Claims

1. A method for producing a synthetic fuel from hydrogen and carbon dioxide, comprising

(a) extracting hydrogen molecules from hydrogen compounds in a hydrogen feedstock to produce a hydrogen-containing feed stream;

(b) extracting carbon dioxide molecules from a dilute gaseous mixture in an atmospheric carbon dioxide feedstock to produce a carbon dioxide containing feed stream; and

(c) processing the hydrogen and carbon dioxide containing feed streams to produce a synthetic fuel;

wherein at least some material used in at least one of the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams is obtained from material produced in another one of the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams; and

wherein the step of extracting carbon dioxide molecules comprises contacting the dilute gaseous mixture with a carbon dioxide capture solution, precipitating at least some captured carbon dioxide into $CaCO_3$ solids, and operating a calciner to calcine the $CaCO_3$ solids to produce a calciner product gas stream comprising the carbon dioxide feed stream.

2. The method as claimed in claim 1, wherein the hydrogen feedstock is water.

3. The method as claimed in claim 1 or 2, wherein the produced material includes water produced during the step of extracting carbon dioxide molecules or the step of processing the hydrogen and carbon dioxide containing feed streams, and at least some of the produced water is used for at least some of the hydrogen feedstock.

4. The method as claimed in claim 3, further comprising extracting water from the calciner product gas stream to produce at least some of the produced water.

5. The method as claimed in claim 4 wherein at least some of the produced water is steam.

6. The method as claimed in claim 1, wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises combining and heating the hydrogen and carbon dioxide containing feed streams, producing a syngas stream, and extracting water from the syngas stream to produce at least some of the produced water.

7. The method as claimed in claim 1 or 2 further comprising feeding at least a portion of the calciner product gas stream to a solid oxide electrolyzer cell used in the step of extracting hydrogen molecules.

8. The method as claimed in claim 1 or 2, wherein the step of extracting carbon dioxide molecules further comprises a slaker, the produced material includes water produced during the step of processing the hydrogen and carbon dioxide containing feed streams and at least some of the water produced is used by the slaker.

9. The method as claimed in any one of claims 1 to 8, wherein the produced material includes oxygen molecules produced during the step of extracting hydrogen molecules, and the method further comprises combusting a fuel using at least a portion of the produced oxygen molecules during at least one of the steps of extracting carbon dioxide molecules and processing the hydrogen and carbon dioxide containing feed streams.

10. The method as claimed in claim 9 wherein combusting at least a portion of the produced oxygen molecules and the fuel produces heat for producing a calciner product gas stream during the step of extracting carbon dioxide molecules.

11. The method as claimed in claim 9 wherein combusting at least a portion of the produced oxygen molecules and the fuel produces heat for producing a syngas stream during the step of processing the hydrogen and carbon dioxide containing feed streams.

12. The method as claimed in claim 9 further comprising regenerating a carbon dioxide rich aqueous capture solution during the step of extracting carbon dioxide molecules using at least a portion of the produced oxygen molecules and a fuel.

13. The method as claimed in any one of claims 1 to 12, wherein the produced material includes a fuel produced during the step of processing the hydrogen and carbon dioxide containing feed streams, and the method further comprises combusting at least a portion of the produced fuel during at least one of the steps of extracting carbon dioxide molecules and processing the hydrogen and carbon dioxide containing feed streams.

14. The method as claimed in claim 13 further comprising regenerating a carbon dioxide rich aqueous capture solution during the step of extracting carbon dioxide molecules using at least a portion of the produced fuel.

15. The method as claimed in any one of claims 1 to 14 wherein at least some energy for performing the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams is provided by an electricity source.

16. The method as claimed in claim 1 wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit at a pressure selected to enable the SGR unit to receive the carbon dioxide containing feed stream from the calciner without being substantially cooled and compressed between the calciner and the SGR unit.

17. The method as claimed in claim 16 wherein the SGR unit is operated at a pressure of between 1 and 10 bar and the received carbon dioxide containing feed stream has a temperature of between 850-900°C.

18. The method as claimed in claim 1, wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, and the method further comprising feeding the carbon dioxide containing feed stream and one or more reactant feed streams into the SGR unit, the one or more reactant feed streams comprising at least one of a hydrogen reactant feed stream, a CH4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

19. The method as claimed in claim 18 further comprising operating the SGR unit to produce a syngas product stream by one or more of a reverse water gas shift (RWGS) reaction, steam methane reforming (SMR) reaction, and a direct methane reforming (DMR) reaction.

20. The method as claimed in claim 19 further comprising treating the syngas product stream to produce one or more recycle streams that provide reactant to the SGR unit.

21. The method as claimed in claim 20 further comprising electrically heating at least one or more of the recycle streams and the reactant feed streams.

22. The method as claimed in claim 16 further comprising heating the SGR unit with thermal energy produced by electricity.

23. The method as claimed in claim 1 wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, further comprising heating the SGR unit with thermal energy produced by combusting an oxidant and a fuel comprising at least one of hydrogen from the hydrogen-containing feed stream, natural gas, or a Fischer Tropsch light end hydrocarbon.

24. The method as claimed in claim 23 wherein the step of extracting carbon dioxide molecules comprises heating the calciner with thermal energy produced by combusting an oxidant and a fuel comprising at least one of hydrogen from the hydrogen-containing stream, natural gas, or a Fischer Tropsch light end hydrocarbons.

