Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supporting Information

Water soluble densely functionalized poly(hydroxycarbonylmethylene) binder for higher performance of hard carbon anode-based sodium-ion batteries.

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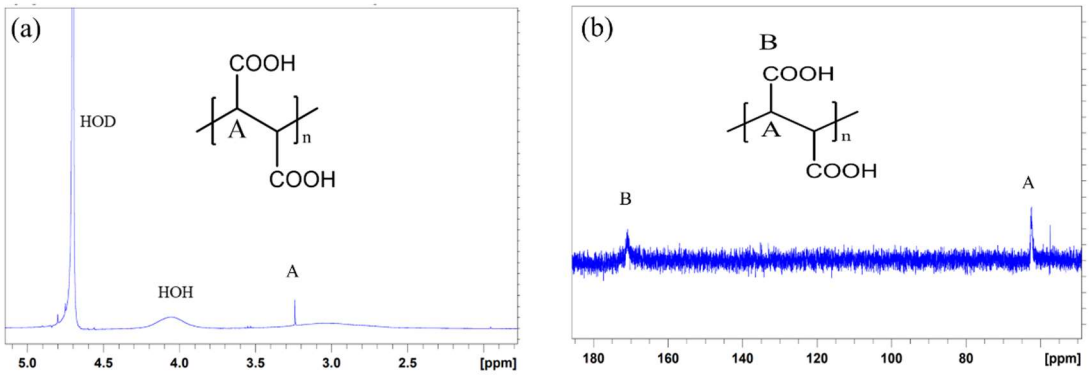

Figure S1: (a) ^{1}H NMR and (b) ^{13}C NMR of PFA.

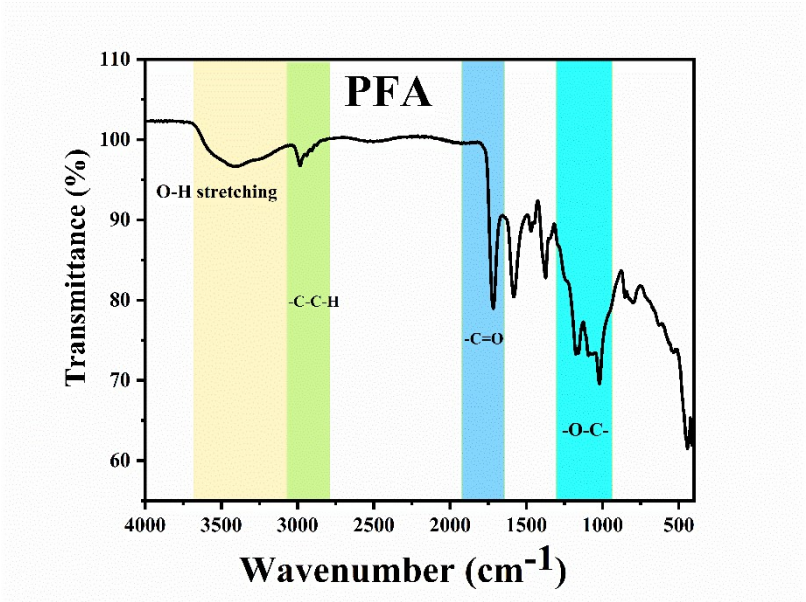

Figure S2: FT-IR profile of PFA.

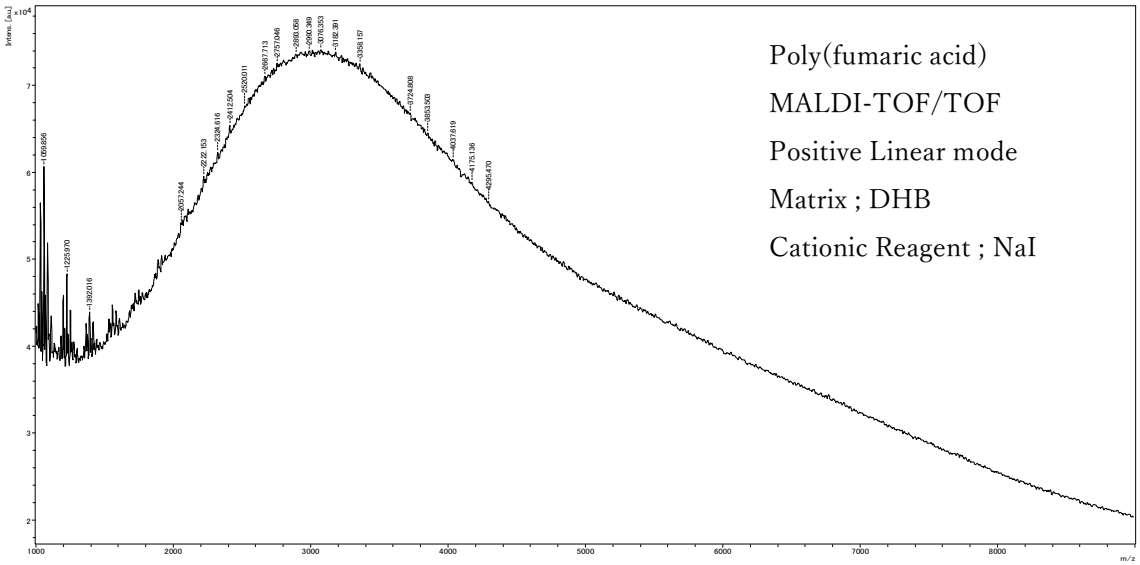

Figure S3: MALDI-TOF data of PFA.

