Leveraging Reversible Chemistry for Materials Sustainability in Energy Storage

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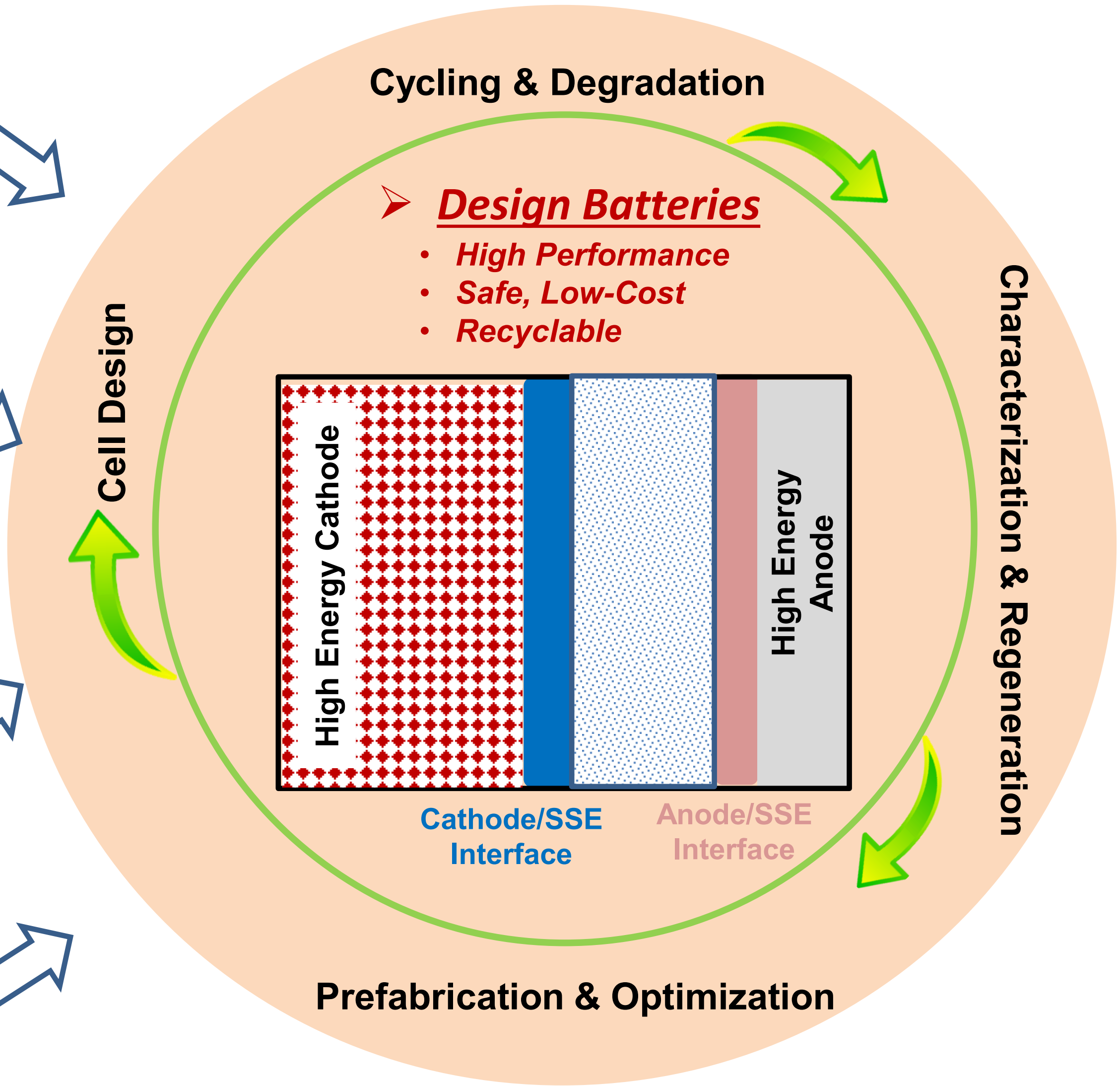
Materials Science and Chemical Technology for Sustainable Energy

