# Development of Anode Materials for Sodium Ion Batteries

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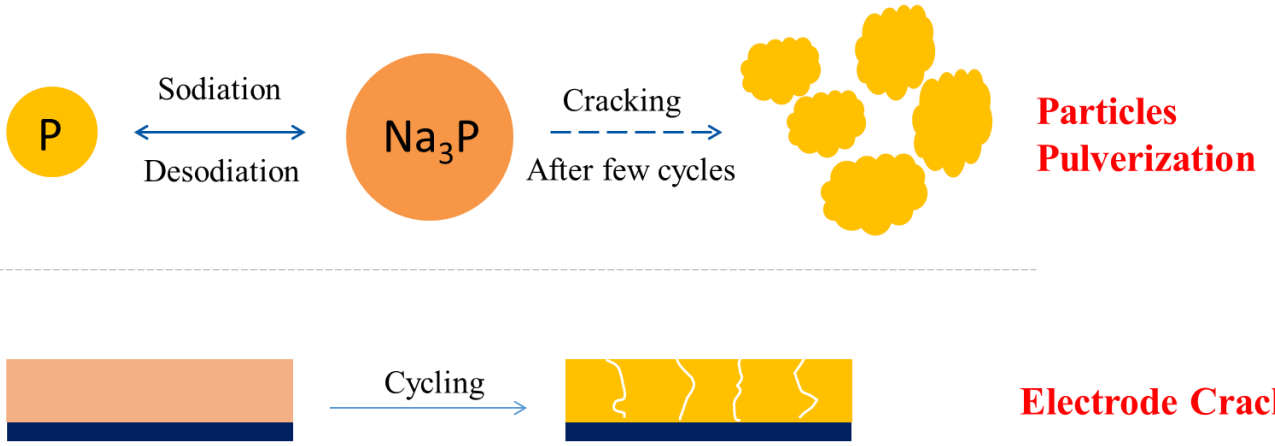
## Red Phosphorus as Anode for Na-ion Batteries:

### Advantage:

- **High theoretical capacity**: 2593 mAh/g, $P+3Na^{+}+3e^{-} \rightarrow Na_3P$

### Challenges:

- **Intrinsically low electrical conductivity: $10^{-14}$ S/cm**
- **Large volume change**




### Strategies:

- **Increase conductivity**:

Build nano-structure with high electronical conductive additives, like graphene, carbon nanotube (CNT), nanoporous carbon.

- **Accommodate large volume change**:

Smaller particles: Ball mill large bulk red phosphorus particles into nanoscale.

Cross-link binder: Build strong chemical bonds among phosphorus, functionalized carbon additive and binder, insuring a strong integrated structure from particle to electrode level.

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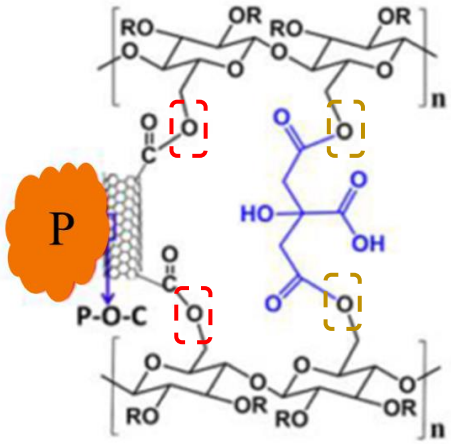
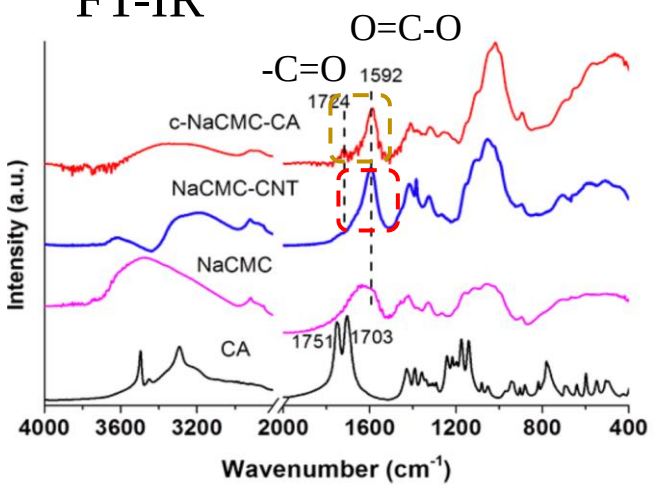
# Project Summary

