Supporting Information

Nitrogen and Sulfur-Codoped Porous Carbon Derived from BSA/Ionic Liquid Polymer Complex: Multifunctional Electrode Materials for Water Splitting and Supercapacitor

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Experimental

Chemicals. N-vinyl imidazole (Im, 98%, Sigma-Aldrich) was distilled under vacuum before use and stored in the refrigerator. Bromoacetonitrile, lithium bis(trifluoro methanesulfonyl)imide (LiTf$_2$N, 99.95%) and bovine serum albumin (BSA, 98%) were purchased from Sigma-Aldrich and used as received. Azobisisobutyronitrile (AIBN, 98%, Tianjin Kaixin Chemical Company, China) was recrystallized from methanol before use and stored in the refrigerator. Carbon cloth (Toray TGP-H-060, Japan) was used for the substrate without any purification and pre-treatment. Nafion (Dupont D520, 5 wt % in ethanol) was purchased from Hesen Electrical Equipments Co., Ltd. (Shanghai, China). Platinum (20 wt% on carbon black, HiSPEC-3000) was brought from Alfa Aesar and used as received. All other reagents were commercially available and were used as received. Poly[1-cyanomethyl-3-vinylimidazolium bis(trifluoromethanesulfonyl)imide] (PIL-Tf$_2$N) was prepared according to a previous report.[S1]

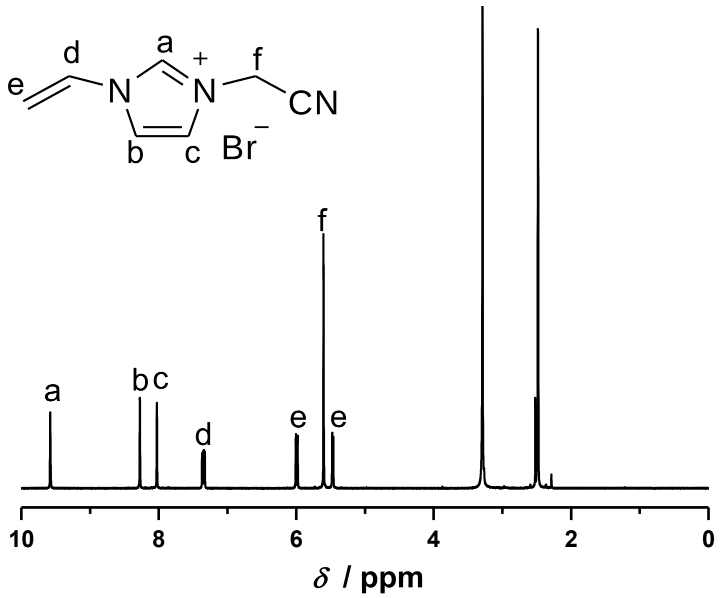

Figure S1 ^{1}H NMR spectrum (400 MHz) of 3-cyanomethyl-1-vinylimidazolium bromide (CMVIm-Br) in DMSO-*d*^{6} at 25 °C.

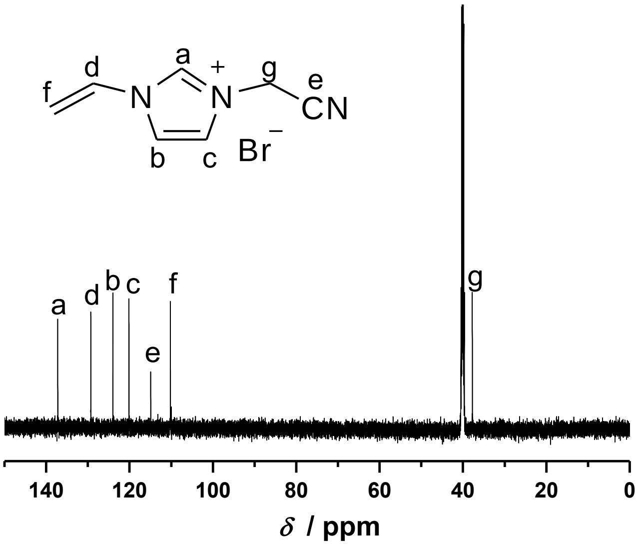

Figure S2 ^{13}C NMR spectrum (100 MHz) of 3-cyanomethyl-1-vinylimidazolium bromide (CMVIm-Br) in DMSO-*d*^{6} at 25 °C.

