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(54) Title: BLUE AMMONIA PRODUCTION

(57) Abstract: A gas stream is pressurized to produce a compressed gas stream. A first portion of a fuel stream is combusted in the presence of the compressed gas stream to produce an exhaust stream. The exhaust stream is flowed to a turbine of an electric generator, thereby causing the turbine to rotate and generate power. Heat is transferred from the exhaust stream to the compressed gas stream. Heat is transferred from the exhaust stream to a working fluid. Heat is transferred from the working fluid to a water stream for generating a steam stream. A second portion of the fuel stream is converted in the presence of oxygen and steam to produce a syngas stream. The syngas stream is separated to produce a carbon dioxide stream and a hydrogen stream. The hydrogen stream is reacted with nitrogen to produce an ammonia stream.



BLUE AMMONIA PRODUCTION

CLAIM OF PRIORITY

[0001] This application claims priority to U.S. Patent Application No. 18/396,221 filed on December 26, 2023, the entire contents of which are hereby incorporated by reference.

5 TECHNICAL FIELD

[0002] This disclosure relates to ammonia production, and in particular, blue ammonia production.

BACKGROUND

[0003] Hydrocarbon reforming involves chemical synthesis of hydrogen gas
10 from hydrocarbons (such as methane) by use of a catalyst or via a partial oxidation process. Steam reforming (sometimes referred to as steam methane reforming) is a type of methane reforming in which hydrocarbons are converted in the presence of steam to form syngas (a mixture of hydrogen and carbon monoxide). In some cases, the syngas can react further to produce carbon dioxide and more hydrogen. Autothermal reforming
15 (ATR) is another type of methane reforming in which oxygen is directly combusted to form syngas. Processes can also include controlled partial oxidation to reform hydrocarbon gas. Components of the syngas (such as carbon monoxide and hydrogen) can be separated and processed to form different chemicals, such as methanol and ammonia. Similarly, syngas can further be processed in the presence of water (for
20 example, in the form of steam) to convert carbon monoxide into carbon dioxide and additional hydrogen.

SUMMARY

[0004] This disclosure describes technologies relating to ammonia production,
25 and in particular, blue ammonia production. This disclosure also describes technologies relating to hydrogen production, and in particular, blue hydrogen production.

[0005] Certain aspects of the subject matter described can be implemented as a method. A gas stream including oxygen is compressed (pressurized) to produce a compressed gas stream. A first portion of a fuel stream including hydrogen atoms is
30 combusted in the presence of the compressed gas stream to produce an exhaust stream.

The exhaust stream is flowed to a turbine of an electric generator, thereby causing the exhaust stream to expand while flowing across the turbine and the turbine to rotate. The electric generator generates electrical power in response to rotation of the turbine. Heat is transferred from to the exhaust stream to the compressed gas stream. After
5 transferring heat from the compressed gas stream to the exhaust stream, heat is transferred from the exhaust stream to a working fluid. After transferring heat from the exhaust stream to the working fluid, heat is transferred from the working fluid to a water stream for generating a steam stream. A second portion of the fuel stream is converted in the presence of oxygen and steam to produce a syngas stream. At least a portion of
10 the steam is sourced from the steam stream generated from the water stream. The syngas stream is separated to produce a carbon dioxide stream and a hydrogen stream. The hydrogen stream is reacted with nitrogen to produce an ammonia stream. At least a portion of the electrical power generated by the electric generator is used to convert the second portion of the fuel stream, separate the syngas stream, react the hydrogen stream
15 with nitrogen, or any combinations of these.

[0006] This, and other aspects, can include one or more of the following features. In some implementations, the gas stream is compressed by a compressor that is coupled to the electric generator. The compressor can include an impeller coupled to a shaft. The shaft of the compressor can be coupled to the turbine wheel of the electric
20 generator and can rotate with the turbine wheel. Rotation of the impeller of the compressor can cause the gas stream to compress. In some implementations, at least a portion of the steam stream is flowed to a second turbine wheel of a second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate. The second
25 electric generator can generate electrical power in response to rotation of the second turbine wheel. In some implementations, at least a portion of carbon monoxide of the syngas stream is converted into carbon dioxide and produce additional hydrogen, thereby producing a shifted syngas stream. In some implementations, separating the syngas stream includes separating carbon dioxide from the shifted syngas stream,
30 thereby producing the carbon dioxide stream. In some implementations, separating the syngas stream includes separating hydrogen from a remaining portion of the shifted syngas stream after the carbon dioxide has been separated, thereby producing the hydrogen stream.

[0007] Certain aspects of the subject matter described can be implemented as a method. A compressor pressurizes an air stream including oxygen to produce a compressed air stream. A first portion of a fuel stream including hydrogen atoms is reacted within a combustion chamber in the presence of the oxygen of the compressed
5 air stream to produce an exhaust stream. The exhaust stream is flowed to a turbine of an electric generator, thereby causing the turbine to rotate. The electric generator generates electrical power in response to rotation of the turbine. A first heat exchanger transfers heat from the exhaust stream exiting the electric generator to the compressed air stream. A second heat exchanger transfers heat from the exhaust stream to a working
10 fluid. A water stream is boiled to produce a steam stream. Boiling the water stream includes transferring heat from the working fluid to the water stream. A second portion of the fuel stream is converted within a reforming unit in the presence of oxygen and steam to produce a syngas stream. At least a portion of the steam is sourced from the steam stream. At least a portion of carbon monoxide of the syngas stream is converted
15 within a shift reactor into carbon dioxide and additional hydrogen, thereby producing a shifted syngas stream. The shifted syngas stream is separated to produce a carbon dioxide stream and a hydrogen stream. The hydrogen stream is reacted with nitrogen to produce an ammonia stream. At least a portion of the electrical power generated by the electric generator is used to convert the second portion of the fuel stream, convert at
20 least the portion of carbon monoxide of the syngas stream, separate the shifted syngas stream, react the hydrogen stream with nitrogen, or any combinations of these.

[0008] In some implementations, the compressor is coupled to the electric generator. The compressor can include an impeller coupled to a shaft. The shaft of the compressor can be coupled to the turbine wheel of the electric generator and rotates with
25 the turbine wheel. Rotation of the impeller of the compressor can cause the air stream to pressurize. In some implementations, at least a portion of the steam stream is flowed to a second turbine wheel of a second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate. The second electric generator can generate electrical
30 power in response to rotation of the second turbine wheel. In some implementations, separating the shifted syngas stream includes separating carbon dioxide from a remaining portion of the shifted syngas stream to produce the carbon dioxide stream and separating hydrogen from a remaining portion of the shifted syngas stream after the

carbon dioxide has been separated to produce the hydrogen stream. In some implementations, the exhaust stream includes approximately 75 mole percent (mol.%) nitrogen and a balance of oxygen, carbon dioxide, and water. In some implementations, the nitrogen that is reacted with the hydrogen stream is at least partially sourced from the exhaust stream. In some implementations, the electric generator generates sufficient electrical power for converting the second portion of the fuel stream, converting at least the portion of carbon monoxide of the syngas stream, separating the shifted syngas stream, and reacting the hydrogen stream with nitrogen, independent of power importation.

10 [0009] Certain aspects of the subject matter described can be implemented as a system. The system includes a fuel stream, a blue hydrogen production subsystem, a blue ammonia production subsystem, and a power and utility subsystem. In some implementations, the system includes a carbon dioxide recovery subsystem. The fuel stream includes hydrogen atoms. The blue hydrogen production subsystem includes a reforming unit configured to receive and react a first portion of the fuel stream, steam, and oxygen to produce a syngas stream. The blue hydrogen production subsystem is configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream. The blue ammonia production subsystem is configured to receive the hydrogen stream from the blue hydrogen production subsystem and nitrogen. The blue ammonia production subsystem is configured to react the hydrogen stream with the nitrogen to produce an ammonia stream. The power and utility subsystem is configured to receive a second portion of the fuel stream. The power and utility subsystem is electrically connected to at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem for providing electrical power to the at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem. The power and utility subsystem includes a compressor, a complementary firing chamber, an electric generator, a first heat exchanger, and a second heat exchanger. The compressor is configured to receive and compress a gas stream comprising oxygen to produce a compressed gas stream. The complementary firing chamber is configured to receive a fuel stream and the compressed gas stream. The combustion chamber is configured to combust the fuel stream in the presence of the oxygen of the compressed gas stream to produce an exhaust stream. The electric generator is in fluid communication with the complementary firing chamber. The electric generator is

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configured to receive the exhaust stream and generate electrical power in response to expansion of the exhaust stream through the electric generator. The first heat exchanger is configured to transfer heat from the gas stream exiting the compressor to the exhaust stream exiting the electric generator to heat the exhaust stream. The second heat exchanger is configured to transfer heat from the exhaust stream exiting the first heat exchanger to a working fluid to heat the working fluid.

[0010] In some implementations, the electric generator is coupled to the compressor. The electric generator can include a turbine wheel configured to rotate in response to the exhaust stream flowing and expanding across the turbine wheel of the electric generator. The compressor can include an impeller coupled to a shaft. The shaft of the compressor can be coupled to the turbine wheel of the electric generator and can rotate with the turbine wheel for compressing the gas stream. In some implementations, the power and utility subsystem includes a third heat exchanger configured to transfer heat from at least a portion of the working fluid to a water stream to preheat the water stream. In some implementations, the power and utility subsystem includes a boiler in fluid communication with the third heat exchanger. The boiler can be configured to receive the water stream from the third heat exchanger and boil the water stream to produce steam. In some implementations, the power and utility subsystem includes a second electric generator in fluid communication with the boiler. The second electric generator can be configured to receive at least a portion of the steam produced by the boiler and generate electrical power in response to expansion of the steam through the second electric generator. In some implementations, the boiler of the power and utility subsystem is in fluid communication with the blue hydrogen production subsystem. At least a portion of the steam received by the blue hydrogen production subsystem can be sourced from the boiler. In some implementations, the blue hydrogen production subsystem includes a shift reactor configured to receive the syngas from the reforming unit and convert at least a portion of carbon monoxide of the syngas into carbon dioxide and produce additional hydrogen for producing a shifted syngas stream. In some implementations, the blue hydrogen production subsystem includes a separation unit configured to separate carbon dioxide from the shifted syngas stream, thereby producing the carbon dioxide stream. The separation unit can be configured to separate hydrogen from a remaining portion of the shifted syngas stream after the carbon dioxide has been separated, thereby producing the hydrogen stream. In some implementations, the system

includes a separation unit configured to separate nitrogen from the exhaust stream, wherein the nitrogen that is reacted with the hydrogen stream by the blue ammonia production subsystem is at least partially sourced from the nitrogen separated from the exhaust stream by the separation unit. In some implementations, the power and utility subsystem is configured to generate sufficient electrical power for delivery to the blue hydrogen production subsystem to produce the carbon dioxide stream and the hydrogen stream and for delivery to the blue ammonia production subsystem to produce the ammonia stream, independent of power importation.

