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Perspective

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Recycling of sodium-ion batteries

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Recycling of sodium-ion batteries

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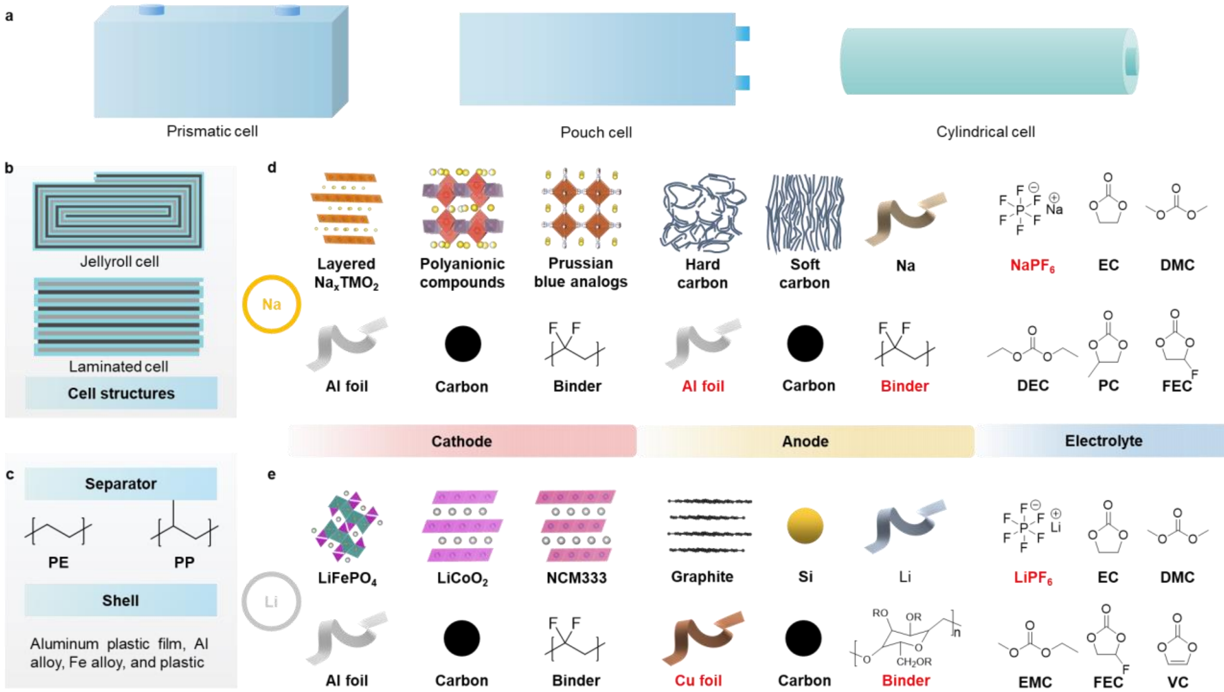
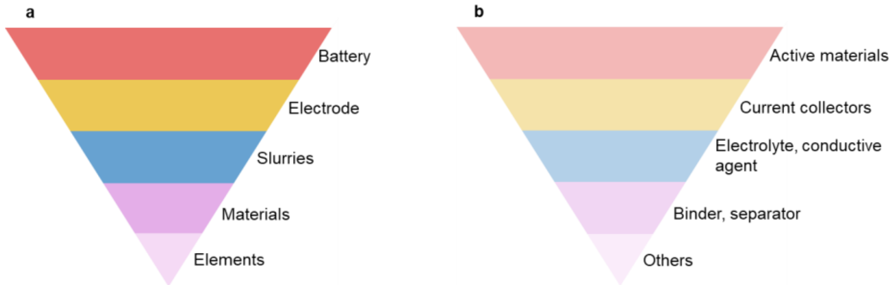
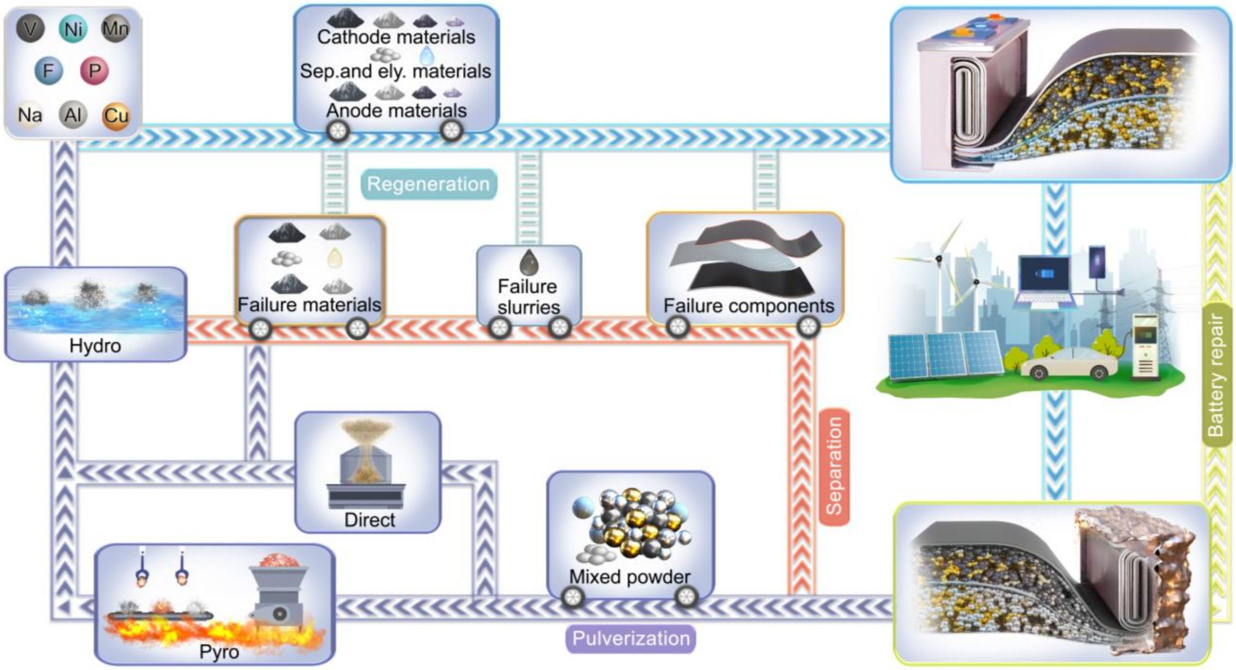


