CLAIMS

~~What is claimed is:~~

1. A process for the production of syngas, the process comprising:

(i) reacting at least a portion of carbon dioxide with hydrogen within an initial reactor to produce an initial product stream including carbon monoxide, water, unreacted carbon dioxide, and unreacted hydrogen; and

(ii) reacting at least a portion of the unreacted carbon dioxide and unreacted hydrogen within a reactor downstream of the first reactor to thereby produce a product stream including carbon monoxide, water, unreacted carbon dioxide, and unreacted hydrogen.

2. The process of any of the preceding claims, where the carbon dioxide and the hydrogen include at least 50 mol % of the reactants within the initial reactor.

~~3. The process of any of the preceding claims, where the reactor includes less than 10 mol % methane relative to the total moles of reactants within the initial reactor.~~

~~4~~3. The process of any of the preceding claims, where the initial product stream has a temperature T1 when exiting the initial reactor, where the product stream has a temperature T2 when exiting the downstream reactor, and where T2 > T1, and where T1 is from about 300 to about 1000 °C, and where T2 is from about 500 to about 1200 °C.

~~5. The process of any of the preceding claims, where T1 is from about 300 to about 1000 °C, and where T2 is from about 500 to about 1200 °C.~~

~~6~~4. The process of any of the preceding claims, where the reactor downstream of the first reactor is a final reactor in series, where the product stream produced by said final reactor is the final product stream, and where the process further includes reacting unreacted carbon dioxide and unreacted hydrogen within said initial product stream within one or more reactors positioned between the initial reactor and the final reactor, and optionally where the one or more reactors positioned between the initial reactor and the final reactor produce a final intermediary product stream, which includes carbon monoxide, water, unreacted hydrogen, and unreacted carbon dioxide, and where said unreacted hydrogen and unreacted carbon dioxide within said final intermediary product stream are reacted within the final reactor.

~~7. The process of any of the preceding claims, where the one or more reactors positioned between the initial reactor and the final reactor produce a final intermediary product stream, which includes carbon monoxide, water, unreacted hydrogen, and unreacted carbon dioxide, and where said unreacted hydrogen and unreacted carbon dioxide within said final intermediary product stream are reacted within the final reactor.~~

~~8~~5. The process of any of the preceding claims, further comprising (i) removing at least a portion of the water from the initial product stream prior to said step of reacting at least a portion of the unreacted carbon dioxide and unreacted hydrogen within the final reactor or (ii) removing at least a portion of the water from the intermediary product stream prior to said step of reacting unreacted carbon dioxide and unreacted hydrogen within one or more reactors positioned between the initial reactor and the final reactor.

~~9. The process of any of the preceding claims, where said step of reacting at least a portion of carbon dioxide with hydrogen within an initial reactor takes place adiabatically.~~

~~10. The process of any of the preceding claims, further including the step of introducing heat to the final reactor.~~

~~11. The process of any of the preceding claims, where the final reactor is a fired-tubular reactor.~~

~~12. The process of any of the preceding claims, further comprising (i) providing a stream including carbon dioxide, (ii) providing a stream including hydrogen, (iii) combining the steam including carbon dioxide with the stream including hydrogen to form a reactant mixture, (iv) optionally heating the reactant mixture to form a heated reactant mixture, and (v) introducing at least one of the reactant mixture and the heated reactant mixture to the initial reactor.~~

~~13. The process of any of the preceding claims, where the stream including hydrogen includes greater than 90 mol % hydrogen, and where the stream including carbon dioxide includes greater than 90 mol % carbon dioxide.~~

~~14. The process of any of the preceding claims, where the stream including hydrogen includes greater than 98 mol % hydrogen, and where the stream including carbon dioxide includes greater than 98 mol % carbon dioxide.~~

~~15~~6. The process of any of the preceding claims, where said step of introducing heat to the final reactor generates carbon dioxide and produces an exhaust stream containing CO_2, and further including capturing at least a portion of the CO_2 contained in said exhaust stream to form a captured stream containing CO_2, and further including introducing at least a portion of the CO_2 contained in said captured stream to the final reactor or to a step upstream of the final reactor for conversion to carbon monoxide.