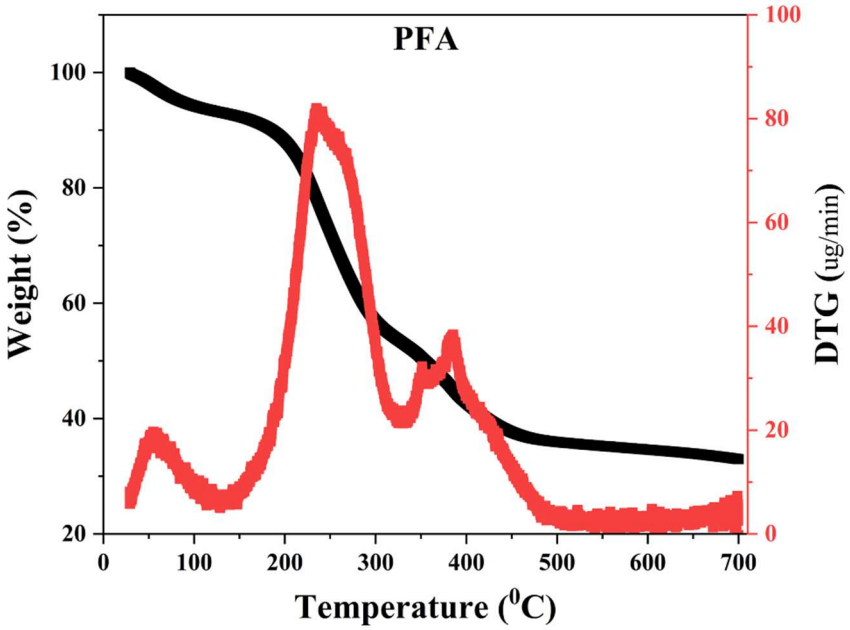

Figure S4: TGA profile of PFA.

Table S1: After CV EIS circuit fitting values of anodic half-cells

Half cells	R_{int}	R_{SEI}	R_{CT}	W	χ^2	Circuit
PFA/HC	1.807	18.1	673.4	0.008354	2.33E-03	RL(QR)(QR)W
PAA/HC	1.81	22.39	4051	0.1843	6.60E-03	RL(QR)(QR)W
PVDF/HC	2.981	31.67	2136	0.008169	1.60E-03	RL(QR)(QR)W

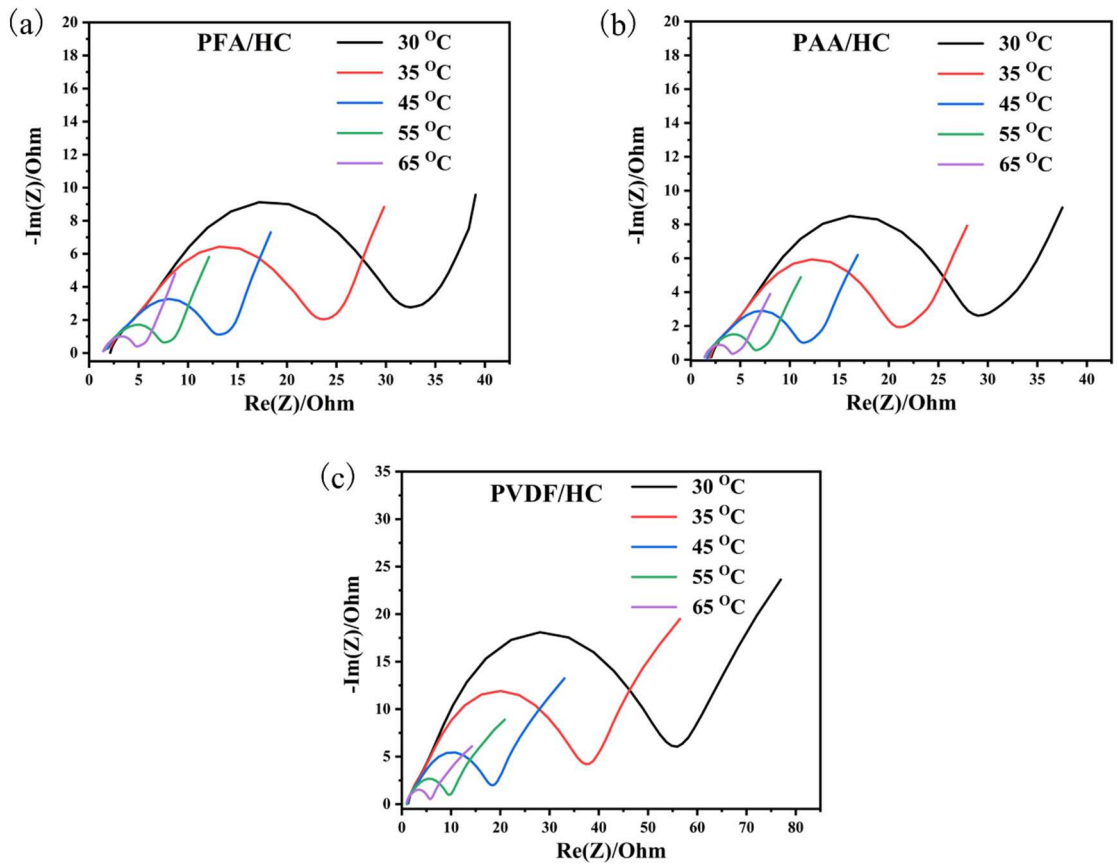

Figure S5: EIS measurement of anodic half-cells (a) PFA/HC, (b) PAA/HC and (c) PVDF/HC at different temperatures.

Table S2: EIS circuit fitting values of anodic half cells at different temperatures.

