Claims:

What is claimed is:

1. A method for combusting a fuel, comprising:

introducing a fuel, an oxidant, and a diluent to a combustion zone;

combusting at least a portion of the fuel to produce an exhaust gas comprising water, carbon dioxide, oxygen, and carbon monoxide;

expanding the exhaust gas to produce mechanical power and an expanded exhaust gas;

determining a concentration of at least one of oxygen and carbon monoxide, in at least one of the exhaust gas and the expanded exhaust gas; and

adjusting an amount of at least one of the oxidant and the fuel introduced to the combustion zone based at least in part on the determined concentration of at least one of oxygen and carbon monoxide to produce an exhaust gas containing a combined amount of oxygen and carbon monoxide of less than about 2 mol%.

2. The method of claim 1, wherein exhaust gas contains a combined amount of oxygen and carbon monoxide of less than about 1.5 mol%.

3. The method of claim 1, wherein the adjustment of at least one of the oxidant and the fuel is adapted to drive an equivalence ratio toward 1.0, wherein the equivalence ratio (phi, ϕ) is equal to $(\text{mol\% fuel/mol\% oxidant})_{actual}/(\text{mol\% fuel/mol\% oxidant})_{stoichiometric}$.

4. The method of claim 3, wherein the equivalence ratio is maintained between about 0.995 and 1.005, wherein proximity to an equivalence ratio of about 1.0 is identified by observation of exhaust gas composition changes, wherein proximity to 1.0 is identified by at least one of about a ten-fold increase in oxygen concentration resulting from a change in phi of less than 0.001 and about a ten-fold decrease in carbon monoxide concentration resulting from a change in phi of less than 0.002.

5. The method of claim 1, further comprising decreasing the amount of oxidant introduced to the combustion zone by about 0.01 vol% to about 0.2 vol% after the equivalence ratio (ϕ) is adjusted to between about 0.997 and about 1.003 to produce an exhaust gas comprising less than about 10 ppmw oxygen and from about 10 ppmw to about 10,000 ppmw carbon monoxide.

6. The method of claim 5, further comprising converting at least a portion of the carbon monoxide in a portion of the compressed exhaust gas to carbon dioxide to produce a recovered exhaust gas comprising less than about 10 ppm carbon monoxide.

7. The method of claim 1, further comprising removing at least a portion of any carbon dioxide from a second portion of the compressed exhaust gas to provide a carbon dioxide-lean gas comprising less than 5 mol% carbon dioxide and a carbon dioxide rich gas comprising greater than about 95 mol% carbon dioxide.

8. The method of claim 7, further comprising introducing the carbon dioxide lean gas to a hydrocarbon reservoir for pressure maintenance.

9. The method of claim 7, further comprising using the carbon dioxide rich gas in an enhanced oil recovery process.

10. The method of claim 1, further comprising cooling the exhaust gas and removing at least a portion of the water from the exhaust gas prior to compressing at least a portion of the exhaust gas.

11. The method of claim 1, wherein the equivalence ratio (ϕ) is adjusted such that the equivalence ratio (ϕ) is greater than 1.0, and wherein the exhaust gas comprises less than 5 ppmw oxygen.

12. The method of claim 11, wherein the exhaust gas comprises greater than about 500 ppmw carbon monoxide.

13. The method of claim 12, further comprising catalytically converting at least a portion of the carbon monoxide in the compressed exhaust gas to carbon dioxide to produce a converted gas comprising less than 1 ppmw oxygen and less than 10 ppmw carbon monoxide.

14. The method of claim 1, wherein the oxidant consists essentially of air, and wherein the exhaust gas further comprises nitrogen.

15. The method of claim 1, wherein the exhaust gas has a carbon dioxide concentration ranging from about 10 mol% to about 34 mol% and a nitrogen concentration ranging from about 0.01 mol% to about 75 mol%.

16. The method of claim 1, wherein the fuel comprises methane and one or more C_2 to C_{10} hydrocarbons.

17. The method of claim 16, further comprising reforming at least a portion of the fuel such that a concentration of the one or more C_2 to C_{10} hydrocarbons is reduced to produce a reformed fuel; and introducing the reformed fuel to the combustion zone.

