

# Trends for the Future of High Energy Density Battery Technology

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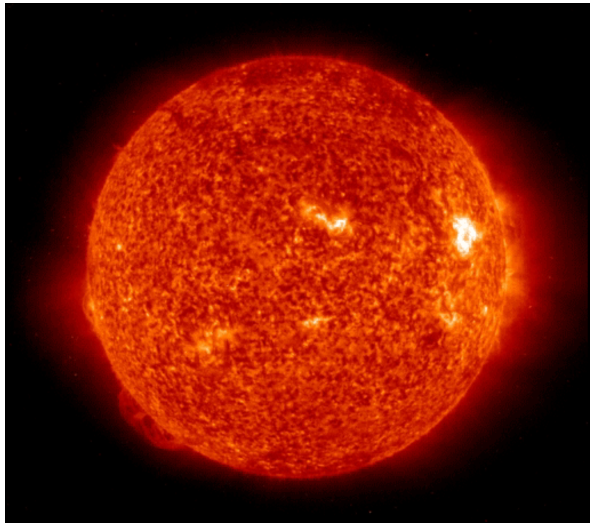



# The Progress of Li-Ion Intercalation Battery Science – Liquid Electrolytes

## Lithium-Ion Liquid Cells

### Cathode Trends:

**NMC:** Drive toward higher **Nickel** continues

- Moving higher than 811
- Major effort to reduce or even eliminate cobalt
  - For example, USP 11,233,239 B2 (1/25/2022)
  - In pilot plant stage by TexPower EV Technologies in Houston

**Phosphates:** Much renewed interest driven by supply chain and cost

- Some work on manganese analogs (iM3NY)
- More science work on vanadium phosphates and oxides

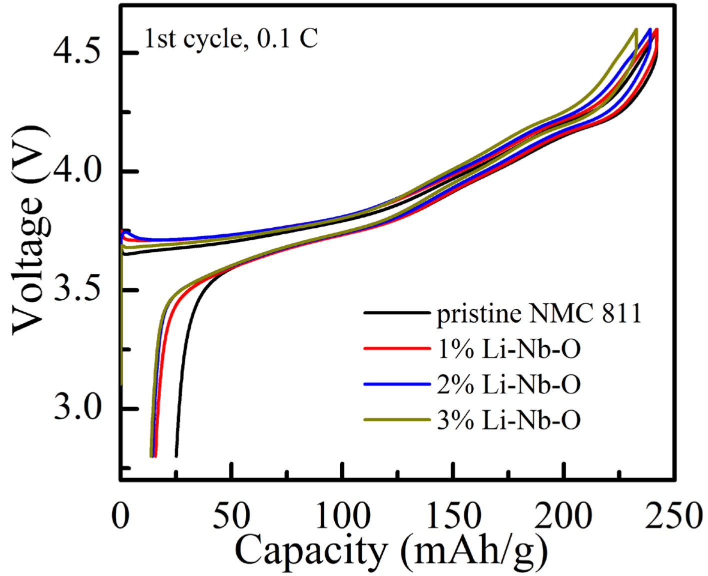
## Sodium-Ion Liquid Cells

Growing science and commercial R&D activity

# NMC: Science addressing Stability and Higher Energy Density

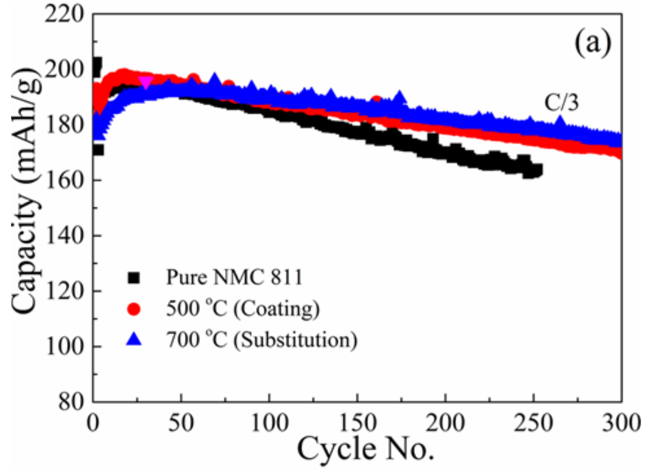
**10-15% capacity loss on 1st cycle can be reduced**

- Coatings and substitution work
  - + enhance capacity retention
  - 811 from some suppliers contain boron
- Coating composition is complex




