Supporting Information

Flame-retardant polymer-enabled space-confined carbonization toward quasi-spherical hard carbon for high-rate sodium storage

Zhuzhu Du,[a] Conghao Yu,[a, b] Lei Liu,[b] Jinmeng Sun*[c] and Wei Ai*[b]

[a] School of Materials Science and Engineering & Institute of Flexible Electronics and Intelligent Textile, Xi'an Polytechnic University, Xi'an 710048, China

[b] State Key Laboratory of Flexible Electronics & Institute of Flexible Electronics, Northwestern Polytechnical University, Xi'an 710072, China

[c] College of Chemistry & Chemical Engineering, Xi'an Shiyou University, Xi'an 710065, China

*Corresponding authors: iamjmsun@xsyu.edu.cn, iamwai@nwpu.edu.cn

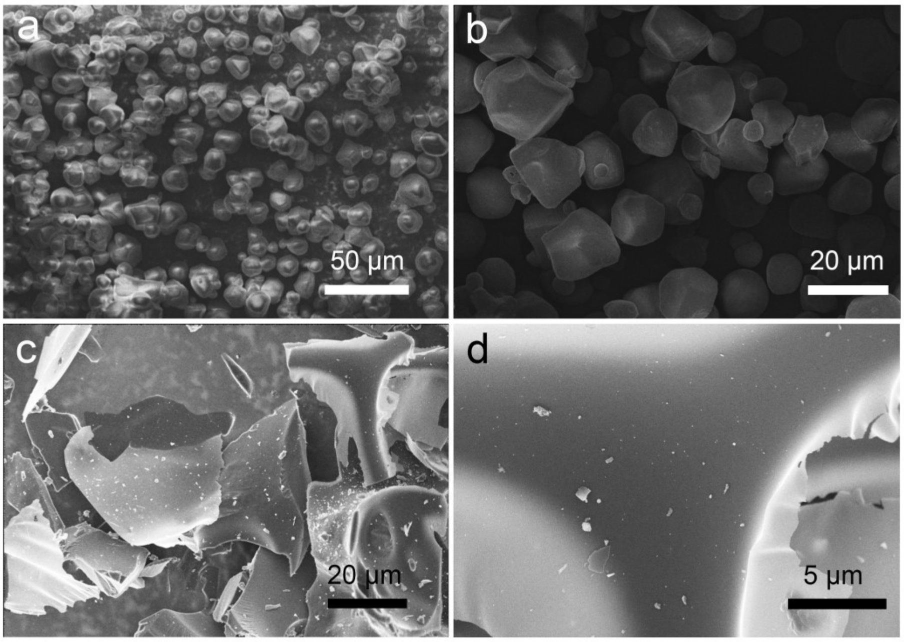


Figure S1. SEM images of (a, b) and (c, d) HC.