Mechanistic Understanding

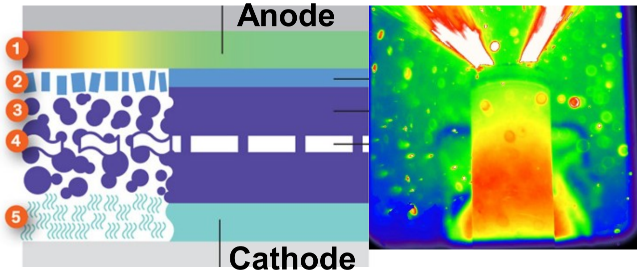
Materials Design & Synthesis

Process Design & Intensification

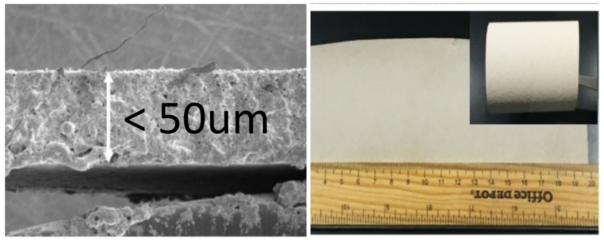
Chemical Synthesis & Conversion



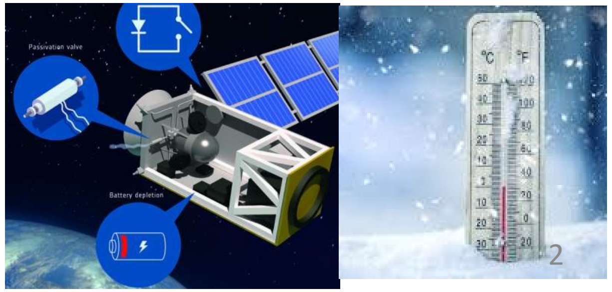
- ***Battery Safety Technology***



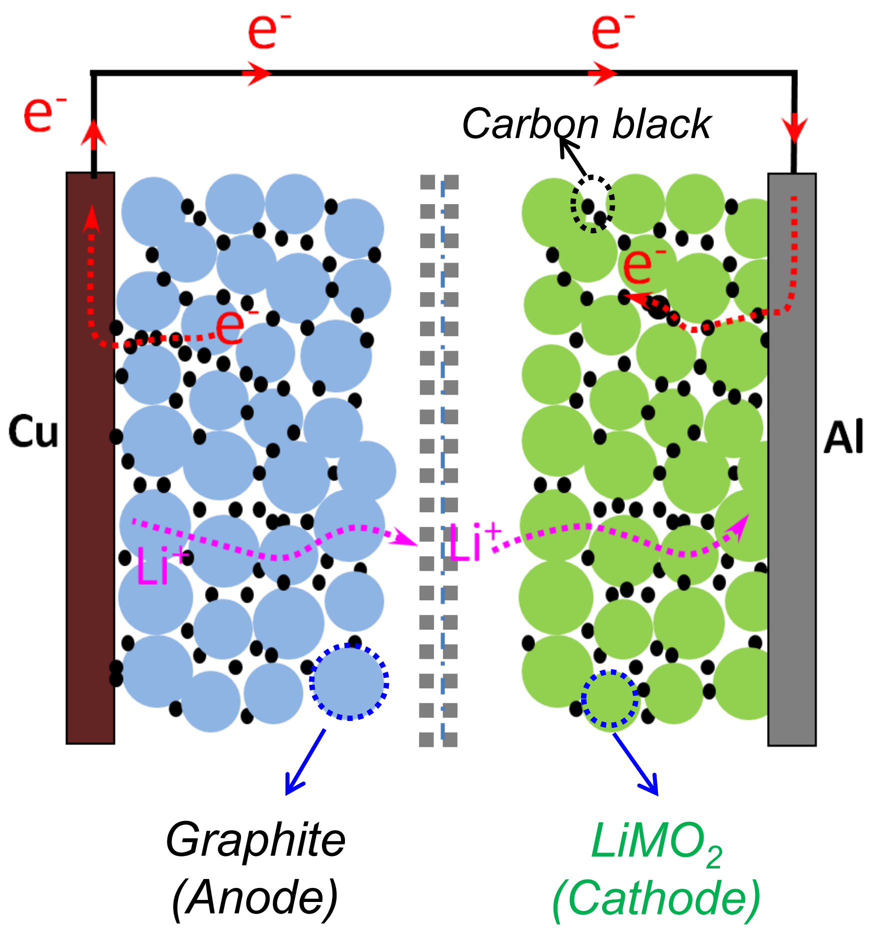
- ***Solid-State Batteries***



- ***Low-Temperature Batteries***



Critical Materials Are Heavily Used in Li-ion Batteries

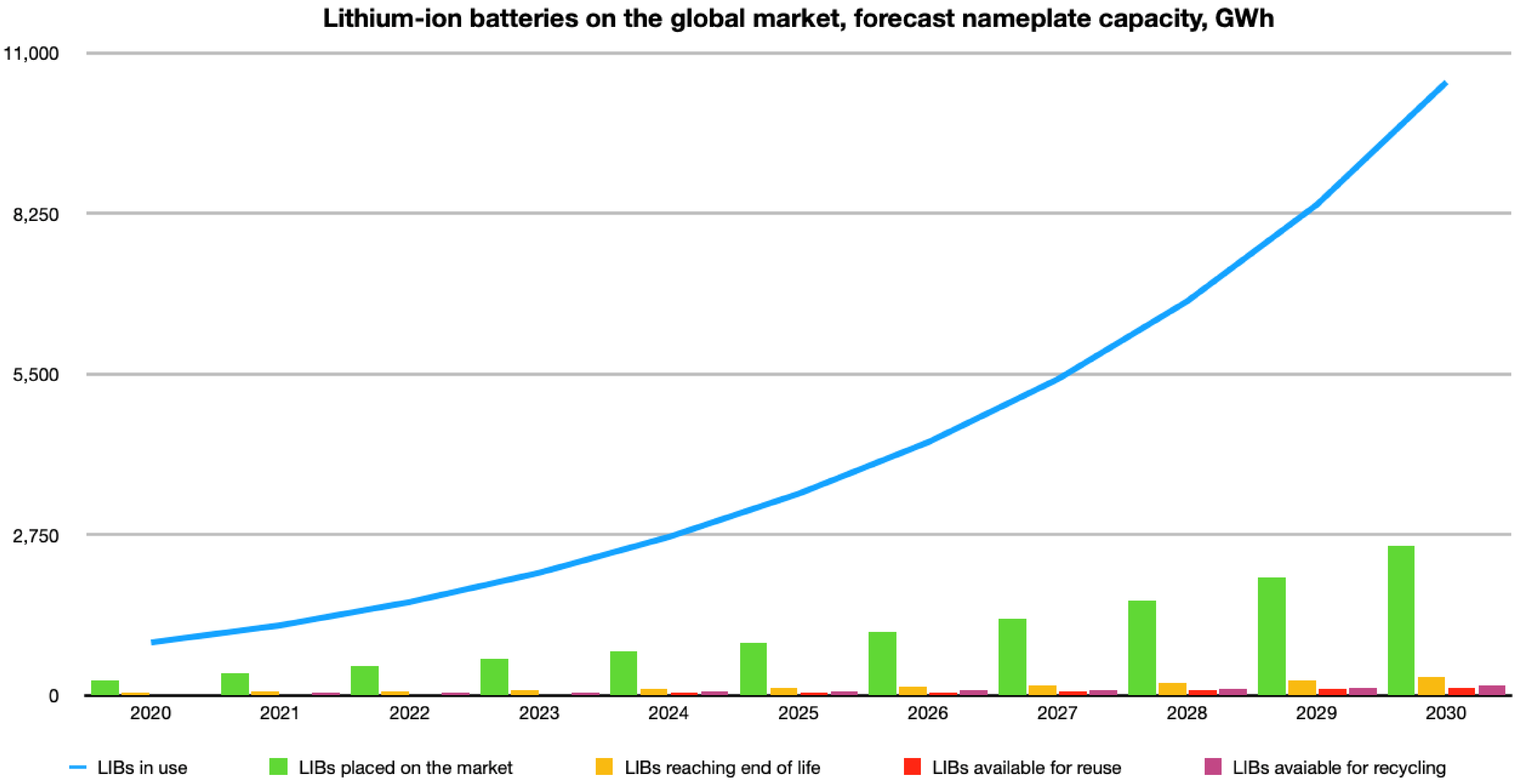


Cathode Materials:

- *$LiFePO_4$*
- *$LiMn_2O_4$*
- *$LiCoO_2$*
- *$Li_xNi_yMn_zCo_{1-y-z}O_2$ (NMC111, NMC532…)*
- *$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$*

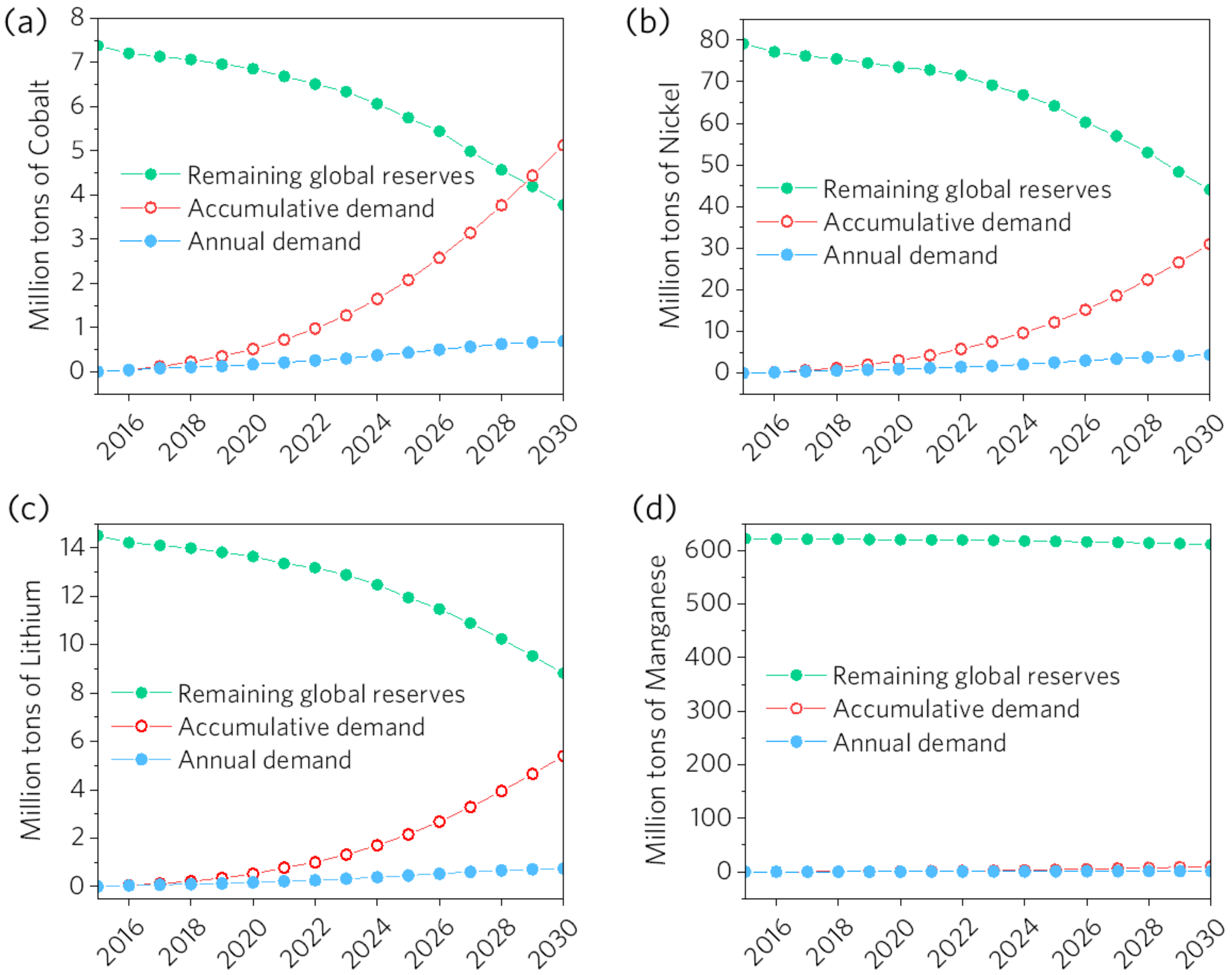
Anode Materials:

- *Graphite, Si..*



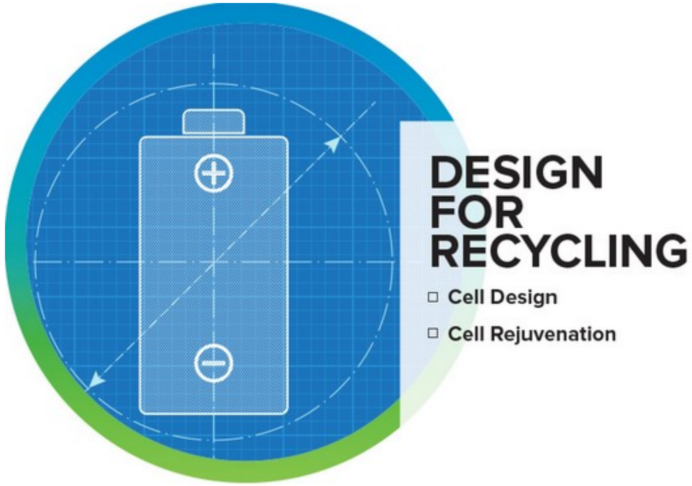
[*The lithium-ion battery life cycle report 2021*]

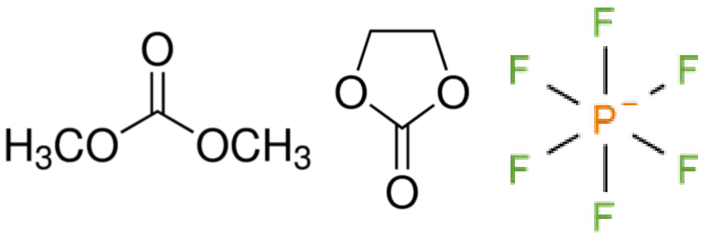
Global Projections of Critical Materials Reserves vs Current Demand