**Battery500 developing "reactivity" effort**

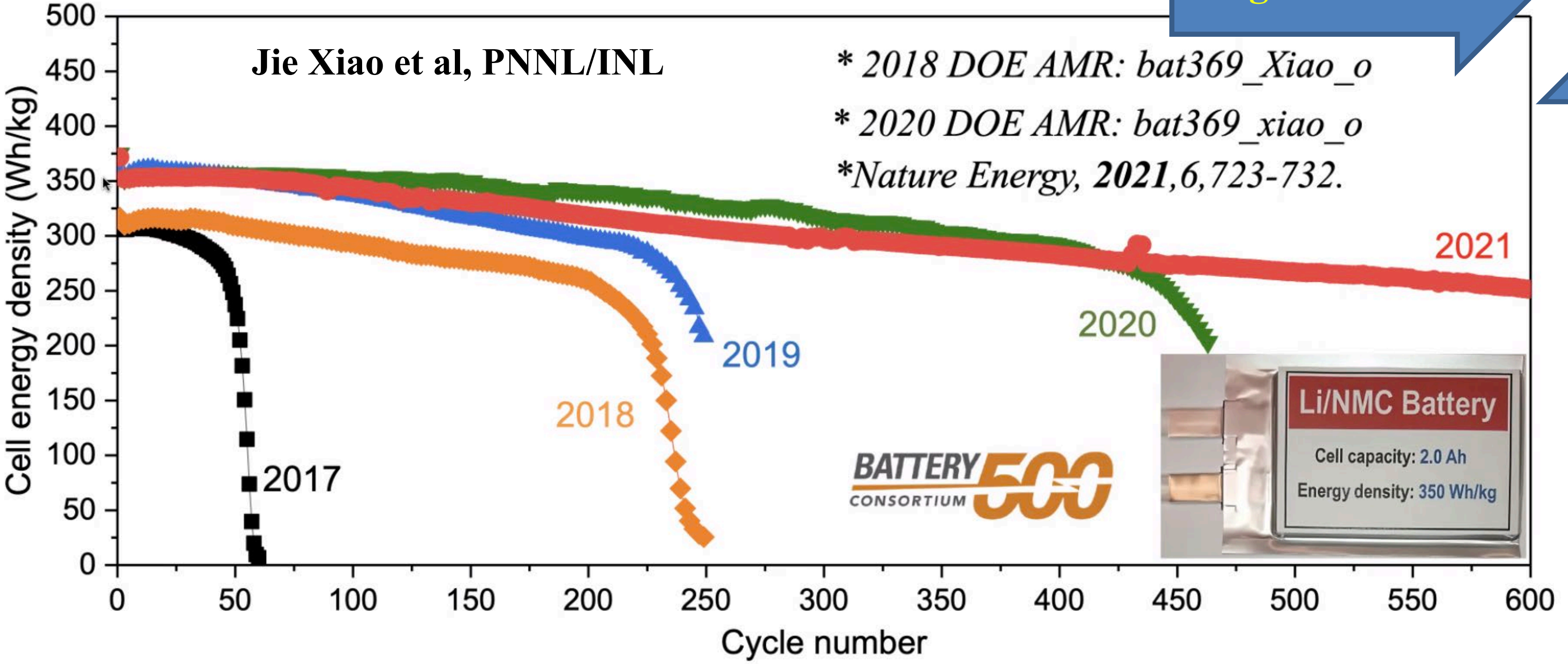
- Stability and side reactions



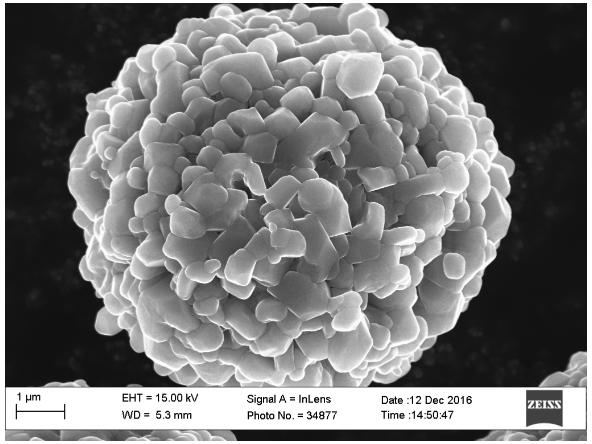

Xin et al ACS Energy Letters, 2021, 6: 1377

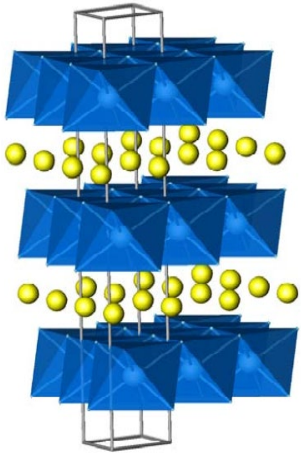
# Battery500 now Achieved 400 Wh/kg with NMC

