CLAIMS

1. A process for cracking ammonia comprising:

providing a heated ammonia gas (14) at super-atmospheric pressure;

feeding the heated ammonia gas (14) at a first temperature (T1) to a first adiabatic reactor (C141) comprising a catalyst bed to crack a portion of the ammonia and produce an intermediate partially cracked ammonia gas (16), wherein the catalyst bed of the first adiabatic reactor (C141) optionally comprises a nickel-based catalyst;

heating (E2103) the intermediate partially cracked ammonia gas (16) to produce a heated intermediate partially cracked ammonia gas (18);

feeding the heated intermediate partially cracked ammonia gas (18), or a heated intermediate partially cracked ammonia gas derived therefrom, at a second temperature (T2) which is lower than the first temperature (T1) to a further adiabatic reactor (C142) comprising a catalyst bed to crack a further portion of the ammonia and produce a partially cracked ammonia gas (20, 22), wherein the catalyst bed of the further adiabatic reactor (C142) optionally comprises at least one catalyst selected from a nickel-based catalyst and a ruthenium-based catalyst;

combusting fuel (60, 70) with an oxidant gas (64) in a furnace (F201) to heat catalyst-containing reactor tubes and form a flue gas (72); and

feeding the partially cracked ammonia gas (22) to the catalyst-containing reactor tubes to cause cracking of further ammonia to produce a cracked gas (24) comprising hydrogen gas, nitrogen gas and residual ammonia,

wherein the partially cracked ammonia gas (20) is heated (E305) to produce a heated partially cracked ammonia gas (22) prior to being fed to the catalyst-containing reactor tubes of the furnace (F201), and

wherein at least some, preferably all, of the duty required to heat the partially cracked ammonia gas (20) is provided by heat exchange (E305) with the cracked gas (24).

2. A process according to Claim 1, wherein the first temperature (T1) is in a range from about 550°C to about 650°C.

3. A process according to Claim 1 or Claim 2, wherein the second temperature (T2) is in a range from about 450°C to about 550°C.

4. A process according to any of the preceding claims, wherein at least some, preferably all, of the duty required to heat the intermediate partially cracked gas (16) is provided by heat exchange (E2103) with the flue gas (72).

5. A process according to Claim 4, wherein a part of the duty required to provide the heated ammonia gas (14) is provided by heat exchange (E2104) with the flue gas (72) upstream of the heat exchange (E2103) with the intermediate partially cracked gas (16) relative to the flow of flue gas (72).

6. A process according to any of the preceding claims comprising

pumping (P101) liquid ammonia (2) containing at least 0.1 mol % water to produce a pumped liquid ammonia (4);

pre-heating (E271, E312) the pumped liquid ammonia (4) to produce a pre-heated liquid ammonia (30);

vaporizing (E311) the pre-heated liquid ammonia (8) to produce an ammonia gas (10); and

heating (E310, E2102, E2104) the pressurized ammonia gas (10) to produce the heated ammonia gas (14) at super-atmospheric pressure,

wherein the water from the liquid ammonia (2) is present in the heated ammonia gas (14), preferably in an amount of no more than 1 mol %.

7. A process according to Claim 6, wherein at least some, preferably a majority, i.e., over 50%, of the heating duty required to provide the heated ammonia gas (14) is provided by heat exchange with the cracked gas (26) downstream of the heat exchange (E305) with the partially cracked ammonia gas (20) relative to the flow of the cracked gas (26).

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

after cooling, e.g., to below 60C, for example to about 50C, recovering hydrogen from the cracked gas (32) in a hydrogen recovery unit (U501) to produce a hydrogen gas product (40) and an offgas (42) comprising nitrogen gas, residual hydrogen gas and residual ammonia gas;

heating (E2112) at least a portion of the offgas (42) to produce heated off gas (60); and

feeding the heated offgas (60) as at least part of the fuel to the furnace (F201).