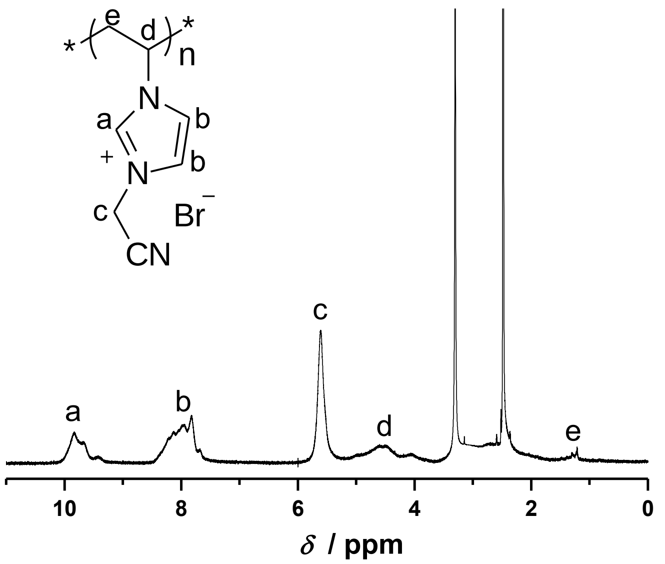

Figure S3 ^{1}H NMR spectrum (400 MHz) of poly(3-cyanomethyl-1-vinylimidazolium bromide) (PIL-Br) in DMSO-*d*^{6} at 25 °C.

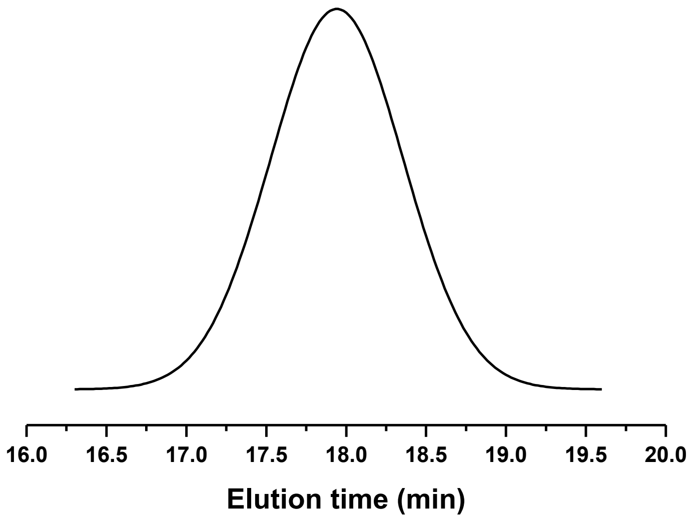

Figure S4 GPC trace of poly(3-cyanomethyl-1-vinylimidazolium bromide).

