CNFs for Flexible Power Sources

Sang-Young Lee

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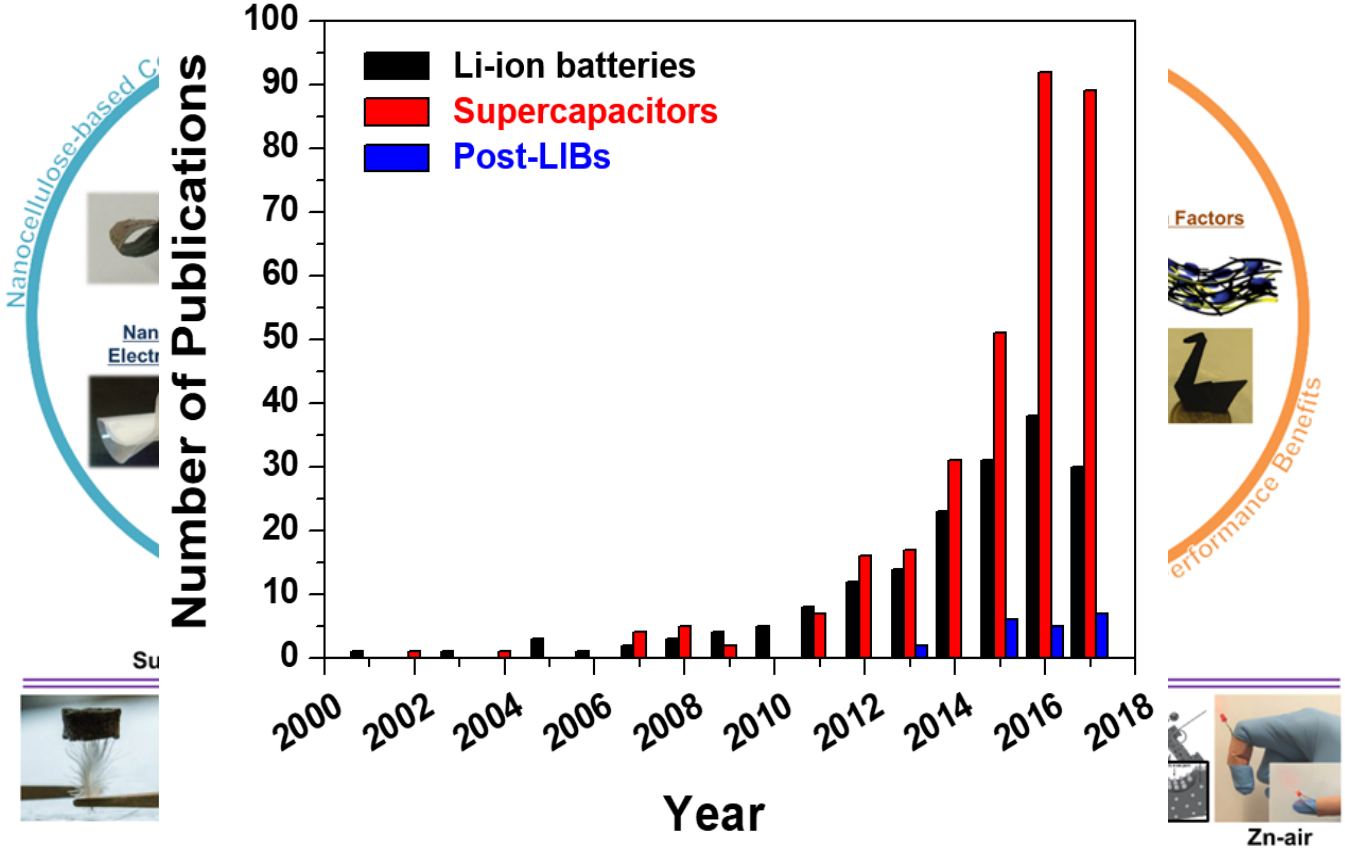
Professor
UNIST

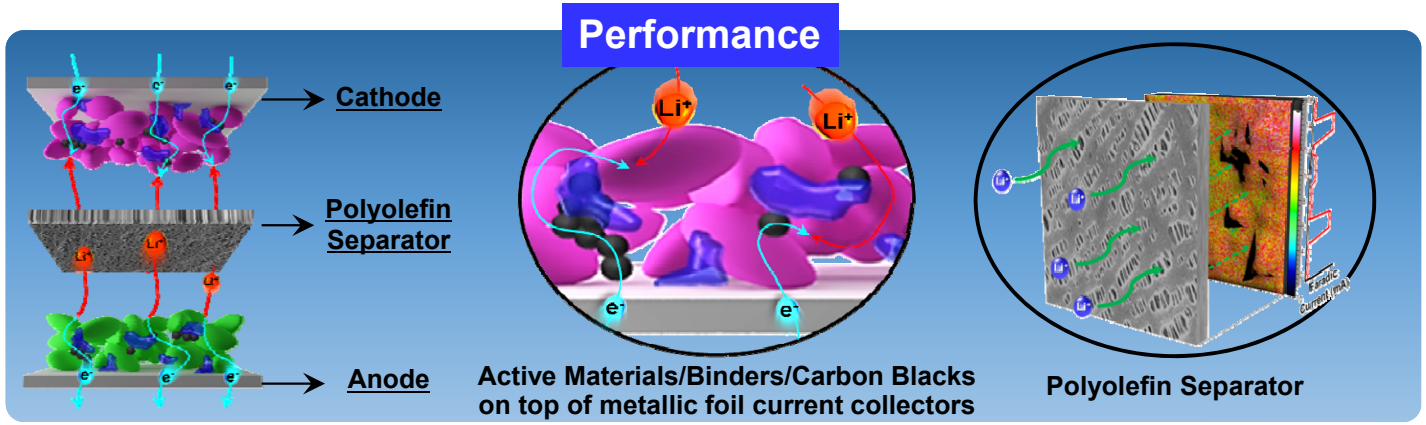
TAPPI

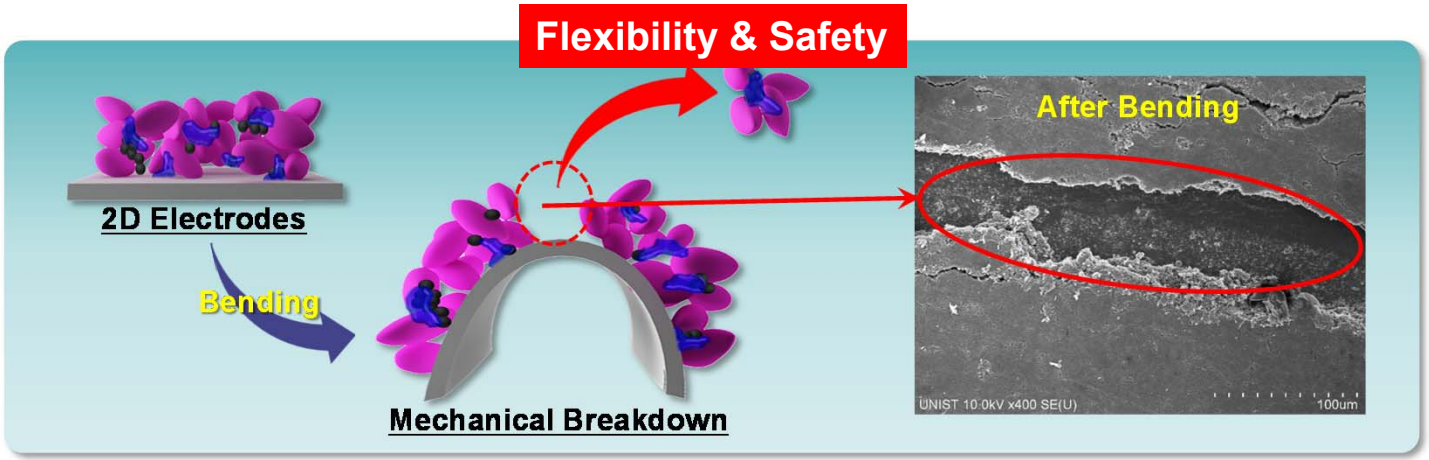
Nanocellulose for Energy Storage Systems



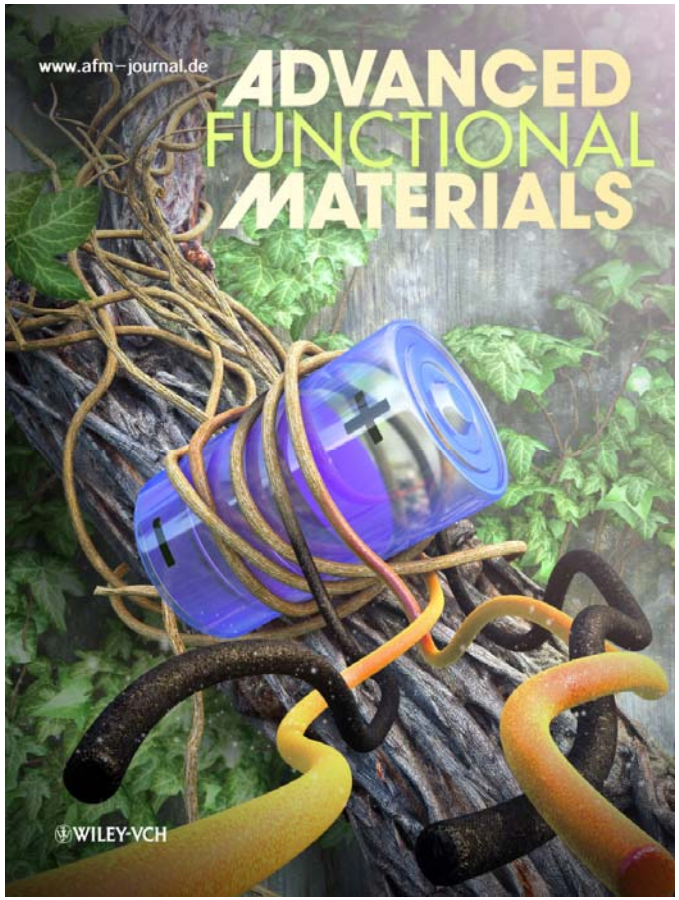
S. Y. Lee et al., Adv. Mater. 31 (2019) 1804826