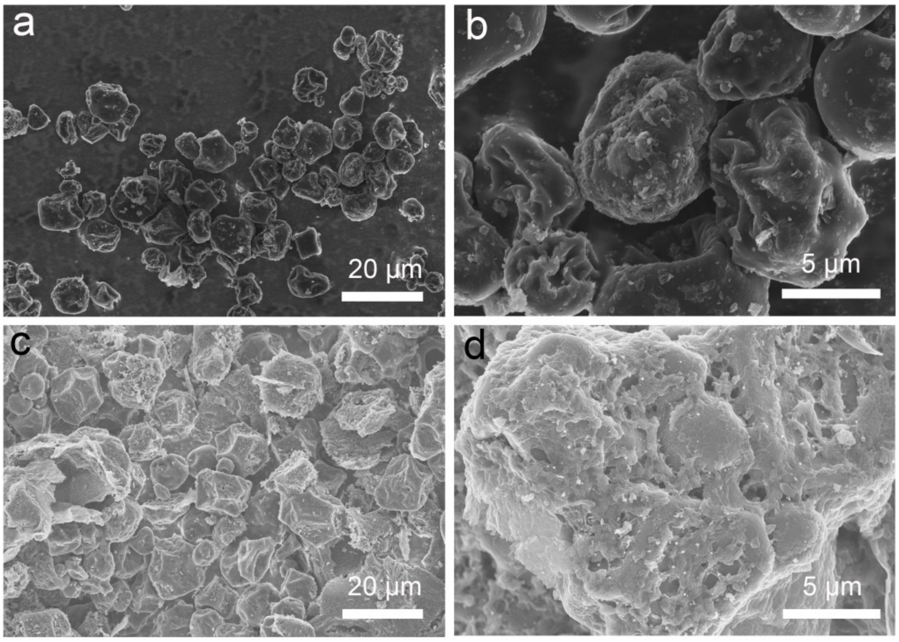


Figure S2. SEM images of QSHC prepared with the starch-to-PPD-PP mass ratio of (a, b) 10:1 and (c, d) 1:1.

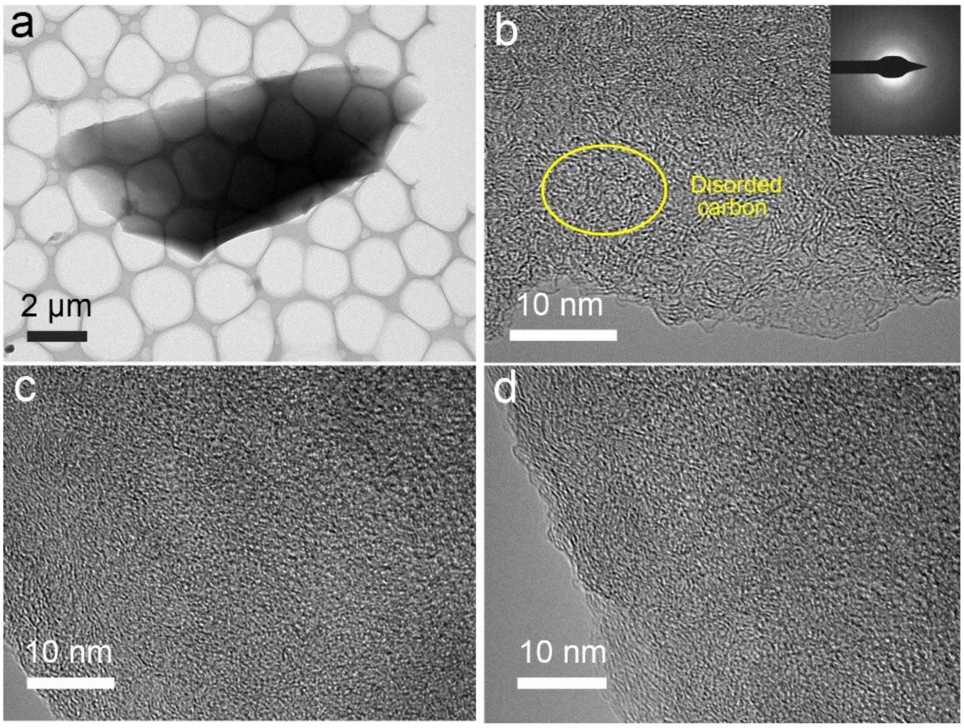


Figure S3. (a) TEM and (b-d) HRTEM images of HC.

