CLAIMS

1. A process for cracking ammonia comprising:

providing a heated, typically superheated, ammonia gas at super-atmospheric pressure;

partially cracking the heated ammonia gas in an adiabatic reaction unit comprising at least one catalyst bed to produce a partially cracked ammonia gas;

heating the partially cracked ammonia gas to produce a heated partially cracked ammonia gas;

combusting a fuel with an oxidant gas in a furnace to heat catalyst-containing reactor tubes and produce a flue gas; and

feeding the heated partially cracked ammonia gas to the catalyst-containing reactor tubes to cause cracking of further ammonia to produce a cracked gas comprising hydrogen gas, nitrogen gas and residual ammonia gas,

wherein at least some, preferably all, of the duty required to heat the partially cracked ammonia gas is provided by heat exchange with the cracked gas.

2. A process according to Claim 1 wherein at least some, preferably a majority, *i.e.*, over 50% and perhaps up to 99%, of the heating duty required to provide the heated ammonia gas is provided by heat exchange with the cracked gas downstream of the heat exchange with the partially cracked ammonia gas relative to the flow of cracked gas.

3. A process according to Claim 1 or Claim 2 comprising:

pumping liquid ammonia containing at least 0.1 mol % water to produce a pumped liquid ammonia;

pre-heating the pumped liquid ammonia to produce a pre-heated liquid ammonia;

vaporizing the pre-heated liquid ammonia to produce an ammonia gas at super-atmospheric pressure; and

heating the ammonia gas to produce the heated ammonia gas,

wherein the water from the liquid ammonia is present in the heated ammonia gas, preferably in an amount of no more than 1 mol %.

4. A process according to any of the preceding claims, wherein the adiabatic reaction unit comprises a first adiabatic reactor and a second adiabatic reactor in series, wherein the first adiabatic reactor comprises a catalyst bed comprising, *e.g.*, contains or consists of, a ruthenium-based catalyst and the second adiabatic reactor comprises, *e.g.*, contains or consists of, a catalyst bed comprising an upstream layer comprising a nickel-based catalyst and a downstream layer comprising a ruthenium-based catalyst, the process comprising:

passing the heated ammonia gas through the catalyst bed of the first adiabatic reactor vessel to produce an intermediate partially cracked ammonia gas;

heating the intermediate gas to produce a heated intermediate gas; and

passing the heated intermediate gas through the catalyst bed of the second adiabatic reactor to produce the partially cracked ammonia gas.

5. A process according to Claim 4wherein at least some, preferably all, of the duty required to heat the intermediate partially cracked gas is provided by heat exchange with the flue gas.

6. A process according to Claim 5 wherein a part of the heating duty required to provide the heated ammonia gas is provided by heat exchange with the flue gas downstream of the heat exchange with the intermediate partially cracked ammonia gas relative to the flow of flue gas.

7. A process according to any of the preceding claims comprising:

after cooling, *e.g.*, to below 60°C, for example to about 50°C, recovering hydrogen from the cracked gas in a hydrogen recovery unit to produce a hydrogen gas product and an off gas comprising nitrogen gas, residual hydrogen gas and residual ammonia gas;

heating at least a portion, optionally all, of the off gas by heat exchange to produce a heated off gas; and

feeding the heated off gas as at least part of the fuel to the furnace.

8. A process according to Claim 7 comprising:

dividing the off gas into a first portion and a second portion, wherein the first portion is heated and fed to the furnace; and

compressing the second portion of the off gas to produce a compressed off gas and recycling the compressed off gas to the hydrogen recovery unit for further hydrogen recovery.

9. Apparatus for cracking ammonia comprising:

an adiabatic reaction unit for partially cracking heated ammonia gas at super-atmospheric pressure, the unit comprising an inlet for heated ammonia gas, at least one catalyst bed having an upstream end in fluid flow communication with the inlet and a downstream end in fluid flow communication with an outlet for partially cracked ammonia gas; and

a furnace comprising:

a radiant section comprising at least one inlet for fuel and oxidant gas in fluid flow communication with at least one burner, catalyst-containing reactor tubes having upstream ends in fluid flow communication with the outlet of the adiabatic reaction unit and downstream ends in fluid flow communication with an outlet for cracked gas; and

a convection section in fluid flow communication with the radiant section and comprising an outlet for flue gas;

wherein the apparatus comprises a heat exchanger arranged for heating partially cracked ammonia gas by heat exchange with cracked gas located between the adiabatic reaction unit and the radiant section of the furnace.

10. Apparatus according to Claim 9 wherein the heat exchanger is a shell-and-tube style heat exchanger and optionally, wherein the shell side of the heat exchanger is in direct fluid flow communication with the cracked gas outlet of the radiant section of the furnace.

11. A process according to any of Claims 1 to 8 or apparatus according to Claim 9 or Claim 10, wherein the or each catalyst bed of the adiabatic reaction unit comprises, *e.g.*, contains or consists of, a nickel-based catalyst and/or a ruthenium-based catalyst.

12. Apparatus according to any of Claims 9 to 11, wherein the adiabatic reaction unit comprises a first adiabatic reactor and a second adiabatic reactor in series;

the first adiabatic reactor comprising the inlet for heated ammonia gas, a catalyst bed comprising a ruthenium-based catalyst having an upstream end in fluid flow communication with the inlet and a downstream end in fluid flow communication with an outlet for intermediate partially cracked ammonia gas; and

the second adiabatic reactor comprising an inlet for heated intermediate partially cracked ammonia gas in fluid flow communication with the outlet of the first adiabatic reactor, a catalyst bed comprising an upstream layer comprising, *e.g.* containing, a nickel-based catalyst and a downstream layer comprising, *e.g.* containing, a ruthenium-based catalyst, said bed having an

upstream end in fluid communication with the inlet and a downstream end in fluid communication with an outlet for partially cracked ammonia gas,

wherein the apparatus comprises an intermediate gas heater arranged for heating intermediate partially cracked ammonia gas and located between the first and second adiabatic reactor vessels.

13. Apparatus according to Claim 12 wherein the intermediate gas heater is a heating coil located in the convection section of the furnace, the heating coil comprising an inlet in direct fluid flow communication with the outlet of the first adiabatic reactor and an outlet in direct fluid flow communication with the inlet of the second adiabatic reactor.

14. Apparatus according to any Claims 9 to 13 comprising:

a hydrogen recovery unit, preferably a PSA unit, for recovering hydrogen gas from cracked gas comprising:

a first inlet in fluid flow communication with the cracked gas outlet of the radiant section of the furnace;

a first outlet for hydrogen gas; and

a second outlet for offgas comprising nitrogen gas, residual ammonia gas and residual hydrogen gas in fluid flow communication with the at least one inlet for fuel of the radiant section of furnace,

wherein the apparatus comprises an offgas heater arranged for heating offgas and located between the second outlet of the hydrogen recovery unit and the at least one inlet for fuel of the radiant section of the furnace.

15. Apparatus according to any of Claims 9 to 14 comprising:

a compression unit for compressing offgas, said compressor comprising:

an inlet in fluid flow communication with the second outlet of the hydrogen recovery unit; and

an outlet in fluid flow communication with the first inlet of the hydrogen recovery unit,

wherein the apparatus comprises a valve arrangement to control flow of offgas to the compression unit and the offgas heater.