CLAIMS

1. A fuel cell system comprising:

(i) at least one fuel cell stack comprising at least one fuel cell, and having an anode inlet, a cathode inlet, an anode off-gas outlet, and a cathode off-gas outlet;

(ii) a cracker for cracking a fuel gas to an at least partly cracked fuel gas, and having a cracker inlet for receiving the fuel gas, and a cracker outlet for exhausting the at least partly cracked fuel gas;

(iii) a recuperative heat exchanger; and

(iv) a heat source;

wherein:

a) the system defines an anode inlet gas fluid flow path for delivering a fuel gas from a first inlet of said recuperative heat exchanger to a first outlet of said recuperative heat exchanger, through said cracker, to a second inlet of said recuperative heat exchanger, to a second outlet of said recuperative heat exchanger and to said anode inlet of the at least one fuel cell stack;

b) the heat source is configured to use off-gases from the anode off-gas outlet and the cathode off-gas outlet to provide heat to the anode inlet gas fluid flow path between the first outlet of said recuperative heat exchanger and the second inlet of said recuperative heat exchanger; and

c) said recuperative heat exchanger is arranged to transfer heat from relatively higher temperature at least partly cracked fuel gas from the cracker outlet to relatively lower temperature fuel gas delivered between the first inlet and the first outlet of the recuperative heat exchanger, so as to raise the temperature of fuel gas delivered between the first inlet and the first outlet of the recuperative heat exchanger for delivery to the cracker inlet, whilst reducing the temperature of the at least partly cracked fuel gas from the cracker, between the second inlet and the second outlet of the recuperative heat exchanger for delivery to the anode inlet.

2. The fuel cell system of claim 1, wherein the heat source comprises a tail gas burner of the fuel cell system.

3. The fuel cell system of claim 1, wherein the heat source comprises a catalytic combuster of the fuel cell system.

4. The fuel cell system of claim 1 or claim 3, wherein the heat source is a catalytic combustion cracker heat exchanger (CCCHX) configured to catalytically combust off-gases from the anode off-gas outlet and the cathode off-gas outlet, the CCCHX having a catalyst for cracking fuel gas coated on the anode inlet gas fluid flow path of the CCCHX and having a catalyst for catalytic combustion of off-gas from the anode off-gas outlet and the cathode off-gas outlet on the off-gas fluid flow path of the CCCHX, the catalytic combustion configured to provide the heat source for cracking the fuel gas.

5. The fuel cell system of any preceding claim, wherein the cracker comprises a second heat exchanger.

6. The fuel cell system of claim 5, further comprising a second gas fluid flow path, the heat source configured to provide heat to the second gas fluid flow path, and wherein the fuel cell system is arranged to transfer heat from the second gas fluid flow path to the anode inlet gas fluid flow path, so as to provide energy for cracking.

7. The fuel cell system of claim 6, wherein the second gas fluid flow path comprises an off-gas fluid flow path from the anode off-gas outlet and the cathode off-gas outlet of the stack to the heat source to the cracker, and wherein the cracker has a catalyst for cracking fuel gas provided on one side of the second heat exchanger, which catalyst forms part of the anode inlet gas fluid flow path.

8. The fuel cell system of any preceding claim, wherein a top up line is provided, configured to provide fuel gas to the heat source, and optionally further comprising control software configured to use top up fuel gas to increase a temperature of the off-gas fluid flow path downstream of the heat source.

9. The fuel cell system of any preceding claim, wherein the anode inlet gas fluid flow path further comprises a pipe from said recuperative heat exchanger to the anode inlet, the pipe configured for heat exchange between the at least partly cracked fuel gas and one or both of:

the at least one fuel cell stack, and

the heat source.

10. The fuel cell system of any preceding claim, wherein a bypass or variable valve to provide flow control is provided between the heat source and the cracker for bypassing or reducing/varying flow of heat from the heat source to the cracker.

11. The fuel cell system of claim 10, wherein there is provided the bypass from the heat source, provided to allow at least a portion of the heat from the heat source to be diverted for alternative operations, or to entirely bypass heating the anode inlet gas fluid flow path within the cracker.

12. The fuel cell system of any preceding claim, wherein the fuel gas is an ammonia-containing fuel gas, wherein the cracker comprises a second heat exchanger, and wherein the cracker has a catalyst for cracking ammonia provided on one side of the second heat exchanger, which catalyst forms part of the anode inlet gas fluid flow path.

13. The fuel cell system of any one of claims 1 to 11, wherein the fuel gas is a methanol-containing fuel gas, wherein the cracker comprises a second heat exchanger, and wherein the cracker has a catalyst for cracking methanol provided on one side of the second heat exchanger, which catalyst forms part of the anode inlet gas fluid flow path.

14. The fuel cell system of any one of the preceding claims, further comprising an anode off-gas recirculation path configured to recycle a portion of anode off-gas from the anode off-gas outlet of the at least one fuel cell stack to the anode inlet of the at least one fuel cell stack, wherein the anode off-gas recirculation path comprises a getter configured to remove uncracked fuel gas from the anode off-gas recirculation path.

15. A method of at least partially cracking fuel gas, comprising providing a system according to any one of the preceding claims, flowing fuel gas through the anode inlet gas fluid flow path, and providing heat via the heat source to the anode inlet gas fluid flow path between the first outlet of said recuperative heat exchanger and the second inlet of said recuperative heat exchanger.

16. The method of claim 15, wherein the heat source is configured to combust off-gases from the anode off-gas outlet and the cathode off-gas outlet, and the off-gas fluid flow path is configured to route combusted off-gas to the cracker at a relatively higher

temperature than the fuel gas, the cracker being configured to transfer heat from the relatively higher temperature combusted off-gas to the relatively lower temperature fuel gas.

17. The method of claim 15 or 16, wherein there are three stages of heat exchange – heat exchange from the heat source to the fuel gas, heat exchange to the supply of fuel gas as fed between the first inlet and the first outlet of the recuperative heat exchanger by the relatively higher temperature at least partly cracked fuel gas from the cracker outlet, and heat exchange to cool that relatively higher temperature at least partly cracked fuel gas by the supply of fuel gas as fed between the first inlet and the first outlet of the recuperative heat exchanger.

18. The method of any one of claims 15 to 17, wherein the fuel gas is an ammonia-containing fuel gas, the method is at a method of at least partially cracking ammonia into nitrogen gas and hydrogen gas, and the cracker has an operational temperature of between 550 degrees C and 900 degrees C, wherein the at least partially cracked fuel gas exiting the cracker contains less than 1000 parts per million of ammonia.

19. The method of any one of claims 15 to 18, wherein the fuel gas is a methanol-containing fuel gas, the method is at a method of at least partially cracking methanol into carbon dioxide gas and hydrogen gas, and the cracker has an operational temperature of between 250 degrees C and 450 degrees C, wherein the at least partially cracked fuel gas exiting the cracker contains less than 1000 parts per million of methanol.

20. A method of start-up of a fuel cell system, the fuel cell system being in accordance with any one of claims 1 to 14 and comprising an oxidant heat exchanger for an oxidant flow to the cathode inlet of the stack, wherein the heat source is for heating the at least one fuel cell stack, the method comprising:

heating the at least one fuel cell stack to a first threshold temperature; and

once the at least one fuel cell stack reaches a first threshold temperature, either commencing or increasing a rate of a flow of the fuel gas to the cracker.