- NMC shows excellent cycling
  - Achieved 350 Wh/kg goal
  - Li metal anode, LiFSI ether electrolyte

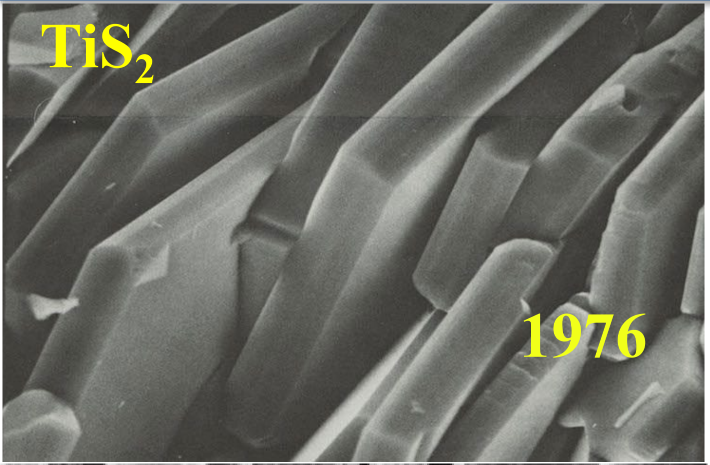


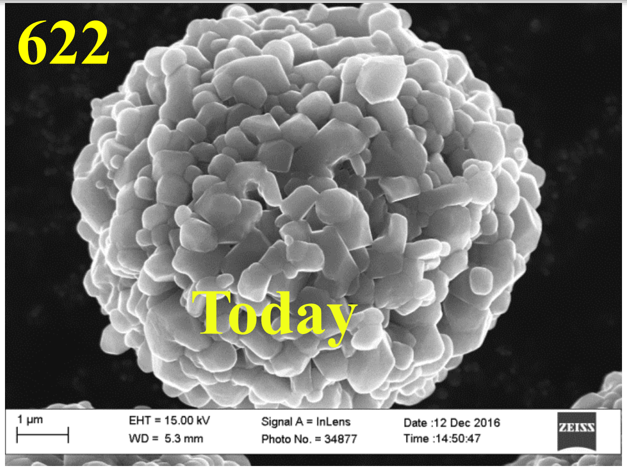


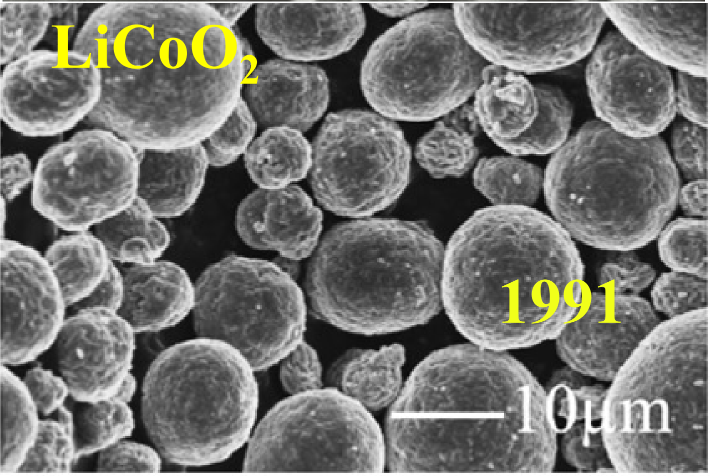


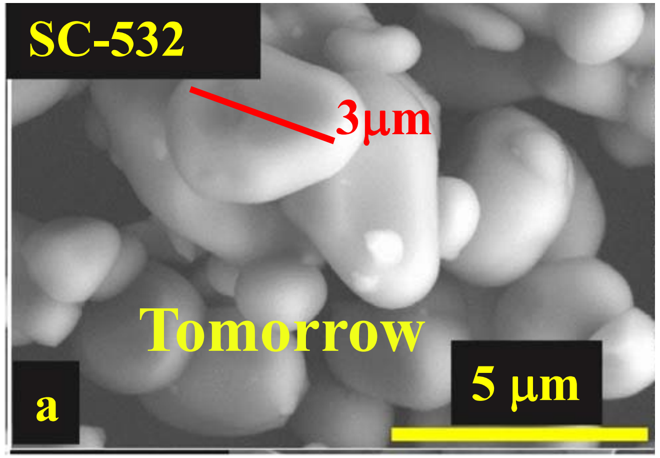



# Intercalation Batteries with Single Crystals allow "Million Miles"



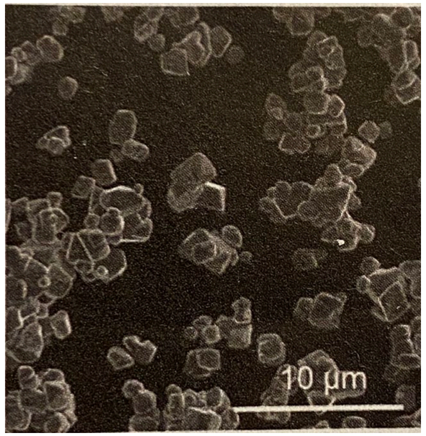

**$LiCoO_2$ Nishi/SONY**
**20 mm particles**
(Figure – Dahn 2007)

*Journal of The Electrochemical Society*, **166** (13) A3031-A3044 (2019)

## Why single crystals?

- Less surface area = less side reactions