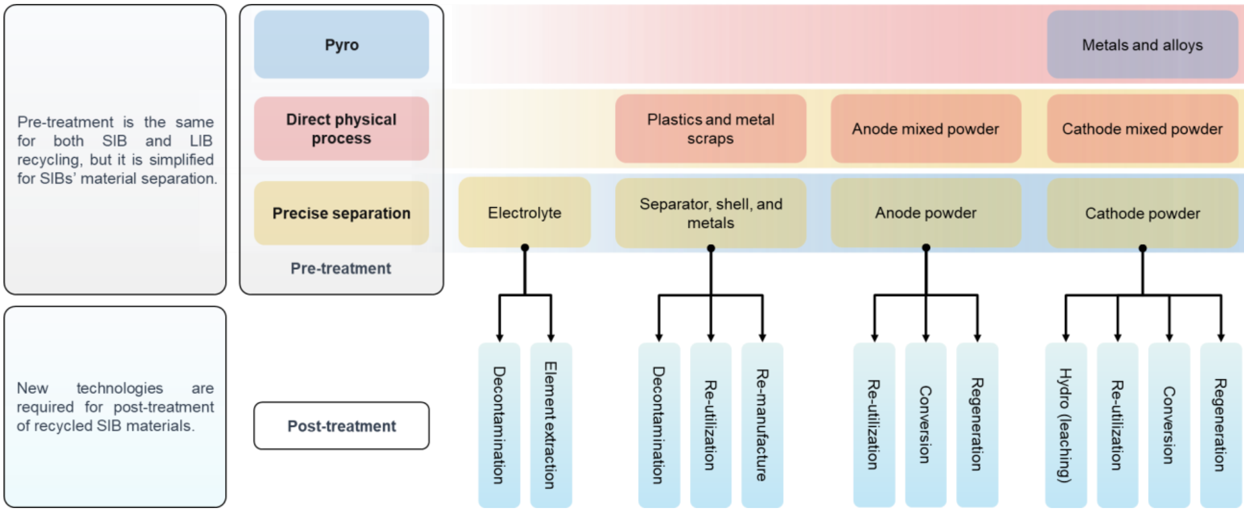
Supplementary Figure 1 | **Cells, structures, and materials utilized in SIBs and LIBs. a.** Shapes of different SIB cell configurations. **b.** The jellyroll and laminated cell structures in SIBs. **c.** Separator and shell material in SIBs. **d-e.** Examples of cathode, anode, and electrolyte materials in SIBs and LIBs.