18. The method of claim 17, wherein the reforming comprises contacting the fuel with one or more catalysts.

19. The method of claim 16, wherein the one or more catalysts comprise nickel, platinum, rhodium, ruthenium, palladium, derivatives thereof, mixtures thereof, or any combination thereof.

20. The method of claim 3, wherein the mol% fuel is equal to $F_{fuel}/(F_{oxidant} + F_{fuel})$, where F_{fuel} is equal to the molar flow rate of fuel and $F_{oxidant}$ is equal to the molar flow rate of oxidant, wherein the mol% oxidant is equal to $F_{oxidant}/(F_{oxidant} + F_{fuel})$, where $F_{oxidant}$ is equal to the molar flow rate of oxidant and F_{fuel} is equal to the molar flow rate of fuel.

21. The method of claim 1, further comprising indirectly transferring heat from the expanded exhaust gas to water, steam, or mixture of water and steam to generate steam and a first cooled exhaust gas.

22. The method of claim 21, further comprising introducing the first cooled exhaust gas to a blower to increase a pressure of the first cooled exhaust gas.

23. The method of claim 21, further comprising removing at least a portion of any water in the first cooled exhaust gas to produce a water condensate and a second cooled exhaust gas, and wherein the compressed exhaust gas comprises the second cooled exhaust gas.

24. The method of claim 21, further comprising introducing the steam to a steam gas turbine coupled to a generator to produce electrical power.

25. The method of claim 1, wherein at least a portion of the mechanical power is used to power a compressor, power a generator, or both.

26. The method of claim 1, further comprising removing at least a portion of the carbon dioxide from the compressed exhaust gas to produce a carbon dioxide-rich gas and a carbon dioxide-lean gas; and compressing the carbon dioxide-lean gas to produce a compressed gas.

27. The method of claim 1, further comprising removing at least a portion of the carbon dioxide from a second portion of the compressed exhaust gas to produce a carbon dioxide-rich gas and a carbon dioxide-lean gas; combusting at least a portion of any residual fuel contained in the carbon dioxide-lean gas to provide a second exhaust gas, and expanding the second exhaust gas to produce mechanical power and an expanded second exhaust gas.

28. The method of claim 1, further comprising removing at least a portion of the carbon dioxide from a second portion of the compressed exhaust gas to produce a carbon dioxide-rich gas and a carbon dioxide-lean gas; catalytically reacting at least a portion of any residual fuel contained in the carbon dioxide-lean gas to provide a second exhaust gas, and expanding the second exhaust gas to produce mechanical power and an expanded exhaust gas.

29. The method of claim 1, wherein the fuel comprises methane and one or more C_2 to C_{10} hydrocarbons.

30. The method of claim 29, further comprising reforming at least a portion of the fuel such that a concentration of the one or more C_2 to C_{10} hydrocarbons is reduced to produce a reformed fuel; and introducing the reformed fuel to the combustion zone.

31. A method for combusting a fuel, comprising:

introducing a fuel, an oxidant, and a diluent to a combustion zone;

combusting at least a portion of the fuel to produce an exhaust gas comprising water, carbon dioxide, oxygen, and carbon monoxide;

expanding the exhaust gas to produce mechanical power and an expanded exhaust gas;

estimating an oxidant to fuel equivalence ratio (ϕ) based on a concentration of oxygen, carbon monoxide, or both in the exhaust gas, the expanded exhaust gas, or both;

adjusting an amount of the fuel, oxidant, or both introduced to the combustion zone based on the estimated oxidant to fuel equivalence ratio (ϕ) to produce an exhaust gas containing a combined amount of oxygen and carbon monoxide of less than about 2 mol%;

compressing at least a portion of the exhaust gas to produce a compressed exhaust gas; and

recycling at least a portion of the compressed exhaust gas to the combustion zone as the diluent.

32. The method of claim 20, wherein adjusting the amount of the fuel, oxidant, or both introduced to the combustion zone comprises:

decreasing an amount of the oxidant, increasing an amount of the fuel, or both, introduced to the combustion zone if the equivalence ratio (ϕ) is less than 1 such that the equivalence ratio (ϕ) increases toward 1; or

decreasing the amount of the fuel, increasing the amount of the oxidant, or both introduced to the combustion zone if the equivalence ratio (ϕ) is greater than 1 such that the equivalence ratio (ϕ) decreases toward 1.