  - Much longer life
- Allow "million+ mile" batteries
  - Why? Allows **grid/EV interaction**

- Cracking of crystals can be limited
  - Keep at ≤ 3 μm
  - Jia Xiao, PNNL
    - Science, 370: 1313 (2020)
    - $LiNi_{\mathbf{0.76}}Mn_{0.14}Co_{0.1}O_2$
- Next step: What is optimum morphology





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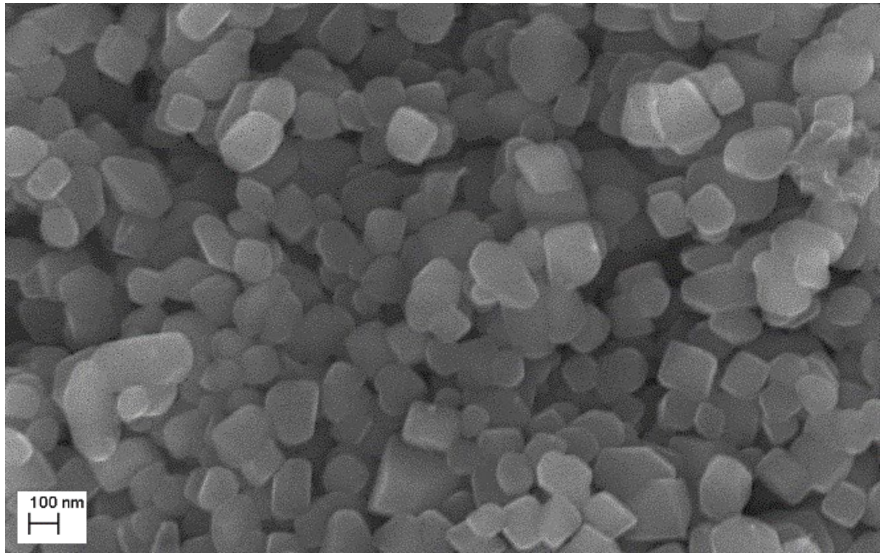
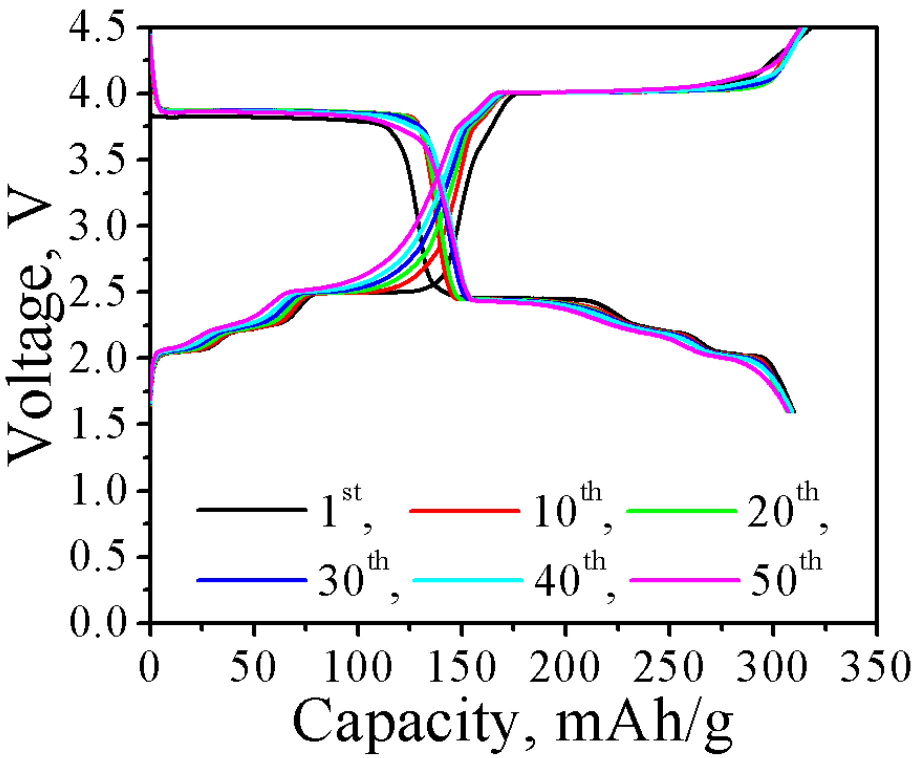
# Proof of Concept achieved for multi-electron cathodes – $Li_2VOPO_4$
# Small cuboid particles allow two Li ions to be reversibly intercalated