[0011] The details of one or more implementations of the subject matter of this disclosure are set forth in the accompanying drawings and the description. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

DESCRIPTION OF DRAWINGS

[0012] FIG. 1A is a schematic diagram of an example system for producing blue ammonia.

[0013] FIG. 1B is a schematic diagram showing various components of the system shown in FIG. 1A.

[0014] FIG. 2 is a flow chart of an example method for producing blue ammonia.

[0015] FIG. 3 is a flow chart of an example method for producing blue ammonia.

DETAILED DESCRIPTION

[0016] This disclosure describes thermally efficient production of blue ammonia with co-generation of power. Ammonia can be produced as a reaction product between nitrogen and hydrogen. Hydrogen can be produced by the production of syngas from fuel feedstocks. There is a growing interest in the energy transition from fossil fuels to renewable energy and sustainable energy in a global effort to reduce carbon emissions. Some examples of decarbonization pathways in the energy transition to renewable energy include increasing energy efficiency, producing and/or using lower-carbon fuels, and carbon capture and storage (CCS). Blue ammonia is ammonia that has been produced by a process/system that captures, uses, and/or sequesters carbon dioxide that is produced as a result of the production of the ammonia. Similarly, blue hydrogen is

hydrogen that has been produced by a process/system that captures, uses, and/or sequesters carbon dioxide that has been produced as a result of the production of the hydrogen. As such, production of blue hydrogen and blue ammonia can be considered decarbonization pathways toward a sustainable and reduced carbon economy.

5 [0017] The system includes a gas turbine to recover work from a gas stream to produce electrical power. The exhaust from the gas turbine is used to generate steam, which can be used as a utility in the system and/or be further used to generate power (for example, by a steam turbine). Fuel is combusted in a chamber, and the exhaust from the chamber is expanded through the gas turbine to generate electrical power. In some
10 implementations, the expansion of the exhaust through the gas turbine facilitates rotation of a compressor coupled to the gas turbine to compress air, which is then flowed into the combustion chamber to facilitate combustion of the fuel. In some implementations, the system applies heat integration by recovering waste heat from the compressed air to heat the exhaust from the gas turbine. Although the system is related to ammonia
15 production by autothermal, steam reforming, and/or partial oxidation of hydrocarbons, the co-generation of power and heat integration included in the system can be implemented in other systems related to production of other gases, such as hydrogen. Implementing the co-generation of power and heat integration can reduce the carbon footprint of such systems. The additional fuel gas usage (for example, by the
20 combustion chamber) can be offset by the reduction in power importation costs, as power is co-generated by the system. The turbine(s) of the system can include co-firing gas turbines, which allow for a variety and range of fuel gases/sources to be used.

[0018] The subject matter described in this disclosure can be implemented in particular implementations, so as to realize one or more of the following advantages.
25 The carbon dioxide produced by the systems and methods described is sequestration-ready in that it is ready for transport (for example, by a pipeline) to be sequestered in a subterranean zone in the Earth as opposed to being released to the atmosphere and contributing to carbon emissions. Thus, the carbon dioxide produced can be sequestered and/or used in another industrial process instead of being released to the atmosphere.
30 The described systems and methods are flexible in that they can receive a range of fuel feedstocks, such as conventional hydrocarbons (for example, natural gas, methane, biogas, or another suitable fuel source). The described systems and methods employ heat integration for recovering and efficiently using waste heat. The described systems

and methods can generate useful electrical power from the recovered waste heat while also producing useful chemical products, such as hydrogen and ammonia. Further, the electrical power generated by the described systems and methods can be used within the systems and methods for increasing power efficiency. The described systems and methods can reduce and/or eliminate the need to import power to perform operations, thereby further reducing the carbon footprint of the overall system/method.

[0019] FIG. 1A depicts a system 100 that can produce blue ammonia. The system 100 includes a blue hydrogen production subsystem 150 and a blue ammonia production subsystem 190. The system 100 includes a power and utility subsystem 110 and a carbon dioxide recovery subsystem 170. The power and utility subsystem 110 can be electrically connected to the blue hydrogen production subsystem 150, the blue ammonia production subsystem 190, the carbon dioxide recovery subsystem 170, or combinations of these for providing electrical power. The power and utility subsystem 100 can provide other utilities (such as steam) to the blue hydrogen production subsystem 150, the blue ammonia production subsystem 190, the carbon dioxide recovery subsystem 170, or combinations of these. The system 100 includes a fuel stream 101 that includes hydrogen atoms. For example, the fuel stream 101 includes a hydrocarbon (such as an alkane, an alkene, an alkyne, a cyclic hydrocarbon, an aromatic hydrocarbon, and/or a non-aromatic hydrocarbon). Some non-limiting examples of the fuel stream 101 include a stream including methane or natural gas (which includes methane). A first portion 101a of the fuel stream 101 flows to the power and utility subsystem 110. A second portion 101b of the fuel stream 101 flows to the blue hydrogen production subsystem 150. The power and utility subsystem 110 generates power and steam using the first portion 101a of the fuel stream 101. At least a portion of the steam 108' (for example, steam 108'a) generated by the power and utility subsystem 110 flows to the blue hydrogen production subsystem 150. The blue hydrogen production subsystem 150 generates hydrogen using the second portion 101b of the fuel stream 101 and the steam 108'a provided by the power and utility subsystem 110. The hydrogen 165 generated by the blue hydrogen production subsystem 150 flows to the blue ammonia production subsystem 190. In some implementations, at least a portion of the steam 108' (for example, steam 108'b) generated by the power and utility subsystem 110 flows to the blue ammonia production subsystem 190. The blue ammonia

production subsystem 190 reacts the hydrogen 165 with nitrogen 192 to produce ammonia 194.

[0020] The blue hydrogen production subsystem 150 and the power and utility subsystem 110 are shown in more detail in FIG. 1B. The power and utility subsystem 110 includes a compressor 103. A gas stream 102 flows to the compressor 103. The gas stream 102 includes oxygen. In some implementations, the gas stream 102 is a stream of air, which includes oxygen. The compressor 103 includes an inlet configured to receive the gas stream 102. The compressor 103 includes an impeller that can rotate. Rotation of the impeller of the compressor 103 can cause the gas stream 102 to pressurize (compress). The compressor 103 includes an outlet configured to discharge the compressed gas stream 102. The gas stream 102 exiting the outlet of the compressor 103 has an operating pressure greater than that of the gas stream 102 entering the inlet of the compressor 103. In some implementations, the gas stream 102 entering the inlet of the compressor 103 has an operating pressure substantially equal to atmospheric pressure. In some implementations, the gas stream 102 exiting the outlet of the compressor 103 has an operating pressure of up to about 25 bar absolute (bara). In some implementations, the gas stream 102 entering the inlet of the compressor 103 has an operating temperature in a range of from about -20 degrees Celsius (°C) to about 50 °C. In some implementations, the gas stream 102 exiting the outlet of the compressor 103 has an operating temperature of up to about 600 °C.

[0021] The power and utility subsystem 110 includes a first heat exchanger 111a. The first heat exchanger 111a includes a first side and a second side. The gas stream 102 flows from the compressor 103 to the first side of the first heat exchanger 111a. The first side of the first heat exchanger 111a includes an inlet configured to receive the gas stream 102 from the compressor 103. The compressed gas stream 102 flows through the first side of the first heat exchanger 111a. The first side of the first heat exchanger 111a includes an outlet configured to discharge the gas stream 102. The gas stream 102 exiting the outlet of the first side of the first heat exchanger 111a can have an operating temperature greater (hotter) than that of the gas stream 102 entering the inlet of the first side of the first heat exchanger 111a. In some implementations, the gas stream 102 exiting the outlet of the first side of the first heat exchanger 111a has an operating temperature of in a range of from about 160 °C to about 600 °C.

[0022] The power and utility subsystem 110 includes a complementary firing (co-firing) chamber 105. The co-firing chamber 105 is a combustion chamber that is capable of combusting a variety of combustible fuels. The gas stream 102 flows from the first heat exchanger 111a to the co-firing chamber 105. The co-firing chamber 105 includes an inlet configured to receive the gas stream 102 from the first side of the first heat exchanger 111a. The first portion 101a of the fuel stream 101 flows to the co-firing chamber 105. In some implementations, the first portion 101a of the fuel stream 101 mixes with the gas stream 102 upstream of the co-firing chamber 105, and the mixture of the first portion 101a of the fuel stream 101 and the gas stream 102 flows into the co-firing chamber 105 via the inlet. In some implementations, the first portion 101a of the fuel stream 101 flows into the co-firing chamber 105 separately from the gas stream 102, for example, via a different inlet of the co-firing chamber 105. In some implementations, the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 has an operating temperature in a range of from about 400 °C to about 600 °C. In some implementations, the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 has an operating temperature greater than about 600 °C. In some implementations, the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 has an operating pressure in a range of from about 20 bara to about 25 bara. In some implementations, the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 has an operating pressure greater than about 25 bara. The co-firing chamber 105 combusts the first portion 101a of the fuel stream 101 in the presence of the gas stream 102, which includes oxygen. Combustion of the first portion 101a of the fuel stream 101 within the co-firing chamber 105 releases heat and produces carbon dioxide in cases in which the fuel stream 101 includes hydrocarbons or other carbon-containing fuel. The flow rates of the gas stream 102 and the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 can be adjusted based on desired operating parameters of the co-firing chamber 105. For example, the flow rates of the gas stream 102 and the first portion 101a of the fuel stream 101 entering the co-firing chamber 105 can be adjusted, such that a ratio of the oxygen from the gas stream 102 to combustibles in the first portion 101a of the fuel stream 101 is sufficient for complete combustion of the first portion 101a of the fuel stream 101 within the co-firing chamber 105. The co-firing chamber 105 includes an outlet configured to discharge an exhaust stream 104 from the co-firing chamber 105. The exhaust stream 104 is the resultant

fluid stream (gas) from combustion of the first portion 101a of the fuel stream 101 in the presence of the gas stream 102. The exhaust stream 104 can include the combustion products produced in the co-firing chamber 105 (such as carbon dioxide and water) and remaining components from the gas stream 102, for example, that may not have reacted within the co-firing chamber 105 (such as nitrogen). The exhaust stream 104 exiting the outlet of the co-firing chamber 105 can have an operating temperature greater (hotter) than those of the gas stream 102 and first portion 101a of the fuel stream 101 entering the co-firing chamber 105. The exhaust stream 104 can include, for example, water (steam), nitrogen (N₂), oxygen (O₂), and carbon dioxide (CO₂). In some cases, the exhaust stream 104 also includes additional components, such as nitrogen oxide (NO_x), carbon monoxide (CO), and any remaining fuel from the first portion 101a of the fuel stream 101 that did not combust in the co-firing chamber 105. In some implementations, the exhaust stream 104 includes steam in a range of from about 3 mole percent (mol.%) to about 9 mol.% (for example, about 6 mol.% steam). In some implementations, the exhaust stream 104 includes nitrogen in a range of from about 70 mol.% to about 80 mol.% (for example, about 77 mol.% nitrogen). In some implementations, the exhaust stream 104 includes oxygen in a range of from about 10 mol.% to about 20 mol.% (for example, about 14 mol.% oxygen). In some implementations, the exhaust stream 104 includes carbon dioxide in a range of from about 1 mol.% to about 5 mol.% (for example, about 3 mol.% carbon dioxide). In some implementations, the exhaust stream 104 exiting the outlet of the co-firing chamber 105 has an operating temperature in a range of from about 1,000 °C to about 1,300 °C. In some implementations, the exhaust stream 104 exiting the outlet of the co-firing chamber 105 has an operating pressure of about 25 bara. The operating pressure of the exhaust stream 104 exiting the outlet of the co-firing chamber 105 can be adjusted based on power generation requirements for the electric generator 107, described in further detail later.