Claims

1. A method for combusting a fuel, comprising:

introducing a fuel, an oxidant, and a diluent to a combustion zone, wherein the oxidant is air, oxygen-enriched air, oxygen-lean air, hydrogen peroxide (H_2O_2), ozone (O_3), a gaseous mixture of oxygen and water, or any combination thereof;

combusting at least a portion of the fuel to produce an exhaust gas comprising water, carbon dioxide, oxygen, and carbon monoxide;

expanding the exhaust gas to produce mechanical power and an expanded exhaust gas;

determining a concentration of at least one of oxygen, hydrogen, nitrogen oxides and carbon monoxide, in at least one of the exhaust gas and the expanded exhaust gas; and

adjusting an amount of at least one of the oxidant and the fuel introduced to the combustion zone using at least the determined concentration of at least one of oxygen, hydrogen, nitrogen oxides and carbon monoxide to produce an exhaust gas containing a combined amount of oxygen and carbon monoxide of less than 2 mol%.

2. The method of claim 1, wherein exhaust gas contains a combined amount of oxygen and carbon monoxide of less than 1.5 mol%.

3. The method of claim 1, wherein exhaust gas contains a combined amount of oxygen and carbon monoxide of less than 1.0 mol%.

4. The method of claim 1, wherein exhaust gas contains a combined amount of oxygen and carbon monoxide of less than 4000 ppm.

5. The method of any one of claims 1 to 4, wherein the adjustment of at least one of the oxidant and the fuel is adapted to drive an equivalence ratio toward 1.0, wherein the equivalence ratio (phi, ϕ) is equal to (mol% fuel/mol% oxidant)$_{actual}$/(mol% fuel/mol% oxidant)$_{stoichiometric}$

6. The method of any one of claims 1 to 5, further comprising introducing the expanded exhaust gas to a heat recovery unit to produce a first cooled exhaust gas and a heated heat transfer medium.

7. The method of claim 6, wherein the heat transfer medium is at least one of water and steam.

8. The method of claim 7, further comprising introducing the steam to a steam gas turbine coupled to at least one of a generator to produce electrical power or another device to produce mechanical power.

9. The method of claim 6, further comprising removing at least a portion of the first cooled exhaust gas from the system to be introduced to at least one of a vent system, flare system or underground storage or containment system.

10. The method of claim 6, further comprising recycling at least a portion of the first cooled exhaust gas to a first compressor to produce a compressed exhaust gas.

11. The method of claim 10, further comprising introducing at least a first portion of the compressed exhaust gas to the combustion zone as the diluent.

12. The method of claim 11, further comprising removing at least a second portion of the compressed exhaust gas from the system.

13. The method of claim 10, further comprising cooling the at least a portion of the first cooled exhaust gas and removing at least a portion of the water from the at least a portion of the first cooled exhaust gas prior to compressing the at least a portion of the first cooled exhaust gas.

14. The method of claim 12, further comprising catalytically converting at least a portion of the carbon monoxide in the second portion of the compressed exhaust gas to carbon dioxide.

15. The method of claim 14, wherein the concentration of carbon monoxide is reduced to less than 500 ppm.

16. The method of any one of the preceding claims, wherein the oxidant consists essentially of air, and wherein the exhaust gas further comprises nitrogen.

17. The method of any one of the preceding claims, wherein the exhaust gas has a carbon dioxide concentration ranging from 10 mol% to 34 mol% and a nitrogen concentration ranging from 0.01 mol% to 75 mol%.

18. The method of any one of the preceding claims, wherein the fuel comprises methane and one or more C_2 to C_{10} hydrocarbons.

19. The method of claim 18, further comprising reforming at least a portion of the fuel such that a concentration of the one or more C_2 to C_{10} hydrocarbons is reduced to produce a reformed fuel; and introducing the reformed fuel to the combustion zone.

20. The method of claim 19, wherein the reforming comprises contacting the fuel with one or more catalysts.

21. The method of claim 20, wherein the one or more catalysts comprise nickel, platinum, rhodium, ruthenium, palladium, derivatives thereof, mixtures thereof, or any combination thereof.