Synthesis is critical
- ε-$VOPO_4$ particles
- ~100-200 nm
- Cuboid particles

Challenges:
- Reactivity
- Rate at 4 V




ChemComm
ROYAL SOCIETY OF CHEMISTRY
COMMUNICATION
Cite this: *Chem. Commun.*, 2018, **54**, 7802
9/c8cc02386g
rsc.li/chemcomm

**Enabling multi-electron reaction of ε-$VOPO_4$ to reach theoretical capacity for lithium-ion batteries†**

Carrie Siu,[a] Ieuan D. Seymour,[b] Sylvia Britto,[b] Hanlei Zhang,[a] Jatinkumar Rana,[a] Jun Feng,[a] Fredrick O. Omenya,[a] Hui Zhou,[a] Natasha A. Chernova,[a] Guangwen Zhou,

- Vanadium is $4^{th}$ most abundant TM
- **Texas A&M effort** on new V oxides

# What is the situation with Sodium-ion Batteries?

- ✓ **Sodium intercalation systems receiving a lot of attention**
  - ✓ Points to keep in mind
    - ✓ Lithium is not the high cost component in Li-ion batteries
    - ✓ 50-70% of energy density of Li-Ion (120-160 Ah/kg)
      - ✓ Unlikely to find use in most portable applications
        - ✓ Exceptions are e-bikes and electric rick-shaws
    - ✓ More slopey discharge
    - ✓ Not lower cost unless cobalt and most of the nickel is eliminated
      - ✓ Na[MnFe]$O_2$ interest seems to have subsided (ANL still active)
    - ✓ Can be shipped at 0 volts