PFA/HC						
Temp/K	R_{int}	R_{SEI}	R_{CT}	W	χ^2	Circuit
303	2.259	2.447	26.81	0.1016	1.59E-03	R(QR)(QR)W
308	2.081	2.225	18.58	0.1164	4.97E-04	R(QR)(QR)W
318	1.855	1.09	9.878	0.1447	6.68E-04	R(QR)(QR)W
328	1.63	0.6573	5.268	0.1757	9.15E-04	R(QR)(QR)W
338	1.39	0.2406	3.401	0.2143	1.33E-03	R(QR)(QR)W
PAA/HC						
Temp/K	R_{int}	R_{SEI}	R_{CT}	W	χ^2	Circuit
303	2.121	2.182	24.21	0.09809	9.56E-04	R(QR)(QR)W

308	1.999	1.627	17.15	0.1172	1.03E-03	R(QR)(QR)W
318	1.739	1.012	8.557	0.1533	1.34E-03	R(QR)(QR)W
328	1.519	0.5291	4.657	0.1937	6.95E-04	R(QR)(QR)W
338	1.33	0.4017	2.815	0.2471	7.48E-04	R(QR)(QR)W
PVDF/HC						
Temp/K	R_{int}	R_{SEI}	R_{CT}	W	χ^2	Circuit
303	1.382	2.149	48.91	0.03752	1.86E-03	R(QR)(QR)W
308	1.304	1.81	32.28	0.04316	1.90E-03	R(CR)(QR)W
318	1.235	1.405	14.75	0.05982	2.13E-03	R(QR)(QR)W
328	1.057	1.148	6.98	0.08079	3.06E-03	R(QR)(QR)W
338	0.8974	0.5047	4.692	0.1745	1.30E-03	R(QR)(QR)W

Table S3: Specific capacity values at different current densities of PFA/HC, PAA/HC and PVDF/HC.

Current density	PFA/HC	PAA/HC	PVDF/HC
10 mA/g	332	316	208
20 mA/g	313	289	189
30 mA/g	303	268	163
60 mA/g	251	200	107
150 mA/g	132	111	68
200 mA/g	119	105	67

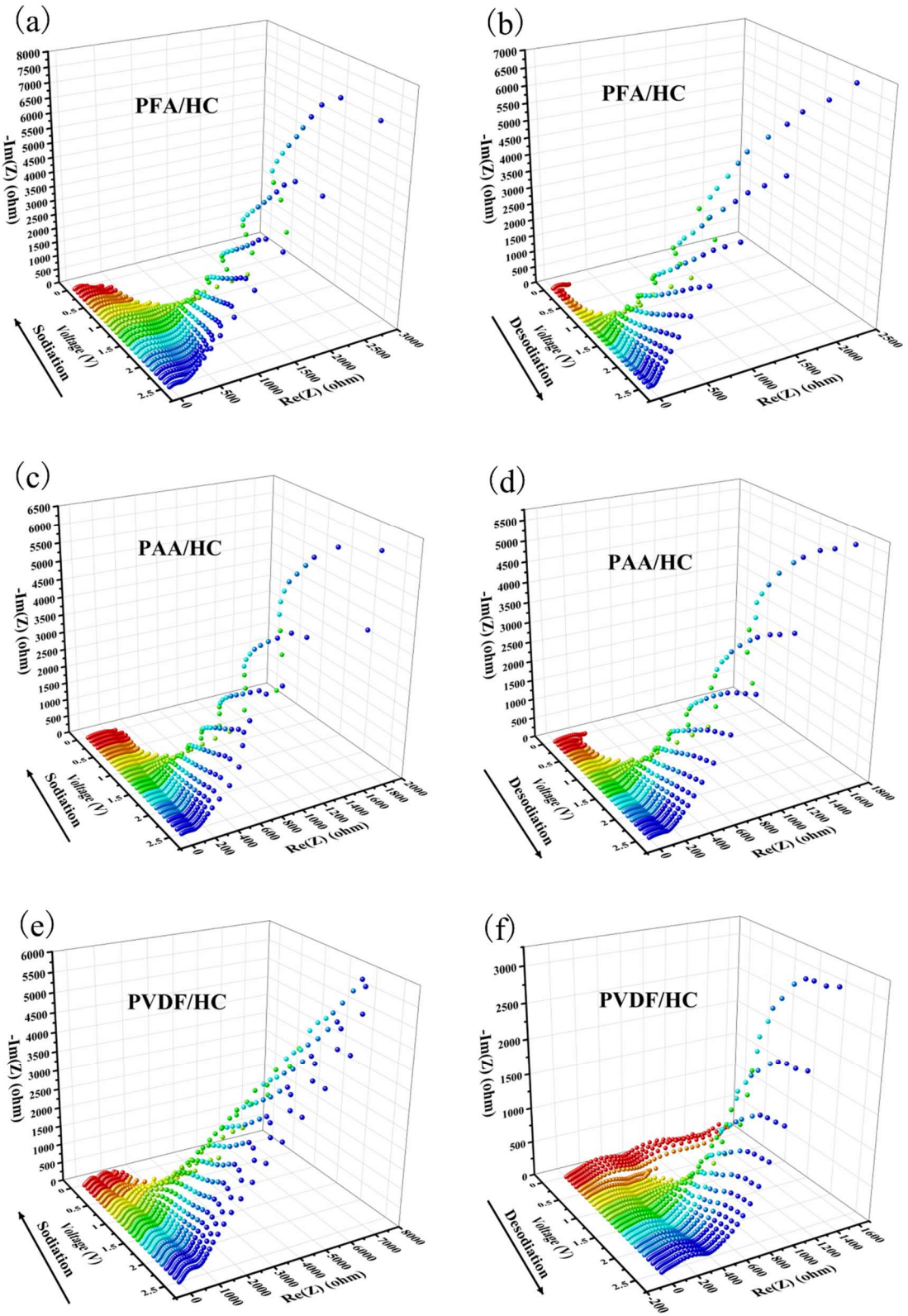

Figure S6: DEIS plot at different potential range of PFA/HC, PAA/HC and PVDF/HC during sodiation and desodiation.