25. The method as claimed in claim 23 wherein the step of extracting hydrogen molecules further comprises producing an oxygen containing stream, at least some of which is used as the oxidant by one or both of the SGR unit and the calciner.

26. The method as claimed in claim 16, further comprising heating a $CaCO_3$ material stream used in extracting carbon dioxide molecules with thermal energy from a syngas product stream from the SGR unit.

27. The method as claimed in claim 26 further comprising directly contacting the $CaCO_3$ material stream with the syngas product stream and operating the SGR in a reverse water gas shift (RWGS) mode, with one or more of a steam methane reforming (SMR) mode, a dry methane reforming (DMR) mode or a combination thereof.

28. The method as claimed in claim 16 further comprising heating the calciner with thermal energy produced by electricity.

29. The method as claimed in claim 1 wherein the step of calcining $CaCO_3$ material comprises operating a fluidized bed reactor vessel of the calciner, and discharging a hot CaO solids stream from the calciner.

30. The method as claimed in claim 29 further comprising pre-heating the $CaCO_3$ material prior to entry into the calciner with thermal energy from a calciner product gas stream.

31. The method as claimed in claim 29 further comprising extracting water from the calciner product gas stream, boiling the extracted water to produce steam, then fluidizing the fluidized bed reactor vessel with the steam.

32. The method as claimed in claim 1, wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, and the method further comprising preheating one or more SGR reactant feed streams before feeding to the SGR unit, with thermal energy from a syngas product stream discharged from the SGR unit.

33. The method as claimed in claim 32 wherein the SGR reactant feed streams comprises at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH_4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream, wherein the carbon dioxide reactant feed stream includes at least some of the carbon dioxide containing feed stream, and the hydrogen reactant feed stream comprises at least some of the hydrogen containing feed stream.

34. The method as claimed in claim 32 further comprising combusting an oxidant and a fuel in an SGR burner of the SGR unit and producing a hot burner exhaust stream, then heating at least one of an oxidant feed stream of the SGR burner and a water reactant feed stream to the SGR unit, using thermal energy from the hot burner exhaust stream.

35. A system for producing a synthetic fuel from hydrogen and carbon dioxide, comprising:

(a) a hydrogen production subsystem configured to extract hydrogen molecules from hydrogen compounds in a hydrogen feedstock to produce a hydrogen containing feed stream;

(b) a carbon dioxide capture subsystem configured to extract carbon dioxide molecules from a dilute gaseous mixture in an atmospheric carbon dioxide feedstock to produce a carbon dioxide containing feed stream; and

(c) a synthetic fuel production subsystem configured to process the hydrogen and carbon dioxide containing feed streams to produce a synthetic fuel;

wherein at least one of the subsystems is physically coupled to at least another one of the subsystems by a material transfer coupling for transferring at least some material produced in one subsystem to at least another one of the subsystems for use therein; and

wherein the hydrogen production subsystem comprises an electrolyzer, and the carbon dioxide capture subsystem comprises a calciner.

36. The system as claimed in claim 35 wherein the hydrogen feedstock is water, and the material transfer coupling comprises an oxidant conduit fluidly coupling the electrolyzer with the carbon dioxide capture subsystem or the synthetic fuel production subsystem, such that oxygen molecules produced by the electrolyzer is transferable via the oxidant conduit to the carbon dioxide capture subsystem or the synthetic fuel production subsystem for use in a combustion operation.

37. The system as claimed in claim 36, wherein the carbon dioxide capture subsystem comprises a calciner heater coupled to the oxidant conduit such that at least some of the oxygen molecules are used in a combustion operation in the calciner heater.

38. The system as claimed in claim 37, wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") heater fluidly coupled to the oxidant conduit such that at least some of the oxygen molecules are used in a combustion operation in the SGR heater.

39. The system as claimed in any one of claims 35 to 38 wherein the material transfer coupling comprises a water conduit and the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit fluidly coupled to the hydrogen production subsystem via the water conduit such that water produced by the SGR unit is transferable to the hydrogen production subsystem as hydrogen feedstock.

40. The system as claimed in any one of claims 35 to 39 wherein the material transfer coupling comprises a water conduit and the carbon dioxide capture subsystem

comprises a slaker, and wherein the SGR unit is fluidly coupled to the slaker via the water conduit such that water produced by the SGR unit is transferable to the slaker.

41. The system as claimed in any one of claims 35 to 40 wherein the material transfer coupling comprises a water conduit and the carbon dioxide capture subsystem comprises a slaker fluidly coupled to the hydrogen production subsystem by the water conduit such that water output by the slaker is transferable to the hydrogen production subsystem as hydrogen feedstock.

42. The system as claimed in any one of claims 35 to 41 wherein the material transfer conduit comprises a fuel conduit, and the calciner is fluidly coupled to the synthetic fuel production subsystem by the fuel conduit such that at least some of the synthetic fuel produced by the synthetic fuel production subsystem is transferable to the calciner for a combustion operation.