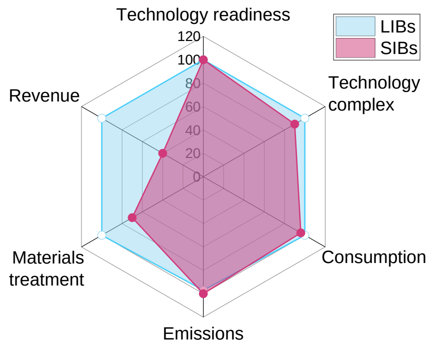
Supplementary Figure 2 | **a.** The economic hierarchy of SIBs. **b.** The economic hierarchy of SIBs materials.



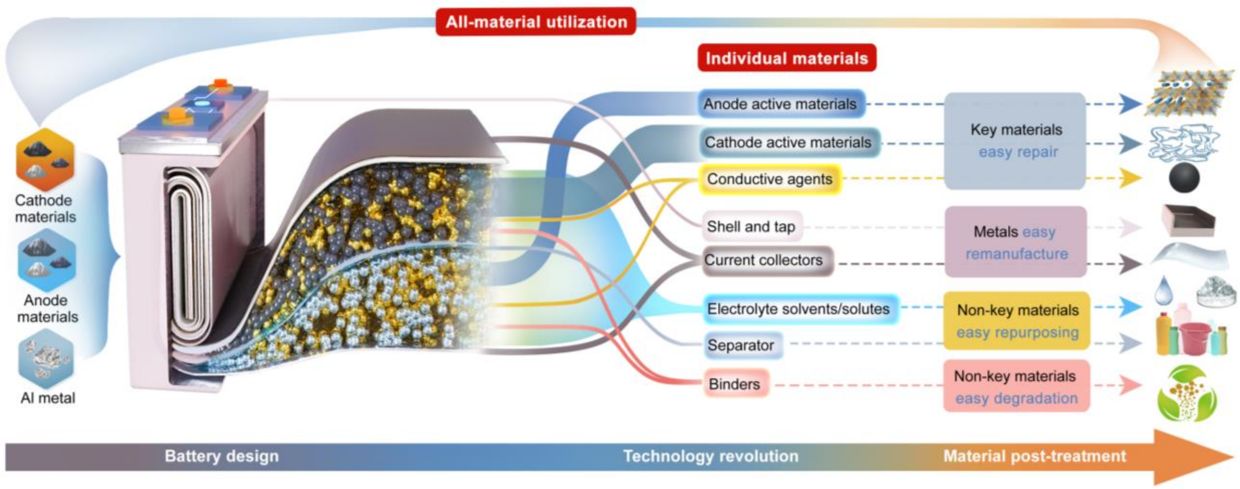
Supplementary Figure 3 | **Battery production, scrap generation, and recycling spent batteries or scraps.** Battery manufacturing combines several input materials to form slurries and electrodes to assemble into a cell. Some of these materials and intermediate products are wasted during the manufacturing and become battery scraps, such as raw materials, slurries, components, and disqualified batteries. Only qualified batteries make it to market to become spent batteries after use. The spent batteries and scraps can be directly regenerated or crushed into mixed powders for processing by Pyro, Direct, Hydro, and/or Regeneration methods. Alternatively, the batteries can be disassembled and recycled as separate material components.



Supplementary Figure 4 | **Strategies for battery recycling and the materials they provide.** All materials could be post-treated in principle, but only cathode materials and metals are currently recycled in practice.