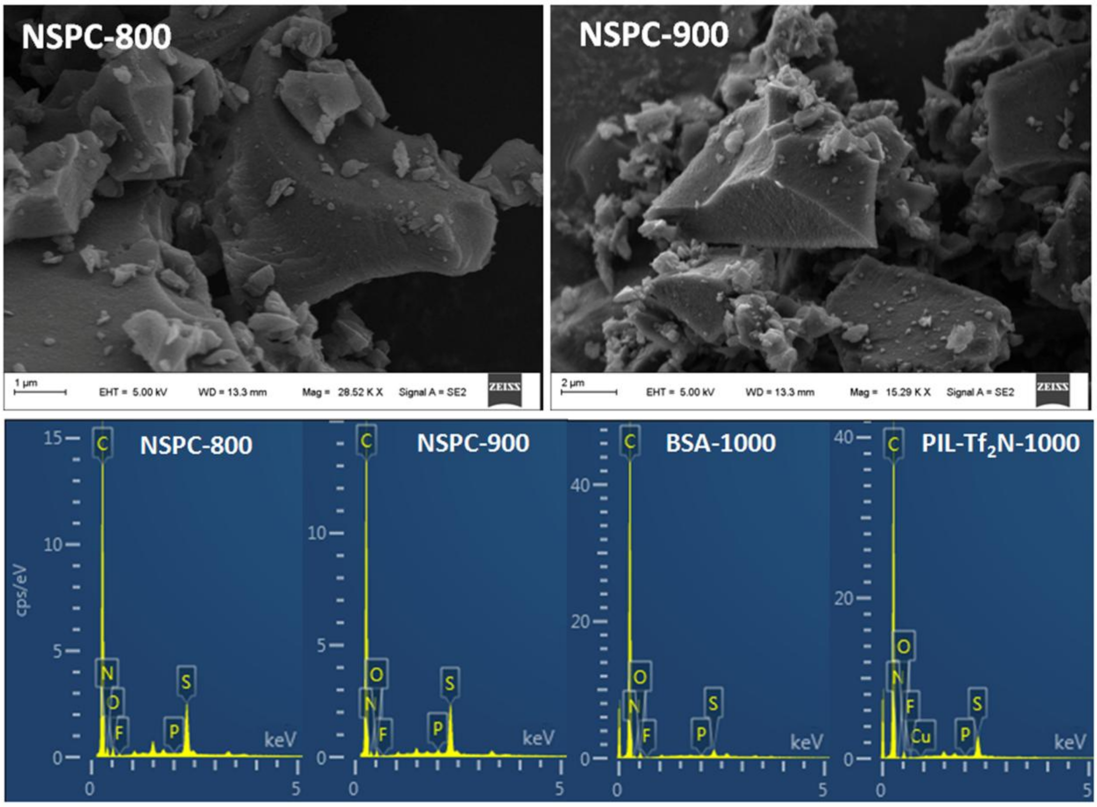

Figure S5 SEM images of different carbon materials (a NSPC-800, b NSPC-900) and energy dispersive X-ray (EDX) spectra of BSA-1000, PIL-Tf$_2$N-1000, NSPC-8000 and NSPC-900.

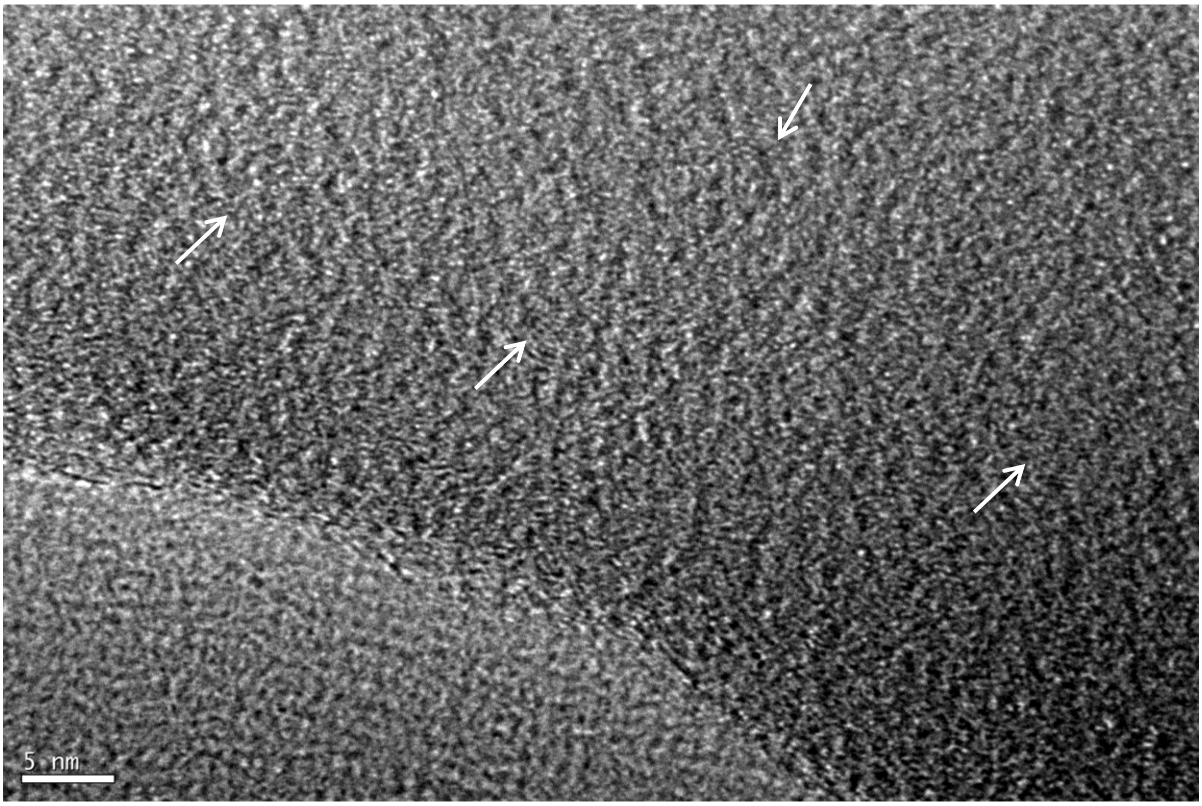

Figure S6. HRTEM image of NSPC-800. The white arrows point out the preferential orientation of the graphitic layers.

