CLAIMS

1. A method for producing ammonia, comprising: (a) carbothermic reduction of a composite material comprising a metal oxide using a carbonaceous reducing agent in a nitrogen atmosphere to form a functional material in a gaseous state; and (b) subjecting the gaseous functional material to a supersonic quenching process whereby the gaseous functional material is supersonically cooled to directly form a solid functional material.

2. The method of claim 1, wherein the gaseous functional material is supersonically cooled at a fluid flow speed of at least 700 m/s.

3. The method of claim 1, further comprising (c) hydrolyzing the solid functional material with a solvent thereby regenerating a composite material comprising a metal oxide and forming hydrous ammonia.

4. The method of claim 3, further comprising (d) subjecting the hydrous ammonia to a heat treatment thereby generating anhydrous ammonia.

5. The method of claim 3, further comprising (e) recycling the regenerated composite material to (a) through (b) to form solid functional material.

6. The method of claim 1 or claim 2, wherein (b) subjecting the gaseous functional material to a supersonic quenching process comprises using a convergent-divergent nozzle.

7. The method of claim 6, wherein using a convergent-divergent nozzle comprises using a convergent-divergent nozzle having a ratio of an exit diameter to a throat diameter in a range of 2: 1 to 2.28:1.

8. The method of claim 6 or 7, wherein the convergent-divergent nozzle comprises a ratio of an exit diameter to a throat diameter of about 2.28: 1.

9. The method of any one of claims 6 to 8, wherein the convergent-divergent nozzle comprises a ratio of an inlet diameter to a throat diameter in a range of 3.75:1 to 4.28:1.

10. The method of any one of claims 6 to 9, wherein the convergent-divergent nozzle comprises a ratio of an inlet diameter to a throat diameter of about 4.28: 1.

11. The method of any one of the preceding claims, wherein the metal oxide is a binary metal oxide or a ternary metal oxide.

12. The method of any one of the preceding claims, the carbonaceous reducing agent is selected from a group consisting of carbon, graphite, charcoal, porous carbon, nano carbon, single and multi-wall carbon nanotube.

13. The method of any one of the preceding claims, wherein the metal oxide comprises metal oxide nanoparticles having a particle size of equal to or less than 100nm.

14. The method of claim 13, wherein the metal oxide nanoparticles comprise a particle size in a range of 20nm to 30nm.

15. An apparatus for producing ammonia comprising: a reaction chamber configured to carry out carbothermic reduction of a composite material comprising metal oxide with a carbonaceous reducing agent in a nitrogen atmosphere to form a functional material in a gaseous state; and a supersonic quenching unit operatively coupled with the reaction chamber and configured to supersonically cool the gaseous functional material to directly form solid functional material.

16. The apparatus of claim 15, wherein the supersonic quenching unit is configured to supersonically cool the gaseous functional material at fluid flow speed of at least 700 m/s.

17. The apparatus of claim 15 or 16, wherein the supersonic quenching unit comprises a convergent-divergent nozzle.

18. The apparatus of claim 17, wherein the convergent-divergent nozzle comprises a ratio of an exit diameter to a throat diameter in a range of 2.1: 1 to 2.28:1.

19. The apparatus of claim 17 or 18, wherein the convergent-divergent nozzle comprises a ratio of an exit diameter to a throat diameter of about 2.28: 1.

20. The apparatus of any one of claims 17 to 19, wherein the convergent-divergent nozzle comprises a ratio of an inlet diameter to a throat diameter in a range of 3.75:1 to 4.28:1.

21. The apparatus of any one of claims 17 to 20, wherein the convergent-divergent nozzle comprises a ratio of an inlet diameter to a throat diameter of about 4.28:1.

22. The apparatus of any one of claims 15 to 20, wherein the supersonic quenching unit is operatively coupled with a conduit.