Claims

1. A method comprising:

(i) first reacting a calcium-bearing starting material with a first acid to produce a first aqueous fraction comprising an aqueous first calcium salt and a first solid fraction comprising one or more solid byproducts;

wherein the calcium-bearing starting material has a chemical composition comprising a plurality of metal elements including at least Ca and Si; and

wherein the one or more solid byproducts comprises a silicon compound;

(ii) separating the first aqueous fraction from the first solid fraction; and

(iii) thermally treating the aqueous first calcium salt in the presence of water to produce a first cement material and to regenerate the first acid.

2. The method of claim 1, wherein the calcium-bearing starting material comprises at least one multinary metal oxide material having a composition comprising Ca and at least one other metal element selected from the group consisting of Al, Si, Fe, Mn, and Mg.

3. The method of claim 1, wherein the calcium-bearing starting material comprises at least one natural rock or mineral comprising basalt, igneous appetites, wollastonite, anorthosite, montmorillonite, bentonite, calcium-containing feldspar, anorthite, diopside, pyroxene, pyroxenite, mafurite, kamafurite, clinopyroxene, colemonite, grossular, augite, pigeonite, margarite, calcium serpentine, garnet, scheilite, skarn, limestone, natural gypsum, appetite, fluorapatite, or any combination of these.

4. The method of claim 1, wherein the calcium-bearing starting material comprises at least one natural rock or mineral comprising basalt, igneous appetites, wollastonite, anorthosite, montmorillonite, bentonite, calcium-containing feldspar, anorthite, diopside, pyroxene, pyroxenite, mafurite, kamafurite, clinopyroxene, colemonite, grossular, augite, pigeonite, margarite, calcium serpentine, garnet, scheilite, skarn, natural gypsum, appetite, fluorapatite, or any combination of these.

5. The method of claim 1, wherein the calcium-bearing starting material is other than $CaCO_3$ or comprises a material other than $CaCO_3$.

6. The method of claim 1, wherein the first acid comprises hydrochloric acid.

7. The method of claim 1, wherein the first reacting step is performed at a temperature of at least 50° C.

8. The method of claim 1, wherein the aqueous first calcium salt is calcium chloride.

9. The method of claim 1, wherein the silicon compound comprises SiO_2.

10. The method of claim 1, wherein the silicon compound comprises >90 dry wt% purity SiO_2.

11. The method of claim 1, wherein the silicon compound comprises silica fume.

12. The method of claim 1, further comprising: forming and isolating oxides of Al, oxides of Mg, and/or oxides of Fe.

13. The method of claim 1, wherein the thermally treating step is performed at a temperature of 1100° C to 1800° C.

14. The method of claim 1, wherein the thermally treating step comprises a step of forming a composite cement material.

15. The method of claim 14, wherein the step of forming the composite cement material comprises heating the first cement material together with one or more additives.

16. The method of claim 15, wherein the one or more additives comprise a byproduct of the first reacting step and/or are formed from the one or more byproducts of the first reacting step.

17. The method of claim 15, wherein the one or more additives comprise the silicon compound.

18. The method of claim 15, wherein the one or more additives comprise an aluminum and/or iron compound.

19. The method of claim 15, wherein the composite cement material comprises Portland cement clinker.

20. An apparatus comprising:

(i) a container configured to react a calcium-bearing starting material with a first acid to produce a first aqueous fraction comprising an aqueous first calcium salt and a first solid fraction comprising one or more solid byproducts,

wherein the calcium-bearing starting material has a chemical composition comprising a plurality of metal elements including at least Ca and Si; and

wherein the one or more solid byproducts comprises a silicon compound;

(ii) a system configured to separate the first aqueous fraction from the first solid fraction; and

(iii) a system configured to thermally treat the aqueous first calcium salt in the presence of water to produce a first cement material and to regenerate the first acid,

wherein (i)-(iii) are operably connected.

21. The method of claim 1, wherein the first cement material is free of $CaCO_3$.

22. The apparatus of claim 19, wherein the first cement material is free of $CaCO_3$.