43. The system as claimed in any one of claim 35 to 42, wherein the material transfer coupling comprises a water conduit and the calciner is fluidly coupled to a high temperature solids removal unit by a calciner product conduit, and the high temperature solids removal unit is fluidly coupled to the hydrogen production subsystem by the water conduit, such that water produced by the calciner is transferable to the hydrogen production subsystem.

44. The system as claimed in claim 43 wherein the high temperature solids removal unit comprises a water removal membrane in fluid communication with the calciner product conduit and the water conduit, such that water is extracted from a calciner product stream contacting the water removal membrane, and the extracted water is directed into the water conduit and at least some carbon dioxide in the remaining calciner product stream is directed to a syngas generation reactor of the synthetic fuel production subsystem.

45. The system as claimed in any one of claims 35 to 43, wherein the material transfer coupling comprises a product conduit and the calciner is coupled to a high temperature solids removal unit by a calciner product conduit, and the high

temperature solids removal unit is coupled to the hydrogen production subsystem by the product conduit, such that product gas produced by the calciner is transferable to the hydrogen production subsystem.

46. The system as claimed in any one of claims 35 to 45 wherein the carbon dioxide capture subsystem comprises an air contactor and a solution processing unit in fluid communication with the air contactor by a carbon dioxide aqueous capture solution, wherein the carbon dioxide aqueous capture solution is thermally coupled to the synthetic fuel production subsystem such that heat is transferable from the synthetic fuel production subsystem into the carbon dioxide aqueous capture solution.

47. The system as claimed in claim 46 wherein the carbon dioxide capture subsystem further comprises a regeneration unit for regenerating a sorbent, the material transfer conduit comprises a second fuel conduit that fluidly couples the regeneration unit to a fuel output of the synthetic fuel production subsystem such that at least a portion of the fuel produced by the synthetic fuel production subsystem is transferable to the regeneration unit for a combustion operation.

48. The system as claimed in claim 47 wherein the material transfer conduit comprises an oxidant conduit that fluidly couples the hydrogen generation subsystem to the regeneration unit such that at least a portion of oxygen molecules produced by the hydrogen generation subsystem is transferable to the regeneration unit for a combustion operation.

49. The system as claimed in claim 46, wherein the carbon dioxide capture subsystem further comprises a regeneration unit and the synthetic fuel production subsystem comprises at least one of a syngas generation reactor ("SGR") unit or a Fischer Tropsch unit fluidly coupled to the regeneration unit such that water produced by at least one of the SGR unit or the Fischer Tropsch unit is transferable to the regeneration unit.

50. The system as claimed in any one of claims 35 to 49 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR"), and wherein at least one of the electrolyzer, SGR, or calciner are electrically driven or heated.

51. The system as claimed in claim 35 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit , wherein the SGR unit has an operating pressure selected to enable the SGR unit to receive the carbon dioxide containing feed stream without being substantially cooled and compressed between the calciner and the SGR unit.

52. The system as claimed in claim 51 wherein the SGR unit has an operating pressure of between 1 and 10 bar and the received carbon dioxide containing feed stream has a temperature of between 850-900°C.

53. The system as claimed in claim 35, wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit comprising one or more reactant inlets fluidly coupled to one or more reactant feed streams comprising at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH_4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

54. The system as claimed in claim 53 wherein the carbon dioxide reactant feed stream comprises at least some of the produced carbon dioxide containing feed stream.

55. The system as claimed in claim 54 wherein the synthetic fuel production subsystem further comprises a syngas treatment unit that receives a syngas product stream from the SGR unit and outputs one or more recycle streams, wherein the recycle streams comprise at least one of water, hydrogen, or carbon dioxide for use by the SGR unit.

56. The system as claimed in claim 55 further comprising at least one electric heater thermally coupled to one or more of the recycle streams and the reactant feed streams, the electric heater comprised of at least one of an inline electric heater, electrical heating tape, resistance heating wire, coils or elements.

57. The system as claimed in any one of claims 51 to 56 wherein the SGR unit is thermally coupled to an electrical heat source comprising an electrical heater.

58. The system as claimed in claim 35 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit comprising an SGR burner and an SGR vessel thermally coupled to the SGR burner, wherein the SGR burner comprises a fuel inlet coupled to the hydrogen containing feed stream to receive hydrogen as fuel for combustion.

59. The system as claimed in any one of claims 51 to 58 wherein the calciner comprises a calciner burner and a calciner reactor vessel thermally coupled to the calciner burner, wherein the calciner burner comprises a fuel inlet coupled to the hydrogen containing feed stream to receive hydrogen as fuel for combustion.

60. The system as claimed in claim 59 wherein one or both of the fuel inlets of the SGR burner and the calciner burner are fluidly coupled to one or more of a natural gas stream and a Fischer Tropsch light end hydrocarbon stream.

61. The system as claimed in any one of claims 58 to 60 wherein the hydrogen production subsystem comprises an electrolyzer which produces the hydrogen containing feed stream and an oxygen containing stream from the hydrogen feedstock, and wherein the oxygen containing stream is fluidly coupled to one or both of the SGR burner and the calciner burner to provide at least some of the oxidant for the combustion.

62. The system as claimed in claim 35 wherein the calciner comprises a fluidized bed reactor vessel.

63. The system as claimed in claim 35 wherein the calciner comprises a kiln reactor vessel and an electric heating element or a burner thermally coupled to the kiln reactor vessel.