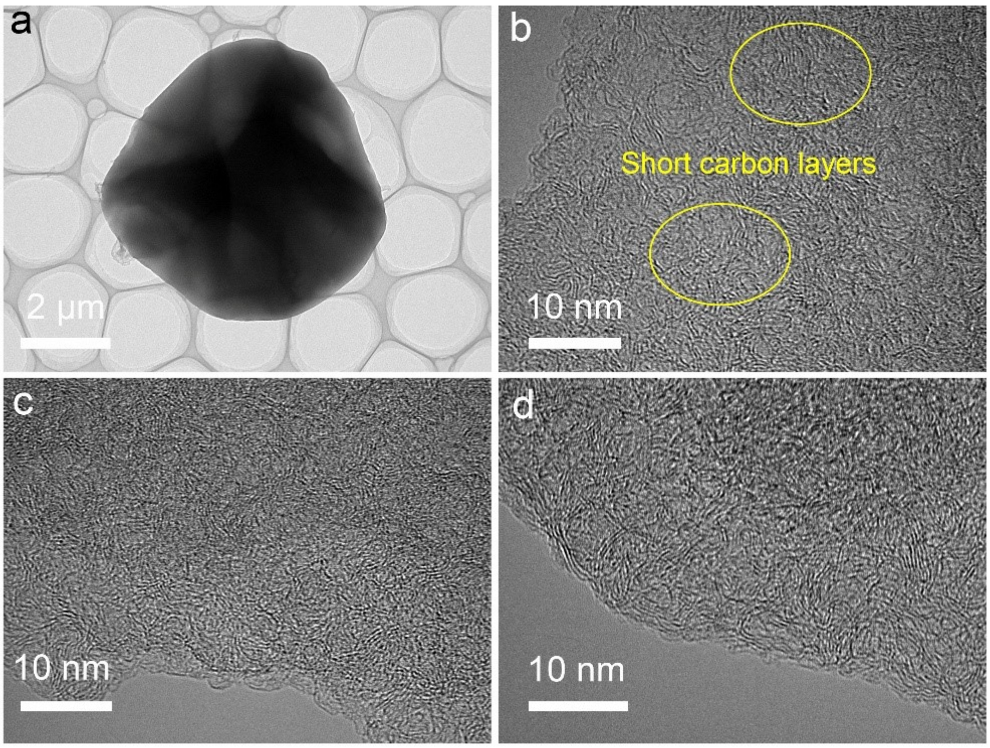


Figure S4. (a) TEM and (b-d) HRTEM images of QSHC.

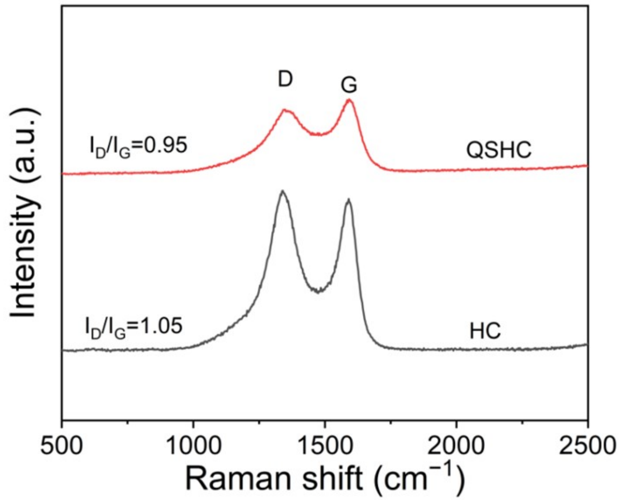


Figure S5. Raman spectra of QSHC and HC.