9. A process according to Claim 8, wherein all of the offgas (42) is fed as fuel to the furnace (F201).

10. A process according to Claim 8 comprising:

dividing the offgas (42) into a first portion (44) and a second portion (46), wherein the first portion (44) is heated (E2112) and fed to the furnace (F201); and

compressing (K681) the second portion (46) of the offgas to produce a compressed offgas (58) and recycling the compressed offgas (58) to the hydrogen recovery unit (U501) for further hydrogen recovery.

11. An apparatus for cracking ammonia comprising:

a first adiabatic reactor (C141) for partially cracking heated ammonia gas at super-atmospheric pressure, the reactor (C141) comprising an inlet for heated ammonia gas (14), a 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 intermediate partially cracked ammonia gas (16), wherein the catalyst bed of the first adiabatic reactor (C141) optionally comprises a nickel-based catalyst;

a further adiabatic reactor (C142) for cracking heated intermediate partially cracked ammonia gas (18), or heated intermediate partially cracked ammonia gas derived therefrom, the reactor (C142) comprising an inlet in fluid flow communication with the outlet of the first adiabatic reactor (C141), a 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 (20), wherein the catalyst bed of the further adiabatic reactor (C142) optionally comprises at least one catalyst selected from a nickel-based catalyst and a ruthenium-based catalyst;

a furnace (F201) comprising:

a radiant section comprising at least one inlet for fuel (60, 70) and oxidant gas (64) 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 further adiabatic reactor (C142) and downstream ends in fluid flow communication with an outlet for cracked gas (24); and

a convection section (90) in fluid flow communication with the radiant section comprising an outlet for flue gas,

a first heat exchanger (E2104) for heating ammonia gas (13) by heat exchange with flue gas (72) in the convection section (90) of the furnace (F201), the first heat exchanger (E2102) comprising an inlet for ammonia gas (12) and an outlet in direct fluid flow communication with the inlet of the first adiabatic reactor (C141),

a second heat exchanger (E2103) for heating intermediate partially cracked ammonia gas (16) by heat exchange with flue gas (72) in the convection section (90) of the furnace, the second heat exchanger E2014) having an inlet in direct fluid flow communication with the outlet of the first adiabatic reactor (C141) and an outlet in fluid flow communication with the inlet of the further adiabatic reactor (C142),

wherein the first heat exchanger (E2104) is located upstream of the second heat exchanger (E2103) within the convection section (90) of the furnace (F201) relative to the flow of flue gas(72) and

wherein the apparatus comprises further heat exchanger (or "economizer") (E305) arranged to heat partially cracked ammonia gas (20) by heat exchange with cracked gas (24) located between the further adiabatic reactor (C142) and the radiant section of the furnace (F201).

12. An apparatus according to Claim 11, wherein the further heat exchanger (E305) is a shell-and-tube style heat exchanger, and optionally wherein the shell side of the heat exchanger (E305) is in direct fluid flow communication with the outlet of the radiant section of the furnace (F201).

13. An apparatus according to Claim 11 or Claim 12 comprising:

a hydrogen recovery unit (U501), preferably a PSA unit, for recovering hydrogen gas from cracked gas (34) comprising:

a first inlet in fluid flow communication with the cracked gas outlet of the radiant section of the furnace (F201);

a first outlet for hydrogen gas (40); and

a second outlet for offgas (42) 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 (F201),

wherein the apparatus comprises an offgas heater (E2112) arranged for heating offgas (44) and located between the second outlet of the hydrogen recovery unit (U501) and the at least one inlet for fuel of the radiant section of the furnace (F201).

14. An apparatus according to Claim 13 comprising:

a compression unit (K681) for compressing offgas (46), said compressor comprising:

an inlet in fluid flow communication with the second outlet of the hydrogen recovery unit (U501); and

an outlet in fluid flow communication with the first inlet of the hydrogen recovery unit (U501),

wherein the apparatus comprises a valve arrangement to control flow of offgas to the compression unit (K681) and the offgas heater (E2112).