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# Effect of Anode Prelithiation on LEO Cycling Life of Graphene Batteries

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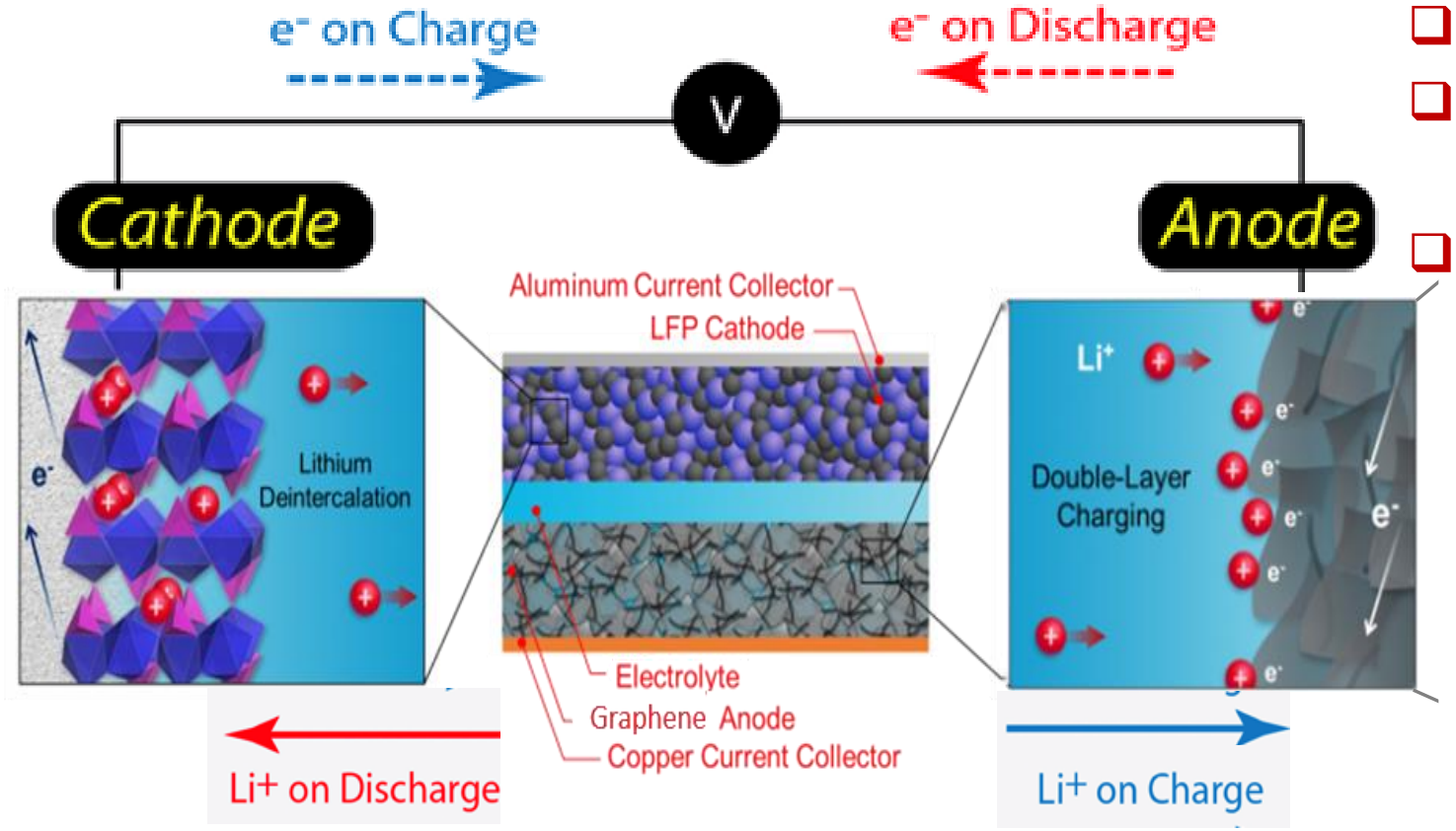
# Batteries for Space Applications

- Critical role in satellite operation
- Low-earth orbit (LEO) satellites: batteries supply power during eclipse

Lithium-Ion Batteries (LIBs)




Space batteries requirements:

- *High energy density*
- *Charge and discharge rates:* LEO satellites circle the earth in 90 minutes; eclipsed for 35 minutes
- *Lifetime:* 5,000 cycles per year
- *Depth of Discharge (DOD):* limited to low levels to reduce stress
- *Weight*: typically 10 to 20% of the overall mass

# Benefits of Graphene

- Graphite is the main anode material in LIBs
- Graphene has 2X the capacity of graphite

| Anode | Capacity, mAh/g |
|---|---|
| Graphite ($LiC_6$) | 372 |
| Graphene ($LiC_3$) | 744 |

## Graphene Benefits

- Specific capacity ~ 1264 mAh $g^{-1}$
- Record in-plane chemical diffusion coefficients for Li at room temperature $7 \times 10^{-5}$ $cm^2$ $s^{-1}$ vs. $10^{-7}$–$10^{-6}$ $cm^2$ $s^{-1}$ in graphite

## Graphene

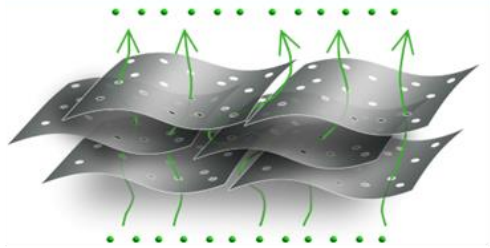



## Technical Challenges

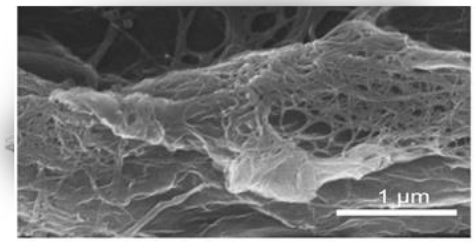
- Graphene re-stacks during electrode preparation
- Irreversible Li insertion, capacity loss with cycling
- Dendrite growth