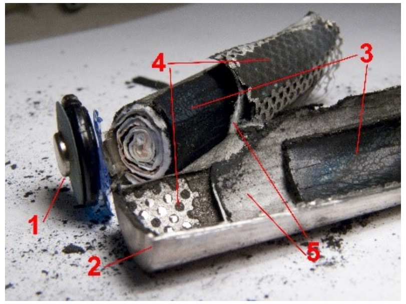


Z. Chen, et al, MRS Energy & Sustain., 2020, DOI: 10.1557/mre.2020.31.

Li-Ion Battery Recycling Principles



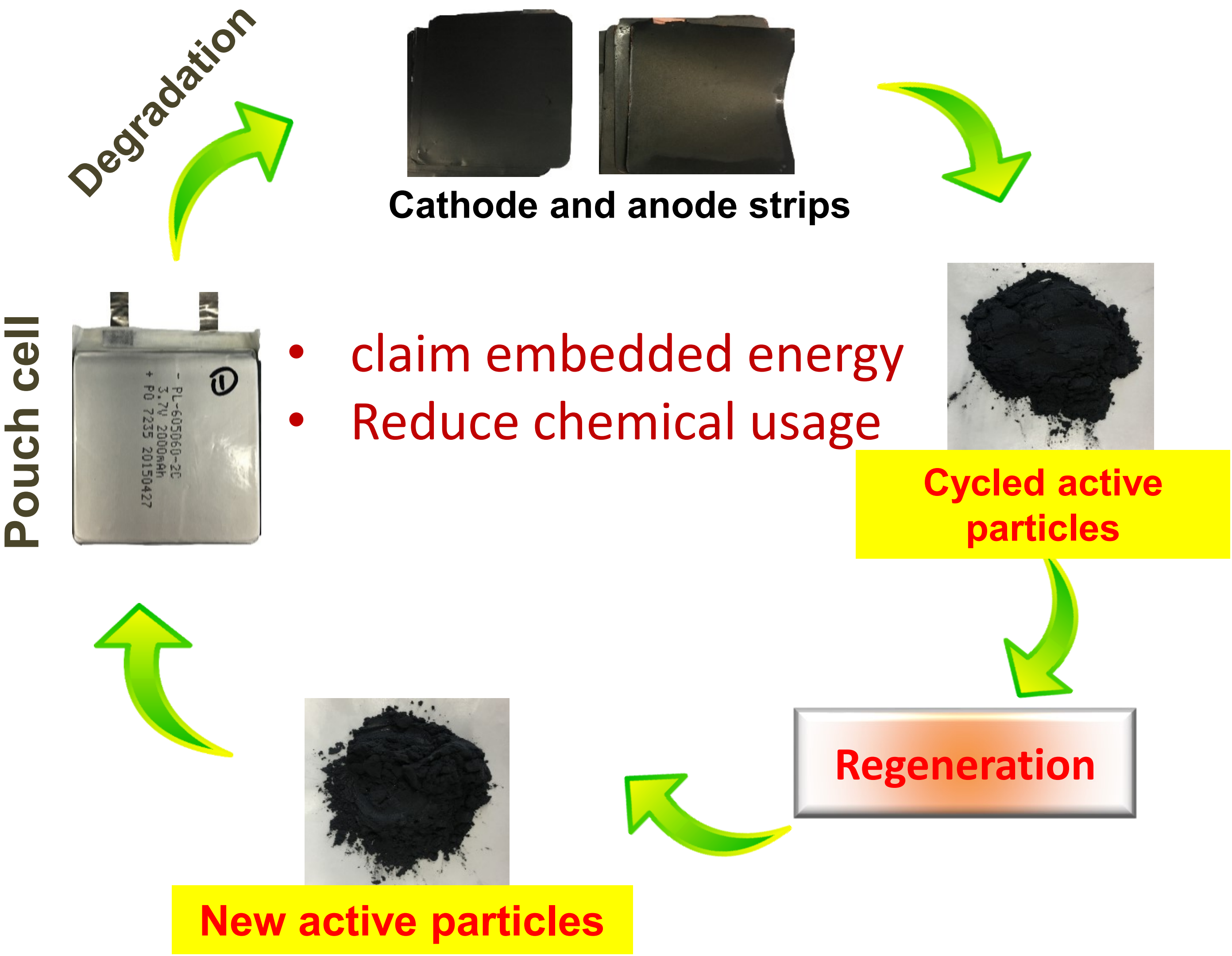




Ease of Recycling

Better Labelling

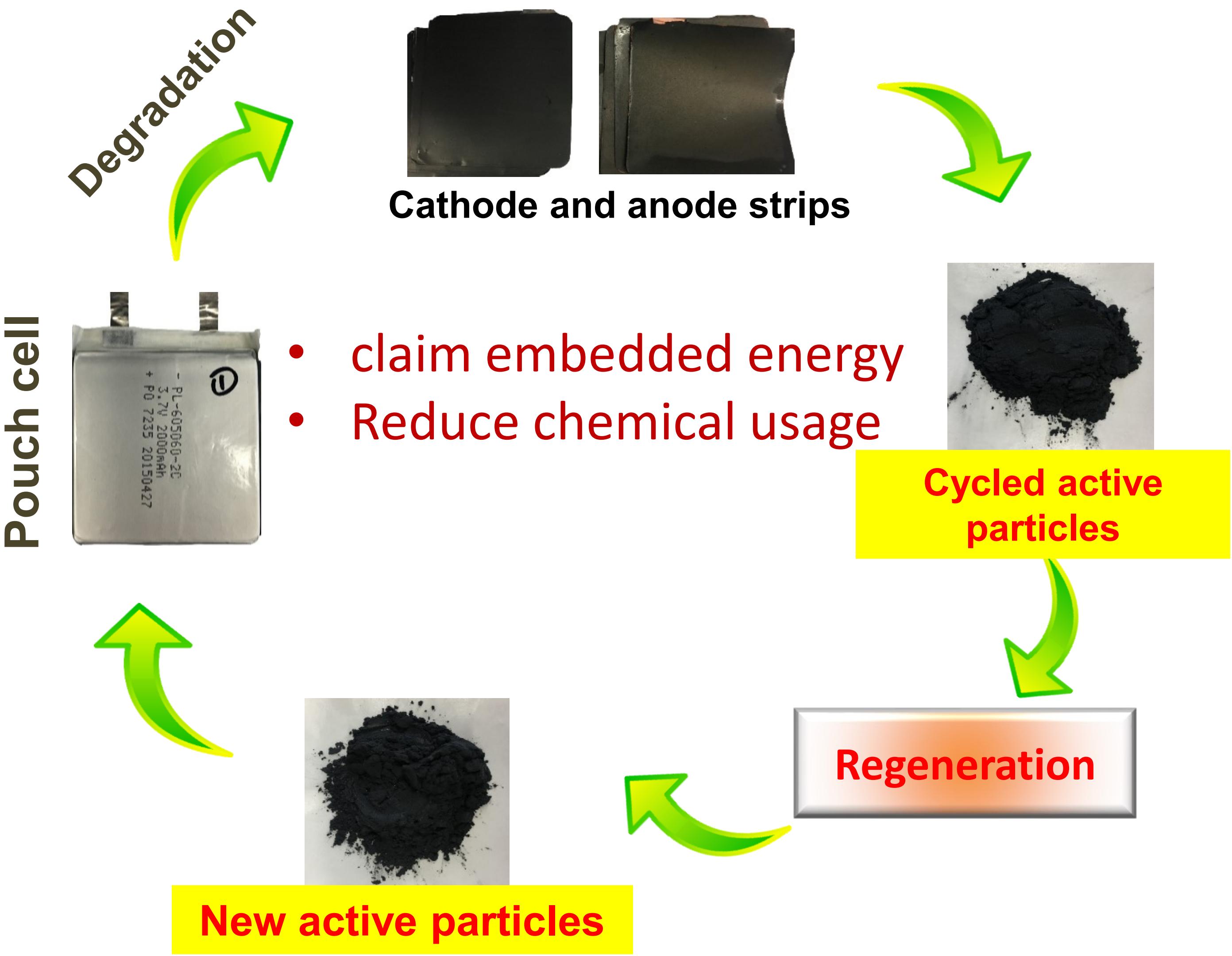
The “Direct” Recycling Process



- *Composition recovery*
- *Structure recovery*

*Y. Shi, **Z. Chen*** et al, Green Chemistry*, 2018, 20, 851-862.

The “Direct” Recycling Process



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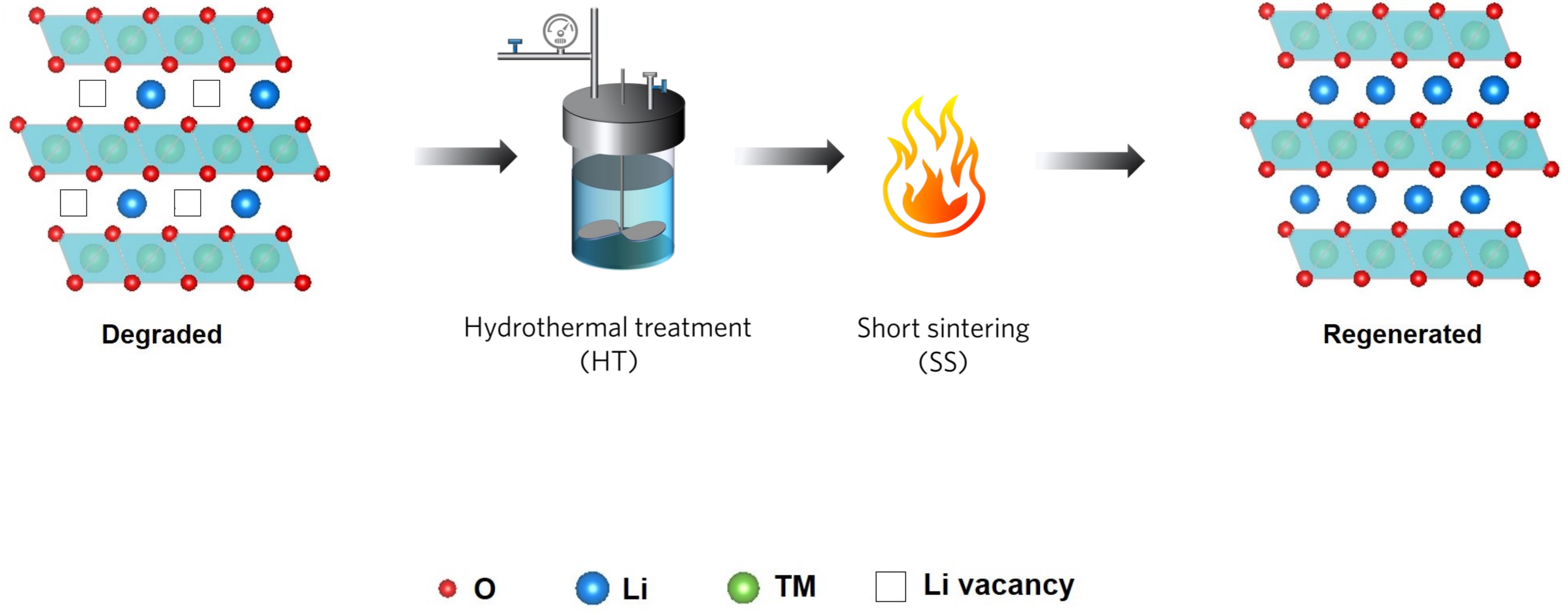
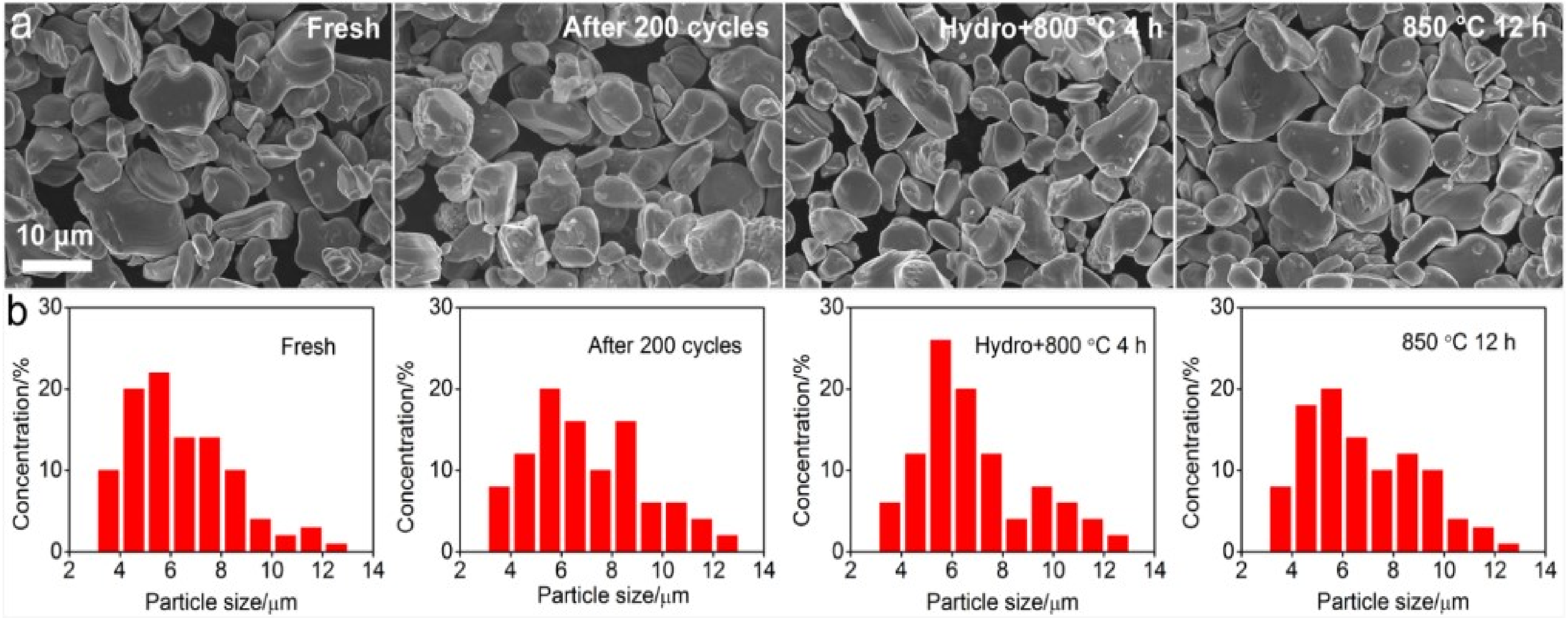
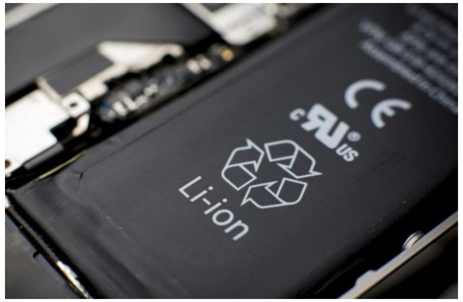
Y. Shi, **Z. Chen*** et al, *Green Chemistry*, 2018, 20, 851-862.