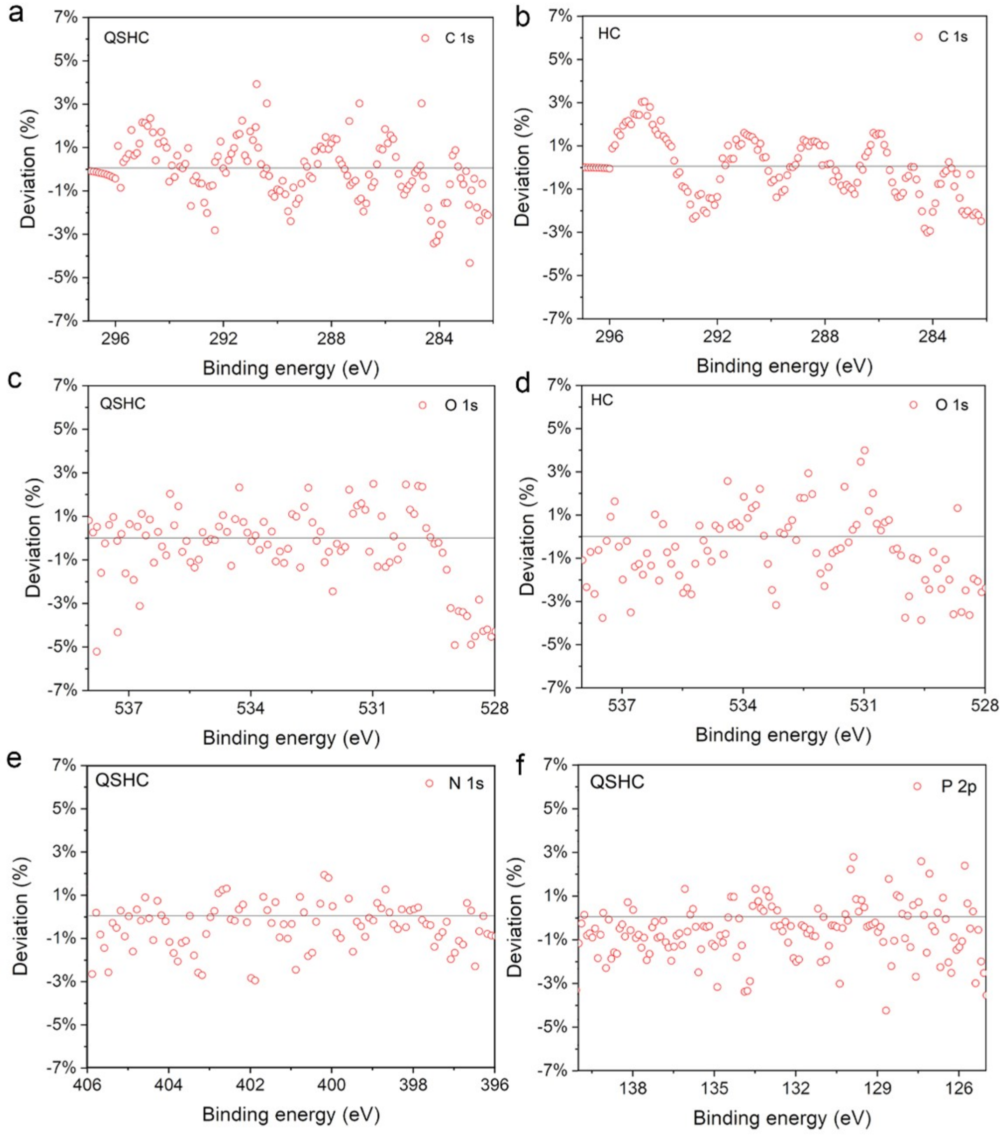
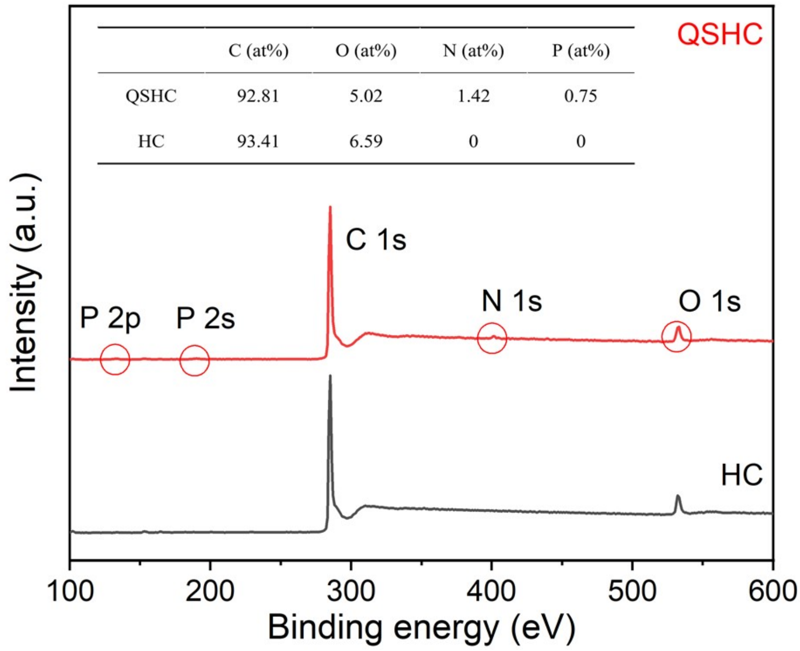


Figure S6. Residual plots of the fitted XPS spectra of (a, b) C 1s, (c, d) O 1s, (e) N 1s, and (f) P 2p, which belong to (a, c, e, f) QSHC and (b, d) HC samples.