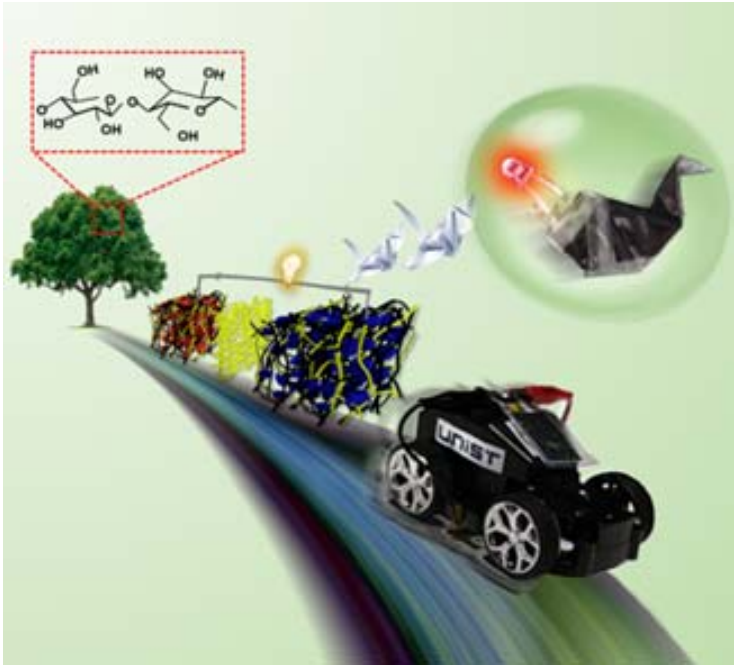
Limits of Current Battery Technologies





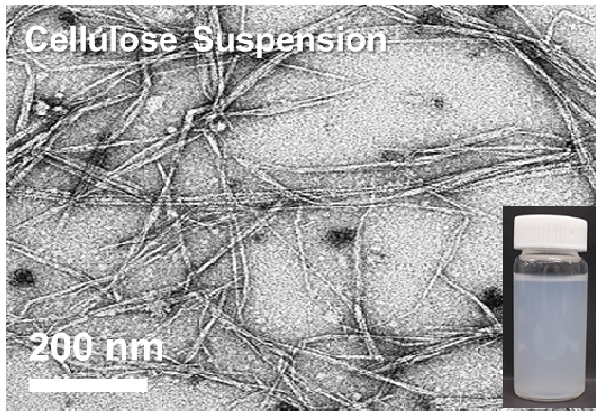
Li-Ion Paper Batteries

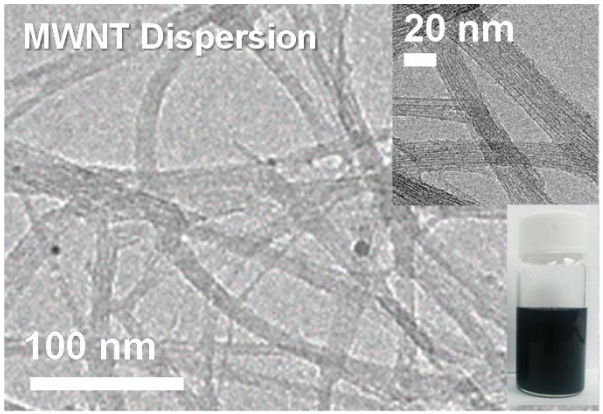




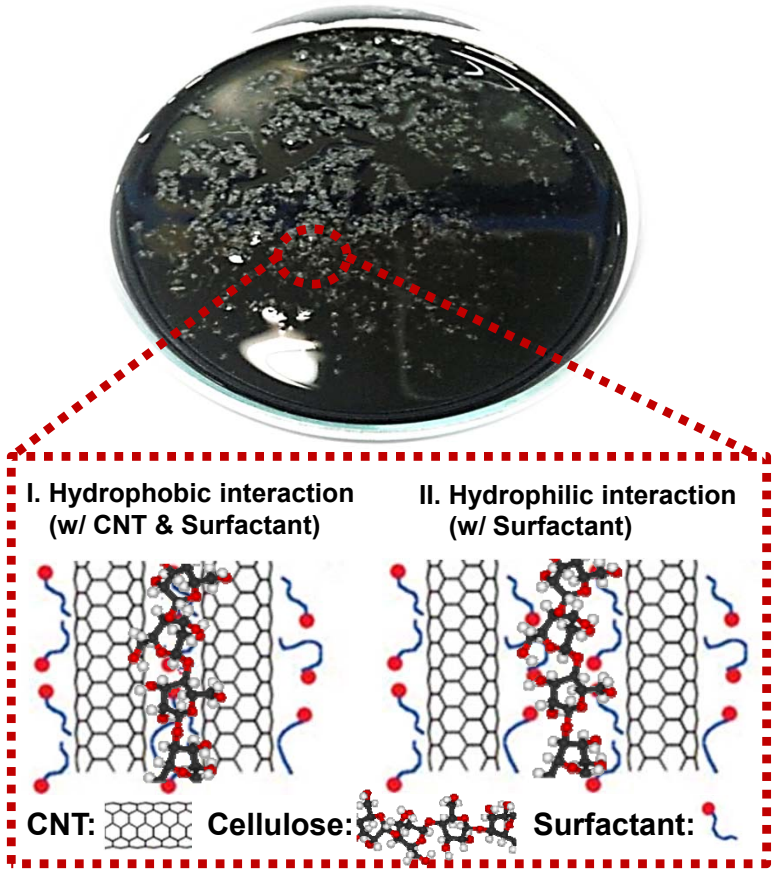
S. Y. Lee et al., Adv. Funct. Mater. 25 (2015) 6029 (front cover image)