The Direct Regeneration Process



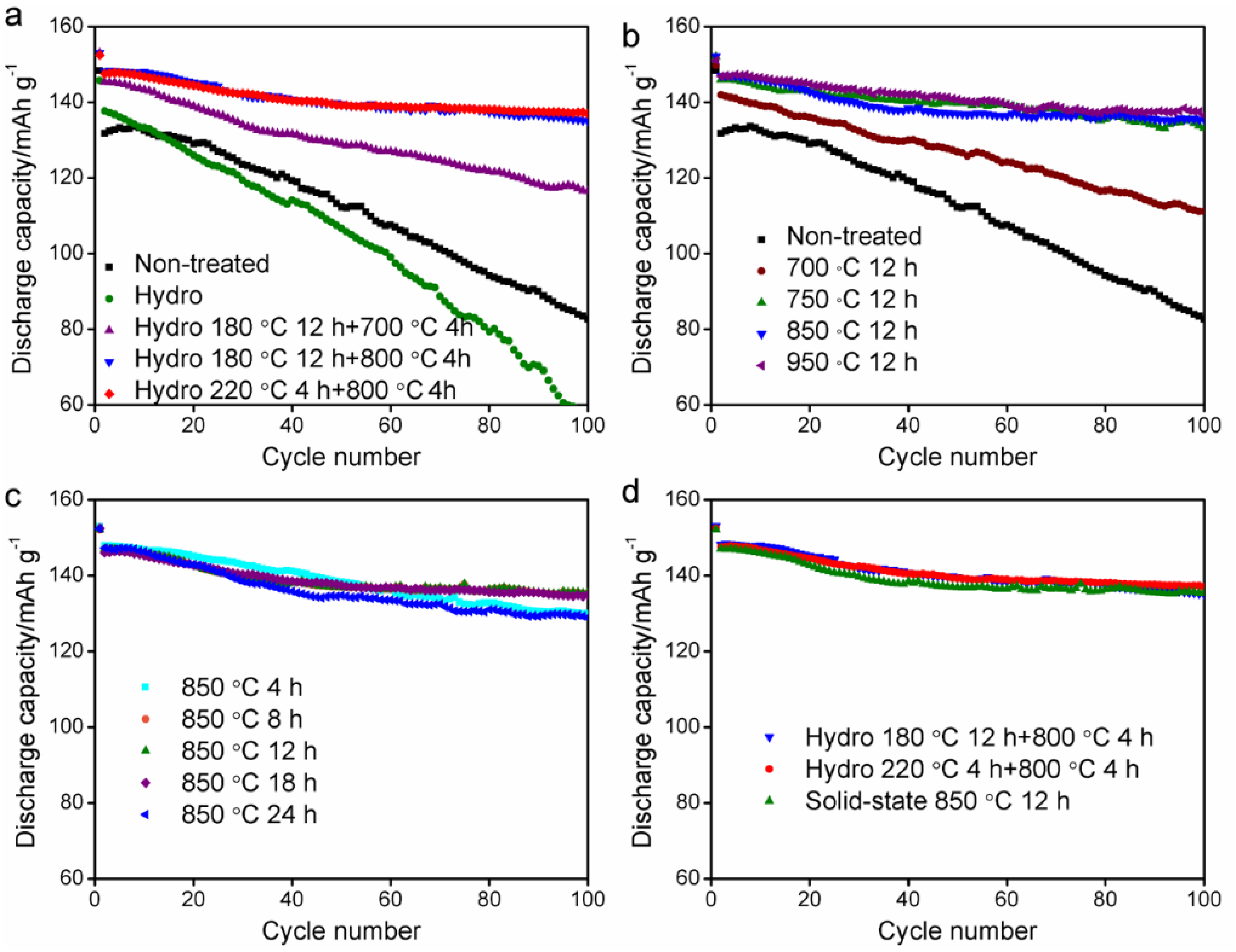
Morphological and Composition Change: the LCO Case



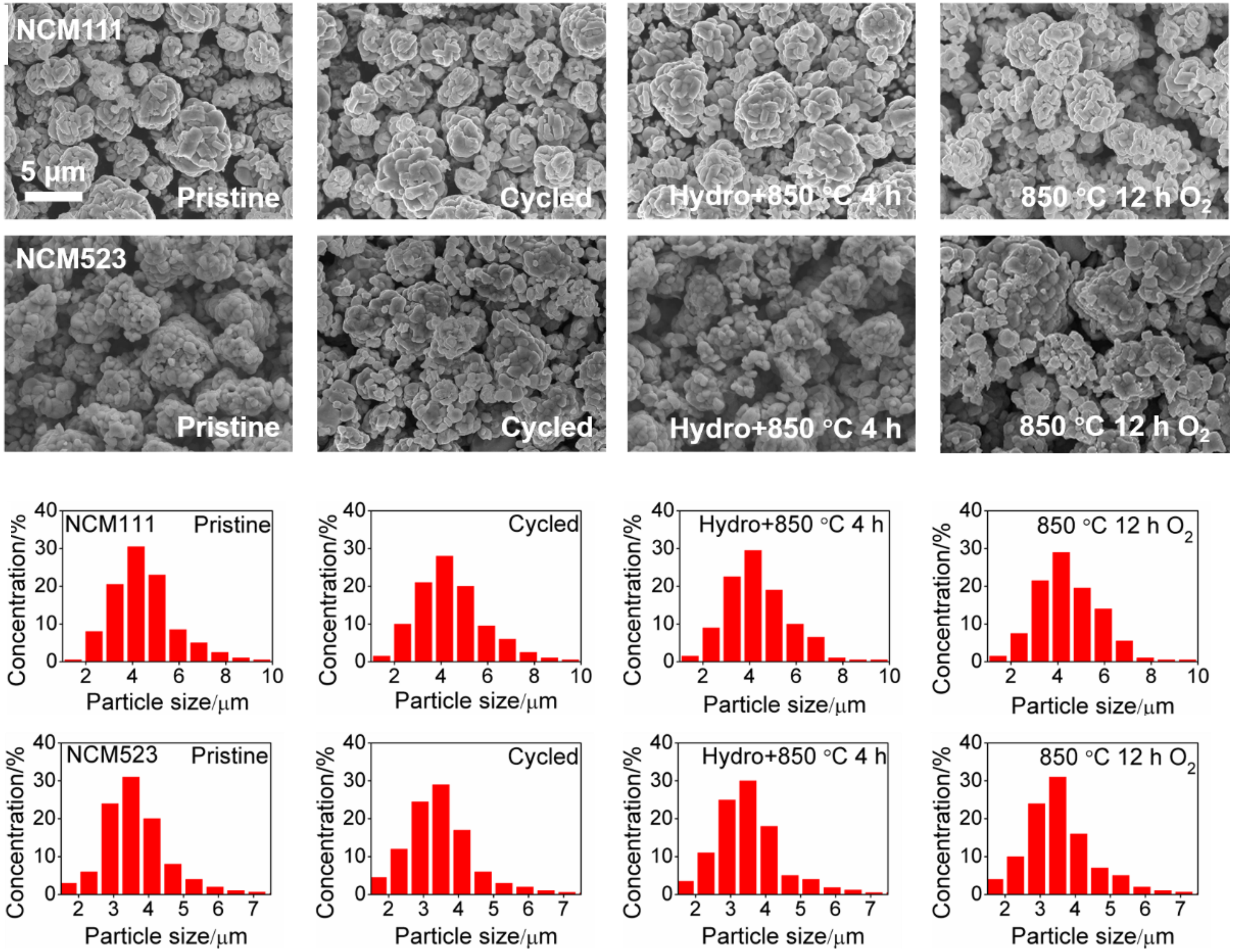


Hydrothermal	No annealing	700 °C 4 h	800 °C 4 h
Composition	$Li_{0.98}CoO_2$	$Li_{0.98}CoO_2$	$Li_{0.98}CoO_2$
Solid-state synthesis	750 °C 12 h	850 °C 12 h	950 °C 12 h
Composition	$Li_{0.99}CoO_2$	$Li_{0.98}CoO_2$	$Li_{0.96}CoO_2$