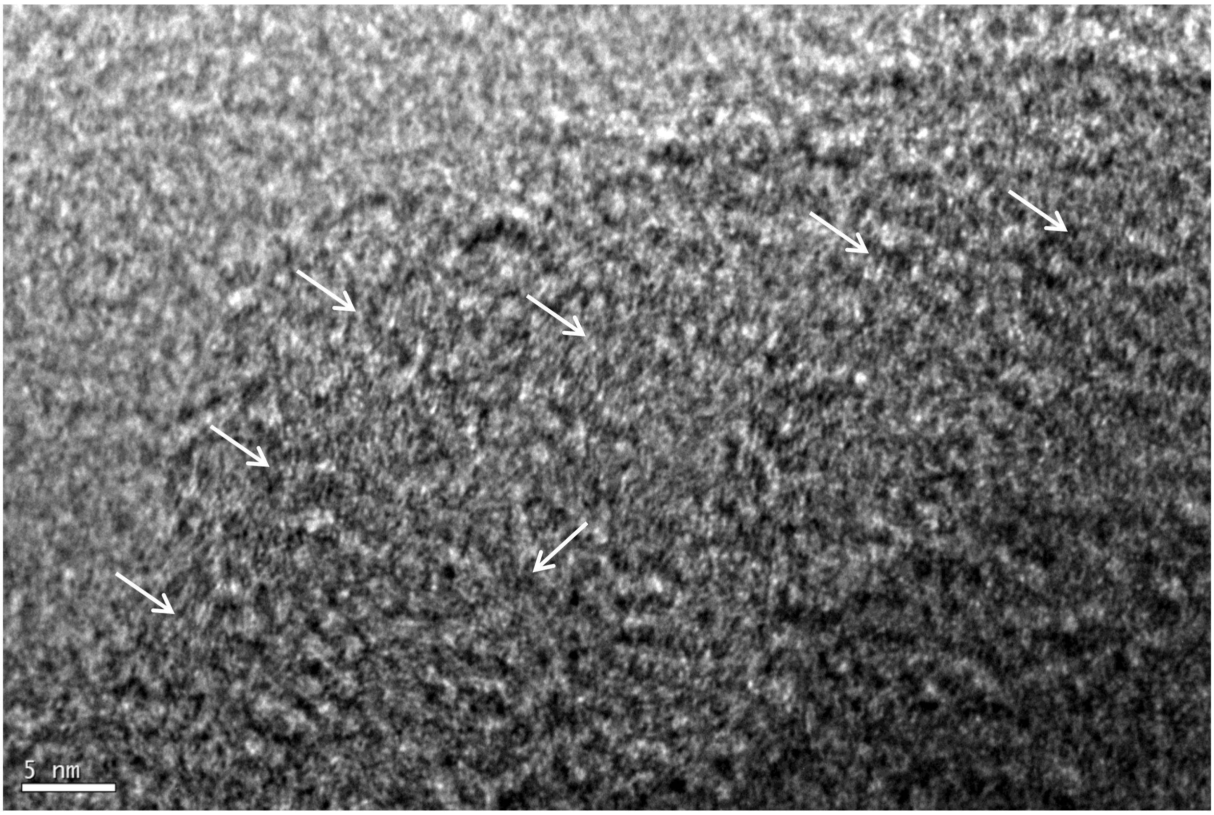

Figure S7. HRTEM image of NSPC-900. The white arrows point out the preferential orientation of the graphitic layers.