Dispersion of CNTs and CNFs





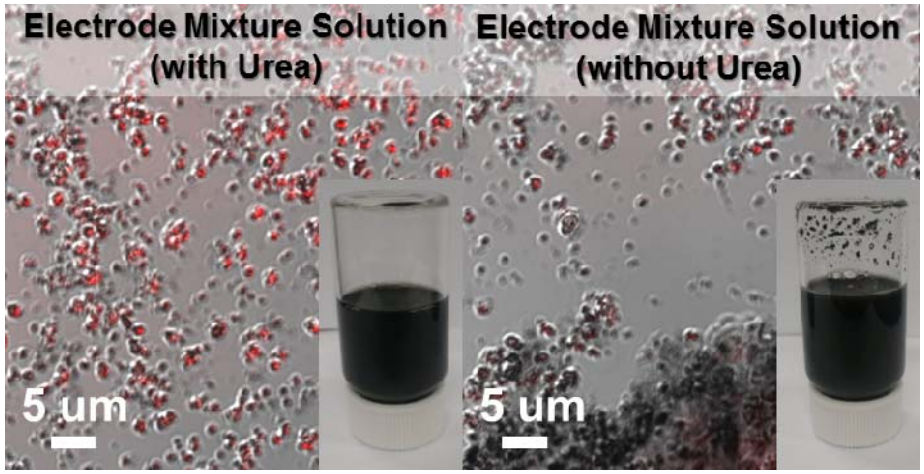
Aggregation of MWNT and CNF



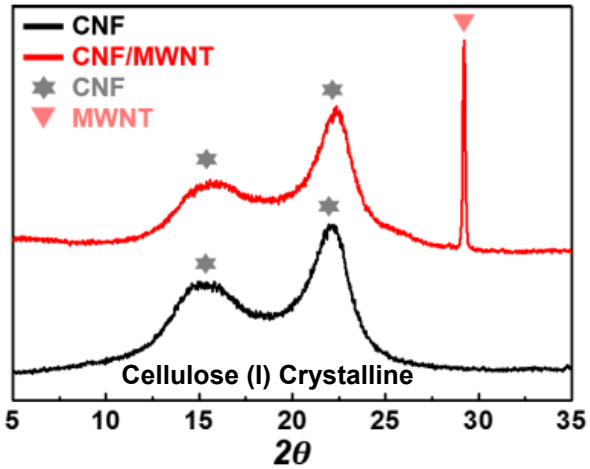
Dispersion of CNTs and CNFs

Urea-assisted, dispersion of Active Materials/CNT/CNF

- Optical Microscope



- XRD

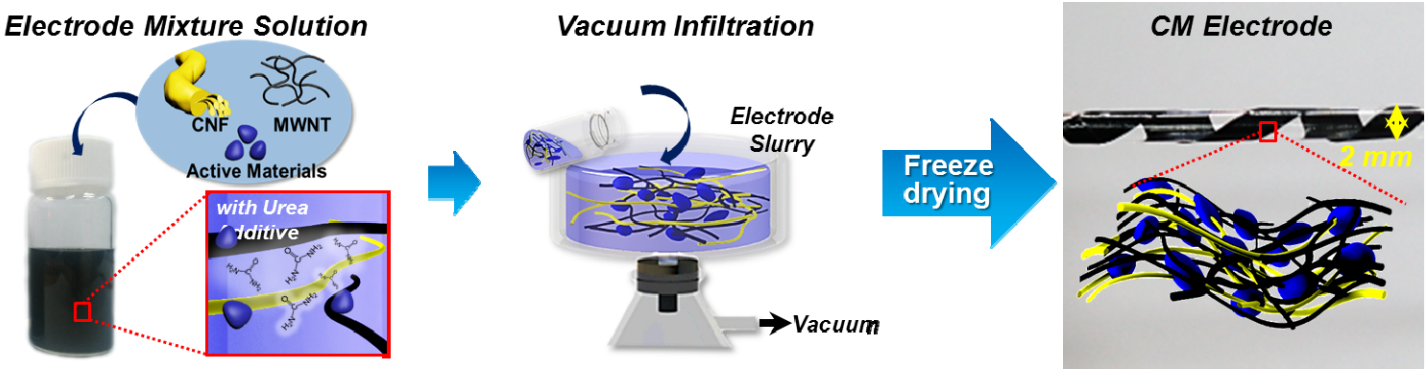


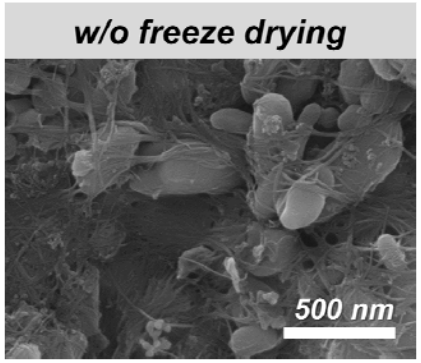
- Cellulose (I) Crystalline

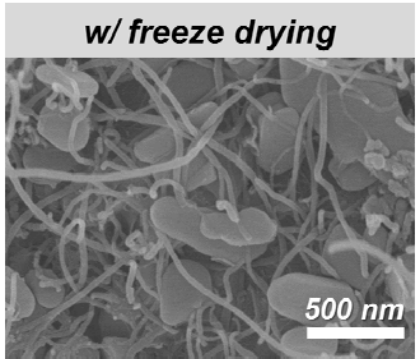
→ Perfect dispersion of CNFs

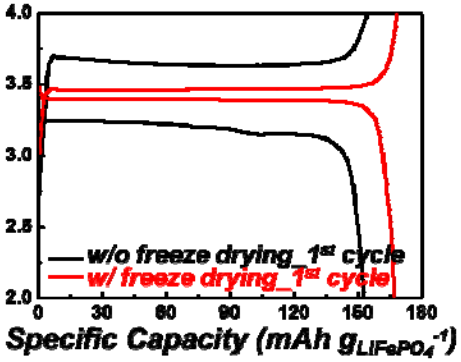
Fabrication of Paper Electrodes

Vacuum infiltration/freeze drying-assisted fabrication of paper electrodes



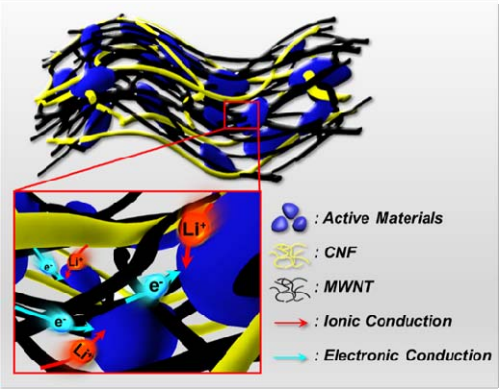


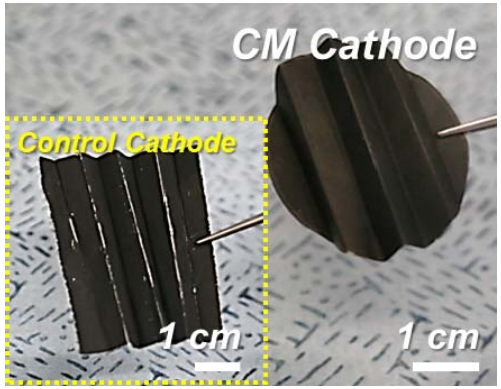


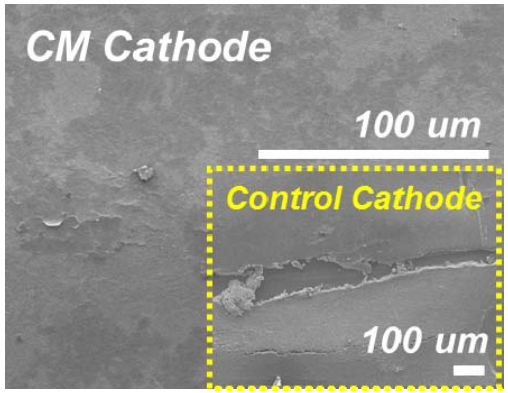


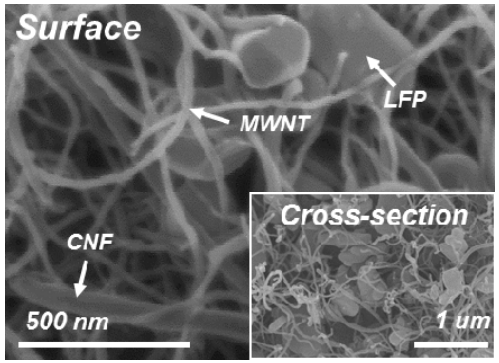
Characteristics of Paper Electrodes

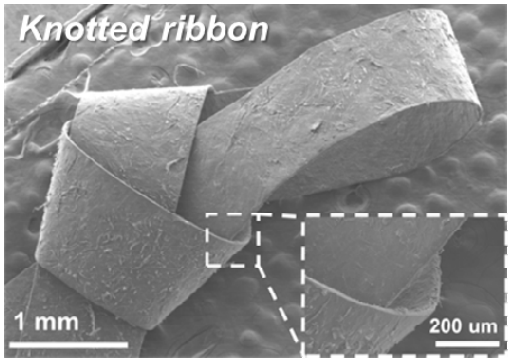
CNT/Cellulose Hetero-Nanonet structure → Superior mechanical flexibility

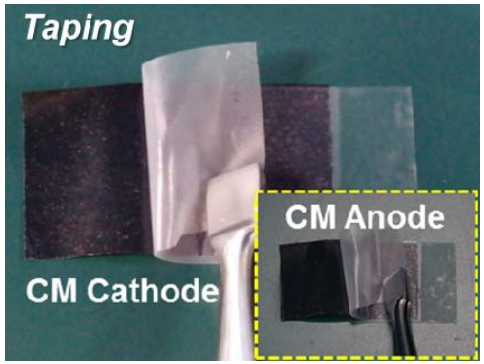






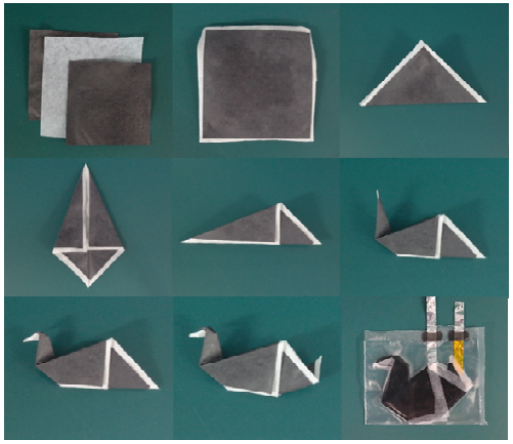


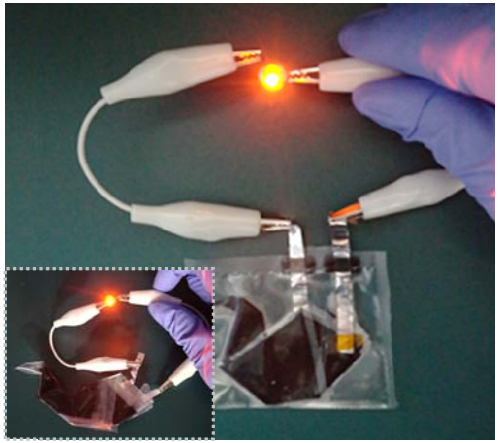


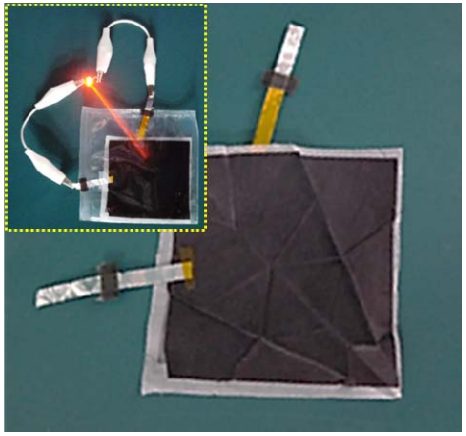


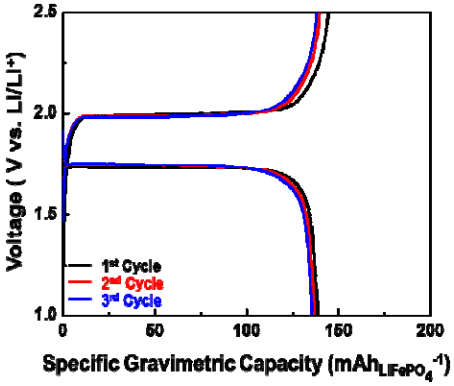
Paper Crane Batteries

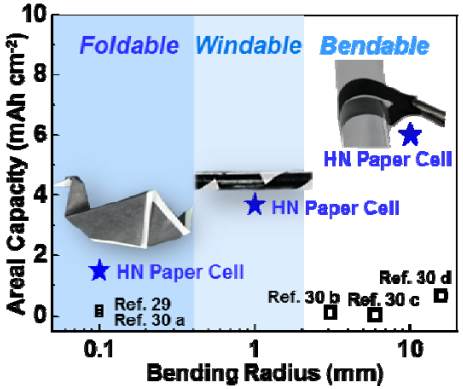
Paper electrodes + Paper separator → Paper Crane Batteries via Origami Folding