	C (at%)	O (at%)	N (at%)	P (at%)
QSHC	92.81	5.02	1.42	0.75
HC	93.41	6.59	0	0

Figure S7. XPS survey spectra of QSHC and HC associated with their atomic contents.

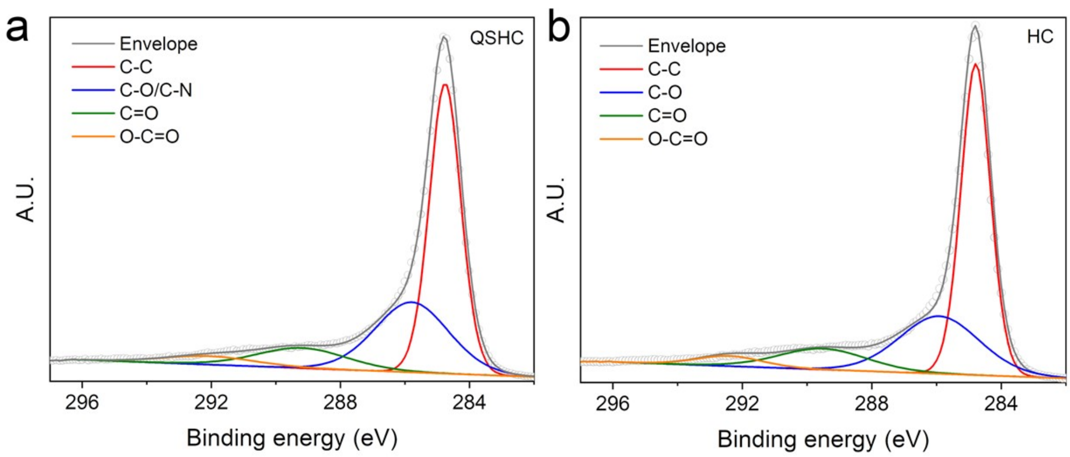


Figure S8. High-resolution C 1s XPS spectra of (a) QSHC and (b) HC.

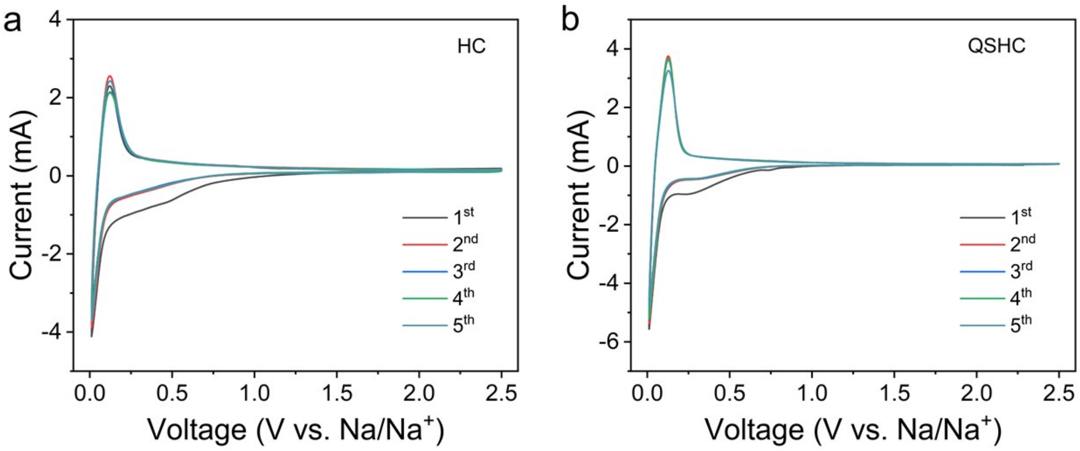


Figure S9. CV profiles of (a) HC and (b) QSHC from 1st to 5th cycles.

