Claims

1. A method comprising:

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;

the one or more solid byproducts comprises a silicon compound;

separating the first aqueous fraction from the first solid fraction; and

treating the first calcium salt to produce a first cement material.

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 3, 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 6, further comprising regenerating the hydrochloric acid.

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

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

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

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

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

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

14. The method of claim 1, wherein treating the first calcium salt to produce a first cement material comprises thermally treating the first calcium salt in the presence of water to produce the first cement material.

15. The method of claim 14, wherein thermally treating the first calcium salt in the presence of water regenerates the first acid.

16. The method of claim 1, wherein thermally treating the first calcium salt to produce a first cement material further comprises adding one or more additives to the first calcium salt prior to treating.

17. The method of claim 16, 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.

18. The method of claim 16, wherein the one or more additives comprise a silicon compound.

19. The method of claim 1, further comprising treating the first cement material to form a composite cement material.

20. The method of claim 19, wherein forming the composite cement material comprises thermally treating the first cement material in combination with one or more additives.

21. The method of claim 20, 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.

22. The method of claim 20, wherein the one or more additives comprise an aluminum and/or iron compound.

23. The method of claim 20, wherein thermally treating is performed at a temperature of 1100° C. to 1800° C.

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

25. 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;

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

(iii) a system configured to treat the first calcium salt, optionally with one or more additives, to produce a first cement material; and

(iv) a system configured to treat the first cement material, optionally in the presence of one or more additives, to produce a composite cement material,

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

26. The apparatus of claim 25, wherein the system for treating the first calcium salt to produce a first cement material is further configured to regenerate the first acid.

27. A method of producing a cement material and a supplementary cementitious material (SCM) comprising

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 comprising a silicon compound;

separating the first aqueous fraction from the first solid fraction;

producing the SCM from the calcium-depleted solid fraction comprising the silicon compound; and

treating the first calcium salt to produce a first cement material.

28. The method of claim 27, further comprising treating the first cement material to produce a composite cement material.

29. The method of claim 28, wherein the composite cement material comprises Portland cement clinker.

30. The method of claim 27, wherein the silicon compound comprises silica fume.

5