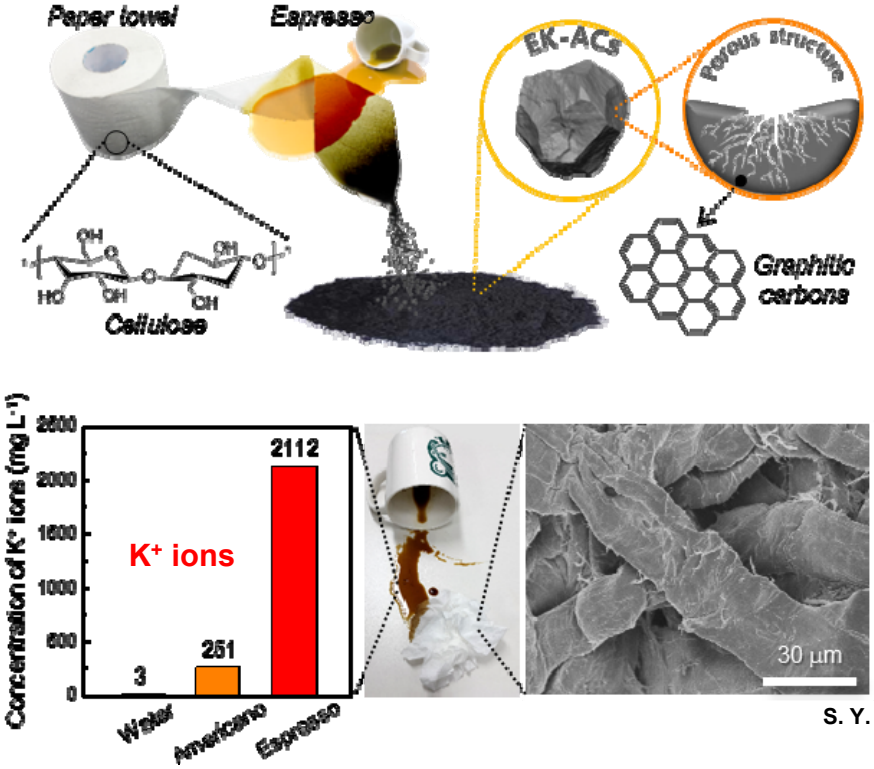






From Wastepaper to Energy

Soaking of paper towels in espresso coffee → Carbonization (600°C/2h) → Activated carbons

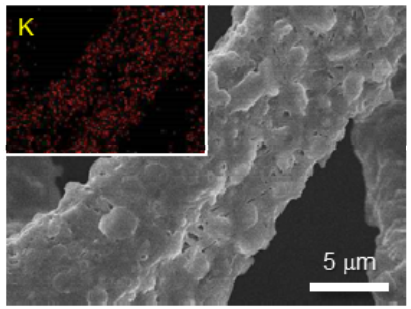


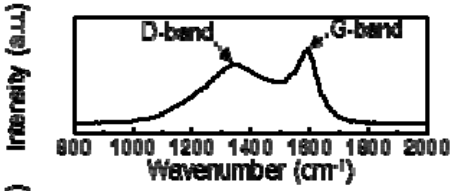
S. Y. Lee et al., ACS AMI, 9 (2017) 22568

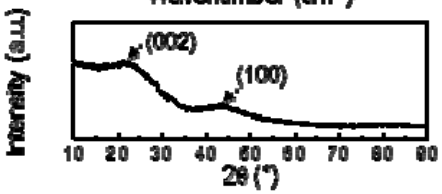
Coffee-driven Activation of Cellulose

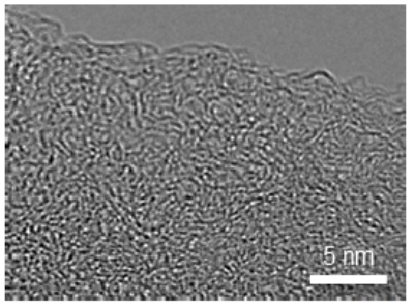
Formation of micropores (< 2 nm)in the coffee-assisted activated carbons

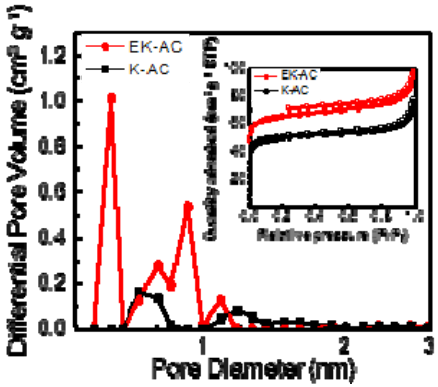
(Specific surface area: 256 m^2 g^{-1} (w/ coffee) vs. 199 m^2 g^{-1} (w/o coffee)





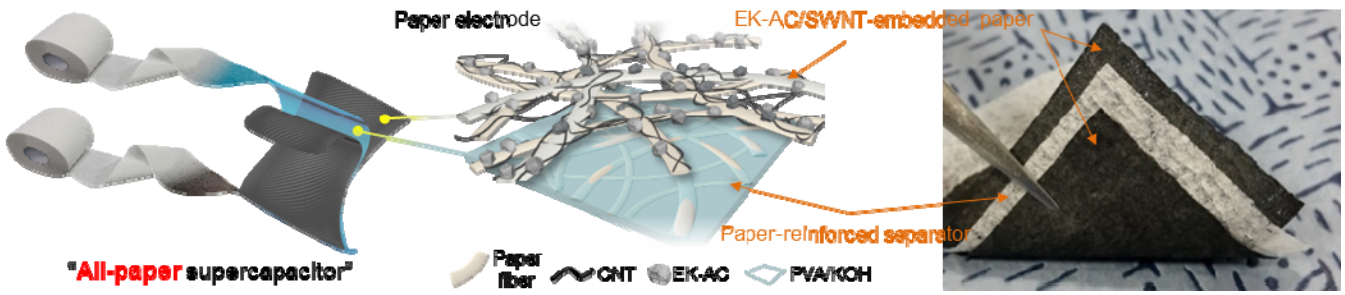


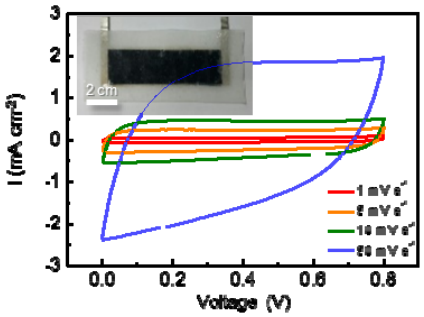


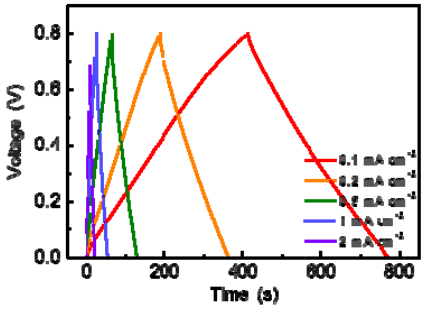


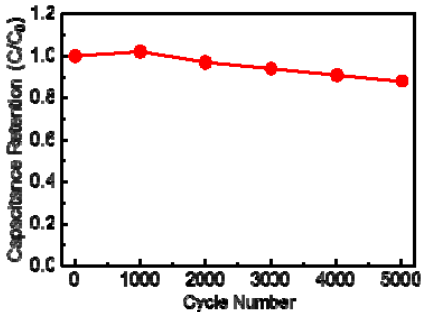
All-Paper Flexible Supercapacitors

All-paper flexible SC = Paper electrode (AC/SWNT-embedded paper towel)
+ Paper electrolyte (PVA/KOH-impregnated paper towel)
+ Paper packaging (PDMS-infiltrated paper towel)