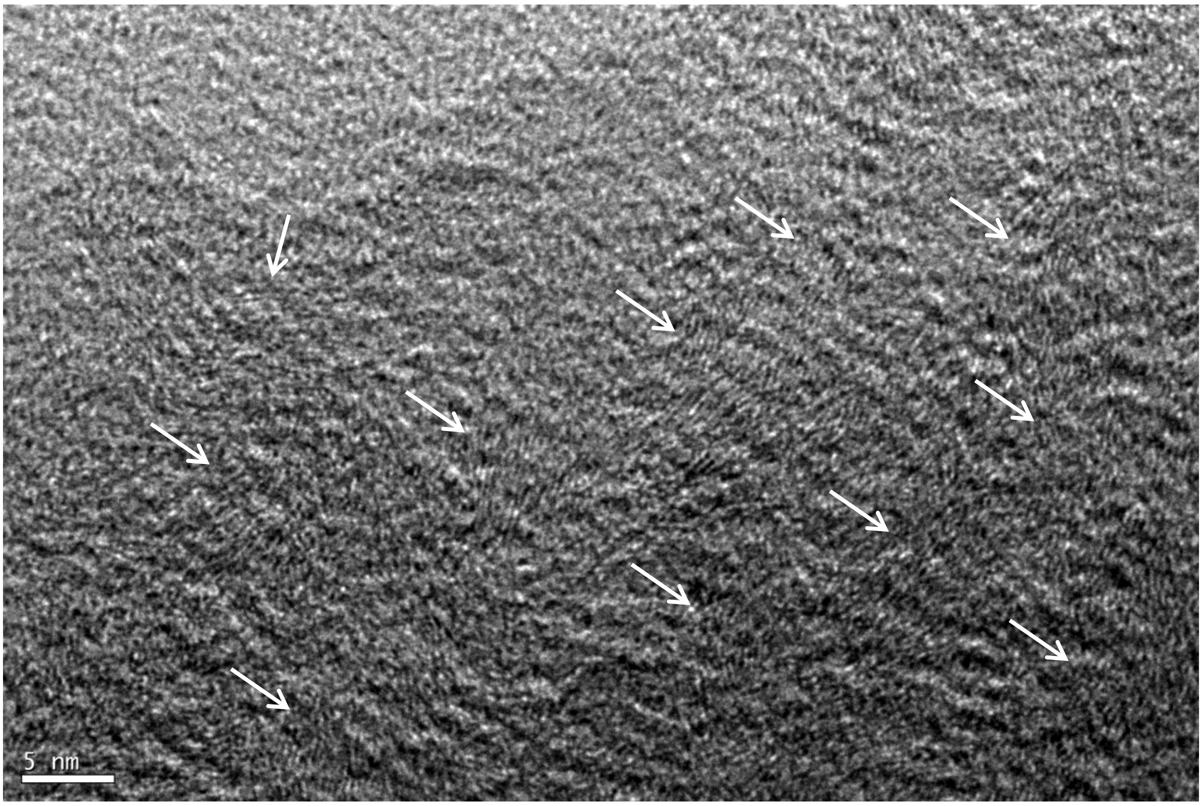

Figure S8. HRTEM image of NSPC-1000. The white arrows point out the preferential orientation of the graphitic layers.

Table S1 Element contain in different carbon materials determined by elemental analysis.

Sample	C	N	O	S
NSPC-800	60.81%	14.30%	2.102%	3.870%
NSPC-900	68.84%	9.11%	1.919%	3.318%
NSPC-1000	80.17%	3.58%	1.651%	2.009%
BSA-1000	81.97%	7.82%	0.792%	1.12%
PIL-Tf_2N-1000	80.27%	2.64%	1.592%	1.878%

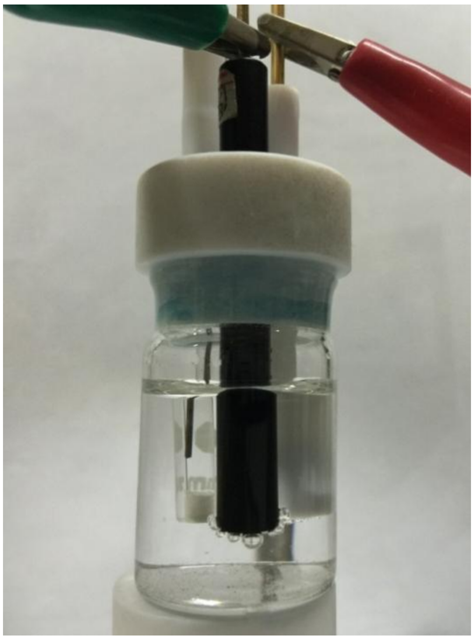

Figure S9 Photograph of the setup for HER test in 0.5 M H_2SO_4 showing the production of hydrogen bubbles on NSPC-1000-loaded glassy carbon electrode. The counter electrode and reference electrode are platinum wire electrode and saturated calomel electrode, respectively.

