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14. ABSTRACT
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a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	19b. TELEPHONE NUMBER 516-236-6661

# RPPR Final Report

## as of 01-Mar-2021

Agency Code:

Proposal Number: 77661CHSB1

Agreement Number: W911NF-20-P-0077

### INVESTIGATOR(S):

**Name:** Donald DeRosa  
**Email:** dderosa@eonixenergy.com  
**Phone Number:** 5162366661  
**Principal:** Y

Organization: **Eonix LLC**

Address: 9310 Aldergate Way APT 4308, Knoxville, TN 379220000

Country: USA

DUNS Number: 079407786

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**Report Date:** 28-Feb-2021

Date Received: 28-Feb-2021

**Final Report** for Period Beginning 30-Sep-2020 and Ending 29-Jan-2021

**Title:** Expeditionary Technology Search (xTechSearch) Dual-Use Technologies to solve challenging Army problems

**Begin Performance Period:** 30-Sep-2020

**End Performance Period:** 29-Jan-2021

**Report Term:** 0-Other

Submitted By: Donald DeRosa

Email: dderosa@eonixenergy.com

Phone: (516) 236-6661

**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

### STEM Degrees:

### STEM Participants:

**Major Goals:** In this project, Eonix proposed the development of a carbonate-free, non-flammable electrolyte to enable the realization of a safer, more stable lithium-ion battery for the Next Generation Combat Vehicle (NGCV). The proposed electrolyte paired a well-known high stability, non-flammable solvent (sulfolane) with a suite of passive and active additives developed by Eonix to address the low temperature and conductivity deficiencies of this solvent, sulfolane, as well as the inability to form a stable solid electrolyte interphase layer. Eonix was tasked with designing an electrolyte with these non-flammable components that matches or exceeds the performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg, Cycle Life 1000, Charge Rate 1C, Discharge Rate 2C) and demonstrating this improvement in a multilayered pouch cell with a graphite anode and NMC532 cathode. To accomplish this research project, Eonix had two technical tasks with subtasks.

The first technical task expected Eonix to design an electrolyte using 5mAh benchtop cells, with an embedded reference electrode for monitoring half-cell potentials, by adjusting passive and active additive concentrations and then designing formation cycles to properly initiate the generation of a stable solid electrolyte interphase. The first subtask focused on the concentration adjustments that resulted in the greatest capacity retention for the cells. The second subtask focused on evaluating the differential capacity peaks to determine the optimal formation protocol that would properly stabilize the anode for reversible cycling of the device in the absence of a carbonate electrolyte. The conclusion of the first technical task was a candidate electrolyte that would meet or exceed the MIL-PERF-32565 performance metrics while using a solvent with a high flashpoint. This task was completed on December 10th, 2020.

The second technical task expected Eonix to fabricate pouch cells with the candidate electrolyte from the first task. This task focused on developing cell fabrication/wetting protocols, determining proper electrolyte loading, and cycling the devices at elevated temperatures. The result of this task were pouch cells that outperformed the incumbent device and demonstrated higher safety than traditional lithium ion batteries in an over voltage test. The target safety tests were completed the last week of January 2021 while the cell cycling study was conducted throughout the project.

**Accomplishments:** During this project Eonix:

- Designed a sulfolane based electrolyte from industrially available chemicals
- Demonstrated the performance of this electrolyte in 220 mAh cells exceeded the energy density of MIL-PERF-32565 energy storage unit
- Measured the performance of this electrolyte at elevated temperatures 50°C
- Demonstrated the improved safety of this electrolyte over the industry standard BASF, carbonate based electrolyte in over voltage tests

## RPPR Final Report as of 01-Mar-2021

During this project, Eonix successfully developed a non-flammable, high temperature lithium-ion battery using the proposed electrolyte that paired a well-known high stability, high flash point (>160C) solvent (sulfolane) with a suite of partially fluorinated passive and active additives to address the physiochemical deficiencies of the selected solvent. This is the first commercially viable sulfolane based electrolyte that is drop-in compatible with existing lithium ion batteries containing artificial graphite anodes and NMC532 cathodes. Pouch cells containing this electrolyte were found to have an energy density greater than 145 Wh/kg which significantly exceeded the target performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg). This energy density is also expected to improve considerably as the pouch cell size increases and the gas pocket seal is removed. The cells also demonstrated a significant improvement in device safety during overvoltage tests, where the cells containing the non-flammable, high temperature electrolyte never ignited and only generated gas at 21V and an internal temperature greater than 200°C. Conversely, cells containing the industry standard BASF electrolyte ignited at 5.52 V and generated a significant hazardous event.

This innovative, non-flammable electrolyte was developed through a two-step process in the first technical task. Novel 5 mAh benchtop cells, with an embedded reference electrode for monitoring half-cell potentials, was employed to monitor the full cell and half-cell electrochemical characteristics concurrently in an effort to adjust the concentrations of the passive and active additives for optimal cell performance. The passive additives were balanced to improve the low temperature performance of the sulfolane solvent and depress the melting point from 25°C to -30°C without participating in electrochemical reactions while in the fully assembled cell. The changes in half cell potentials measured with the embedded reference electrode along with the differential charge analysis on the first cycle determined if the presence of passive additives at varying concentrations engaged in faradaic reactions. Once a non-reactive passive additive was selected and the concentration was optimized, this technique was employed to select a sacrificial active additive and initiator that would form a stable solid electrolyte interphase on the anode. A key finding by Eonix was determining that presence of an initiator was critical to forming a robust interphase.

After successfully developing a sulfolane based electrolyte, Eonix developed cell fabrication/wetting protocols, determined proper electrolyte loading, and cycled the devices at elevated temperatures. The wetting and fabrication protocols for the pouch cells were found to significantly impact the outcome of the device. The electrolyte needed to be injected into the cell at an elevated temperature to properly wet the system and the vacuum pressure during sealing was reduced significantly relative to standard cell assembly procedures. This resulted in pouch cells with an energy density greater than 145 Wh/kg which significantly exceeded the target performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg). This energy density is expected to scale significantly with increases in the pouch form factor. Furthermore, these cells were found to cycle successfully at temperatures as high as 50°C. During the overvoltage safety evaluation, the cells containing the candidate electrolyte significantly outperformed cells with BASF's electrolyte. The BASF standard electrolyte cells ignited at 5.52V and generated a significant hazardous event, while the cells containing the candidate electrolyte never ignited and only failed at internal temperatures above 200°C. At the conclusion of Phase I, Eonix has a prototype lithium ion battery that demonstrates significantly safer and more durable properties than existing lithium ion batteries for the NGCV program.