Table S4: DEIS circuit fitting values of PFA/HC sodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.365	1.719	37.62	124.2	0.5427	1.79E-04	RL(QR)(QR)(QR)W
0.11	2.354	1.437	148.8	206.6	1.42E+11	6.88E-04	RL(QR)(QR)(QR)W
0.209	2.372	1.519	229.9	234	9.04E+06	1.72E-03	RL(QR)(QR)(QR)W
0.309	2.352	1.556	235.9	240.6	4.21E+06	1.31E-03	RL(QR)(QR)(QR)W
0.408	2.35	1.579	236	252.5	3.50E+05	1.37E-03	RL(QR)(QR)(QR)W
0.508	1.962	0.8489	280.2	1.43E+11	5.96E+09	2.81E-03	RL(QR)(QR)(QR)W
0.608	2.385	1.732	188.3	251.1	0.074	7.36E-04	RL(QR)(QR)(QR)W
0.807	2.455	0.9483	215.5	329.1	0.04566	1.48E-03	RL(QR)(QR)(CR)W
0.907	2.449	1.765	291.2	372.6	0.04383	2.52E-04	RL(QR)(QR)(QR)W
1.01	2.438	1.734	340.2	600.9	0.07672	1.84E-04	RL(QR)(QR)(QR)W
1.11	2.444	1.574	384.4	1274	1.38E+19	2.16E-04	RL(QR)(QR)(QR)W
1.21	2.385	2.605	419.1	4170	1.60E+06	4.99E-04	RL(QR)(QR)(QR)W
1.3	2.415	2.309	421.1	1638	0.002178	6.61E-04	RL(QR)(QR)(QR)W
1.4	2.409	2.363	419.1	1.03E+04	0.002334	8.74E-04	RL(QR)(QR)(QR)W
1.5	2.731	1.663	415.1	2.61E+04	0.002432	1.20E-03	RL(QR)(QR)(CR)W
1.6	2.465	2.32	399.3	5.10E+04	0.00242	1.18E-03	RL(QR)(QR)(QR)W
1.7	2.411	2.366	386.3	5.03E+0	0.002424	1.22E-	RL(QR)(QR)(QR)

				4		03	W
1.8	2.745	1.65	374	6.16E+04	0.002397	1.38E-03	RL(QR)(QR)(CR)W
1.9	2.42	2.413	355.3	7.51E+04	0.002343	1.16E-03	RL(QR)(QR)(QR)W
2	2.351	2.59	339.5	6.89E+04	0.002329	1.08E-03	RL(QR)(QR)(QR)W
2.1	2.756	1.676	324.8	6.81E+04	0.002333	1.12E-03	RL(QR)(QR)(CR)W
2.2	2.692	1.939	304.3	7.13E+04	0.002317	9.44E-04	RL(QR)(QR)(QR)W
2.3	2.697	1.995	278.8	6.53E+04	0.002332	8.55E-04	RL(QR)(QR)(QR)W
2.4	2.1	3.272	232.3	4.97E+04	0.002381	7.40E-04	RL(QR)(QR)(QR)W
2.5	2.589	2.376	143.1	1.85E+04	0.002629	1.23E-03	RL(QR)(QR)(QR)W

Table S5: DEIS circuit fitting values of PFA/HC desodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.545	1.116	79.1	86.3	0.2147	3.82E-04	RL(QR)(QR)(CR)W
0.11	2.415	2.34	11.5	46.04	0.2457	3.90E-04	RL(QR)(QR)(QR)W
0.209	1.695	10.27	26.29	62.31	1.29E+08	6.02E-04	RL(QR)(QR)(QR)W
0.309	1.575	9.4	29.65	132	3.11E+07	3.40E-04	RL(QR)(QR)(QR)W
0.408	1.394	9.128	142.7	35.67	2.22E+07	3.50E-04	RL(QR)(QR)(QR)W
0.508	1.156	9.011	12.47	47.45	4.16E+06	4.59E-04	RL(QR)(QR)(QR)W
0.608	2.435	1.804	18.87	21.1	0.08354	1.40E-04	RL(QR)(QR)(QR)W