64. The system as claimed in claim 35, wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit, the synthetic fuel production subsystem further comprises a heat exchanger thermally coupled to a syngas product stream from the SGR unit and to a $CaCO_3$ material stream from the carbon dioxide capture subsystem, such that thermal energy is transferrable from the syngas product stream to the $CaCO_3$ material stream.

65. The system as claimed in claim 64 wherein the heat exchanger comprises at least one of a bubbling fluidized bed (BFB) heat exchanger or a cyclone heat exchanger.

66. The system as claimed in claim 65 wherein the BFB or cyclone heat exchanger comprises a refractory or ceramic lined vessel inside which the $CaCO_3$ material stream and syngas product stream are in direct contact, and the SGR unit is configured to operate in a reverse water gas shift (RWGS) mode, with one or more of a steam methane reforming (SMR) mode, a dry methane reforming (DMR) mode or a combination thereof.

67. The system as claimed in claim 35 wherein the calciner is thermally coupled to an electric heat source.

68. The system as claimed in claim 67 wherein the calciner comprises
a fluidized bed reactor vessel with a solids feed inlet for receiving $CaCO_3$ material, a fluidizing stream inlet for receiving a calciner fluidizing fluid comprising steam, a product gas stream outlet for discharging a calciner product gas stream, and a solids product outlet for discharging a produced CaO solids stream; and
an electric heating element thermally coupled to the reactor vessel for heating the fluidizing stream and $CaCO_3$ material therein.

69. The system as claimed in claim 68 wherein the electric heating element is encased in a metal sheath extending into a bubbling bed zone of the reactor vessel, or is thermally coupled to a refractory lined wall of the reactor vessel.

70. The system as claimed in claim 68 or 69 further comprising

a water knockout and solids removal unit having an inlet fluidly coupled to the calciner product gas stream, a water outlet for discharging water removed from the product gas stream, a dust outlet for discharging dust removed from the product gas stream, and a carbon dioxide outlet for discharging a carbon dioxide product stream;

a compressor having an inlet for receiving the carbon dioxide product stream and compressing same; and

a boiler unit having an inlet for receiving the discharged water, and an outlet for discharging steam for the calciner fluidizing fluid.

71. The system as claimed in claim 35 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit and a ceramic heat exchanger thermally coupled to a syngas product stream discharged from the SGR unit and to one or more SGR reactant feed streams fed to the SGR unit, such that the one or more SGR reactant feed streams are preheated by thermal energy from the syngas product stream before being fed to the SGR unit.

72. The system as claimed in claim 71 wherein the SGR reactant feed streams comprise at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

73. The system as claimed in claim 72, wherein the carbon dioxide reactant feed stream comprises the carbon dioxide containing feed stream produced by the calciner, and the hydrogen reactant feed stream comprises the hydrogen containing feed stream produced by the hydrogen production subsystem.

74. The system as claimed in claim 73 wherein the synthetic fuel production subsystem further comprises a Fischer Tropsch unit having an inlet coupled to the syngas product stream cooled and discharged from the ceramic heat exchanger and at least one outlet for discharging the Fischer Tropsch light end hydrocarbon feed stream and a water stream.

75. The system as claimed in any one of claims 71 to 74 wherein SGR unit comprises an SGR vessel thermally coupled to an SGR burner that produces a hot burner exhaust stream that is thermally coupled to at least one of a heat exchanger for heating an oxidant feed stream of the SGR burner and a boiler for heating a water feed stream to the SGR vessel.

76. The system as claimed in any one of claims 71 to 75 wherein the calciner comprises a calciner burner, and the hydrogen production subsystem comprises an electrolyzer which produces the hydrogen containing feed stream and an oxygen containing stream from the hydrogen feedstock, and wherein the oxygen containing stream is fluidly coupled to the calciner burner to provide the oxidant.

77. The system as claimed in any one of claims 71 to 74 wherein the SGR unit comprises an SGR vessel thermally coupled to an electrical heater.

78. A method for producing a synthetic fuel from hydrogen and carbon dioxide, comprising

(a) extracting hydrogen molecules from hydrogen compounds in a hydrogen feedstock to produce a hydrogen-containing feed stream;

(b) extracting carbon dioxide molecules from a dilute gaseous mixture in a carbon dioxide feedstock to produce an atmospheric carbon dioxide containing feed stream; and

(c) processing the hydrogen and carbon dioxide containing feed streams to produce a synthetic fuel;

wherein at least some energy used for at least one of the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams is obtained from energy produced by another one of the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams; and

wherein the step of extracting carbon dioxide molecules comprises contacting the dilute gaseous mixture with a carbon dioxide capture solution, precipitating at least some captured carbon dioxide into $CaCO_3$ solids, and operating a calciner to calcine the $CaCO_3$ solids to produce a calciner product gas stream comprising the carbon dioxide feed stream.

79. The method as claimed in claim 78 wherein at least a portion of the energy used for extracting the hydrogen molecules, extracting the carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams is electricity supplied by an external energy source.

80. The method as claimed in claim 78 or 79 wherein the at least some energy is thermal energy used in at least one of the steps of extracting hydrogen molecules, extracting carbon dioxide molecules, and processing the hydrogen and carbon dioxide containing feed streams.

