Agricultural Residues for Water-Environment-Energy Nexus

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The Timeline of Net-Zero Policy Implantation

- Taiwan's 2050 Net-Zero pathway has been set, with over **$3 billion (USD)** annually allocated and a projected **$27 billion (USD)** investment by 2030.
- The Climate Change Response Act was amended in 2023, and the Net-Zero Science and Technology Program (NZST) now invests **$500 million (USD) per year** in potential projects.



Apr. 2021

Former president Tsai announced Taiwan's 2050 Net-Zero Transition target

Mar. 2022

Taiwan announced the 2050 Net-Zero Transition Plan.

Dec. 2022

National Development Council-Bilingual Nation Policy official release Taiwan's 2050 Net-Zero Transition 12 key strategies

Feb. 2023

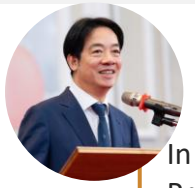
Announced the revision of the Greenhouse Gas Management Act into the Climate Change Response Act and the Amendment of Articles

Mar. 2023

The Executive Yuan approved NZST Program and established the Advisory Committee of the Program.

May. 2023

The Taiwan Science and Technology Office for Net-Zero Emission (T-STONE) was officially established



May. 2024

In the presidential inauguration President Lai declared "As we face the dangers of climate change, we must be resolved in our transition to net-zero emissions by the year 2050."

August. 2024

President Lai presides over first meeting of **National Climate Change Committee**

Jan. 2025

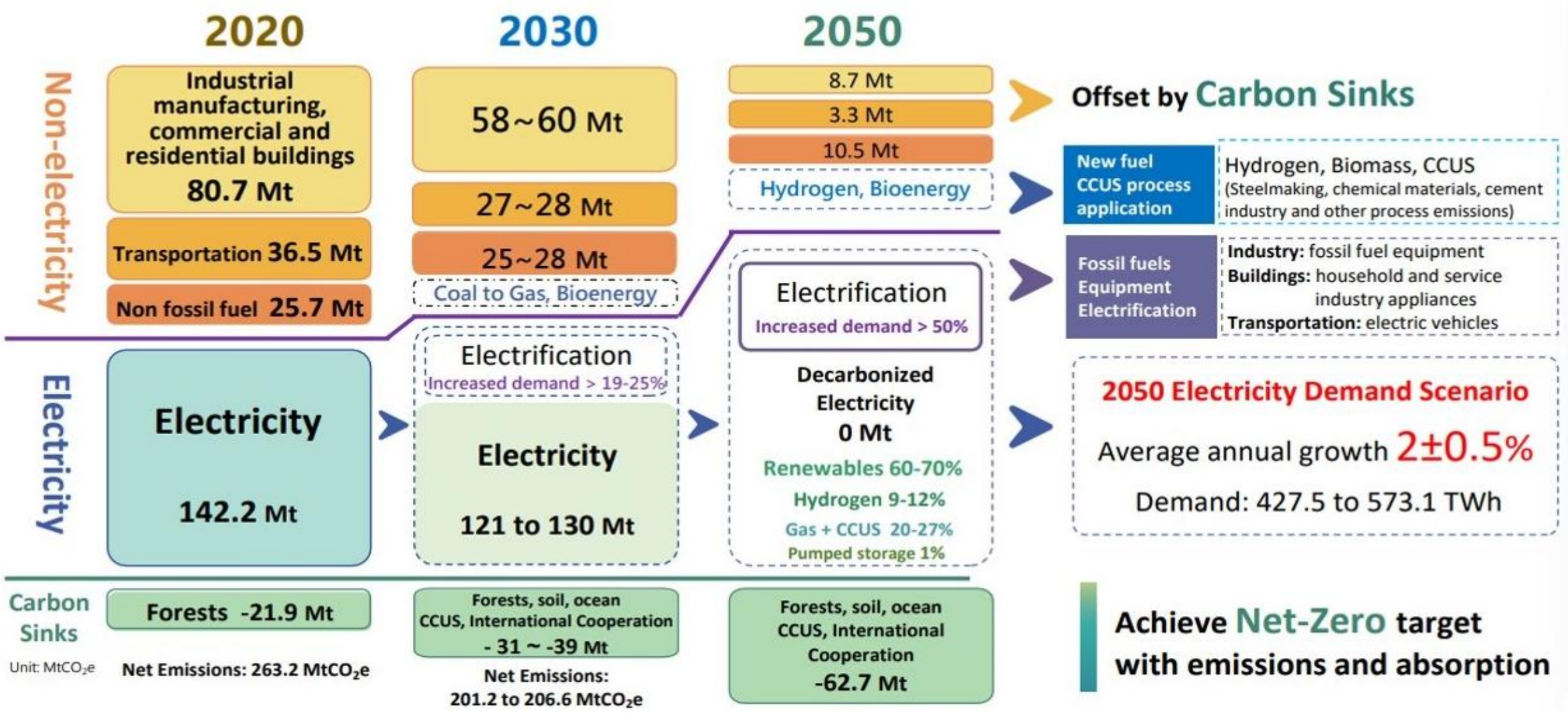
In the 3rd meeting of NCCC concluded

① **Reset carbon reduction targets**, covering the years 2030, 2032, and 2035.

② Announce a **comprehensive Carbon Action Plan**, which includes top-down "Flagship Carbon Reduction Action Plans" across six major sectors.

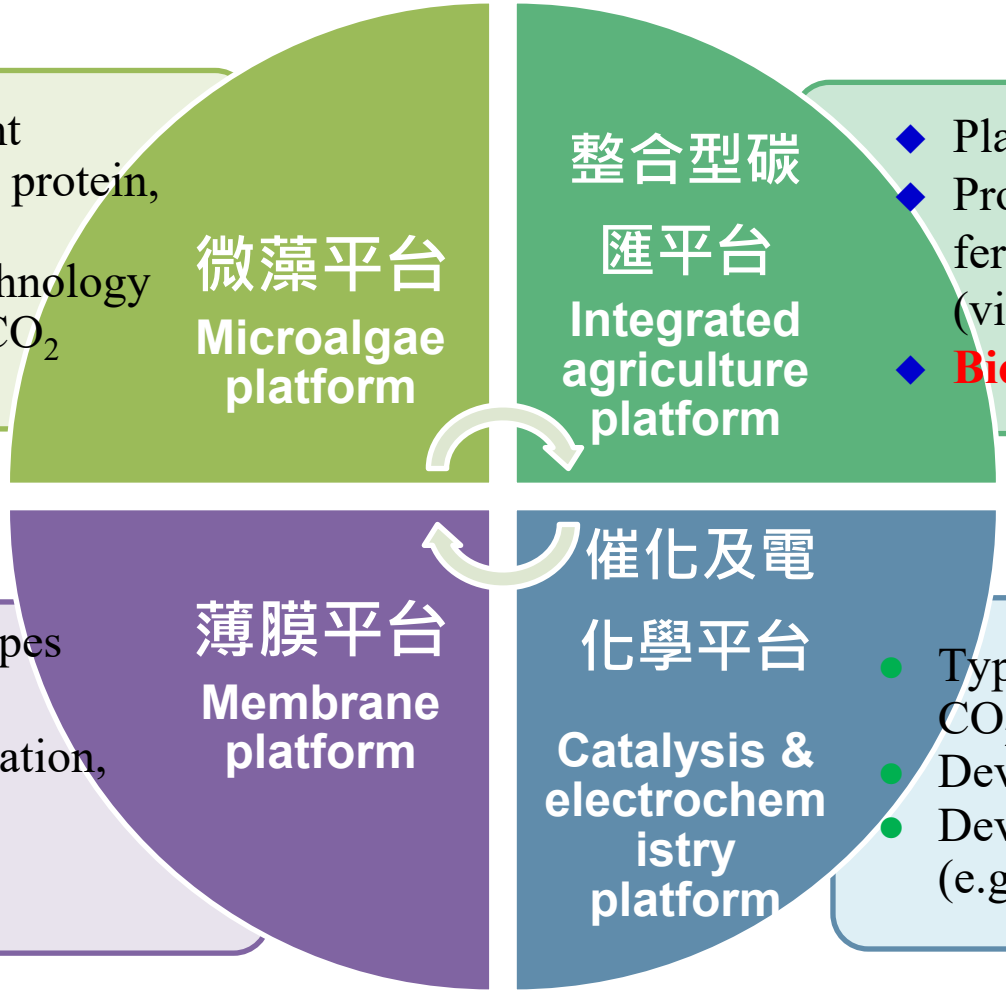
③ Committee members call for strengthened **public communication**.

Taiwan's 2050 Net-Zero Emission Plan and Pathway



Integrated Platform for CCU projects

- NSTC has allocated a total budget of NTD 107M (0.53B Yen) for CCU each year in 2023-2027.
- The Phase II project in 2027 – 2030 will focus on CCU and circular economy



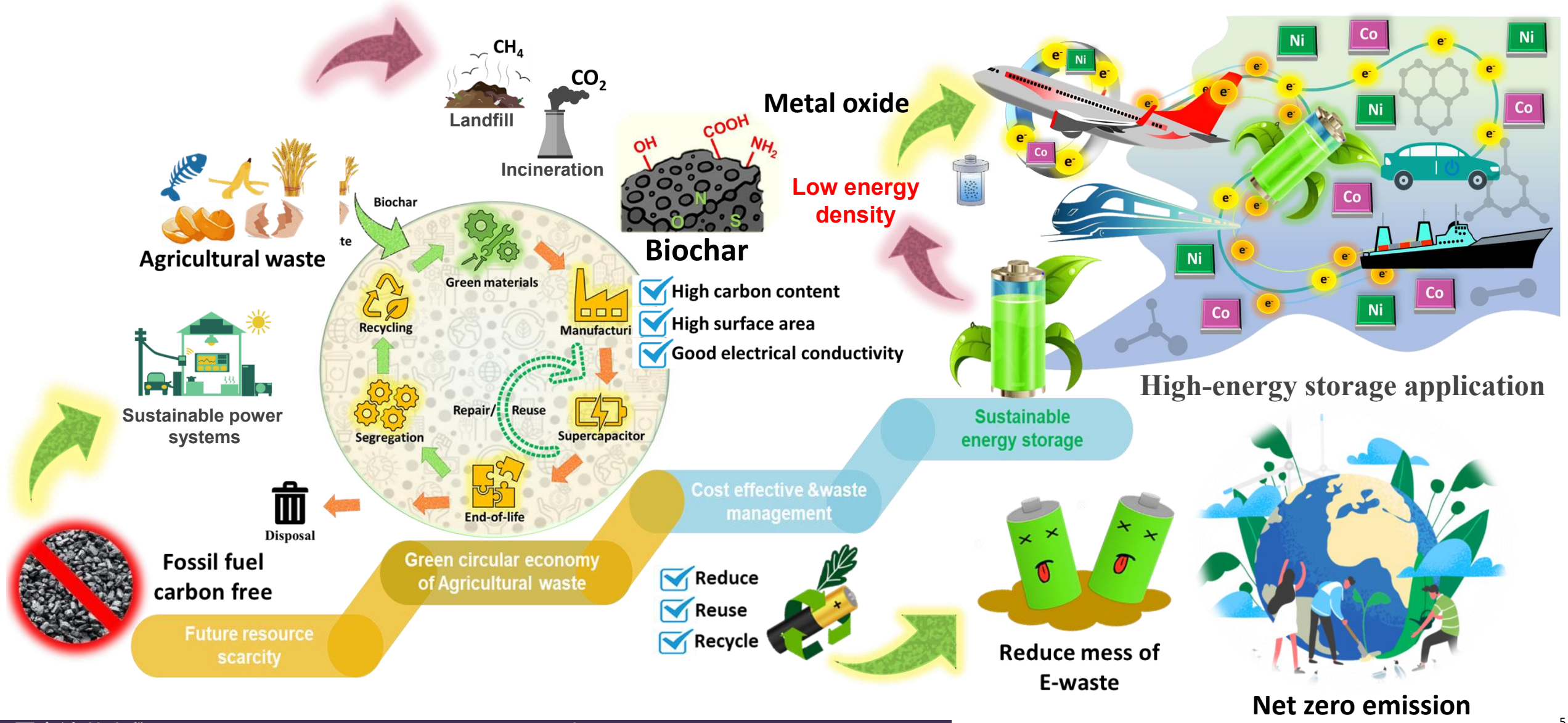
- ✓ Type of microalgae (different functional components, e.g., protein, lipids)
- ✓ Cultivation and scale-up technology
- ✓ Performance evaluation of CO_2 biofixation.

- ◆ Plant and soil carbon sink
- ◆ Production and utilization of fertilizers & growth stimulators (via circular economy)
- ◆ **Biochar applications**

- ➢ Membrane materials and types (e.g.: organic, inorganic)
- ➢ Membrane functions (separation, adsorption, reaction.)
- ➢ Integration

- ● Type of chemicals produced and CO_2 conversion methods
- ● Development of catalysts
- ● Development of battery materials (e.g., electrodes)

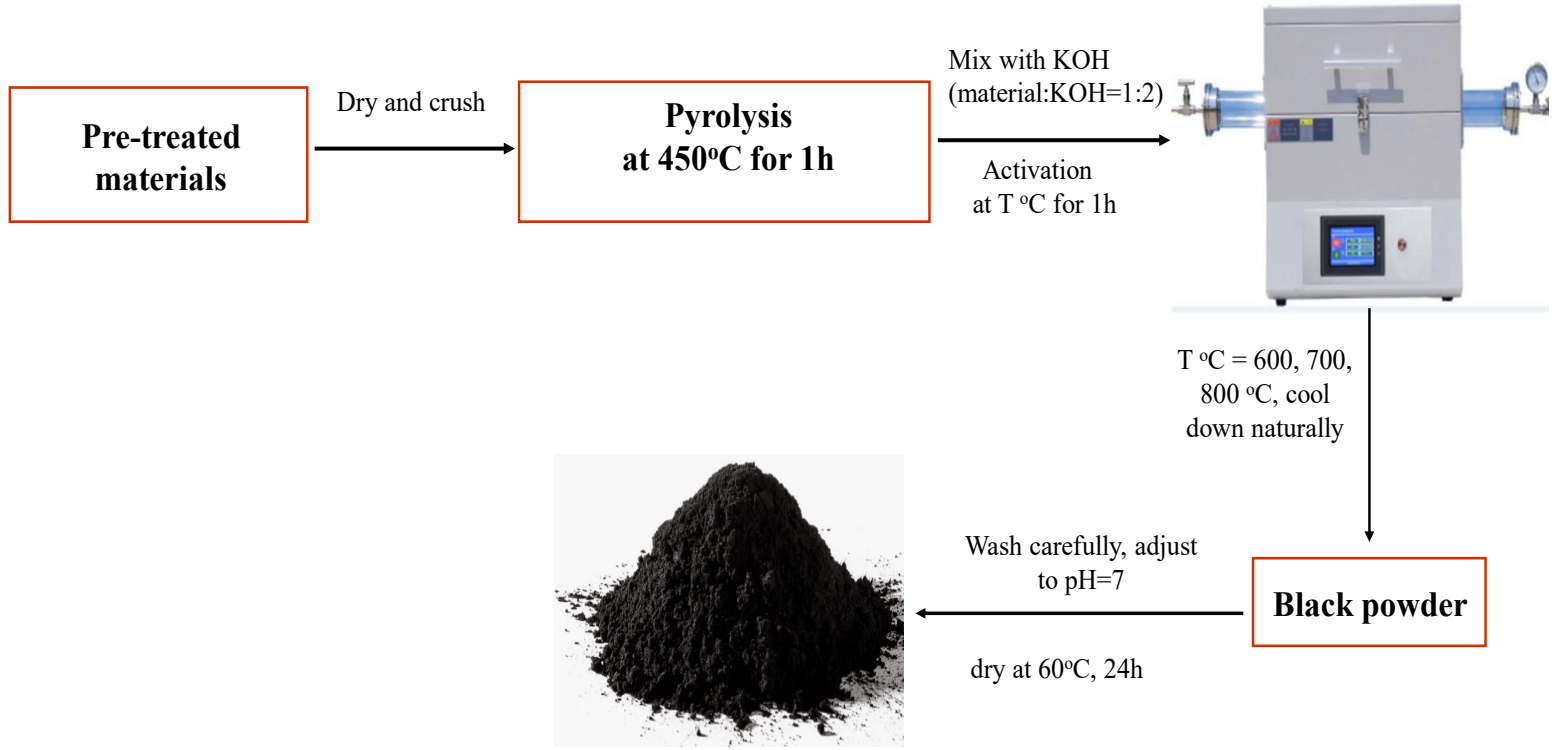
Green circular economy of agricultural residues

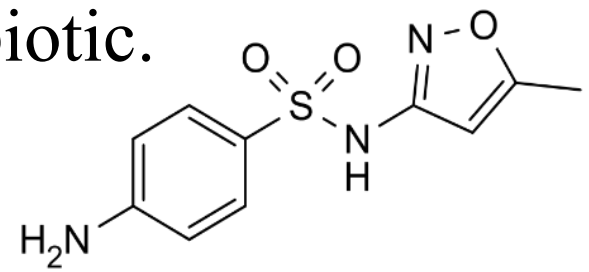


Biochar-based nanocomposites for Water Purification and Pollutant removals

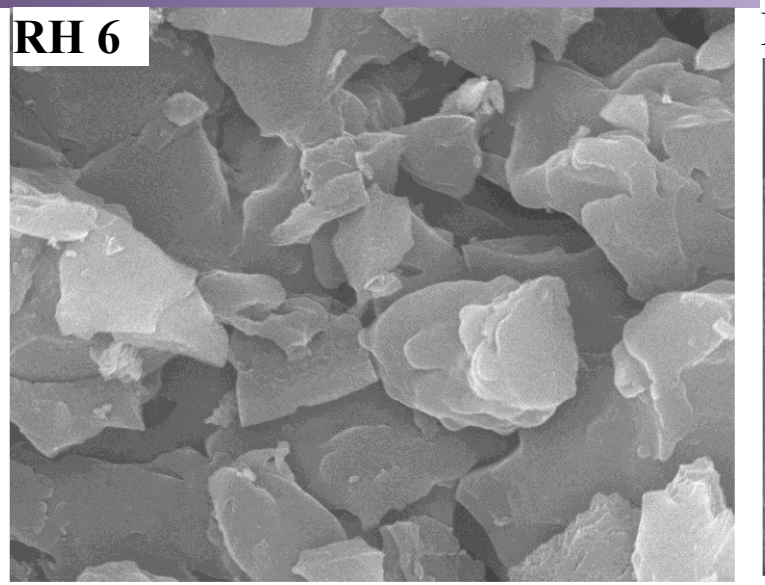
Preparation of agrowastes

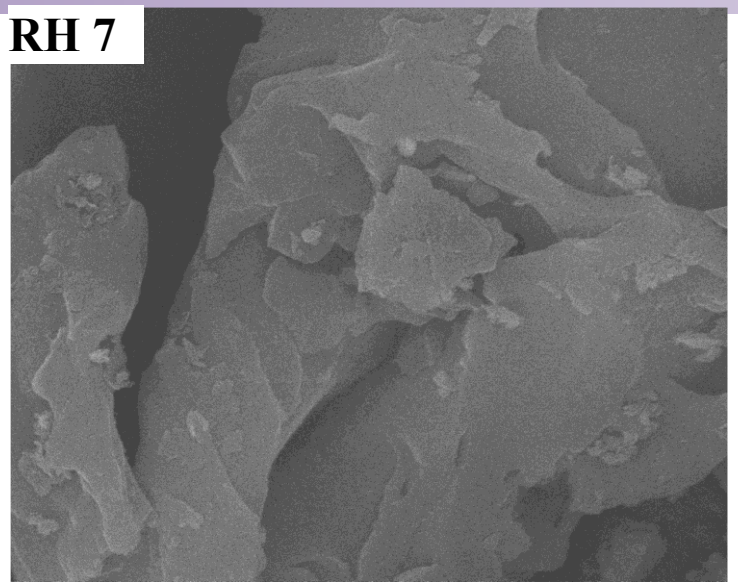
- Agricultural wastes
  - Rice husk (RH)
  - Coconut Fiber (CF)
  - Sunflower Seed (SF)
- Temperature
  - 600, 700, and 800 °C
- Pollutant
  - Sulfamethoxazole (SMX) is a polar sulfonamide antibiotic.
  - pKa: 5.7; water solubility: 400 mg/L; log Kow: 0.89