0.707	2.594	1.456	18.59	23.08	0.06783	1.63E-04	RL(QR)(QR)(QR)W
0.807	2.557	1.35	22	46.23	0.05167	8.10E-05	RL(QR)(QR)(CR)W
0.907	2.546	1.342	22.63	80.81	0.03703	9.53E-05	RL(QR)(QR)(CR)W
1.01	2.383	1.966	22.75	160.9	0.02413	1.44E-04	RL(QR)(QR)(QR)W
1.11	2.33	2.165	23.11	359.7	0.01376	1.74E-04	RL(QR)(QR)(QR)W
1.21	2.398	1.768	27.68	2007	0.02313	1.01E-04	RL(QR)(QR)(QR)W
1.3	2.379	1.795	28.62	5982	0.0148	1.16E-04	RL(QR)(QR)(QR)W
1.4	2.361	1.814	29.33	1.28E+04	1.28E-02	1.71E-04	RL(QR)(QR)(QR)W
1.6	2.349	1.823	32.26	2.55E+04	0.01142	1.93E-04	RL(QR)(QR)(QR)W
1.7	2.33	1.821	32.23	3.07E+04	0.01124	1.93E-04	RL(QR)(QR)(QR)W
1.8	2.325	1.797	34	3.42E+04	0.01092	2.19E-04	RL(QR)(QR)(QR)W
1.9	2.342	1.698	34.78	3.64E+04	0.01053	2.53E-04	RL(QR)(QR)(QR)W
2	2.345	1.679	35.94	4.12E+04	0.01029	2.66E-04	RL(QR)(QR)(QR)W
2.1	2.354	1.61	37.12	3.92E+04	0.01021	2.55E-04	RL(QR)(QR)(QR)W
2.2	2.517	1.19	38.47	3.98E+04	0.01032	3.22E-04	RL(QR)(QR)(QR)W
2.3	2.016	9.975	37.5	4491	0.01363	7.82E-04	RL(QR)(QR)(CR)W
2.4	2.468	1.107	40.56	3.69E+04	0.001046	2.57E-04	RL(QR)(QR)(CR)W
2.5	2.348	1.523	39.56	3.15E+04	0.009525	3.48E-04	RL(QR)(QR)(QR)W

Table S6: DEIS circuit fitting values of PAA/HC sodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.287	19.81	60.84	168.8	0.1727	9.90E-05	RL(QR)(QR)(QR)W
0.11	2.047	50.04	106.2	172.5	2.148	1.24E-04	RL(QR)(QR)(QR)W
0.209	2.26	33.6	43.78	193.4	0.09581	6.91E-05	RL(QR)(QR)(QR)W
0.309	2.272	25.51	36.49	192.1	0.07324	4.88E-05	RL(QR)(QR)(QR)W
0.408	2.269	20.79	28.38	193.3	0.06476	4.96E-05	RL(QR)(QR)(QR)W
0.508	2.288	19.18	23.79	187	0.05677	5.38E-05	RL(QR)(QR)(QR)W
0.608	2.285	18.56	18.71	191.7	0.05165	3.99E-05	RL(QR)(QR)(QR)W
0.807	2.261	41.17	66.59	122.8	0.03645	6.83E-05	RL(QR)(QR)(QR)W
0.907	2.282	53.38	65.45	133.4	0.02846	1.37E-04	RL(QR)(QR)(QR)W
1.01	2.295	51.81	105.2	121.3	0.02067	1.05E-04	RL(QR)(QR)(QR)W
1.11	2.337	46.32	115.1	218.1	0.01296	1.57E-04	RL(QR)(QR)(QR)W
1.21	2.386	49.35	104.9	2365	9.75E+07	2.50E-04	RL(QR)(QR)(QR)W
1.3	2.304	31.73	127.8	8415	6.38E+10	1.06E-04	RL(QR)(QR)(QR)W
1.4	2.339	34.91	118.5	2.31E+04	0.0138	1.32E-04	RL(QR)(QR)(QR)W
1.5	2.296	41.66	107.1	3.72E+04	0.009627	1.42E-04	RL(QR)(QR)(QR)W
1.6	2.315	48.56	97.12	5.15E+04	0.008618	1.51E-04	RL(QR)(QR)(QR)W
1.7	2.329	54.56	87.99	6.25E+0	0.007831	1.40E-	RL(QR)(QR)(QR)

				4		04	W
1.8	2.213	49.12	159.5	1.01E+05	4.07E+06	1.45E-04	RL(QR)(QR)(QR)W
1.9	2.315	54.99	80.95	8.07E+04	0.007148	1.33E-04	RL(QR)(QR)(QR)W
2	2.298	65.54	66.48	8.14E+04	0.006817	1.23E-04	RL(QR)(QR)(QR)W
2.1	2.287	58.21	70.28	8.04E+04	0.006509	1.10E-04	RL(QR)(QR)(QR)W
2.2	2.223	63.02	145.7	1.36E+05	5.56E+06	1.31E-04	RL(QR)(QR)(QR)W
2.3	2.446	32.61	88.68	6.04E+04	0.005608	7.54E-05	RL(QR)(QR)(QR)W
2.4	2.359	57.98	134.1	6.69E+04	2.94E+09	8.10E-05	RL(QR)(QR)(QR)W
2.5	2.485	26.04	119.2	1.21E+05	2.33E+05	1.43E-03	RL(QR)(QR)(QR)W

Table S7: DEIS circuit fitting values of PAA/HC desodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.346	17.33	44.61	185.7	0.1766	4.58E-05	RL(QR)(QR)(QR)W
0.11	2.591	13.05	19.6	141.5	0.1573	5.19E-05	RL(QR)(QR)(QR)W
0.209	2.666	16.35	113	248	0.6655	5.24E-04	RL(QR)(QR)(QR)W
0.309	2.598	12.2	97.88	117.6	13.36	3.52E-05	RL(QR)(QR)(QR)W
0.408	2.618	7.97	79.62	124.8	0.0738	1.63E-05	RL(QR)(QR)(QR)W
0.508	2.13	2.555	96.91	133.1	0.06544	2.38E-05	RL(QR)(QR)(CR)W
0.608	2.56	6.151	6.408	126.2	0.057	2.41E-05	RL(QR)(QR)(CR)W