81. The method as claimed in claim 80, wherein at least some of the thermal energy used in processing the hydrogen and carbon dioxide containing feed streams is produced during a calcination operation in extracting carbon dioxide molecules, and the produced thermal energy is transferred by the carbon dioxide containing feed stream.

82. The method as claimed in claim 80 or 81 wherein oxygen molecules are produced during the step of extracting hydrogen molecules, and the method further comprises heating the oxygen molecules by the thermal energy produced during the step of extracting carbon dioxide molecules.

83. The method as claimed in claim 82, wherein during the step of extracting carbon dioxide molecules, the heated oxygen molecules and a fuel are combusted in a combustion operation.

84. The method as claimed in claim 83, wherein the combustion operation provides heat to the calciner, and some thermal energy from calcium oxide material produced in the calciner is used to heat the oxygen molecules.

85. The method as claimed in any one of claims 80 to 84 wherein the method further comprises distilling and refining the synthetic fuel, and at least some of the thermal energy produced during the step of extracting carbon dioxide molecules is used during the distilling and refining of the synthetic fuel or used to generate power.

86. The method as claimed in any one of claims 80 to 85, wherein the hydrogen feedstock comprises water, and the method further comprises heating at least a portion of the water using at least a portion of the thermal energy produced during the step of extracting carbon dioxide molecules.

87. The method as claimed in claim 86, wherein at least some of the heated water is produced during the step of extracting carbon dioxide molecules.

88. The method as claimed in any one of claims 80 to 87 further comprising heating a material stream produced during the step of extracting carbon dioxide molecules using at least some of the thermal energy produced during the step of processing the hydrogen and carbon dioxide containing feed streams.

89. The method as claimed in any one of claims 80 to 88 further comprising preheating a material stream flowing into a syngas generation reactor ("SGR") during the step of processing the hydrogen and carbon dioxide containing feed streams, using thermal energy produced by the SGR.

90. The method as claimed in claim 80 further comprising regenerating a sorbent used during the step of extracting carbon dioxide molecules using thermal energy produced during the step of processing the hydrogen and carbon dioxide containing feed streams.

91. The method as claimed in claim 78 wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit at a pressure selected to enable the SGR unit to receive the carbon dioxide containing feed stream from the calciner without being substantially cooled and compressed between the calciner and the SGR unit.

92. The method as claimed in claim 91 wherein the SGR unit is operated at a pressure of between 1 and 10 bar and the received carbon dioxide containing feed stream has a temperature of between 850-900°C.

93. The method as claimed in claim 78, wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, and the method further comprising feeding the carbon dioxide containing feed stream and one or more reactant feed streams into the SGR unit, the one or more reactant feed streams comprising at least one of a hydrogen reactant feed stream, a CH_4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

94. The method as claimed in claim 93 further comprising operating the SGR unit to produce a syngas product stream by one or more of a reverse water gas shift (RWGS) reaction, steam methane reforming (SMR) reaction, and a direct methane reforming (DMR) reaction.

95. The method as claimed in claim 94 further comprising treating the syngas product stream to produce one or more recycle streams that provide reactant to the SGR unit.

96. The method as claimed in claim 95 further comprising electrically heating at least one or more of the recycle streams and the reactant feed streams.

97. The method as claimed in claim 91 further comprising heating the SGR unit with thermal energy produced by electricity.

98. The method as claimed in claim 78 wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, and the method further comprising heating the SGR unit with thermal energy produced by combusting an oxidant and a fuel comprising at least one of hydrogen from the hydrogen-containing feed stream, natural gas, or a Fischer Tropsch light end hydrocarbon.

99. The method as claimed in claim 98 further comprising heating the calciner with thermal energy produced by combusting an oxidant and a fuel comprising at least one of hydrogen from the hydrogen-containing stream, natural gas, or Fischer Tropsch light end hydrocarbons.

100. The method as claimed in claim 98 wherein the step of extracting hydrogen molecules further comprises producing an oxygen containing stream, at least some of which is used as the oxidant by one or both of the SGR unit and the calciner.

101. The method as claimed in claim 91, further comprising heating the $CaCO_3$ material stream used in extracting carbon dioxide molecules with thermal energy from a syngas product stream from the SGR unit.

102. The method as claimed in claim 101 further comprising directly contacting the $CaCO_3$ material stream with the syngas product stream and operating the SGR in a reverse water gas shift (RWGS) mode, with one or more of a steam methane reforming (SMR) mode, a dry methane reforming (DMR) mode or a combination thereof.

103. The method as claimed in claim 91 further comprising heating the calciner with thermal energy produced by electricity.

104. The method as claimed in claim 103 wherein the step of extracting carbon dioxide molecules further comprises calcining $CaCO_3$ material in a fluidized bed reactor vessel of the calciner, and discharging a hot CaO solids stream from the calciner.

105. The method as claimed in claim 104 further comprising pre-heating the $CaCO_3$ material prior to entry into the calciner with thermal energy from a calciner product gas stream.

106. The method as claimed in claim 104 further comprising extracting water from the calciner product gas stream, boiling the extracted water to produce steam, then fluidizing the fluidized bed reactor vessel with the steam.