# Graphene Materials for Next Generation LIBs

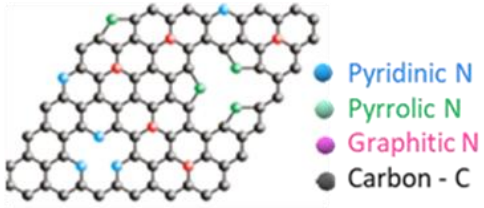
## Graphene Materials



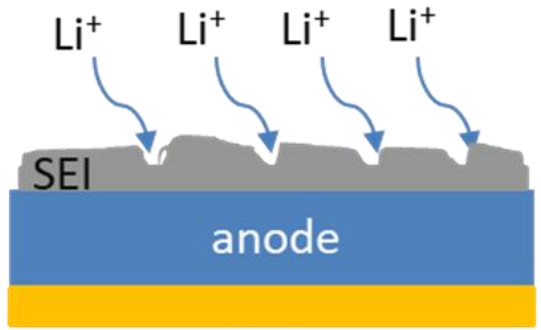
hybrid graphene - carbon nanotube



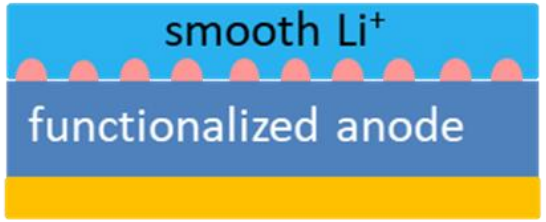

added lithiophilic sites




## Prelithiation




dendrite free



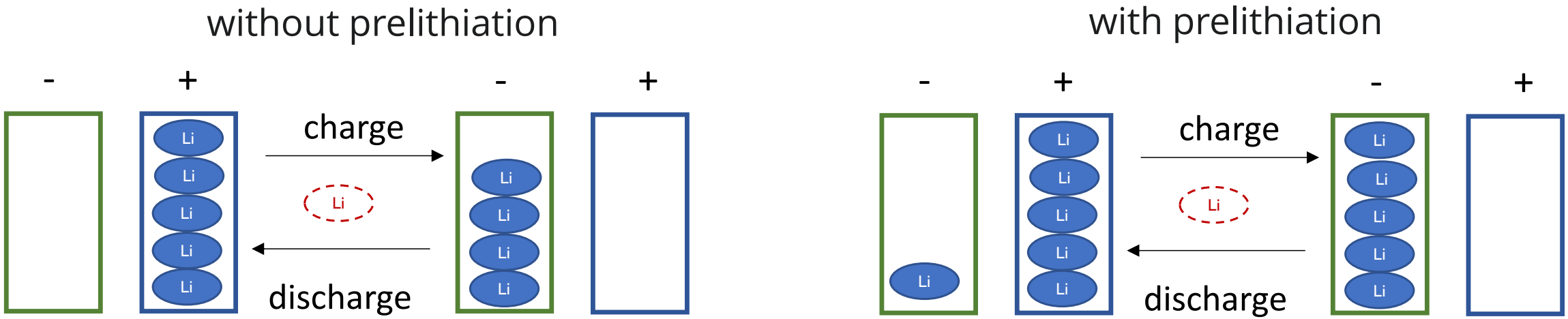

## Next Generation Lithium Ion Battery




- high energy density
- light weight
- safe dendrite free
- high cycling stability
- long calendar life
- conformal design
- scalable manufacturing

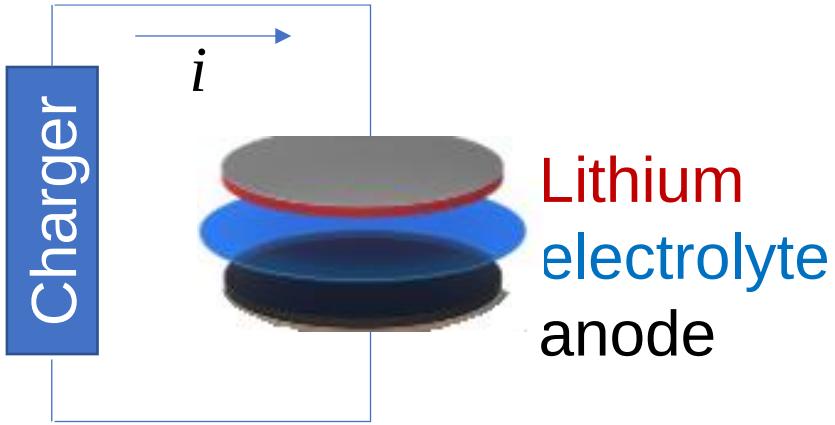
# Prelithiation of Graphene Anodes

## LIBs Operation



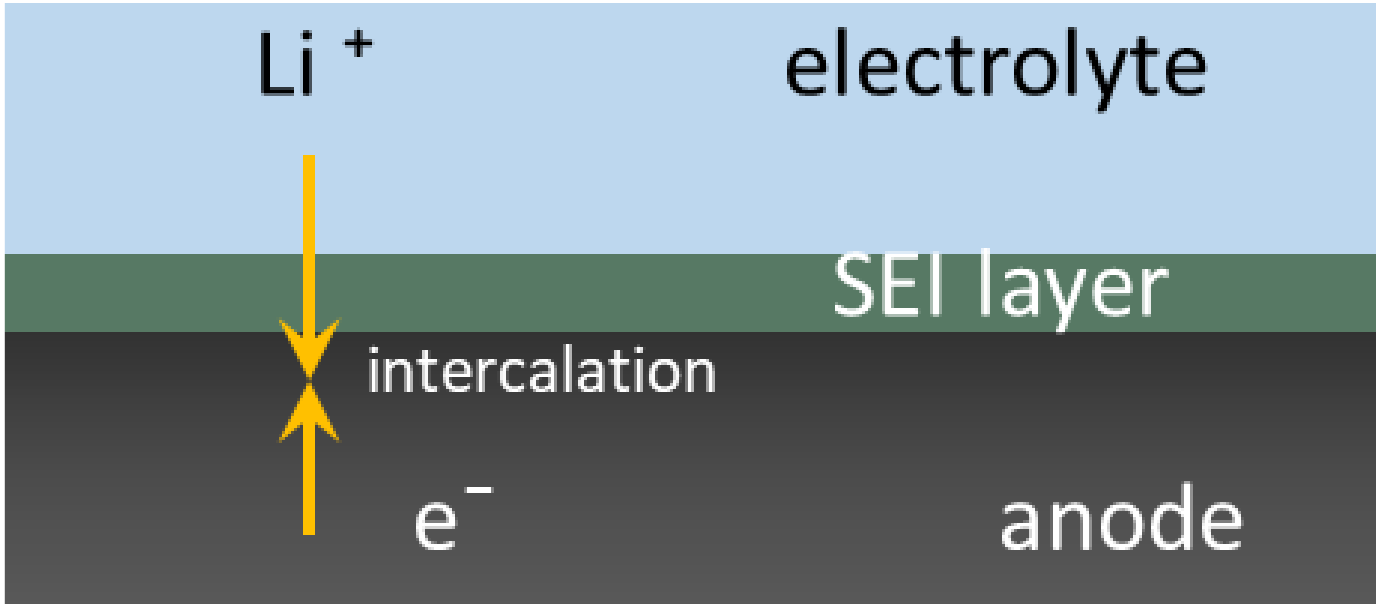

## Electrochemical Prelithiation

- ❑ Compensates initial capacity loss
- ❑ Raises working voltage
- ❑ Decreases electrolyte consumption