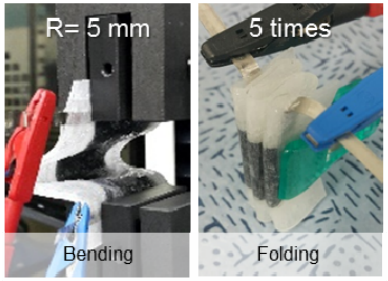


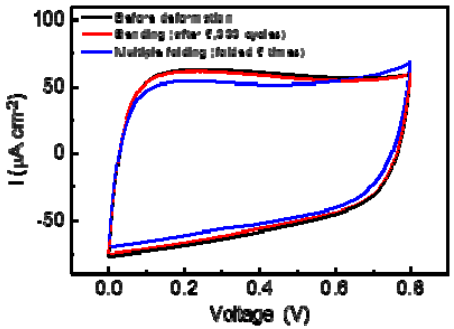


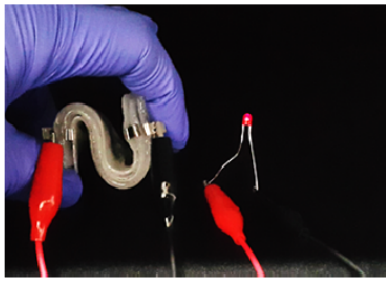


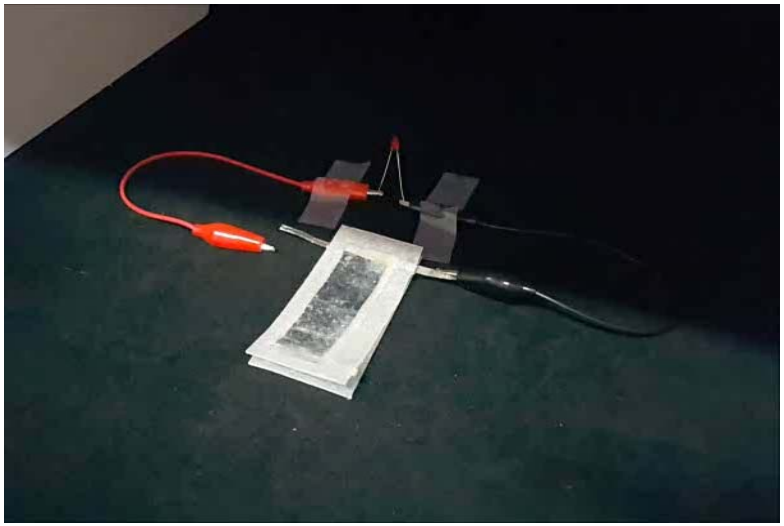


All-Paper Flexible Supercapacitors

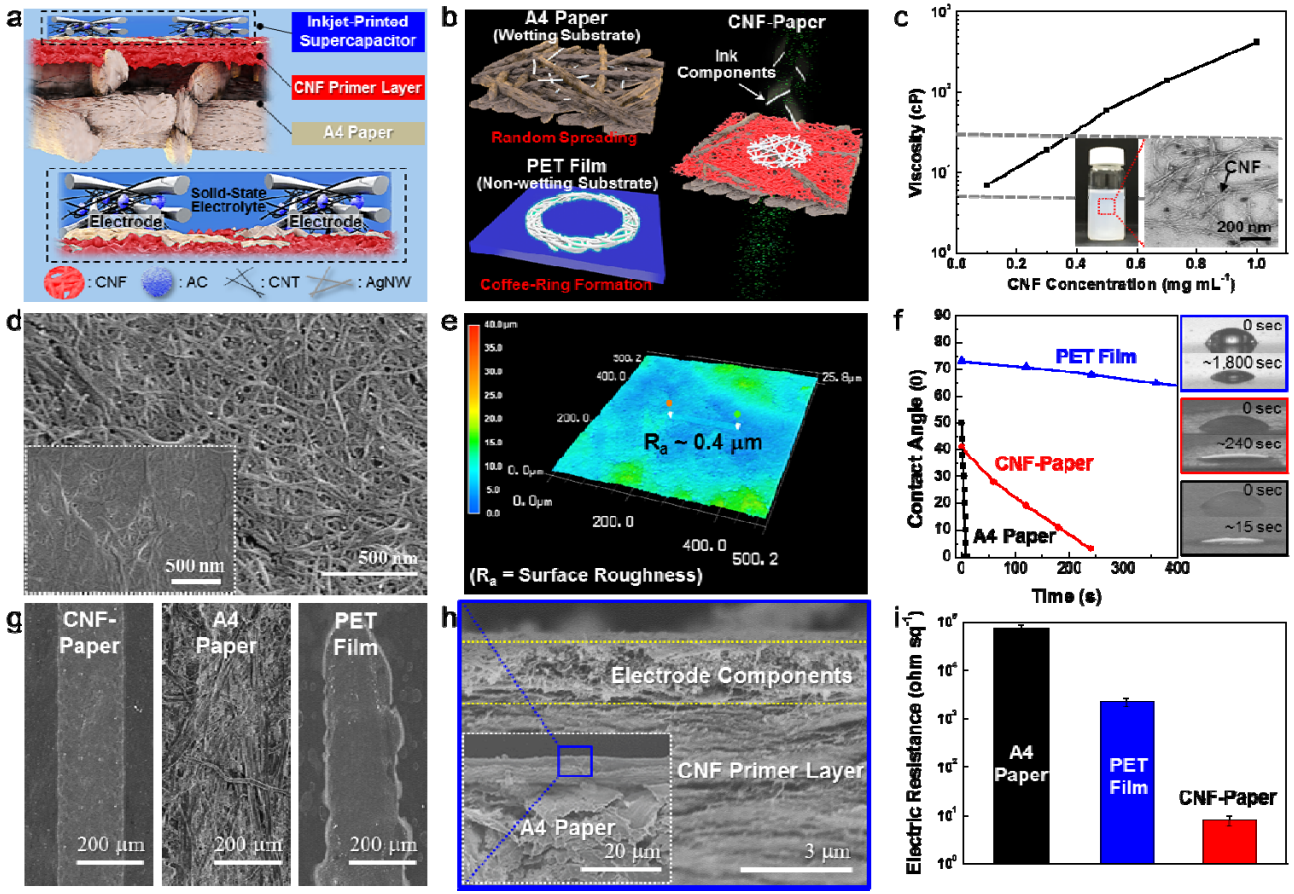






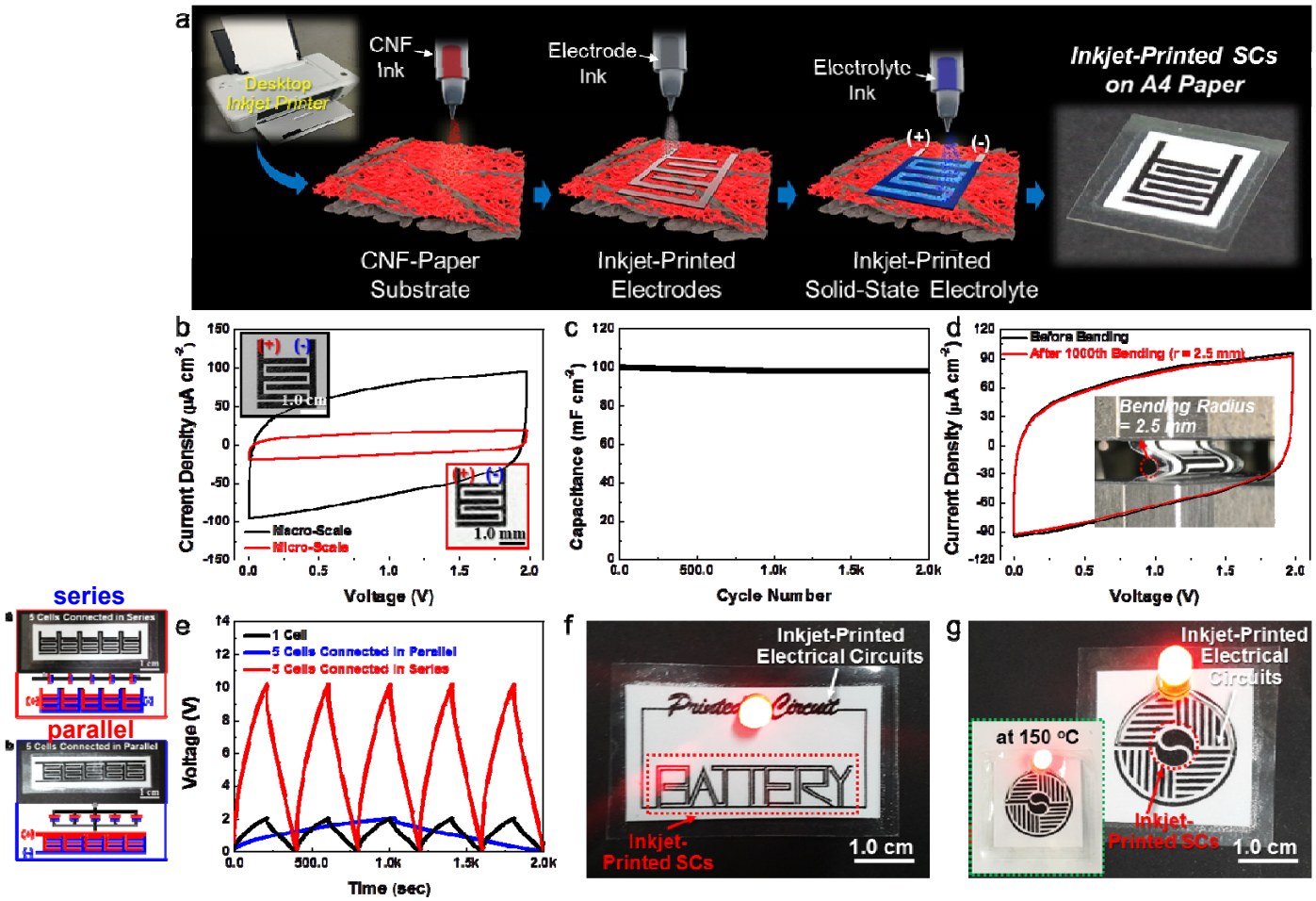


Inkjet-Printed SCs on A4 Paper

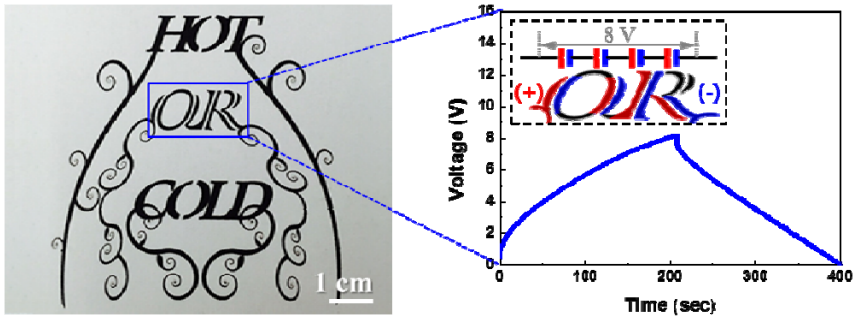


S. Y. Lee et al., EES, 9 (2016) 2812 (highlighted as a back cover image)

Inkjet-Printed SCs on A4 Paper

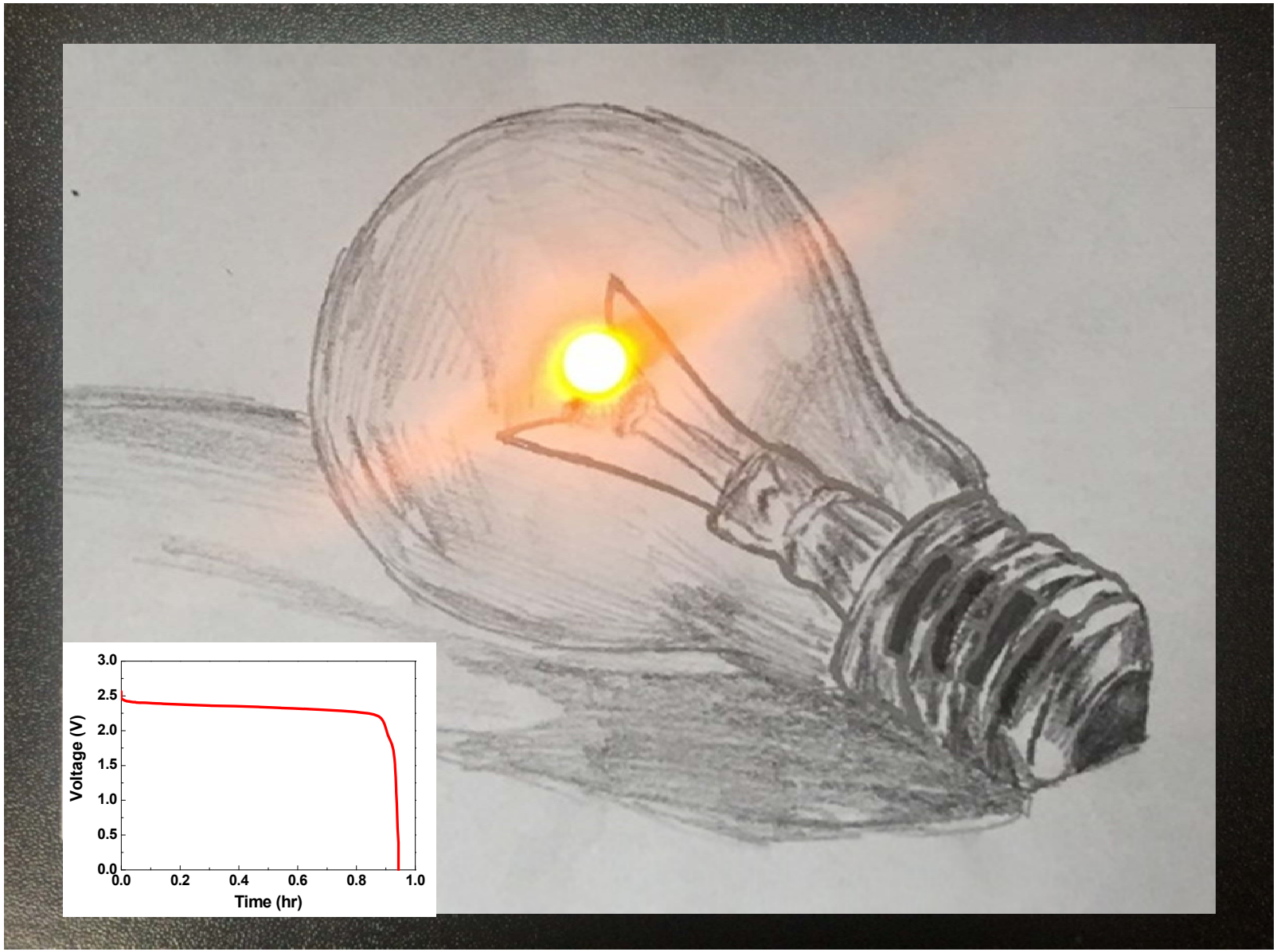


Inkjet-Printed SCs on A4 Paper