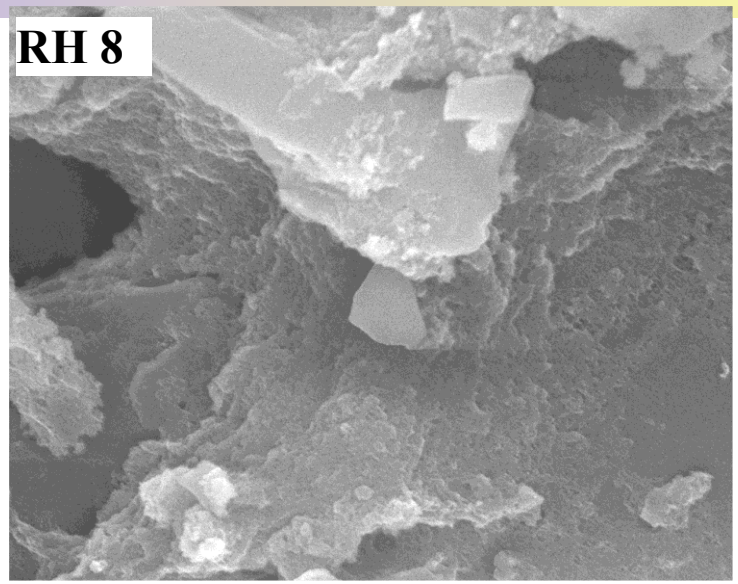


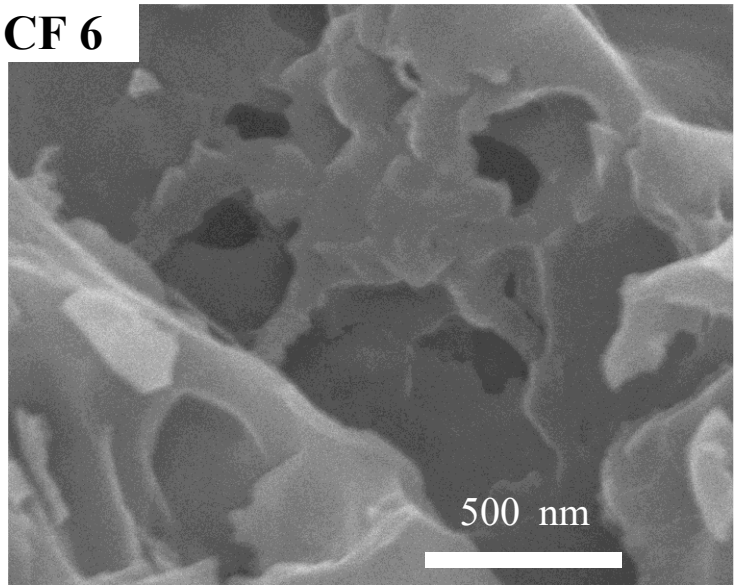


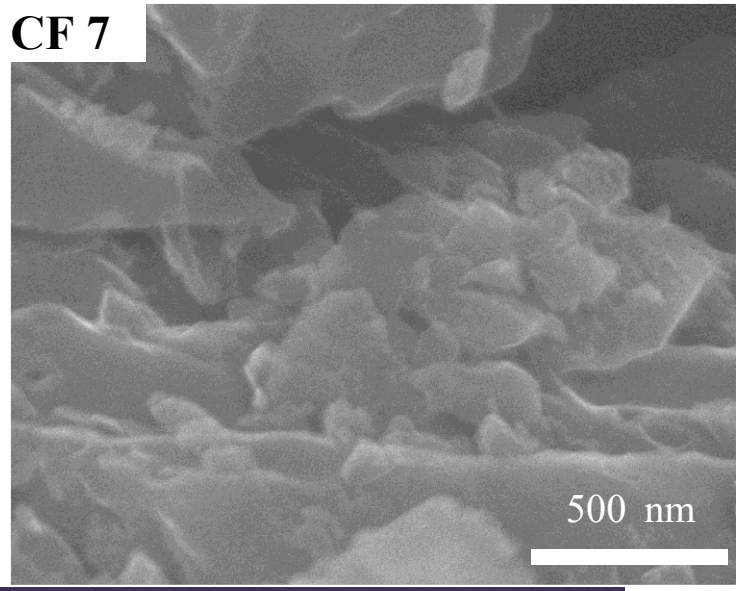
SEM images of RH and CF

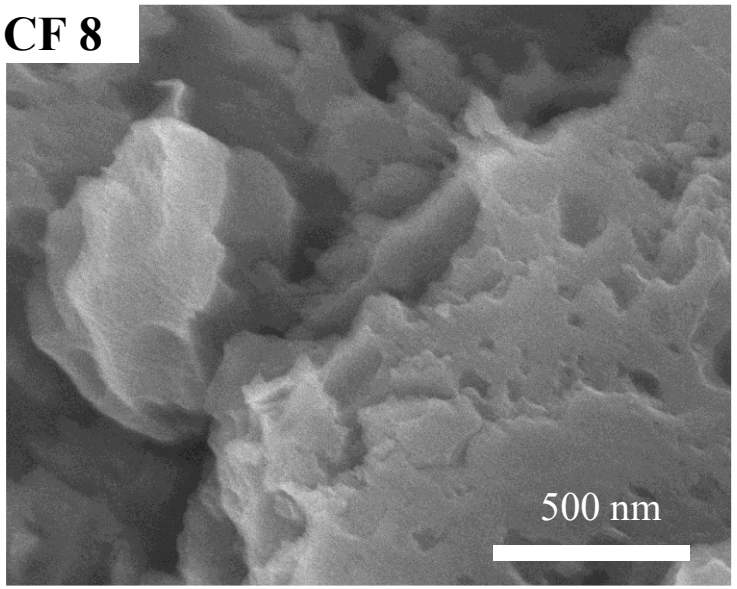




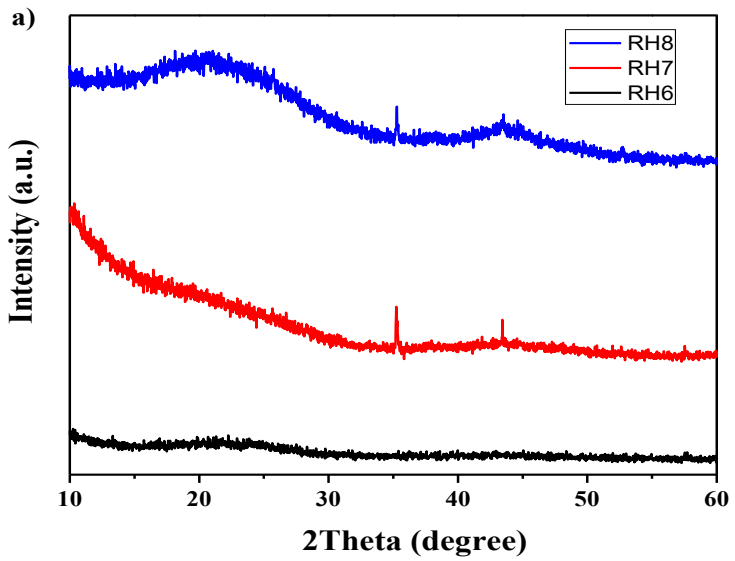


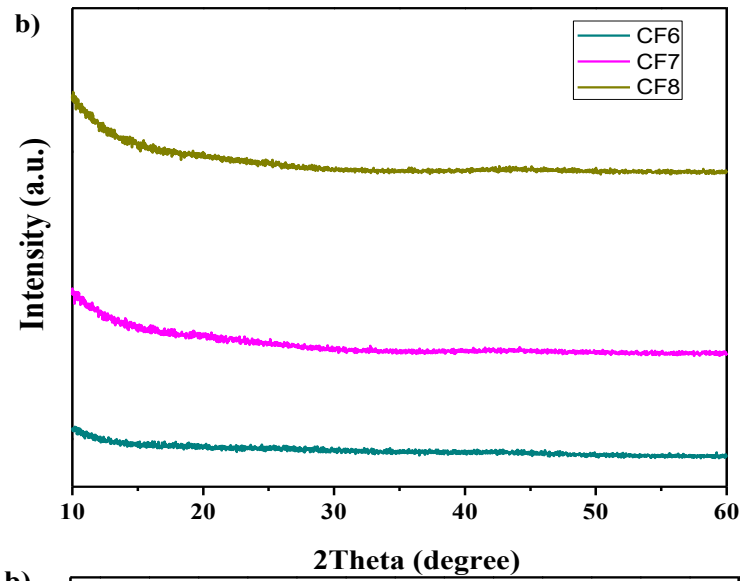


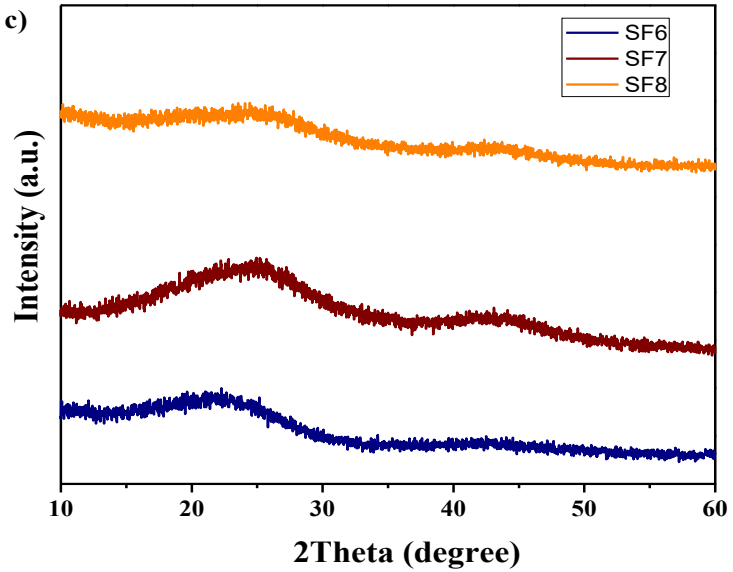


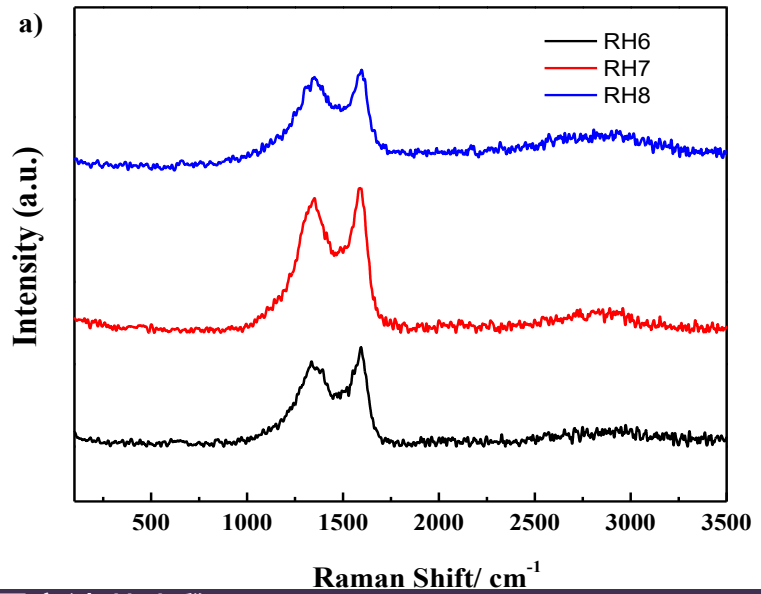


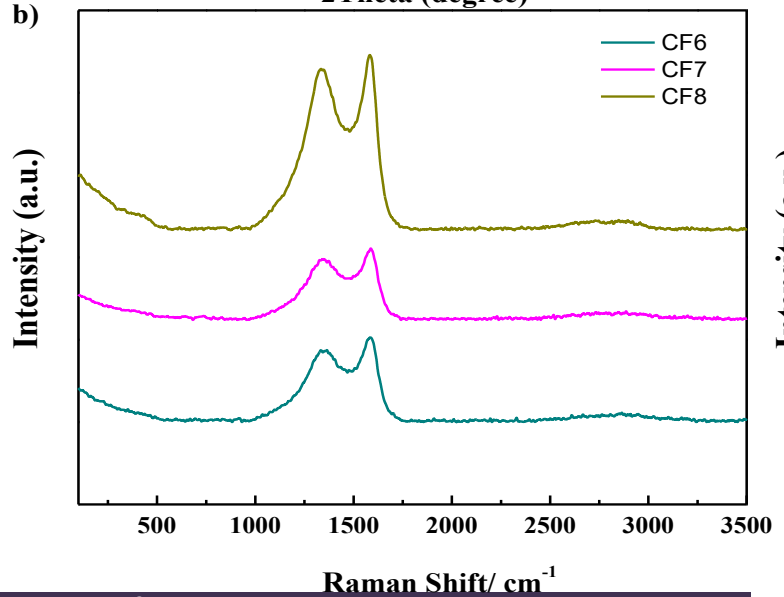
XRD patterns and Raman spectra

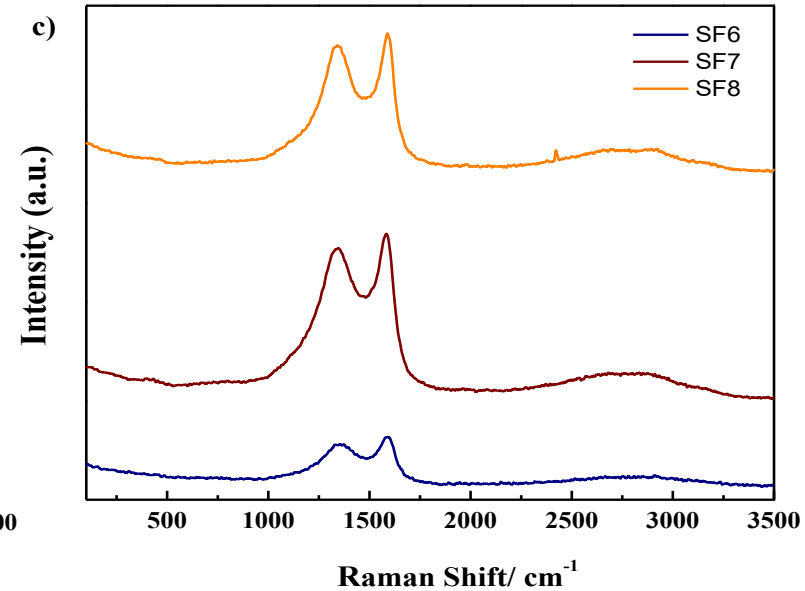




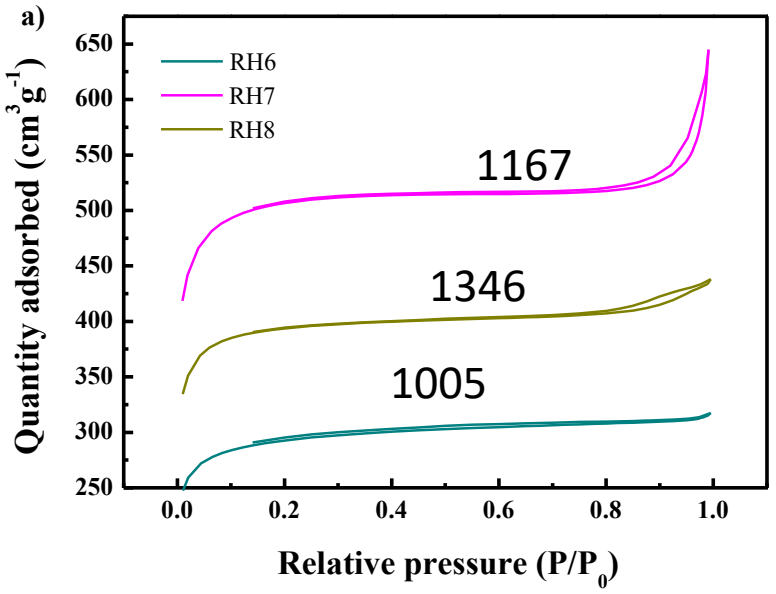


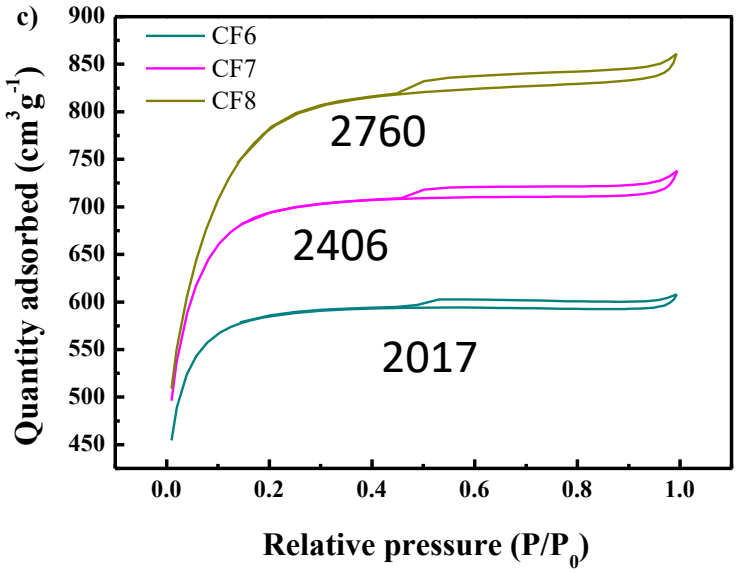


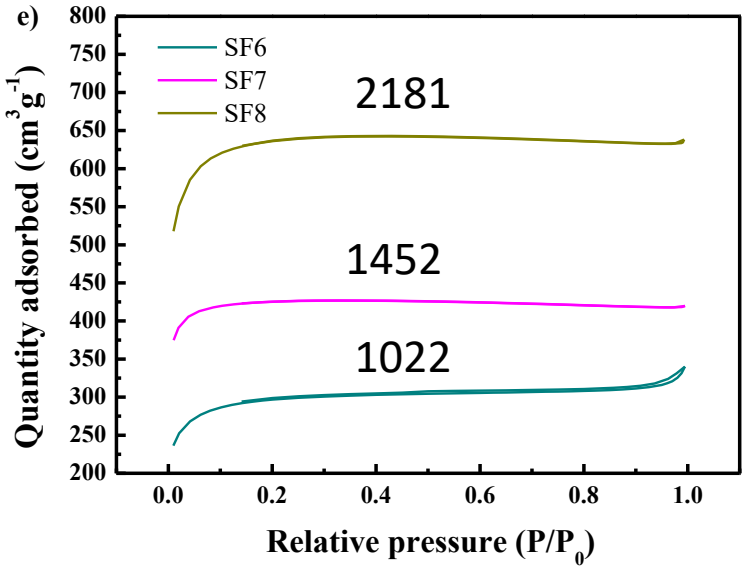


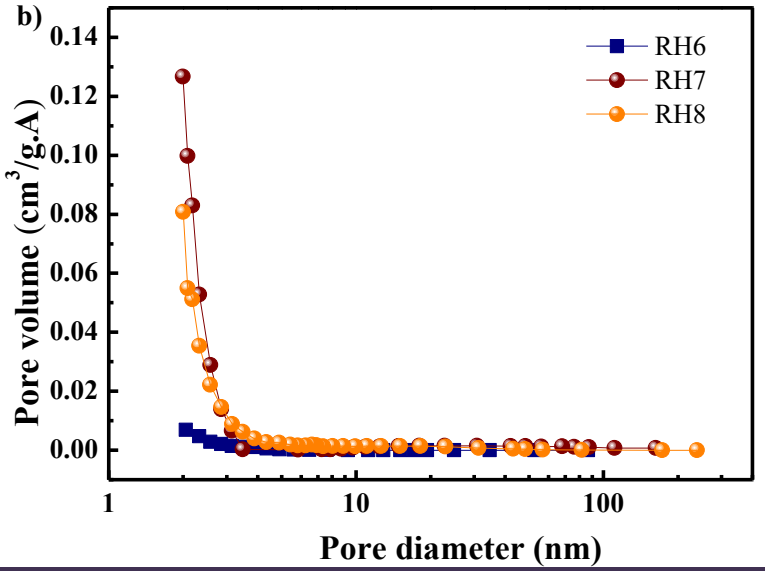


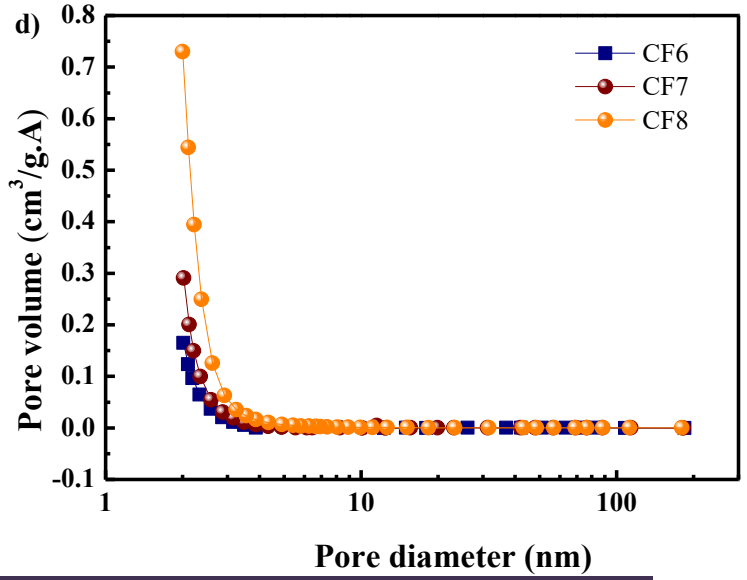
BET and pore size distribution

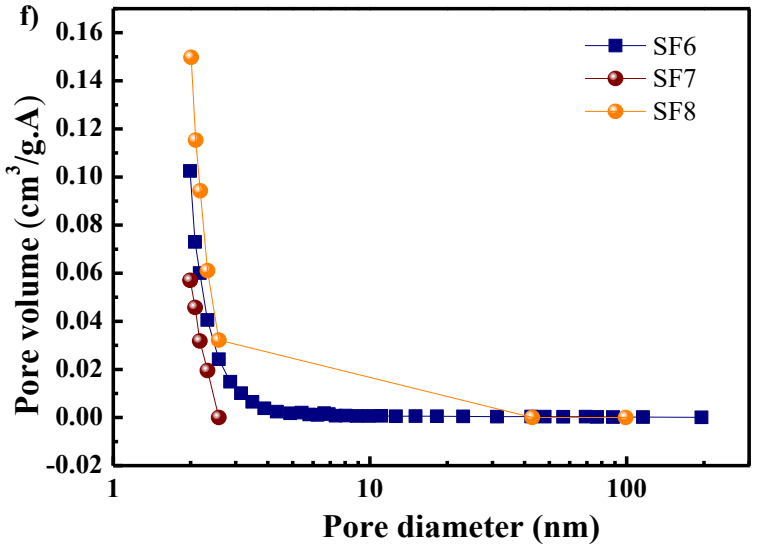










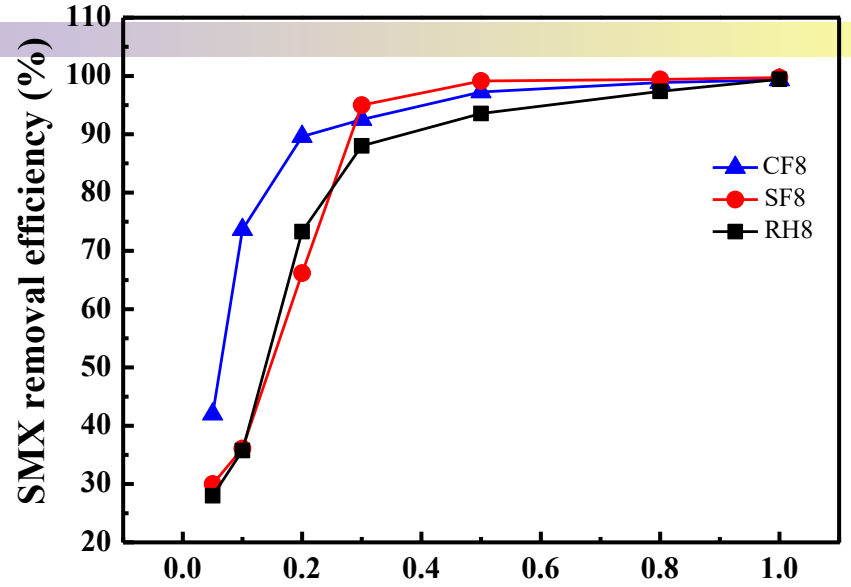


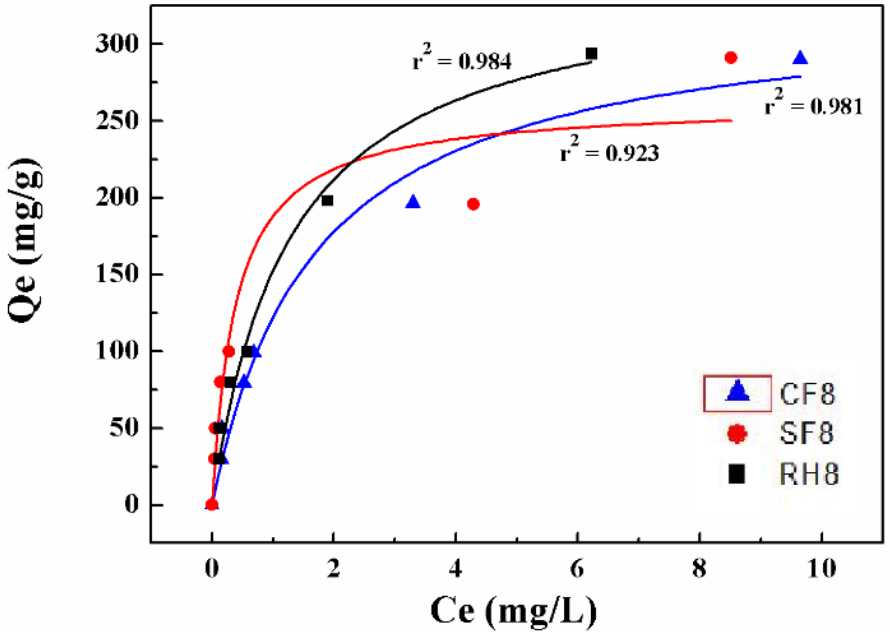
Adsorption of SMX over biochars

- SMX: 100 mg/L