**Training Opportunities:** Nothing to Report

**Results Dissemination:** Nothing to Report

**Honors and Awards:** Nothing to Report

**Protocol Activity Status:**

**Technology Transfer:** Nothing to Report

### **PARTICIPANTS:**

**Participant Type:** PD/PI

**Participant:** Don Michael DeRosa II

**Person Months Worked:** 4.00

**Funding Support:**

Project Contribution:

International Collaboration:

International Travel:

**RPPR Final Report**  
as of 01-Mar-2021

National Academy Member: N  
Other Collaborators:

**Participant Type:** Technician  
**Participant:** Spencer Flottman  
**Person Months Worked:** 4.00  
Project Contribution:  
International Collaboration:  
International Travel:  
National Academy Member: N  
Other Collaborators:

**Funding Support:**



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## **Phase I Final Report**

**1. Contract and Proposal Number:** W911NF20P0077 and AX194-166-0204

**2. Contractors Name and Address:** Eonix LLC  
9310 Aldergate Way APT 4308  
Knoxville, TN 37922

**3. Title of Project:** Expeditionary Technology Search (xTechSearch) Dual-Use Technologies to solve challenging Army problems

**4. Contract Performance Period:** 30-SEP-2020 to 29-JAN-2020

**5. Total Contract Amount:** \$99,617.00

**6. Amount of Funds paid by DFAS to Date:** \$49,808.50

**7. Total amount invoiced to Date:** \$74,712.75

**8. Number of employees working on the project:** 2

**9. Number of new employees placed on the contract this month:** 0

## Project Overview: What problem is begin Solved?

The Army's ambitious Next Generation Combat Vehicle (NGCV) program calls for the increased electrification of vehicles to improve fuel efficiency and operational range, permit operations in electric-only silent mode, and provide battery backup for onboard soldiers. Unfortunately, the implementation of these advanced technologies in the NGCV is stifled by absence of a safe, durable energy storage option for the battlefield. The use of conventional lithium ion batteries (LIB) that have enabled electrification for the consumer vehicle market in the NGCV would result in a significant battlefield vulnerability due to the flammable and explosive tendencies of LIBs in extreme conditions. Currently, costly thermal battery management systems (BMS) are engineered into systems containing LIBs to improve safety. Eonix proposes the development of a next generation non-flammable electrolyte that is drop-in compatible with current lithium ion batteries to enable the first energy storage device that can be safely, simply, and extensively implemented in the NGCV without the need for complex, costly BMS to manage safety. The development of non-flammable LIBs will enable the NGCV to be safely electrified, allowing Warfighters to realize the tactical and operational benefits of electrification without also assuming the risk and vulnerabilities of conventional flammable LIBs.

## Project Goals

In this project, Eonix proposed the development of a carbonate-free, non-flammable electrolyte to enable the realization of a safer, more stable lithium-ion battery for the Next Generation Combat Vehicle (NGCV). The proposed electrolyte paired a well-known high stability, non-flammable solvent (sulfolane) with a suite of passive and active additives developed by Eonix to address the low temperature and conductivity deficiencies of this solvent, sulfolane, as well as the inability to form a stable solid electrolyte interphase layer. Eonix was tasked with designing an electrolyte with these non-flammable components that matches or exceeds the performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg, Cycle Life 1000, Charge Rate 1C, Discharge Rate 2C) and demonstrating this improvement in a multilayered pouch cell with a graphite anode and NMC532 cathode. To accomplish this research project, Eonix had two technical tasks with subtasks.

## Project Accomplishments

During this project Eonix:

- Designed a sulfolane based electrolyte from industrially available chemicals
- Demonstrated the performance of this electrolyte in 220 mAh cells exceeded the energy density of MIL-PERF-32565 energy storage unit
- Measured the performance of this electrolyte at elevated temperatures 50°C
- Demonstrated the improved safety of this electrolyte over the industry standard BASF, carbonate based electrolyte in over voltage tests

During this project, Eonix successfully developed a non-flammable, high temperature lithium-ion battery using the proposed electrolyte that paired a well-known high stability, high flash point (>160C) solvent (sulfolane) with a suite of partially fluorinated passive and active additives to address the physiochemical deficiencies of the selected solvent. This is the first commercially viable sulfolane based electrolyte that is drop-in compatible with existing lithium

Contract:W911NF20P0077

Proposal:AX194-166-0204

Eonix – 9310 Aldergate Way APT4308 Knoxville, TN 37922

ion batteries containing artificial graphite anodes and NMC532 cathodes. Pouch cells containing this electrolyte were found to have an energy density greater than 145 Wh/kg which significantly exceeded the target performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg). This energy density is also expected to improve considerably as the pouch cell size increases and the gas pocket seal is removed. The cells also demonstrated a significant improvement in device safety during overvoltage tests, where the cells containing the non-flammable, high temperature electrolyte never ignited and only generated gas at 21V and an internal temperature greater than 200°C. Conversely, cells containing the industry standard BASF electrolyte ignited at 5.52V and generated a significant hazardous event.

### Technical Feasibility: Very Feasible

Eonix was able to develop a first-generation lithium-ion battery prototype featuring the proposed non-flammable, high temperature electrolyte. This prototype was constructed from a commercially manufactured “dry cell” thereby indicating that the proposed electrolyte developed during this project can be incorporated in presently manufactured batteries with ease (Image 1.)

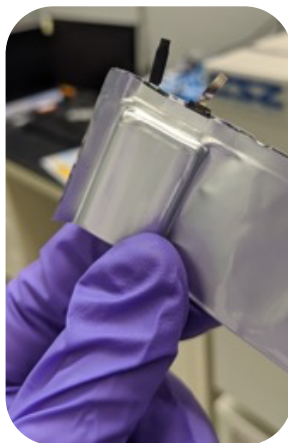


Image 1. Photo of a 220 mAh sized pouch cell fabricated with the high temperature, non-flammable sulfolane based electrolyte.

