Supporting Materials

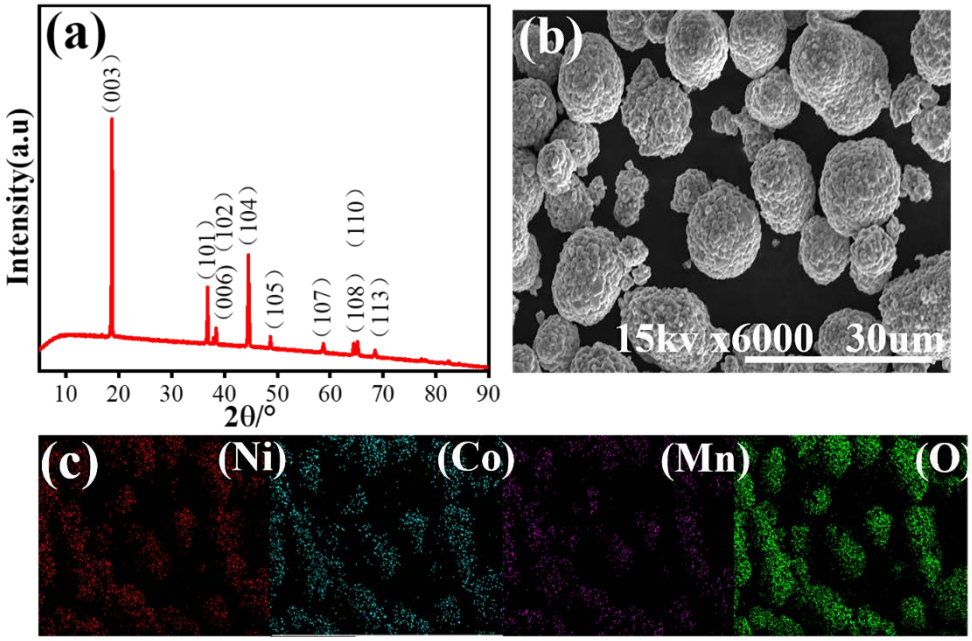

Fig. S1 (a) XRD spectrum, (b) SEM image, and (c) EDS mapping of waste $LiNi_xCo_yMn_zO_2$ cathode materials.

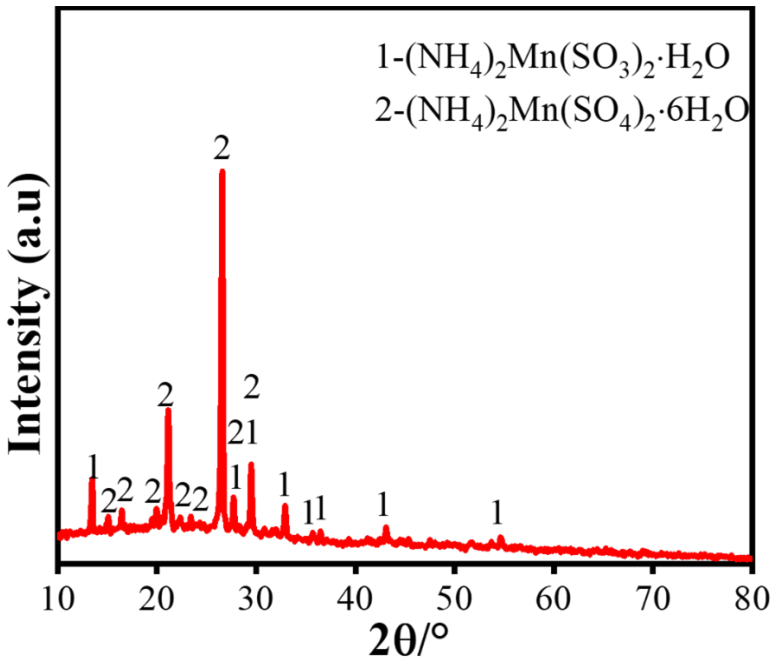

Fig. S2 XRD spectrum of the residue of the ammonia leaching process.