	Langmuirian			
	q_{max}	b	R_L	r^2
CF8	**333**	0.63	0.050	0.983
SF8	**285**	1.75	0.018	0.947
RH8	**344**	0.85	0.038	0.987

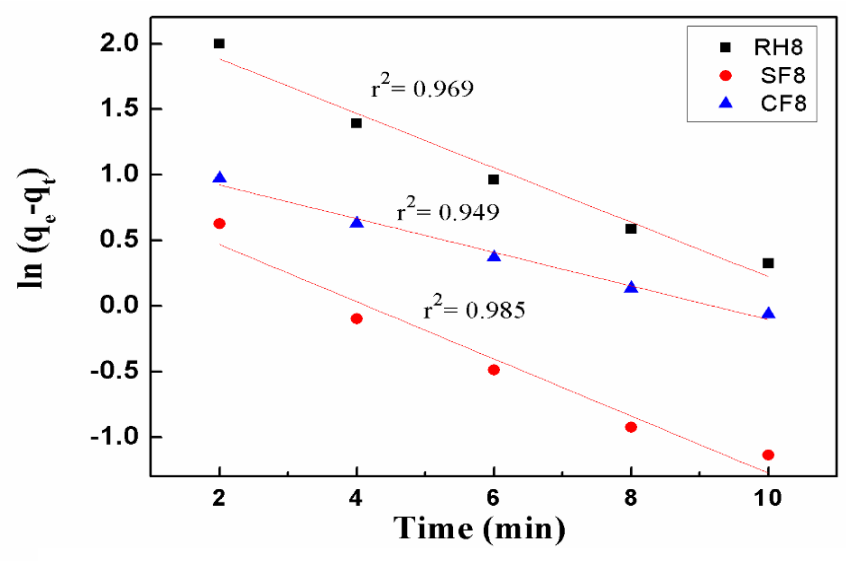
	Freundlich		
	K_F	1/n	r^2
CF8	103.7	0.50	0.939
SF8	131.9	0.37	0.926
RH8	126.8	0.53	0.936



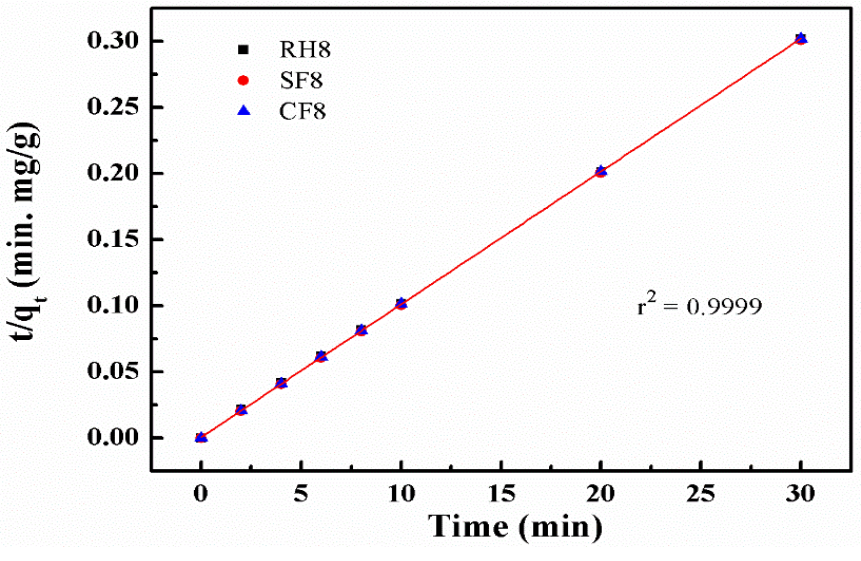


Adsorption kinetics

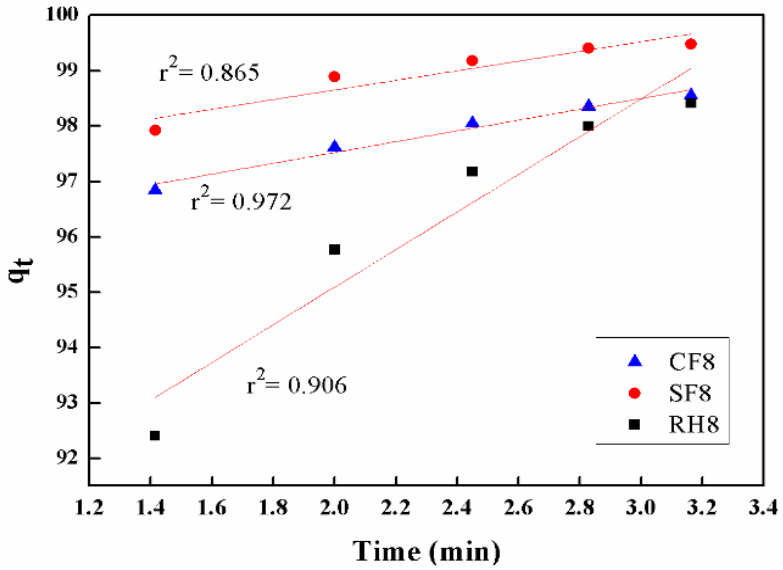
Pseudo-1st kinetic



Pseudo-2nd kinetic

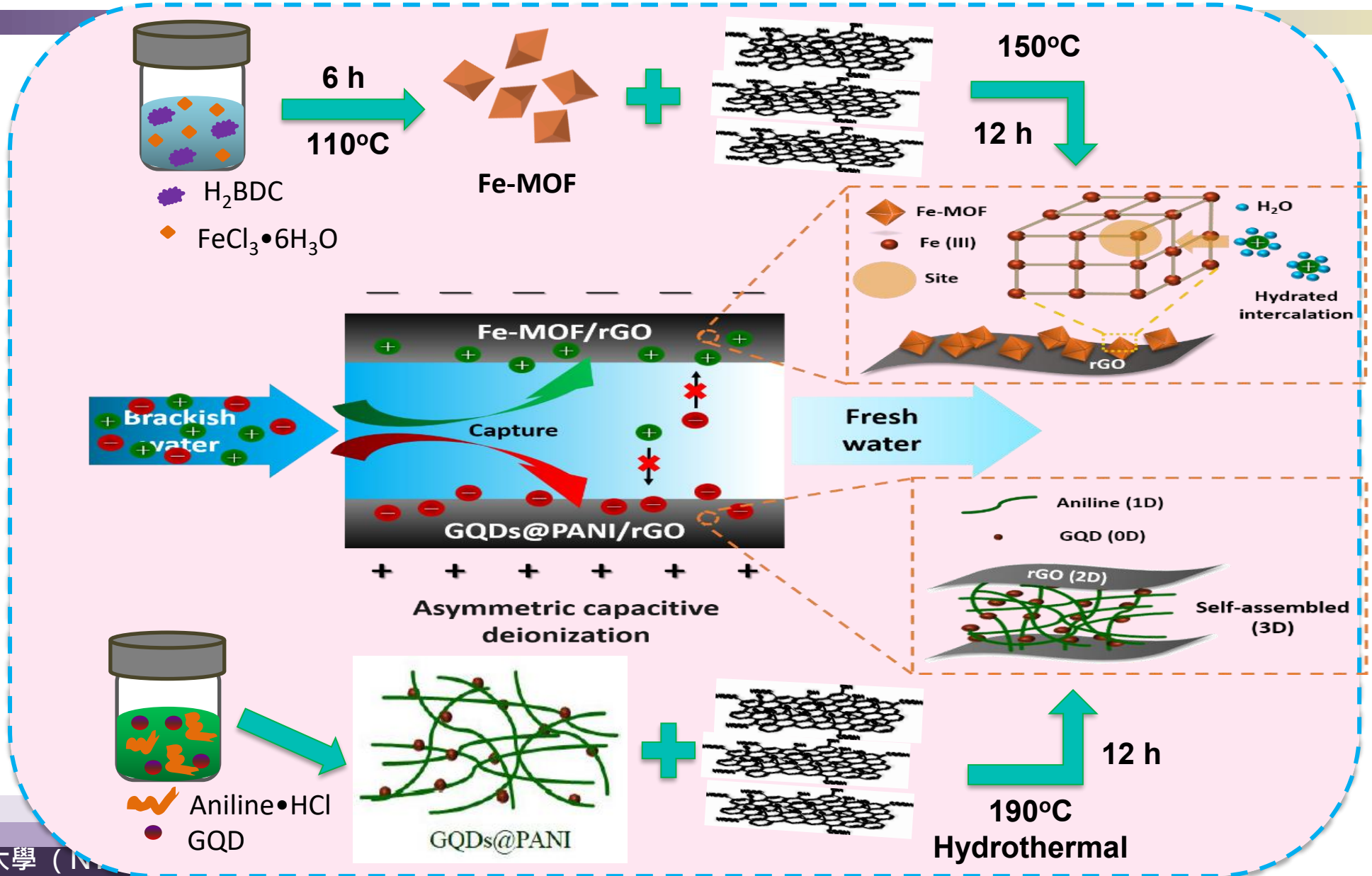


Intra-particle diffusion



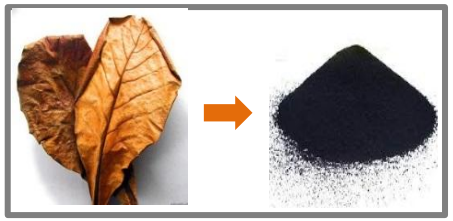
	$q_{e,exp}$ (mg/g)	q_e (mg/g)	k_2 (g mg^{-1} min^{-1})	r^2
Pseudo-second-order				
CF8	99.3	99.5	0.163	0.999
SF8	99.7	99.8	0.356	1.00
RH8	99.4	99.8	0.081	0.999

Design of CDI for Cr(VI) removal



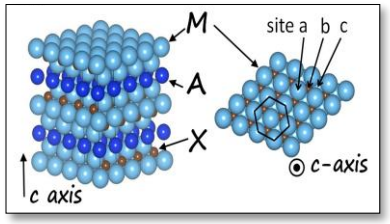
Asymmetric CDI for Cr(VI) removal

Biochar (Badam tree leaves)

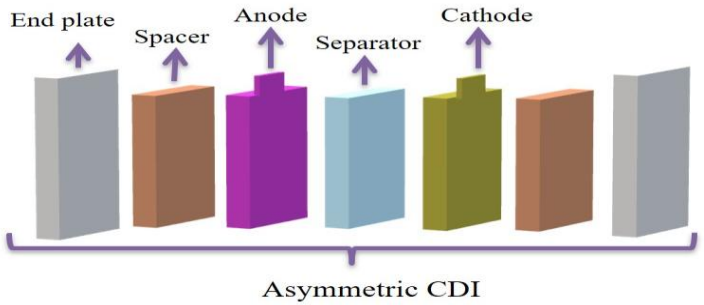


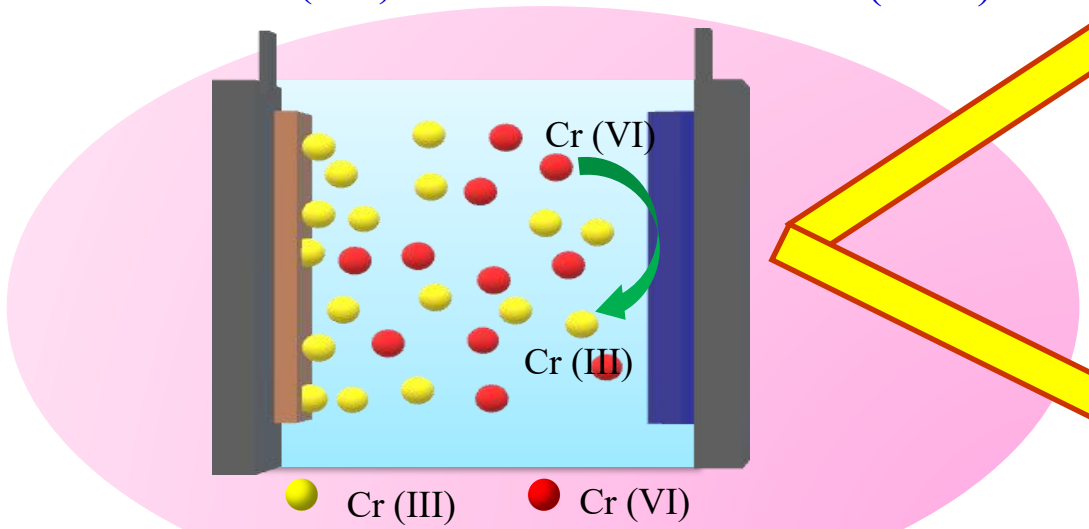
Anode (AB)