Exploring the LCO Regeneration Conditions



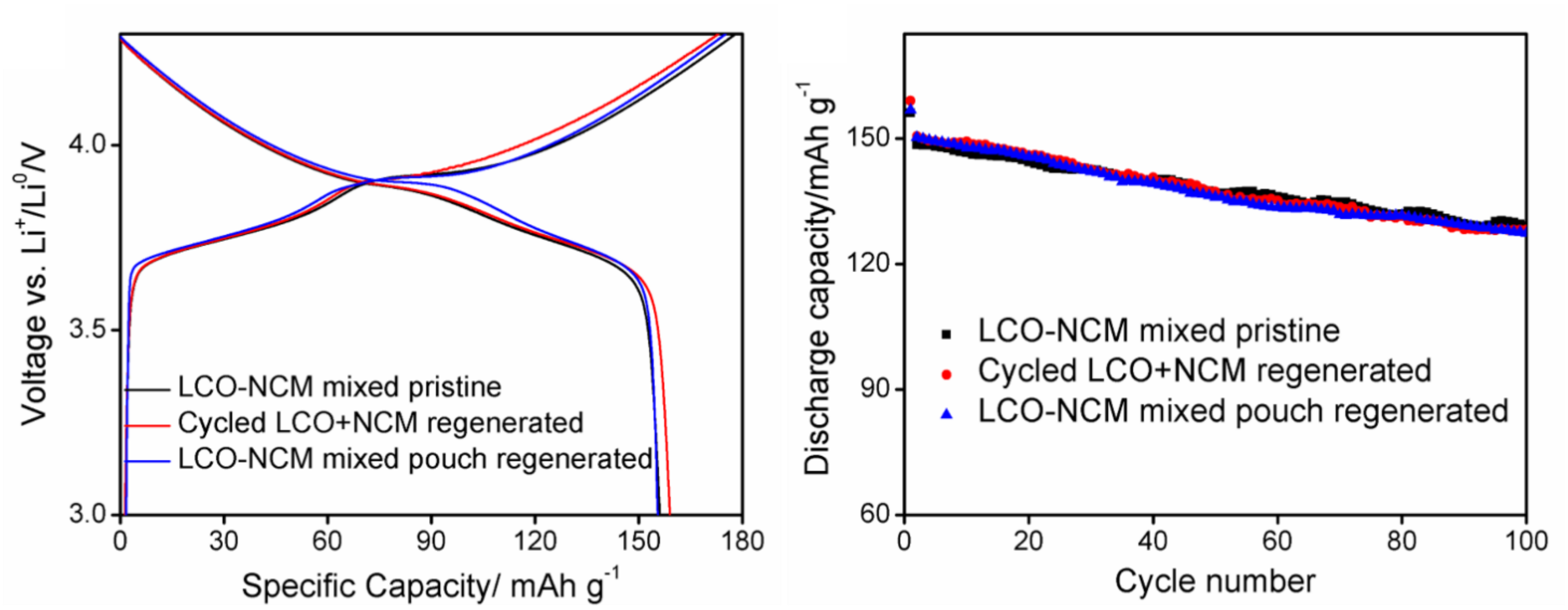
Recovery of Complicated NMC



Regeneration of $LiNi_xMn_yCo_zO_2$ (NMC)

Sample	NCM111	NCM523
Pristine	$Li_{0.995}Ni_{0.331}Co_{0.341}Mn_{0.329}O_{2.012}$	$Li_{1.009}Ni_{0.492}Co_{0.209}Mn_{0.305}O_{2.015}$
Cycled	$Li_{0.786}Ni_{0.328}Co_{0.340}Mn_{0.325}O_{1.996}$	$Li_{0.788}Ni_{0.490}Co_{0.208}Mn_{0.302}O_{1.985}$
Hydro only	$Li_{1.012}Ni_{0.329}Co_{0.341}Mn_{0.326}O_{2.009}$	$Li_{1.006}Ni_{0.491}Co_{0.209}Mn_{0.304}O_{2.012}$
Hydro+850 ℃ 4 h	$Li_{1.019}Ni_{0.330}Co_{0.340}Mn_{0.327}O_{2.011}$	$Li_{1.021}Ni_{0.490}Co_{0.209}Mn_{0.303}O_{2.013}$
850 ℃ 12 h air	$Li_{1.016}Ni_{0.331}Co_{0.340}Mn_{0.325}O_{2.010}$	$Li_{1.017}Ni_{0.490}Co_{0.207}Mn_{0.304}O_{2.014}$
850 ℃ 12 h oxygen	$Li_{1.016}Ni_{0.331}Co_{0.341}Mn_{0.326}O_{2.012}$	$Li_{1.018}Ni_{0.491}Co_{0.208}Mn_{0.304}O_{2.013}$

Regeneration of Mixed Cathodes

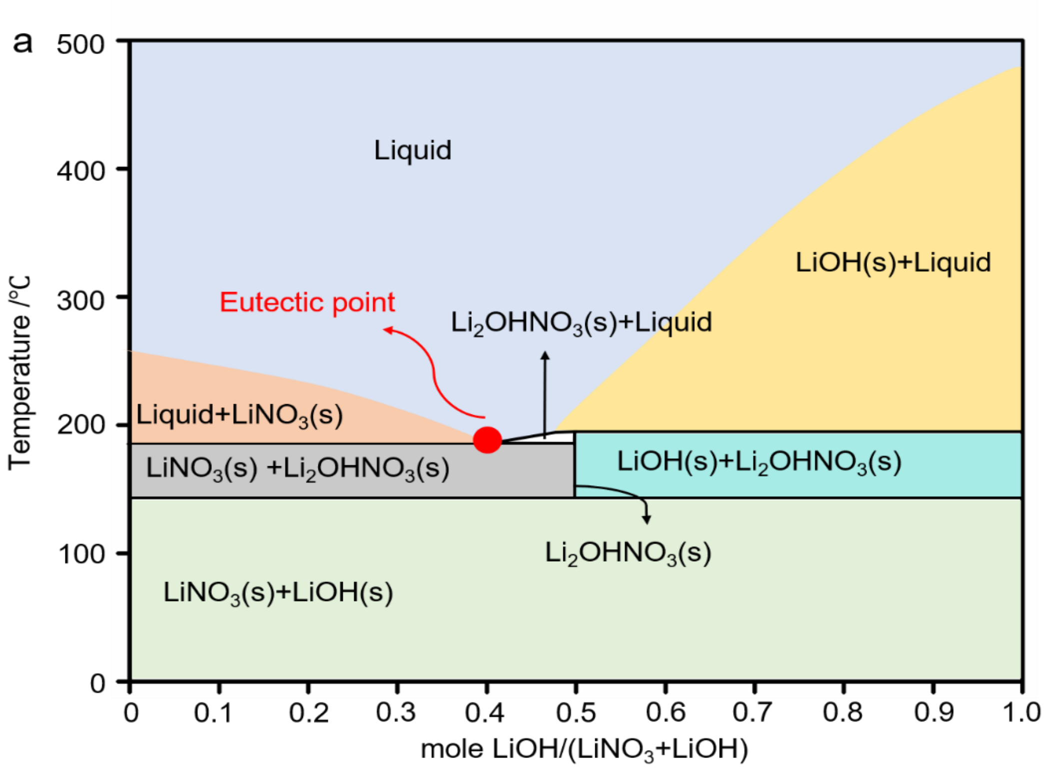


LCO-NCM mixed: materials mixed in the same cell

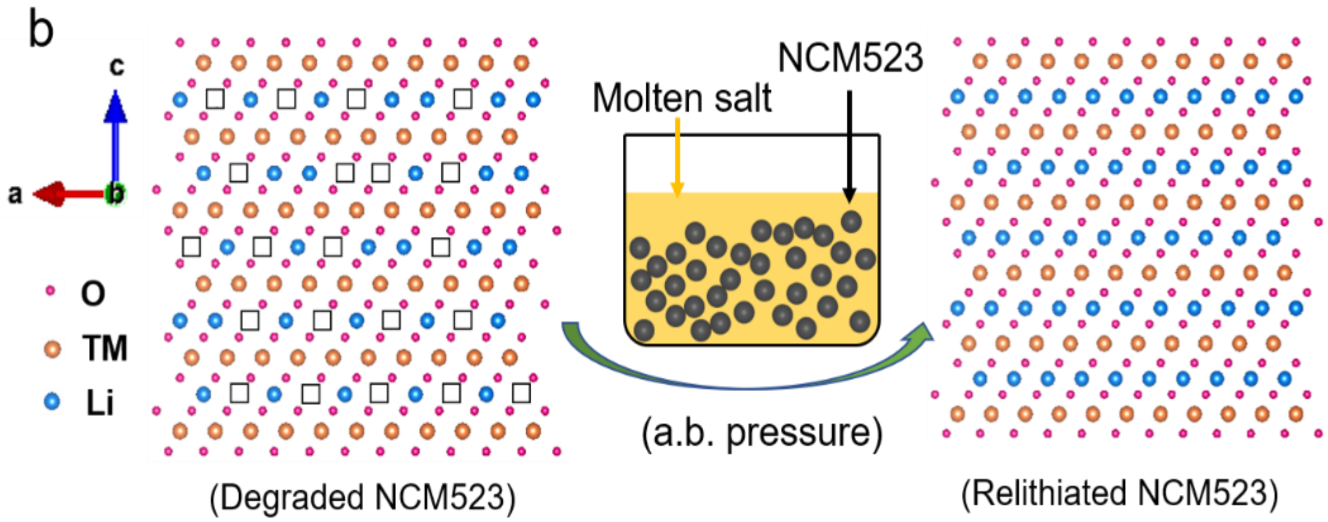
LCO+NCM mixed: cells with different materials and then mixed