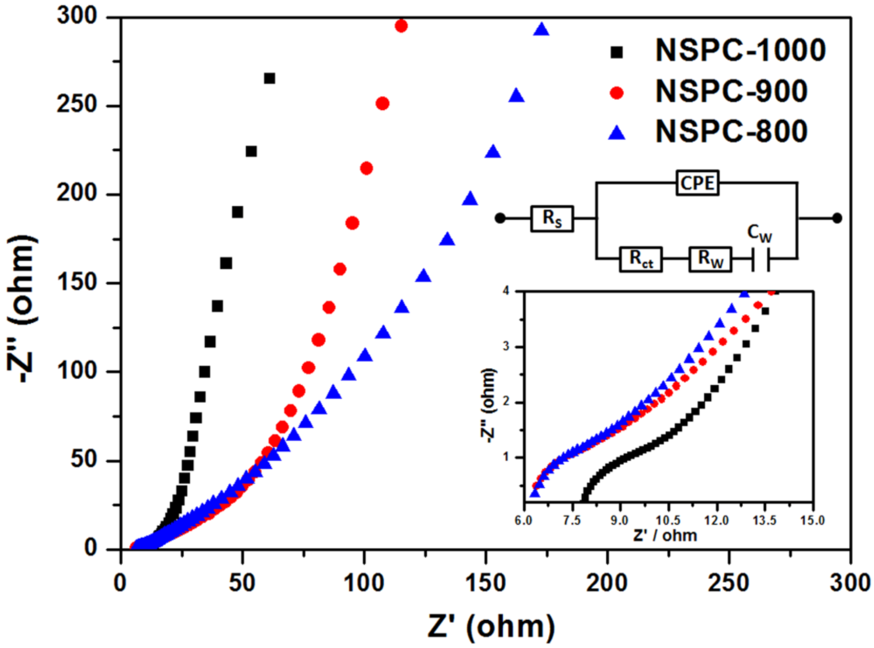

Figure S10 Electrochemical impedance spectroscopy (EIS) data for NSPC materials in H_2SO_4 (overpotential = 175 mV, 309 mV, 417 mV, corresponding to NSPC-1000, NSPC-900 and NSPC-800, respectively).

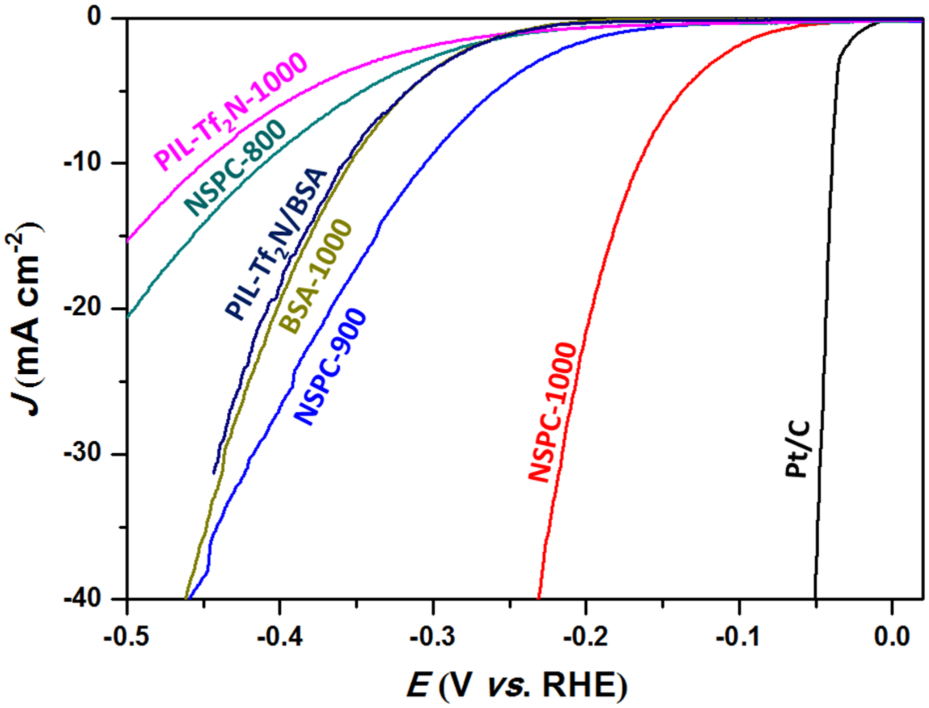

Figure S11 LSV curves of different carbon materials after iR correction of the data in Figure 4a (for HER test). In the iR-corrected data for HER, NSPC-1000 exhibits a current density of 10 mA cm^{-2} at the overpotential of 165 mV in 0.5 M H_2SO_4 solution.

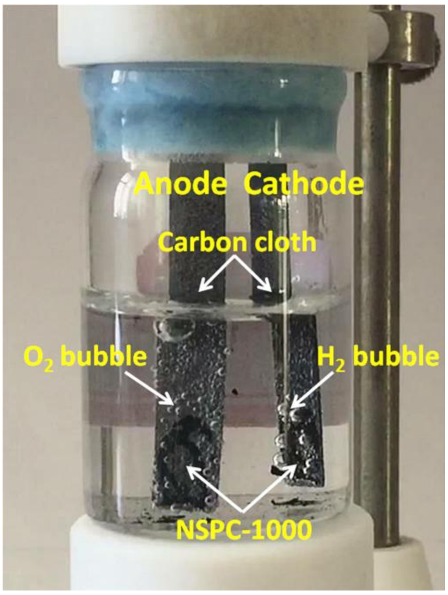

Figure S12 Photograph of the two-electrode setup showing the generation of hydrogen and oxygen bubbles on CC.

Table S2 HER performance of NSPC-1000 in this work, in comparison with the results of some representative carbon-based and non-noble electrocatalysts from recent publications.