Supplementary Figure 5 | **Radar chart showing the recycling of spent LIBs and SIBs.**



Supplementary Figure 6 | **Prospective SIB recycling technologies and ideal outcome.** The ideal outcome is to recover and utilize all materials from spent SIBs, except those prone to rapid degradation. Advancements in SIB structure and material design guided by the principles of the recycling technology revolution would enable the effective isolation and recycling of individual materials from spent SIBs.

Supplementary Table 1 | **Materials, prices, and percentage in LIBs and SIBs.** The pricing information is acquired from ref. 1, 2, and 3. The value of recycled materials is assumed to be the same as the price after regeneration.

	Cathode active material	Current collector	Conductive agent	Binder	Anode active material	Current collector	Conductive agent	Binder	Shell	Separator	Electrolyte
LIBs	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	Al foil	Carbon black	PVDF	Graphite	Cu foil	Carbon black	CMC/SBR	Al alloy	Polyolefin	$LiPF_6$ in carbonate
Price \$ kg^{-1}	40.80	2.90	9.20	64.60	9.10	9.20	9.20	1.69	2.90	0.30 \$/m^2	8.90
Percentage wt.%	34.9	7.82	0.68	1.27	18.38	15.44	0.68	0.68	3.91	2.26	13.98
Revenue \$ kg $battery^{-1}$	14.24	0.23	0.06	0.82	1.67	1.42	0.06	0.01	0.11	1.27	1.24
Revenue percentage%	67.34	1.07	0.30	3.88	7.91	6.72	0.30	0.05	0.54	6.00	5.88
SIBs	$NaCu_{1/3}Fe_{1/3}Mn_{1/3}O_2$	Al foil	Carbon black	PVDF	Hard carbon	Al foil	Carbon black	PVDF	Al alloy	Polyolefin	$NaPF_6$ in carbonate
Price \$ kg^{-1}	15.80	2.90	9.20	64.60	7.69	2.90	9.20	64.60	2.90	0.30 \$/m^2	6.10
Percentage wt.%	38.71	8.68	0.76	1.41	20.39	8.68	0.76	0.76	4.33	2.51	13.01
Revenue \$ kg $battery^{-1}$	6.12	0.25	0.07	0.91	1.57	0.25	0.07	0.49	0.12	1.17	0.79
Revenue percentage%	51.75	2.13	0.59	7.71	13.27	2.13	0.59	4.15	1.06	9.90	6.72

Supplementary Table 2 | **Practical price and revenue of recycled materials in LIBs and SIBs.**

	Cathode active material	Current collector	Conductive agent	Binder	Anode active material	Current collector	Conductive agent	Binder	Shell	Separator	Electrolyte
LIBs	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$	Al foil	Carbon black	PVDF	Graphite	Cu foil	Carbon black	CMC/SBR	Al alloy	Polyolefin	$LiPF_6$ in carbonate
Value of recycled materials $ kg^{-1}	32.31	1.54	0	0	0.46	8.15	0	0	1.54	0	0
Percentage wt.%	34.90	7.82	0.68	1.27	18.38	15.44	0.68	0.68	3.91	2.26	13.98
Revenue $ kg $battery^{-1}$	11.28	0.12	0	0	0.08	1.26	0	0	0.06	0	0
SIBs	$NaCu_{1/3}Fe_{1/3}Mn_{1/3}O_2$	Al foil	Carbon black	PVDF	Hard carbon	Al foil	Carbon black	PVDF	Al alloy	Polyolefin	$NaPF_6$ in carbonate
Value of recycled materials $ kg^{-1}	5.00	1.54	0	0	0.46	1.54	0	0	1.54	0	0
Percentage wt.%	38.71	8.68	0.76	1.41	20.39	8.68	0.76	0.76	4.33	2.51	13.01
Revenue by regeneration $ kg $battery^{-1}$	1.94	0.13	0	0	0.09	0.13	0	0	0.07	0	0
Revenue by elements $ kg $battery^{-1}$	0.61	0.13	0	0	0.09	0.13	0	0	0.07	0	0

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