[0023] The power and utility subsystem 110 includes the electric generator 107. The electric generator 107 can include a gas turbine that includes a stator and rotor. The rotor of the gas turbine can include an impeller. The exhaust stream 104 flows from the co-firing chamber 105 to the electric generator 107. The gas turbine of the electric generator 107 can include an inlet configured to receive the exhaust stream 104. As the exhaust stream 104 flows through the gas turbine and expands (decreases pressure), the impeller of the gas turbine rotates. Rotation of the impeller (a part of the rotor) in

relation to the stator of the electric generator 107 generates electrical power. The electrical power generated by the electric generator 107 can, for example, be provided to and used by any component of system 100 that requires power to operate. For example, the electrical power generated by the electric generator 107 can be provided to a component of the blue hydrogen production subsystem 150, to a component of the blue ammonia production subsystem 190, to a component used in sequestering carbon dioxide (such as a component of the carbon dioxide recovery subsystem 170), or any combinations of these. The gas turbine of the electric generator 107 can include an outlet configured to discharge the exhaust stream 104. The exhaust stream 104 exiting the outlet of the electric generator 107 has an operating pressure less than that of the exhaust stream 104 entering the inlet of the electric generator 107. Expansion of the exhaust stream 104 flowing through the gas turbine of the electric generator 107 can cause the exhaust stream 104 to cool. Thus, the exhaust stream 104 exiting the outlet of the electric generator 107 can have an operating temperature less (colder) than that of the exhaust stream 104 entering the inlet of the electric generator 107. As shown in FIG. 1B, the electric generator 107 can be coupled to the compressor 103 via a shaft 109. For example, the impeller of the gas turbine can be coupled to the shaft 109, and the impeller of the compressor 103 can be coupled to the shaft 109. Rotation of the gas turbine can drive rotation of the impeller of the compressor 103 to pressurize the gas stream 102. In some implementations, the impeller of the gas turbine (electric generator 107) and the impeller of the compressor 103 are coupled to the shaft 109, such that the respective impellers co-rotate. In some implementations, the impeller of the gas turbine (electric generator 107) and the impeller of the compressor 103 are coupled to the shaft 109 by a gearbox, gear train, or clutch mechanism, such that the respective impellers rotate at different rotational speeds. In some implementations, the exhaust stream 104 exiting the outlet of the electric generator 107 has an operating temperature in a range of from about 650 °C to about 800 °C. In some implementations, the exhaust stream 104 exiting the outlet of the electric generator 107 has an operating pressure in a range of from about 2 bara to about 5 bara.

[0024] The exhaust stream 104 flows from the electric generator 107 to the second side of the first heat exchanger 111a. The second side of the first heat exchanger 111a includes an inlet configured to receive the exhaust stream 104 from the electric generator 107. The exhaust stream 104 flows through the second side of the first heat

exchanger 111a. The first heat exchanger 111a is configured to transfer heat from the exhaust stream 104 flowing through the second side to the gas stream 102 flowing through the first side. The gas stream 102 and the exhaust stream 104 do not come into direct contact with one another in the first heat exchanger 111a. Instead, the first heat exchanger 111a provides an intermediary heat transfer area to facilitate transfer of heat from the exhaust stream 104 to the gas stream 102. Although shown in FIG. 1B as having a counter-flow configuration in which the streams 102, 104 generally flow parallel to each other in opposite directions, the first heat exchanger 111a can optionally have a different flow configuration, such as parallel flow configuration (streams 102, 104 generally flow parallel to each other in the same direction) or cross-flow configuration (streams 102, 104 generally flow perpendicular to one another). The second side of the first heat exchanger 111a includes an outlet configured to discharge the exhaust stream 104. The exhaust stream 104 exiting the outlet of the second side of the first heat exchanger 111a can have an operating temperature less (colder) than that of the exhaust stream 104 entering the inlet of the second side of the first heat exchanger 111a.

[0025] The power and utility subsystem 110 includes a second heat exchanger 111b. The second heat exchanger 111b includes a first side and a second side. The exhaust stream 104 flows from the second side of the first heat exchanger 111a to the first side of the second heat exchanger 111b. The first side of the second heat exchanger 111b includes an inlet configured to receive the exhaust stream 104 from the first heat exchanger 111a. The exhaust stream 104 flows through the first side of the second heat exchanger 111b. The first side of the second heat exchanger 111b includes an outlet configured to discharge the exhaust stream 104. A working fluid 106 flows to the second side of the second heat exchanger 111b. The working fluid 106 is a fluid that acts as an intermediary heat transfer fluid for transferring heat between two different fluid streams. The working fluid 106 can be, for example, a heating oil, air, or water. The second side of the second heat exchanger 111b includes an inlet configured to receive the working fluid 106. The working fluid 106 flows through the second side of the second heat exchanger 111b. The second heat exchanger 111b is configured to transfer heat from the exhaust stream 104 flowing through the first side to the working fluid 106 flowing through the second side. The exhaust stream 104 and the working fluid 106 do not come into direct contact with one another in the second heat exchanger 111b. Instead, the

second heat exchanger 111b provides an intermediary heat transfer area to facilitate transfer of heat from the exhaust stream 104 to the working fluid 106. Although shown in FIG. 1B as having a counter-flow configuration in which the streams 104, 106 generally flow parallel to each other in opposite directions, the second heat exchanger 111b can optionally have a different flow configuration, such as parallel flow configuration (streams 104, 106 generally flow parallel to each other in the same direction) or cross-flow configuration (streams 104, 106 generally flow perpendicular to one another). The second side of the second heat exchanger 111b includes an outlet configured to discharge the working fluid 106. The exhaust stream 104 exiting the outlet of the first side of the second heat exchanger 111b can have an operating temperature less (colder) than that of the exhaust stream 104 entering the inlet of the first side of the second heat exchanger 111b. The working fluid 106 exiting the outlet of the second side of the second heat exchanger 111b can have an operating temperature greater (hotter) than that of the working fluid 106 entering the inlet of the second side of the second heat exchanger 111b. In some implementations, the exhaust stream 104 entering the inlet of the first side of the second heat exchanger 111b has an operating pressure in a range of from about 2 bara to about 5 bara. In some implementations, the exhaust stream 104 exiting the outlet of the first side of the second heat exchanger 111b has an operating pressure in a range of from about 1 bara to about 2 bara. In some implementations, the exhaust stream 104 entering the inlet of the first side of the second heat exchanger 111b has an operating temperature in a range of from about 650 °C to about 870 °C, from about 650 °C to about 800 °C, from about 830 °C to about 870 °C, from about 840 °C to about 860 °C, or from about 845 °C to about 855 °C (for example, about 850 °C). In some implementations, the exhaust stream 104 exiting the outlet of the first side of the second heat exchanger 111b has an operating temperature in a range of from about 150 °C to about 200 °C, from about 140 °C to about 180 °C, from about 150 °C to about 170 °C, or from about 155 °C to about 165 °C (for example, about 160 °C).

[0026] The power and utility subsystem 110 includes a third heat exchanger 111c. The third heat exchanger 111c includes a first side and a second side. The working fluid 106 flows from the second side of the second heat exchanger 111b to the first side of the third heat exchanger 111c. The first side of the third heat exchanger 111c includes an inlet configured to receive the working fluid 106 from the second heat exchanger 111b. The working fluid 106 flows through the first side of the third heat

exchanger 111c. The first side of the third heat exchanger 111c includes an outlet configured to discharge the working fluid 106. A water stream 108 flows to the second side of the third heat exchanger 111c. The second side of the third heat exchanger 111c includes an inlet configured to receive the water stream 108. The water stream 108
5 flows through the second side of the third heat exchanger 111c. The third heat exchanger 111c is configured to transfer heat from the working fluid 106 flowing through the first side to the water stream 108 flowing through the second side. The working fluid 106 and the water stream 108 do not come into direct contact with one another in the third heat exchanger 111c. Instead, the third heat exchanger 111c provides an intermediary
10 heat transfer area to facilitate transfer of heat from the working fluid 106 to the water stream 108. Although shown in FIG. 1B as having a counter-flow configuration in which the streams 106, 108 generally flow parallel to each other in opposite directions, the third heat exchanger 111c can optionally have a different flow configuration, such as parallel flow configuration (streams 106, 108 generally flow parallel to each other in
15 the same direction) or cross-flow configuration (streams 106, 108 generally flow perpendicular to one another). The second side of the third heat exchanger 111c includes an outlet configured to discharge the water stream 108. The working fluid 106 exiting the outlet of the first side of the third heat exchanger 111c can have an operating temperature less (colder) than that of the working fluid 106 entering the inlet of the first
20 side of the third heat exchanger 111c. The water stream 108 exiting the outlet of the second side of the third heat exchanger 111c can have an operating temperature greater (hotter) than that of the water stream 108 entering the inlet of the second side of the third heat exchanger 111c. The working fluid 106 thus acts as an intermediary heat transfer fluid that transfers heat from the exhaust stream 104 to the water stream 108 via heat
25 exchangers 111b, 111c. In some implementations, the working fluid 106 flows from the outlet of the first side of the third heat exchanger 111c to the carbon dioxide recovery subsystem 170, where the working fluid 106 can, for example, be used for carbon dioxide separation, purification, and/or preparation for use as a product or diverting to a carbon sequestration reservoir.

30 [0027] The power and utility subsystem 110 includes a boiler 113. The water stream 108 flows from the third heat exchanger 111c to the boiler 113. The boiler 113 includes an inlet configured to receive the water stream 108 from the third heat exchanger 111c. The boiler 113 includes a heater that is configured to provide heat to

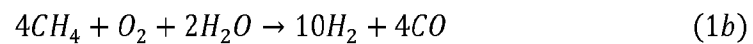
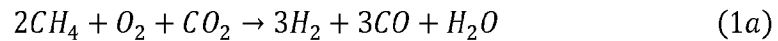
the water stream 108, thereby boiling the water stream 108 to produce steam. The boiler 113 includes an outlet configured to discharge a steam stream 108' that includes the steam generated by the boiler 113. The boiler 113 can be any type of boiler known in the art, such as a hot water boiler, an electric boiler, a gas boiler, a low pressure boiler, a high pressure boiler, and oil boiler, a water tube boiler, a La Mont boiler, a Benson boiler, a Loeffler boiler, a fire tube boiler, or a shell boiler. In some implementations, a portion of the first portion 101a of the fuel stream 101 can be combusted by the boiler 113 to produce at least a portion of the necessary heat for boiling the water stream 108 to produce the steam stream 108'.