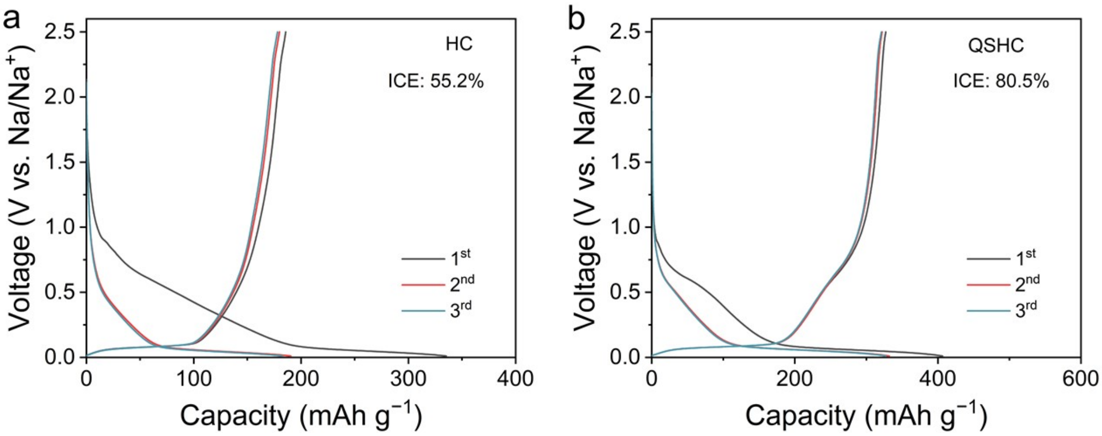


Figure S10. GCD curves of (a) HC and (b) QSHC for the initial 3 cycles.

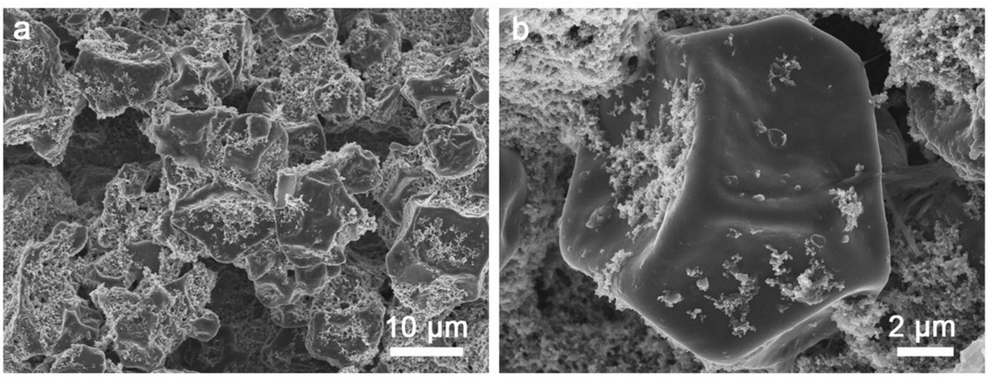


Figure S11. (a, b) SEM images of QSHC electrode after 100 cycles at 1 A g^{-1}.

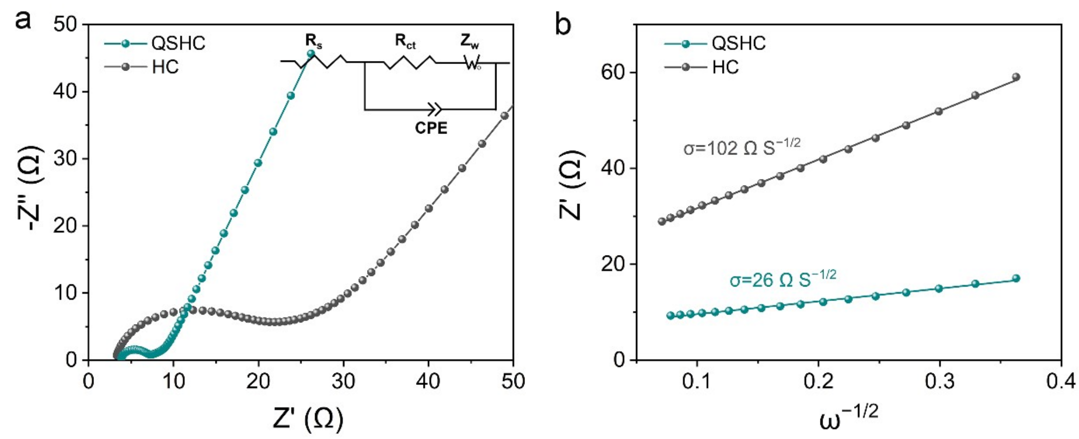


Figure S12. (a) EIS curves of QSHC and HC-based coin cells. (b) Linear fitting relationship between Z' and $\omega^{-1/2}$ for QSHC and HC electrodes.