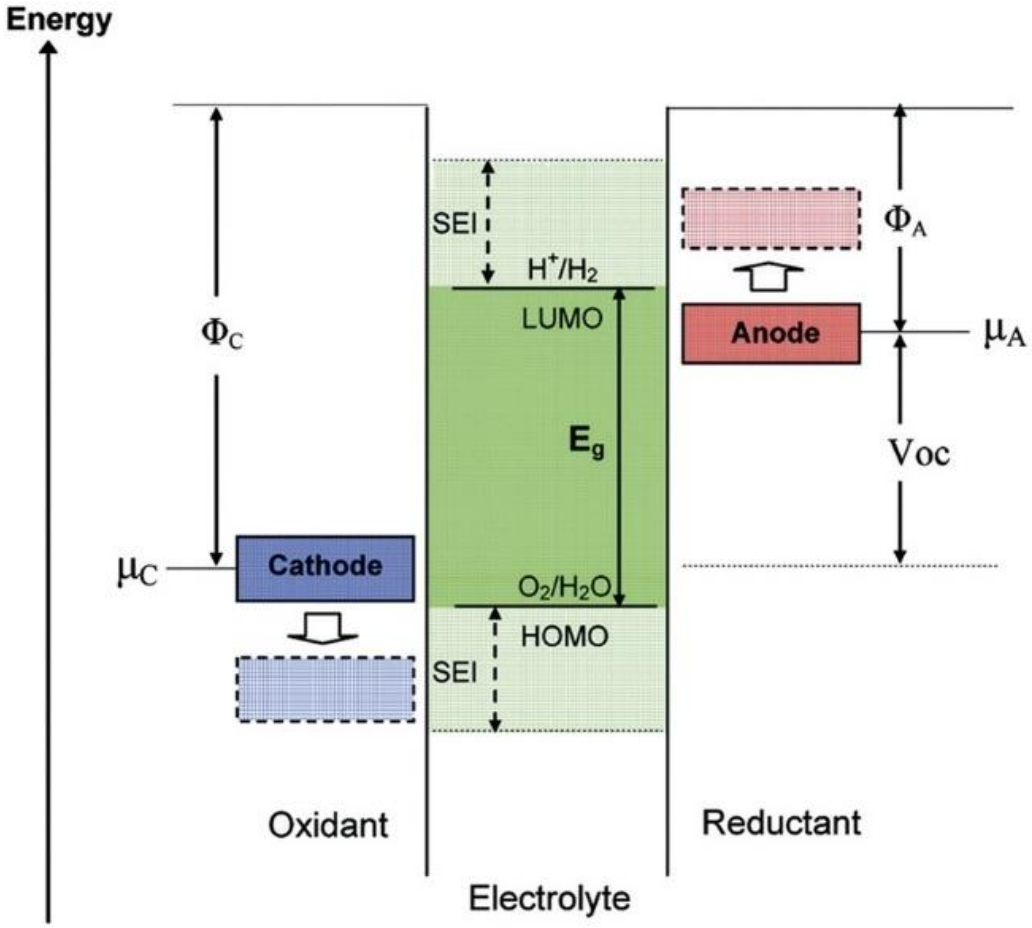
# Role of Electrolyte in Prelithiation Process

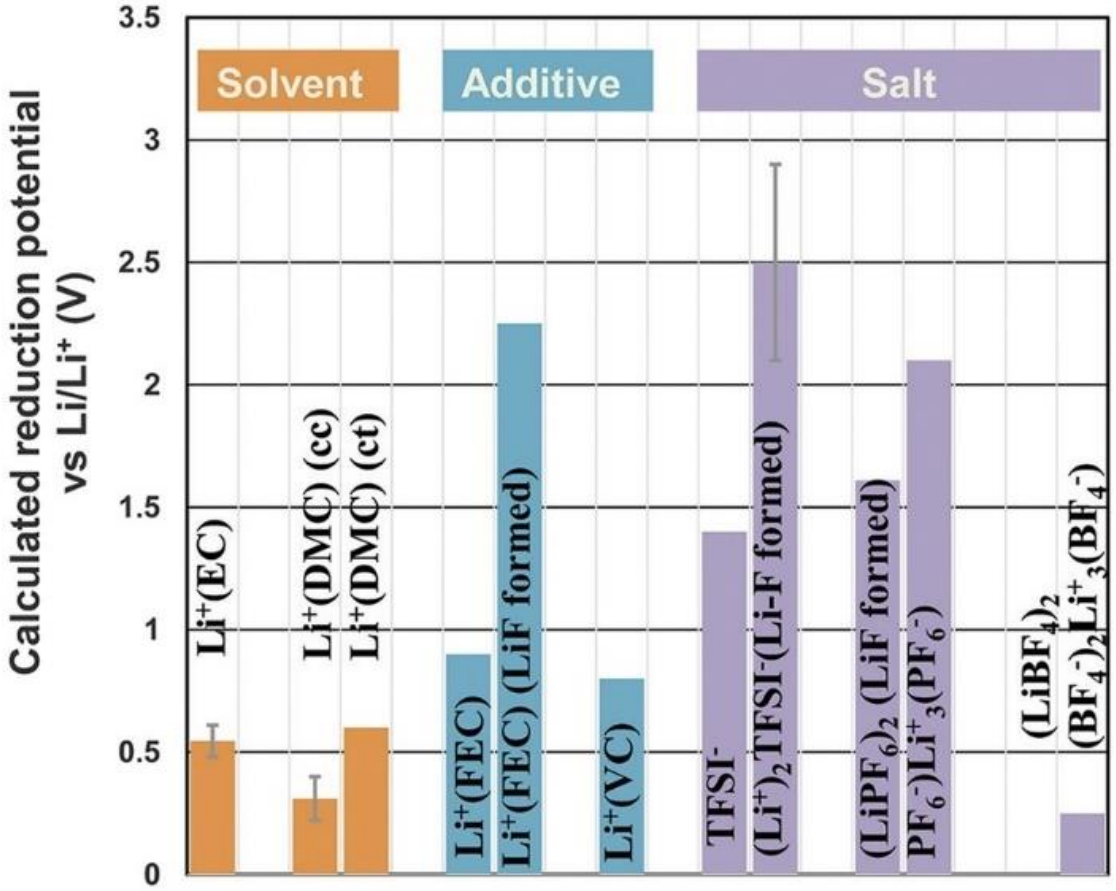
**Solid Electrolyte Interface (SEI)**




- Cyclability of the anodes is affected by the structure and composition of the formed SEI
- Electrolyte determines the formed SEI