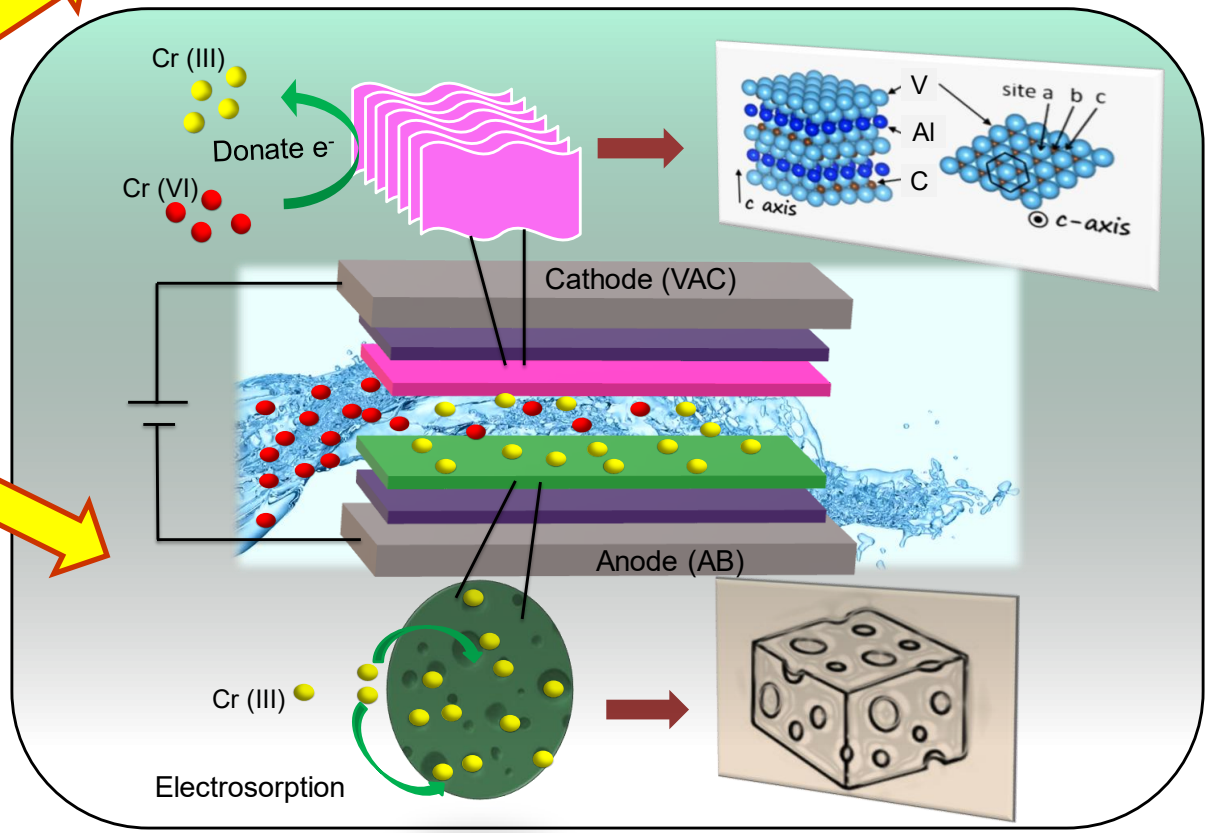
V_2AlC-OH



Cathode (VAC)



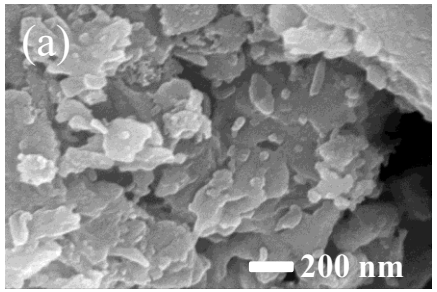


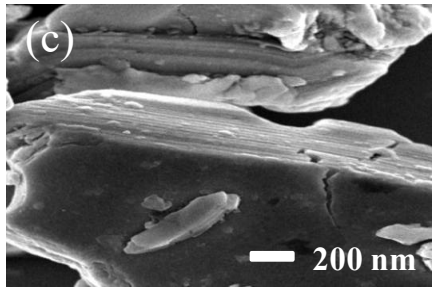


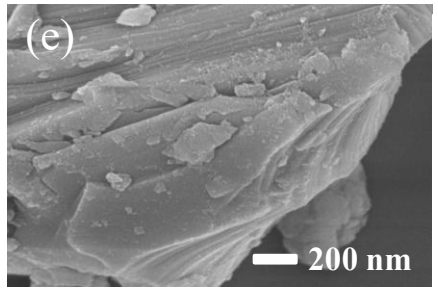
$$Cr_2O_7^{2-}(aq) + 7H_2O + 6\,e^- \rightarrow 2\,Cr^{3+}(aq) + 14\,OH^-$$

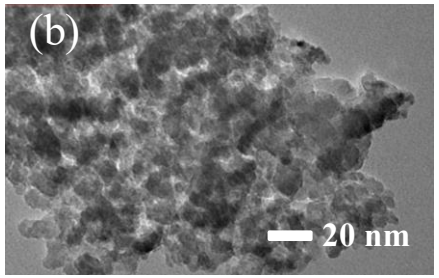
Nguyen et al., Chem. Eng. J. 475 (2023) 146439

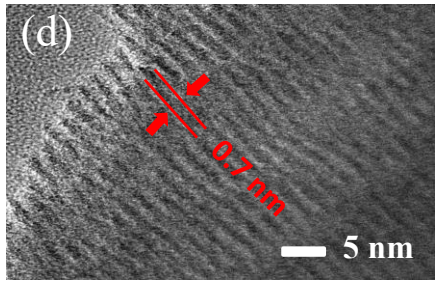
SEM/TEM and XPS spectra

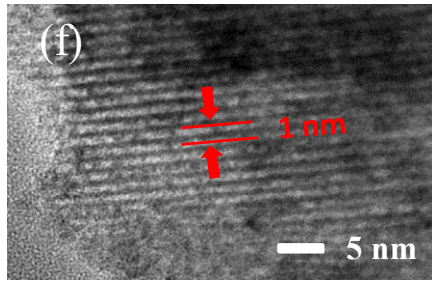


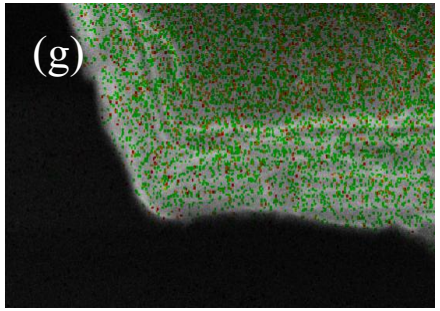






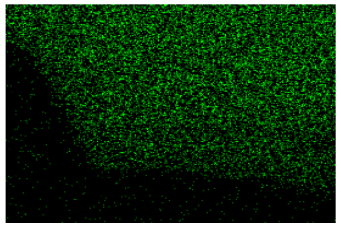


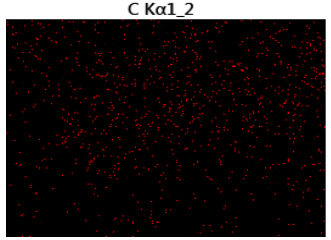


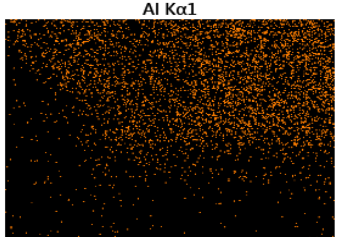


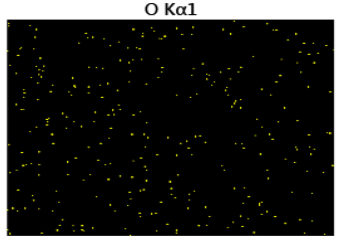


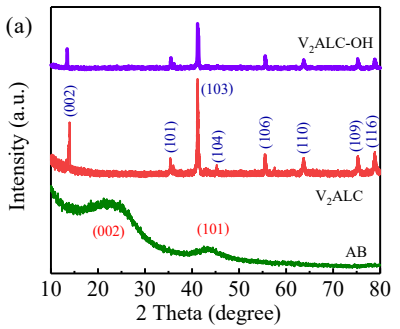
Element	Wt (%)
V	54.3
C	23.9
Al	11.2
O	10.6

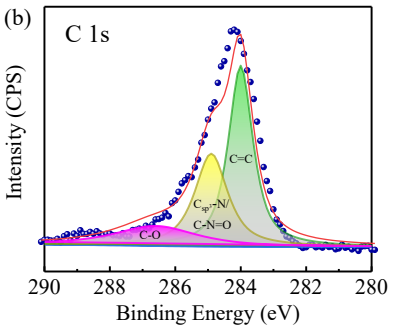


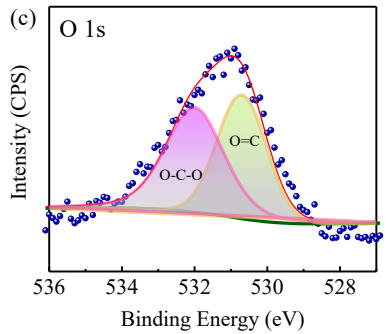


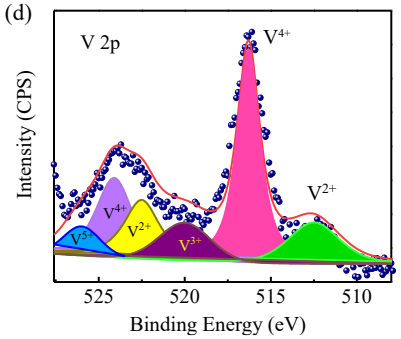


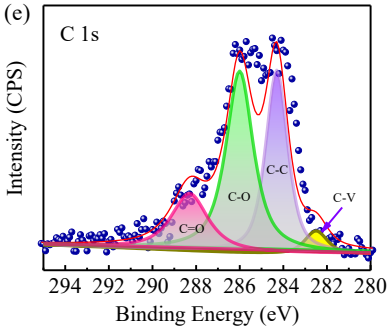


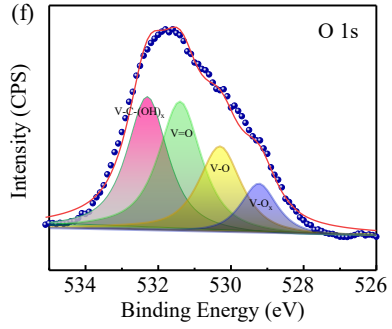


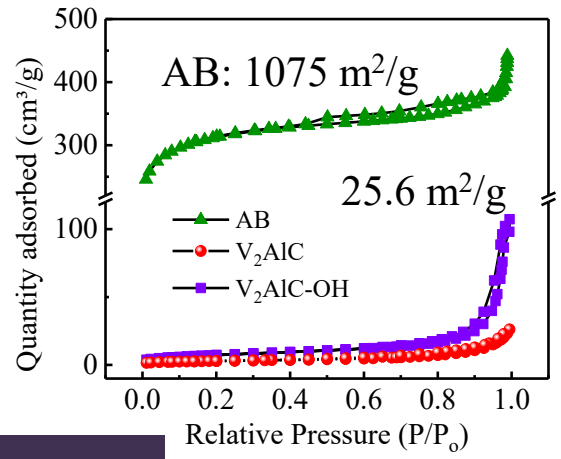


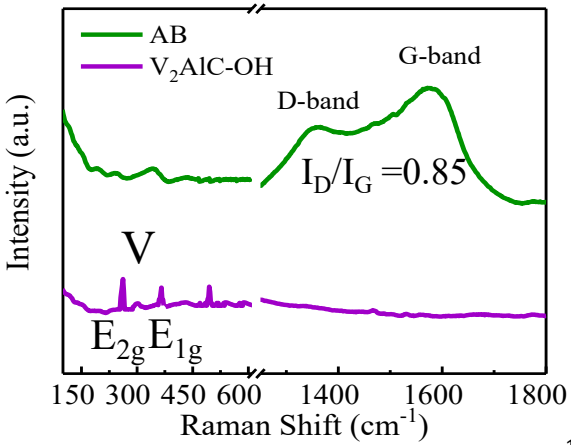






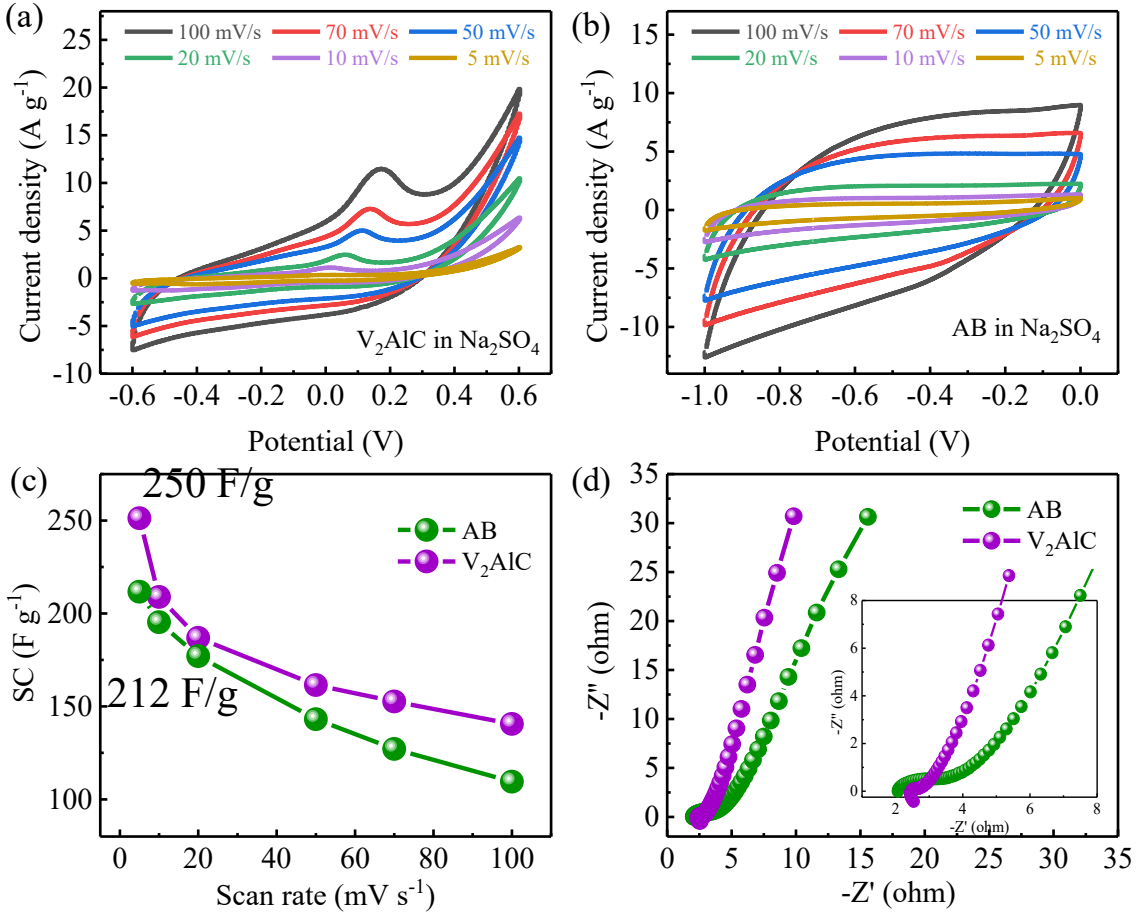






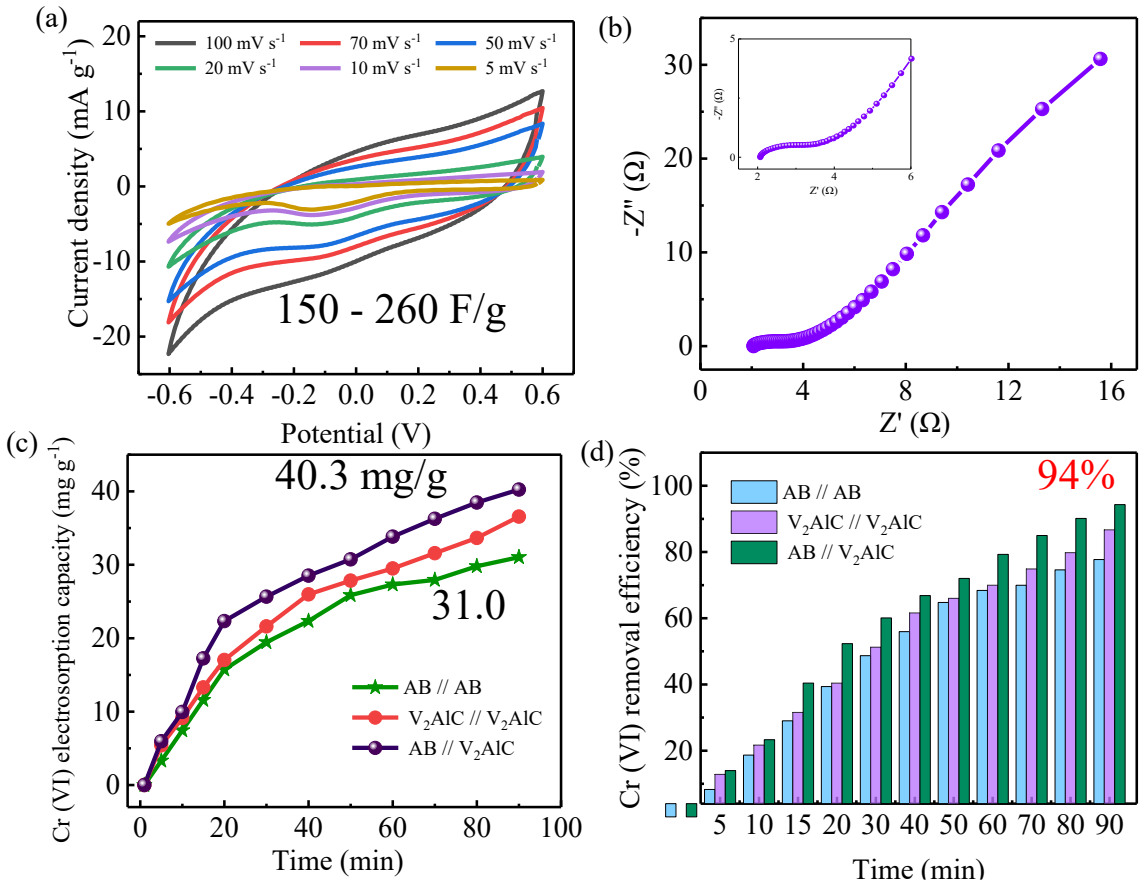
Electrochemical performance of AB/V_2AlC