*Y. Shi, **Z Chen**, et al, ACS Energy Lett., 2018, 3, 1683.*

Ambient Pressure Re-lithiation in Eutectic Mixtures

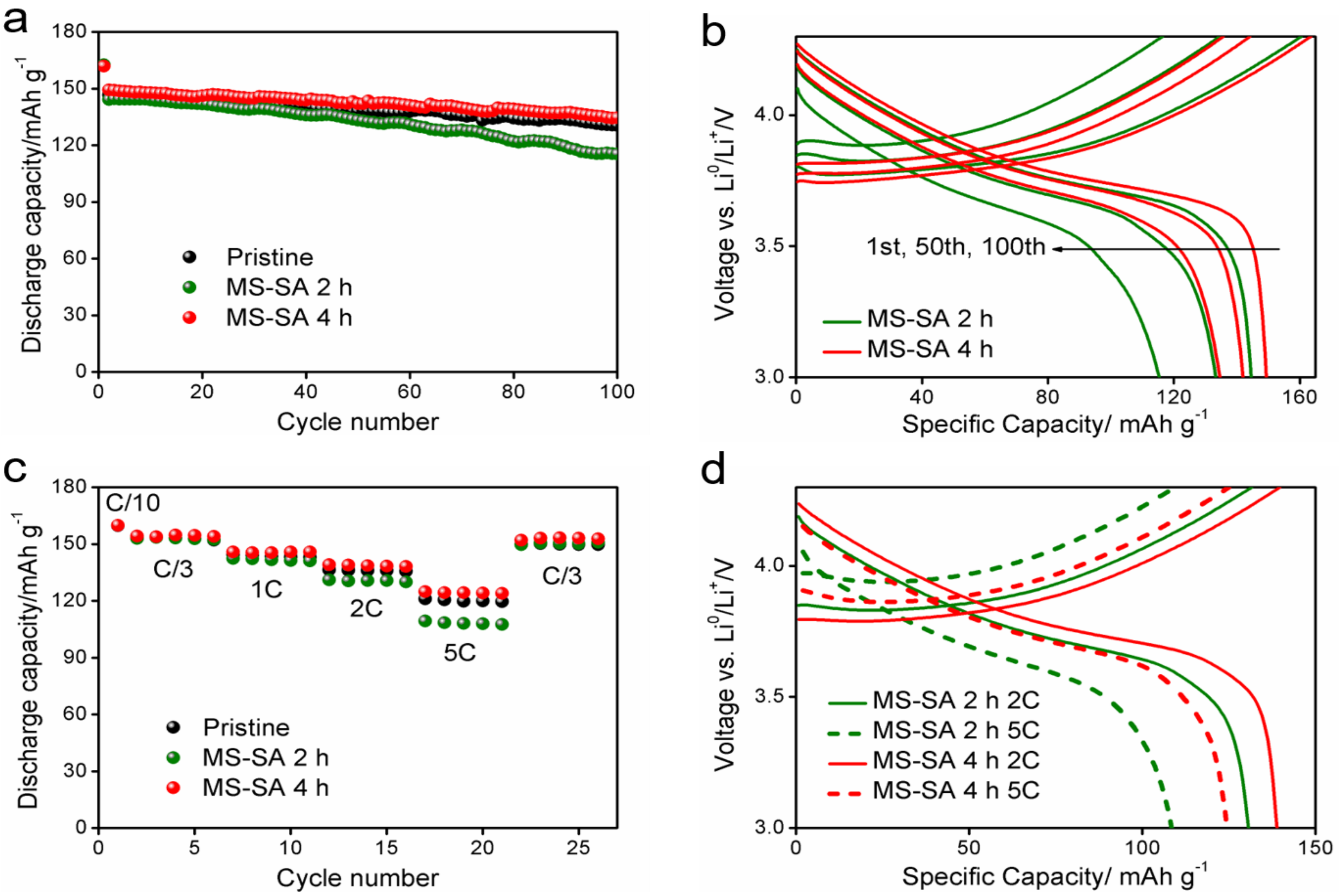


Relithiation of 50% degraded NCM

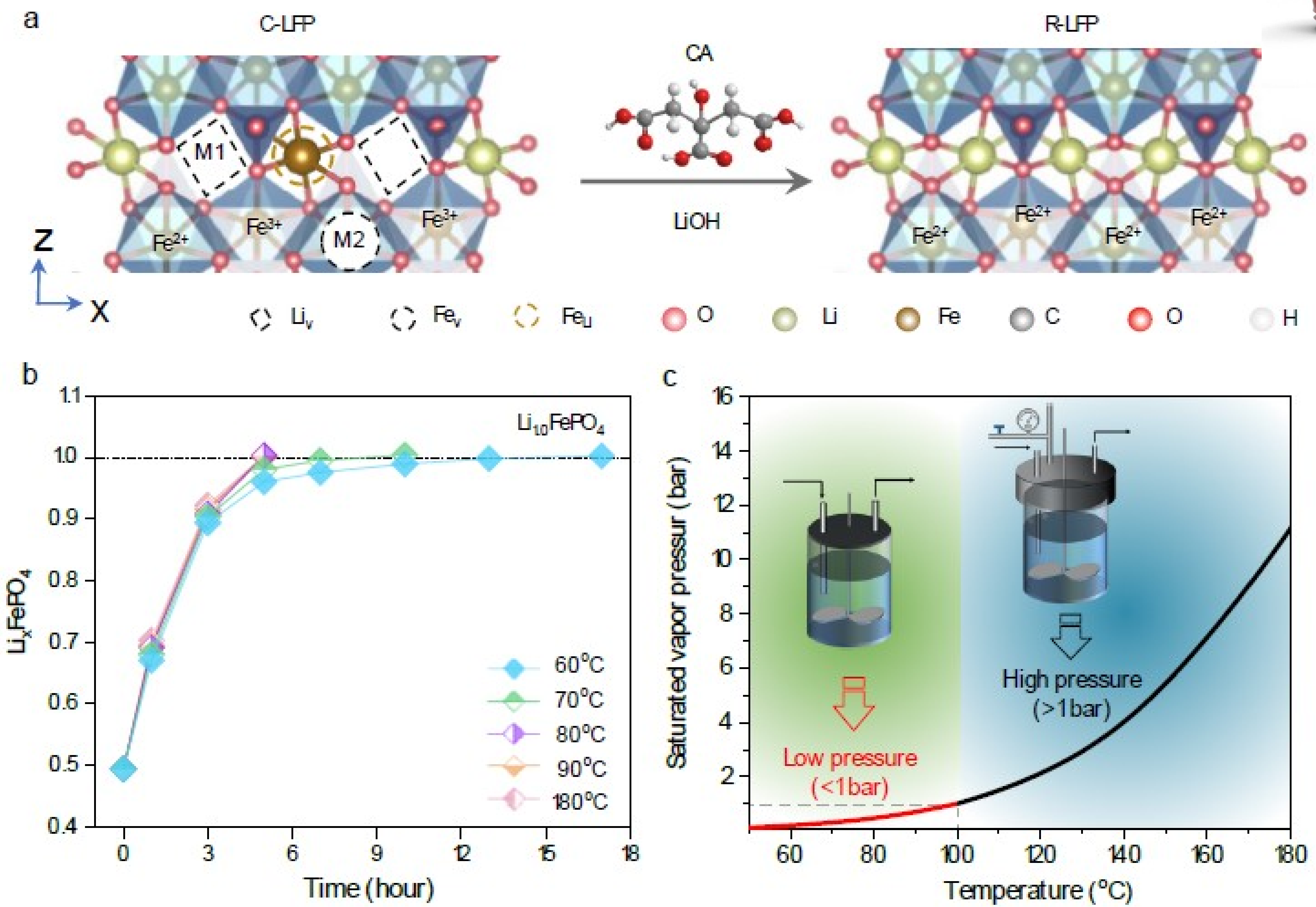


*S. Yang, **Z. Chen** .et al, Adv. Energy. Mater, 2019, 9,* 1900454.