107. The method as claimed in claim 78, wherein the step of processing the hydrogen and carbon dioxide containing feed streams comprises operating a syngas generation reactor ("SGR") unit, and the method further comprising preheating one or more SGR reactant feed streams before feeding to the SGR unit, with thermal energy from a syngas product stream discharged from the SGR unit.

108. The method as claimed in claim 107 wherein the SGR reactant feed streams comprising at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH_4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream, wherein the carbon dioxide reactant feed stream includes at least some of the carbon dioxide feed stream, and the hydrogen reactant feed stream comprises at least some of the hydrogen containing feed stream.

109. The method as claimed in claim 107 further comprising combusting an oxidant and a fuel in an SGR burner of the SGR unit and producing a hot burner exhaust stream, then heating at least one of an oxidant feed stream of the SGR burner and a water feed stream to the SGR vessel, using thermal energy from the hot burner exhaust stream.

110. A system for producing a synthetic fuel from hydrogen and carbon dioxide, comprising:

(a) a hydrogen production subsystem configured to extract hydrogen molecules from hydrogen compounds in a hydrogen feedstock to produce a hydrogen containing feed stream;

(b) a carbon dioxide capture subsystem configured to extract carbon dioxide molecules from a dilute gaseous mixture in an atmospheric carbon dioxide feedstock to produce a carbon dioxide containing feed stream; and

(c) a synthetic fuel production subsystem configured to process the hydrogen and carbon dioxide containing feed streams to produce a synthetic fuel;

wherein at least one of the subsystems is thermally coupled to at least another one of the subsystems, such that at least some of the thermal energy produced by one subsystem is transferrable to at least another one of the subsystems; and

wherein the hydrogen production subsystem comprises an electrolyzer, and the carbon dioxide capture subsystem comprises a calciner.

111. The system as claimed in claim 110, wherein at least one of the subsystems is fluidly coupled to at least another one of the subsystems, such that at least some of the fluids produced by one subsystem is transferrable to at least another one of the subsystems.

112. The system as claimed in claim 110 or 111 wherein the calciner is thermally coupled to the synthetic fuel production subsystem such that thermal energy output by the calciner is transferrable to the synthetic fuel production subsystem.

113. The system as claimed in claim 112 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit thermally and fluidly coupled to the calciner, such that heat energy and carbon dioxide output from the calciner is transferrable to the SGR unit.

114. The system as claimed in claim 113 wherein at least one of the calciner and the SGR unit is fluidly coupled to an oxygen output of the hydrogen production subsystem such that at least some oxygen produced by the hydrogen production subsystem is usable in a combustion operation to heat the at least one of the calciner and the SGR unit.

115. The system as claimed in claim 113 wherein at least one of the calciner and the SGR unit is fluidly coupled to a hydrogen fuel source such that hydrogen from the hydrogen fuel source is usable in a combustion operation to heat at least one of the calciner and the SGR unit.

116. The system as claimed in any one of claims 110 to 115 further comprising at least one of a distillation and refining unit or a power generation unit fluidly coupled to the system for producing a synthetic fuel from hydrogen and carbon dioxide, wherein the carbon dioxide capture subsystem comprises one or both of a calciner and a slaker, and at least one of the calciner and the slaker is thermally coupled to at least one of the distillation and refining unit or the power generation unit such that thermal energy output by at least one of the calciner and the slaker is transferable to at least one of the distillation and refining unit or the power generation unit.

117. The system as claimed in any one of claims 110 to 116 wherein a material stream from the calciner is thermally coupled to an oxygen stream flowing from the hydrogen production subsystem to the calciner, such that thermal energy output by the calciner is transferable to the oxygen stream.

118. The system as claimed in any one of claims 110 to 117 wherein the calciner is thermally and fluidly coupled to the hydrogen production subsystem such that thermal energy and a product fluid output by the calciner are transferrable to the hydrogen production subsystem.

119. The system as claimed in any one of claims 110 to 118 wherein the carbon dioxide capture subsystem comprises a slaker with a water output that is fluidly and thermally coupled to the hydrogen production subsystem such that water and thermal energy output by the slaker is transferable to the hydrogen production subsystem.

120. The system as claimed in any one of claims 110 to 119 wherein the calciner is thermally coupled to a water source which is fluidly coupled to the hydrogen production subsystem, such that thermal energy output by the calciner is usable to generate steam.

121. The system as claimed in any one of claims 110 to 120 wherein the calciner is fluidly coupled to a fuel output of the synthetic fuel production subsystem, such that at least some of the synthetic fuel produced by the synthetic fuel production subsystem is combustible by the calciner to generate thermal energy.

122. The system as claimed in any one of claims 110 to 121 wherein the carbon dioxide capture subsystem comprises a $CaCO_3$ material stream, and the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit producing a syngas stream and a heat exchanger thermally coupled to the syngas stream and to the material stream, wherein thermal energy generated by the SGR unit and carried by the syngas stream is transferable to the $CaCO_3$ material stream by the heat exchanger.

123. The system as claimed in any one of claims 110 to 122 wherein a product gas output from the calciner is fluidly and thermally coupled to the hydrogen production subsystem, such that product gases and thermal energy produced by the calciner are transferable to the hydrogen production subsystem.