# Electrolyte Compositions for Graphene Batteries




Reduction order:
EC > DMC > VC > FEC > EMC > DEC

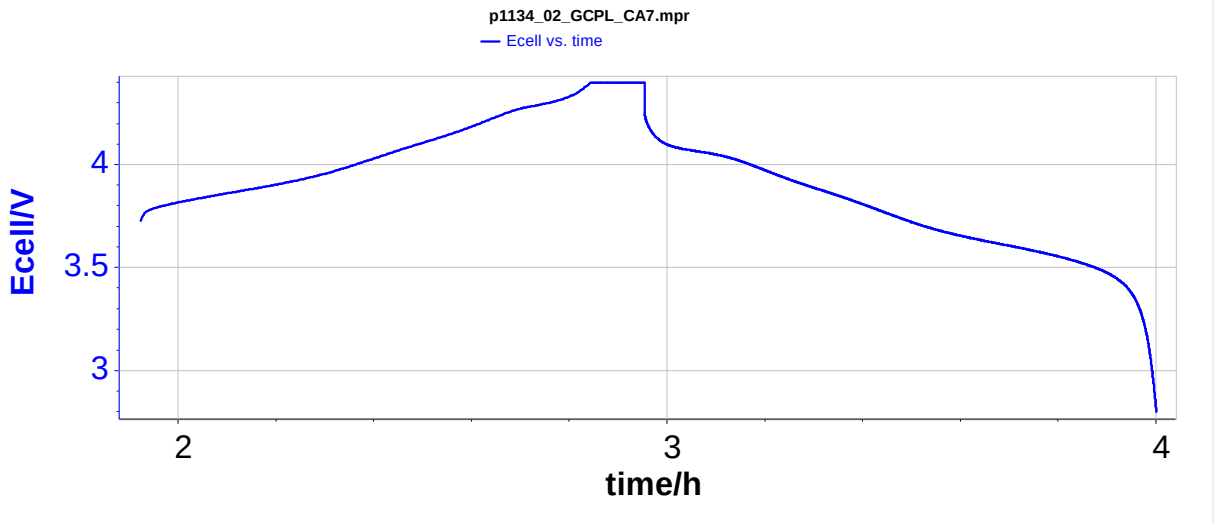
Goodenough and Kim, J. Power Sources 2011, 196, 6688.
Delp et al., Electrochimica Acta 2016, 209, 498.

# Electrolyte Compositions for Graphene Batteries

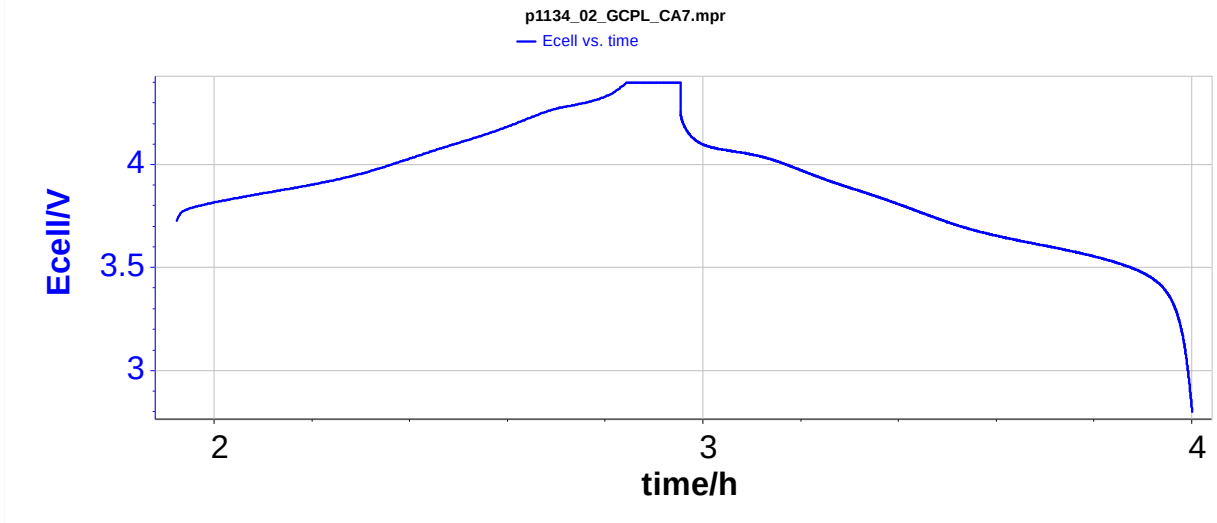
| Electrolyte | LiTFSI | Vinylene (%) | Li salt (%) | FEC (%) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | 1M | | | |
| 3 | 1M | 5% | | |
| 4 | 1M | 5% | 5% | |
| 5 | 1M | 5% | 10% | |
| 6 | 1M | 5% | 10% | 5% |