[0028] The blue hydrogen production subsystem 150 includes an air separation unit 152. Air 151 flows to the air separation unit 152. The air separation unit 152 separates oxygen 151a from a remaining portion 151b of the air 151. The air separation unit 152 can include typical equipment known in the art for separating oxygen from air, such as cryogenic distillation or non-cryogenic processes (for example, pressure swing adsorption or membrane technologies). The remaining portion 151b of the air 151 is substantially free of oxygen and can include, for example, nitrogen and carbon dioxide. In some implementations, nitrogen is separated from the air 151, such that the remaining portion 151b of the air 151 is substantially free of nitrogen. The remaining portion 151b of the air 151 is mixed with the second portion 101b of the fuel stream 101 and the steam 108' produced by the boiler 113 of the power and utility subsystem 110.

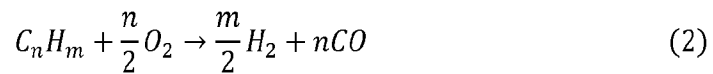
[0029] The blue hydrogen production subsystem 150 includes a heater 154. The mixture 153 (remaining portion 151b of the air 151, second portion 101b of the fuel stream 101, and steam 108') flows to the heater 154. The heater 154 heats the mixture 153, such that the mixture 153 exiting the heater 154 has an operating temperature that is greater (hotter) than the mixture 153 entering the heater 154. The heater 154 can include typical equipment known in the art for heating fluids, such as a heat exchanger, an electric heater, or a gas heater (for example, a furnace).

[0030] The blue hydrogen production subsystem 150 includes a reforming unit 156. The reforming unit 156 can include an autothermal reformer. The mixture 153 flows from the heater 154 to the reforming unit 156. The reforming unit 156 includes an inlet configured to receive the mixture 153 from the heater 154. The oxygen 151a flows from the air separation unit 152 to the reforming unit 156. In some implementations, the oxygen 151a mixes with the mixture 153 upstream of the reforming unit 156, and the

mixture (oxygen 151a and mixture 153) flows into the reforming unit 156 via the inlet. In some implementations, the oxygen 151a flows into the reforming unit 156 separately from the mixture 153, for example, via a different inlet of the reforming unit 156. The autothermal reformer of the reforming unit 156 can include an autothermal reforming catalyst for accelerating a reaction of methane with oxygen, carbon dioxide, carbon monoxide, and steam to produce syngas 155, which is a mixture including hydrogen and carbon monoxide. The reforming unit 156 can include a partial oxidation reactor for reacting hydrocarbon(s) present in the mixture 153 with oxygen, carbon monoxide, carbon dioxide, and/or steam to produce the syngas 155. The reforming unit 156 partially oxidizes hydrocarbon(s) (such as methane). The oxidation of methane is exothermic. The reactions shown in Equations 1a and 1b occur within the autothermal reformer 156.



The partial oxidation of other hydrocarbons is also exothermic. The partial oxidation of hydrocarbons is generalized by Equation 2 and can occur within the reforming unit 156.



The reforming unit 156 includes an outlet configured to discharge the syngas 155 that was produced in the reforming unit 156. The syngas 155 includes hydrogen, carbon monoxide, and water (for example, in the form of steam). In some cases, the syngas 155 includes additional components, such as carbon dioxide.

[0031] The blue hydrogen production subsystem 150 includes a shift reactor 158. The syngas 155 flows from the reforming unit 156 to the shift reactor 158. The shift reactor 158 includes an inlet configured to receive the syngas 155 from the reforming unit 156. The shift reactor 158 includes a water-gas shift catalyst for accelerating a reaction between carbon monoxide and water to form carbon dioxide and hydrogen. Thus, additional hydrogen is produced within the shift reactor 158. Some non-limiting examples of water-gas shift catalysts include iron oxide-chromium oxide-based catalysts and copper-based catalysts. For example, the water-gas shift catalyst can include iron oxide, chromium oxide, magnesium oxide, copper oxide, zinc oxide, aluminum oxide, or any combinations of these. Methane is partially oxidized in the

reforming unit 156. The oxidation of methane is exothermic. The equilibrium reaction shown in Equation 3 occurs within the shift reactor 158.



The shift reactor 158 includes an outlet configured to discharge a shifted syngas 157.

5 The shifted syngas 155 includes hydrogen and carbon dioxide. In some cases, the shifted syngas 157 includes additional components, such as carbon monoxide and water. In comparison to the syngas 155 entering the shift reactor 158, the shifted syngas 157 exiting the shift reactor 158 includes a greater hydrogen gas content, a greater carbon dioxide content, a lesser carbon monoxide content, and a lesser water content.

10 [0032] The blue hydrogen production subsystem 150 includes a purification unit 160. The shifted syngas 157 flows from the shift reactor 158 to the purification unit 160. The purification unit 160 separates the shifted syngas 157 into a carbon dioxide stream 159 and a crude hydrogen stream 163. The composition of the carbon dioxide stream 159 is substantially comprised of carbon dioxide and is substantially free of other
15 components, such as nitrogen, water, and hydrogen. The composition of the crude hydrogen stream 163 includes hydrogen and can include additional components, such as nitrogen and carbon monoxide. The purification unit 160 can include typical equipment known in the art for separating carbon dioxide from other gases, such as sorbent/solvent technologies, membrane technologies, and cryogenic distillation.

20 [0033] The blue hydrogen production subsystem 150 includes a compressor 162. The carbon dioxide stream 159 flows from the purification unit 160 to the compressor 162. The compressor 162 pressurizes the carbon dioxide stream 159 into a compressed carbon dioxide stream 161 for subsequent transport and/or sequestration. For example, the compressed carbon dioxide stream 161 can flow to the carbon dioxide recovery
25 subsystem 170 for further pressurization and purification based on desired specifications. As another example, the compressed carbon dioxide stream 161 can be transported to a user or injected into a subterranean formation, such that the carbon dioxide is not released into the atmosphere.

[0034] The blue hydrogen production subsystem 150 includes a hydrogen
30 separation unit 164. The crude hydrogen stream 163 flows from the purification unit 160 to the hydrogen separation unit 164. The hydrogen separation unit 160 separates hydrogen from the crude hydrogen stream 163 to produce a purified hydrogen stream 165. The composition of the purified hydrogen stream 165 is substantially comprised

of hydrogen and is substantially free of other components. The hydrogen separation unit 164 can include typical equipment known in the art for separating hydrogen from other gases, such as pressure swing adsorption. The hydrogen stream 165 can flow, for example, to the blue ammonia production subsystem 190 to be reacted with nitrogen 192 to produce the ammonia 194. In some implementations, at least a portion of the nitrogen 192 used by the blue ammonia production subsystem 190 to produce the ammonia 194 can be sourced from the nitrogen that has been separated from the hydrogen by the hydrogen separation unit 164. In some implementations, at least a portion of the nitrogen 192 used by the blue ammonia production subsystem 190 to produce the ammonia 194 can be sourced from the nitrogen that has been separated from the air 151 by the air separation unit 152.

[0035] The carbon dioxide recovery subsystem 170 includes an inlet configured to receive at least a portion of the compressed carbon dioxide stream 161 from the blue hydrogen production subsystem 150. For example, a portion of or all of the compressed carbon dioxide stream 161 flows from the blue hydrogen production subsystem 150 to the carbon dioxide recovery subsystem 170. At least a portion of (for example, all of) the carbon dioxide 167 produced by the power and utility subsystem 110 (for example, from the exhaust stream 104) can flow from the power and utility subsystem 110 to the carbon dioxide recovery subsystem 170. In some implementations, the carbon dioxide 167 from the power and utility subsystem 110 flows into the carbon dioxide recovery subsystem 170 separately from the compressed carbon dioxide stream 161 from the blue hydrogen production subsystem 150, for example, via a different inlet of the carbon dioxide recovery subsystem 170. In some implementations, the carbon dioxide 167 from the power and utility subsystem 110 mixes with the compressed carbon dioxide stream 161 from the blue hydrogen production subsystem 150 and flows together into the carbon dioxide recovery subsystem 170. The carbon dioxide recovery subsystem 170 processes the carbon dioxide (161, 167) to produce a carbon dioxide stream 171 with characteristics matching its intended use, for example, for sale and/or transport to an end user or sequestration in a carbon sequestration reservoir. The carbon dioxide recovery subsystem 170 can include, for example, a compressor for pressurizing the carbon dioxide (161, 167). The carbon dioxide recovery subsystem 170 can include separation units, for example, a pressure swing adsorption unit and/or a molecular sieve unit for purifying the carbon dioxide (161, 167).

[0036] In each of the configurations described with respect to the system 100 (shown in FIG. 1A and partially in FIG. 1B) at its subsystems (such as the power and utility subsystem 110, the blue hydrogen production subsystem 150, and the blue ammonia production subsystem 190), process streams (also referred to as “streams”) are
5 flowed within each subsystem of the system 100 and between subsystems of the system 100. The process streams can be flowed using one or more flow control systems implemented throughout the system 100 (and/or its subsystems). A flow control system can include one or more flow pumps to pump the process streams (such as the steam 108'), one or more compressors to pressurize the process streams, one or more flow
10 pipes through which the process streams are flowed, and one or more valves to regulate the flow of streams through the pipes.

[0037] In some implementations, a flow control system can be operated manually. For example, an operator can set a flow rate for each pump and/or compressor by changing the position of a valve (open, partially open, or closed) to regulate the flow
15 of the process streams through the pipes in the flow control system. Once the operator has set the flow rates and the valve positions for all flow control systems distributed across the system 100 (and/or its subsystems), the flow control system can flow the streams within a unit or between units under constant flow conditions, for example, constant volumetric or mass flow rates. To change the flow conditions, the operator can
20 manually operate the flow control system, for example, by changing the valve position.

[0038] In some implementations, a flow control system can be operated automatically. For example, the flow control system can be connected to a computer system to operate the flow control system. The computer system can include a computer-readable medium storing instructions (such as flow control instructions)
25 executable by one or more processors to perform operations (such as flow control operations). For example, an operator can set the flow rates by setting the valve positions for all flow control systems distributed across the system 100 (and/or its subsystems) using the computer system. In such implementations, the operator can manually change the flow conditions by providing inputs through the computer system.
30 In such implementations, the computer system can automatically (that is, without manual intervention) control one or more of the flow control systems, for example, using feedback systems implemented in one or more units and connected to the computer system. For example, a sensor (such as a pressure sensor or temperature sensor) can be

connected to a pipe through which a process stream flows. The sensor can monitor and provide a flow conditions (such as a pressure or temperature) of the process stream to the computer system. In response to the flow condition deviating from a set point (such as a target pressure value or target temperature value) or exceeding a threshold (such as a threshold pressure value or threshold temperature value), the computer system can automatically perform operations. For example, if the pressure or temperature in the pipe exceeds the threshold pressure value or the threshold temperature value, respectively, the computer system can provide a signal to open a valve to relieve pressure or a signal to shut down process stream flow.