CV curves of V_2AlC and AB



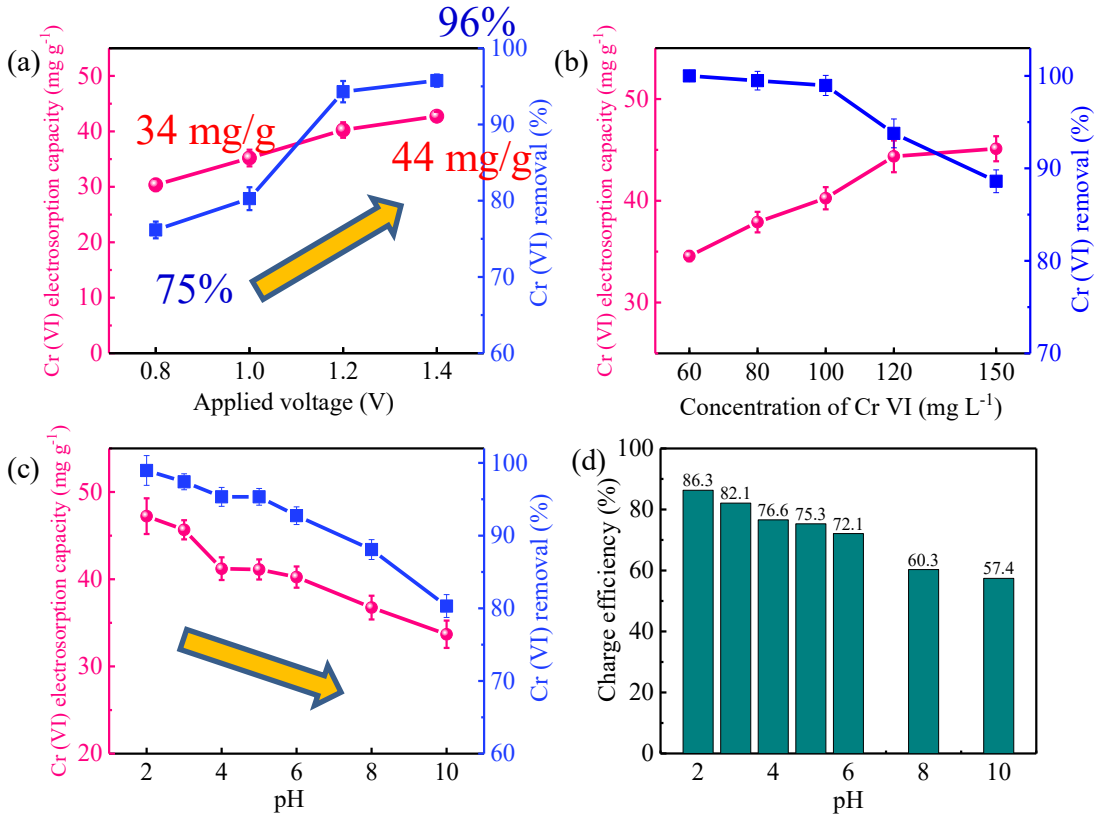
Low resistance of *ca.* 2 Ω

Asymmetric device of AB//V_2AlC



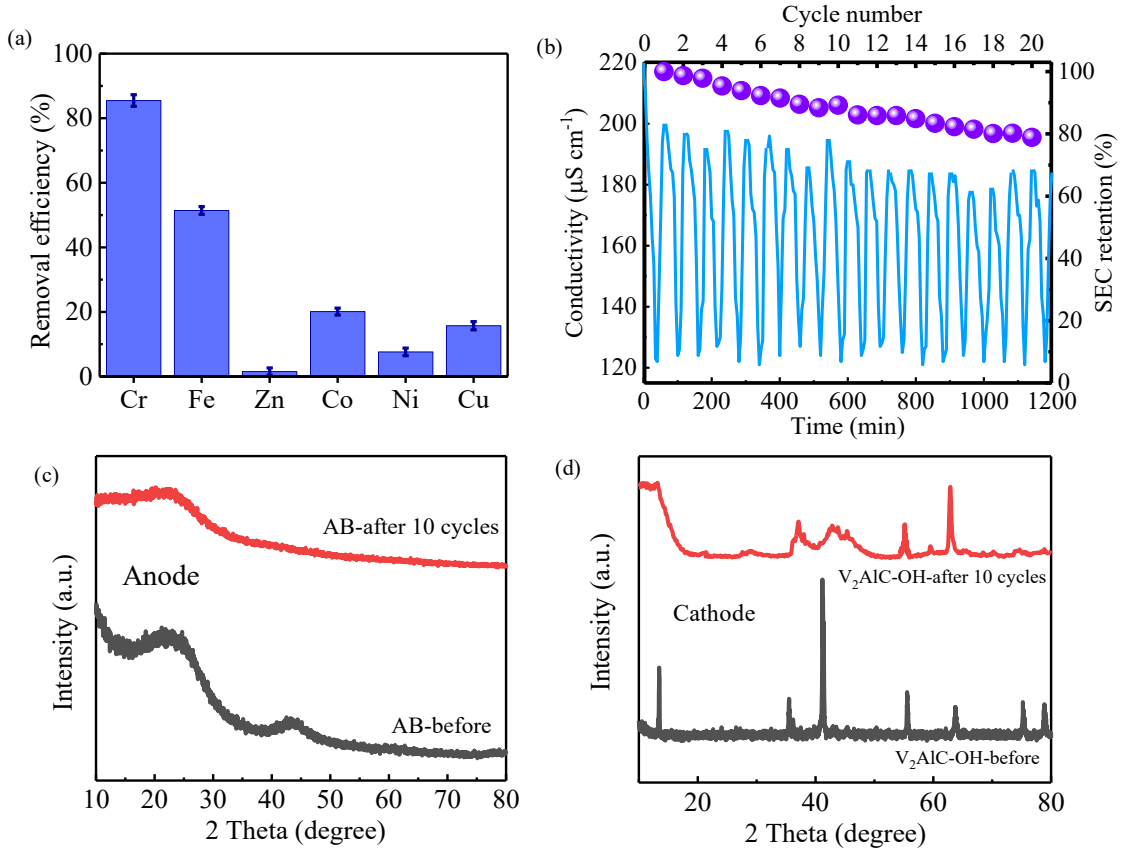
Nguyen et al., Chem. Eng. J. 475 (2023) 146439

Cr(VI) removal by AB/V_2AlC



$$Cr_2O_7^{2-}(aq) + H_2O \rightarrow 2HCrO_4^-$$
$$HCrO_4^- + H^+ + 3e^- \rightarrow CrO_3{}^{3-} + H_2O$$
$$HCrO_4^- + 4H^+ + 2e^- \rightarrow [Cr(OH)_6]^{3-} + 2H_2O$$

Putting 100 mg/L metal ion together in a solution
Cr: 86%, Fe^{3+}: 51%, Co: 20%, Cu: 18%



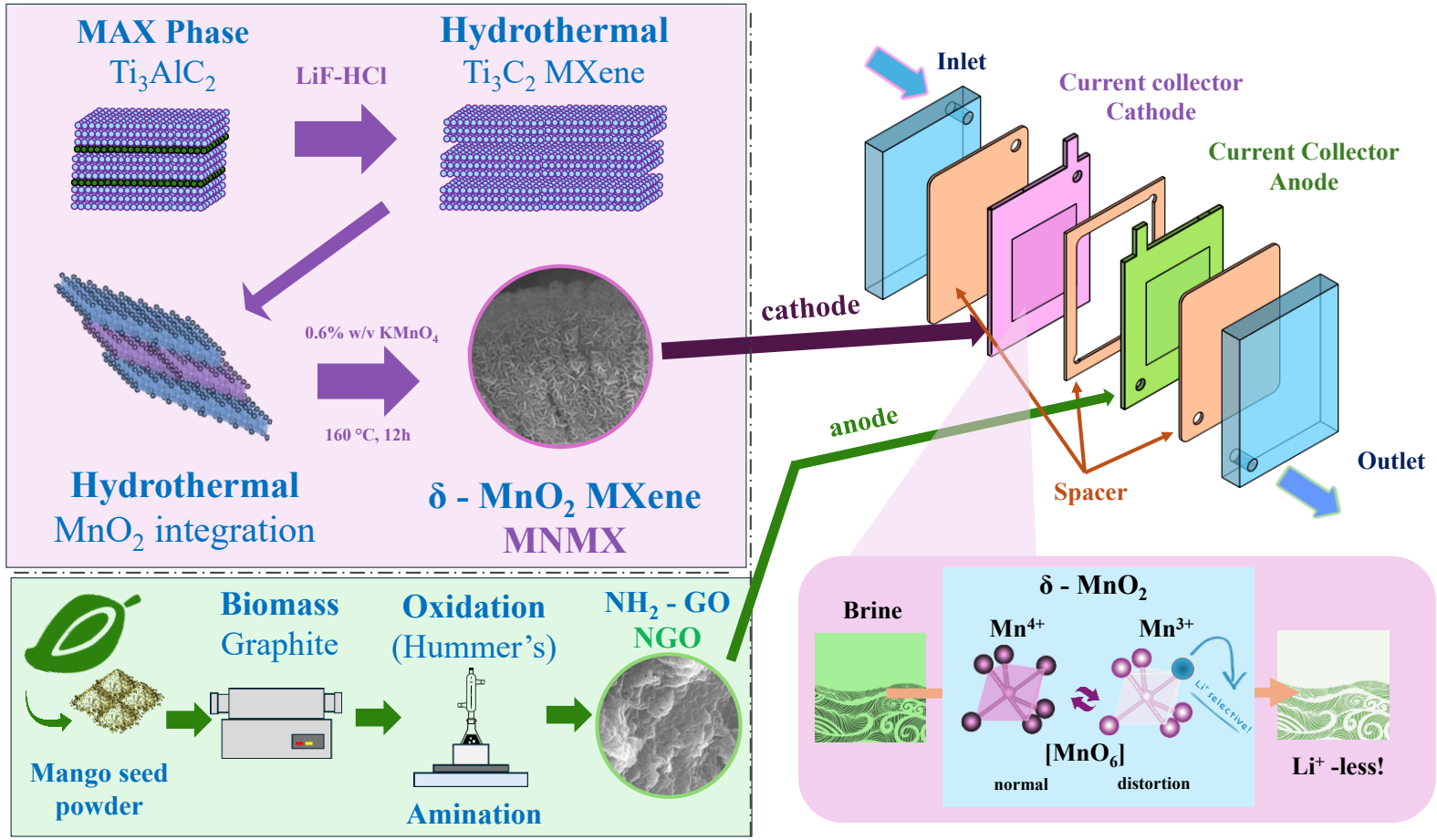
Nguyen et al., Chem. Eng. J. 475 (2023) 146439

Biochar-based nanocomposites for Environment – Resource Recovery

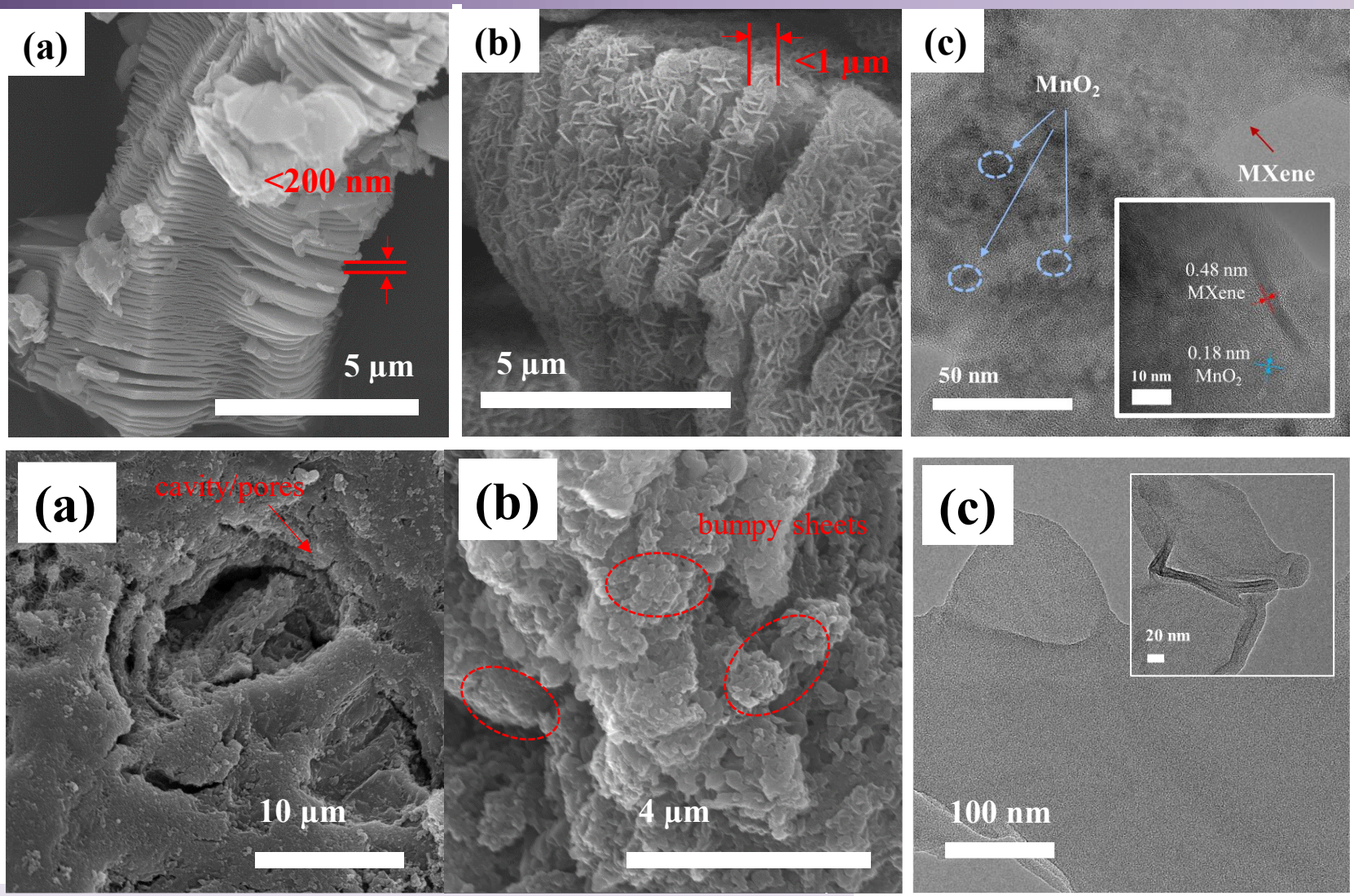
Asymmetric CDI for Li^+ recovery

- Asymmetric CDI
  - Anode: NH_2-biochar (Mango seed powder)
  - Cathode:
- **Li selectivity**

$$\rho_i^{Li} = \frac{\left(\frac{C_0^{Li} - C_t^{Li}}{C_0^{Li}}\right)}{\left(\frac{C_0^{i} - C_t^{i}}{C_0^{i}}\right)}$$



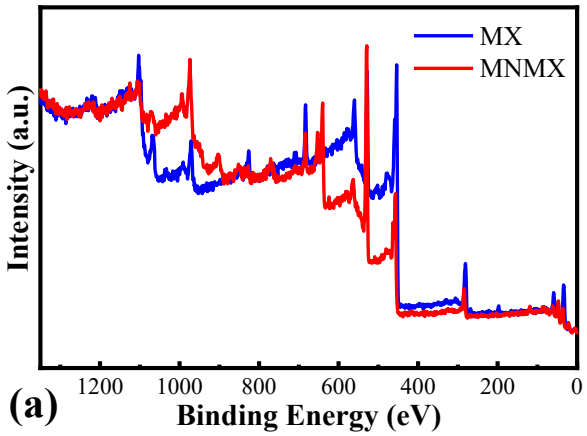
SEM and TEM of MNMX and Biochars

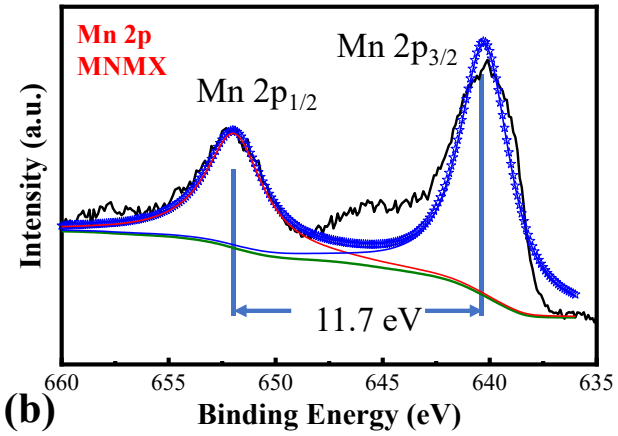


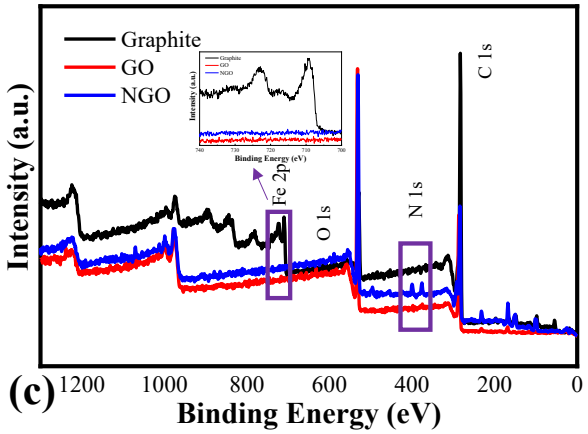
δ-MnO_2-MXene

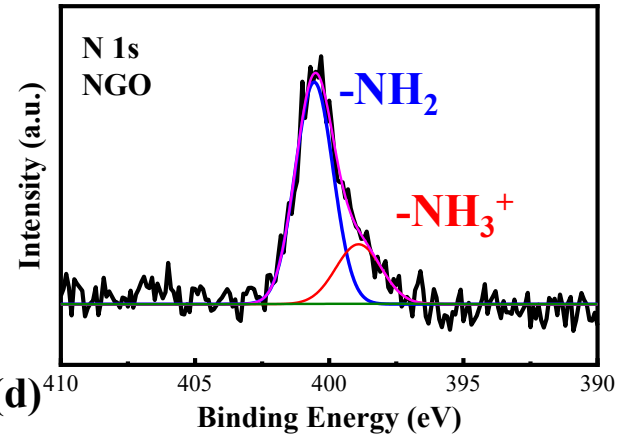
NH_2-Biochar, and then converted to graphene oxide-like activated biochar