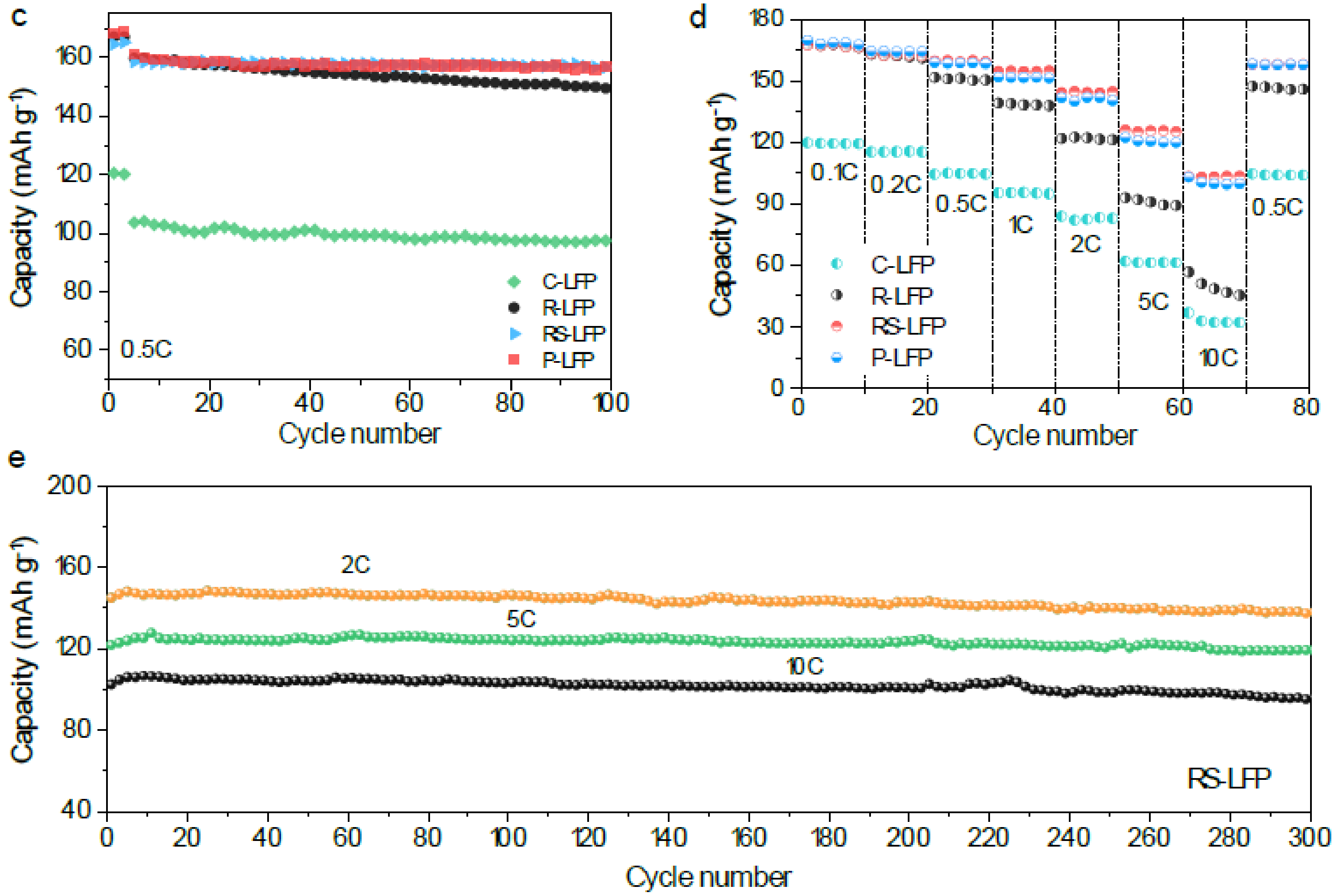
EC Data for Regeneration of NCM523



Direct Recycling of $LiFePO_4$

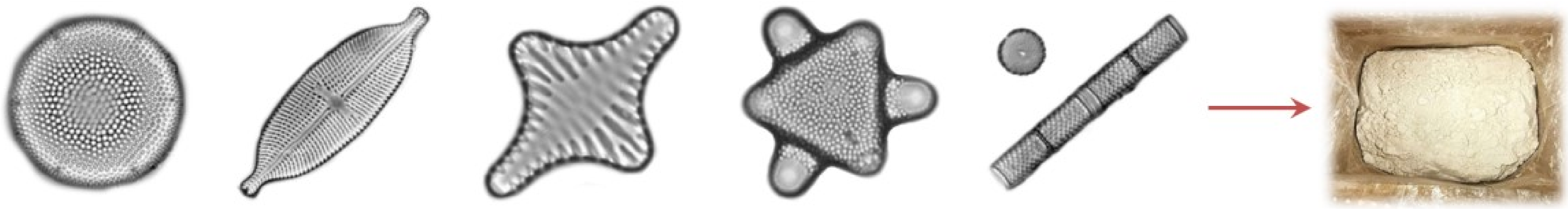


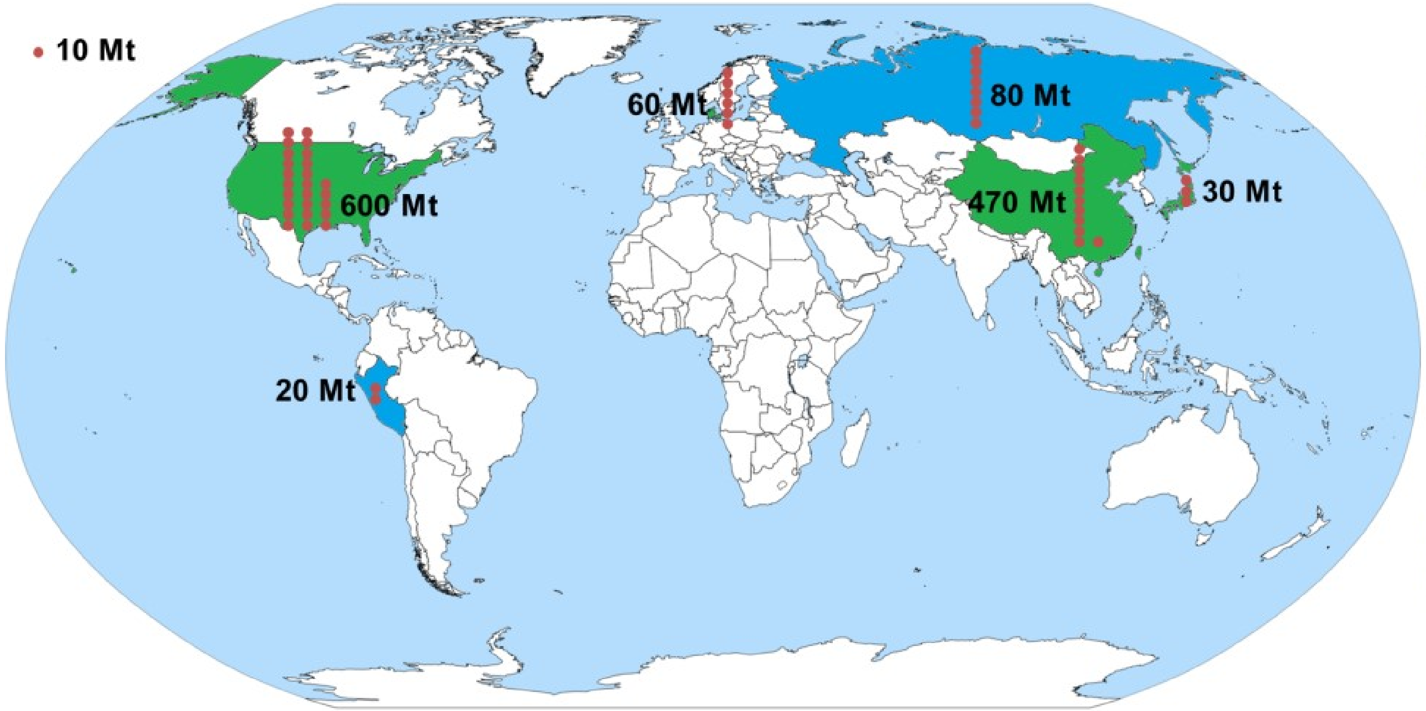
Performance of Reg. $LiFePO_4$



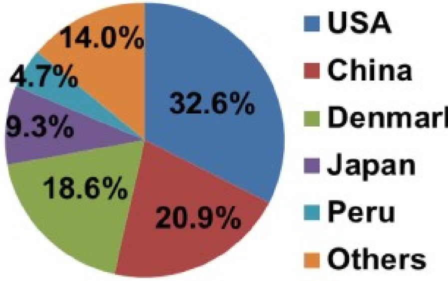
Z. Chen, et al, 2020, ***Joule***, doi.org/10.1016/j.joule.2020.10.008.

Diatomite: A Great Resource

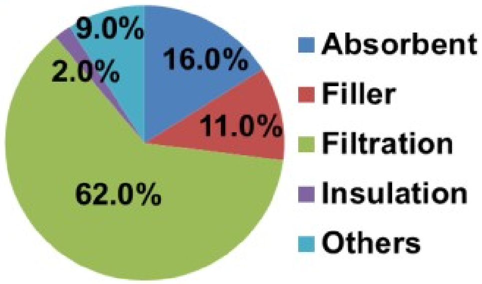




World proved reserve >2 billion ton, world output >3 million ton, low cost of 10~1000 $/t