10 [0039] FIG. 2 is a flow chart of a method 200 for producing blue ammonia. The system 100 can, for example, implement method 200. At block 202, a gas stream (such as the gas stream 102) is compressed to produce a compressed gas stream. As described previously, the gas stream 102 includes oxygen. The gas stream 102 can be compressed at block 202 by the compressor 103. At block 204, a first portion of a fuel stream (such as the first portion 101a of the fuel stream 101) is combusted in the presence of the compressed gas stream 102 to produce an exhaust stream (such as the exhaust stream 104). As described previously, the fuel stream 101 includes hydrogen atoms. The first portion 101a of the fuel stream 101 can be combusted at block 204 in the co-firing chamber 105. At block 206, the exhaust stream 104 is flowed to a turbine of an electric generator (such as the electric generator 107), thereby causing the exhaust stream 104 to expand while flowing across the turbine and the turbine to rotate. At block 208, the electric generator 107 generates electrical power in response to rotation of the turbine. At block 210, heat is transferred from the exhaust stream 104 to the compressed gas stream 102. The heat can be transferred from the exhaust stream 104 to the gas stream 102 at block 210 by the first heat exchanger 111a. At block 212, heat is transferred from the exhaust stream 104 to a working fluid (such as the working fluid 106). The heat can be transferred from the exhaust stream 104 to the working fluid 106 at block 212 by the second heat exchanger 111b. At block 214, heat is transferred from the working fluid 106 to a water stream (such as the water stream 108) for generating a steam stream (such as the steam stream 108'). The heat can be transferred from the working fluid 106 to the water stream 108 at block 214 by the third heat exchanger 111c. The water stream 108 can be boiled by the boiler 113 to generate the steam stream 108'. For example, the heat that is transferred from the working fluid 106 to the water stream 108 at block 214

can be a pre-heating step prior to boiling in the boiler 113 to generate the steam stream 108'. Thus, transferring heat from the working fluid 106 to the water stream 108 at block 214 can reduce the heating duty required by the boiler 113 to boil the water stream 108 to generate the steam stream 108'. At block 216, a second portion (such as the second portion 101b) of the fuel stream 101 is converted in the presence of oxygen and steam to produce a syngas stream (such as the syngas stream 155). The second portion 101b of the fuel stream 101 can be converted at block 216 by the reforming unit 156. The oxygen at block 216 can be, for example, the oxygen 151a separated from the air 151 by the air separation unit 152. The steam at block 216 can be, for example, the steam stream 108' or at least partially sourced from the steam stream 108'. At block 218, the syngas stream 155 is separated to produce a carbon dioxide stream (such as the carbon dioxide stream 161) and a hydrogen stream (such as the hydrogen stream 165). Separating the syngas stream 155 at block 218 can include processing the syngas stream 155, for example, by the shift reactor 158, the purification unit 160, and the hydrogen separation unit 164. At block 220, the hydrogen stream 165 is reacted with nitrogen (such as the nitrogen 192) to produce an ammonia stream (such as the ammonia 194). The hydrogen stream 165 can be reacted with the nitrogen 192 at block 220 by the blue ammonia production subsystem 194. At least a portion of the electrical power generated by the electric generator 107 at block 208 is used to convert the second portion 101b of the fuel stream 101 at block 216, separate the syngas stream 155 at block 218, react the hydrogen stream 165 with nitrogen at block 220, or any combinations of these.

[0040] FIG. 3 is a flow chart of a method 300 for producing blue ammonia. The system 100 can, for example, implement method 200. At block 302, an air stream (such as the gas stream 102) is pressurized by a compressor (such as the compressor 103) to produce a compressed air stream. At block 304, a first portion of a fuel stream (such as the first portion 101a of the fuel stream 101) is reacted within a combustion chamber (such as the co-firing chamber 105) in the presence of the oxygen of the compressed air stream (such as the gas stream 102) to produce an exhaust stream (such as the exhaust stream 104). At block 306, the exhaust stream 104 is flowed to a turbine of an electric generator (such as the electric generator 107), thereby causing the turbine to rotate. At block 308, the electric generator 107 generates electrical power in response to rotation of the turbine. At block 310, heat is transferred by a first heat exchanger (such as the first heat exchanger 111a) from the exhaust stream 104 exiting the electric generator 107

to the compressed air stream. At block 312, heat is transferred by a second heat exchanger (such as the second heat exchanger 111b) from the exhaust stream 104 to a working fluid (such as the working fluid 106). At block 314, a water stream (such as the water stream 108) is boiled to produce a steam stream (such as the steam stream 108'). Boiling the water stream 108 at block 314 can include transferring heat by a third heat exchanger (such as the third heat exchanger 111c) from the working fluid 106 to the water stream 108 to pre-heat the water stream 108 and subsequently boiling the water stream 108 by the boiler 113. At block 316, a second portion (such as the second portion 101b) of the fuel stream 101 is converted in the presence of oxygen and steam within an autothermal reformer (such as the autothermal reformer of the reforming unit 156) to produce a syngas stream (such as the syngas stream 155). The oxygen at block 316 can be, for example, the oxygen 151a separated from the air 151 by the air separation unit 152. The steam at block 316 can be, for example, the steam stream 108' or at least partially sourced from the steam stream 108'. At block 318, at least a portion of carbon monoxide of the syngas stream 155 is converted within a shift reactor (such as the shift reactor 158) into carbon dioxide, and additional hydrogen is produced. Conversion of carbon monoxide of the syngas stream 155 at block 318 produces a shifted syngas stream (such as the shifted syngas stream 157). At block 320, the shifted syngas stream 157 is separated to produce a carbon dioxide stream (such as the carbon dioxide stream 161) and a hydrogen stream (such as the hydrogen stream 165). Separating the shifted syngas stream 157 at block 320 can include processing the shifted syngas stream 157, for example, by the purification unit 160 and the hydrogen separation unit 164. At block 322, the hydrogen stream 165 is reacted with nitrogen (such as the nitrogen 192) to produce an ammonia stream (such as the ammonia 194). The hydrogen stream 165 can be reacted with the nitrogen 192 at block 322 by the blue ammonia production subsystem 194. At least a portion of the electrical power generated by the electric generator 107 at block 308 is used to convert the second portion 101b of the fuel stream 101 at block 316, convert at least the portion of carbon monoxide of the syngas stream 155 at block 318, separate the shifted syngas stream 157 at block 320, react the hydrogen stream 165 with nitrogen at block 322, or any combinations of these.

[0041] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of features that may be specific to particular implementations.

Certain features that are described in this specification in the context of separate implementations can also be implemented, in combination, in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations, separately, or in any sub-combination. Moreover, although previously described features may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

10 [0042] As used in this disclosure, the terms “a,” “an,” or “the” are used to include one or more than one unless the context clearly dictates otherwise. The term “or” is used to refer to a nonexclusive “or” unless otherwise indicated. The statement “at least one of A and B” has the same meaning as “A, B, or A and B.” In addition, it is to be understood that the phraseology or terminology employed in this disclosure, and not
15 otherwise defined, is for the purpose of description only and not of limitation. Any use of section headings is intended to aid reading of the document and is not to be interpreted as limiting; information that is relevant to a section heading may occur within or outside of that particular section.

[0043] As used in this disclosure, the term “about” or “approximately” can allow
20 for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1% of a stated value or of a stated limit of a range.

[0044] As used in this disclosure, the term “substantially” refers to a majority of, or mostly, as in at least about 50%, 60%, 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9%, 99.99%, or at least about 99.999% or more.

25 [0045] Values expressed in a range format should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a range of “0.1% to about 5%” or “0.1% to 5%” should be interpreted to
30 include about 0.1% to about 5%, as well as the individual values (for example, 1%, 2%, 3%, and 4%) and the sub-ranges (for example, 0.1% to 0.5%, 1.1% to 2.2%, 3.3% to 4.4%) within the indicated range. The statement “X to Y” has the same meaning as “about X to about Y,” unless indicated otherwise. Likewise, the statement “X, Y, or Z”

has the same meaning as “about X, about Y, or about Z,” unless indicated otherwise.

[0046] Particular implementations of the subject matter have been described. Other implementations, alterations, and permutations of the described implementations are within the scope of the following claims as will be apparent to those skilled in the art. While operations are depicted in the drawings or claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed (some operations may be considered optional), to achieve desirable results. In certain circumstances, multitasking or parallel processing (or a combination of multitasking and parallel processing) may be advantageous and performed as deemed appropriate.

[0047] Moreover, the separation or integration of various system modules and components in the previously described implementations should not be understood as requiring such separation or integration in all implementations, and it should be understood that the described components and systems can generally be integrated together or packaged into multiple products.

[0048] Accordingly, the previously described example implementations do not define or constrain the present disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of the present disclosure.

EMBODIMENTS

[0049] In an example implementation (or aspect), a method comprises: compressing a gas stream comprising oxygen to produce a compressed gas stream; combusting a first portion of a fuel stream comprising hydrogen atoms in the presence of the compressed gas stream to produce an exhaust stream; flowing the exhaust stream to a turbine of an electric generator, thereby causing the exhaust stream to expand while flowing across the turbine and the turbine to rotate; generating, by the electric generator, electrical power in response to rotation of the turbine; transferring heat from the exhaust stream to the compressed gas stream; after transferring heat from the exhaust stream to the compressed gas stream, transferring heat from the exhaust stream to a working fluid; after transferring heat from the exhaust stream to the working fluid, transferring heat from the working fluid to a water stream for generating a steam stream; converting a second portion of the fuel stream in the presence of oxygen and steam to produce a syngas stream, wherein at least a portion of the steam is sourced from the

steam stream generated from the water stream; separating the syngas stream to produce a carbon dioxide stream and a hydrogen stream; and reacting the hydrogen stream with nitrogen to produce an ammonia stream, wherein at least a portion of the electrical power generated by the electric generator is used to convert the second portion of the fuel stream, separate the syngas stream, react the hydrogen stream with nitrogen, or any combinations thereof.

[0050] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the gas stream is compressed by a compressor that is coupled to the electric generator, wherein the compressor comprises an impeller coupled to a shaft, wherein the shaft of the compressor is coupled to the turbine wheel of the electric generator and rotates with the turbine wheel, wherein rotation of the impeller of the compressor causes the gas stream to compress.

[0051] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the method comprises: flowing at least a portion of the steam stream to a second turbine wheel of a second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate; and generating, by the second electric generator, electrical power in response to rotation of the second turbine wheel.

[0052] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the method comprises converting at least a portion of carbon monoxide of the syngas stream into carbon dioxide and produce additional hydrogen, thereby producing a shifted syngas stream.

