Supplementary Information (SI) for New Journal of Chemistry.

Supporting Information

Biomass-derived hard carbon with tunable microstructures toward sustainable and high-rate sodium-ion batteries

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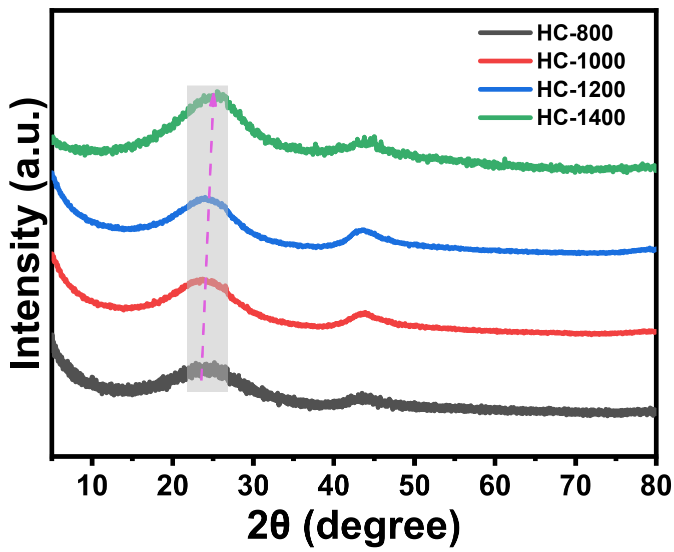

Figure S1 XRD patterns of the synthesized HC-X samples.

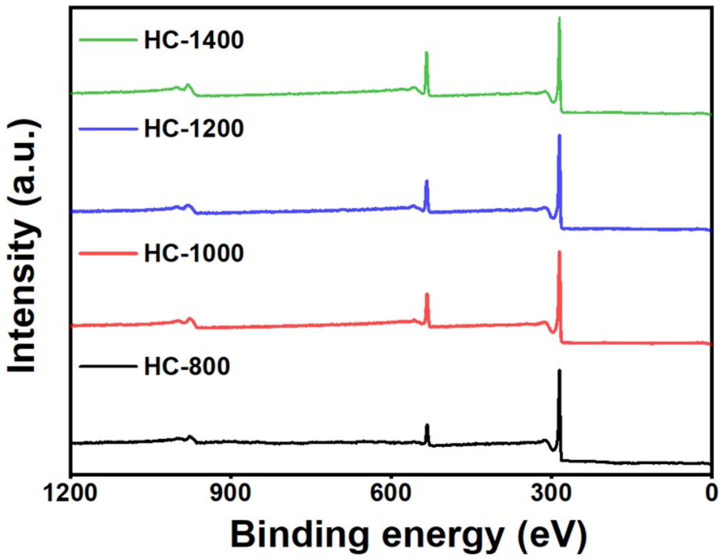

Figure S2 XPS spectra of the synthesized HC-X samples.