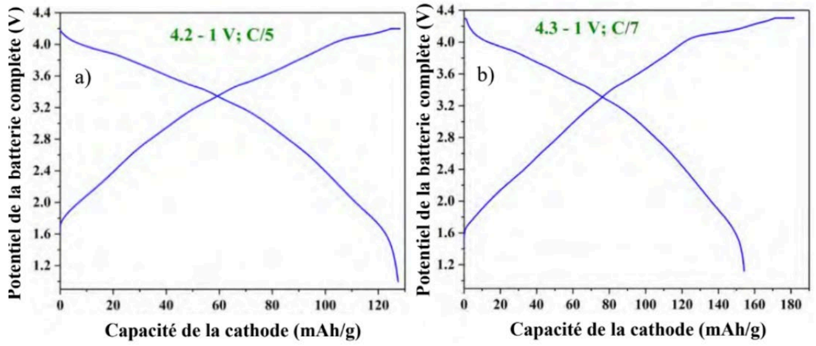


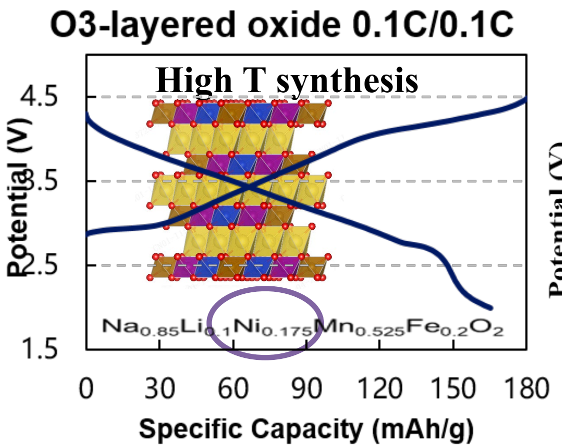

**Figure 8.6.** *Profil de tension de la cellule Faradion à l'échelle de 10 mAh*

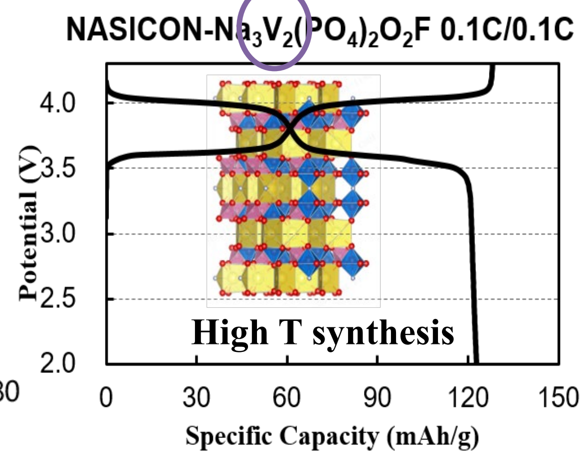
# Na-ion Battery Development --- Alternatives of Li-ion battery

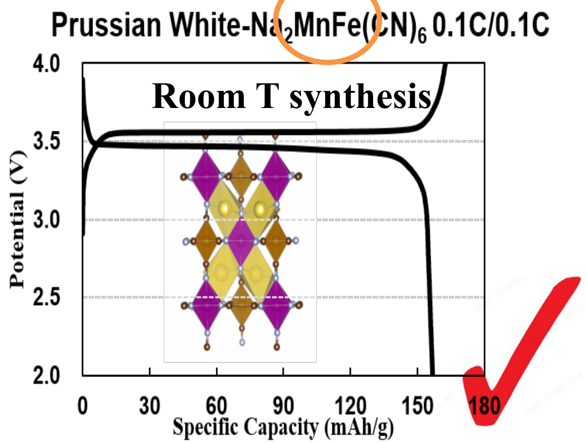
CATL 宁德时代

## Key issues now: Selection and Development of the Proper Anode and Cathode Materials

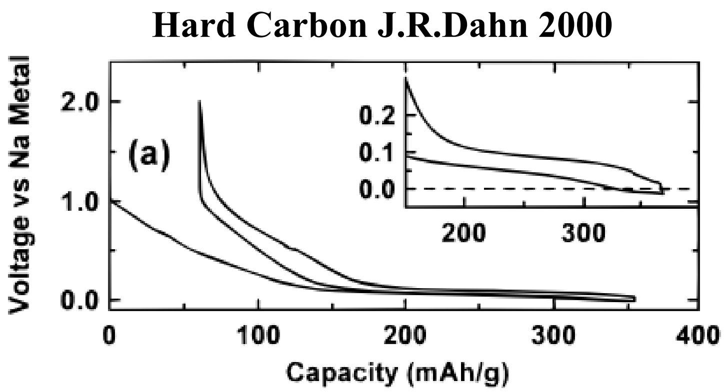
- **Cathode**




- **Anode**




- Advantage:
  - Higher conductivity;
  - Higher theoretical capacity (≈200mAh/g)
- Disadvantage:
  - More phase transition;
  - Hard to balance cost/stability/capacity;

- Advantage:
  - More stability;
- Disadvantage:
  - Lower electronic conductivity;
  - Higher price and less resource of V;
  - Lower theoretical capacity (≈ 120mAh/g);

- Advantage:
  - Cost (synthesis + Fe/Mn);
  - Proper capacity (160mAh/g)
- Disadvantage:
  - Lower electronic conductivity;
  - More hygroscopic

- Graphite:10-30mAh/g→
- Hard Carbon: J.R.Dahn 2000, 300mAh/g→
- Still <365mAh/g (vs. Graphite in LIB)
- How to improve the capacity?