[0053] In an example implementation (or aspect) combinable with any other example implementation (or aspect), separating the syngas stream comprises: separating carbon dioxide from the shifted syngas stream, thereby producing the carbon dioxide stream; and separating hydrogen from a remaining portion of the shifted syngas stream after the carbon dioxide has been separated, thereby producing the hydrogen stream.

[0054] In an example implementation (or aspect), a method comprises: pressurizing, by a compressor, an air stream comprising oxygen to produce a compressed air stream; reacting, within a combustion chamber, a first portion of a fuel stream comprising hydrogen atoms in the presence of the oxygen of the compressed air stream to produce an exhaust stream; flowing the exhaust stream to a turbine of an electric generator, thereby causing the turbine to rotate; generating, by the electric

generator, electrical power in response to rotation of the turbine; transferring, by a first heat exchanger, heat from the exhaust stream exiting the electric generator to the compressed air stream; transferring, by a second heat exchanger, heat from the exhaust stream to a working fluid; boiling a water stream to produce a steam stream, wherein
5 boiling the water stream comprises transferring heat from the working fluid to the water stream; converting, within a reforming unit, a second portion of the fuel stream in the presence of oxygen and steam to produce a syngas stream, wherein at least a portion of the steam is sourced from the steam stream; converting, within a shift reactor, at least a portion of carbon monoxide of the syngas stream into carbon dioxide and producing
10 additional hydrogen, thereby producing a shifted syngas stream; separating the shifted syngas stream to produce a carbon dioxide stream and a hydrogen stream; and reacting the hydrogen stream with nitrogen to produce an ammonia stream, wherein at least a portion of the electrical power generated by the electric generator is used to convert the second portion of the fuel stream, convert at least the portion of carbon monoxide of the
15 syngas stream, separate the shifted syngas stream, react the hydrogen stream with nitrogen, or any combinations thereof.

[0055] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the compressor is coupled to the electric generator, wherein the compressor comprises an impeller coupled to a shaft, wherein the shaft of
20 the compressor is coupled to the turbine wheel of the electric generator and rotates with the turbine wheel, wherein rotation of the impeller of the compressor causes the air stream to pressurize.

[0056] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the method comprises: flowing at least a portion of
25 the steam stream to a second turbine wheel of a second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate; and generating, by the second electric generator, electrical power in response to rotation of the second turbine wheel.

[0057] In an example implementation (or aspect) combinable with any other
30 example implementation (or aspect), separating the shifted syngas stream comprises separating carbon dioxide from a remaining portion of the shifted syngas stream to produce the carbon dioxide stream and separating hydrogen from a remaining portion of the shifted syngas stream after the carbon dioxide has been separated to produce the

hydrogen stream.

[0058] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the exhaust stream comprises approximately 75 mole percent (mol.%) nitrogen and a balance of oxygen, carbon dioxide, and water.

5 [0059] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the nitrogen that is reacted with the hydrogen stream is at least partially sourced from the exhaust stream.

[0060] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the electric generator generates sufficient electrical
10 power for converting the second portion of the fuel stream, converting at least the portion of carbon monoxide of the syngas stream, separating the shifted syngas stream, and reacting the hydrogen stream with nitrogen, independent of power importation.

[0061] In an example implementation (or aspect), a system comprises: a fuel stream comprising hydrogen atoms; a blue hydrogen production subsystem comprising
15 a reforming unit configured to receive and react a first portion of the fuel stream, steam, and oxygen to produce a syngas stream, wherein the blue hydrogen production subsystem is configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream; a blue ammonia production subsystem configured to receive the hydrogen stream from the blue hydrogen production subsystem and nitrogen, wherein
20 the blue ammonia production subsystem is configured to react the hydrogen stream with the nitrogen to produce an ammonia stream; and a power and utility subsystem configured to receive a second portion of the fuel stream, wherein the power and utility subsystem is electrically connected to at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem for providing electrical power to
25 the at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem, wherein the power and utility subsystem comprises: a compressor configured to receive and compress a gas stream comprising oxygen to produce a compressed gas stream; a complementary firing chamber configured to receive a fuel stream and the compressed gas stream, wherein the combustion chamber
30 is configured to combust the fuel stream in the presence of the oxygen of the compressed gas stream to produce an exhaust stream; an electric generator in fluid communication with the complementary firing chamber, wherein the electric generator is configured to receive the exhaust stream and generate electrical power in response to expansion of the

exhaust stream through the electric generator; a first heat exchanger configured to transfer heat from the gas stream exiting the compressor to the exhaust stream exiting the electric generator to heat the exhaust stream; and a second heat exchanger configured to transfer heat from the exhaust stream exiting the first heat exchanger to a working fluid to heat the working fluid.

[0062] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the electric generator is coupled to the compressor, wherein the electric generator comprises a turbine wheel configured to rotate in response to the exhaust stream flowing and expanding across the turbine wheel of the electric generator, wherein the compressor comprises an impeller coupled to a shaft, wherein the shaft of the compressor is coupled to the turbine wheel of the electric generator and rotates with the turbine wheel for compressing the gas stream.

[0063] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the power and utility subsystem further comprises a third heat exchanger configured to transfer heat from at least a portion of the working fluid to a water stream to preheat the water stream.

[0064] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the power and utility subsystem further comprises: a boiler in fluid communication with the third heat exchanger, wherein the boiler is configured to receive the water stream from the third heat exchanger and boil the water stream to produce steam; and a second electric generator in fluid communication with the boiler, wherein the second electric generator is configured to receive at least a portion of the steam produced by the boiler and generate electrical power in response to expansion of the steam through the second electric generator.

[0065] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the boiler of the power and utility subsystem is in fluid communication with the blue hydrogen production subsystem, wherein at least a portion of the steam received by the blue hydrogen production subsystem is sourced from the boiler.

[0066] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the blue hydrogen production subsystem further comprises: a shift reactor configured to receive the syngas from the reforming unit and convert at least a portion of carbon monoxide of the syngas into carbon dioxide and

produce additional hydrogen for producing a shifted syngas stream; and a separation unit configured to separate carbon dioxide from the shifted syngas stream, thereby producing the carbon dioxide stream, wherein the separation unit is configured to separate hydrogen from a remaining portion of the shifted syngas stream after the carbon
5 dioxide has been separated, thereby producing the hydrogen stream.

[0067] In an example implementation (or aspect) combinable with any other example implementation (or aspect), wherein the system comprises a separation unit configured to separate nitrogen from the exhaust stream, wherein the nitrogen that is reacted with the hydrogen stream by the blue ammonia production subsystem is at least
10 partially sourced from the nitrogen separated from the exhaust stream by the separation unit.

[0068] In an example implementation (or aspect) combinable with any other example implementation (or aspect), the power and utility subsystem is configured to generate sufficient electrical power for delivery to the blue hydrogen production
15 subsystem to produce the carbon dioxide stream and the hydrogen stream and for delivery to the blue ammonia production subsystem to produce the ammonia stream, independent of power importation.

CLAIMS

WHAT IS CLAIMED IS:

1. A method comprising:

compressing a gas stream comprising oxygen to produce a compressed gas
5 stream;

combusting a first portion of a fuel stream comprising hydrogen atoms in the
presence of the compressed gas stream to produce an exhaust stream;

flowing the exhaust stream to a turbine of an electric generator, thereby causing
the exhaust stream to expand while flowing across the turbine and the turbine to
10 rotate;

generating, by the electric generator, electrical power in response to rotation of
the turbine;

transferring heat from the exhaust stream to the compressed gas stream;

after transferring heat from the compressed gas stream to the exhaust stream,

15 transferring heat from the exhaust stream to a working fluid;

after transferring heat from the exhaust stream to the working fluid, transferring
heat from the working fluid to a water stream for generating a steam stream;

converting a second portion of the fuel stream in the presence of oxygen and
steam to produce a syngas stream, wherein at least a portion of the steam is sourced
20 from the steam stream generated from the water stream;

separating the syngas stream to produce a carbon dioxide stream and a hydrogen
stream; and

reacting the hydrogen stream with nitrogen to produce an ammonia stream,
wherein at least a portion of the electrical power generated by the electric generator
25 is used to convert the second portion of the fuel stream, separate the syngas stream,
react the hydrogen stream with nitrogen, or any combinations thereof.

2. The method of claim 1, wherein the gas stream is compressed by a compressor that
is coupled to the electric generator, wherein the compressor comprises an impeller
30 coupled to a shaft, wherein the shaft of the compressor is coupled to the turbine wheel
of the electric generator and rotates with the turbine wheel, wherein rotation of the
impeller of the compressor causes the gas stream to compress.

3. The method of claim 2, further comprising:
flowing at least a portion of the steam stream to a second turbine wheel of a second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate; and
5 generating, by the second electric generator, electrical power in response to rotation of the second turbine wheel.
4. The method of claim 3, further comprising converting at least a portion of carbon monoxide of the syngas stream into carbon dioxide and produce additional hydrogen,
10 thereby producing a shifted syngas stream.
5. The method of claim 4, wherein separating the syngas stream comprises:
separating carbon dioxide from the shifted syngas stream, thereby producing the carbon dioxide stream; and
15 separating hydrogen from a remaining portion of the shifted syngas stream after the carbon dioxide has been separated, thereby producing the hydrogen stream.
6. A method comprising:
20 pressurizing, by a compressor, an air stream comprising oxygen to produce a compressed air stream;
reacting, within a combustion chamber, a first portion of a fuel stream comprising hydrogen atoms in the presence of the oxygen of the compressed air stream to produce an exhaust stream;
25 flowing the exhaust stream to a turbine of an electric generator, thereby causing the turbine to rotate;
generating, by the electric generator, electrical power in response to rotation of the turbine;
transferring, by a first heat exchanger, heat from the exhaust stream exiting the electric generator to the compressed air stream;
30 transferring, by a second heat exchanger, heat from the exhaust stream to a working fluid;

boiling a water stream to produce a steam stream, wherein boiling the water stream comprises transferring heat from the working fluid to the water stream;

converting, within a reforming unit, a second portion of the fuel stream in the presence of oxygen and steam to produce a syngas stream, wherein at least a portion
5 of the steam is sourced from the steam stream;

converting, within a shift reactor, at least a portion of carbon monoxide of the syngas stream into carbon dioxide and producing additional hydrogen, thereby producing a shifted syngas stream;

separating the shifted syngas stream to produce a carbon dioxide stream and a
10 hydrogen stream; and

reacting the hydrogen stream with nitrogen to produce an ammonia stream, wherein at least a portion of the electrical power generated by the electric generator is used to convert the second portion of the fuel stream, convert at least the portion of carbon monoxide of the syngas stream, separate the shifted syngas stream, react
15 the hydrogen stream with nitrogen, or any combinations thereof.

7. The method of claim 6, wherein the compressor is coupled to the electric generator, wherein the compressor comprises an impeller coupled to a shaft, wherein the shaft of the compressor is coupled to the turbine wheel of the electric generator and rotates with
20 the turbine wheel, wherein rotation of the impeller of the compressor causes the air stream to pressurize.

