CLAIMS

1. A process for producing lithium metal from a lithium-containing silicate mineral, the process comprising:

mixing the silicate mineral with a nitric acid;

subjecting the mixture to a leaching process having conditions such that lithium values in the silicate mineral are leached from the silicate mineral as lithium nitrate;

decomposing the lithium nitrate to lithium oxide by a thermal treatment;

subjecting the lithium oxide to a carbothermal reduction stage in a carbothermal reduction furnace in which the lithium oxide is mixed with a source of carbon;

wherein the carbothermal reduction stage is operated at a temperature sufficient to cause the lithium oxide to be reduced to lithium metal and the carbon source to be oxidised into gaseous form.

2. A process according to claim 1, wherein, immediately following the reduction stage, the lithium metal as vapour and the gaseous oxidised carbon are rapidly cooled so as to form liquid lithium metal.

3. A process according to claim 2, wherein the lithium metal vapour and the gaseous oxidised carbon are rapidly cooled by expansion.

4. A process according to claim 2 or 3, wherein the lithium metal vapour and the gaseous oxidised carbon are rapidly cooled by supersonic expansion through a convergent-divergent nozzle.

5. A process according to any one of claims 2 to 4, wherein a mixture of the liquid lithium metal and the gaseous oxidised carbon is separated one from the other, such as by passing the mixture through a cyclone separator.

6. A process according to any one of the preceding claims, wherein, in the acid leach the silicate mineral is mixed with nitric acid under conditions such that lithium values in the silicate mineral are leached from the silicate mineral as lithium nitrate.

7. A process according to claim 6, wherein the leach conditions comprise increased temperature and/or pressure to accelerate leaching of lithium values from the silicate mineral as lithium nitrates, but such that non-lithium values in the silicate mineral tend not to be leached from the silicate mineral.

8. A process according to claim 7, wherein the leach conditions further comprise reacting the silicate mineral in a stoichiometric excess of nitric acid, for a controlled period of time, wherein the controlled period is terminated by:

(i) neutralising residual free nitric acid; and/or

(ii) heating the product of leaching so as to distil the excess of nitric acid along with water as vapour.

9. A process according to claim 8, wherein in (i) the residual free nitric acid is neutralised by an alkaline lithium compound that comprises one or more of: Li_2O, LiOH and Li_2CO_3.

10. A process according to claim 8 or 9, wherein in (ii) the excess of nitric acid and water vapour are distilled off as vapours in a drying stage, and wherein the distilled nitric acid and water vapour are collected for reuse in the acid leach and/or for regenerating nitric acid.

11. A process according to any one of claims 6 to 10, further comprising a crystallisation stage in which a solution of lithium nitrate produced by the acid leach is concentrated and crystallised to form crystalline $LiNO_3$.

12. A process according to claim 11, wherein the crystallised $LiNO_3$ is separated from solution, such as by centrifugation, and wherein the separated crystalline $LiNO_3$ is thermally treated, at a temperature that causes decomposition of the $LiNO_3$ into Li_2O, and such that a gaseous stream that comprises oxides of nitrogen is produced.

13. A process according to claim 12, wherein the thermal treatment comprises indirect heating of the $LiNO_3$, such as by the catalysed burning of ammonia in an excess of air, with the gaseous stream being collected for reuse in the acid leach and/or for regenerating nitric acid.

14. A system for producing lithium metal from a lithium-containing silicate mineral, the system comprising:

a leaching reactor in which a mixture of the silicate mineral and nitric acid is subjected to conditions such that lithium values in the silicate mineral are leached from the silicate mineral as lithium nitrate;

a thermal treatment unit configured to operate at a temperature that causes lithium nitrate from the leaching reactor to decompose into solid Li_2O;

a carbothermal reduction furnace in which a blend of the solid Li_2O and a source of carbon is heated to a temperature sufficient to cause the lithium oxide to be reduced to lithium metal and the carbon source to be oxidised into gaseous form.