## Technical Section

### Work Schedule

Electrolyte to Non-flammable, High Temperature Batteries

Objectives	October	November	December	January
Task 1: Adjust Passive and Active additive concentrations/Design formation cycles	Task. 1			
	T1.1 Concentration Adjs.	T1.2 Formation Cycle		
Task 2: 220mAh Pouch Cell with Sulfolane Based Electrolyte	Task. 2			
	T2.1 Cell Fabrication/Wetting	T2.1 Electrolyte Loading	T2.1 Pouch Cell Cycling	

**Task 1: Adjust Passive and Active additive concentrations/Design Formation Cycles**

**Task Schedule:** 30-SEPT-2020 to 10-DEC-2020 (Completed)

Contract:W911NF20P0077

Proposal:AX194-166-0204

Eonix – 9310 Aldergate Way APT4308 Knoxville, TN 37922

## Accomplishments:

- Designed sulfolane electrolyte with fluorinated additives
- Designed a formation cycle that significantly improved performance
- Successfully cycled devices over 300 times
- Measured performance from 19 to 50°C
- Performed Post-mortem analysis on Cathodes and Anodes with Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy

Cell ID	Cell Notes	Anode	Cathode	Electrolyte Composition	Date	Status	Temp. (C)
NX46_A1138	0.36mA form, 1.8mA Bulk, 4.2V	Artificial Graphite	NMC 532	1M LiX 90% Sulfolane 10% SAC 0% IA	10/1/20	Finished	19
NX47_A0919	0.36mA form, 1mA Bulk, 4.2V	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/1/20	Finished	19
NX47_A0920	0.36mA form, 1.8mA Bulk, 4.2V	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/1/20	Finished	19
NX48_A0382	0.2mA form, 1mA Bulk, 4.2V.	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/7/20	SEM/EDS	19
NX48_A0383	0.2mA form, 1mA Bulk, 4V.	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/7/20	SEM/EDS	19
NX48_A0385	0.2mA form, 1mA Bulk, 4.2V.	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/7/20	SEM/EDS	19
NX48_A0922	Fast Formation	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/7/20	SEM/EDS	19
NX49_A1135	Pouch Cell comparison	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/23/20	SEM/EDS	19
NX50_A1136	Pouch Cell comparison	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	10/23/20	SEM/EDS	19 - 40
NX51_A1137	SAC Concentration Study	Artificial Graphite	NMC 532	1M LiX 84% Sulfolane 15% SAC 1% IA	10/23/20	SEM/EDS	19 - 40
NX51_A1138	SAC Concentration Study	Artificial Graphite	NMC 532	1M LiX 84% Sulfolane 15% SAC 1% IA	10/23/20	SEM/EDS	19 - 40
NX52_A1203	SAC Concentration Study	Artificial Graphite	NMC 532	1M LiX 79% Sulfolane 20% SAC 1% IA	10/23/20	SEM/EDS	19 - 40
NX52_A1206	SAC Concentration Study	Artificial Graphite	NMC 532	1M LiX 79% Sulfolane 20% SAC 1% IA	10/23/20	SEM/EDS	19 - 40
NE1_A0382	SAC/Wetting Concentration Study	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	11/11/20	Cycling	40
NE2_A0922	SAC/Wetting Concentration Study	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	11/22/20	Cycling	40
NE3_A1138	SAC/Wetting Concentration Study	Artificial Graphite	NMC 532	1M LiX 84% Sulfolane 15% SAC 1% IA	11/22/20	Cycling	40
NE4_A1203	SAC/Wetting Concentration Study	Artificial Graphite	NMC 532	1M LiX 79% Sulfolane 20% SAC 1% IA	11/22/20	Cycling	40
NE5_A0920	PA Concentration Study	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	12/15/20	Cycling	40
NE6_A0385	PA Concentration Study	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA + 5%PA1	12/15/20	Cycling	40
NE7_A0383	PA Concentration Study	Artificial Graphite	NMC 532	1M LiX 74% Sulfolane 10% SAC 1% IA + 15%PA2	12/15/20	Cycling	40
NE8_A0384	PA Concentration Study	Artificial Graphite	NMC 532	1M LiX 50% Sulfolane 10% + 50%PA3	12/15/20	Cycling	40

Table 1. The table above lists the notes, status, and electrolyte composition for the benchtop atlas cells fabricated during project. Each cell contains a lithium ring reference electrode and FS-5-222 separator with a thickness of 25 microns.

**Description of Task:** This innovative, non-flammable electrolyte was developed through a two-step process in the first technical task. Twenty one (21) novel 5 mAh benchtop cells, with an embedded reference electrode for monitoring half-cell potentials, was employed to monitor the full cell and half-cell electrochemical characteristics concurrently in an effort to adjust the concentrations of the passive and active additives for optimal cell performance. The passive additives were balanced to improve the low temperature performance of the sulfolane solvent and depress the melting point from 25°C to -30°C without participating in electrochemical reactions while in the fully assembled cell. The changes in half cell potentials measured with the embedded reference electrode along with the differential charge analysis on the first cycle determined if the presence of passive additives at varying concentrations engaged in faradaic reactions. Once a non-reactive passive additive was selected and the concentration was optimized, this technique was employed to select a sacrificial active additive and initiator that would form a stable solid electrolyte interphase on the anode. A key finding by Eonix was determining that presence of an initiator was critical to forming a robust interphase.

Once the electrolyte additives were properly balanced, the formation cycle was designed with the same novel 5 mAh benchtop cells, with an embedded reference electrode for monitoring

half-cell potentials. The development of a formation cycle proved to be critical to the success of the sulfolane based electrolyte (Figure 1.) The slower the formation cycle in terms of current density resulted in a lower overall cell capacity. Analysis of the differential charge plots revealed there was an electron consuming reaction at 2.3V that may have contributed to anion consumption. A formation cycle was then designed to avoid the 2.3V reaction and promote electrochemical reactions at elevated potentials which yielded devices that significantly outperformed the slow formation cells (Figure 2.). Eonix evaluated this formation protocol with artificial graphite and NMC532 electrodes from other manufacturers as well and found that the successful formation cycles as well as concentrations were consistent (Figure 3.)