Catalyst	**Electrolyte**	**Overpotential at j = 10 mA cm^{-2} (mV)**	**Tafel slope (mV dec^{-1})**	**Ref.**
C_3N_4/FTO	0.1 M PBS 0.1 M KOH	250 100	/	S2
C_3N_4@NG	0.5 M H_2SO_4 0.1 M KOH	240 >600	51.5 /	S3
g-C_3N_4 nanoribbon-G	0.5 M H_2SO_4	207	54	S4
C_3N_4	0.1 M PBS 0.1 M KOH	600 (at j = 0.8 mA cm^{-2}) 300 (at j = 0.8 mA cm^{-2})	120	S5
MPSA/GO-1000	0.5 M H_2SO_4 0.1 M KOH	210 (at j = 30 mA cm^{-2}) 470	/ /	S6
N,P-graphene-1	0.5 M H_2SO_4 0.1 M KOH	420 >600	/ /	S7
SNCTs	0.5 M H_2SO_4	76 (at j = 0.2 mA cm^{-2})	126	S8
N,S codoped graphene 500C	0.5 M H_2SO_4	276	81	S9
SHG	0.1 M KOH	310	112	S10
N-G	0.1 M KOH	510	*157*	S11
NiMoNx/C	0.1 M $HClO_4$	/	35.9	S12
Co-NRCNTs	0.5 M H_2SO_4 0.1 M KOH	260 >400	69 /	S13
1T-MoS_2 nanosheets	0.5 M H_2SO_4	>200	41-46	S14

Exfoliated WS_2 nanosheets	0.5 M H_2SO_4	210 mV	60	S15
Exfoliated MoS_2 nanosheets	0.5 M H_2SO_4	195	54	S16
CoOx@CN	0.5 M H_2SO_4	232	115	S17
Monolayer MoS_2 supported by NPG	0.5 M H_2SO_4	226	46	S18
NSPC-1000	0.5 M H_2SO_4 1.0 M KOH	**172** **234**	44 59	*This work*

Table S3. Comparison of the HER activity of NSPC-1000 in the present study and leading literature results.

Entry	Catalyst	Overpotential (mV)	Tafel slope (mV dec^{-1})	Electrolyte	Reference
1	SA900ZC (*S. aureus* cell)	200	58.4	0.5M H_2SO_4	S19
2	HPC-900 (Human hair)	100	57.4	0.5M H_2SO_4	S20
3	NPCSBF-1000 (Chinese steamed bread flour)	220	77	0.5M H_2SO_4	S21
4	S/N-CLs (*Magnolia liliiflora* flowers)	90 (onset potential)	73	0.5 M H_2SO_4	S22
5	CS-900 silk cocoon	317	173	0.5M H_2SO_4	S23
6	MoS_2/SNCF Silk cocoon	102	60	0.5M H_2SO_4	S24
7	MoP/CF sodium alginate	<200	56.4	0.5 M H_2SO_4	S25
8	MoS_2/AC (Glucose)	80 (onset potential)	40	0.5 M H_2SO_4	S26
9	NSPC-1000	172	44.3	0.5 M H_2SO_4	This work
		234	58.9	1.0 M KOH	

Table S4 OER performance of NSPC-1000 in this work, in comparison with the results of some representative carbon-based electrocatalysts from recent publications.

Catalyst	**Electrolyte**	**Overpotential at *j* = 10 mA cm^{-2} (V)**	**Tafel slope (mV dec^{-1})**	**Ref.**
SHG	0.1 M KOH	1.60	71	S10
N-doping graphite	0.1 M KOH	1.61	/	S27
Oxidized carbon cloth	0.1 M KOH	1.72	82	S28
N, P-codoped graphene/ carbon nanosheets	0.1 M KOH	1.57	70	S29
N,O-codoped carbon hydrogen film	0.1 M KOH	1.63	141	S30
N, S-codoped G	0.1 M KOH	1.65	59	S31
N,O,P-tridoped porous carbon	1.0 M KOH	1.63	84	S32
N-doped G/CNTs hybrids	0.1 M KOH	1.63	83	S33
TCCN	0.1 M KOH	1.65	74.6	S34
MnxOy/NC, CoxOy/NC	0.1 M KOH	1.64–1.68	/	S35
N, O dual-doped carbon	0.1 M KOH	1.70	141	S36
$Mn_3O_4/CoSe_2$	0.1 M KOH	1.68	49	S37
$NiCo_2O_4$-graphene	0.1 M KOH	1.69	156	S38
g-C_3N_4-graphene film	0.1 M KOH	1.65	128	S39
NSPC-1000	0.1 M KOH	1.69 (on GCE) 1.59 (on CC)	88 70	This work

Table S5. Comparison of capacitance performance of NSPC-1000 in the present study and leading literature results.