15. A system according to claim 14, further comprising a flash-cooling apparatus in which the resultant lithium metal is condensed as a liquid.

16. A system according to claim 15, wherein the flash-cooling apparatus comprises a convergent-divergent nozzle.

17. A system according to claim 15 or 16, further comprising a cyclone separator in which the condensed liquid lithium metal from the flash-cooling apparatus and the gaseous oxidised carbon are separated.

18. A system according to any one of claims 14 to 17, wherein the thermal treatment unit comprises a roaster.

19. A system according to any one of claims 14 to 18, further comprising a nitric acid plant, the nitric acid plant arranged to receive gaseous streams that contain oxides of nitrogen and/or nitric acid vapour from the leaching reactor, the thermal treatment unit and/or from the carbothermal reduction furnace, the nitric acid plant being further arranged to produce nitric acid for use in the leaching reactor.

20. A system according to any one of claims 14 to 19, wherein the leaching reactor comprises:

a pressure vessel such as an autoclave in which leaching is conducted at elevated temperatures and pressures; or

a digestion reactor such as a hollow-flite screw conveyor in which leaching is conducted at elevated temperatures but at atmospheric pressure.

21. A system according to any one of claims 14 to 20, further comprising a crystallizer in which a lithium nitrate solution from the leaching reactor is concentrated and crystallised to form crystalline $LiNO_3$.

22. A system according to claim 21, further comprising a heated holding vessel in which the crystalline $LiNO_3$ is heated to a molten state, prior to the molten $LiNO_3$ being passed to the thermal treatment unit.

~~**23.** A process for recovering lithium from a lithium-containing silicate mineral, the process comprising:~~

~~mixing the silicate mineral with nitric acid;~~

~~subjecting the mixture to a leaching process having conditions such that lithium values in the silicate mineral are leached from the silicate mineral as lithium nitrate;~~

~~wherein the leaching process conditions comprise increased temperature and/or pressure of the leaching process such as to accelerate leaching of lithium values from the silicate mineral as lithium nitrates, but such that non-lithium values in the silicate mineral tend not to be leached from the silicate mineral.~~

~~**24.** A process according to claim 23, wherein the leaching process conditions comprise reacting the silicate mineral in a stoichiometric excess of nitric acid, for a controlled period of time, wherein the controlled period is terminated by:~~

~~(i) neutralising residual free nitric acid; and/or~~

~~(ii) heating the product of leaching so as to distil the excess of nitric acid along with water as vapour.~~

~~**25.** A process according to claim 24, wherein in (i) the residual free nitric acid is neutralised by recycling a proportion of alkaline lithium compounds produced as part of the process for recovering lithium, with the alkaline lithium compounds that are recycled comprising one or more of: Li_2O, LiOH and Li_2CO_3.~~

~~**26.** A process according to claim 24 or 25, wherein in (i), a leached product mass resulting from the leaching process is passed to a solid-liquid separation stage in which solids in the leached product mass are separated from a solution comprising lithium nitrate, with the solids being separated from the~~

process as tailings.

27. A process according to claim 26, wherein in (ii) the excess of nitric acid and water vapour are distilled off as vapours in a drying stage, and wherein the distilled nitric acid and water vapour are collected for reuse in the leaching process and/or for regenerating nitric acid.

28. A process according to any one of claims 24 to 27, further comprising a crystallisation stage in which a solution of lithium nitrate produced by the leaching process is concentrated and crystallised to form relatively pure crystalline $LiNO_3$.

29. A process according to claim 28, wherein the crystallised $LiNO_3$ is separated from solution, such as by centrifugation, and wherein the separated crystalline $LiNO_3$ is subjected to a thermal decomposition process, at a temperature that causes decomposition of the $LiNO_3$ into Li_2O, and such that a gaseous stream that comprises oxides of nitrogen is produced.

30. A process according to claim 29, wherein the thermal decomposition process comprises indirect heating of the $LiNO_3$, such as by the catalysed burning of ammonia in an excess of air, with the gaseous stream being collected for reuse in the leaching process and/or for regenerating nitric acid.