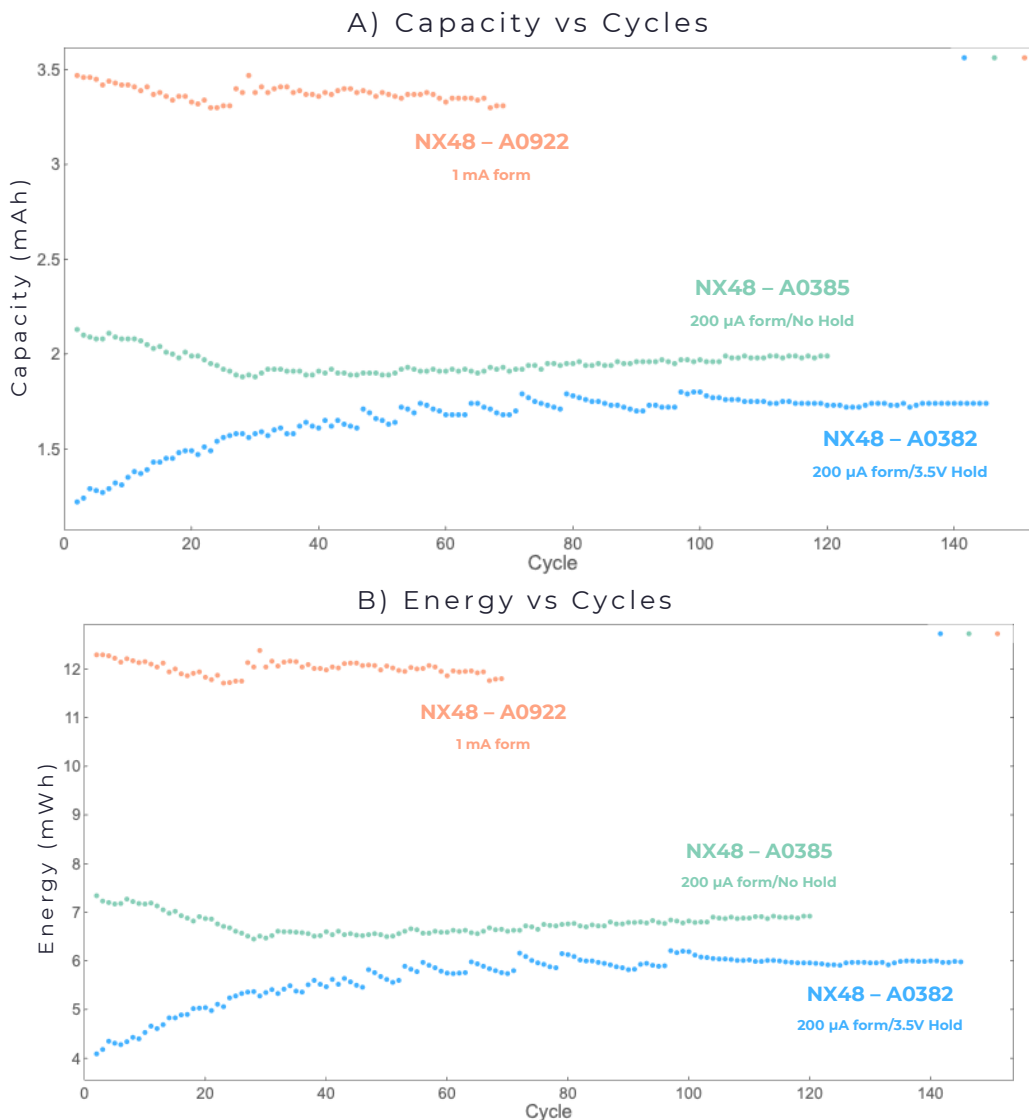


Figure 1. The discharge capacity (A) and energy (B) of NX48-A0382, NX48-0385, and NX48-0922 across the charge discharge cycles are displayed above. The fast formation cell (NX48-0922) displayed the highest performance while the slow formation with an activation voltage hold displayed the worst performance.

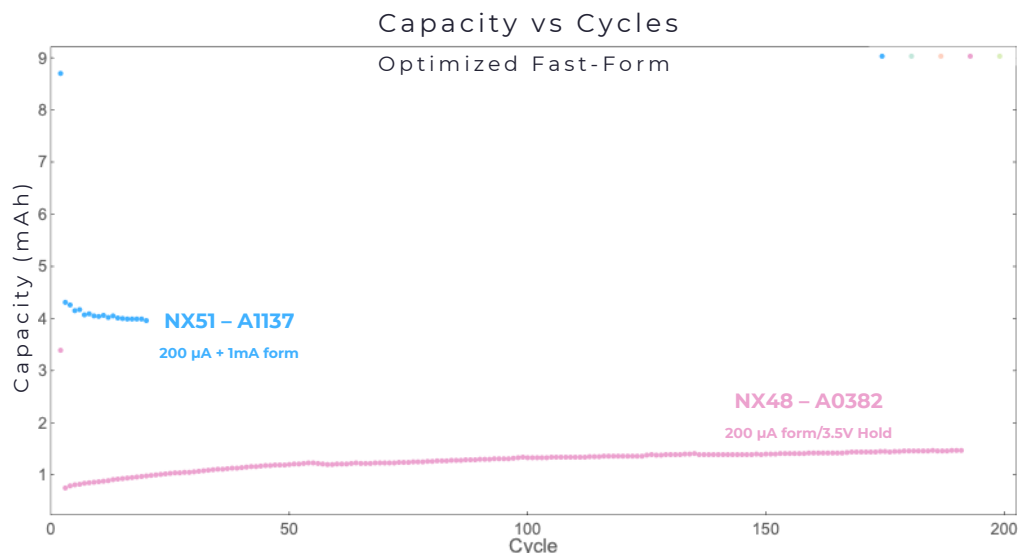


Figure 2. The discharge capacity of NX48-A0382 and NX51-A1137 across the charge discharge cycles are displayed above. The optimized fast formation cell (NX51-1137) displayed the highest performance relative to the slow formation cells represented by NX48-A0382.