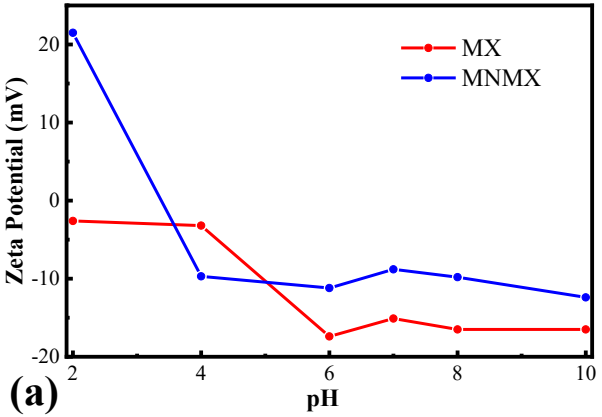
Surface characterization

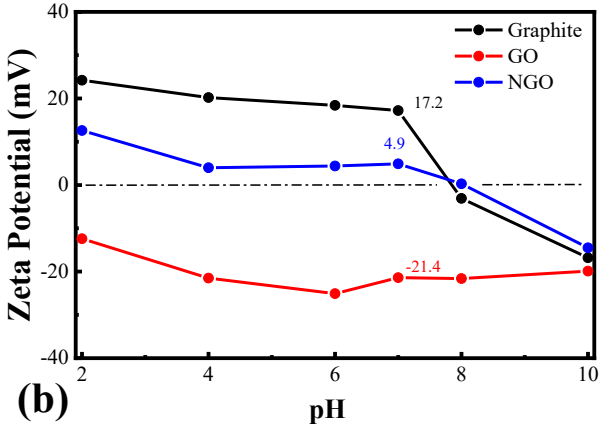


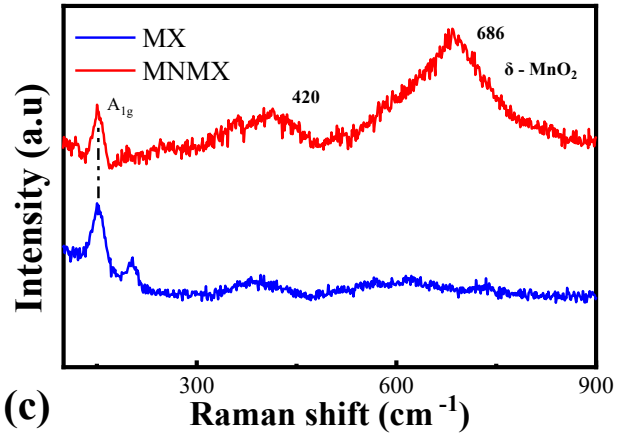


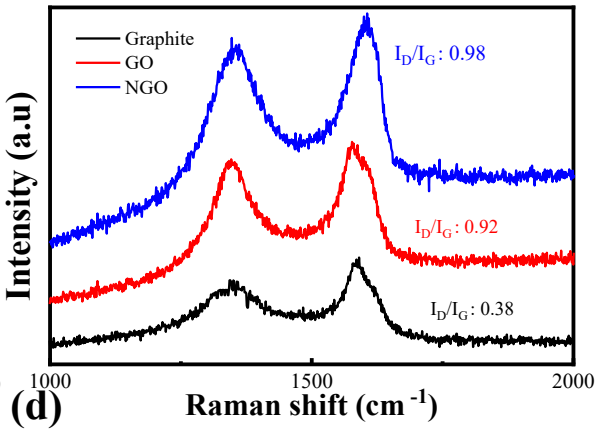




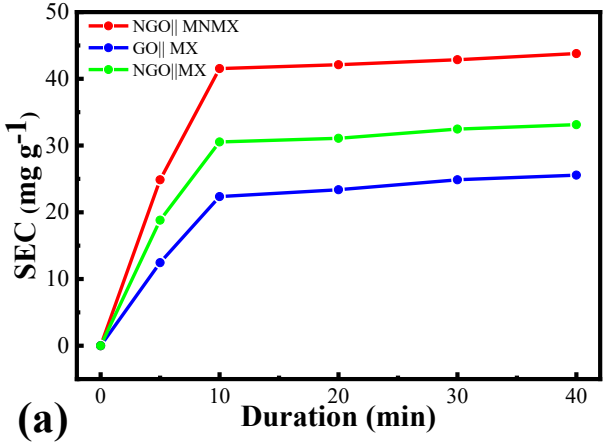


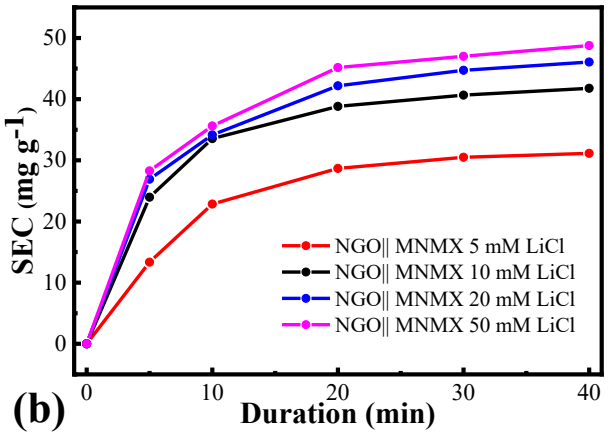


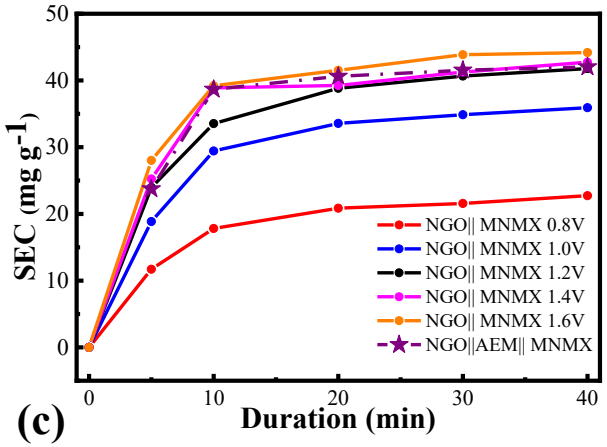


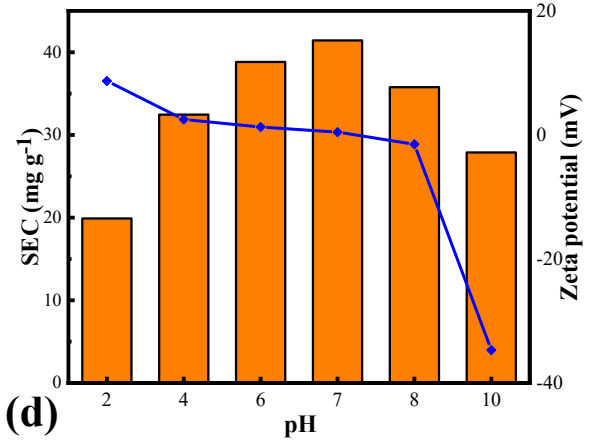


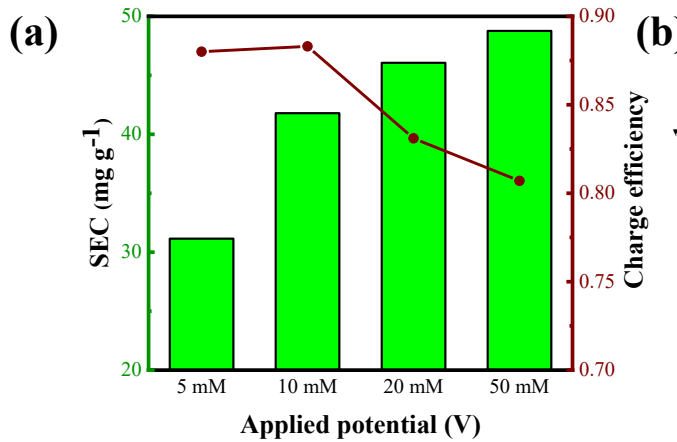
CDI performance for Li electrosorption

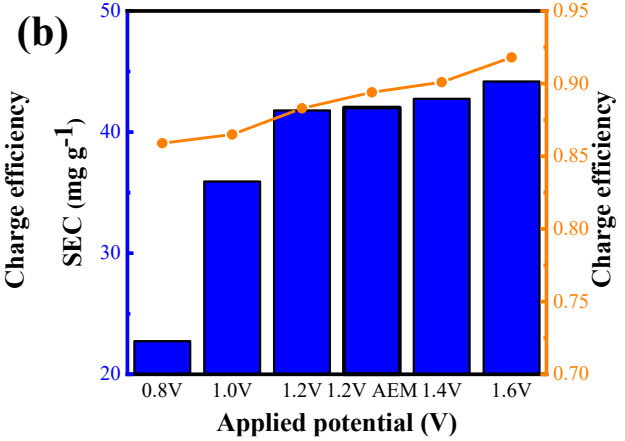


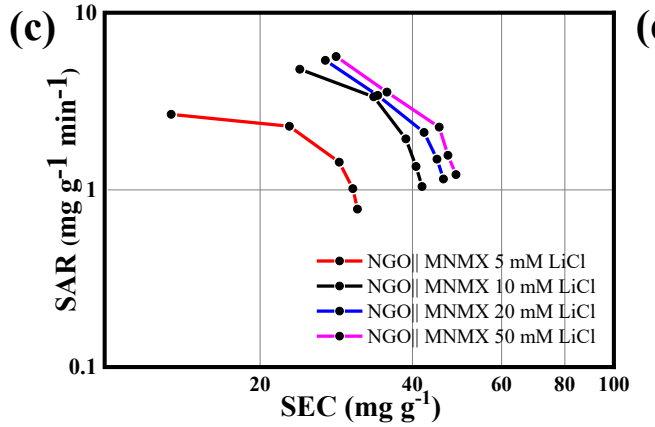


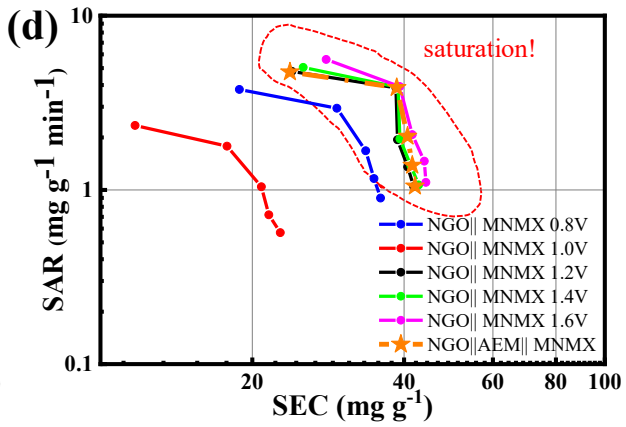










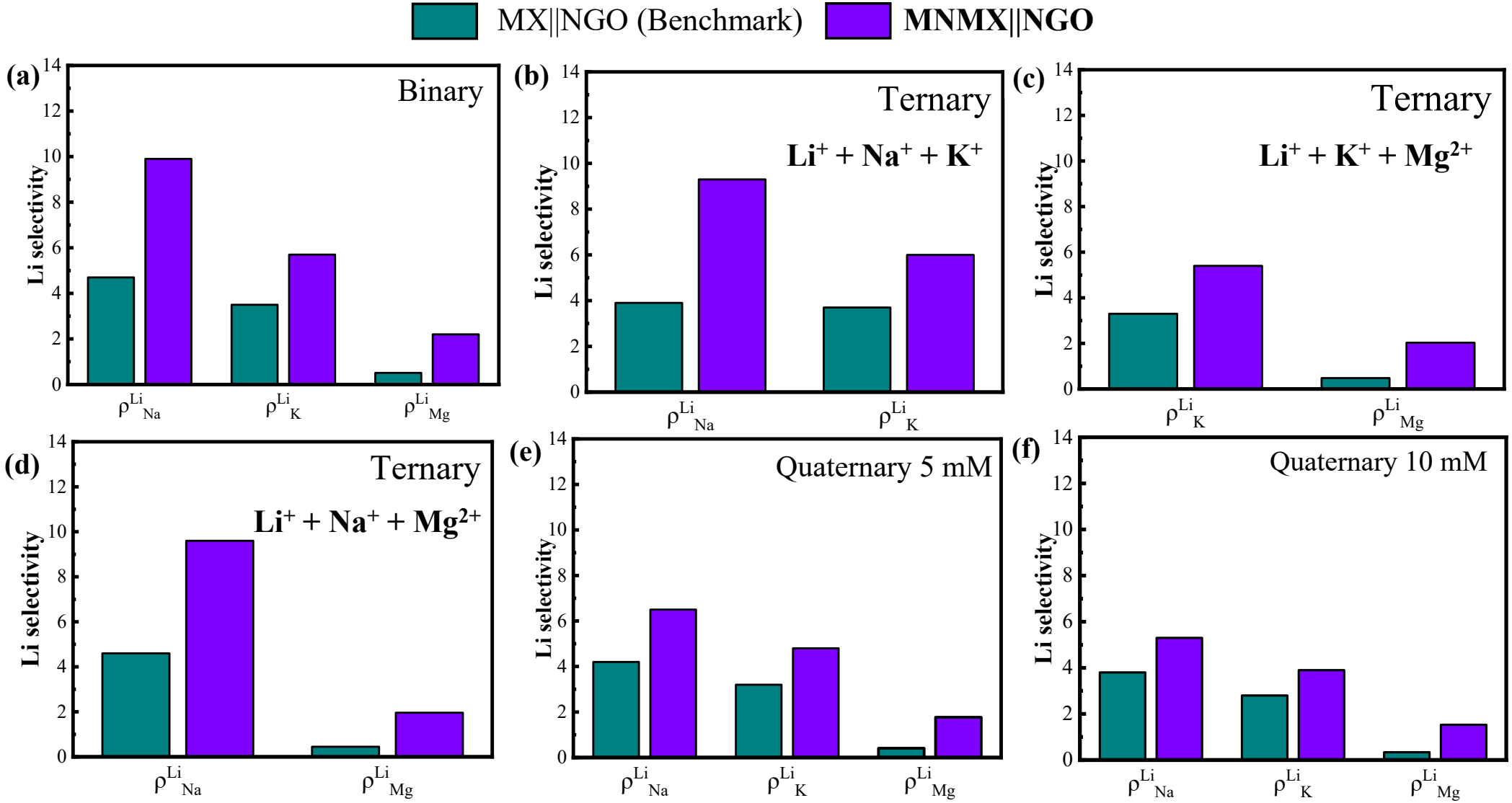


Li ion selectivity

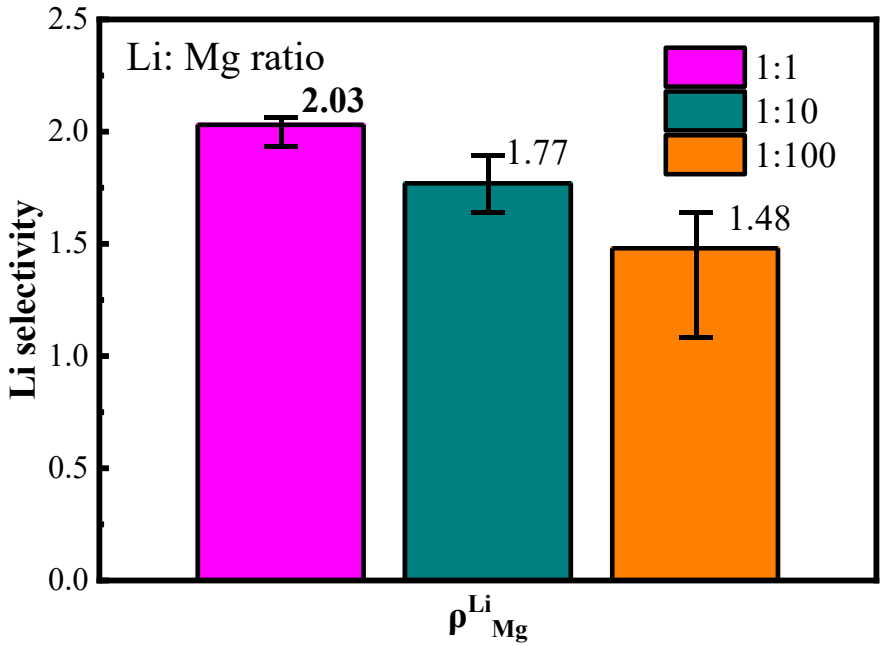
$\rho_{Mg}^{Li} = 2.2$

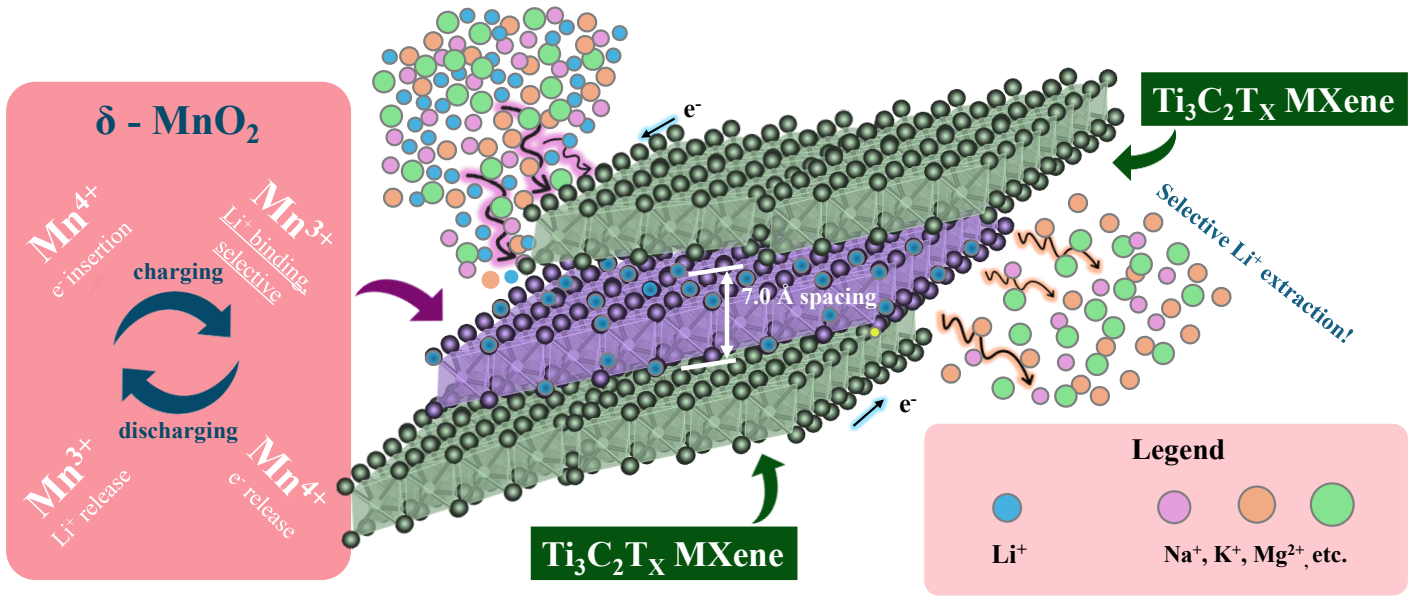
$\rho_{Na}^{Li} = 9.8$

$\rho_{K}^{Li} = 5.8$



Selectivity and possible mechanism





Cation	Hydrated radius (Å)	Hydration energy (kJ mol^{-1})
Li^+	3.82	-515
Na^+	3.58	-422.6
K^+	3.31	-338.9
Mg^{2+}	4.28	-1953.9

Biochar-Based Nanocomposites for Energy Storage

Tunable Carbon Architectures from Agricultural Waste via NaOH Dry-Mixing



Trapa shell
(Water Caltrop)