~~16. The process of any of the preceding claims, where said step of capturing at least a portion of the exhaust CO_2 stream includes capturing at least 50% of the carbon dioxide generated to produce the heat.~~

~~17. The process of any of the preceding claims, where said step of capturing at least a portion of the exhaust CO_2 stream includes capturing at least 90% of the carbon dioxide generated to produce the heat.~~

~~18. The process of any of the preceding claims, where the final product stream includes carbon monoxide and hydrogen.~~

~~19. The process of any of the preceding claims, where the final product stream is a synthesis gas stream.~~

~~20~~7. The process of any of the preceding claims, further comprising the step of converting at least a portion of the final product stream to at least one of a hydrocarbon, methanol, and an alcohol.

~~21. The process of any of the preceding claims, further comprising the step of converting at least a portion of the final product stream to methanol.~~

~~22. The process of any of the preceding claims, further comprising the step of converting at least a portion of the final product stream to an alcohol.~~

~~23~~8. The process of any of the preceding claims, where said step of reacting at least a portion of carbon dioxide with hydrogen ~~performing a final reverse water-gas shift reaction~~ produces an exhaust stream containing excess heat, and further comprising the step of transferring said excess heat to at least one of the carbon

dioxide containing feed stream and the reactant mixture prior to said step of (i) reacting at least a portion of the carbon dioxide with hydrogen in an initial reactor.

~~24~~9. The process of any of the preceding claims, where said step of introducing heat to the final reactor includes introducing heat from a carbon-free heat source, and where the carbon-free heat source includes at least one of electrical power, nuclear power, wind power, solar power, hydropower, combustion of hydrogen, and combustion of a carbon-free fuel.

~~25. The process of any of the preceding claims, where the carbon-free heat source includes at least one of electrical power, nuclear power, wind power, solar power, hydropower, combustion of hydrogen, and combustion of a carbon-free fuel.~~

~~26. The process of any of the preceding claims, further comprising the step of capturing carbon dioxide from a point source to form a captured stream including carbon dioxide stream, and further comprising introducing at least a portion of the captured stream including carbon dioxide to the initial reactor.~~

~~27. The process of any of the preceding claims, where the point source is an industrial source of carbon dioxide or a power plant.~~

~~28~~10. The process of any of the preceding claims, further comprising the step of capturing carbon dioxide from atmospheric air to form a direct-air captured stream including carbon dioxide, and further comprising introducing at least a portion of the direct-air captured stream including carbon dioxide to the initial reactor.

~~29~~11. A process for the production of syngas, the process comprising:

(i) providing a reactant stream including carbon dioxide;

(ii) providing a reactant stream including hydrogen;

(iii) combining the reactant stream including carbon dioxide with the reactant stream including hydrogen to form a mixed reactant stream;

(iv) heating the mixed reactant stream to form a heated mixed reactant stream;

(v) introducing the heated mixed reactant stream to an adiabatic reactor including a reverse water-gas shift catalyst;

(vi) allowing the hydrogen and carbon dioxide to react within the adiabatic reactor to thereby form an initial product stream including carbon monoxide, water, hydrogen, and carbon dioxide;

(vii) removing the initial product stream from the adiabatic reactor, where said initial product stream, upon exiting the adiabatic reactor, has a temperature T1;

(viii) removing at least a portion of the water in the initial product stream from the initial product stream to form a water-lean initial product stream;

(ix) introducing the initial product stream to a fired-tubular reactor including a reverse water-gas shift catalyst, where said fired-tubular reactor produces an exhaust stream including produced carbon dioxide and excess heat;

(x) heating the product stream to a temperature T3 within the fired-tubular reactor, where T3 is greater than or equal to T1, to thereby react the carbon dioxide and hydrogen within the initial product stream to form a final product stream;

(xi) routing at least a portion of the excess heat to said step of heating the mixed reactant stream to form a heated mixed reactant stream; and

(xii) routing at least a portion of the produced carbon dioxide to said adiabatic reactor, or said fired-tubular reactor.

