Supplementary material

Recovery of valuable metals from mixed spent lithium-ion batteries by multi-step directional precipitation

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Fig. S1. Flowchart of mechanical disassembly to obtain mixed spent cathode powders.

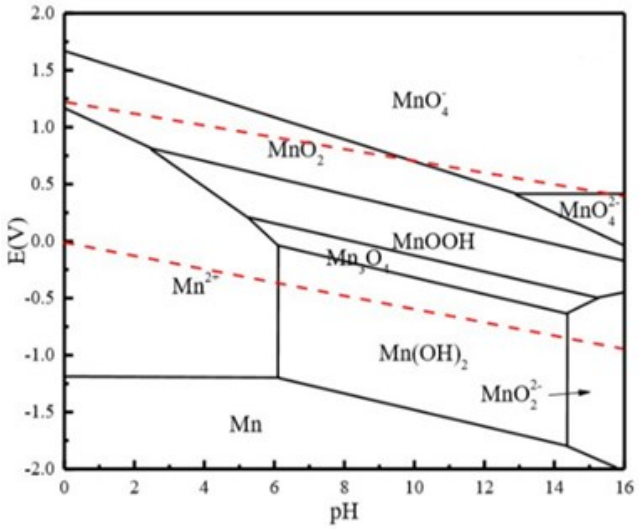

Fig. S2. E−pH diagrams of Mn-H_2O system

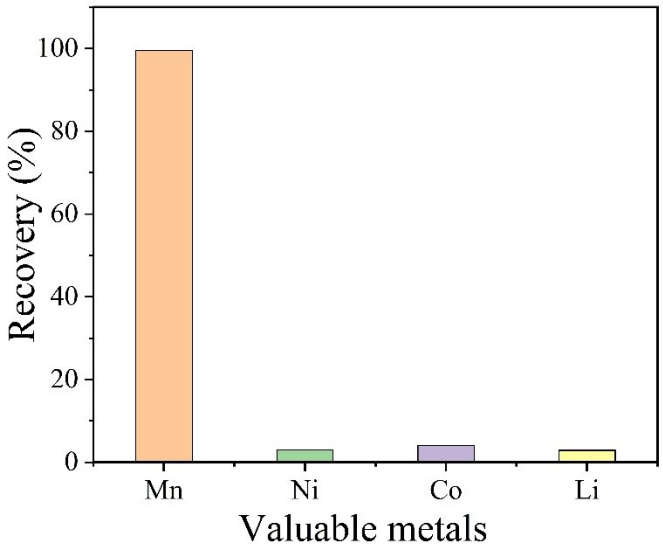

Fig. S3. Recovery rate of Mn, Ni, Co and Li during Mn precipitation separation process.

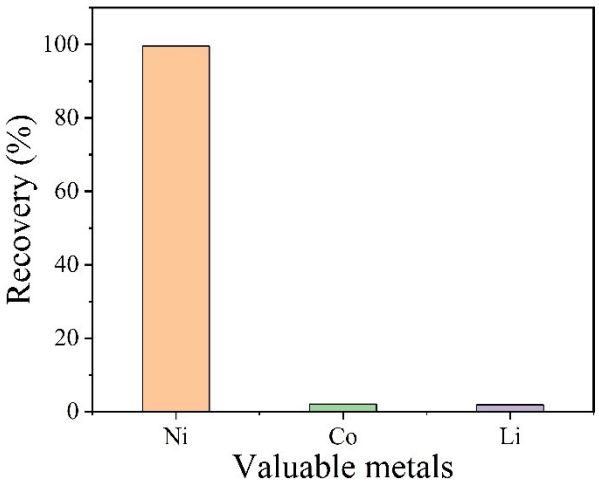

Fig. S4. Recovery rate of Ni, Co and Li during Ni precipitation separation process.