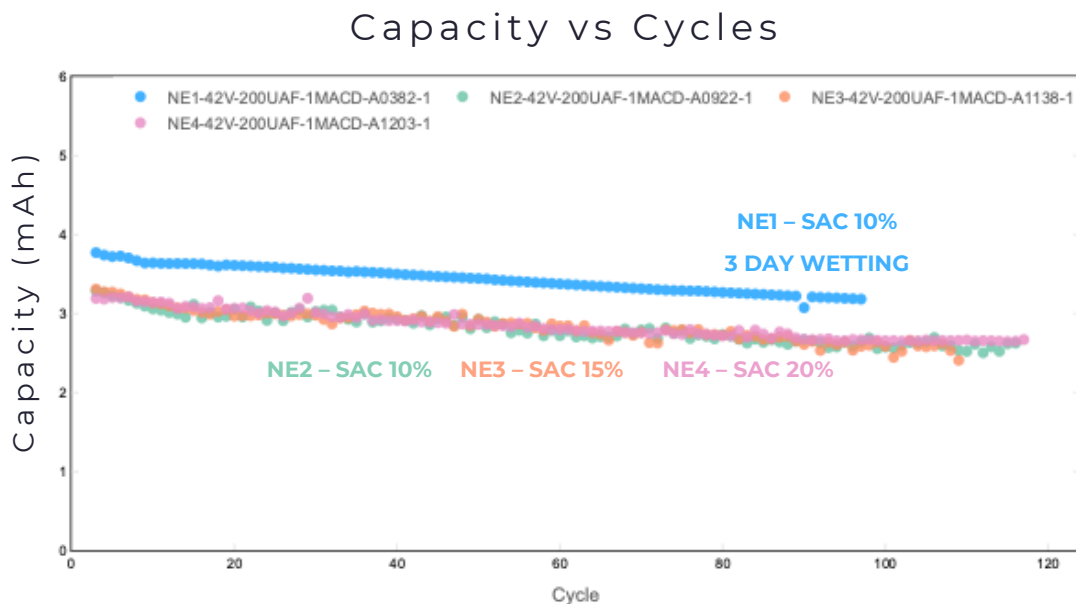


Figure 3. The discharge capacity of NE1, NE2, NE3, and NE4 across the charge discharge cycles are displayed above. The cell containing 10% SAC concentration, was fast formed and allowed to wet (NE1) significantly out performed the other NE cells.

At the conclusion of Task 1, the stability of the most recently constructed cells (NE-class) were evaluated at 50°C (Figure 4.). The cells exhibited higher degradation rates than at 40°C, which may in part be a consequence of this specific manufacturers electrodes that had consistently lower capacity retention values. Despite this increase in degradation, the cells utilizing the designed fast formation cycle demonstrated higher capacity retention (NE1). These results showcase the importance of a well-designed formation protocol to minimize capacity loss.

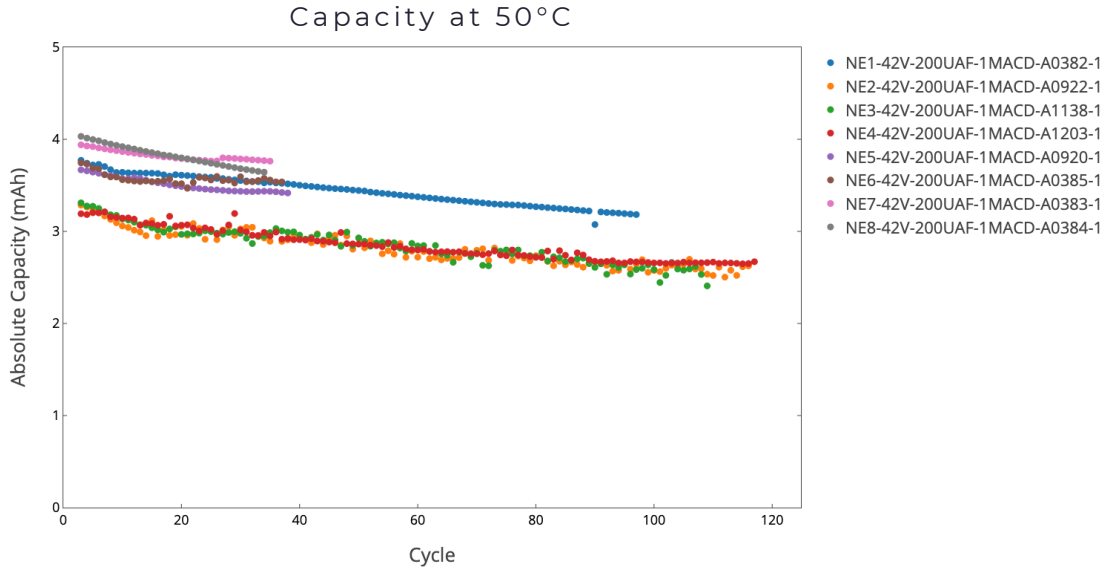
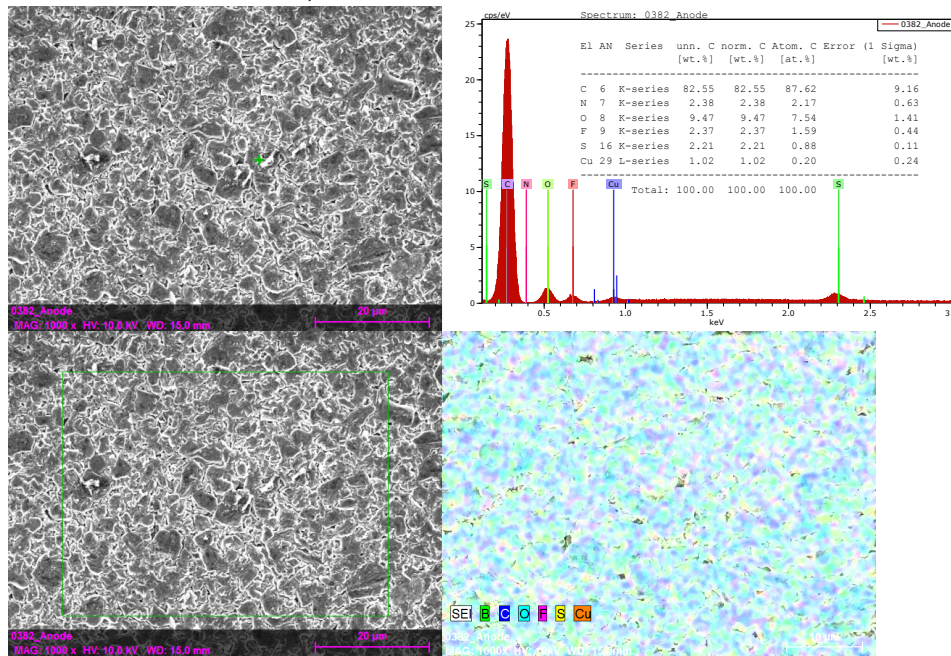