# Pouch Cells with Prelithiated Graphene Anodes

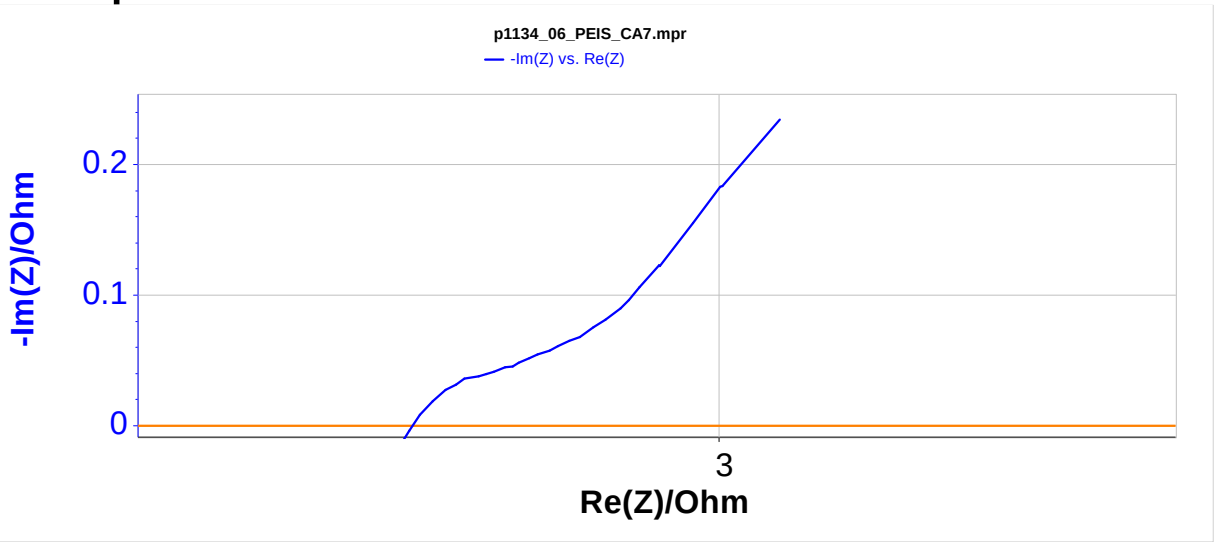
1C E = 300 Wh/kg



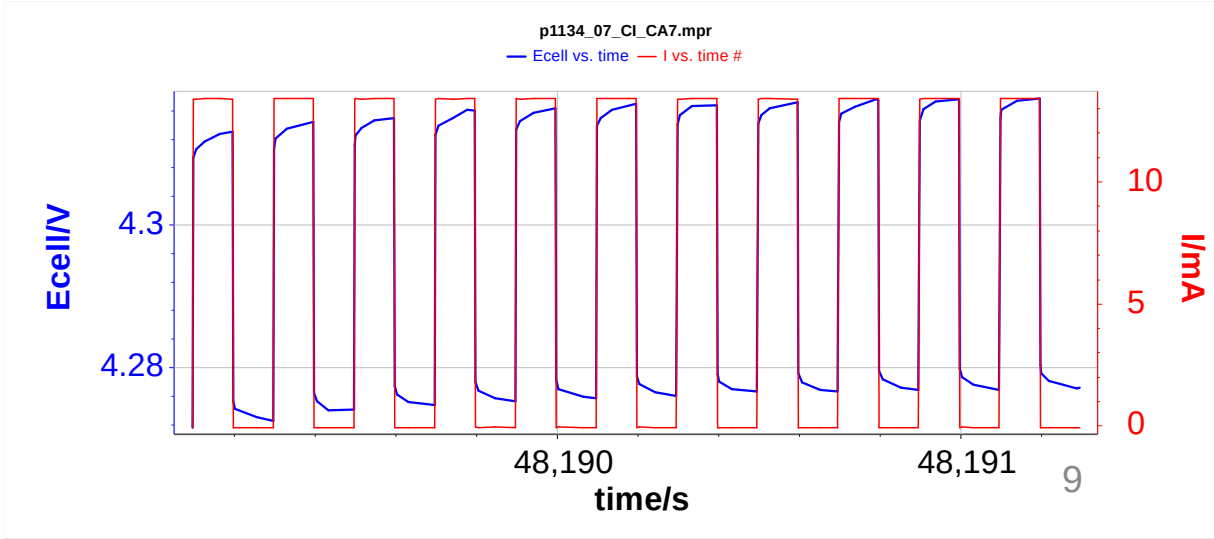

C/2.25 E = 318 Wh/kg C=33.4mAh




Impedance 2.25 Ohm