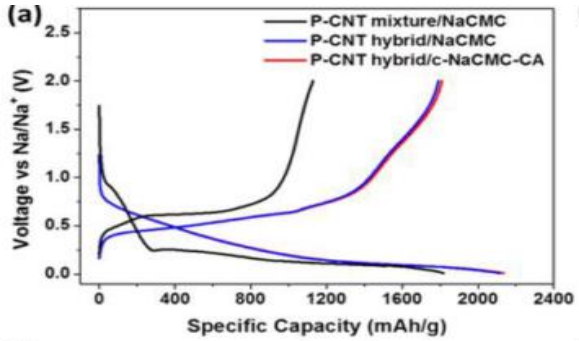
PennState Energy Nanostructure Lab. of

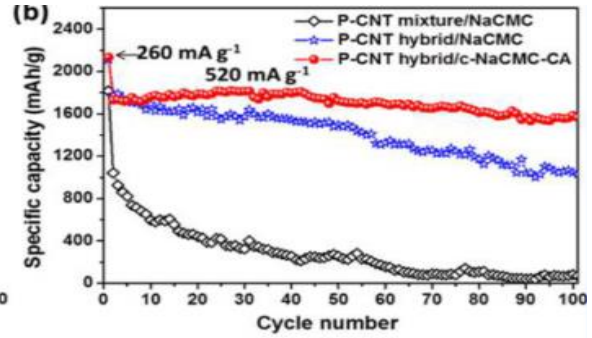
## P-CNT hybrid

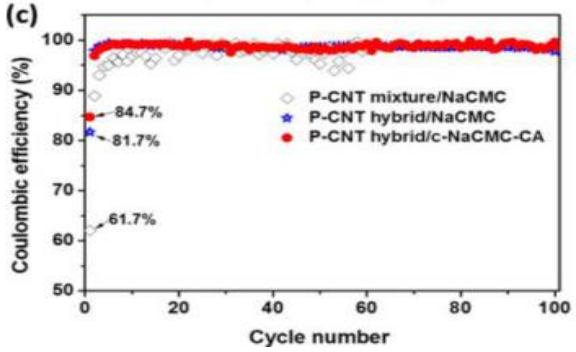


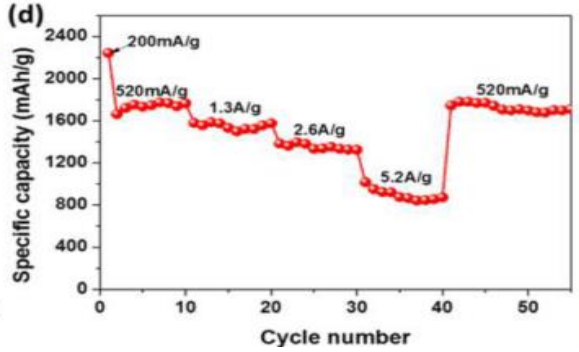

## FT-IR



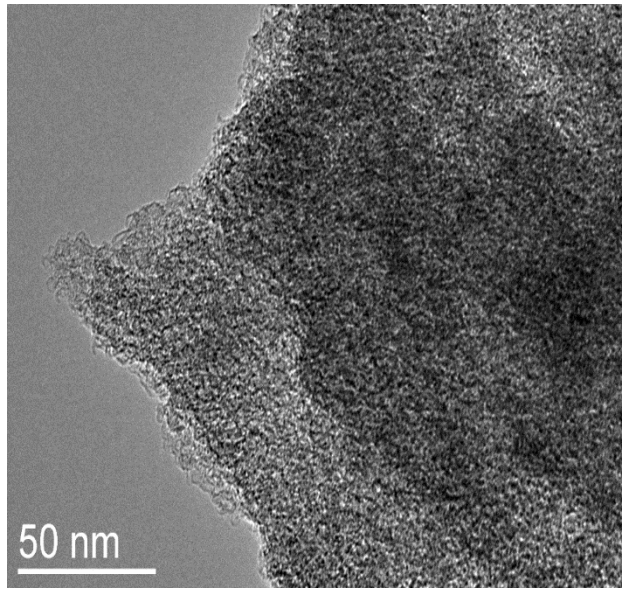



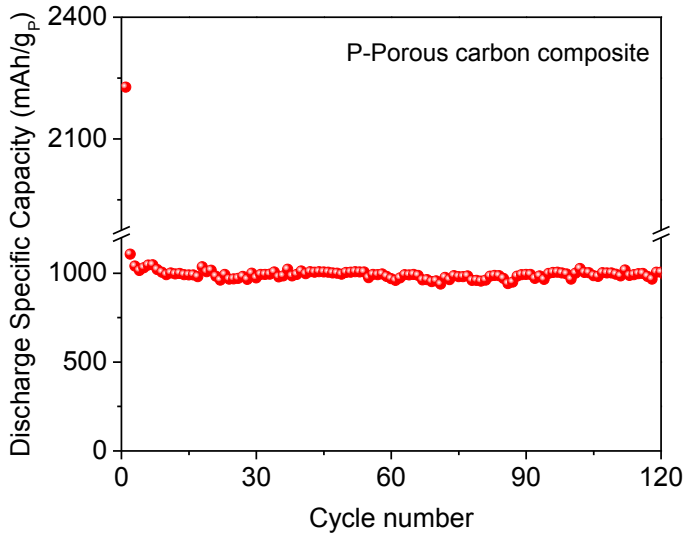




Song, J., Yu, Z., et. al., ACS Nano, 2015, 9(12), 11933–11941.




## Porous carbon-P composite




## Sodium ion conductor: $Na_3P_{0.65}As_{0.35}S_4$