Figure 4. The discharge capacity of NE1, NE2, NE3, NE4, NE5, NE6, NE7, and NE8 across the charge discharge cycles are displayed above. The cell containing 10% SAC concentration, was fast formed and allowed to wet (NE1) has continued to significantly outperform the other NE cells.

Additionally, at the conclusion of Task 1, Eonix disassembled eight cells( NX48, NX49, NX50, NX51, NX52) to measure the impact of this innovative electrolyte on the morphology and surface composition of the cathode and anode using SEM and EDS. A key finding of this study were the compositional differences between fast formation and slow formation cells. The cells that were slowly formed and exhibited lower capacity retention after the first cycle had lower relative percentages of oxygen and fluorine. Conversely, the fast formed devices that performed significantly better had distinctly higher oxygen and fluorine on the surface (Figure 5). Eonix plans to investigate this further using additional characterization techniques.

A) Slow Formation Anode



Contract:W911NF20P0077

Proposal:AX194-166-0204

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### B) Fast Formation Anode

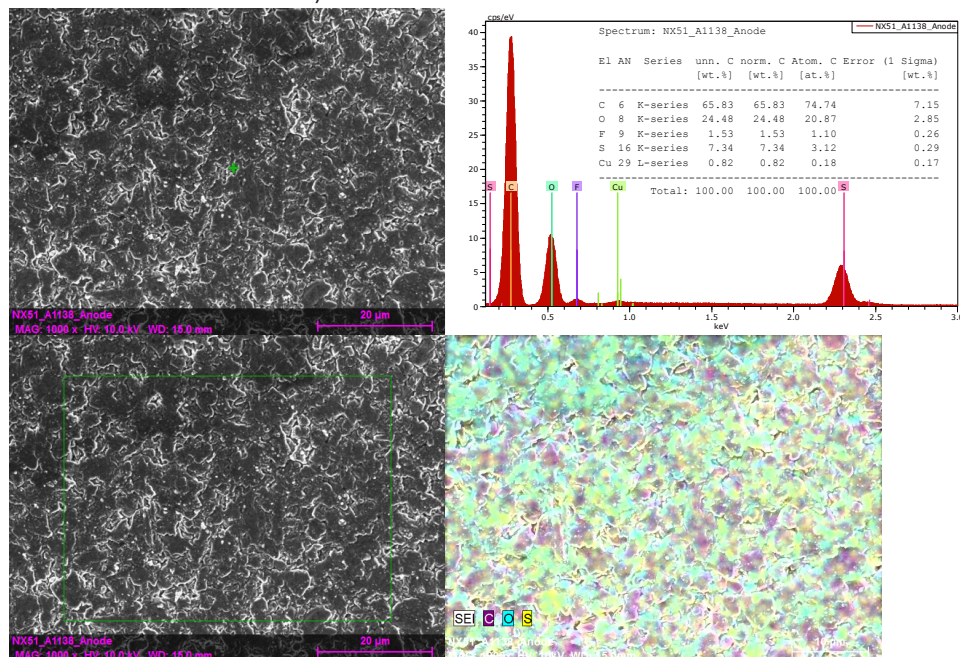


Figure 5. The SEM images and EDS results for cells that underwent slow and fast formation cycle protocols reveal differences in percent surface composition.

## Task 2: 220mAh Pouch Cell with Sulfolane Based Electrolyte

Task Schedule: 30-SEPT-2020 to 29-JAN-2021

### Accomplishments:

- Fabricated Pouch Cells with the candidate Electrolyte
- Developed an assembly and electrolyte loading process
- Successfully cycled devices up to 1000 times
- Measured performance from 19 to 50°C
- Conducted an over voltage safety test
- Demonstrated significant safety advantages of the designed electrolyte

Cell ID	Cell Notes	Anode	Cathode	Electrolyte Composition	Status	Temp. (C)
NXPC1	No Additives	Artificial Graphite	NMC 532	1M LiX 100% Sulfolane	Finished	19
NXPC2	No Additives	Artificial Graphite	NMC 532	1M LiX 100% Sulfolane	Finished	19
NXPC3	10% Sacrificial Additive	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10%	Finished	19
NXPC4	10% Sacrificial Additive, 1% Initiator	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Finished	19
NXPC5	New Vacuum Sealing Technique	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC	Finished	19
NXPC6	Carbonate Baseline	Artificial Graphite	NMC 532	Carbonate Baseline	Safety Test	40
NXPC7	New Vacuum Sealing Technique	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Safety Test	40
NXPC8	Variable Pre-Sealing Wetting Time	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Failed	19
NXPC9	Variable Pre-Sealing Wetting Time	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Finished	19
NXPC10	Variable Pre-Sealing Wetting Time	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Finished	19
NXPC11	Variable Vacuum Time	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Failed	19
NXPC12	Variable Vacuum Time	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Failed	19
NXPC13	Variable Vacuum Pressure	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Finished	19
NXPC14	Variable Vacuum Pressure	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Finished	19
NXPC15	Variable Sealing Temperature	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Cycling	40-50
NXPC16	Variable Sealing Temperature	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Cycling	40-50
NXPC17	Variable Sealing Temperature	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Safety Test	40-50
NXPC18	Variable Sealing Temperature	Artificial Graphite	NMC 532	1M LiX 89% Sulfolane 10% SAC 1% IA	Failed	40-50
NXPC19	Carbonate Baseline	Artificial Graphite	NMC 532	Carbonate Baseline	Safety Test	19
NXPC20	Carbonate Baseline	Artificial Graphite	NMC 532	Carbonate Baseline	Safety Test	19

Table 2. The table above lists the notes, status, and electrolyte composition for the pouch cells fabricated during the project. Each cell was vacuum sealed in an inert argon environment.