0.707	2.114	10.39	137.4	0.5975	0.05051	5.77E-05	RL(QR)(QR)(QR)W
0.807	2.554	9.894	31.36	119	0.04118	2.08E-05	RL(QR)(QR)(QR)W
0.907	2.454	24.01	58.59	102.1	0.03157	2.99E-05	RL(QR)(QR)(QR)W
1.01	2.401	32.65	91.84	115.8	0.02219	6.16E-05	RL(QR)(QR)(QR)W
1.11	2.332	48.07	75.2	225	0.01247	7.80E-05	RL(QR)(QR)(QR)W
1.21	2.293	63.6	65.77	2781	1.34E+08	1.18E-04	RL(QR)(QR)(QR)W
1.3	2.225	41.35	87.96	5383	0.00965	5.94E-05	RL(QR)(QR)(QR)W
1.4	2.263	43.81	84.81	1.65E+04	0.008158	8.29E-05	RL(QR)(QR)(QR)W
1.6	2.25	37.35	94.3	2.89E+04	0.007061	7.97E-05	RL(QR)(QR)(QR)W
1.7	2.293	44.92	79.33	1.98E+04	5.44E-03	2.14E-04	RL(QR)(QR)(CR)W
1.8	2.255	38.54	94.24	3.84E+04	0.006341	1.23E-04	RL(QR)(QR)(QR)W
1.9	2.248	36.56	95.32	4.25E+04	0.006198	1.22E-04	RL(QR)(QR)(QR)W
2	2.243	36.67	95.54	4.41E+04	0.005946	1.29E-04	RL(QR)(QR)(QR)W
2.1	2.31	41.04	88.94	2.97E+04	0.004959	1.97E-04	RL(QR)(QR)(CR)W
2.2	2.275	40.11	90.94	3.11E+04	0.004794	1.96E-04	RL(QR)(QR)(CR)W
2.3	2.179	23.98	113.2	4.49E+04	0.005645	1.46E-04	RL(QR)(QR)(CR)W
2.4	2.276	40.51	91.79	2.76E+04	0.004534	2.53E-04	RL(QR)(QR)(CR)W
2.5	2.297	38.94	93.11	2.48E+04	0.004405	2.80E-04	RL(QR)(QR)(CR)W

Table S8: DEIS circuit fitting values of PVDF/HC sodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.19	162.7	321.9	519.8	2.23E-02	1.78E-04	RL(QR)(QR)(QR)W
0.11	2.266	149.4	353.1	444.7	1.23E-02	3.40E-05	RL(QR)(QR)(QR)W
0.209	2.294	142.7	367.3	421.8	9.65E-03	4.27E-05	RL(QR)(QR)(QR)W
0.309	2.321	136.6	386.2	434.3	9.15E-03	3.14E-05	RL(QR)(QR)(QR)W
0.408	2.346	130.7	398.3	448	8.29E-03	8.05E-05	RL(QR)(QR)(QR)W
0.508	2.372	130.7	417.3	534.9	8.82E-03	7.11E-05	RL(QR)(QR)(QR)W
0.608	2.363	129	423.3	673.1	8.73E-03	7.16E-05	RL(QR)(QR)(QR)W
0.807	2.395	131	498.7	1052	6.22E-03	1.08E-04	RL(QR)(QR)(QR)W
0.907	2.363	132.3	504.2	1428	5.45E-03	1.12E-04	RL(QR)(QR)(QR)W
1.01	2.338	130.2	527	1854	4.80E-04	6.95E-05	RL(QR)(QR)(QR)W
1.11	2.295	130.2	525.5	2823	4.60E-02	5.24E-05	RL(QR)(QR)(QR)W
1.21	2.224	127.5	518.1	3426	2.43E-03	5.07E-05	RL(QR)(QR)(QR)W
1.3	1.637	185.7	357.4	1.24E+04	3.35E+11	4.25E-04	RL(QR)(QR)(CR)W
1.4	2.132	123.9	490.2	6972	1.87E-03	4.89E-05	RL(QR)(QR)(QR)W
1.5	1.491	189.2	363.8	1.05E+04	1.83E-03	3.94E-04	RL(QR)(QR)(CR)W
1.6	1.458	186.7	1.26E+04	362.5	1.71E-03	4.10E-04	RL(QR)(QR)(CR)W
1.7	2.054	114.7	472.5	2831	7.46E-04	3.45E	RL(QR)(QR)(QR)

						-05	W
1.8	2.045	114.1	465.5	2608	7.03E-04	3.22E-05	RL(QR)(QR)(QR)W
1.9	2.045	110.1	441.6	956.3	5.67E-04	8.12E-05	RL(QR)(QR)(CR)W
2	1.458	168.2	352.5	1037	5.41E-04	3.51E-04	RL(QR)(QR)(CR)W
2.1	1.521	161	347.3	960.4	5.11E-04	3.35E-04	RL(QR)(QR)(CR)W
2.2	2.015	113.5	411.3	1220	5.10E-04	1.48E-04	RL(QR)(QR)(CR)W
2.3	2.061	113.4	423.9	1155	5.17E-04	1.21E-04	RL(QR)(QR)(CR)W
2.4	1.521	166.7	869.7	361.8	5.34E-04	3.69E-04	RL(QR)(QR)(CR)W
2.5	1.537	180.2	342.5	2.45E+04	5.79E-03	4.09E-04	RL(QR)(QR)(CR)W

Table S9: DEIS circuit fitting values of PVDF/HC desodiation.