# Two Main classes of Sodium-ion Battery Cathodes?

- ✓ **Faradion is pursuing nickel-based layered oxides**
  - ✓ Using nickel-based cathode, $NaNi_y[Mn,Mg,Ti]_{1-y}O_2$
  - ✓ Hard carbon anode
  - ✓ Fairly standard electrolyte, $NaPF_6$ carbonates
  - ✓ Capacity 120-160 mAh/g
  - ✓ Claim that can be held at 0 volts (Na limited)

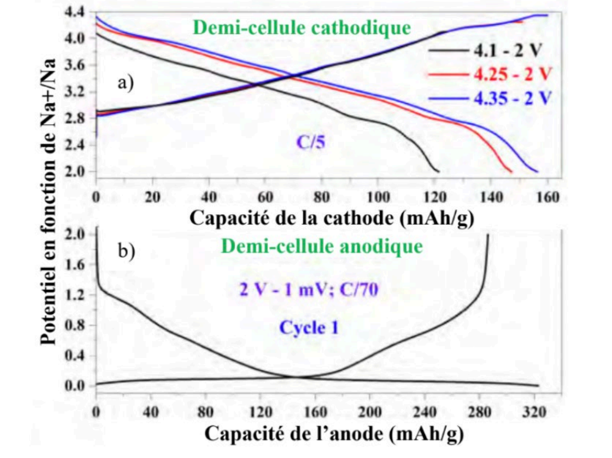
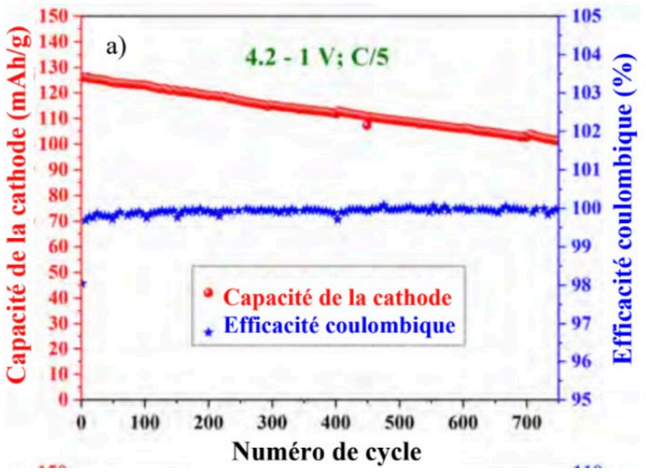



**Figure 8.5.** *Performances de la cathode et de l'anode Faradion en demi-cellule (en fonction du Na métal)*



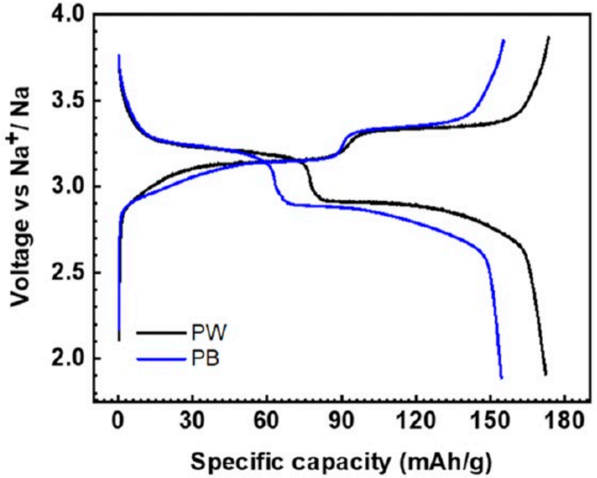

Barker et al, Faradion in

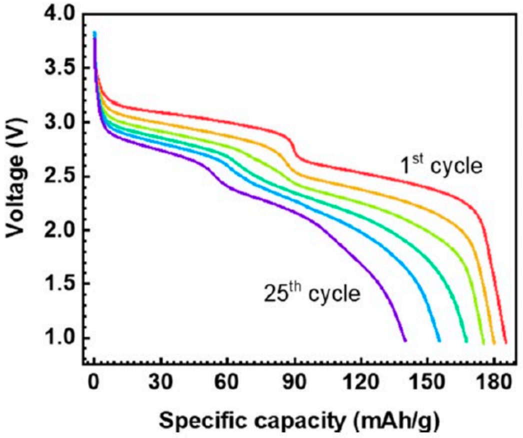
Les batteries Na-ion

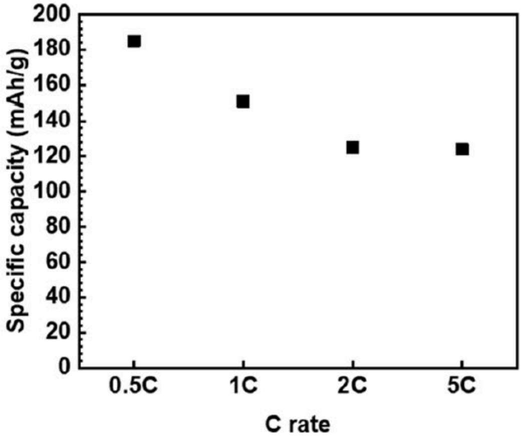
Laure Monconduit Laurence Croguennec Sep 2021

