional carbons in dry-process manufacturing

Graphite flakes containing multifunctional carbon and hybrid binder



~230µm initial free-standing anode



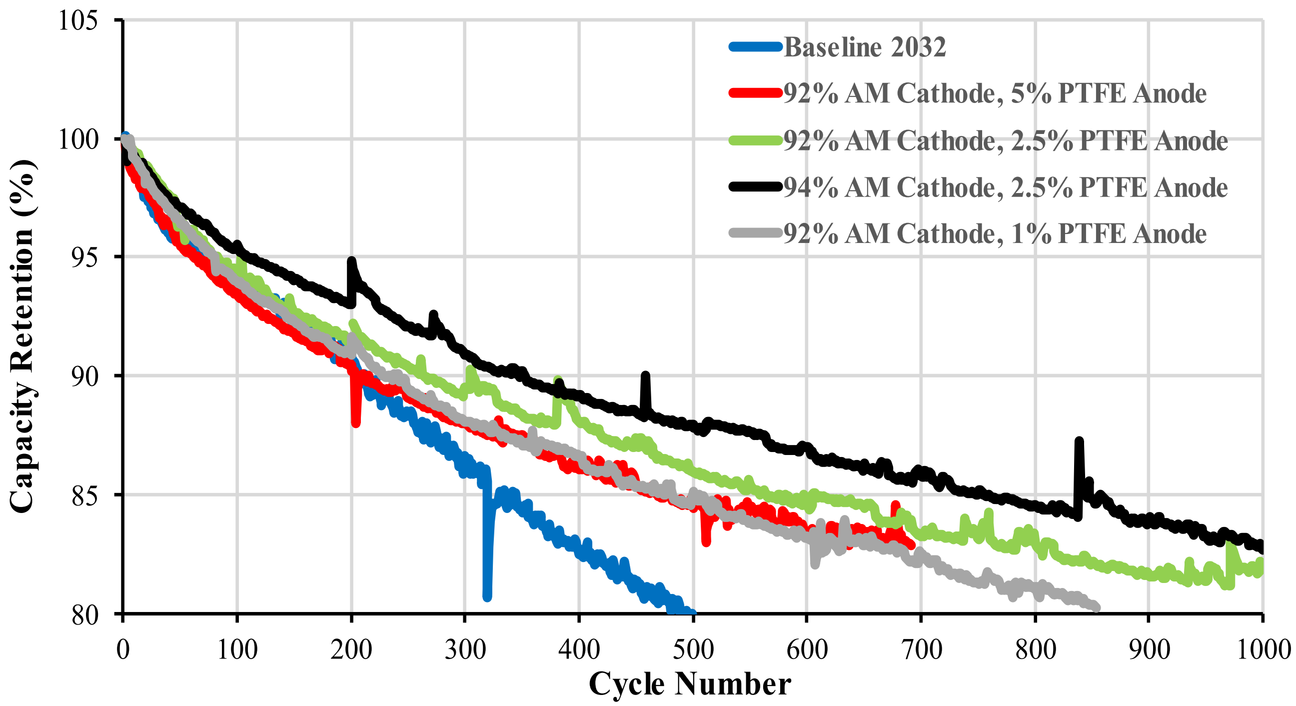
Anode with multifunctional carbon and hybrid binder
Sampled Young's Modulus: 337 MPa
Sampled UTS: ~0.6 MPa

Results and Achievements (3)

- **Double Layer Pouch Cells Using Only Dry-Process Electrodes**
  - Decreasing PTFE content is instrumental for high-capacity performance in double-layer/multi-layer pouch cells

Anode PTFE Content (%)	Cathode (NMC811) Active Material (%)	Initial Cycling Capacity (mAh/g)	# of Cycles at 80% Capacity
5	**92**	**89.0**	**500**
5	92	130.3	691*
2.5	92	137.2	1000
2.5	94	144.1	1000
1	92	171.7	854*

*Cycle testing still on-going
Black indicates baseline 2032 full-cell
Blue indicates cells trending above 500 cycles
Green indicates cells meeting 1000 cycle goal



Capacity retention data of full dry-process DLPs with various PTFE contents when cycled at C/3

Cells with 1% PTFE scale-up to ~230-250 Wh/kg, meeting program goals!

Future Work, Technology Transfer, & Impact

Future Work:

- Build multi-layer pouch cells for deliverable scale testing
- Integrate other materials (i.e. Si and S) for process compatibility

Technology Transfer:

- Navitas is looking to further scale-up the dry-processing technology outlined both for internal products as well as with external partners to MWh capacities
- Cabot and Arkema are looking to further validate and commercialize materials developed during this program for wholesale

Impact:

- Will aid in the commonization in the anode and cathode processing equipment, supply chain and operator training for lithium-ion battery OEM’s concerning solvent-free manufacturing

Questions?

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