

## CLAIMS

What is claimed is:

1. A method for recycling lithium-ion batteries, comprising the steps of:
  - a) discharging the lithium-ion batteries;
  - b) chopping the lithium-ion batteries into pieces to provide a mixture of a structural part, a first conductive metal part coated with a cathode layer, and a second conductive metal part coated with an anode layer;
  - c) immersing the pieces of the chopped lithium-ion batteries into a polar solvent to form a heterogeneous mixture;
  - d) processing the heterogeneous mixture with mechanical agitation for a time period from about 30 minutes to about 5 hours to dissolve a binder material in the cathode and anode layers;
  - e) screening the processed heterogeneous mixture to separate the structural part, first conductive metal part, and second conductive metal part from finer electrode materials comprising cathode and anode materials to provide a suspension comprised of the polar solvent and the finer electrode materials; and
  - f) isolating the finer electrode materials in the suspension from the polar solvent;

wherein the polar solvent is water, alcohol, ketone or a combination thereof;

wherein the cathode material is a lithium transition metal oxide selected from the group consisting of  $\text{LiCoO}_2$ ,  $\text{LiNiO}_2$ ,  $\text{LiNi}_x\text{Mn}_y\text{O}_2$ ,  $\text{LiNi}_x\text{Co}_y\text{O}_2$ ,  $\text{Li}_{1+z}\text{Ni}_x\text{Mn}_y\text{Co}_{1-x-y}\text{O}_2$ ,  $\text{LiNi}_x\text{Co}_y\text{Al}_z\text{O}_2$ ,  $\text{LiV}_2\text{O}_5$ ,  $\text{LiTiS}_2$ ,  $\text{LiMoS}_2$ ,  $\text{LiMnO}_2$ ,  $\text{LiCrO}_2$ ,  $\text{LiMn}_2\text{O}_4$ ,  $\text{LiFeO}_2$ ,  $\text{LiFePO}_4$ , and combinations thereof; wherein each x is independently from 0.3 to 0.8; each y is independently from 0.1 to 0.45; and each z is independently from 0 to 0.2; and

wherein the binder material in each of the cathode and anode layers is independently a water-based binder material, or a mixture of water-based and organic-based binder materials.
2. The method of claim 1, wherein the cathode material is a nickel-rich cathode material selected from  $\text{LiNiO}_2$ ,  $\text{LiNi}_x\text{Mn}_y\text{O}_2$ ,  $\text{LiNi}_x\text{Co}_y\text{O}_2$ ,  $\text{Li}_{1+z}\text{Ni}_x\text{Mn}_y\text{Co}_{1-x-y}\text{O}_2$ ,  $\text{LiNi}_x\text{Co}_y\text{Al}_z\text{O}_2$ , and combinations thereof; wherein each x is independently from 0.5 to 0.8; each y is independently from 0.1 to 0.4; and each z is independently from 0 to 0.2.
3. The method of claim 2, wherein the nickel-rich cathode material is

$\text{LiNi}_{0.8}\text{Mn}_{0.2}\text{O}_2$ ,  $\text{LiNi}_{0.6}\text{Mn}_{0.4}\text{O}_2$ ,  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$ ,  $\text{LiNi}_{0.6}\text{Co}_{0.4}\text{O}_2$ , NMC532, NMC622, NMC811, NCA or a combination thereof.

4. The method of claim 1, wherein the pieces of the chopped lithium-ion batteries have an average length from about 0.5 inch to about 4.0 inches, or of about one quarter inch or less.

5. The method of claim 1, wherein each of the first and second conductive metal parts is independently selected from the group consisting of an aluminum thin plate, a copper thin plate, a gold thin plate, a silver thin plate, and a platinum thin plate.

6. The method of claim 1, wherein the polar solvent further comprises a salt selected from the group consisting of lithium carbonate, lithium bicarbonate, lithium phosphate, sodium carbonate, sodium bicarbonate, sodium phosphate, potassium carbonate, potassium bicarbonate, potassium phosphate, ammonium carbonate, ammonium bicarbonate, ammonium phosphate, and combinations thereof.

7. The method of claim 6, wherein the polar solvent has a pH from about 6 to about 8.

8. The method of claim 1, wherein the alcohol is selected from methanol, ethanol, isopropanol, n-propanol, t-butanol, or a combination thereof.

9. The method of claim 1, wherein a weight ratio of water to the alcohol is from about 5:95 to about 95:5.

10. The method of claim 1, wherein the mechanical agitating step is performed by a stirrer, an ultrasonicator, or a combination thereof.

11. The method of claim 10, wherein the stirrer is a high shearing mixer, a planetary stirring mixer, or a stirring mixer, and wherein the ultrasonicator is an ultrasonic bath or an ultrasonic probe.

12. The method of claim 1, wherein the mechanical agitation in step d) is performed at room temperature.

13. The method of claim 1, wherein the heterogeneous mixture in step d) is heated

at a temperature from about 35 °C to about 100 °C, or from about 55 °C to about 75 °C.

14. The method of claim 1, wherein the water-based binder material is selected from the group consisting of styrene-butadiene rubber, acrylated styrene-butadiene rubber, acrylonitrile-butadiene rubber, nitrile butadiene rubber, acrylonitrile-styrene-butadiene copolymer, polybutadiene, polyvinylpyrrolidone, polyvinylpyridine, polyvinyl alcohol, polyvinyl acetate, polyacrylonitrile, cellulose, carboxymethyl cellulose, hydroxypropyl cellulose, cellulose acetate, cellulose acetate butyrate, cellulose acetate propionate, cyanoethylcellulose, polyacrylic acid, polyacrylate, polymethacrylic acid, polymethacrylate, polyacrylamide, a salt of alginic acid, and combinations thereof

15. The method of claim 1, wherein the organic-based binder material is selected from the group consisting of polytetrafluoroethylene, perfluoroalkoxy polymer, polyvinylidene fluoride, copolymer of tetrafluoroethylene and hexafluoropropylene, fluorinated ethylene-propylene copolymer, terpolymer of tetrafluoroethylene, hexafluoropropylene and vinylidene fluoride, and combinations thereof.

16. The method of claim 1, wherein the finer electrode materials further comprise a conductive agent.

17. The method of claim 1, wherein the finer electrode materials are screened by passing through a sieve having a mesh width between 2 mm and 4 mm, or between 0.5 mm and 1.0 mm.

18. The method of claim 1, wherein isolation of the finer electrode materials is performed by filtration, decanting, settling, centrifugation, or a combination thereof.

19. The method of claim 1, wherein the recovery of finer electrode material is at least 90%, or at least 95%.

20. The method of claim 1, wherein the percentage of impurity in the recovered finer electrode material is less than 2%, less than 1%, less than 0.5%, less than 0.1%, or less than 0.05%.