~~30~~12. A process for the production of syngas, the process comprising:

(i) providing a reactant stream including carbon dioxide;

(ii) providing a reactant stream including hydrogen;

(iii) combining the reactant stream including carbon dioxide with the reactant stream including hydrogen to form a mixed reactant stream;

(iv) heating the mixed reactant stream to form a heated mixed reactant stream;

(v) introducing the heated mixed reactant stream to an initial adiabatic reactor including a reverse water-gas shift catalyst;

(vi) allowing the hydrogen and carbon dioxide to react within the initial adiabatic reactor to thereby form an initial product stream including carbon monoxide, water, hydrogen, and carbon dioxide;

(vii) removing the initial product stream from the initial adiabatic reactor, where said initial product stream, upon exiting the initial adiabatic reactor, has a temperature T1;

(viii) removing at least a portion of the water in the initial product stream from the initial product stream to form a water-lean initial product stream;

(ix) heating the water-lean initial product stream to form a heated water-lean initial product stream;

(x) introducing the heated water-lean initial product stream to a downstream adiabatic reactor including a reverse water-gas shift catalyst;

(xi) allowing the hydrogen and carbon dioxide to react within the downstream adiabatic reactor to thereby form an intermediary product stream including carbon monoxide, water, hydrogen, and carbon dioxide;

(xii) removing the intermediary product stream from the downstream adiabatic reactor, where said intermediary product stream, upon exiting the downstream adiabatic reactor, has a temperature T2;

(xiii) removing at least a portion of the water in the intermediary product stream to form a water-lean intermediary product stream;

(xiv) optionally heating the water-lean intermediary product stream to form a heated, water-lean intermediary product stream at temperature T02;

(xv) optionally Introducing the heated, water-lean intermediary product stream to a downstream adiabatic reactor including a reverse water-gas shift catalyst and allowing the carbon dioxide and hydrogen in the heated, water-lean intermediary product stream to react and thereby ultimately form a final intermediary product stream;

(xvi) introducing the intermediary product stream or the final intermediary product stream to a fired-tubular reactor including a reverse water-gas shift catalyst, where said fired-tubular reactor produces an exhaust stream including produced carbon dioxide and excess heat;

(xvii) heating the intermediary or final intermediary product stream to a temperature T3 within the fired-tubular reactor, where T3 is greater than or equal to T2, and where T3 is greater than or equal to T1, to thereby react the carbon dioxide and hydrogen within the intermediary product stream or the final intermediary product stream to form a final product stream;

(xviii) routing at least a portion of the excess heat to said step of heating the mixed reactant stream to form a heated mixed reactant stream or to said step of heating the initial product stream to form a heated initial product stream; and

(xix) routing at least a portion of the produced carbon dioxide to said adiabatic reactor, said downstream adiabatic reactor, or said fired-tubular reactor.

~~31~~13. A RWGS system comprising:

(i) an initial RWGS reactor including a reverse water-gas shift catalyst, said RWGS reactor adapted to facilitate the reaction of hydrogen and carbon dioxide to thereby form an initial product stream including carbon monoxide, water, hydrogen, and carbon dioxide;

(ii) downstream of said initial RWGS reactor, a water removal unit for removing water from the initial product stream;

(iii) optional one or more intermediary RWGS reactors, positioned in series, downstream of said initial RWGS reactor, each optional intermediary RWGS reactor including a water-gas shift catalyst, said optional intermediary reactors adapted to facilitate the reaction of hydrogen and carbon dioxide to form intermediary product streams and ultimately form a~~n~~ final intermediary product stream including carbon monoxide, water, hydrogen, and carbon dioxide;

(iv) optional a water removal unit~~s~~ for removing water from the intermediary product streams and final intermediary product stream; and

(v) a final RWGS reactor downstream of and positioned in series to said initial RWGS reactor and said optional one or more intermediary RWGS reactors, said final RWGS reactor including a water-gas shift catalyst, said final RWGS reactor adapted to facilitate the reaction of hydrogen and carbon dioxide to thereby form a final product stream including carbon monoxide, water, hydrogen, and carbon dioxide.

~~32~~14. The system of any of the preceding claims, further comprising a heating source in thermal communication with said final RWGS reactor, said heating source including an exhaust conduit in thermal communication with one or more upstream heating sources.

~~33~~15. The system of any of the preceding claims, further comprising a carbon dioxide capture unit; said carbon dioxide capture unit in fluid communication with said exhaust conduit and adapted to remove carbon dioxide from exhaust gases exiting said heating source.