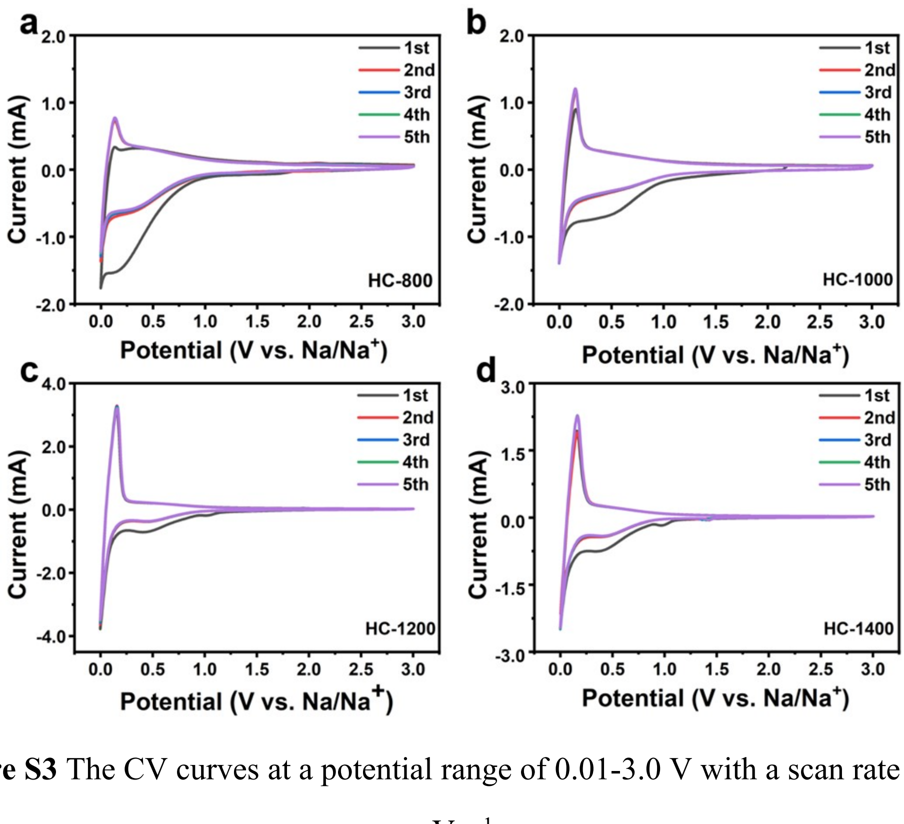

Figure S3 The CV curves at a potential range of 0.01-3.0 V with a scan rate of 0.1 mV s^{-1}.

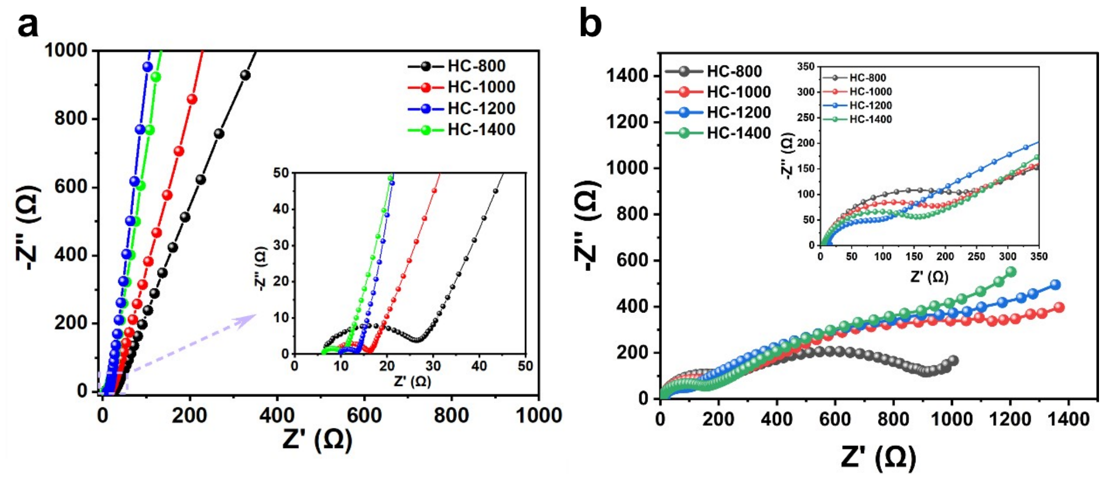

Figure S4 EIS curves of HC-X electrodes before cycling (a) and after 300 cycles (b) (inset is the enlarged image).

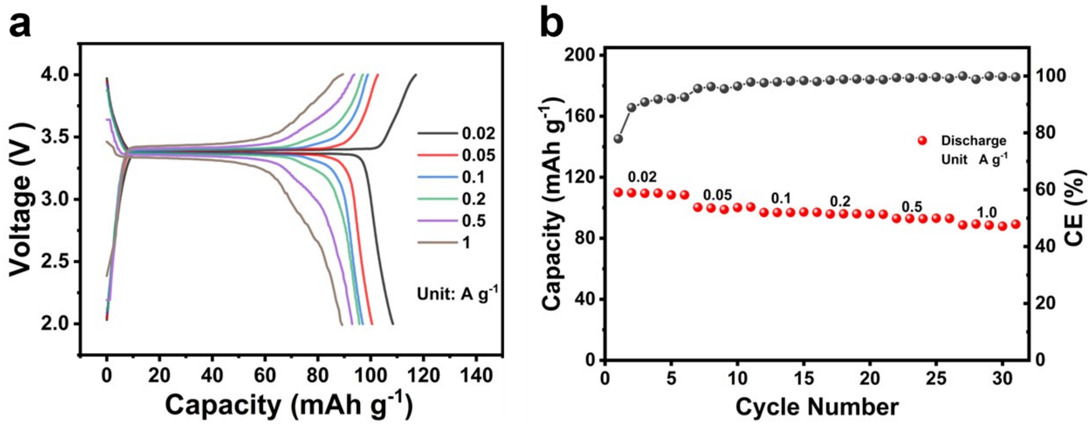

Figure S5 Charge-discharge curves and capacity performance for NVP half-cell at different current densities.