8. The method of claim 7, further comprising:

flowing at least a portion of the steam stream to a second turbine wheel of a
25 second electric generator, thereby causing the portion of the steam stream to expand while flowing across the second turbine wheel and the second turbine wheel to rotate; and

generating, by the second electric generator, electrical power in response to rotation of the second turbine wheel.

9. The method of claim 8, wherein separating the shifted syngas stream comprises separating carbon dioxide from a remaining portion of the shifted syngas stream to produce the carbon dioxide stream and separating hydrogen from a remaining portion
30

of the shifted syngas stream after the carbon dioxide has been separated to produce the hydrogen stream.

10. The method of claim 9, wherein the exhaust stream comprises approximately 75
5 mole percent (mol.%) nitrogen and a balance of oxygen, carbon dioxide, and water.

11. The method of claim 10, wherein the nitrogen that is reacted with the hydrogen stream is at least partially sourced from the exhaust stream.

10 12. The method of claim 11, wherein the electric generator generates sufficient electrical power for converting the second portion of the fuel stream, converting at least the portion of carbon monoxide of the syngas stream, separating the shifted syngas stream, and reacting the hydrogen stream with nitrogen, independent of power importation.

15 13. A system comprising:

a fuel stream comprising hydrogen atoms;

a blue hydrogen production subsystem comprising a reforming unit configured to receive and react a first portion of the fuel stream, steam, and oxygen to produce a syngas stream, wherein the blue hydrogen production subsystem is configured to
20 separate the syngas stream into a carbon dioxide stream and a hydrogen stream;

a blue ammonia production subsystem configured to receive the hydrogen stream from the blue hydrogen production subsystem and nitrogen, wherein the blue ammonia production subsystem is configured to react the hydrogen stream with the nitrogen to produce an ammonia stream; and

25 a power and utility subsystem configured to receive a second portion of the fuel stream, wherein the power and utility subsystem is electrically connected to at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem for providing electrical power to the at least one of the blue hydrogen production subsystem or the blue ammonia production subsystem, wherein the
30 power and utility subsystem comprises:

a compressor configured to receive and compress a gas stream comprising oxygen to produce a compressed gas stream;

a complementary firing chamber configured to receive a fuel stream and the compressed gas stream, wherein the combustion chamber is configured to combust the fuel stream in the presence of the oxygen of the compressed gas stream to produce an exhaust stream;

5 an electric generator in fluid communication with the complementary firing chamber, wherein the electric generator is configured to receive the exhaust stream and generate electrical power in response to expansion of the exhaust stream through the electric generator;

10 a first heat exchanger configured to transfer heat from the gas stream exiting the compressor to the exhaust stream exiting the electric generator to heat the exhaust stream; and

a second heat exchanger configured to transfer heat from the exhaust stream exiting the first heat exchanger to a working fluid to heat the working fluid.

15 14. The system of claim 13, wherein the electric generator is coupled to the compressor, wherein the electric generator comprises a turbine wheel configured to rotate in response to the exhaust stream flowing and expanding across the turbine wheel of the electric generator, wherein the compressor comprises an impeller coupled to a shaft, wherein the shaft of the compressor is coupled to the turbine wheel of the electric generator and
20 rotates with the turbine wheel for compressing the gas stream.

15. The system of claim 14, wherein the power and utility subsystem further comprises a third heat exchanger configured to transfer heat from at least a portion of the working fluid to a water stream to preheat the water stream.

25

16. The system of claim 15, wherein the power and utility subsystem further comprises:

a boiler in fluid communication with the third heat exchanger, wherein the boiler is configured to receive the water stream from the third heat exchanger and boil the water stream to produce steam; and

30 a second electric generator in fluid communication with the boiler, wherein the second electric generator is configured to receive at least a portion of the steam produced by the boiler and generate electrical power in response to expansion of the steam through the second electric generator.

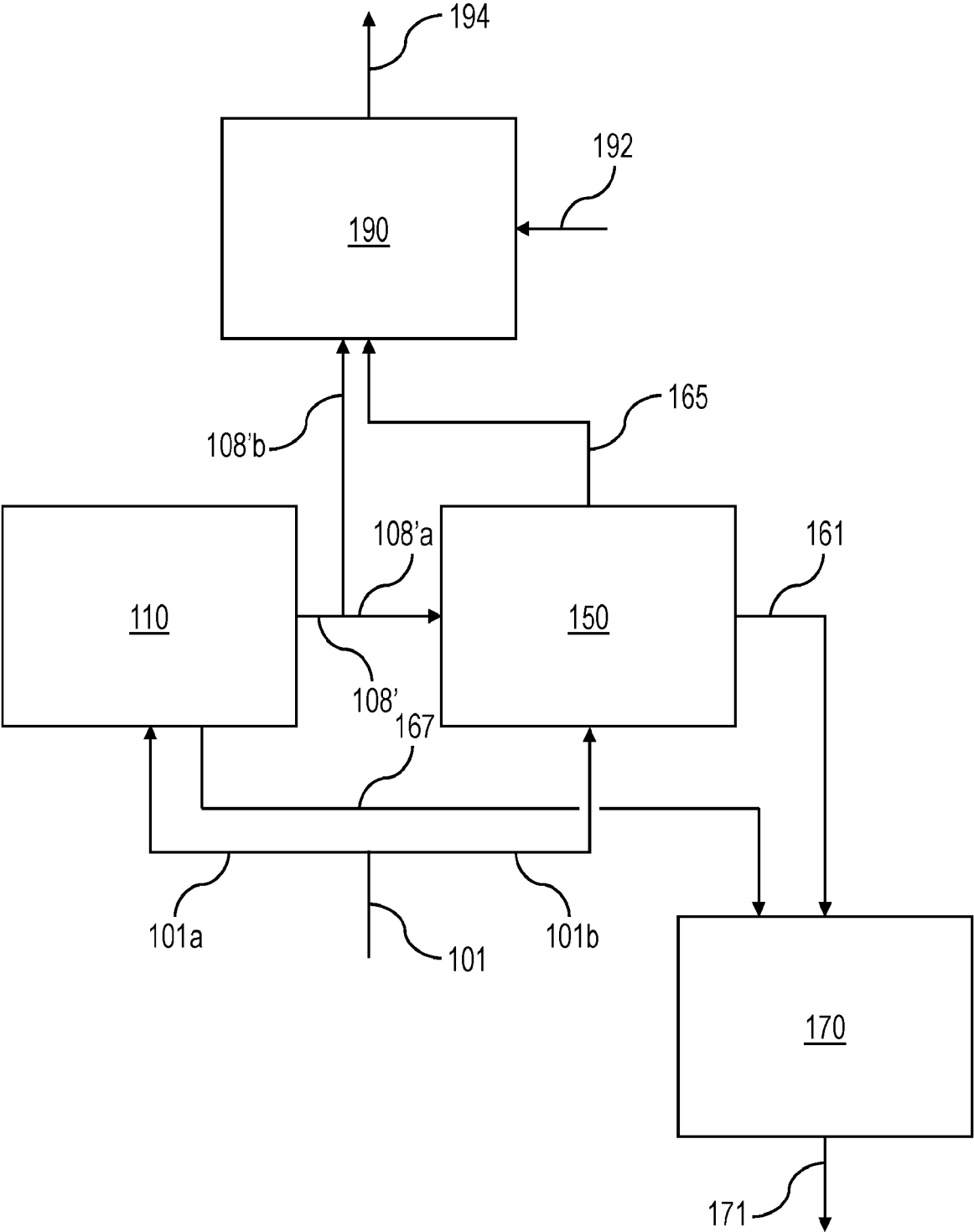
17. The system of claim 16, wherein the boiler of the power and utility subsystem is in fluid communication with the blue hydrogen production subsystem, wherein at least a portion of the steam received by the blue hydrogen production subsystem is sourced
5 from the boiler.

18. The system of claim 17, wherein the blue hydrogen production subsystem further comprises:

- a shift reactor configured to receive the syngas from the reforming unit and
10 convert at least a portion of carbon monoxide of the syngas into carbon dioxide and produce additional hydrogen for producing a shifted syngas stream; and
- a separation unit configured to separate carbon dioxide from the shifted syngas stream, thereby producing the carbon dioxide stream, wherein the separation unit is configured to separate hydrogen from a remaining portion of the shifted syngas
15 stream after the carbon dioxide has been separated, thereby producing the hydrogen stream.

19. The system of claim 18, further comprising a separation unit configured to separate nitrogen from the exhaust stream, wherein the nitrogen that is reacted with the hydrogen
20 stream by the blue ammonia production subsystem is at least partially sourced from the nitrogen separated from the exhaust stream by the separation unit.

20. The system of claim 19, wherein the power and utility subsystem is configured to generate sufficient electrical power for delivery to the blue hydrogen production
25 subsystem to produce the carbon dioxide stream and the hydrogen stream and for delivery to the blue ammonia production subsystem to produce the ammonia stream, independent of power importation.



