Claims

1. A method for operating a fuel cell system, the fuel cell system comprising a plurality of cell units arranged in a stack, each cell unit comprising an anode and a cathode separated by an electrolyte, and the fuel cell system comprising an anode inlet for supply of anode inlet gas to each cell unit and an anode outlet for removal of anode off gas from each cell unit, the method comprising, at start-up of the fuel cell system:

heating the stack to a first threshold temperature;

providing an unreformed hydrocarbon fuel to the anode inlet at a first fuel flow rate from a fuel supply when but not before the stack is above the first threshold temperature;

recirculating anode off gas from the anode outlet to the anode inlet while providing unreformed fuel to the anode inlet;

drawing a current from the fuel cell system while recirculating the anode off gas; and

monitoring the stack temperature, and when the stack temperature reaches a second threshold temperature, greater than the first threshold temperature, increasing the fuel flow rate of the unreformed hydrocarbon fuel and current draw.

2. The method of claim 1, wherein the current is drawn while maintaining voltage of the fuel cell above a voltage threshold, wherein the voltage threshold is between 0.6 and 0.8V

3. The method of any preceding claim, wherein at least one of the anode and the electrolyte comprises ceria, or wherein the anode comprises CGO, or wherein the electrolyte comprises CGO.

4. The method of any preceding claim, wherein the unreformed hydrocarbon fuel provided during start-up above the first threshold temperature has the same composition as the unreformed hydrocarbon fuel provided to the anode inlet during steady state operation.

5. The method of any preceding claim, wherein the first threshold temperature is in the range 400 to 500C, preferably 400 to 450C.

6. The method of any preceding claim, wherein recirculating anode off gas provides water produced by the stack to the anode inlet of the stack, and the method comprises reforming of the unreformed hydrocarbon fuel using the recirculated water at a reforming catalyst positioned between each cell unit and an adjacent cell unit.

7. The method of any preceding claim, further comprising a shutdown procedure, the shutdown procedure comprising reducing the fuel flow rate of the unreformed hydrocarbon fuel and the current draw, while maintaining the stack voltage above a threshold value.

8. The method of claim 7, further comprising stopping the unreformed hydrocarbon fuel supply when but not before the stack temperature is below the first threshold temperature.

9. A fuel cell system comprising:

a plurality of cell units arranged in a stack, each cell unit comprising an anode and a cathode separated by an electrolyte, and the fuel cell system comprising an anode inlet for supply of anode inlet gas to each cell unit and an anode outlet for removal of anode off gas from each cell unit;

means for heating the stack;

means for measuring a temperature of the stack;

a fuel inlet configured for connection to a supply of unreformed hydrocarbon fuel and configured to provide the unreformed hydrocarbon fuel to the anode inlet;

an anode off gas recirculation loop configured to provide a gas flow path to recirculate anode off gas from the anode outlet to the anode inlet;

means for drawing a current from the fuel cell system;

a controller configured to receive input from the means for measuring and provide output to the recirculation loop and to the means for drawing current, for controlling the recirculation loop, the supply of unreformed hydrocarbon fuel, and the means for drawing current, all in response to the means for measuring; and

wherein there is no means configured to supply water to the fuel cell system from an external source or from a water tank; and

wherein the controller is configured to, at start-up of the fuel cell system:

control heating of the stack to a first threshold temperature;

control supply of unreformed hydrocarbon fuel to the anode inlet, to provide non-zero fuel flow when but not before the controller determines that first threshold temperature is reached;

control the flow rate of anode off gas in the anode off gas recirculation loop at a first non-zero flow rate;

allow current to be drawn from the fuel cell; and

incrementally increase the supply of unreformed hydrocarbon fuel to the anode inlet and incrementally increase the current draw, when the controller determines that

the stack reaches a second threshold temperature, greater than the first threshold temperature, to raise the temperature and current to steady state conditions.

10. The fuel cell system of claim 9, wherein the anode off gas recirculation loop comprises means configured to vary the flow rate of anode off gas in the anode off gas recirculation loop, controlled by the controller in response to the means for measuring and the means for drawing a current, wherein the anode off gas recirculation loop further comprises a flowpath for anode off gas from the anode outlet, via a heater section, a mixing section configured to mix anode off gas with unreformed hydrocarbon fuel, and to the anode inlet.

11. The fuel cell system of claim 9 or 10, wherein each cell unit in the stack is separated from an adjacent cell unit by an interconnect structure, the interconnect structure having a coating on a side facing and in fluidic communication with the anode of the adjacent cell unit, the coating comprising a reforming catalyst configured to reform the unreformed hydrocarbon fuel to hydrogen for use in the stack.

12. The fuel cell system of any one of claims 9 to 11, wherein:
the electrolyte allows oxygen ion transport, and/or at least one of the anode and the electrolyte comprises ceria, or wherein the anode comprises CGO, or wherein the electrolyte comprises CGO.

13. The fuel cell system of any one of claims 9 to 12, wherein the controller is configured to adjust the supply of unreformed hydrocarbon fuel to the anode inlet, flow rate of anode off gas in the anode off gas recirculation loop, and current draw while maintaining voltage of the fuel cell above a threshold voltage, and wherein the controller is configured to control (a) the oxygen to carbon ratio of gas in communication with the anode and (b) the temperature of the stack.

14. A controller configured to receive signals indicative of one or both of an anode inlet temperature and anode outlet gas temperature and to control a flow rate of anode off gas through an anode off gas recirculation loop in accordance with the method of any one of claims 1 to 8.