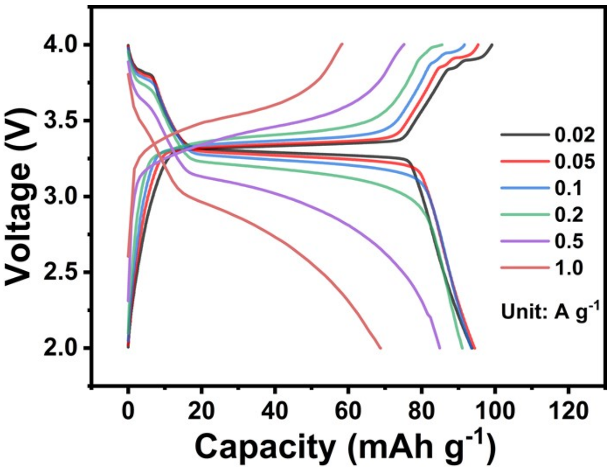

Figure S6 Charge-discharge curves for NVP||HC-1200 full cell at different current densities.

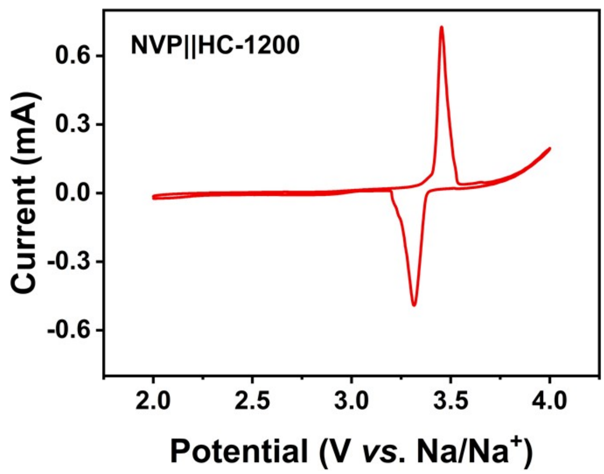

Figure S7 The CV curves of full cell at a potential range of 2.0-4.0 V with a scan rate of 0.1 mV s^{-1}.

Table S1 Comparisons of different biomass-derived hard carbon materials as anodes for SIBs.

Precursor	Pyrolysis temperature	Capacity (mAh g^{-1})/Current density (A g^{-1})	ICE	Rate capability (mAh g^{-1}) /Current density (A g^{-1})	Cycle Number- Capacity (mAh g^{-1})/Current density (A g^{-1})	Ref
Platanus Flosses	1300 ℃	259.5/0.1	80%	107.2/2.0	100-258/0.1	1
Renewable Cotton	1300 ℃	315/0.03	83%	180/0.3	100-305/0.03	2
Corncob	1300 ℃	280/0.03	79.6%	90/0.6	100-250/0.03	3
Waste hemp hurd	800 ℃	261.7/0.03	73%	79/1.0	300-~45/2	4
Peanut shells	600 ℃	~200/0.25	~33%	~145/1.0	400-190/0.25	5
Peanut shells	800 ℃	261/0.03	~60%	100/1.5	100-257/0.03	6
Tissue	1300 ℃	338/0.02	91.2%	170/2 A g^{-1}	1000-286/0.2	7
Lignin	1100 ℃	299/0.02	68%	77/3.0	300-298/0.02	8
Pine pollen	900 ℃	221.5/0.1	59.8%	87.3/5.0	200-203/0.1	9
Eggshell membranes	1300 ℃	310/0.02	89%	142/0.5	250-306/0.02	10
Kelp	1300 ℃	334/0.025	64.0%	96/1.0	300-205/0.2	11
Lotus stems	1400 ℃	351/0.04	70%	150/0.5	450-330/0.1	12
Walnut shell	1000 ℃	257/0.05	71%	48/2.0	300-170/0.1	13
Cherry petals	1000 ℃	310.2/0.02	67.3%	25/10.0	500-131.5/0.5	14
Red yeast rice powder	**1200 ℃**	**306.6/0.02**	**64.0%**	**110.8/2.0**	**300-298.6/0.02**	**This work**

Reference

(1) Hou, Z. D.; Lei, D.; Jiang, M. W.; Gao, Y. Y.; Zhang, X.; Zhang, Y.; Wang, J. G., Biomass-Derived Hard Carbon with Interlayer Spacing Optimization toward Ultrastable Na-Ion Storage. *ACS Appl. Mater. Interfaces* **2023,** *15* (1), 1367-1375.

(2) Li, Y. M.; Hu, Y. S.; Titirici, M. M.; Chen, L. Q.; Huang, X. J., Hard Carbon Microtubes Made from Renewable Cotton as High-Performance Anode Material for Sodium-Ion Batteries. *Adv. Energy Mater.* **2016,** *6* (18), 1600659.