ISTE Group

- ✓ **CATL and Natron are pursuing ferrocyanides** (Prussian blue/white); *$Na_2(Fe,Mn)[Fe(CN)_6]$*
  - ✓ Capacity same as LFP – 169 mAh/g (CATL targeting 200 Wh/kg)
  - ✓ High rate
  - ✓ Low cost




Lim et al ACS AEM 2021

# What are the battery systems of the future? – Some changes from 2021

- ✓ **Lithium intercalation systems will dominate for next 5-10 years**
  - ✓ NMCA likely to be dominant
  - ✓ Phosphates seeing **much greater** interest: $LiFePO_4$/$LiMnPO_4$ /$LiVOPO_4$
  - ✓ **Need safe and stable electrolytes**

- ✓ **Lots of publicity for solid state batteries (are they really safer?**
- ✓ **Interest in "million-mile batteries"**
  - ✓ Grid connected vehicles
  - ✓ Larger particles, slower charging capability
- ✓ **Interest growing in high energy density cells, ≥ 400 Wh/kg @ cell level for aircraft**
  - ✓ High nickel NMC


- ✓ **Sodium-ion cells seeing renewed interest**
- ✓ **Lithium sulfur has the highest ED but is a real bear,**
  - ✓ **but maybe only one that can achieve ≥ 500 Wh/kg**
  - ✓ Concern about low volumetric energy density

# Vision and Goals of NENY EDA BBBRC proposal

## NEW ENERGY NEW YORK

### VISION

*"Establishing a domestic supply chain for lithium-based batteries requires a national commitment to both solving breakthrough scientific challenges for new materials and developing a manufacturing base that meets the demands of the growing electric vehicle (EV) and stationary grid storage markets."*

**Jennifer M. Granholm**, Secretary of Energy, U.S. Department of Energy

### *A National Hub For Battery Innovation, Manufacturing, And Workforce Development*

New Energy New York will help the U.S. meet the demand for domestic battery products by accelerating the budding battery development and manufacturing ecosystem in the Southern Tier and Finger Lakes regions of Upstate New York. The initiative will leverage and expand on existing research, development, testing, and workforce assets to meet the demand of the emerging manufacturing industry spurred by the iM3NY Li-ion gigafactory set to open in Greater Binghamton in 2022. The program seeks to create a new manufacturing economy, built on a foundation of equity and environmental justice, supporting economic resurgence in underdeveloped areas in Upstate New York. The program leverages the vision set by the Southern Tier Regional Economic Development Council of becoming "a leader in innovation and integration of battery technology and the energy storage sector."

# Projects within New Energy New York

1. Battery-NY Technology and Manu
2. Workforce Development
3. Supply Chain Development
4. Climate Justice Initiative
5. Innovation and Entrepreneurship

Contacts: Stan Whittingham (Bob Galyen is our Advisor)
https://newenergynewyork.com

Battery-NY needs equipment manufacturers

**PROJECTS**

1. **BATTERY-NY:** A Battery Technology and Manufacturing Center hosted by Binghamton University in an Opportunity Zone to (1) develop and enable the advanced manufacturing of battery technologies, and (2) establish a robust manufacturing infrastructure to support the battery industry and its supply chain.
2. **Workforce Development:** The project will develop a host of coordinated and innovative programs throughout the supported regions for the training of the workforce required to support the storage manufacturing ecosystem, with dedicated programs to promote equity and participation of individuals from underrepresented and disadvantaged backgrounds.
3. **Supply Chain Development:** To support the rapid growth in energy storage projects and the consequent increasing demand for a strong and qualified supply chain, the project will implement a strategy for building and supporting a robust storage supply chain throughout Upstate New York, including a supplier catalogue and a supplier certification program.
4. **Climate Justice Initiative:** The project will develop groundbreaking programs to mitigate potential negative aspects of the growth of the storage manufacturing ecosystem, such as funds for the support of main street businesses, demolitions, pollution prevention, and DEI initiatives.
5. **Energy Storage Acceleration:** The project will establish New York State as the premier destination for realizing energy storage technologies and startups from prototyping to scale-up to manufacturing. While leveraging and expanding existing successful programs, it will develop new programs for proof-of-concept support, acceleration of nascent and mature startups, and the development of new incubation models and facilities.