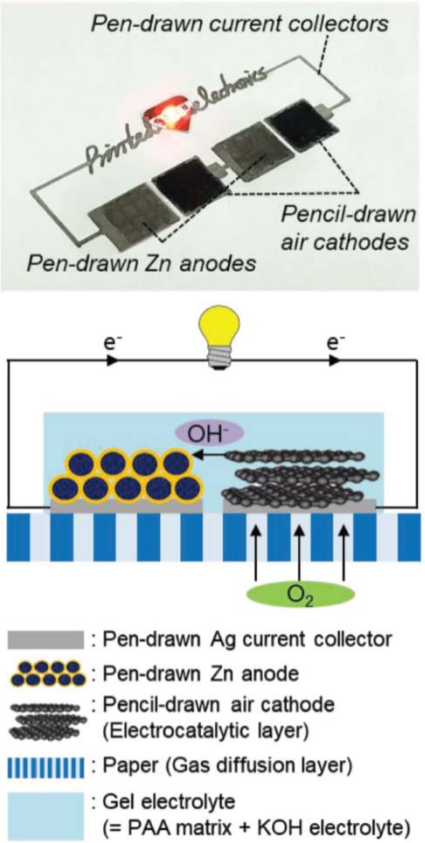
Cold Water (@ 10 °C)

Hot Water (@ 80 °C)

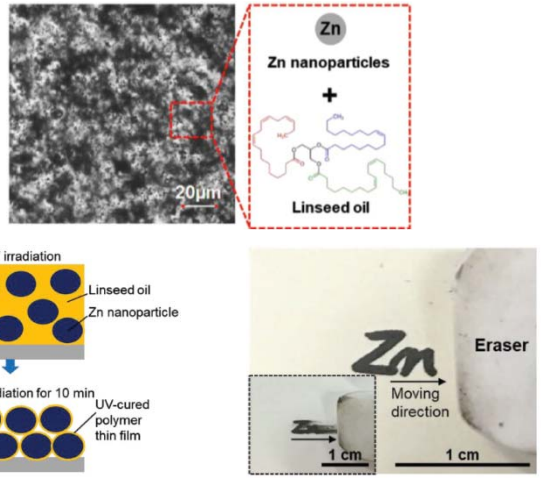

Voltage (V)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Time (hr)

Hand-Drawn Zn-Air Batteries

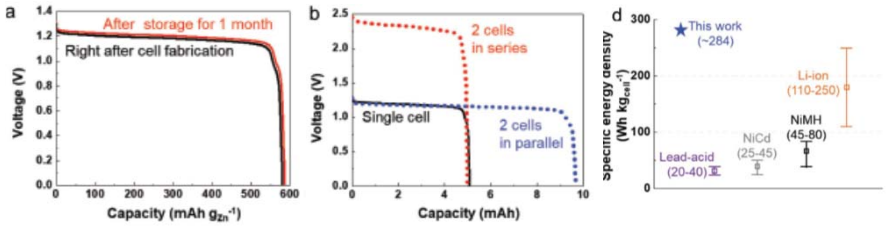
- **Structure of all-hand-drawn ZAB.**



- **UV curing-assisted pen-drawn Zn anodes.**

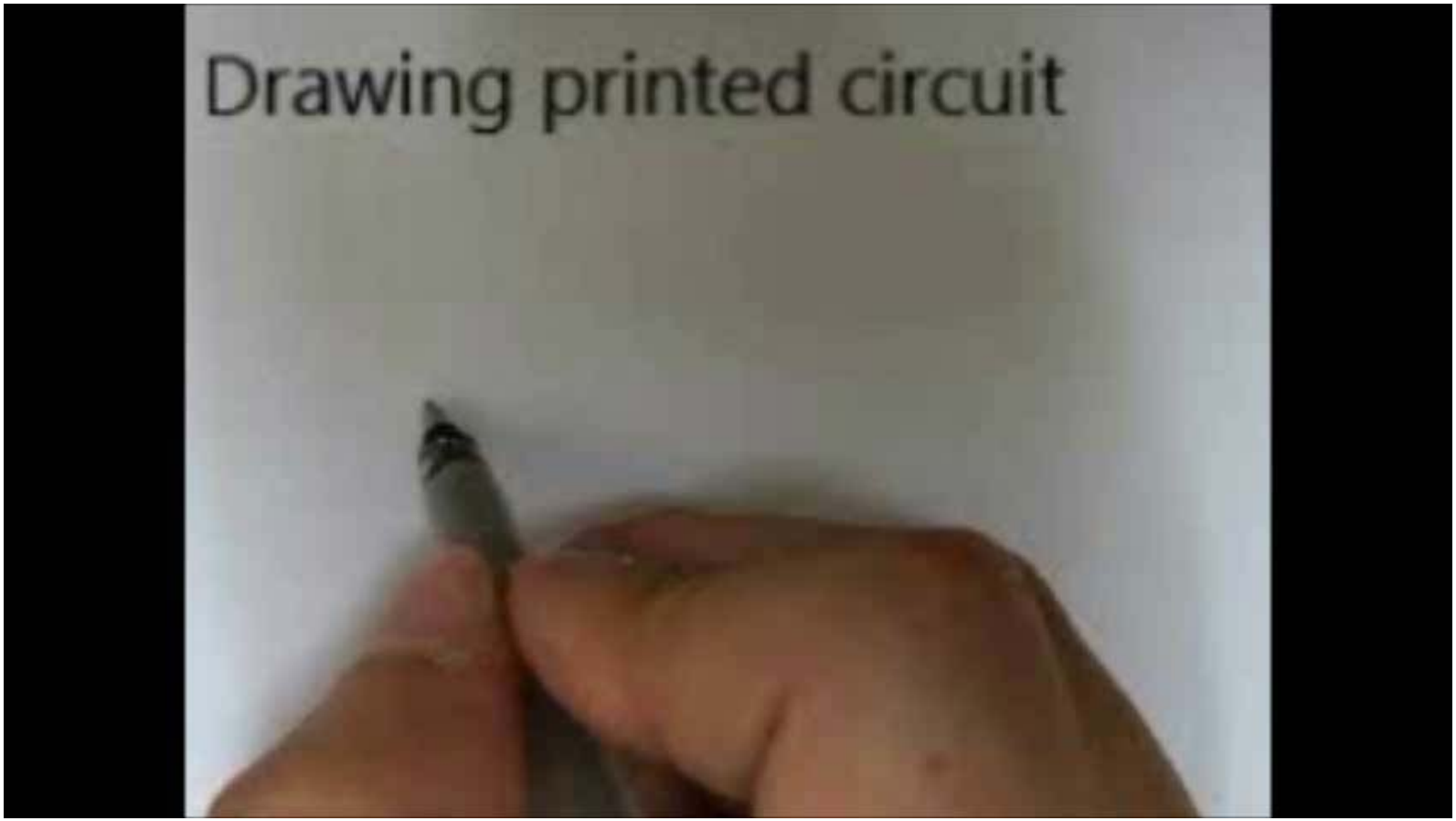


- **Electrochemical characterization of all-hand-drawn ZAB.**



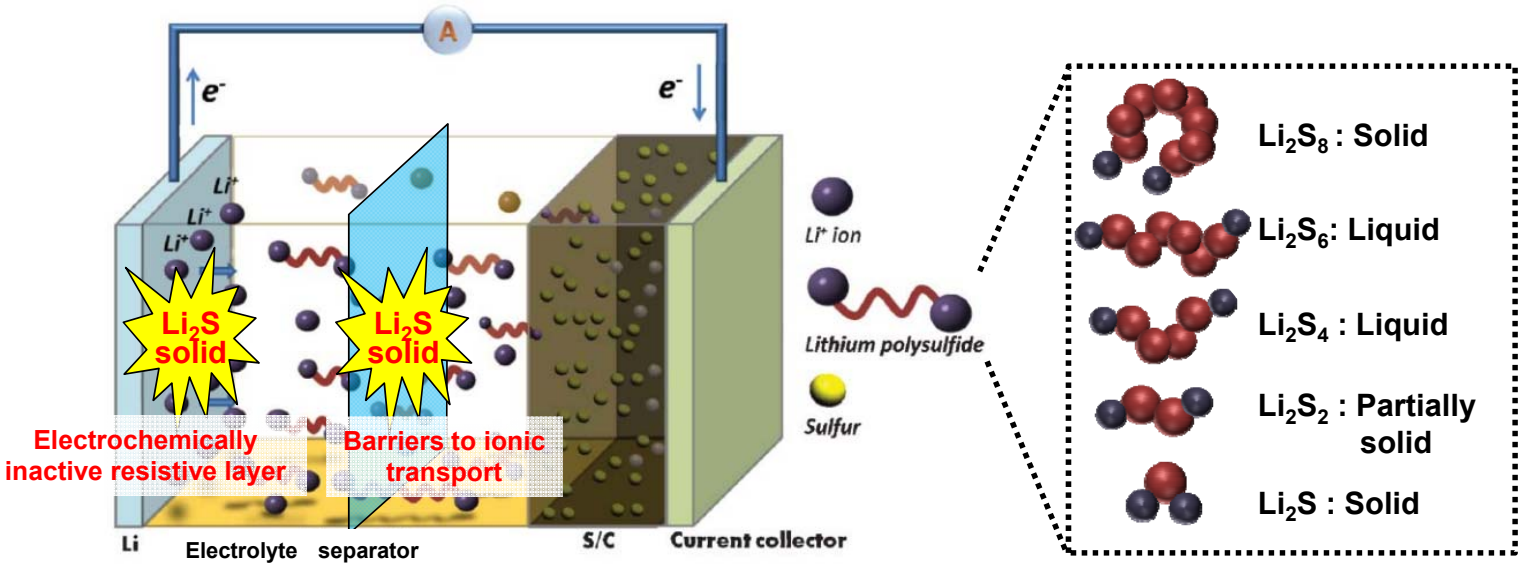
S. Y. Lee et al., Adv. Sustainable Syst. 2 (2018) 1700132 (cover image)