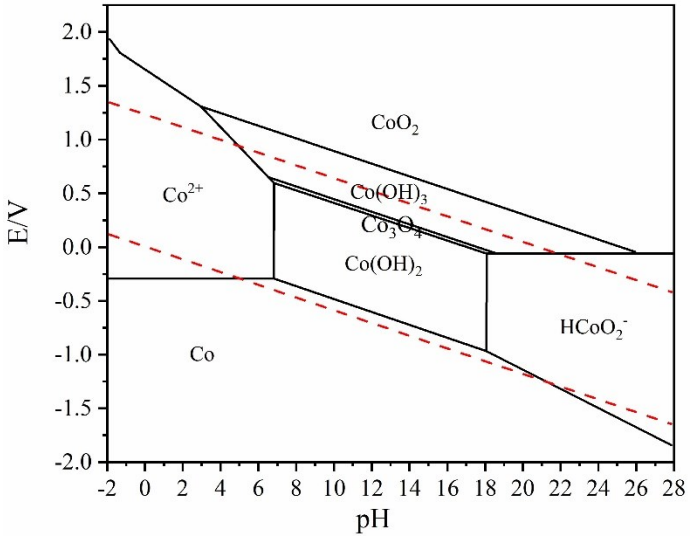

Fig. S5. E−pH diagrams of Co-H_2O system

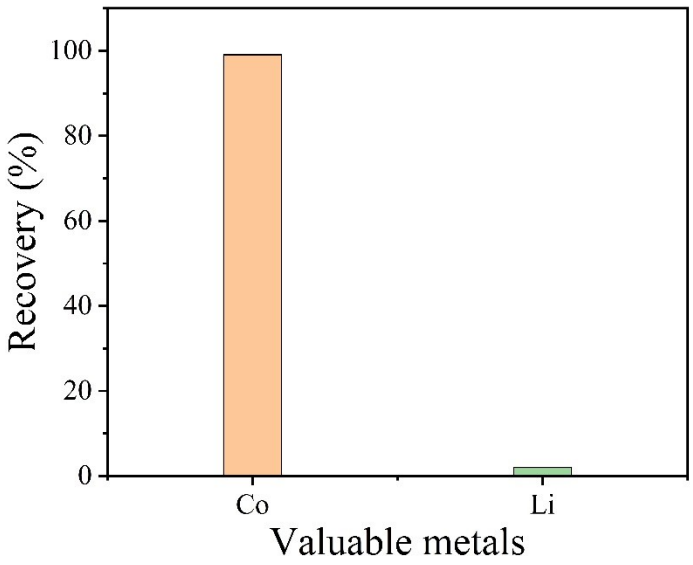

Fig. S6. Recovery rate of Co and Li during Co precipitation separation process.

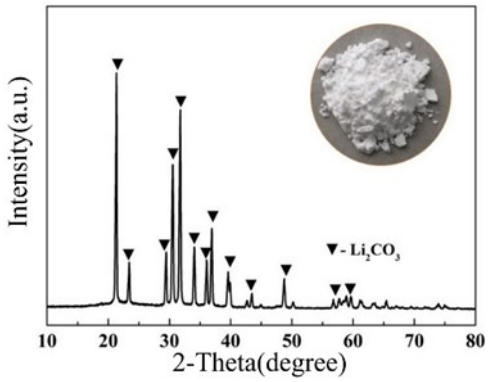

Fig. S7. Images of XRD pattern of the precipitate product after treating with Na_2CO_3

Table S1. Contents of various elements from spent residues.

Element	Li	Ni	Co	Mn	Fe	Cu	Al
Content (%)	5.22	12.06	25.94	9.25	2.86	1.07	0.85

Table S2. Contents of metals in the leaching solution after impurity removal

element	Li	Mn	Ni	Co	Al	Fe	Cu
Contents (g/L)	1.861	3.142	4.512	9.333	0.002	0.004	0.002

Table S3. The change of valuable metal content in leachate during the separation process

Metals / Contents (g/L)	Mn	Ni	Co	Li
Leachate	3.14	4.51	9.33	1.86
After separating Mn	0.02	4.34	9.05	1.83
After separating Ni	<0.02	0.02	8.96	1.80
After separating Co	<0.02	<0.02	0.07	1.76

Table S4. Electrode reaction and standard electrode potential

No.	electrode reactions	Electrode potential
1	$Co^{3+}+e^{-}=Co^{2+}$	+1.83
2	$MnO_2+4H^{+}+2e^{-}=Mn^{2+}+2H_2O$	+1.224
3	$NiO_2+4H^{+}+2e^{-}=Ni^{2+}+2H_2O$	+1.678
4	$S_2O_8^{2-}+2H^{+}+2e^{-}=2HSO_4^{-}$	+2.123
5	$Mn^{3+}+e^{-}=Mn^{2+}$	+1.541