(3) Tang, Y.; He, J. W.; Peng, J.; Yang, J.; Wu, Z. Y.; Liu, P.; Zhou, K. J.; Hu, S. H.; Hu, L.; Wang, X. Y., Electrochemical Behavior of the Biomass Hard Carbon Derived from Waste Corncob as a Sodium-Ion Battery Anode. *Energy Fuels* **2024,** *38* (8), 7389-7398.

(4) Antorán, D.; Alvira, D.; Peker, M. E.; Malón, H.; Irusta, S.; Sebastián, V.; Manyà, J. J., Waste Hemp Hurd as a Sustainable Precursor for Affordable and High-Rate Hard Carbon-Based Anodes in Sodium-Ion Batteries. *Energy Fuels* **2023,** *37* (13), 9650-9661.

(5) Lv, W. M.; Wen, F. S.; Xiang, J. Y.; Zhao, J.; Li, L.; Wang, L. M.; Liu, Z. Y.; Tian, Y. J., Peanut Shell Derived Hard Carbon as Ultralong Cycling Anodes for Lithium and Sodium Batteries. *Electrochim. Acta* **2015,** *176*, 533-541.

(6) Ren, X.; Xu, S.-D.; Liu, S.; Chen, L.; Zhang, D.; Qiu, L., Lath-Shaped Biomass Derived Hard Carbon as Anode Materials With Super Rate Capability for Sodium-Ion Batteries. *J. Electroanal. Chem.* **2019,** *841*, 63-72.

(7) Hou, B. H.; Wang, Y. Y.; Ning, Q. L.; Li, W. H.; Xi, X. T.; Yang, X.; Liang, H. J.; Feng, X.; Wu, X. L., Self-Supporting, Flexible, Additive-Free, and Scalable Hard Carbon Paper Self-Interwoven by 1D Microbelts: Superb Room/Low-Temperature Sodium Storage and Working Mechanism. *Adv. Mater.* **2019,** *31* (40), 1903125.

(8) Dou, X. W.; Hasa, I.; Hekmatfar, M.; Diemant, T.; Behm, R. J.; Buchholz, D.; Passerini, S., Pectin, Hemicellulose, or Lignin? Impact of the Biowaste Source on the

Performance of Hard Carbons for SodiumIon Batteries. *ChemSusChem* **2017,** *10* (12), 2668-2676.

(9) Zhang, Y. J.; Li, X.; Dong, P.; Wu, G.; Xiao, J.; Zeng, X. Y.; Zhang, Y. J.; Sun, X. L., Honeycomb-like Hard Carbon Derived from Pine Pollen as High-Performance Anode Material for Sodium-Ion Batteries. *ACS Appl. Mater. Interfaces* **2018,** *10* (49), 42796-42803.

(10) Zhao, X.; Ding, Y.; Xu, Q.; Yu, X.; Liu, Y.; Shen, H., Low-Temperature Growth of Hard Carbon with Graphite Crystal for Sodium-Ion Storage with High Initial Coulombic Efficiency: A General Method. *Adv. Energy Mater.* **2019,** *9* (10), 1803648.

(11) Wang, P. Z.; Zhu, X. S.; Wang, Q. Q.; Xu, X.; Zhou, X. S.; Bao, J. C., Kelp-derived Hard Carbons as Advanced Anode Materials for Sodium-Ion Batteries. *J. Mater. Chem. A* **2017,** *5* (12), 5761-5769.

(12) Zhang, N.; Liu, Q.; Chen, W. L.; Wan, M.; Li, X. C.; Wang, L. L.; Xue, L. H.; Zhang, W. X., High Capacity Hard Carbon Derived from lotus Stem as Anode for Sodium Ion Batteries. *J. Power Sources* **2018,** *378*, 331-337.

(13) Wahid, M.; Gawli, Y.; Puthusseri, D.; Kumar, A.; Shelke, M. V.; Ogale, S., Nutty Carbon: Morphology Replicating Hard Carbon from Walnut Shell for Na Ion Battery Anode. *Acs Omega* **2017,** *2* (7), 3601-3609.

(14) Zhu, Z. Y.; Liang, F.; Zhou, Z. R.; Zeng, X. Y.; Wang, D.; Dong, P.; Zhao, J. B.; Sun, S. G.; Zhang, Y. J.; Li, X., Expanded Biomass-Derived Hard Carbon with Ultrastable Performance in Sodium-Ion Batteries. *J. Mater. Chem. A* **2018,** *6* (4), 1513-1522.