

WHAT IS CLAIMED IS:

1. A method to form calcium carbonate comprising vaterite, comprising:
 - (i) calcining limestone to form lime and a gaseous stream comprising carbon dioxide;
 - (ii) dissolving the lime in an aqueous N-containing inorganic salt solution under one or more dissolution conditions to produce a first aqueous solution comprising calcium salt, and a gaseous stream comprising ammonia;
 - (iii) recovering the gaseous stream comprising carbon dioxide and the gaseous stream comprising ammonia and subjecting the gaseous streams to a cooling process under one or more cooling conditions to condense a second aqueous solution comprising ammonium bicarbonate, ammonium carbonate, ammonia, or combinations thereof; and
 - (iv) treating the first aqueous solution comprising calcium salt with the second aqueous solution comprising ammonium bicarbonate, ammonium carbonate, ammonia, or combinations thereof under one or more precipitation conditions to form a precipitation material comprising calcium carbonate and a supernatant solution, wherein the calcium carbonate comprises vaterite.
2. The method of claim 1, wherein the calcination is carried out in shaft kiln, rotary kiln, or electric kiln.
3. The method of claim 1 or 2, wherein the lime is underburnt lime, soft burnt lime, dead burnt lime, or combinations thereof.
4. The method of any one of the preceding claims, wherein the N-containing inorganic salt is selected from the group consisting of ammonium halide, ammonium sulfate, ammonium sulfite, ammonium nitrate, ammonium nitrite, and combinations thereof.
5. The method of claim 4, wherein the ammonium halide is ammonium chloride.
6. The method of any one of the preceding claims, wherein the first aqueous solution further comprises ammonia and/or N-containing inorganic salt.
7. The method of any one of the preceding claims, wherein molar ratio of the N-containing inorganic salt : lime is between about 0.5:1-2:1.
8. The method of any one of the preceding claims, wherein the one or more dissolution conditions are selected from the group consisting of temperature between about 30-200°C; pressure between about 0.1-10 atm; N-containing salt wt% in water between about 0.5-50%; and combinations thereof.
9. The method of any one of the preceding claims, wherein no external source of carbon dioxide and/or ammonia is used and the process is a closed loop process.
10. The method of any one of the preceding claims, wherein the gaseous stream comprising ammonia further comprises water vapor.

11. The method of claim 10, wherein the gaseous stream further comprises between about 20-90% water vapor.
12. The method of any one of the preceding claims, wherein no external water is added to the cooling process.
13. The method of any one of the preceding claims, wherein the one or more cooling conditions comprise temperature between about 0-100°C; pressure between about 0.5-50 atm; pH of the aqueous solution between about 8-12; flow rate of the CO₂; ratio of CO₂:NH₃ between about 0.1:1-20:1; or combinations thereof.
14. The method of any one of the preceding claims, wherein the second aqueous solution further comprises ammonium carbamate.
15. The method of any one of the preceding claims, wherein the second aqueous solution is formed by condensation of the gases.
16. The method of any one of the preceding claims, wherein the one or more precipitation conditions are selected from the group consisting of pH of the first aqueous solution of between 7-9, temperature of the solution between 20-60°C, residence time of between 5-60 minutes, or combinations thereof.
17. The method of any one of the preceding claims, wherein the first aqueous solution further comprises solids.
18. The method of claim 17, further comprising separating the solids from the first aqueous solution before the treatment step by filtration and/or centrifugation.
19. The method of claim 18, wherein the separated solids are added to the precipitation material as filler.
20. The method of claim 18 or 19, wherein the separated solids further comprise residual ammonium halide when the N-containing inorganic salt is the ammonium halide.
21. The method of claim 20, further comprising recovering the residual ammonium halide from the solids using a recovery process selected from the group consisting of rinsing, thermal decomposition, pH adjustment, and combinations thereof.
22. The method of claim 17, wherein the solids are not separated from the first aqueous solution and the first aqueous solution is subjected to the treatment step to produce the precipitation material further comprising the solids.
23. The method of any one of the claims 17-22, wherein the solids comprise silicates, iron oxides, alumina, or combinations thereof.
24. The method of any one of the claims 17-23, wherein the solids are between 1-40 wt% in the aqueous solution, in the precipitation material, or combinations thereof.