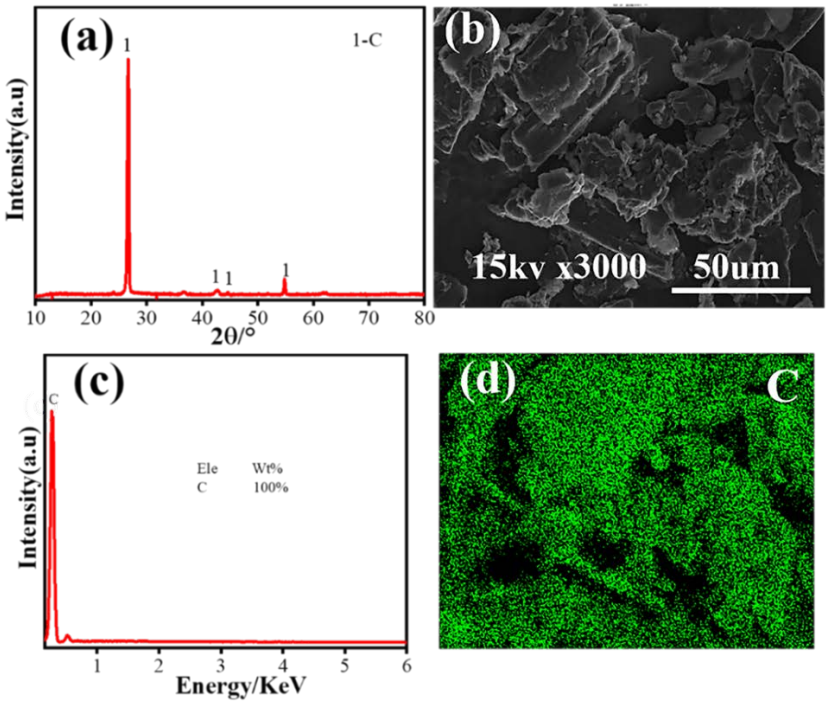

Fig. S3 (a) XRD spectrum, (b) SEM image and (c, d) ESD of sulfuric acid leaching residue.

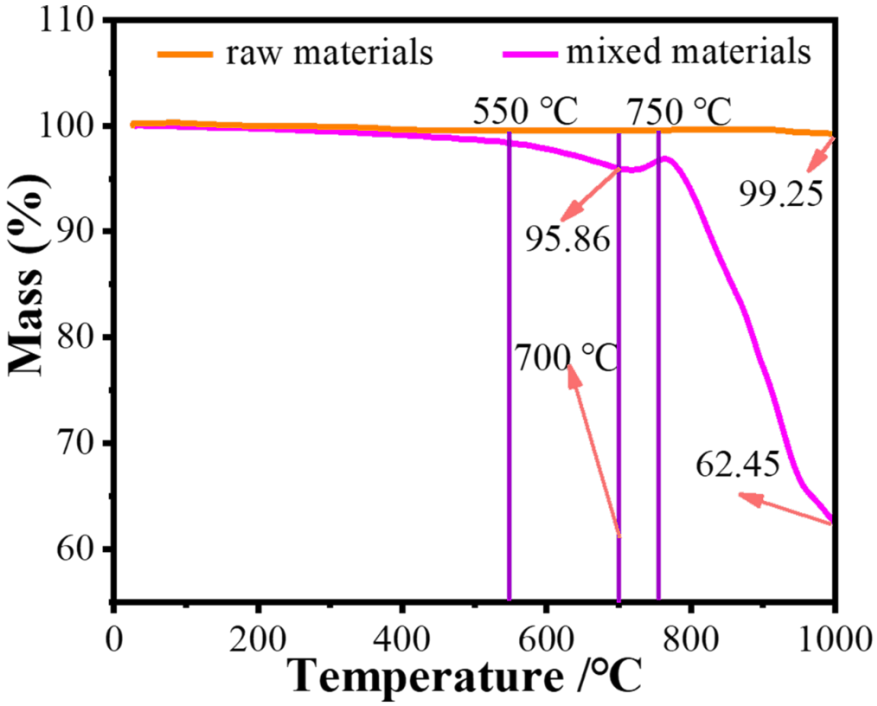

Fig. S4 TG curves of the raw and mixed materials.

Table S1 Response surface design of experiments and the corresponding results.