124. The system as claimed in any one of claims 110 to 123, wherein a product stream of the calciner is fluidly and thermally coupled to a high temperature solids removal unit, and the high temperature solids removal unit is fluidly and thermally coupled to the hydrogen production subsystem, such that water and thermal energy produced by the calciner is transferable to the hydrogen production subsystem.

125. The system as claimed in claim 124 wherein a carbon dioxide output of the calciner is fluidly and thermally coupled to the SGR unit, such that carbon dioxide and heat energy is transferable to the SGR unit.

126. The system as claimed in any one of claim 110 to 120 wherein the synthetic fuel production subsystem comprises a first heat exchanger and a first syngas generation reactor ("SGR") unit, wherein the first heat exchanger is fluidly coupled to an SGR feed stream comprising a hydrogen feed stream flowing from the hydrogen production subsystem to the first SGR unit, and thermally coupled to a product stream

output of the first SGR unit, such that thermal energy produced by the first SGR unit and carried by a product stream from the first SGR unit is transferable by the first heat exchanger to preheat the feed stream.

127. The system of claim 126 wherein the carbon dioxide capture subsystem comprises a slaker and the product stream is fluidly coupled to the slaker such that at least a portion of the water in the product stream is removed in the slaker.

128. The system of claim 127 wherein the synthetic fuel production subsystem further comprises a second heat exchanger fluidly coupled to the product stream, and a second SGR unit fluidly coupled to the product stream and thermally coupled to the heat exchanger such that at least a portion of the thermal energy produced by the second SGR unit is transferable by the second heat exchanger to preheat the product stream upstream of the second SGR unit.

129. The system as claimed in any one of claims 110 to 127 wherein the synthetic fuel production subsystem comprises a multiple-stage SGR assembly having an inlet in fluid communication with a product outlet of the hydrogen production subsystem and comprising at least two syngas generation reactor ("SGR") units and high-temperature hydrogen unit stages in a sequential fluid coupling, wherein each high-temperature hydrogen unit removes at least a portion of water from a product stream output by each SGR unit.

130. The system as claimed in any one of claims 110 to 129 wherein the carbon dioxide capture subsystem comprises an air contactor and a solution processing unit in fluid communication with the air contactor by a carbon dioxide aqueous capture solution, wherein the carbon dioxide aqueous capture solution is thermally coupled to the synthetic fuel production subsystem such that thermal energy is transferable from the synthetic fuel production subsystem into the carbon dioxide aqueous capture solution.

131. The system as claimed in claim 130 wherein the carbon dioxide capture subsystem further comprises a regeneration unit comprising a sorbent and is fluidly coupled to the solution processing unit by a rich carbon dioxide aqueous capture solution, and is

thermally coupled to the synthetic fuel production subsystem such that thermal energy from the synthetic fuel production subsystem is transferable to the regeneration unit to regenerate the sorbent.

132. The system as claimed in claim 131, wherein the regeneration unit is fluidly coupled to a fuel output of the synthetic fuel production subsystem such that at least a portion of fuel produced by the synthetic fuel production subsystem is combustible by the regeneration unit.

133. The system as claimed in claim 132 wherein the regeneration unit is thermally coupled to the hydrogen production subsystem such that thermal energy produced by the hydrogen production subsystem is transferable to the regeneration unit to regenerate the sorbent.

134. The system as claimed in claim 131 wherein the synthetic fuel production subsystem comprises an SGR unit, and at least one of the SGR unit and regeneration unit is thermally coupled to an electrical heat source comprising an electrical heater.

135. The system as claimed in any one of claims 110 to 130 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR"), and wherein at least one of the electrolyzer, SGR, or calciner are electrically driven or heated.

136. The system as claimed in claim 110 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit, wherein the SGR unit has an operating pressure selected to enable the SGR unit to receive the carbon dioxide containing feed stream without being substantially cooled and compressed between the calciner and the SGR unit.

137. The system as claimed in claim 136 wherein the SGR unit has an operating pressure of between 1 and 10 bar and the received carbon dioxide containing feed stream has a temperature of between 850-900°C.

138. The system as claimed in claim 110, wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit comprising one or more reactant inlets fluidly coupled to one or more reactant feed streams comprising at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH_4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

139. The system as claimed in claim 138 wherein the carbon dioxide reactant feed stream comprises at least some of the produced carbon dioxide containing feed stream.

140. The system as claimed in claim 139 wherein the synthetic fuel production subsystem further comprises a syngas treatment unit that receives a syngas product stream from the SGR unit and outputs one or more recycle streams, wherein the recycle streams comprise at least one of water, hydrogen, or carbon dioxide for use by the SGR unit.

141. The system as claimed in claim 140 further comprising at least one electric heater thermally coupled to one or more of the recycle streams and the reactant feed streams, the electric heater comprising at least one of an inline electric heater, electrical heating tape, resistance heating wire, coils or elements.

142. The system as claimed in any one of claims 136 to 141 wherein the SGR unit is thermally coupled to an electrical heat source comprising an electrical heater.

143. The system as claimed in claim 110 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit comprising an SGR burner and an SGR vessel thermally coupled to the SGR burner, wherein the SGR burner comprises a fuel inlet coupled to the hydrogen containing feed stream to receive hydrogen as fuel for combustion.