V	R_{int}	R_{SEI}	R_{CT}	R_{diff}	W	χ^2	Circuit
0.001	2.35	156.8	349.5	513.3	1.98E-02	3.85E-05	RL(QR)(QR)(QR)W
0.11	2.437	154	354.4	609.2	1.95E-02	4.88E-05	RL(QR)(QR)(QR)W
0.209	2.492	146.6	358.5	588.6	9.46E-04	5.13E-05	RL(QR)(QR)(QR)W
0.309	2.464	152.4	324.9	681.3	9.03E-03	1.24E-04	RL(QR)(QR)(QR)W
0.408	2.497	141.6	352.4	527.7	8.74E-03	1.96E-04	RL(QR)(QR)(QR)W
0.508	2.448	139.1	162.5	235.6	2.79E-02	1.56E-04	RL(QR)(QR)(QR)W
0.608	2.385	121	148.3	177.1	2.58E-02	7.17E-05	RL(QR)(QR)(QR)W

0.707	0.04427	99.48	376.9	1.07(0.6609)	3.21E-02	7.20E-04	RL(QR)(QR)(QR)W
0.807	2.274	119.9	159.3	275.2	3.63E-02	1.19E-04	RL(QR)(QR)(QR)W
0.907	2.246	133.6	161.8	267.2	2.96E-02	8.85E-05	RL(QR)(QR)(QR)W
1.01	2.479	72.19	136.6	289.5	1.62E-02	4.84E-04	RL(QR)(QR)(CR)W
1.11	2.203	153.9	154	265.9	1.26E-02	5.20E-05	RL(QR)(QR)(QR)W
1.21	2.292	110.4	122.1	203.5	5.54E-03	7.29E-04	RL(QR)(QR)(CR)W
1.3	2.127	133.1	163	1410	3.52E-03	5.05E-05	RL(QR)(QR)(QR)W
1.4	2.152	141.1	156.6	1.18E+04	3.64E-03	6.90E-05	RL(QR)(QR)(QR)W
1.6	1.693	89.14	222.5	2.51E+04	3.81E-03	2.24E-04	RL(QR)(QR)(CR)W
1.7	2.221	140.5	169.1	2.77E+05	3.87E-03	2.20E-04	RL(QR)(QR)(QR)W
1.8	1.604	96.44	232.3	1.38E+05	3.79E-03	3.34E-04	RL(QR)(CR)(CR)W
1.9	2.235	134.7	196.5	6.51E+05	3.79E-03	3.26E-04	RL(QR)(QR)(QR)W
2	1.427	121.1	218.4	9.82E+13	3.72E-03	4.51E-04	RL(QR)(QR)(QR)W
2.1	2.418	120	228.3	1.71E+05	3.50E-03	4.18E-04	RL(QR)(QR)(QR)W
2.2	2.348	126.5	228.8	2.60E+05	3.36E-03	4.19E-04	RL(QR)(QR)(QR)W
2.3	2.405	125.2	237.2	4.03E+05	3.27E-03	4.30E-04	RL(QR)(QR)(QR)W
2.4	2.179	137.7	229.1	1.35E+05	3.19E-03	4.77E-04	RL(QR)(QR)(QR)W
2.5	2.376	129	239.5	8.04E+04	3.10E-03	5.67E-04	RL(QR)(QR)(QR)W

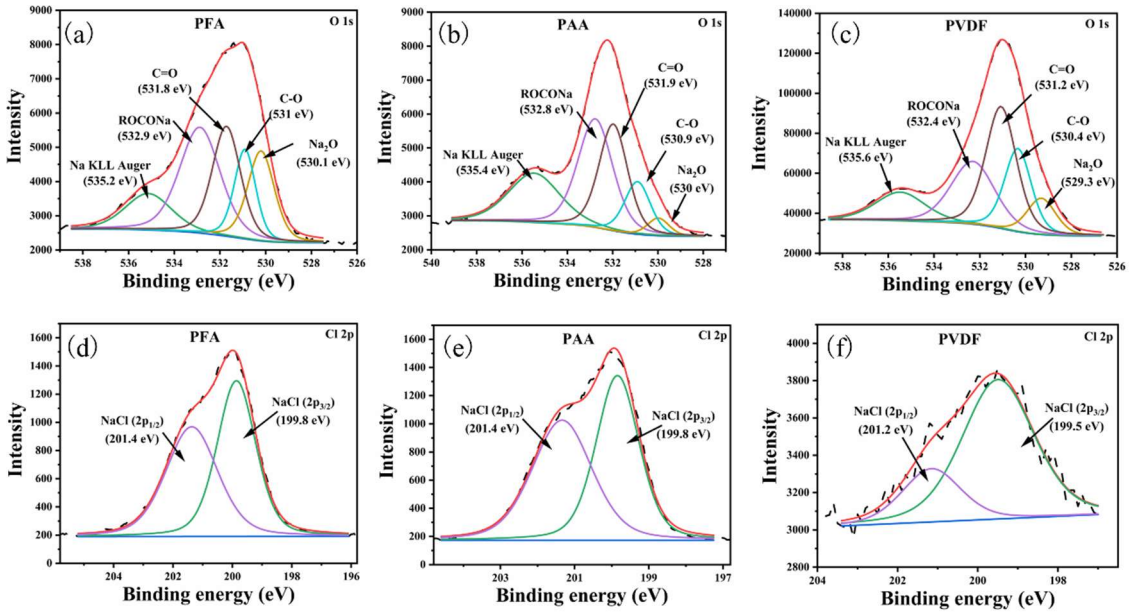

Figure S7: XPS analysis of O 1s and Cl 2p of cycled HC electrode containing different binders.

Table S10: Elemental composition percentage obtained from area under the curve of the C 1s XPS spectra.