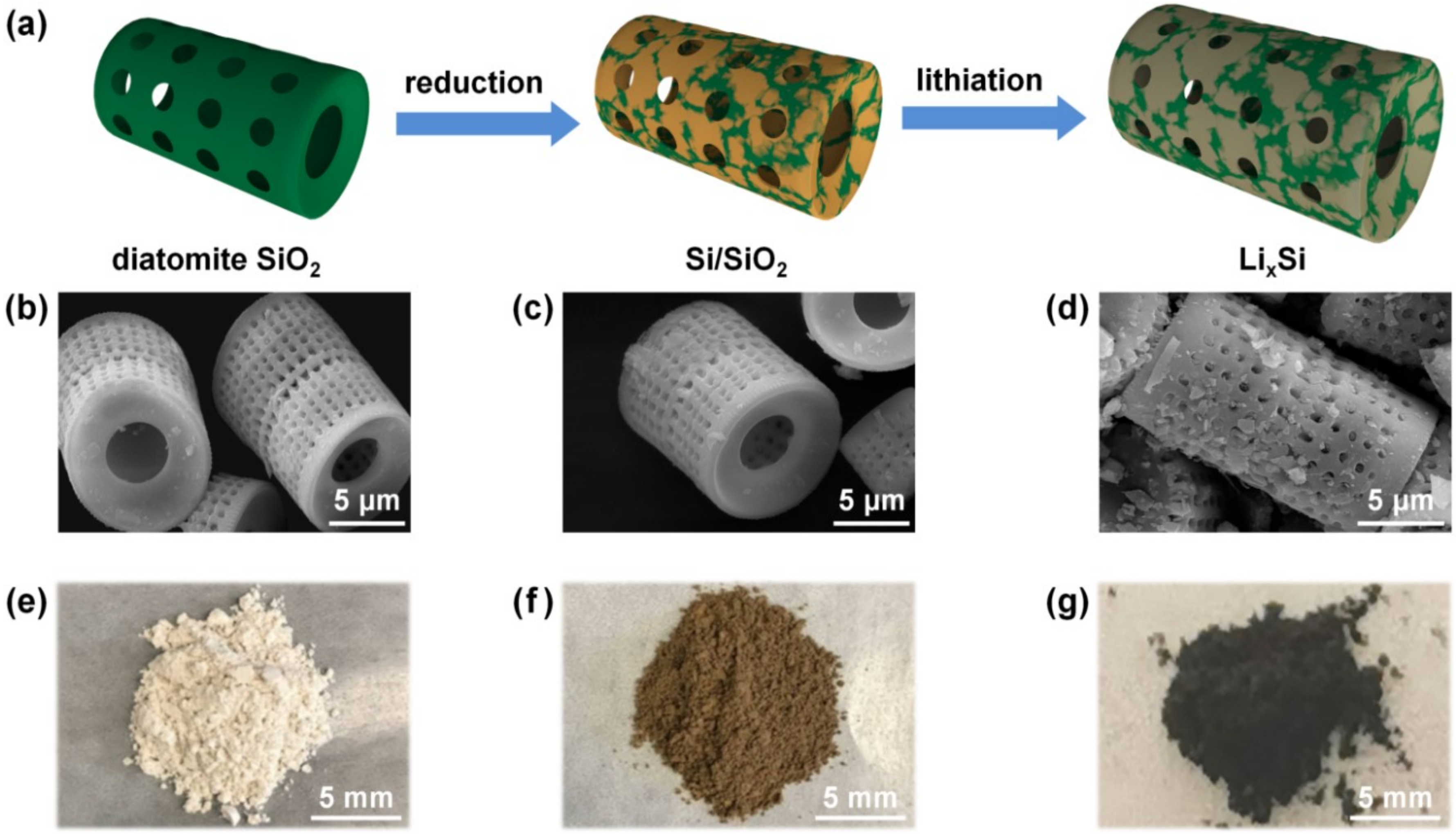
Output in 2017

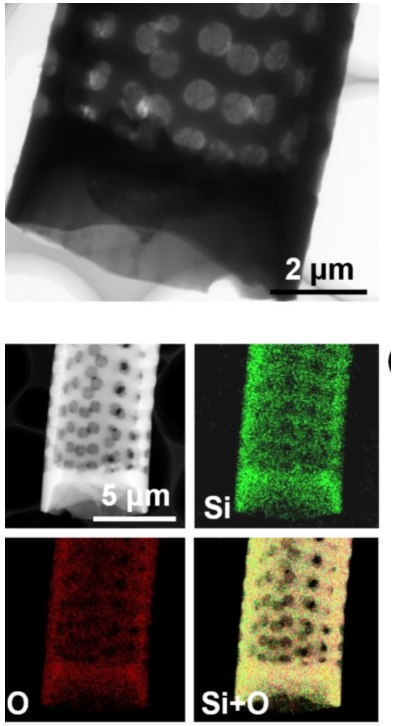


Application fields

United States Geological Survey

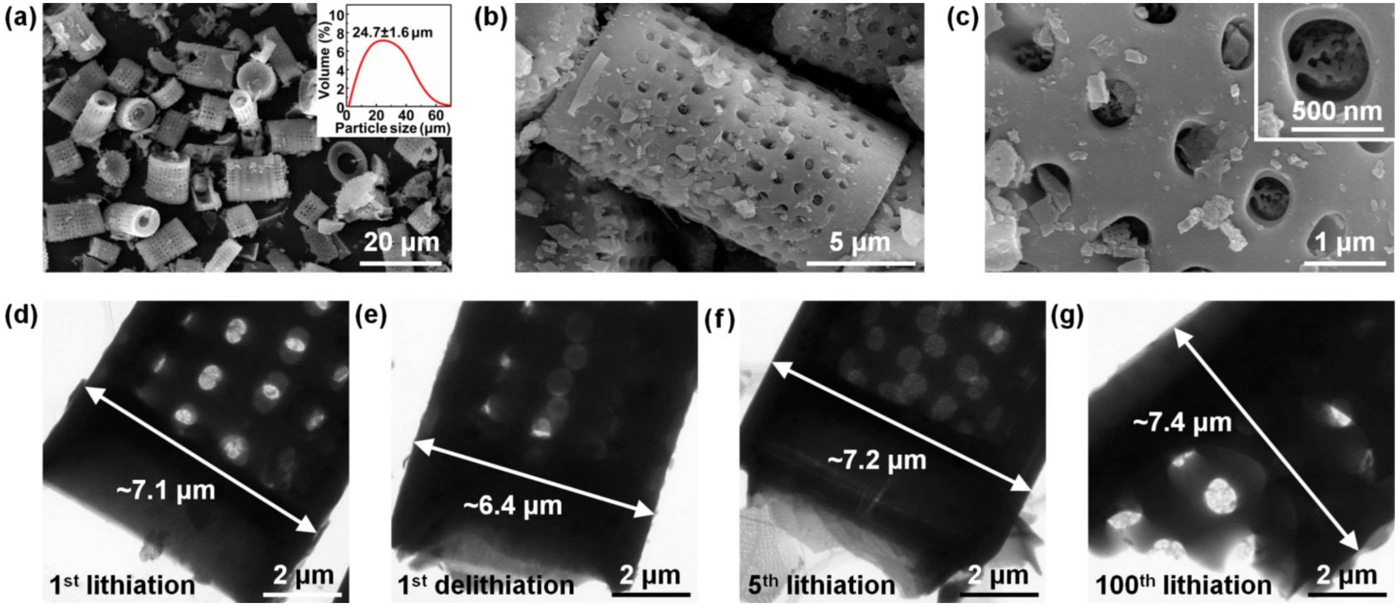
Diatomite-Derived Si Anode

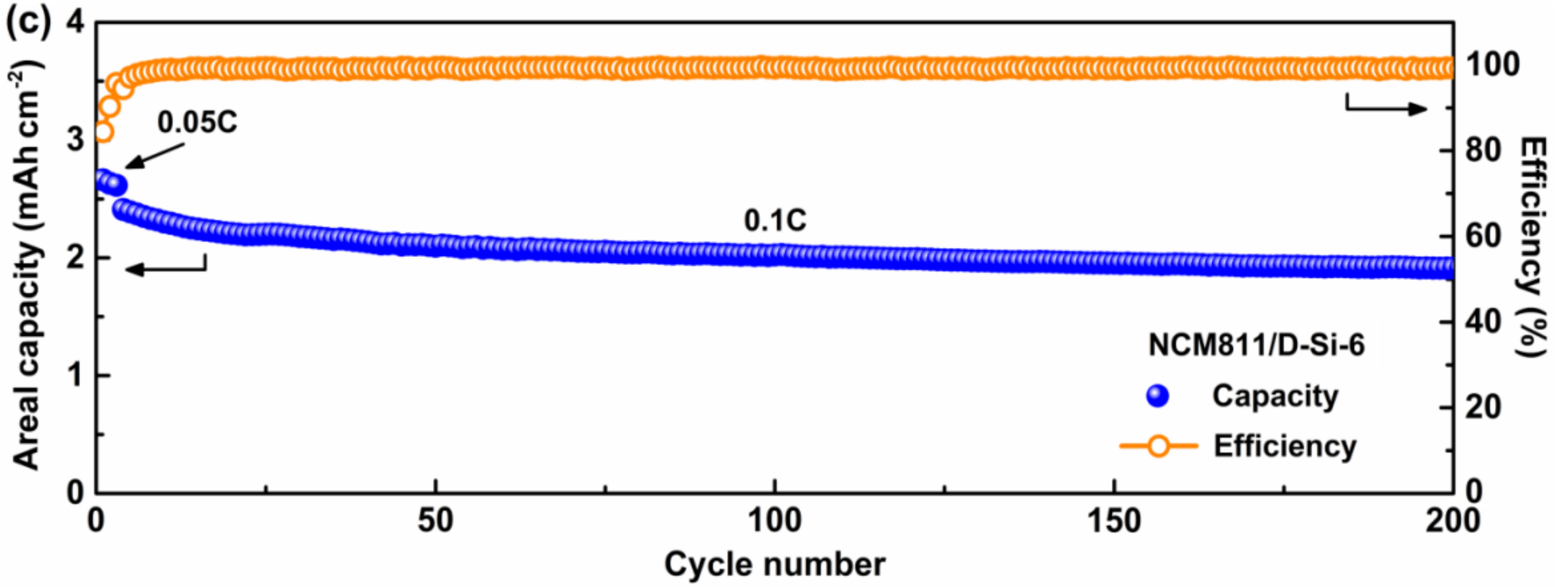




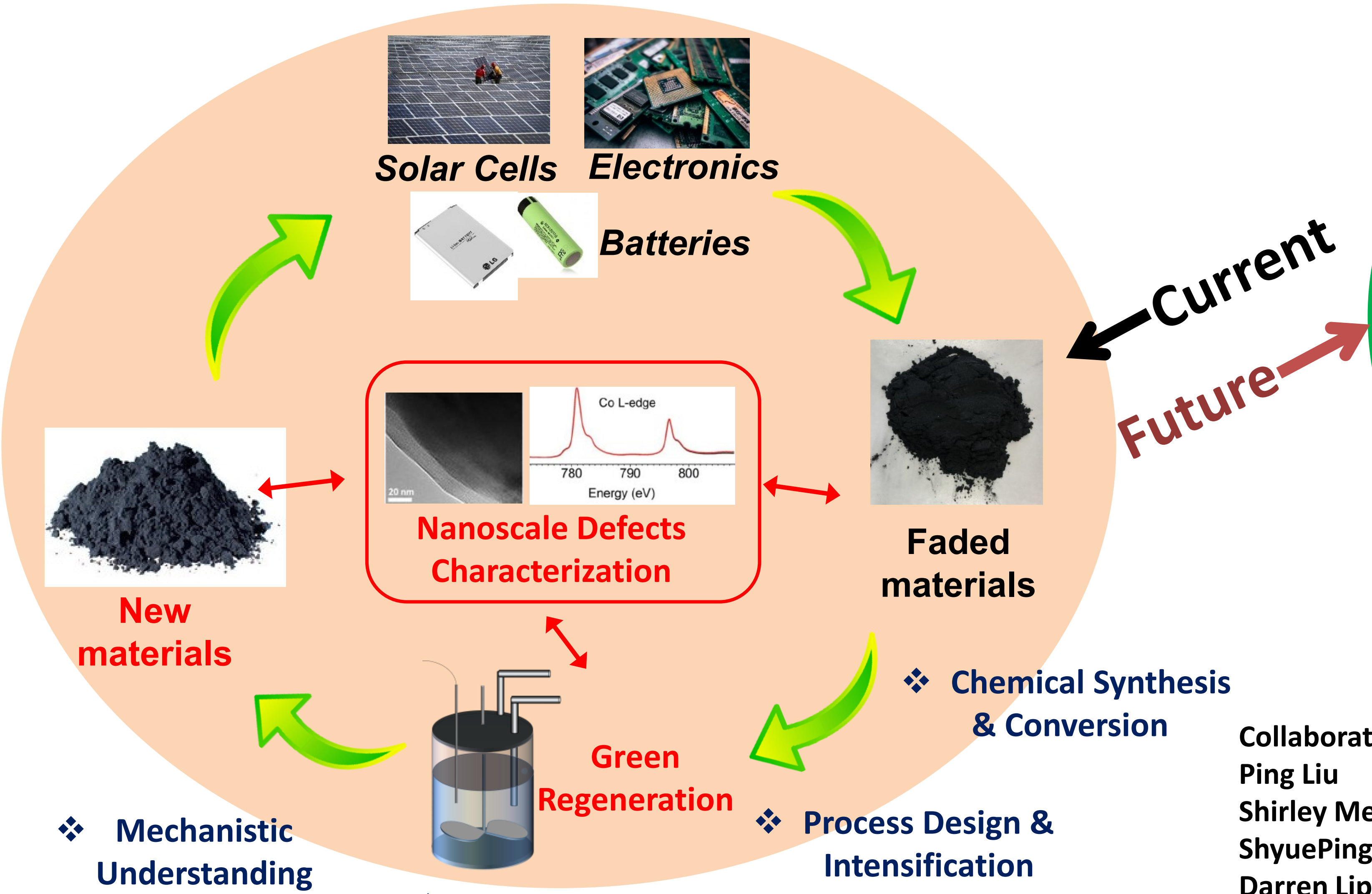
Z. Chen, et al, Adv. Funct. Mater., 2020, 30, 2005956.

Stable Cycling





Materials Science and Chemical Technology for Sustainable Energy



❖ Materials Design & Synthesis

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Thank you!