31. A process according to claim 29 or 30, wherein the Li_2O is:

(a) slaked with water in a slaking stage so as to convert the Li_2O to LiOH and to cause the LiOH to dissolve into solution;

(b) converted to lithium metal such as by a process of carbothermal reduction.

32. A process according to claim 31, wherein the LiOH solution from (a) is subjected to a further crystallisation stage, in which the LiOH solution is concentrated and crystallised to form crystalline lithium hydroxide monohydrate $LiOH.H_2O$, with the crystallised $LiOH.H_2O$ then being separated from solution, such as by centrifugation.

33. A process according to claim 32 wherein the lithium hydroxide solution that is separated from the crystalline lithium hydroxide monohydrate is employed for one or both of:

- recycling to the leaching process for use in terminating the reaction of the silicate mineral with the nitric acid, the lithium hydroxide solution neutralising residual or remaining free nitric

acid;

- scrubbing of carbon dioxide from process off-gases, whereby a lithium carbonate-rich stream is produced, with a proportion of this stream comprising lithium carbonate in solid form.

34. A process according to claim 33, wherein the lithium carbonate in solid form is separated and classified, whereby a coarser fraction forms a lithium carbonate product of the process, and whereby a finer fraction is recycled with the stream to scrubbing of the carbon dioxide.

35. A process according to any one of claims 23 to 34, wherein the silicate mineral is pre-treated so as to activate the lithium values therein prior to mixing the silicate mineral with the nitric acid solution, with the pre-treatment comprising a thermal treatment such as calcination or roasting, or a mechanical treatment such as milling or fine grinding.

36. A system for recovering lithium from a lithium-containing silicate mineral, the system comprising a leaching reactor in which a mixture of the silicate mineral and nitric acid is subjected to conditions such that lithium values in the silicate mineral are leached from the silicate mineral as lithium nitrate, but such that non-lithium values in the silicate mineral tend not to be leached from the silicate mineral.

37. A system according to claim 36, wherein the leaching reactor comprises:

- (i) a pressure vessel such as an autoclave, and wherein the conditions for leaching comprise elevated temperatures and pressures; or

- (ii) a digestion reactor such as a hollow-flite screw conveyor, and wherein the conditions for leaching comprise elevated temperatures but atmospheric pressure.

38. A system according to claim 37, further comprising a neutralization vessel in which a lithium nitrates aqueous phase resulting from the leaching reactor is neutralised with recycled product comprising alkaline lithium compounds.

39. A system according to claim 38, further comprising a solids-liquids separation stage, such as a filtration apparatus, in which solids from the leaching reactor are separated from the lithium nitrates aqueous phase, with the solids being separated as process tailings.

40. A system according to claims 39, further comprising a crystallizer in which the lithium nitrates

solution is concentrated and crystallised to form crystalline LiNO3.

41. A system according to claim 40, further comprising a heated holding vessel in which the crystalline LiNO3 is heated to a molten state.

42. A system according to claim 41, further comprising a thermal treatment unit, such as a roaster, the thermal treatment unit configured to operate at a temperature that causes the molten LiNO3 to decompose into solid Li2O.

43. A system according to claim 42, further comprising a carbothermal reduction furnace in which a blend of solid Li2O and a source of carbon is heated, followed by a flash-cooling apparatus, such as a convergent-divergent nozzle, in which the resultant lithium metal is condensed.

44. A system according to any one of claims 36 to 43, further comprising a nitric acid plant, wherein gaseous streams that contain oxides of nitrogen and/or nitric acid vapour are passed to the nitric acid plant to produce nitric acid for use in the leaching reactor.

45. A system according to claim 44, further comprising a scrubbing vessel in which system flue gases are scrubbed with a lithium hydroxide solution that is produced by the slaking with water of the crystalline LiNO3, the scrubbing vessel configured to form a lithium carbonate-rich stream.