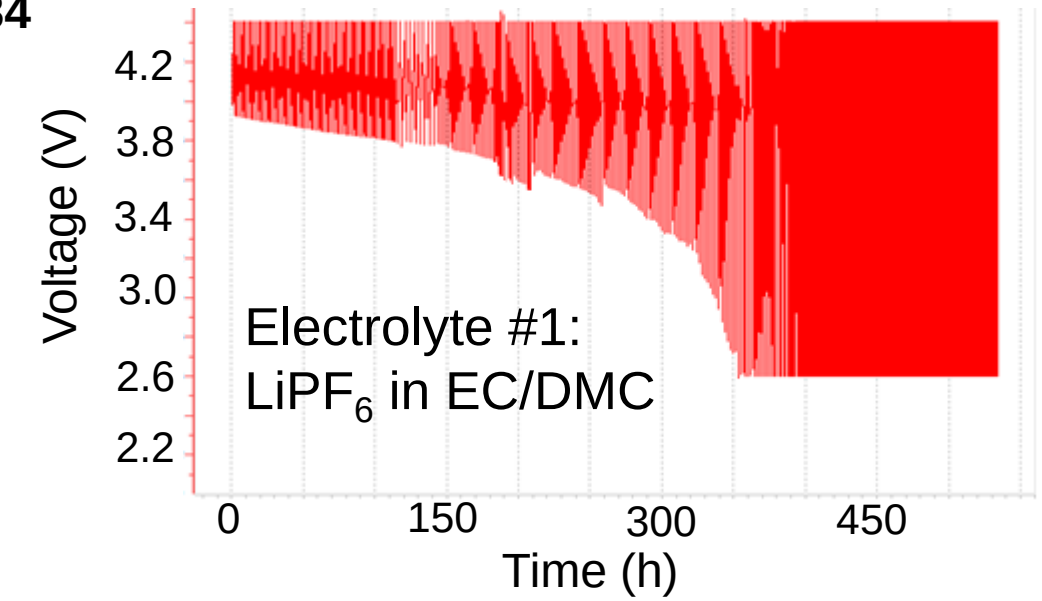


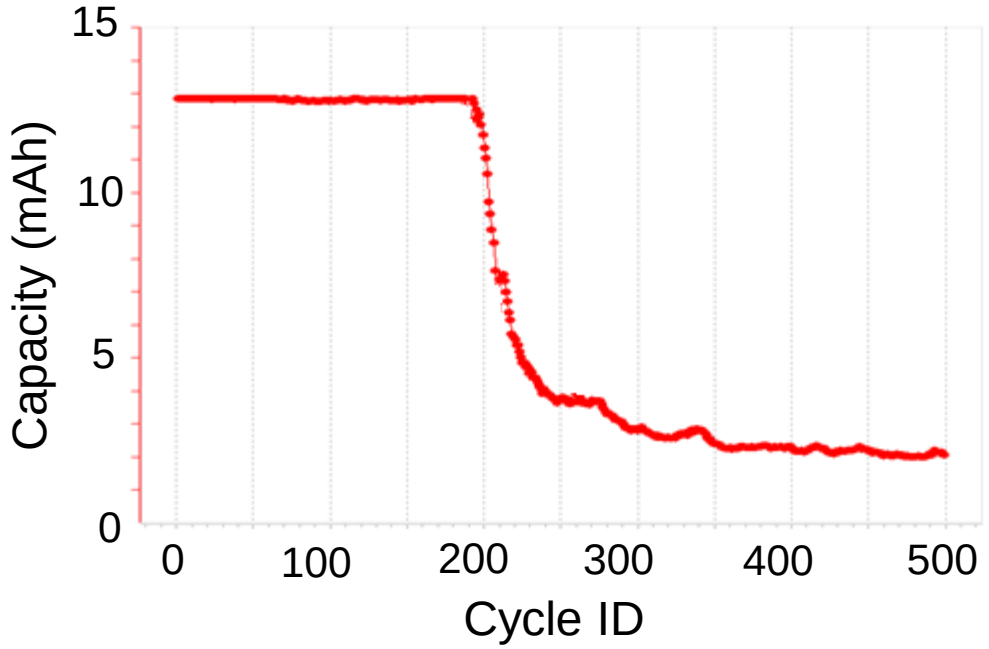

DCR Rc=2.77Ohm



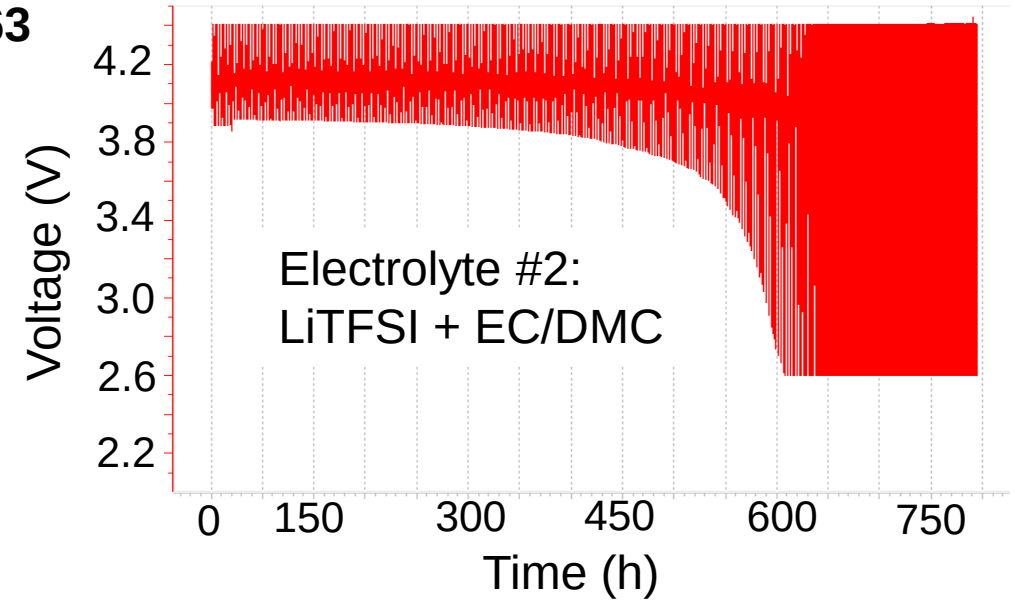
# Effect of Electrolyte on LEO Cycling at 40% DoD