25. The method of any one of the preceding claims, further comprising dewatering the precipitation material to separate the precipitation material from the supernatant solution.
26. The method of any one of the preceding claims, wherein the precipitation material and the supernatant solution comprise residual N-containing inorganic salt.
27. The method of claim 26, wherein the residual N-containing inorganic salt comprises ammonium halide, ammonium sulfate, ammonium sulfite, ammonium hydrosulfide, ammonium thiosulfate, ammonium nitrate, ammonium nitrite, or combinations thereof.
28. The method of claim 26 or 27, further comprising removing and optionally recovering ammonia and/or N-containing inorganic salt from the residual N-containing inorganic salt comprising removing and optionally recovering the residual N-containing inorganic salt from the supernatant aqueous solution and/or removing and optionally recovering the residual N-containing inorganic salt from the precipitation material.
29. The method of claim 28, further comprising recovering the residual N-containing inorganic salt from the supernatant aqueous solution using recovery process selected from the group consisting of thermal decomposition, pH adjustment, reverse osmosis, multi-stage flash, multi-effect distillation, vapor recompression, distillation, and combinations thereof.
30. The method of claim 28, wherein the step of removing and optionally recovering the residual N-containing inorganic salt from the precipitation material comprises heating the precipitation material between about 300-360°C to evaporate the N-containing inorganic salt from the precipitation material with optional recovery by condensation of the N-containing inorganic salt.
31. The method of claim 30, wherein the N-containing inorganic salt is ammonium chloride which evaporates from the precipitation material in a form comprising ammonia gas, hydrogen chloride gas, chlorine gas, or combinations thereof.
32. The method of any one of the claims 28-31, further comprising recycling the recovered residual ammonia and/or N-containing inorganic salt back to the dissolving and/or treating step of the process.
33. The method of any one of the preceding claims, wherein the vaterite is stable vaterite or reactive vaterite.
34. The method of claim 33, further comprising adding water to the precipitation material comprising reactive vaterite and transforming the vaterite to aragonite wherein the aragonite sets and hardens to form cement or cementitious product.
35. The method of claim 34, wherein the cementitious product is a formed building material selected from masonry unit, construction panel, conduit, basin, beam, column, slab, acoustic barrier, insulation material, and combinations thereof.

36. The method of claim 33, further comprising adding water to the precipitation material comprising reactive vaterite and transforming the vaterite to aragonite wherein the aragonite sets and hardens to form non-cementitious product.
37. A product formed by the method according to any one of the preceding claims.
38. A system to form calcium carbonate comprising vaterite, comprising:
- (i) a calcining reactor configured to calcine limestone to form lime and a gaseous stream comprising carbon dioxide;
 - (ii) a dissolution reactor configured for dissolving the lime in an aqueous N-containing inorganic salt solution under one or more dissolution conditions to produce a first aqueous solution comprising calcium salt, and a gaseous stream comprising ammonia;
 - (iii) a cooling reactor configured for recovering the gaseous stream comprising carbon dioxide and the gaseous stream comprising ammonia and subjecting the gaseous streams to a cooling process under one or more cooling conditions to condense a second aqueous solution comprising ammonium bicarbonate, ammonium carbonate, ammonia, or combinations thereof; and
 - (iv) a treatment reactor configured for treating the first aqueous solution comprising calcium salt with the second aqueous solution comprising ammonium bicarbonate, ammonium carbonate, ammonia, or combinations thereof under one or more precipitation conditions to form a precipitation material comprising calcium carbonate and a supernatant solution, wherein the calcium carbonate comprises vaterite.
39. The system of claim 38, wherein the dissolution reactor is integrated with the cooling reactor.