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FIG. 1A

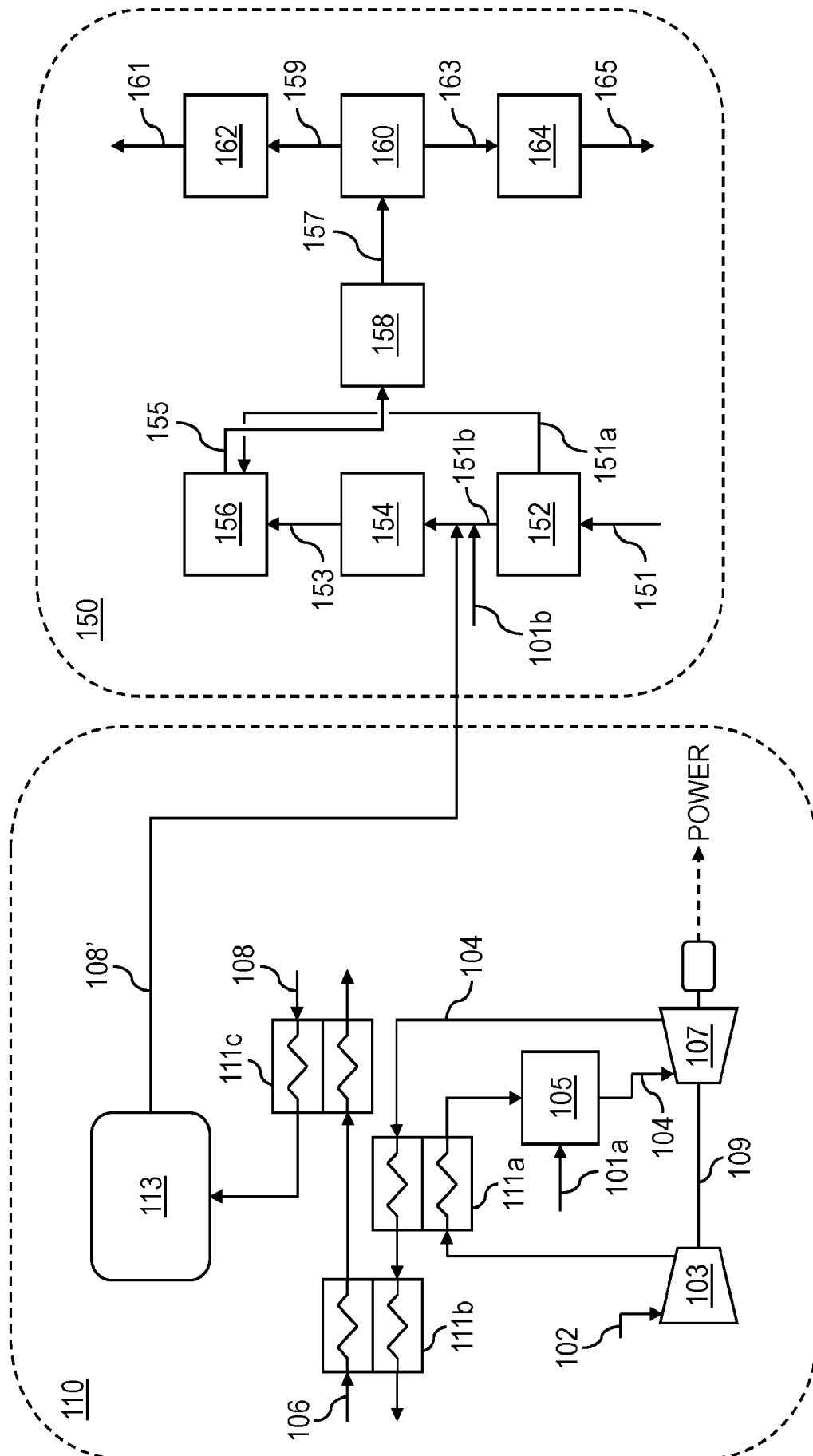
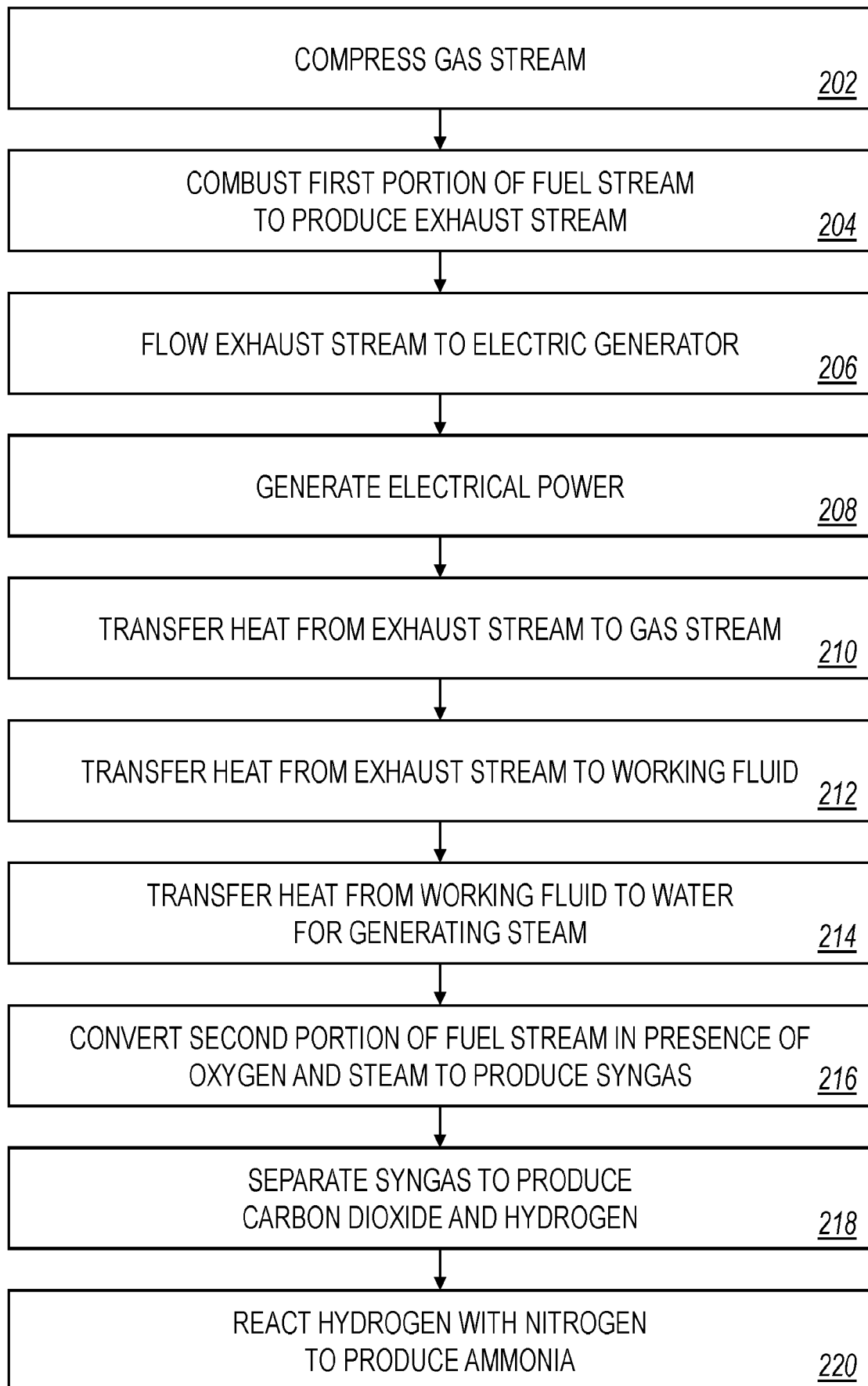
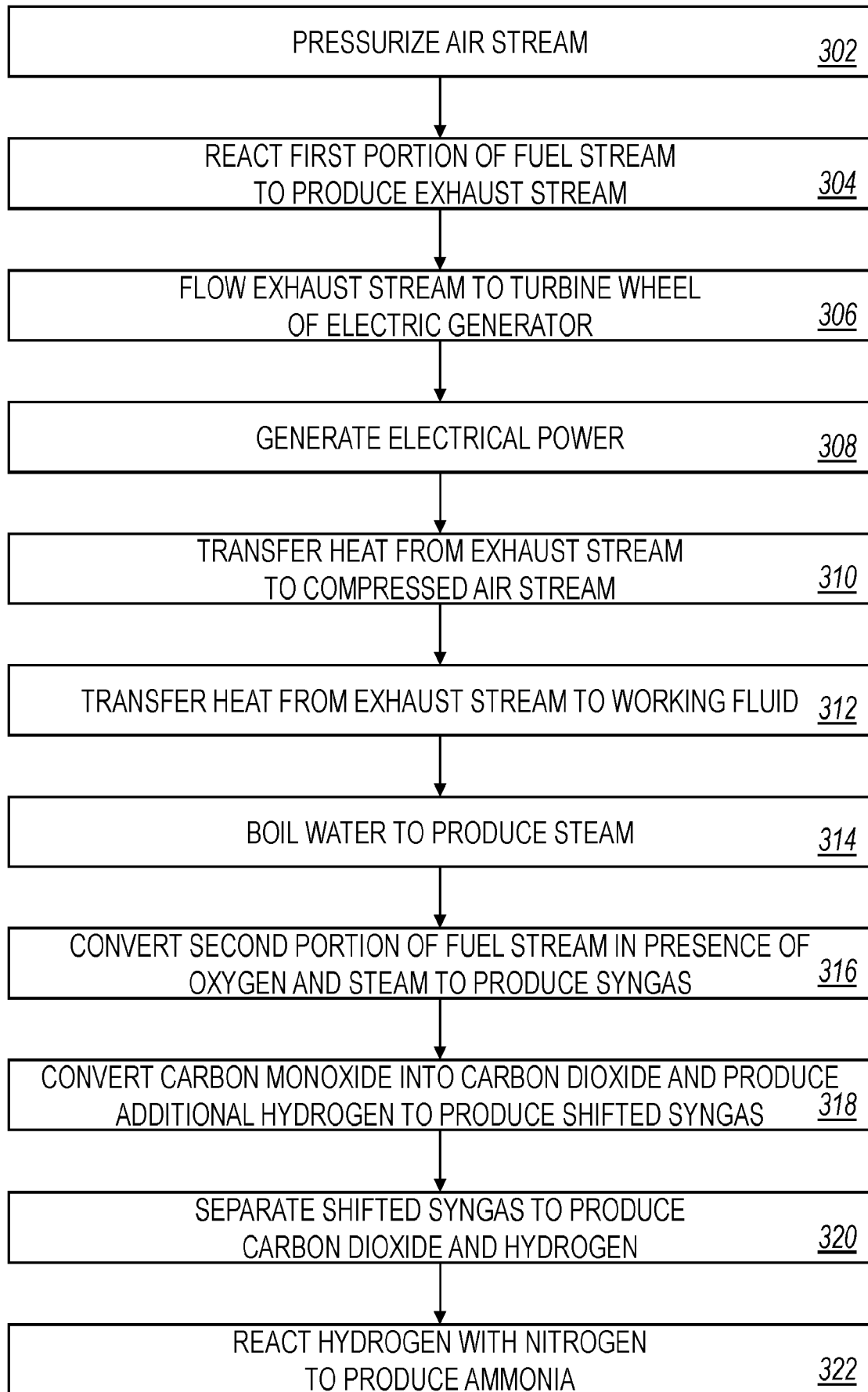


FIG. 1B

200**FIG. 2**

**FIG. 3**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/060757

A. CLASSIFICATION OF SUBJECT MATTER

INV. C01B3/02

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C01B C01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2023/064046 A1 (CORBETTA MICHELE [IT] ET AL) 2 March 2023 (2023-03-02) paragraph [0098] - paragraph [0111]; figure 1	1-20
A	US 2013/127163 A1 (PALAMARA JOHN EUGENE [US] ET AL) 23 May 2013 (2013-05-23) paragraph [0056] - paragraph [0057]; figure 3	1-9, 12-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 March 2025

Date of mailing of the international search report

03/04/2025

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/060757

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Martin T White: "Components of a thermal power system", , 26 September 2020 (2020-09-26), XP093262353, Retrieved from the Internet: URL:https://martintwhite.github.io/orc101/post3_components.html [retrieved on 2025-03-23] the whole document -----	1,6,13, 15,16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/060757

Patent document cited in search report			Publication date		Patent family member(s)			Publication date	
US 2023064046	A1	02-03-2023	AU	2021213293	A1	14-07-2022			
			AU	2024200390	A1	15-02-2024			
			BR	112022015076	A2	20-09-2022			
			CA	3165966	A1	05-08-2021			
			CN	114981206	A	30-08-2022			
			EP	4097044	A1	07-12-2022			
			EP	4230854	A2	23-08-2023			
			US	2023064046	A1	02-03-2023			
			US	2024158227	A1	16-05-2024			
			WO	2021151885	A1	05-08-2021			

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			CN	103121661	A	29-05-2013			
			EP	2594528	A1	22-05-2013			
			US	2013127163	A1	23-05-2013			