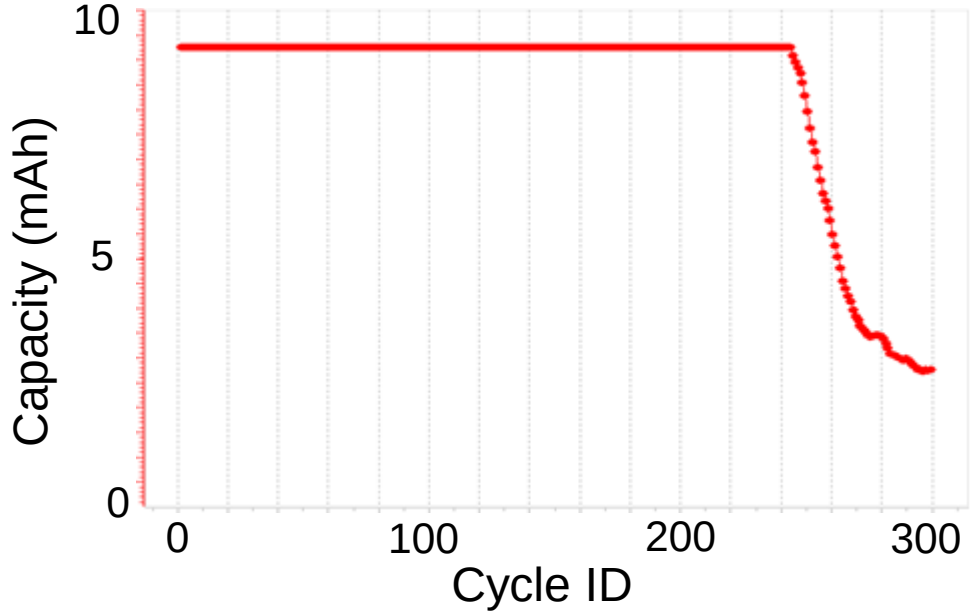
**p1134**



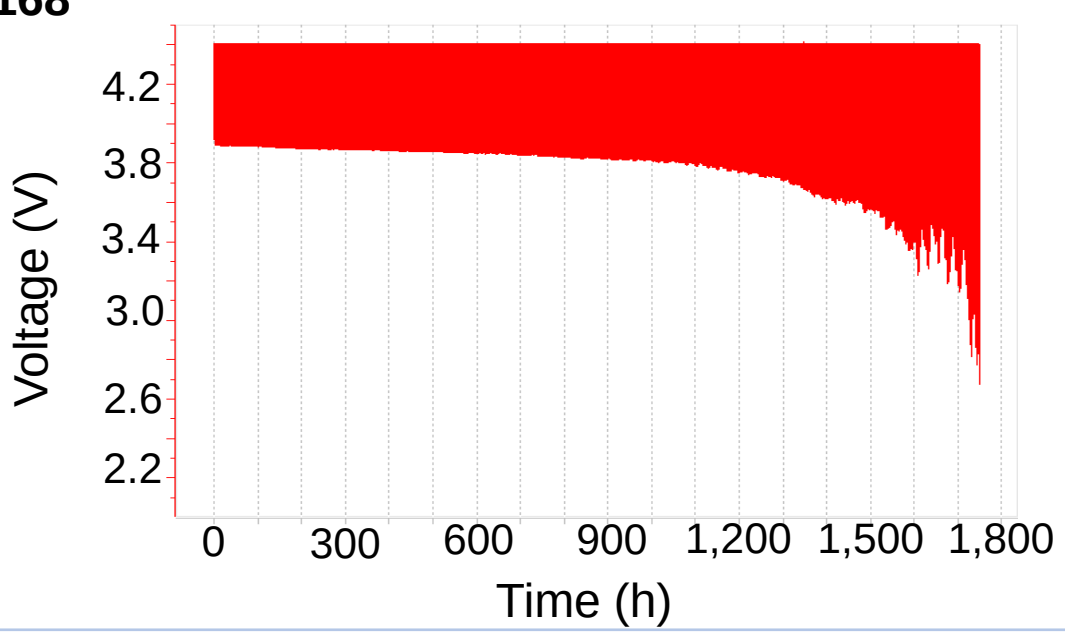

**p1163**

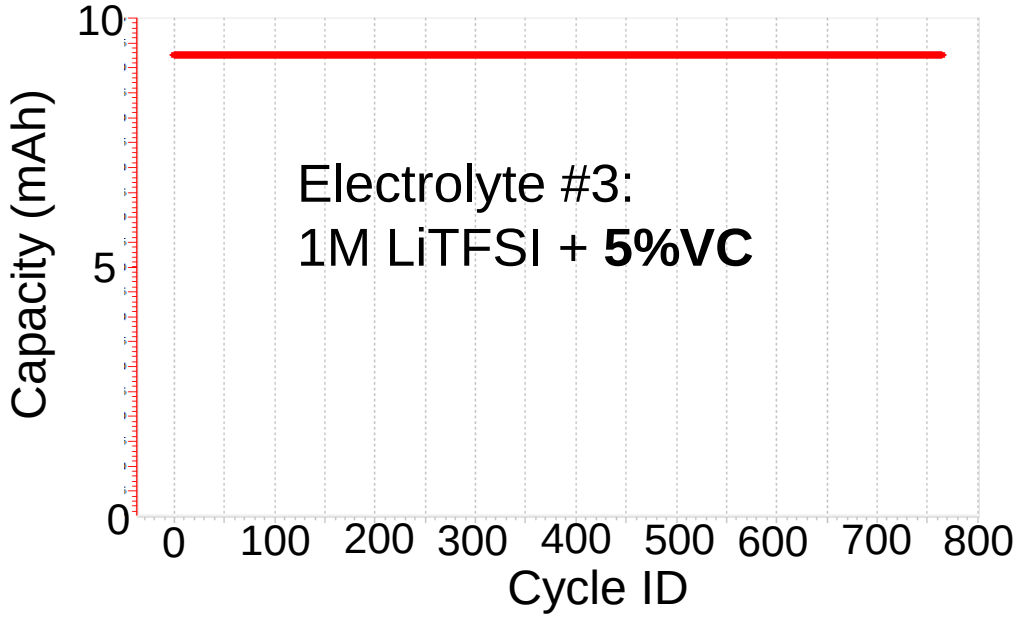


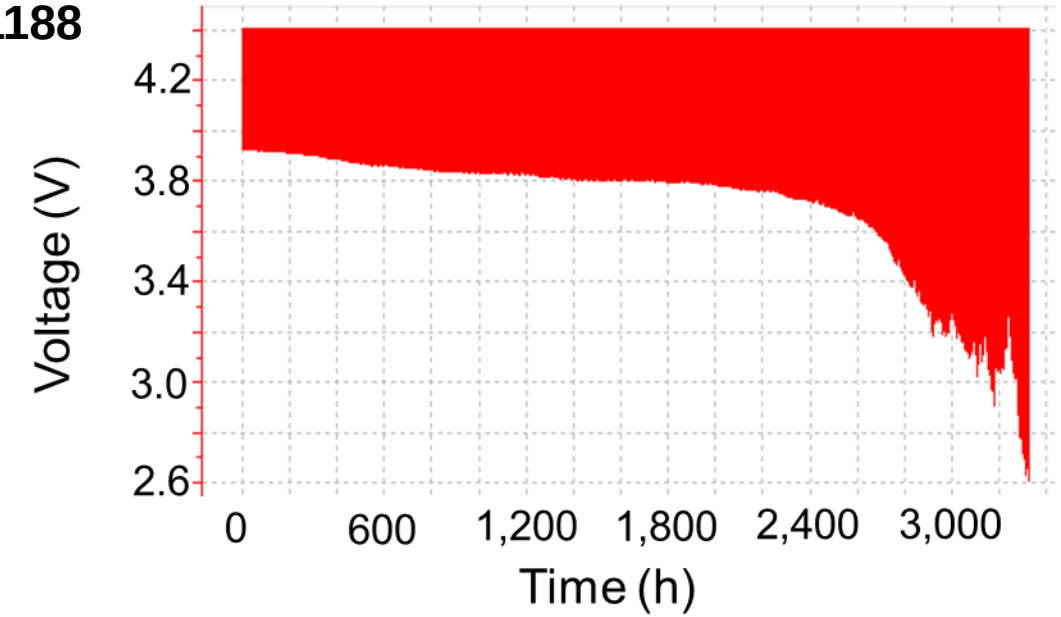
# Effect of Electrolyte on LEO Cycling of Graphene Batteries