Entry	Material	Specific capacitance	Density of Current	Electrolyte	Reference
1	GA650	272 F/g	1 A/g	1 M H_2SO_4	S40
2	HPC-650	312 F/g	1 A/g	1 M H_2SO_4	S41
3	PHC-4	476 F cm^{-3}	1mV s^{-1}	6 M KOH	S42
4	SSC	669 mF cm^{-2}	1 mA cm^{-2}	6 M KOH	S43
5	N-HC-800	275 F g^{-1}	0.2 A/g	6 M KOH	R44
6	T-N-PC	411 F g^{-1}	1 A/g	1 M Na_2SO_4	S45
7	HCPC-800	217 F g^{-1}	5 mV s^{-1}	6 M KOH	S46
8	WB-PC-700	413 F g^{-1}	1 A/g	6 M KOH	S47
9	NPCs	465 Fg^{-1}	1 A/g	0.1 KOH	S48
10	NSPC-1000	495 Fg^{-1}	0.1 A/g	1 M H_2SO_4	This work

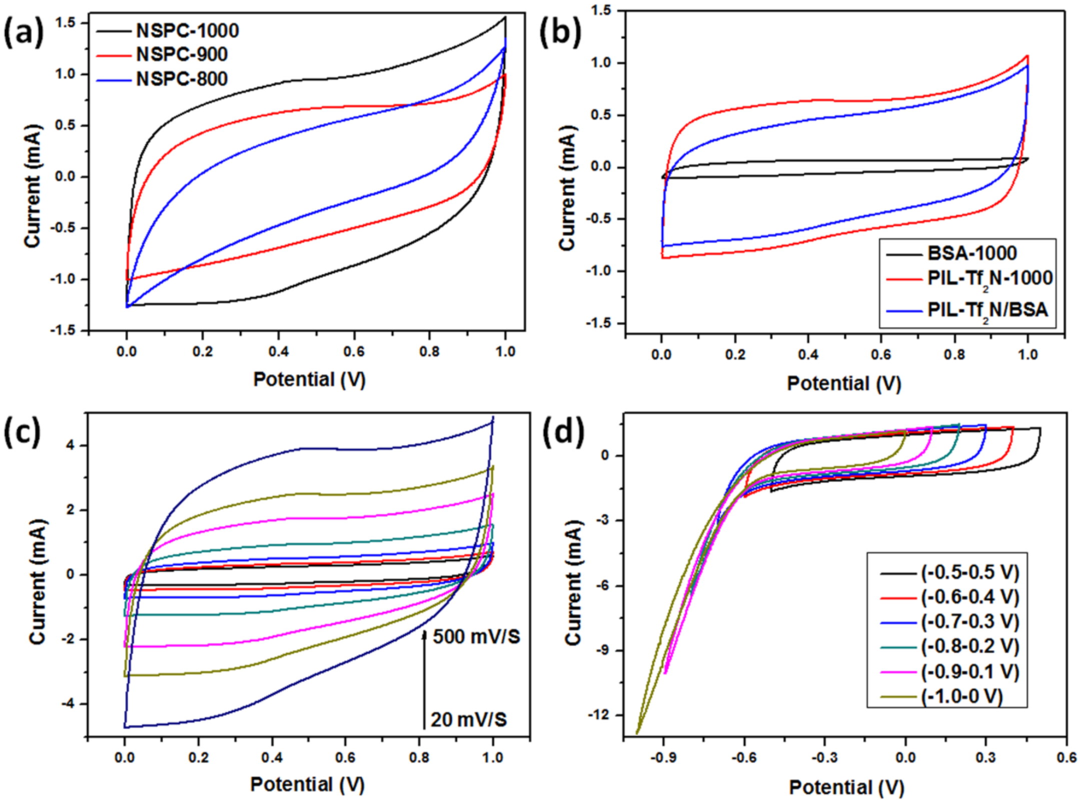

Figure S13 Electrochemical performances of carbon electrode materials. (a) Cyclic voltammetry (CV) profiles of NSPCs; (b) CV profiles of BSA-1000 and PIL-Tf_2N-1000 and PIL-Tf_2N/BSA (it was prepared by mixing PIL-Tf_2N-1000 and BSA-1000 (7:1, w/w)); (c) CV curves of NSPC-1000 at different scan rates; (d) CV curves of NSPC-1000 in different potential windows, scan rate 100 mV s^{-1}. All the measurements were conducted in 0.5 M H_2SO_4 electrolyte.

Supporting information, Video

Video S1: HER using NSPC-1000 loaded carbon cloth as both anode and cathode.

This movie shows the H_2 and O_2 evolution on NSPC-1000 loaded carbon cloth electrodes in the electrochemical cell at an applied potential from 0.1 to −0.7 V. (electrolyte: 0.5 M H_2SO_4; NSPC-1000 loading: 0.25 mg cm^{-2})

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