Elemental species	PFA	PAA	PVDF
C=C	13.3%		
C-C	33.1%	60.5%	56.8%
C-O	24.8%	28.5%	16.5%
C=O	16.8%	6.3%	9%
Na_2CO_3	11.7%	4.5%	8.5%
C-F			8.9%

Table S11: Elemental composition percentage obtained from area under the curve of the O 1s XPS spectra.

Elemental species	PFA	PAA	PVDF
Na_2O	20.9%	3.4%	9.3%
C-O	18.6%	12.2%	20%
C=O	22.9%	27.5%	33.3%
ROCONa	24.4%	34%	24.5%
Na KLL Auger	13%	22.7%	12.6%

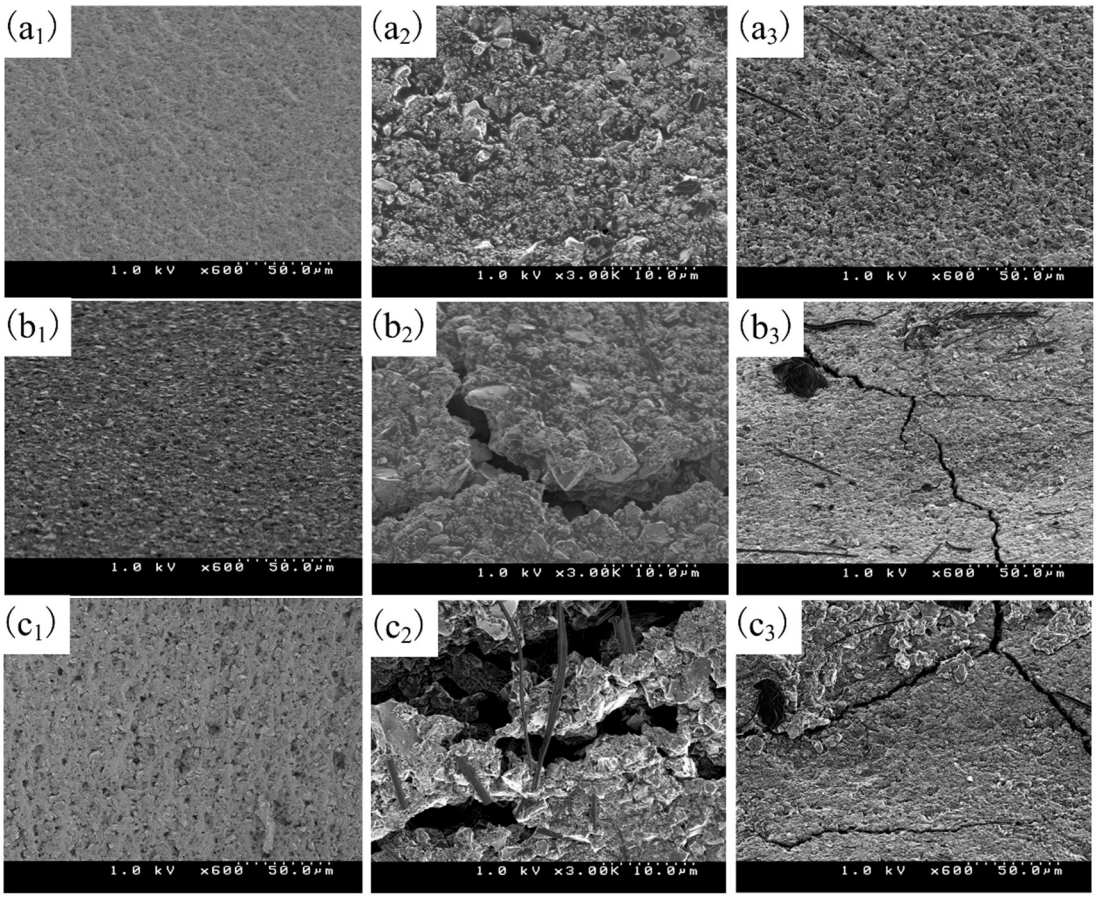

Figure S8: Top view SEM images of pristine HC electrodes with (a_1) PFA, (b_1) PAA and (c_1) PVDF binders. Top view SEM images of cycled HC electrodes with (a_2)(a_3) PFA, (b_2)(b_3) PAA and (c_2)(c_3) PVDF binders at two different magnifications (10 μm and 50 μm).

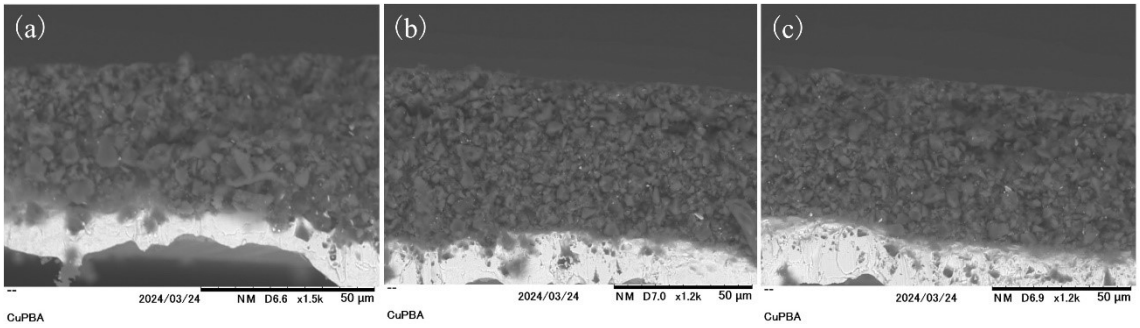

Figure S9: Cross-section view of pristine HC electrodes containing (a) PFA, (b) PAA and (c) PVDF binder.