**Description of Task:** After successfully developing a sulfolane based electrolyte, Eonix developed cell fabrication/wetting protocols, determined proper electrolyte loading, and cycled the devices at elevated temperatures (Image 2). The wetting and fabrication protocols for the pouch cells were found to significantly impact the outcome of the device (Figure 6). The electrolyte needed to be injected into the cell at an elevated temperature to properly wet the system and the vacuum pressure during sealing was reduced significantly relative to standard cell assembly procedures. This resulted in pouch cells with an energy density greater than 145 Wh/kg which significantly exceeded the target performance of the MIL-PERF-32565 energy storage unit (72 Wh/kg) (Figure 7). This energy density is expected to scale significantly with increases in the pouch form factor.

A) External Incubators



B) Internal Incubators with cells

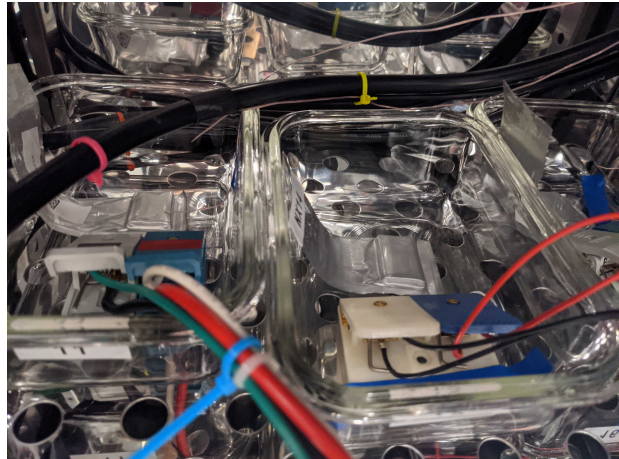


Image 2. Photo of a 220 mAh sized pouch cell fabricated with the high temperature, non-flammable sulfolane based electrolyte.

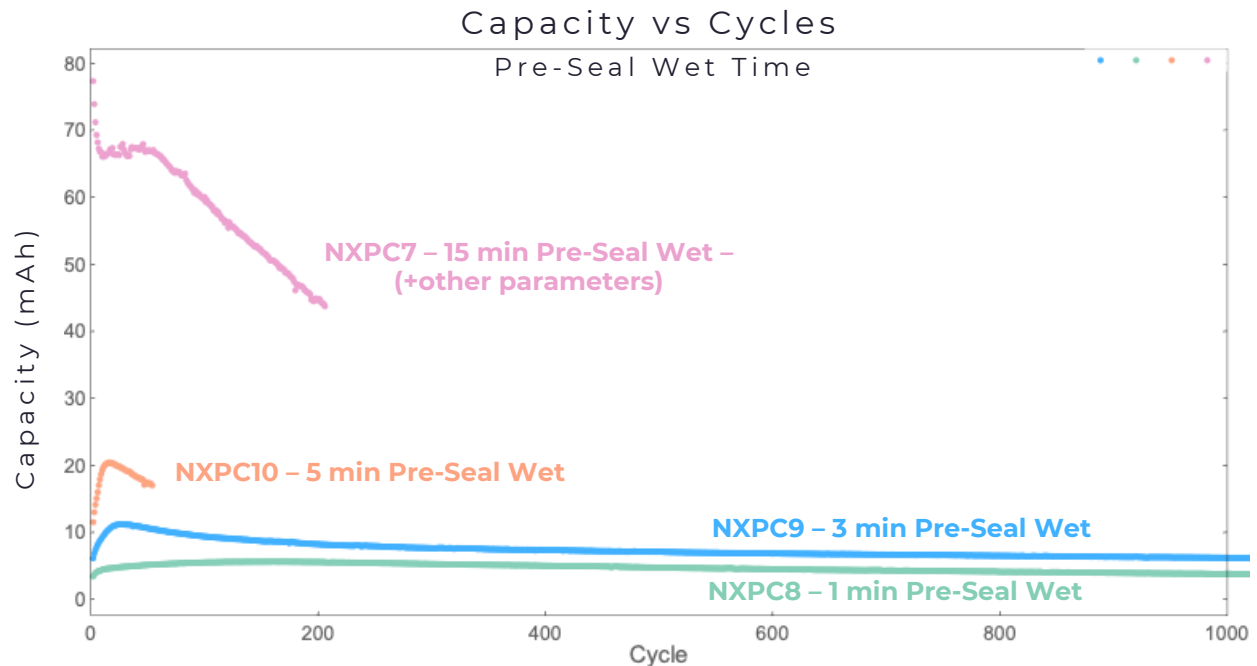


Figure 6. The discharge capacity of NXPC8, NXPC9, NXPC10 and NXPC7 across the charge discharge cycles are displayed above. The device that was allowed to wet for 15 minutes prior to sealing, NXPC7 fabricated during POP1, continues to significantly out perform devices with reduced wetting times. The best performing cell, NXPC7, also may have benefited from a reduced vacuum pressure which is currently under evaluation.