22. The method of claim 3, wherein the mol% fuel is equal to $F_{fuel}/(F_{oxidant} + F_{fuel})$, where F_{fuel} is equal to the molar flow rate of fuel and $F_{oxidant}$ is equal to the molar flow rate of oxidant, wherein the mol% oxidant is equal to $F_{oxidant}/(F_{oxidant} + F_{fuel})$, where $F_{oxidant}$ is equal to the molar flow rate of oxidant and F_{fuel} is equal to the molar flow rate of fuel.

23. The method of any one of claims 6 to 15, further comprising introducing the first cooled exhaust gas to a blower to increase a pressure of the first cooled exhaust gas.

24. The method of any one of claims 6 to 15, further comprising removing at least a portion of any water in the first cooled exhaust gas to produce a water condensate and a second cooled exhaust gas, and wherein the compressed exhaust gas comprises the second cooled exhaust gas.

25. The method of any one of the preceding claims, wherein at least a portion of the mechanical power is used to power a compressor, power a generator, or both.

26. The method of claim 22, wherein adjusting the amount of the fuel, oxidant, or both introduced to the combustion zone comprises:

decreasing an amount of the oxidant, increasing an amount of the fuel, or both, introduced to the combustion zone if the equivalence ratio (ϕ) is less than 1 such that the equivalence ratio (ϕ) increases toward 1; or

decreasing the amount of the fuel, increasing the amount of the oxidant, or both introduced to the combustion zone if the equivalence ratio (ϕ) is greater than 1 such that the equivalence ratio (ϕ) decreases toward 1.

27. The method of claim 12, further comprising removing at least a portion of any carbon dioxide from a second portion of the compressed exhaust gas to provide a carbon dioxide-lean gas and a carbon dioxide-rich gas.

28. The method of claim 27, further comprising introducing the carbon dioxide-lean gas to a hydrocarbon reservoir for pressure maintenance.

29. The method of claim 27, further comprising using the carbon dioxide-rich gas in an enhanced oil recovery process.

30. The method of claim 28, further comprising compressing the carbon dioxide-lean gas to produce a compressed gas.

31. The method of any one of claims 27 to 30, further comprising combusting at least a portion of any residual combustible material contained in the carbon dioxide-lean gas to provide a second exhaust gas, and expanding the second exhaust gas to produce mechanical power and an expanded second exhaust gas.

32. The method of any one of claims 27 to 31, further comprising catalytically reacting at least a portion of any residual combustible material contained in the carbon dioxide-lean gas to provide a second exhaust gas, and expanding the second exhaust gas to produce mechanical power and an expanded exhaust gas.

33. The method of any one of the preceding claims, further comprising compressing the oxidant prior to being introduced to the combustor.

34. The method of any one of the preceding claims, further comprising controlling the oxidant flow rate by use of at least one of a compressor, valve, and nozzle.

35. The method of any one of the preceding claims, further comprising controlling the fuel flow rate by the use of at least one of a valve, pump, nozzle, turbine meter, venturi flow meter, and orifice plate.

36. The method of any one of the preceding claims, wherein the concentration of at least one of oxygen, hydrogen, nitrogen oxides and carbon monoxide, in at least one of the exhaust gas and the expanded exhaust gas is determined by using at least one of lambda, zirconia oxygen, titania, galvanic, infrared, and oxide film sensors.

37. The method of claim 14, wherein the remaining concentration of carbon monoxide is less than 500 ppm after catalytically converting it.

38. A method for combusting a fuel, comprising:

introducing a fuel, an oxidant, and a diluent to a combustion zone;

combusting at least a portion of the fuel to produce an exhaust gas comprising water, carbon dioxide, oxygen, and carbon monoxide;

expanding the exhaust gas to produce mechanical power and an expanded exhaust gas;

estimating an oxidant to fuel equivalence ratio (ϕ) based on a concentration of at least one of oxygen, hydrogen, nitrogen oxides, and carbon monoxide in the exhaust gas, the expanded exhaust gas, or both;

adjusting an amount of the fuel, oxidant, or both introduced to the combustion zone based on the estimated oxidant to fuel equivalence ratio (ϕ) to produce an exhaust gas containing a combined amount of oxygen and carbon monoxide of less than 2 mol%;

compressing at least a portion of the exhaust gas to produce a compressed exhaust gas; and

recycling at least a portion of the compressed exhaust gas to the combustion zone as the diluent.