Biochar



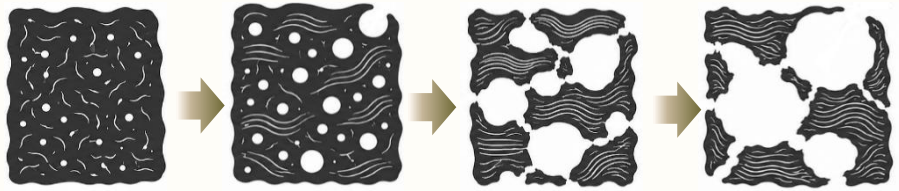
Dry mixing
With NaOH

NaOH/ Biochar ratio

Temperature

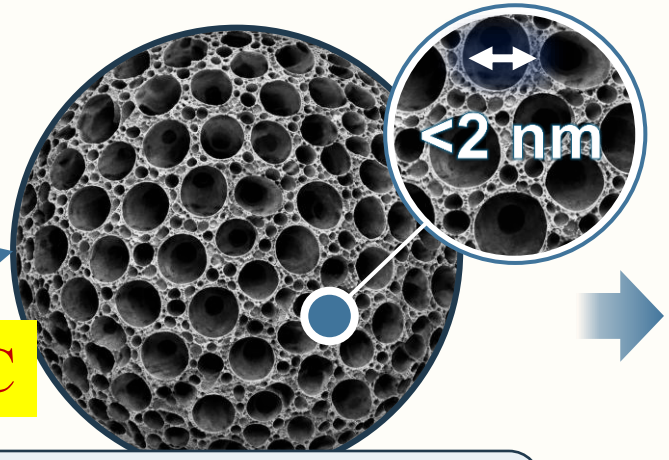
700 - 900 °C, 3:1

Critical point
of Structural transition

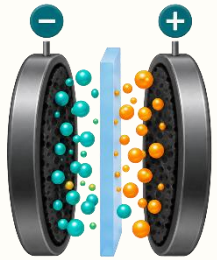


Pore creation | Pore opening | Pore widening | Wall rapture and Pore merging

800 °C

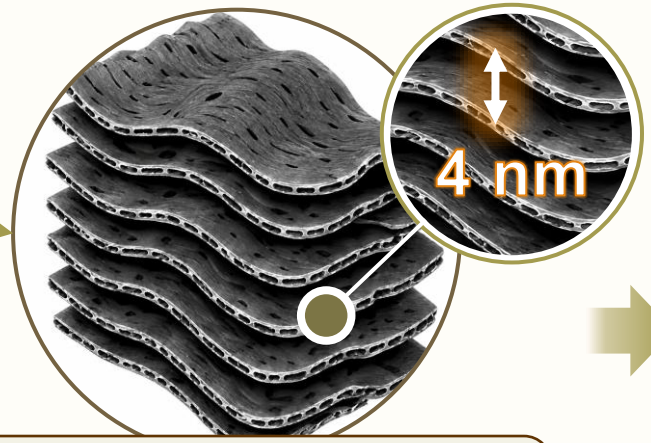


Micropore-dominated
porous carbon
2054 $m^2 g^{-1}$



Supercapacitor
with ionic electrolyte

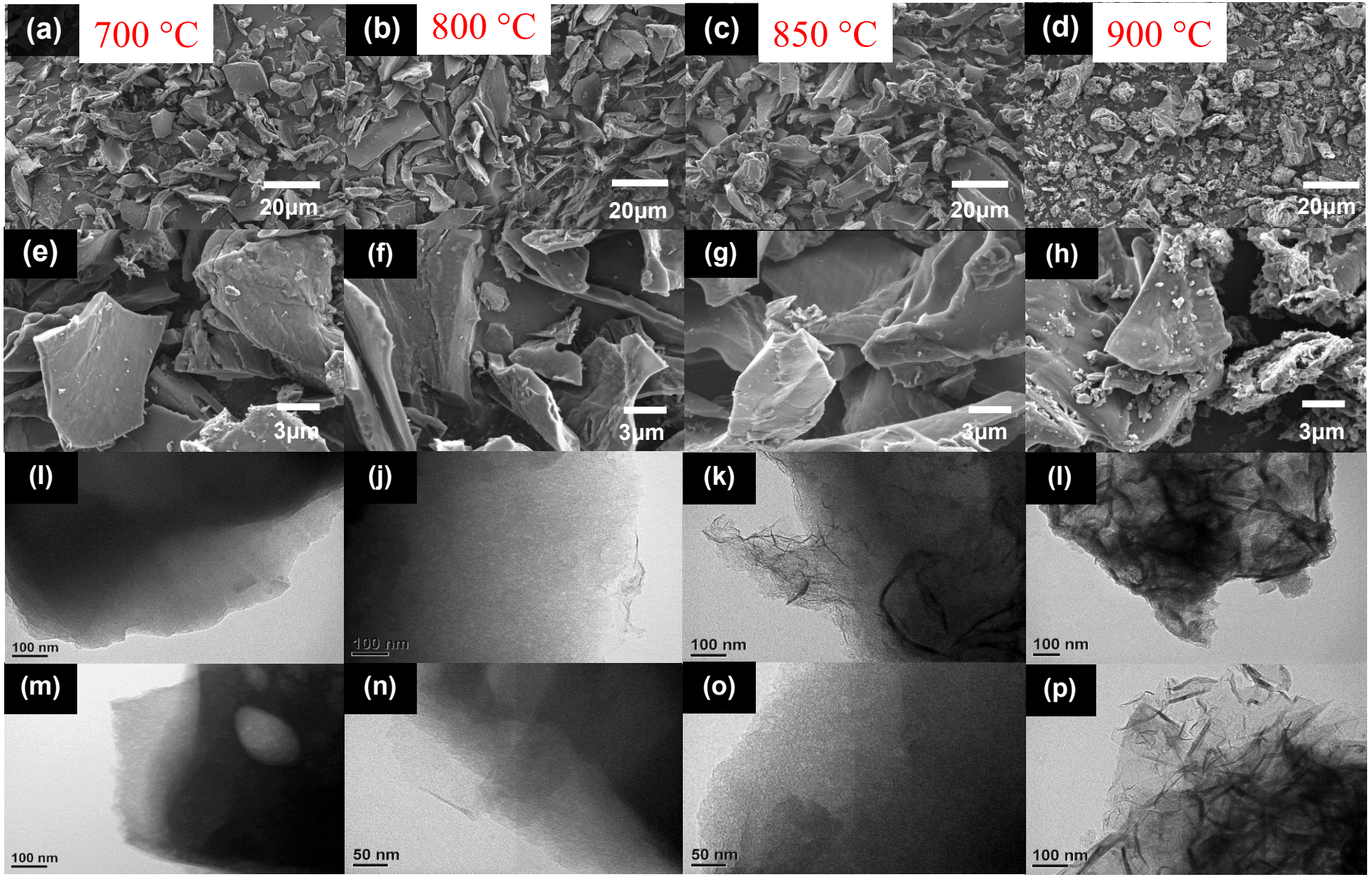
900 °C



Ordered lamellar carbon
313 mAh g^{-1} at 0.1 A g^{-1}

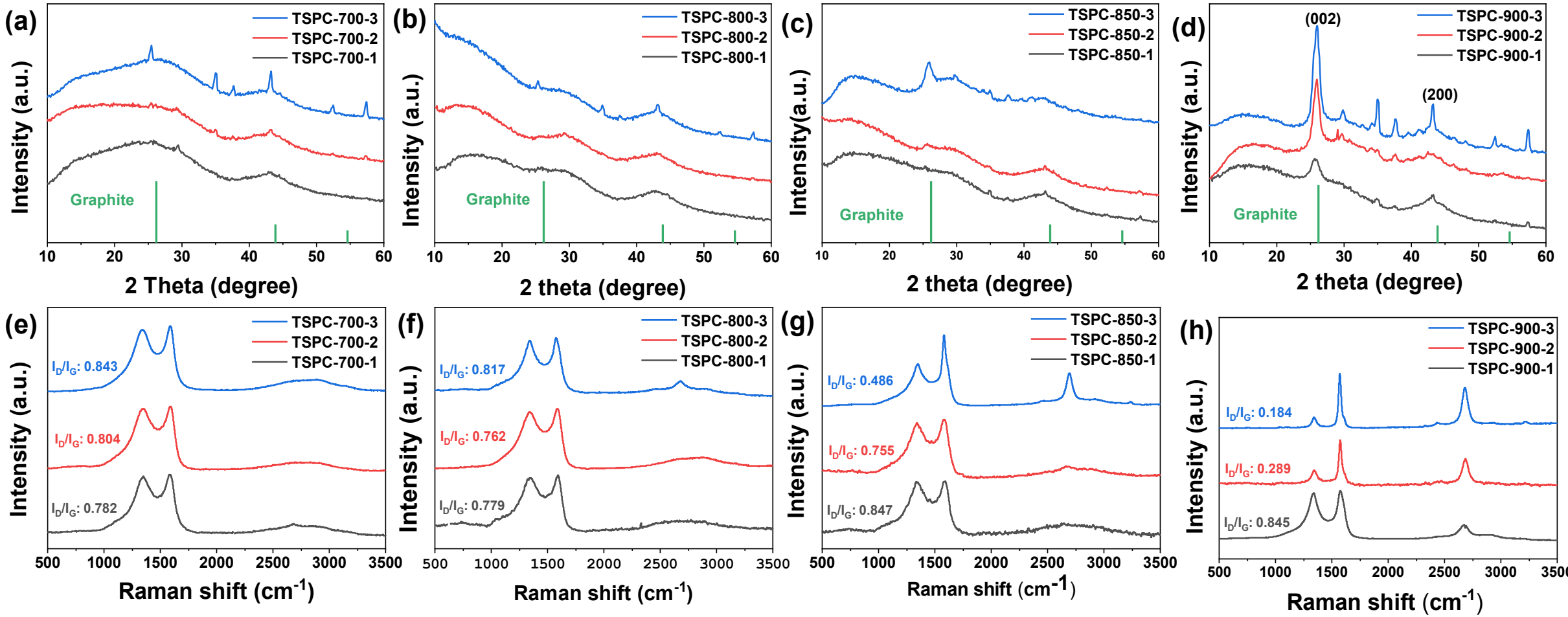


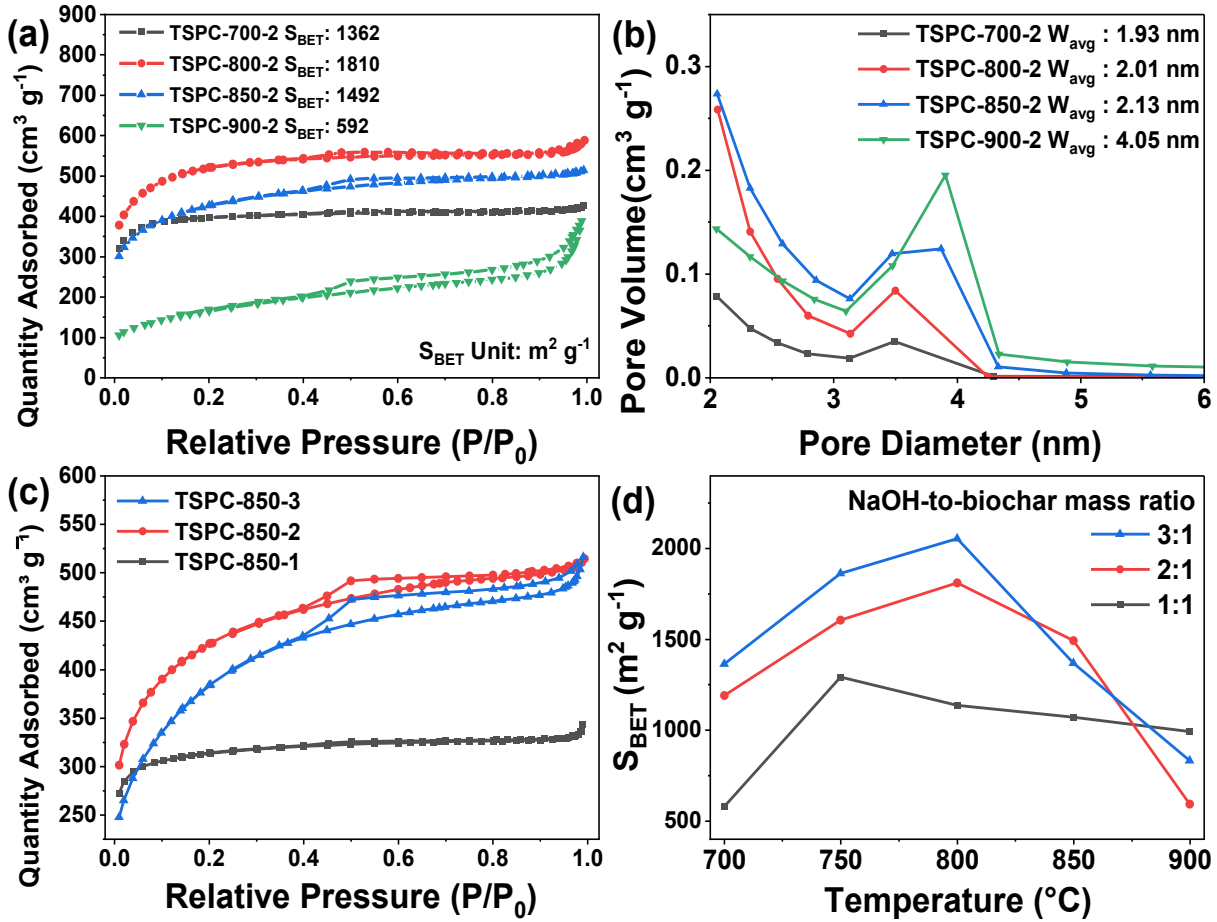
Anode of
Li-ion battery



SEM and TEM images of Trapa-shell-derived biochars at 700, 800, 850, and 900 °C

XRD patterns and Raman spectra

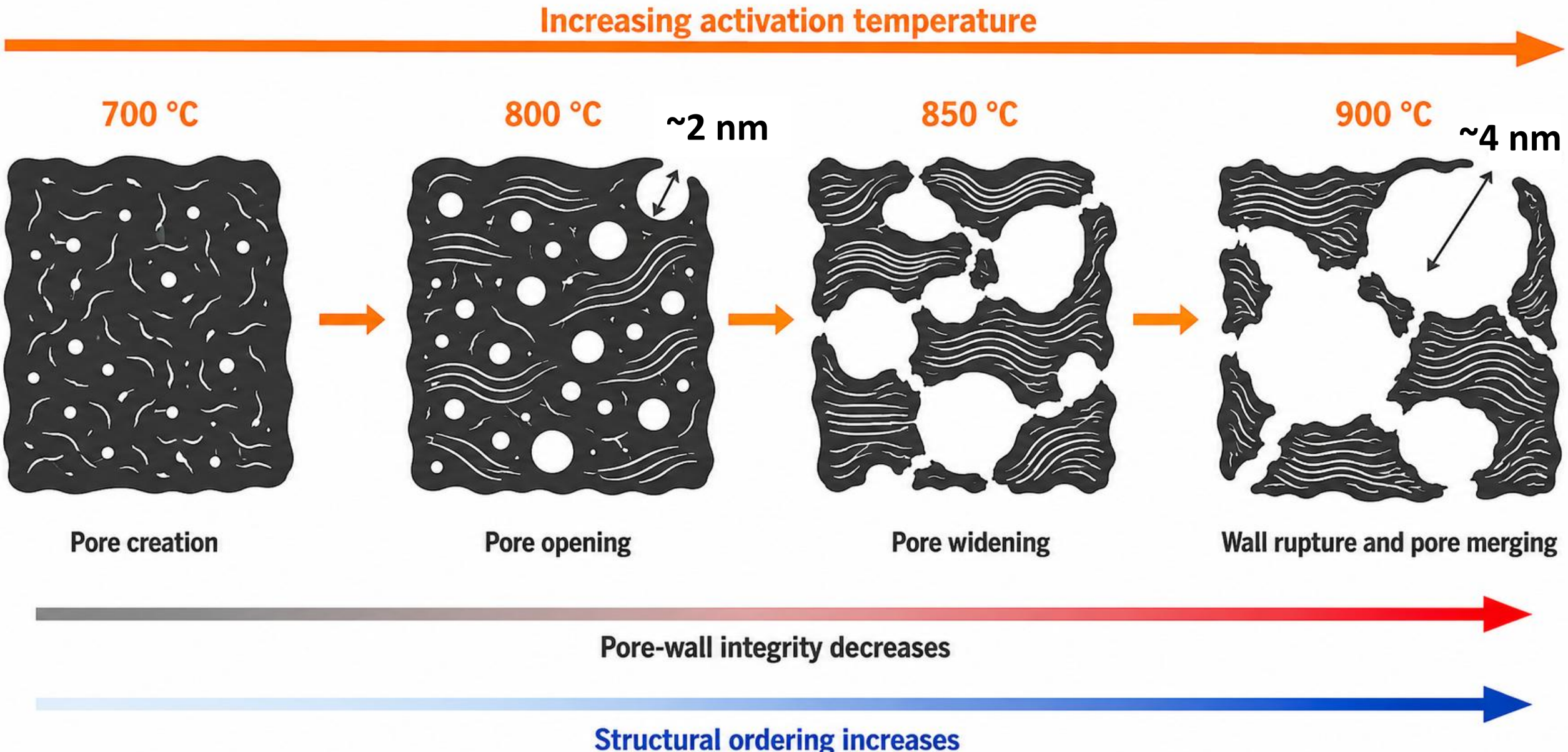




NaOH-to-TSB mass ratio	700 ˚C	800 ˚C	850 ˚C	900 ˚C
1:1	578.9	1137.5	1070.1	991.7
2:1	1362.6	1810.1	1491.6	591.7
3:1	1188.8	2054.5	1368.9	831.3

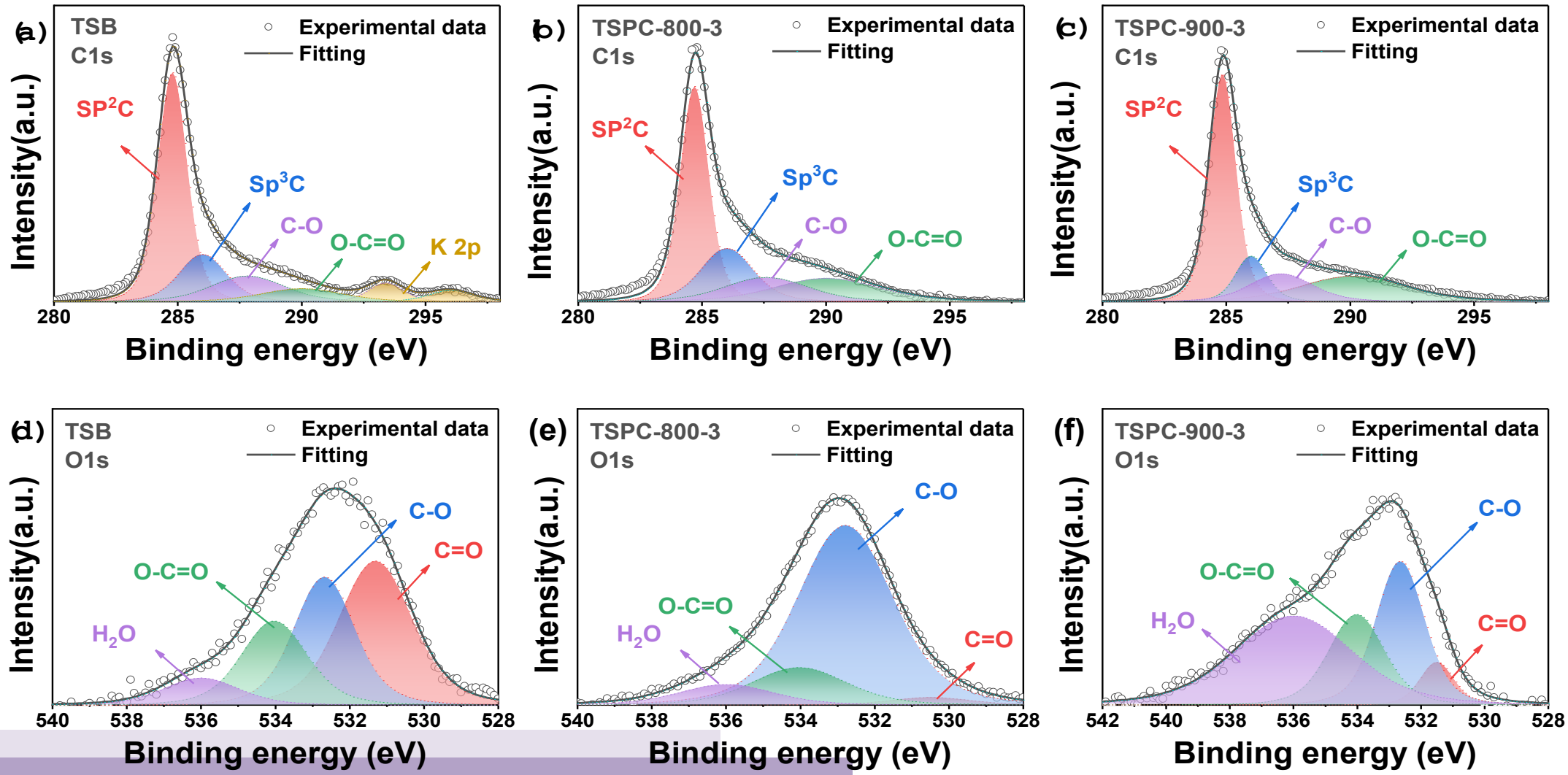
- The specific surface area of TSPC at 800 °C is optimal.
- The optimal NaOH-to-TSB ratio is 3:1