### Pouch Capacity at 40 - 50°C

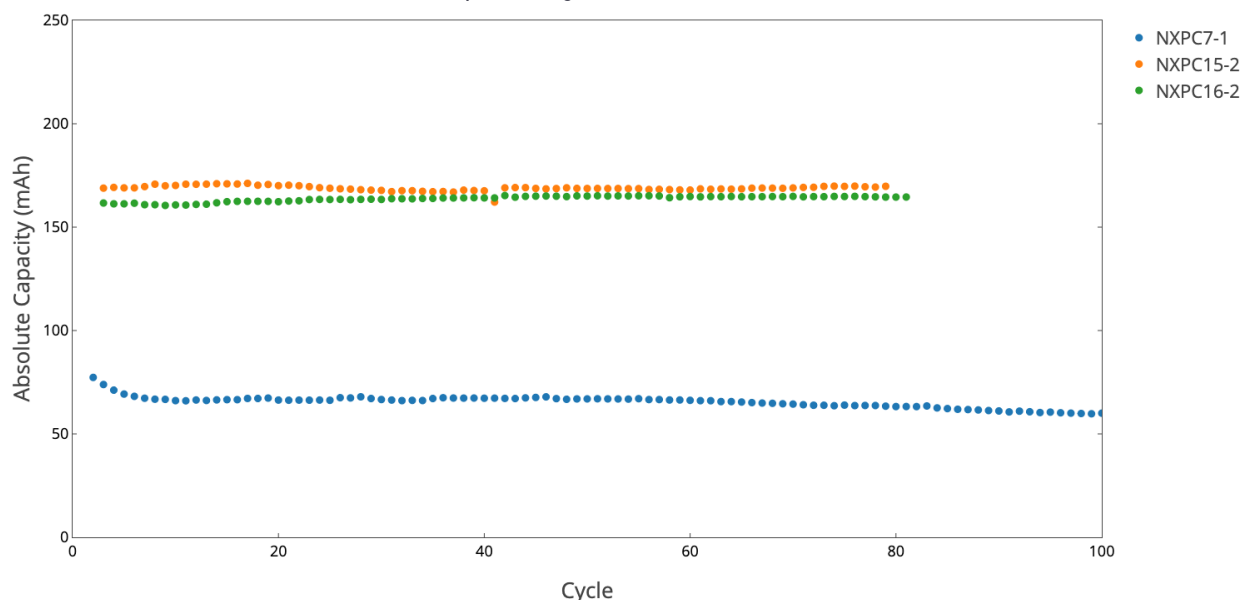


Figure 7. The discharge capacity of NXPC7, NXPC15, and NXPC16 across the charge discharge cycles are displayed above. The devices with the new sealing procedure and fast formation protocol continue to outperform the previous champion cell (NXPC7).

Furthermore, these cells were found to cycle successfully at temperatures as high as 50°C. During the overvoltage safety evaluation, the cells containing the candidate electrolyte significantly outperformed cells with BASF’s electrolyte. The BASF standard electrolyte cells ignited at 5.52V and generated a significant hazardous event, while the cells containing the candidate electrolyte never ignited and only failed at internal temperatures above 200°C(Image 3). At the conclusion of Phase I, Eonix has a prototype lithium-ion battery that demonstrates significantly safer and more durable properties than existing lithium-ion batteries for the NGCV program.

## Overvoltage Induced Failure Experiment

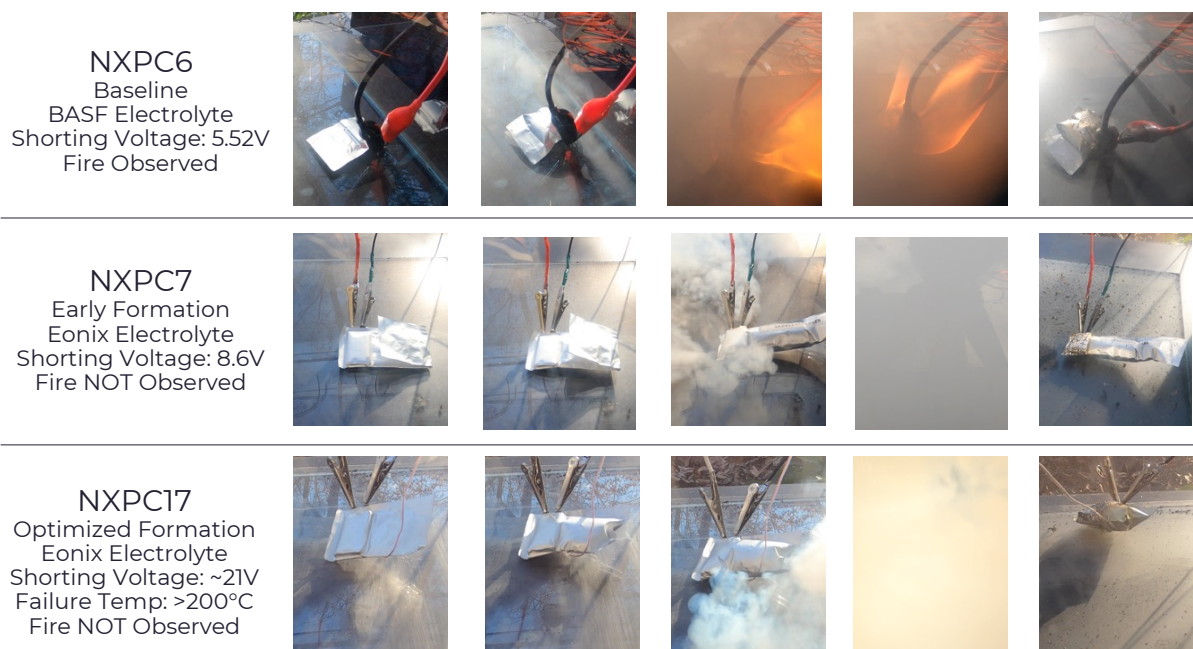


Image 3. Still images of three 220 mAh sized pouch cells (NXPC6, NXPC7, NXPC17) that were evaluated under over voltage conditions. Each cell was charged until the cells shorted or generated sufficient gas to break the pouch cell seal.

## Conclusion

During this project, Eonix developed and demonstrated a scalable sulfolane based electrolyte that is drop-in compatible with currently manufactured lithium-ion batteries, stable to cycle at 50°C, and significantly safer than the incumbent carbonate-based electrolytes in overvoltage failure incidents. The Eonix developed electrolyte can withstand higher voltages and does not ignite during overvoltage induced failure. This approach shows significant merit as a potentially safe energy storage technology that enables the Army's NGCV program to harness the high energy density of lithium ion batteries without also assuming the risk of flammability.