Serial number	Factor 1 A: A (mol/L)	Factor2 B: B (mol/L)	Factor 3 C: C (mL/g)	Response1 nickel (%)	Response 2 cobalt (%)	Response 3 manganese (%)
1	1.5	2.5	60	96.3988	91.7392	0.325529
2	1.5	2.5	60	93.2364	94.6419	0.486069
3	0	2.5	100	4.29677	4.90473	0.00486531
4	3	2.5	100	99.9398	99.3991	5.44502
5	1.5	0	100	81.5269	15.8428	1.94356
6	1.5	5	100	99.9922	99.9508	8.08081
7	0	0	60	3.03635	2.61904	0.0234540
8	1.5	0	20	55.8942	4.64277	1.50071
9	1.5	2.5	60	96.4501	99.1184	1.13053
10	1.5	5	20	68.3682	38.1826	0.547940
11	3	0	60	71.7428	11.5235	2.54459
12	0	2.5	20	0.111406	0.0188092	0.00202000
13	0	5	60	0.133251	2.94524	0.00808800
14	3	2.5	20	70.4478	25.1658	0.219783
15	1.5	2.5	60	99.0922	99.9746	1.04356
16	1.5	2.5	60	99.9334	95.4456	0.239800
17	3	5	60	99.9987	99.4752	6.91496

Table S2 Analysis of variance and significance test of the regression coefficients of the nickel quadric model.

Source	Sum of Squares	df	Mean Square	F value	P value
Model	25033.48	9	2781.50	190.87	< 0.0001
A–A	13989.07	1	13989.07	959.93	< 0.0001
B–B	396.35	1	396.35	27.20	0.0012
C–C	1033.62	1	1033.62	70.93	< 0.0001
AB	243.00	1	243.00	16.67	0.0047
AC	160.11	1	160.11	10.99	0.0129
BC	8.97	1	8.97	0.6158	0.4583
A^2	7793.47	1	7793.47	534.79	< 0.0001
B^2	444.63	1	444.63	30.51	0.0009
C^2	446.74	1	446.74	30.66	0.0009
Residual	102.01	7	14.57		
Lack of Fit	74.20	3	24.73	3.56	0.1259
Pure Error	27.81	4	6.95		
Cor Total	25135.49	16			

Table S3 Analysis of variance and significance test of the regression coefficients of the cobalt quadric model.

Source	Sum of Squares	df	Mean Square	F value	P value
Model	32287.27	9	3587.47	136.90	< 0.0001
A–A	6332.39	1	6332.39	241.64	< 0.0001
B–B	5300.68	1	5300.68	202.27	< 0.0001
C–C	2891.32	1	2891.32	110.33	< 0.0001
AB	1919.56	1	1919.56	73.25	< 0.0001
AC	1202.26	1	1202.26	45.88	0.0003
BC	639.28	1	639.28	24.39	0.0017
A^2	5506.34	1	5506.34	221.90	< 0.0001
B^2	3759.29	1	3759.29	143.45	< 0.0001
C^2	2990.17	1	2990.17	114.10	< 0.0001
Residual	183.44	7	26.21		
Lack of Fit	137.78	3	45.93	4.02	0.1060
Pure Error	45.66	4	11.41		
Cor Total	32470.71	16			

Table S4 Analysis of variance and significance test of the regression coefficients of the manganese quadric model.

Source	Sum of Squares	df	Mean Square	F value	P value
Model	100.31	9	11.15	22.34	0.0002
A–A	28.45	1	28.45	57.02	0.0001
B–B	11.38	1	11.38	22.8	0.002
C–C	21.79	1	21.79	43.68	0.0003
AB	4.81	1	4.81	9.64	0.0172
AC	6.82	1	6.82	13.67	0.0077
BC	12.57	1	12.57	25.19	0.0015
A^2	0.0171	1	0.0171	0.0342	0.8585
B^2	11.66	1	11.66	23.37	0.0019
C^2	2.12	1	2.12	4.24	0.0784
Residual	3.49	7	0.4989		
Lack of Fit	2.81	3	0.9355	5.45	0.0674
Pure Error	0.6861	4	0.1715		
Cor Total	103.8	16			