Hand-Drawn Zn-Air Batteries



Li-S Batteries: Shuttle Effect

The dissolved polysulfides diffuse from cathode to anode through separator, and are deposited as solid-state Li_2S_2/Li_2S at separator and/or anode



RSC Advances, **2013**, 3, 3540

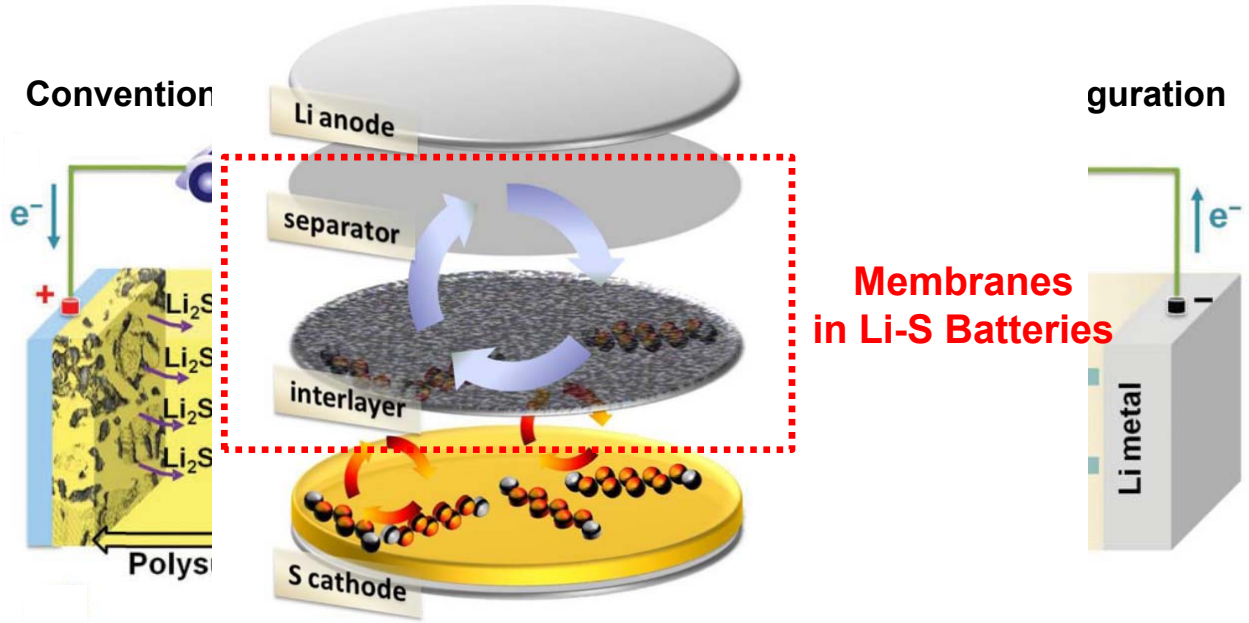
Li-S Batteries: Shuttle Effect

❖ **Membranes (including interlayers) for Lithium-Sulfur Batteroes**

i) Facile ion transport

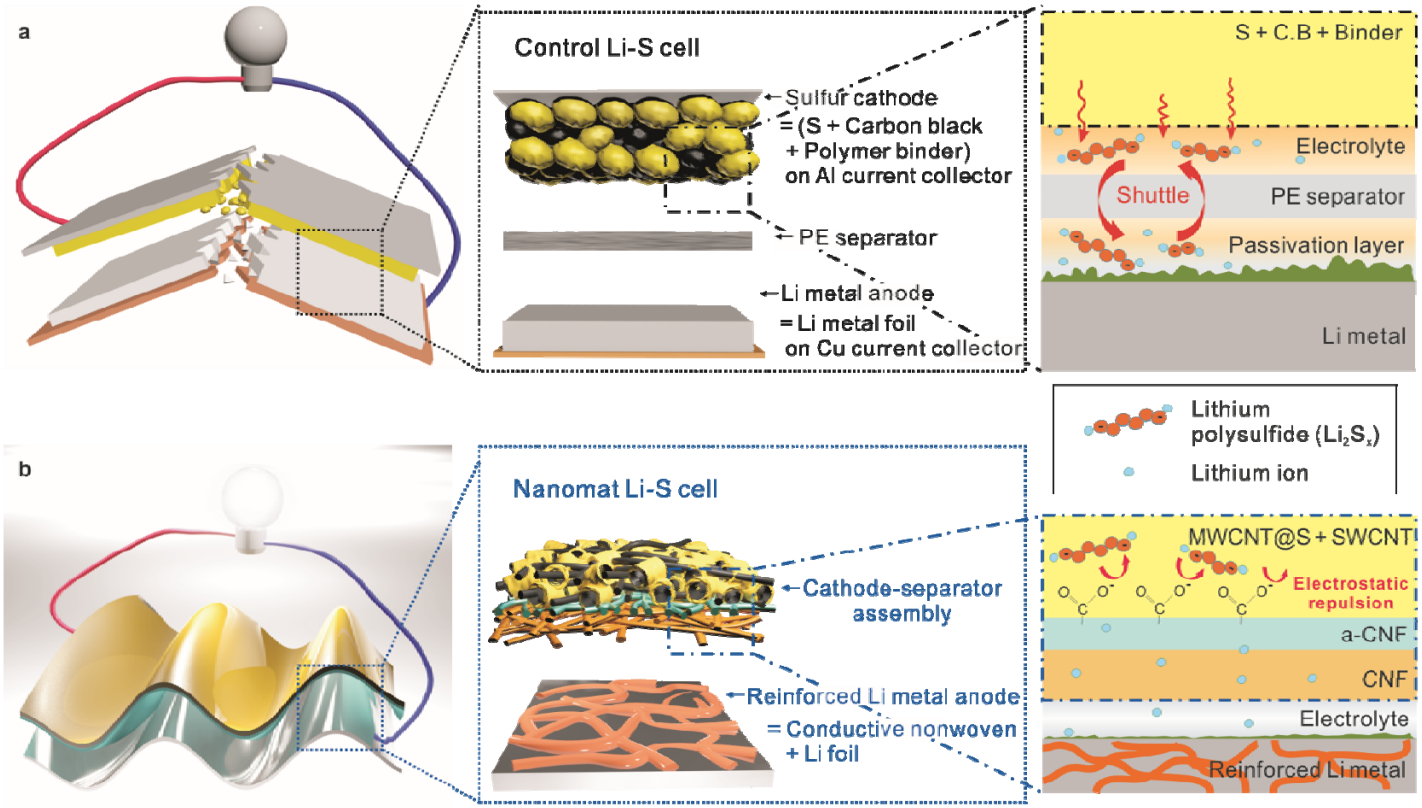
ii) Minimum thickness/weight

iii) Localize the dissolved polysulfides between cathodes and membranes



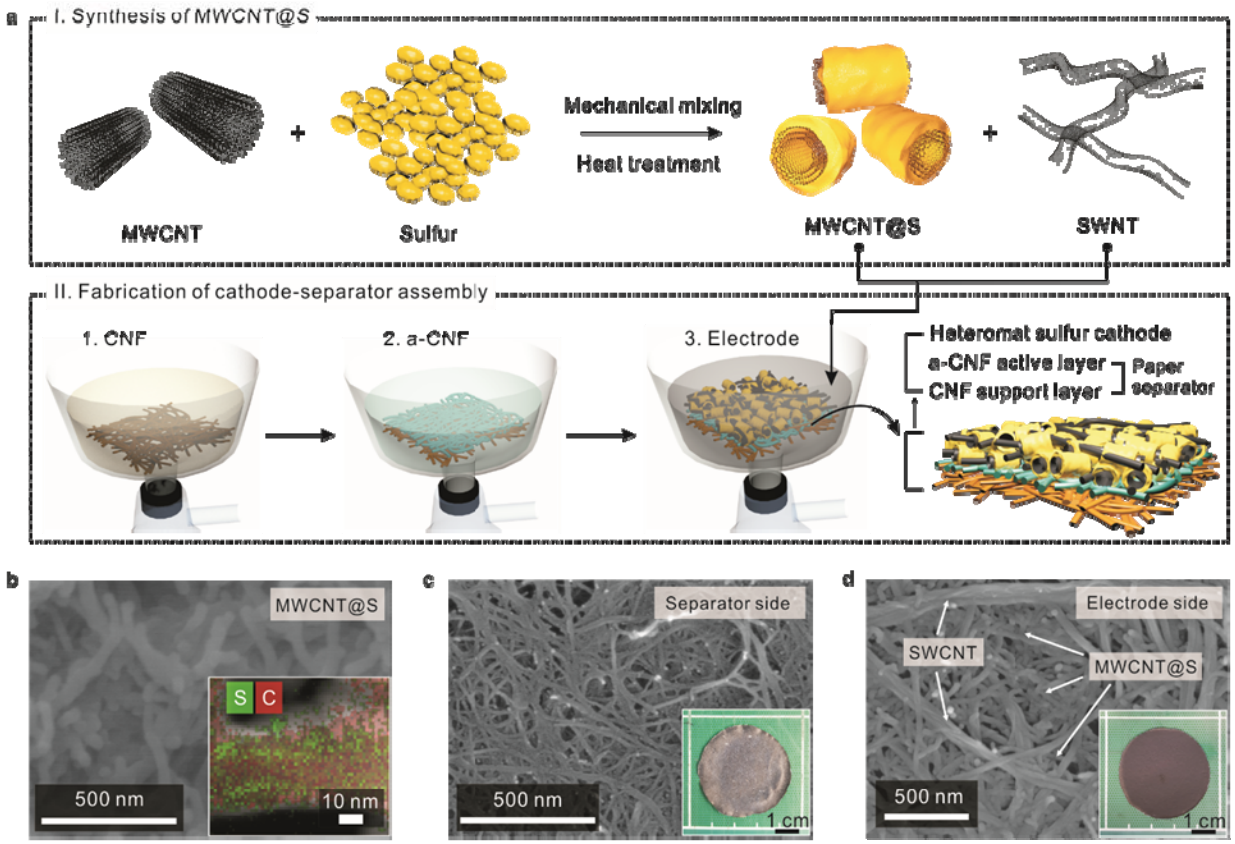