Mechanism for pore formation



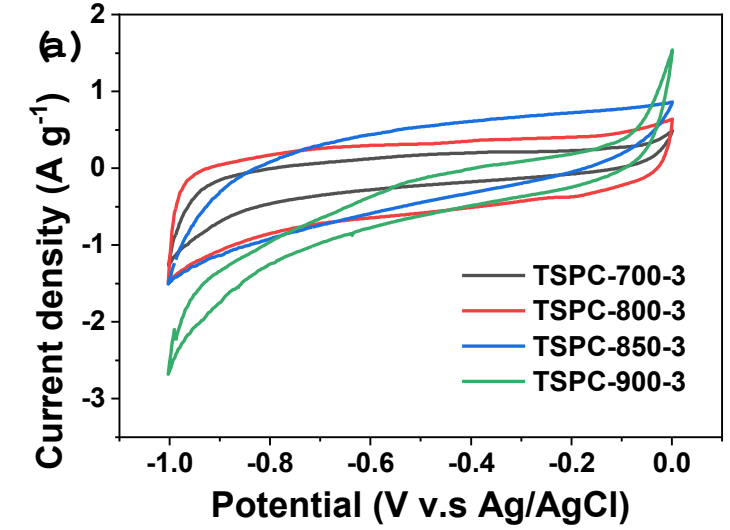
XPS spectra of Trapa at 800 and 900 °C

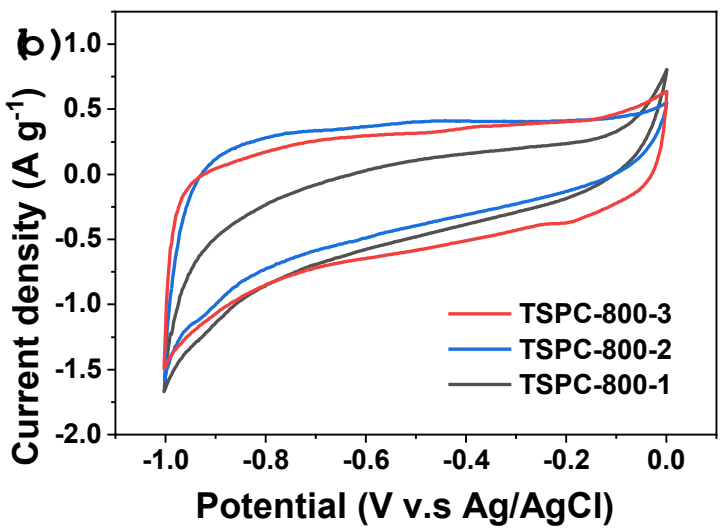
Pristine biochar | 800 °C | 900 °C

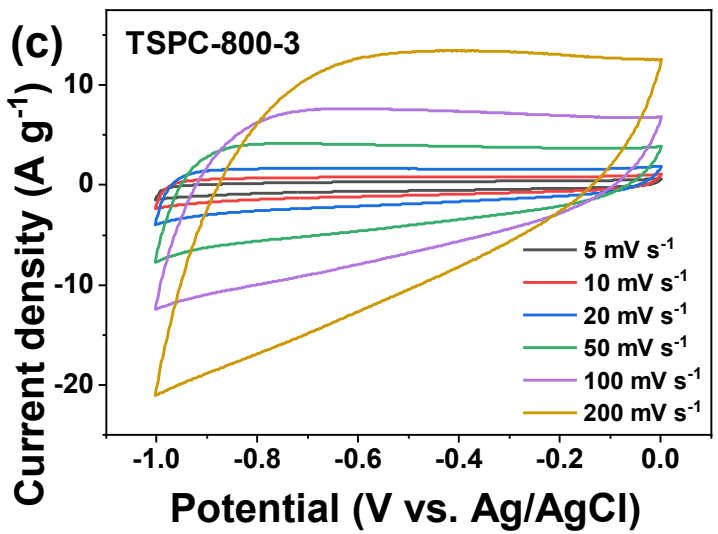


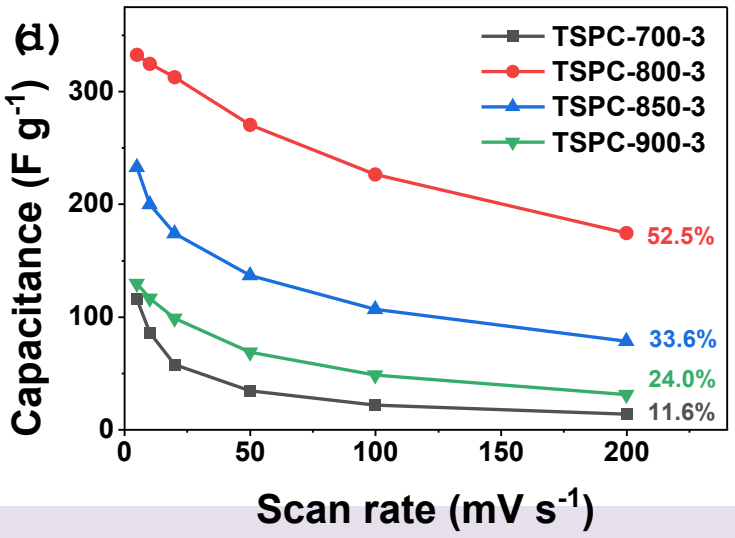
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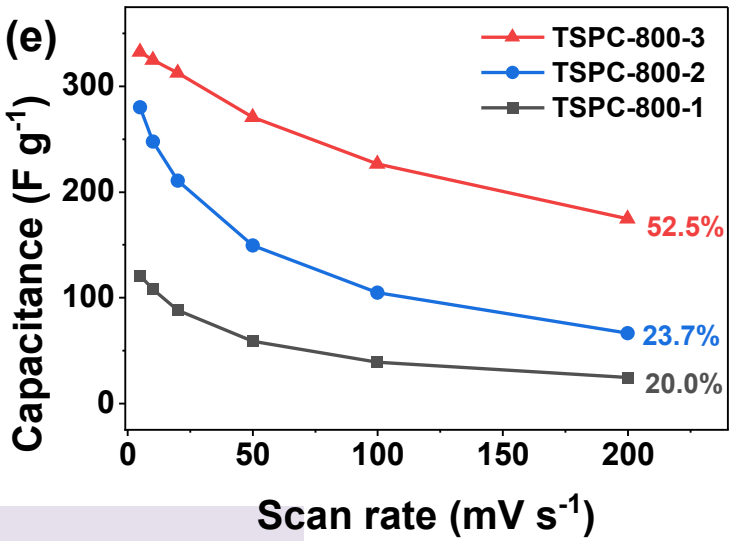
Electrochemical performance

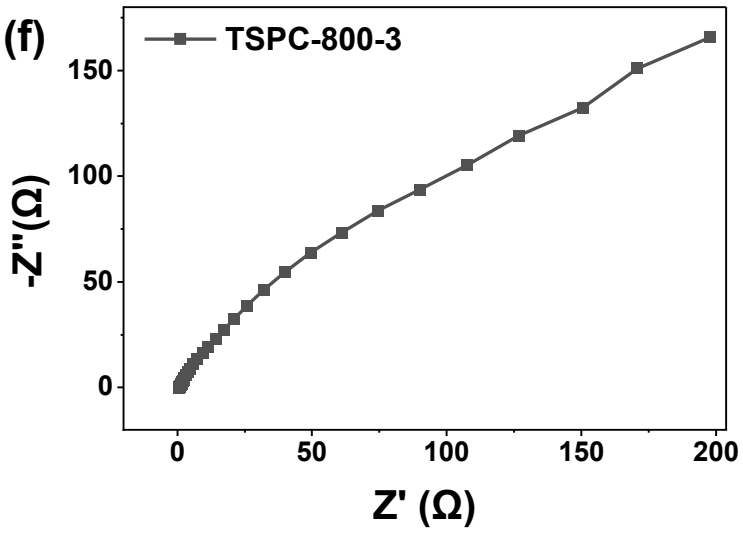






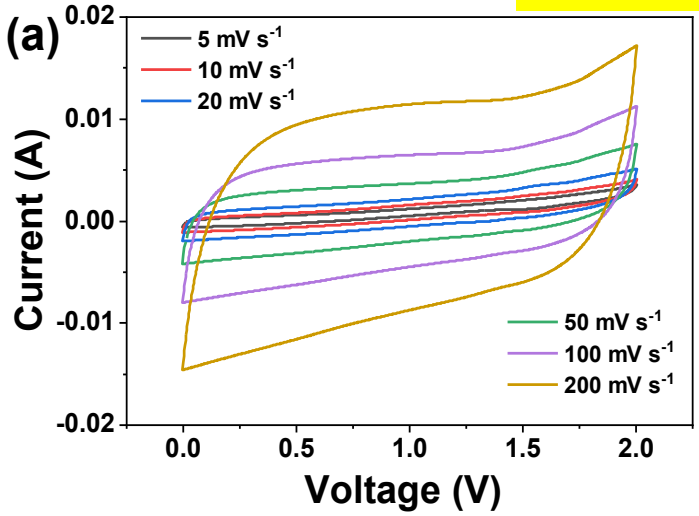


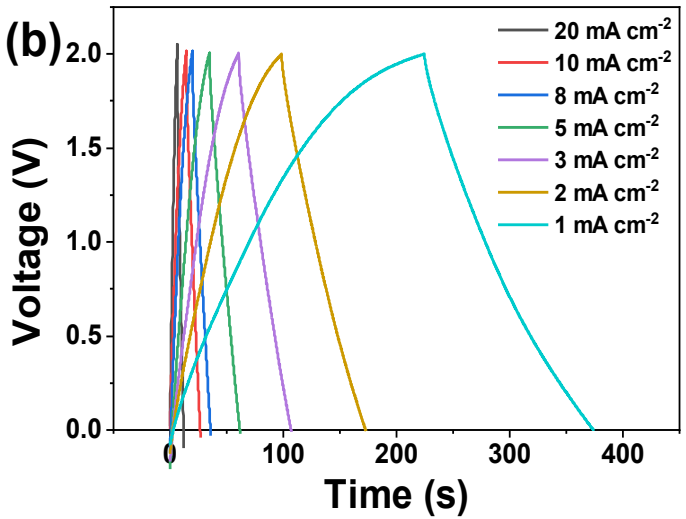


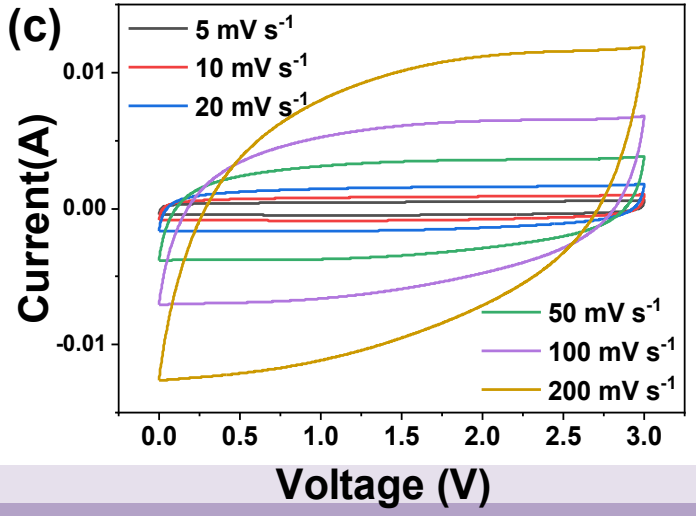


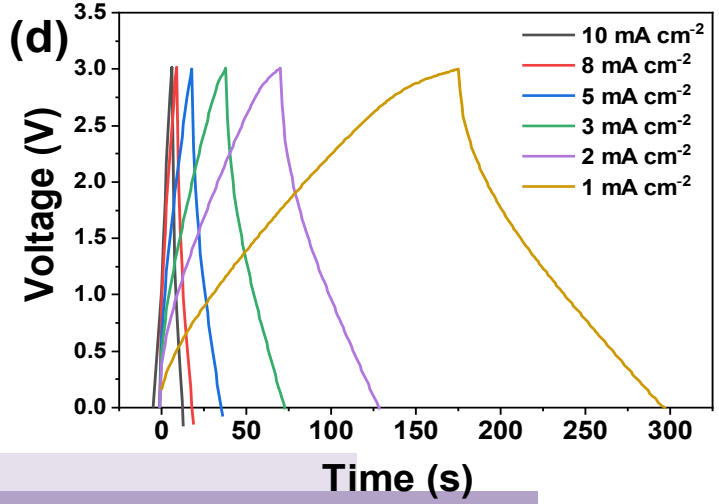
Supercapacitor application

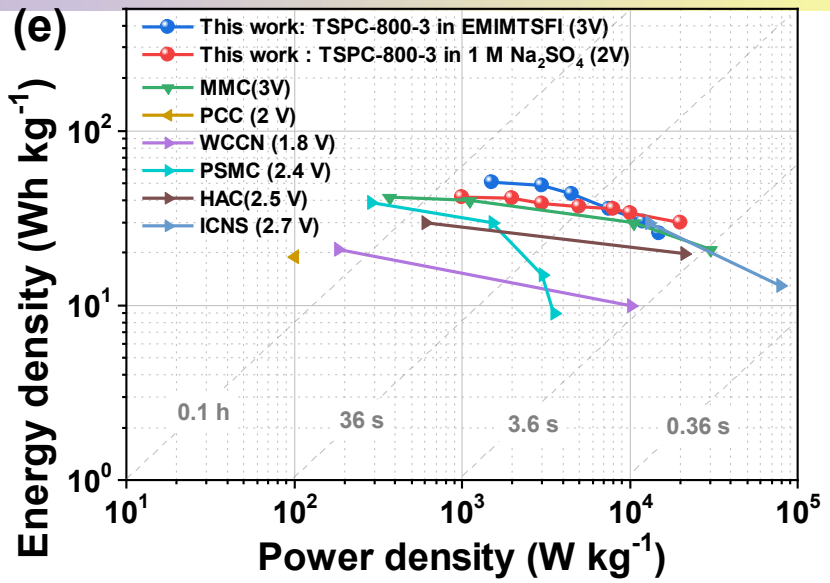
TSPC-800-3

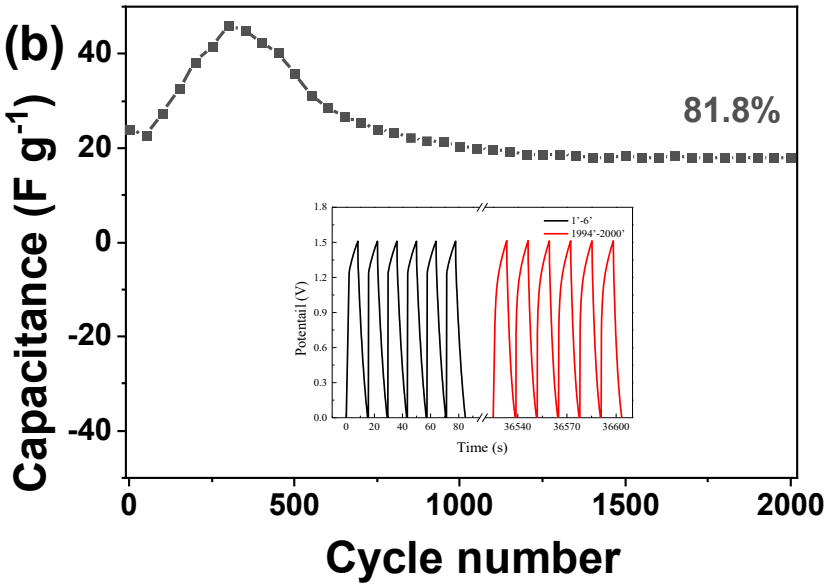




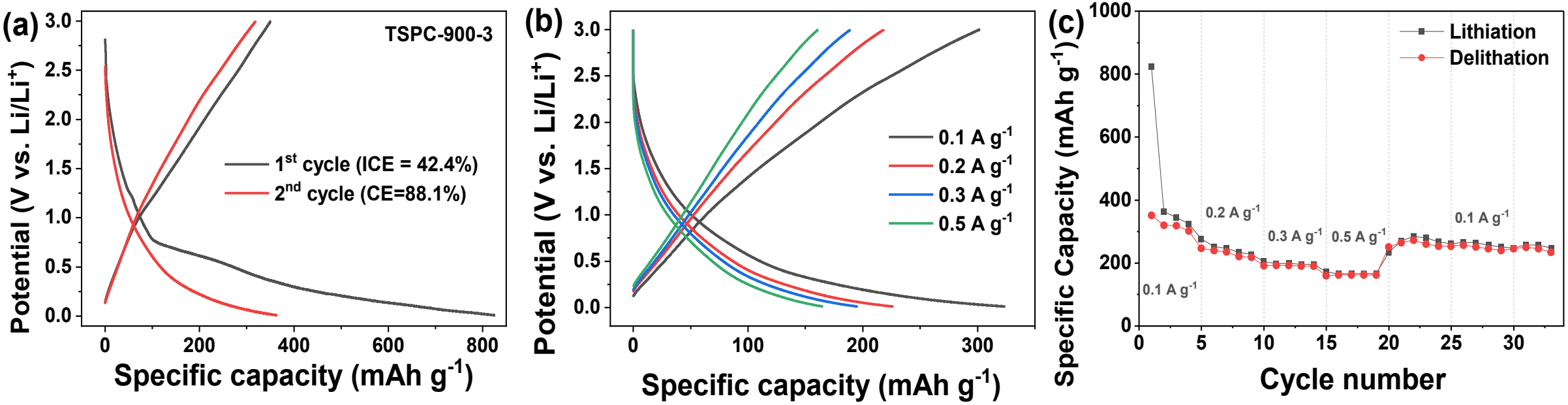








LIB applications for TSPC-900-3



- 1st cycle: 820(Lithiation)/348(delithiation) mAh/g (CE is 42.4%).
  - Due to the solid-electrolyte interphase (SEI) and irreversible Li trapping.
- 313 mAh/g at 0.1 A/g and remains 260 – 280 mAh/g for 5 – 35 cycles.

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Conlcusions

- The agrowaste-derived biochar is a promising alternative electrode materials and adsorbent for water-environment-energy nexus.
- Temperature and alkaline-to-biochar ratio play crucial roles in determining the morphology and pore textures.
- Formation of asymmetric electrode materials is beneficial for water purification, pollutant removal, resource recovery, and energy storage.
- For Trapa-based biochar, calcination at 800 °C for 3 h can form micropore materials, while 900 °C can form lamella structure.

Thank you for your attention





We thank the NSTC, Taiwan for the financial support.

NSTC 國家科學及技術委員會
National Science and Technology Council