Table S1. Nitrogen sorption results of HC and QSHC.

	Adsorption volume (cm^3 STP g^{-1})	Specific surface area (m^2 g^{-1})	Total pore volume (cm^3 g^{-1})	Average pore size (nm)
HC	86.146	343	0.177	4.703
QSHC	30.567	111	0.077	9.727

Table S2. Fitting parameters, references, and RSS of the XPS spectra.

	Background type	Peak shape	RSS (Residual Sum of Squares)	References
C 1s	Shirley	LG30	QSHC: 472.35 HC: 397.22	*J. Mater. Chem. A* 2014, 2, 12924
O 1s			QSHC: 113.53 HC: 141.18	*Adv. Funct. Mater.* 2021, 31, 2104137
N 1s			QSHC: 6.64	*Adv. Mater.* 2023, 35, 2211461
P 2p			QSHC: 4.27	*Adv. Funct. Mater.* 2025, 35, 2426075

Table S3. Performance comparison of QSHC with previously reported HC anodes for sodium storage.

Sample	Rate	Plateau capacity contribution (%)	Cycling	ICE (%)	Ref.
QSHC	**180 mAh g^{-1} at 1A g^{-1}**	**71.1**	**171 mAh g^{-1} at 1A g^{-1} (2000 cycles)**	**80.5**	**This work**
HC300-1000	60 mAh g^{-1} at 1 A g^{-1}	55.4	~250 mAh g^{-1} at 0.1 A g^{-1} (100 cycles)	82.5	*Energy Storage Mater.* 2022, 51, 620
PCLC	106.1 mAh g^{-1} at 1 A g^{-1}	59.4	246.8 mAh g^{-1} at 0.3 A g^{-1} (1000 cycles)	88.4	*Energy Storage Mater.* 2023, 56, 532
HCG	106 mAh g^{-1} at 1 A g^{-1}	25	198 mAh g^{-1} at 0.1 A g^{-1} (200 cycles)	80.1	*Chem. Eng. J.* 2022, 432, 133257
SSHC	198.5 mAh g^{-1} at 2 A g^{-1}	-	158 mAh g^{-1} at 3A g^{-1} (1000 cycles)	-	*J. Mater. Chem. A* 2020, 8, 14993
CS@2%PP	92 mAh g^{-1} at 0.5 A g^{-1}	73.3	272 mAh g^{-1} at 0.025 A g^{-1} (50 cycles)	81	*Energy Technol.* 2019, 7, 1900779
HC-SC	122 mAh g^{-1} at 1 A g^{-1}	-	241 mAh g^{-1} at 0.05 A g^{-1} (100 cycles)	92.7	*Mater. Lett.* 2023, 330, 133368
BHCS-1200	198.5 mAh g^{-1} at 2 A g^{-1}	~60	180 mAh g^{-1} at 0.1 A g^{-1} (1000 cycles)	65.4	*J. Mater. Chem. A* 2022, 10, 17225

Table S4. Fitted parameters using the Nyquist equivalent circuit model.

	R_s (Ω)	R_{ct} (Ω)
QSHC	3.205	2.736
HC	3.838	13.012

Table S5. Power and energy density of QSHC//NCPFC full cell at different current densities.

	Current density (A g^{-1})				
	0.1	0.2	0.5	1.0	2.0
Power (W)	56.5	112.1	298.2	541.1	938.3
Power density (W kg^{-1})	424.6	842.7	2241.6	4066.9	7052.5
Energy (Wh)	45.3	43.5	40.2	36.0	31.9
Energy density (Wh kg^{-1})	340.4	327.1	302.2	270.4	239.7
Mass loading of active materials	M_p: 4.0 mg cm^{-2}; A_p: 1.54 cm^2 M_n: 1.2 mg cm^{-2}; A_n: 1.13 cm^2				