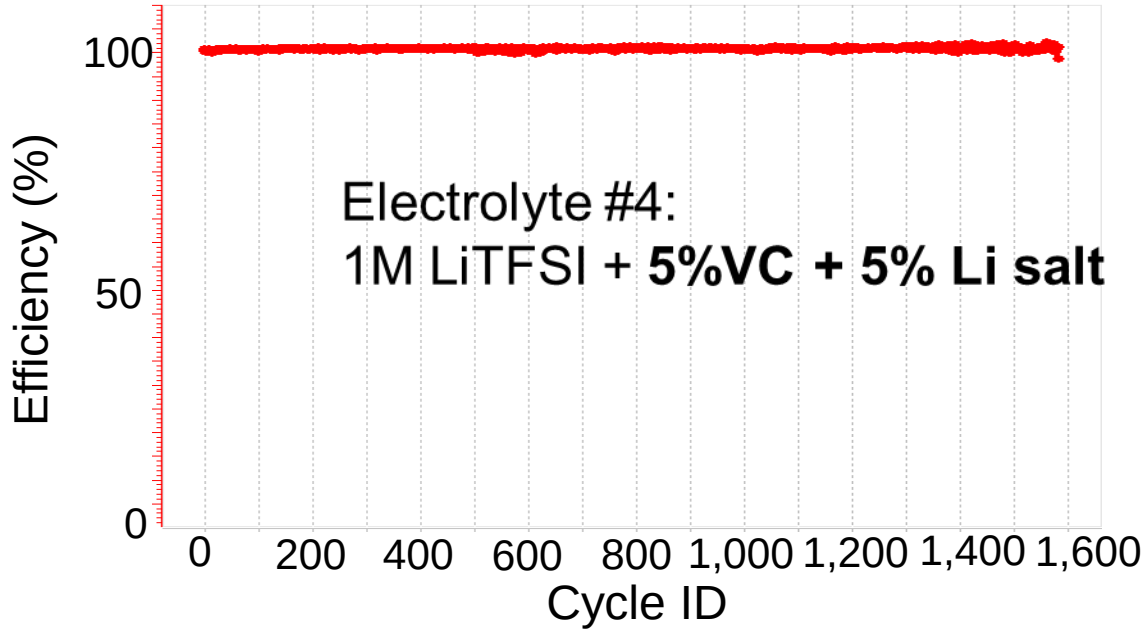
**p1168**



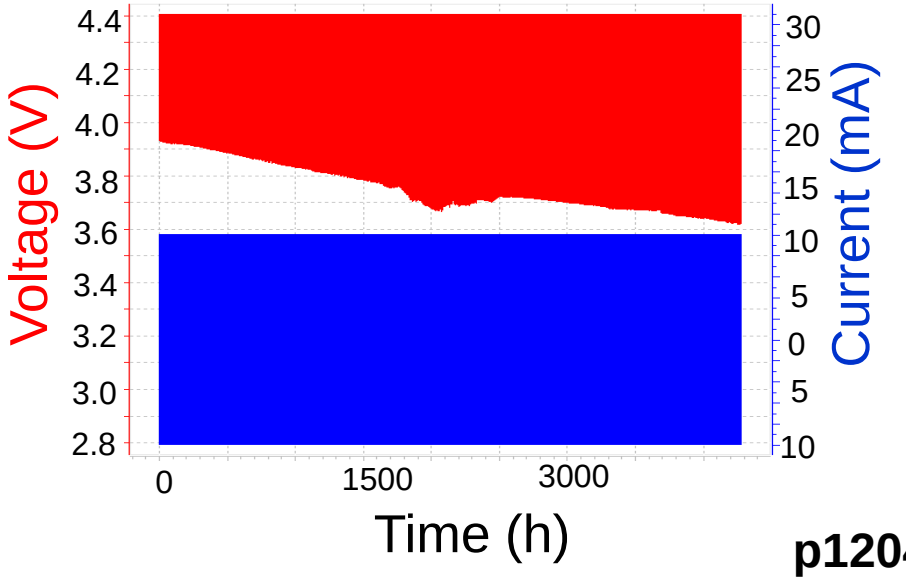

**p1188**

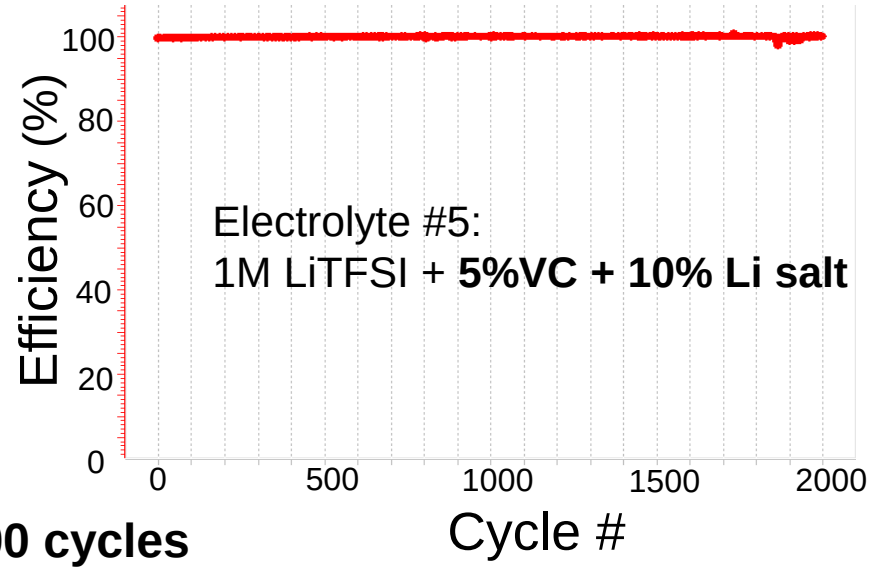


# Effect of Electrolyte on LEO Cycling of Graphene Batteries

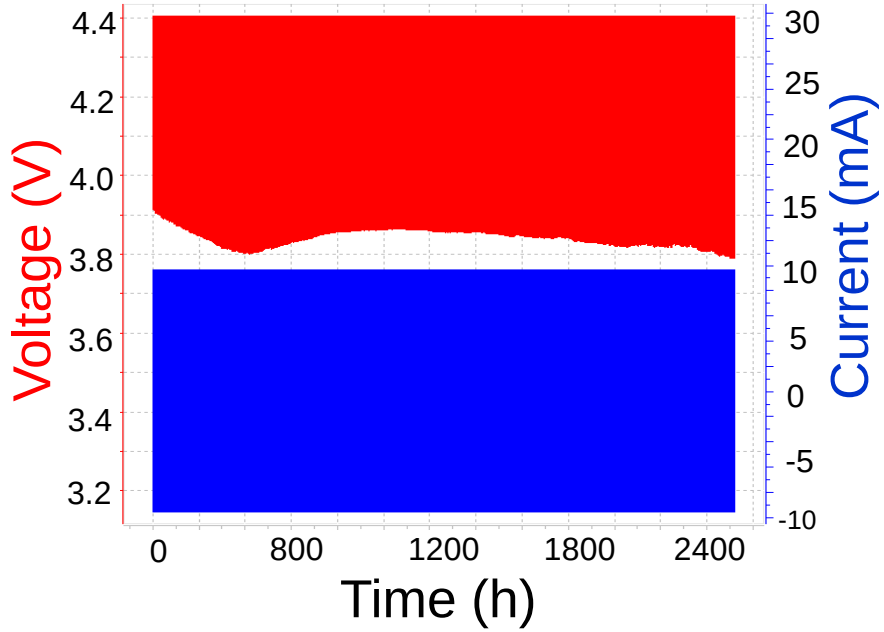
**p1191 2,000 cycles**

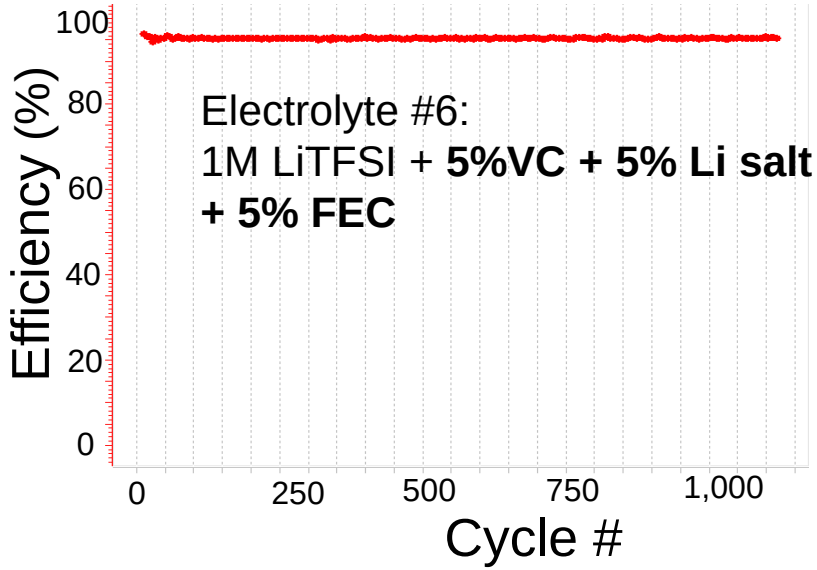



LEO cycling
40% DoD

**p1204 1,500 cycles**

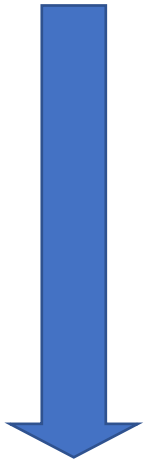


# Effect of Electrolyte on LEO Cycling Stability

| Electrolyte | LiTFSI | Vinylene (VC) % | Li salt % | FEC % | Cells | LEO Cycles |
|---|---|---|---|---|---|---|
| 1 | | | | | p1134 | 189 |
| 2 | 1M | | | | p1163 | 245 |
| 3 | 1M | 5% | | | p1168 | 765 |
| 4 | 1M | 5% | 5% | | p1188 | 1585 |
| 5 | 1M | 5% | 10% | | p1191 | 2000+ |
| 6 | 1M | 5% | 10% | 5% | p1204 | 1500+ |

Cycling Stability



**Li salt in combination of additives such as VC and FEC form stable SEI increasing the cycling stability of the graphene-based anodes.**

# Summary

- Graphene-based batteries with high energy density > 350 Wh/kg and Coulombic efficiency of > 95% using prelithiated graphene anodes
- The composition of the electrolyte plays critical role in the stability of the battery cycling performance
- A combination of Li salts and carbonate additives can be used to form a high-performance stable SEI and regenerate the prelithiated graphene surface during LEO cycling
- The graphene batteries have stable performance for more than 2000 cycles at 40% DOD with capacity retention of 100 % and stable resistance

# Acknowledgement

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TPOC Alec Jackson