Adv. Mater., **2014**, 26, 625

Li-S Paper Batteries

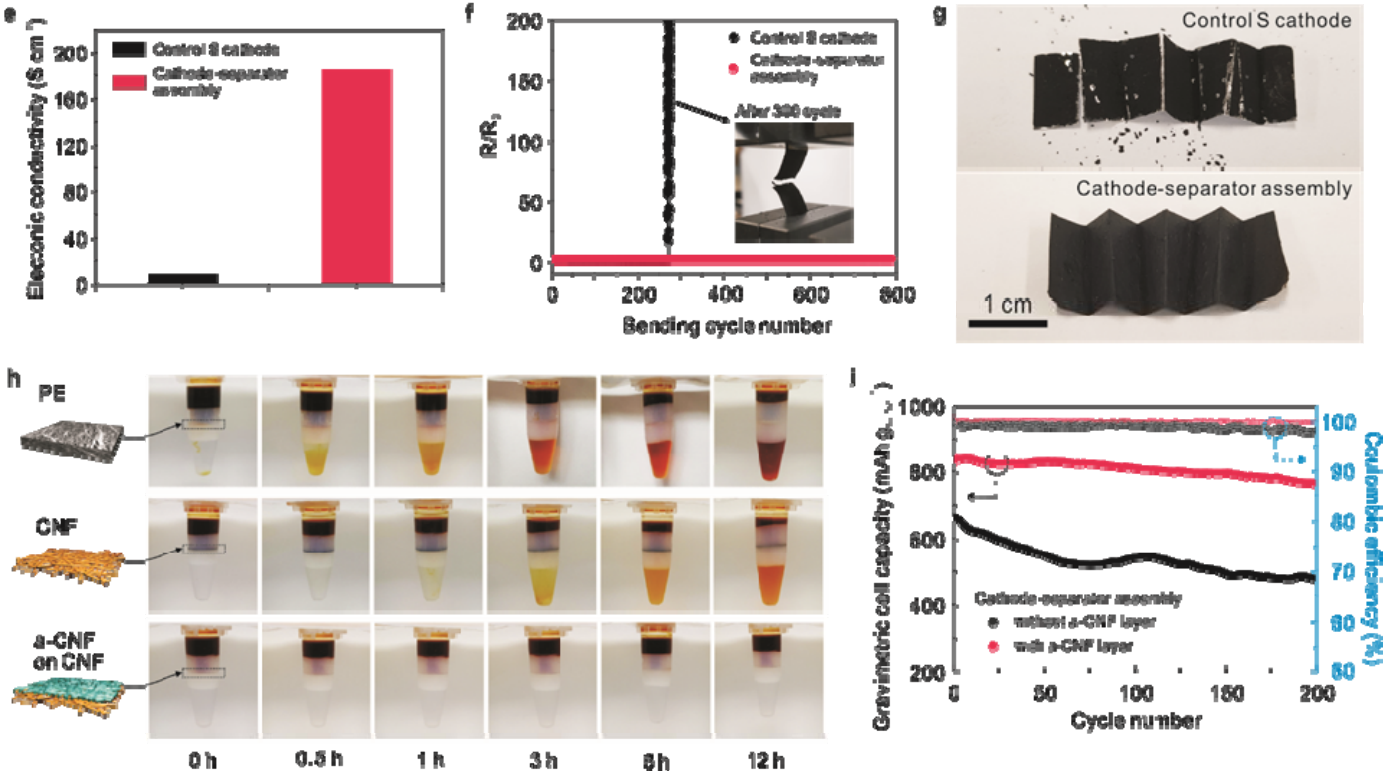


S. Y. Lee et al., Energy & Environ. Sci. 12 (2019) 177
(Featured as "2018 Energy & Environmental Sci. HOT Articles)

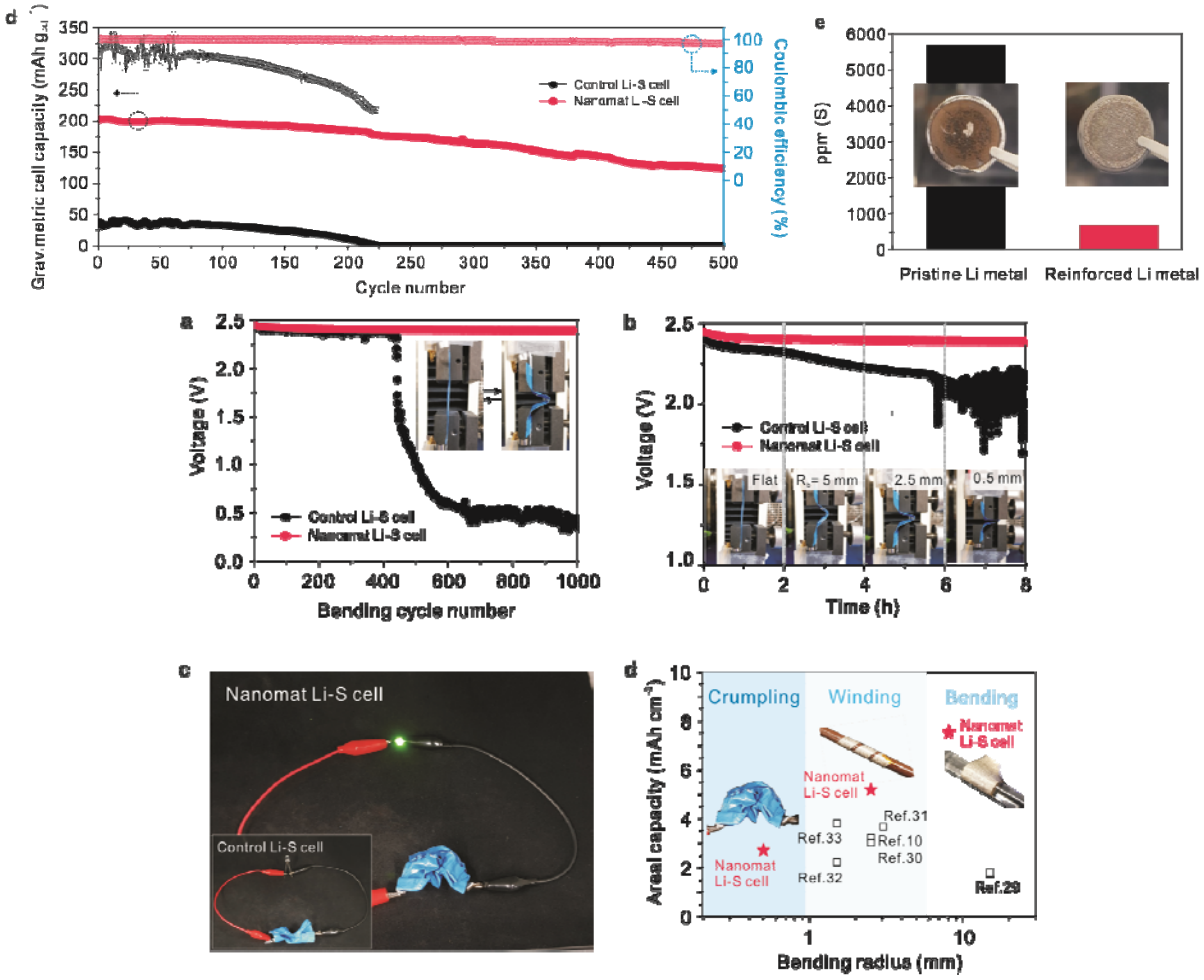
Li-S Paper Batteries



Li-S Paper Batteries

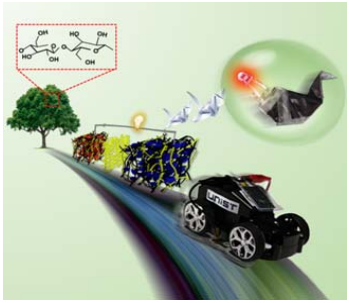


Li-S Paper Batteries

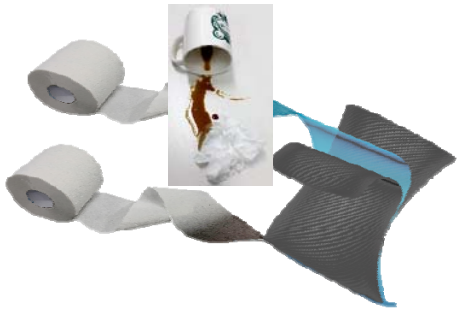


Summary

I. Li-Ion Paper Batteries



II. All-Paper SCs



III. Li-S Paper Batteries

CNFs

as an key element for advanced batteries

Thank you

PRESENTED BY:
SANG-YOUNG LEE
Professor
UNIST