144. The system as claimed in any one of claims 136 to 143 wherein the calciner comprises a calciner burner and a calciner reactor vessel thermally coupled to the calciner burner, wherein the calciner burner comprises a fuel inlet coupled to the hydrogen containing feed stream to receive hydrogen as fuel for combustion.

145. The system as claimed in claim 144 wherein one or both of the fuel inlets of the SGR burner and the calciner burner are fluidly coupled to one or more of a natural gas stream and a Fischer Tropsch light end hydrocarbon stream.

146. The system as claimed in any one of claims 142 to 145 wherein the electrolyzer produces the hydrogen containing feed stream and an oxygen containing stream from the hydrogen feedstock, and wherein the oxygen containing stream is fluidly coupled to a calciner burner to provide at least some of the oxidant for the combustion.

147. The system as claimed in claim 110 wherein the calciner comprises a fluidized bed reactor vessel.

148. The system as claimed in claim 110 wherein the the calciner comprises a kiln reactor vessel and an electric heating element or a burner thermally coupled to the kiln reactor vessel.

149. The system as claimed in claim 110, wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit, the synthetic fuel production subsystem further comprises a heat exchanger thermally coupled to a syngas product stream from the SGR unit and to a $CaCO_3$ material stream from the carbon dioxide capture subsystem, such that thermal energy is transferrable from the syngas product stream to the $CaCO_3$ material stream.

150. The system as claimed in claim 149 wherein the heat exchanger comprising at least one of a bubbling fluidized bed (BFB) heat exchanger or a cyclone heat exchanger.

151. The system as claimed in claim 150 wherein the BFB or cyclone heat exchanger comprises a refractory or ceramic lined vessel inside which the $CaCO_3$ material stream and syngas product stream are in direct contact, and the SGR unit is configured to operate in a reverse water gas shift (RWGS) mode, with one or more of a steam methane reforming (SMR) mode, a dry methane reforming (DMR) mode or a combination thereof.

152. The system as claimed in claim 110 wherein the calciner is thermally coupled to an electric heat source.

153. The system as claimed in claim 152 wherein the calciner comprises
a fluidized bed reactor vessel with a solids feed inlet for receiving $CaCO_3$ material, a fluidizing stream inlet for receiving a calciner fluidizing fluid comprising steam, a product gas stream outlet for discharging a calciner product gas stream, and a solids product outlet for discharging a produced CaO solids stream; and
an electric heating element thermally coupled to the reactor vessel for heating the fluidizing stream and $CaCO_3$ material therein.

154. The system as claimed in claim 153 wherein the electric heating element is encased in a metal sheath extending into a bubbling bed zone of the reactor vessel, or is thermally coupled to a refractory lined wall of the reactor vessel.

155. The system as claimed in claim 153 or 154 further comprising a water knockout and solids removal unit having an inlet fluidly coupled to the calciner product gas stream, a water outlet for discharging water removed from the product gas stream, a dust outlet for discharging dust removed from the product gas stream, and carbon dioxide outlet for discharging a carbon dioxide product stream;
a compressor having an inlet for receiving the carbon dioxide product stream and compressing same; and
a boiler unit having an inlet for receiving the discharged water, and an outlet for discharging steam for the calciner fluidizing fluid.

156. The system as claimed in claim 110 wherein the synthetic fuel production subsystem comprises a syngas generation reactor ("SGR") unit and a ceramic heat exchanger thermally coupled to a syngas product stream discharged from the SGR unit and to one or more SGR reactant feed streams fed to the SGR unit, such that the one or more SGR reactant feed streams are preheated by thermal energy from the syngas product stream before being fed to the SGR unit.

157. The system as claimed in claim 156 wherein the SGR reactant feed streams comprising at least one of a carbon dioxide reactant feed stream, a hydrogen reactant feed stream, a CH4 reactant feed stream, a water reactant feed stream, or a Fischer Tropsch light end hydrocarbon reactant feed stream.

158. The system as claimed in claim 157, wherein the carbon dioxide reactant feed stream comprises the carbon dioxide containing feed stream produced by the calciner, and the hydrogen reactant feed stream comprises the hydrogen containing feed stream produced by the hydrogen production subsystem.

159. The system as claimed in claim 158 wherein the synthetic fuel production subsystem further comprises a Fischer Tropsch unit having an inlet coupled to the syngas product stream cooled and discharged from the ceramic heat exchanger and at least one outlet for discharging the Fischer Tropsch light end hydrocarbon feed stream and a water stream.

160. The system as claimed in any one of claims 156 to 159 wherein SGR unit comprises an SGR vessel thermally coupled to an SGR burner that produces a hot burner exhaust stream that is thermally coupled to at least one of a heat exchanger for heating an oxidant feed stream of the SGR burner and a boiler for heating a water reactant feed stream to the SGR vessel.

161. The system as claimed in claim 160 wherein the carbon dioxide capture subsystem comprises a calciner having a calciner burner, and the hydrogen production subsystem comprises an electrolyzer which produces the hydrogen containing feed stream and an oxygen containing stream from the hydrogen feedstock, and wherein the oxygen containing stream is fluidly coupled to at least one of the SGR burner and the calciner burner to provide the oxidant.

162. The system as claimed in any one of claims 156 to 159 wherein the SGR unit comprises an SGR vessel thermally coupled to an electrical heater.