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(71) **Demandeur/Applicant:**
EXXONMOBIL UPSTREAM RESEARCH COMPANY,
US

(72) **Inventeurs/Inventors:**
HERSHKOWITZ, FRANK, US;
NELSON, ERIC D., US;
MCMAHON, PATRICK D., US

(74) **Agent**: BORDEN LADNER GERVAIS LLP

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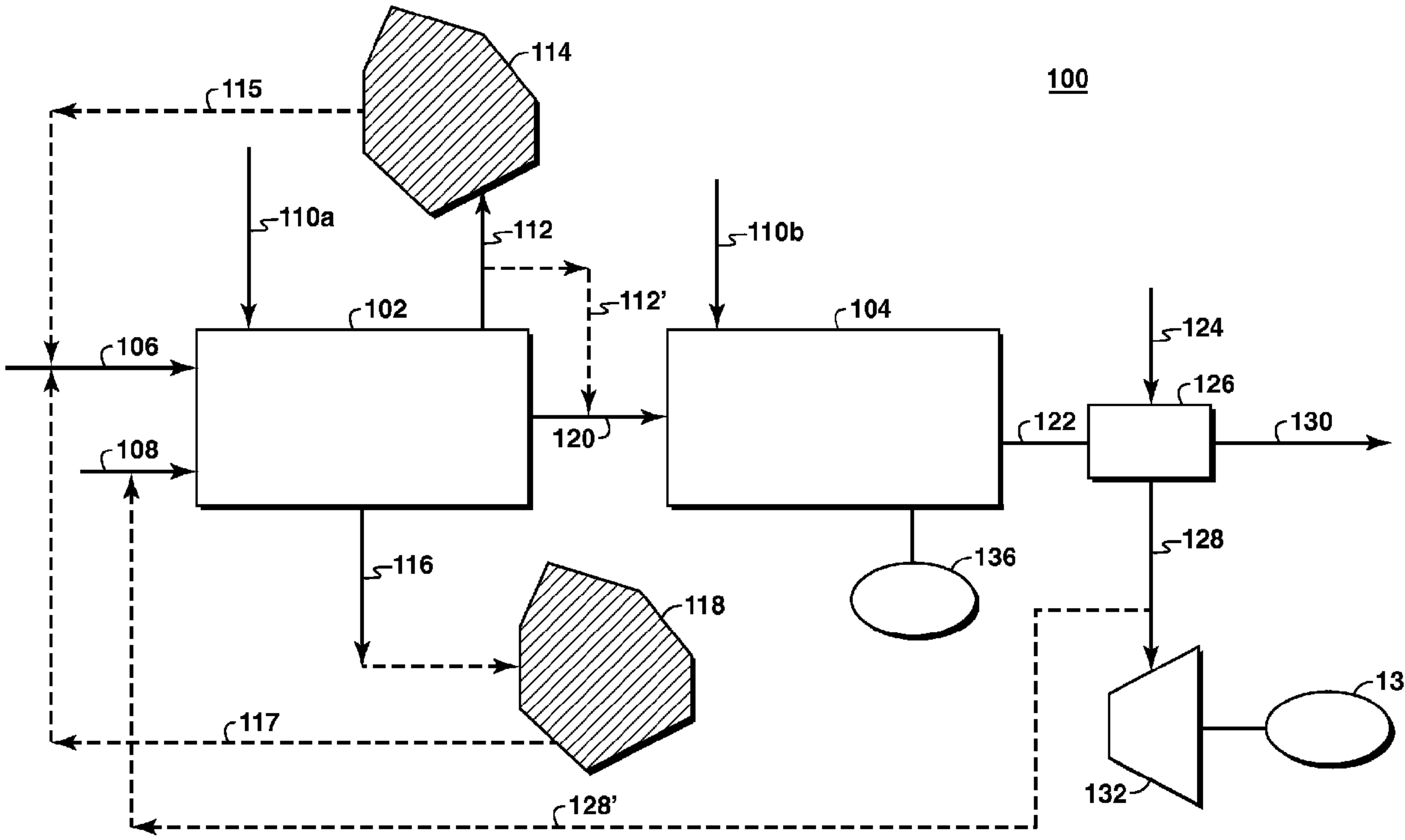

FIG. 1

(57) Abrégé/Abstract:

Methods and systems for low emission power generation in hydrocarbon recovery processes are provided. One system includes integrated pressure maintenance and miscible flood systems with low emission power generation. The system may also include integration of a pressure swing reformer (PSR), air-blown auto-thermal reformer (ATR), or oxygen- blown ATR with a gas power turbine system, preferably a combined cycle gas power turbine system. Such systems may be employed to capture and utilize greenhouse gases (GHG) and generate power for use in hydrocarbon recovery operations.

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(71) **Applicant** *(for all designated States except US)*: **EXXONMOBIL UPSTREAM RESEARCH COMPANY** [US/US]; CORP-URC-SW-359, P.O. Box 2189, Houston, TX 77252-2189 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **HERSHKOWITZ, Frank** [US/US]; 509 Lyon Road, Liberty Corner, NY 07938 (US). **NELSON, Eric, D.** [US/US]; 8003 Windswept Lane, Houston, TX 77063 (US). **MCMAHON, Patrick, D.** [US/US]; 107 N. Westwinds Circle, The Woodlands, TX 77382 (US).

(74) **Agents**: **BROWN, Adam, P.** et al.; Exxonmobil Upstream Research Company, CORP-URC-SW-359, P.O. Box 2189, Houston, TX 77252-2189 (US).

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(54) **Title**: LOW EMISSION POWER GENERATION AND HYDROCARBON RECOVERY SYSTEMS AND METHODS

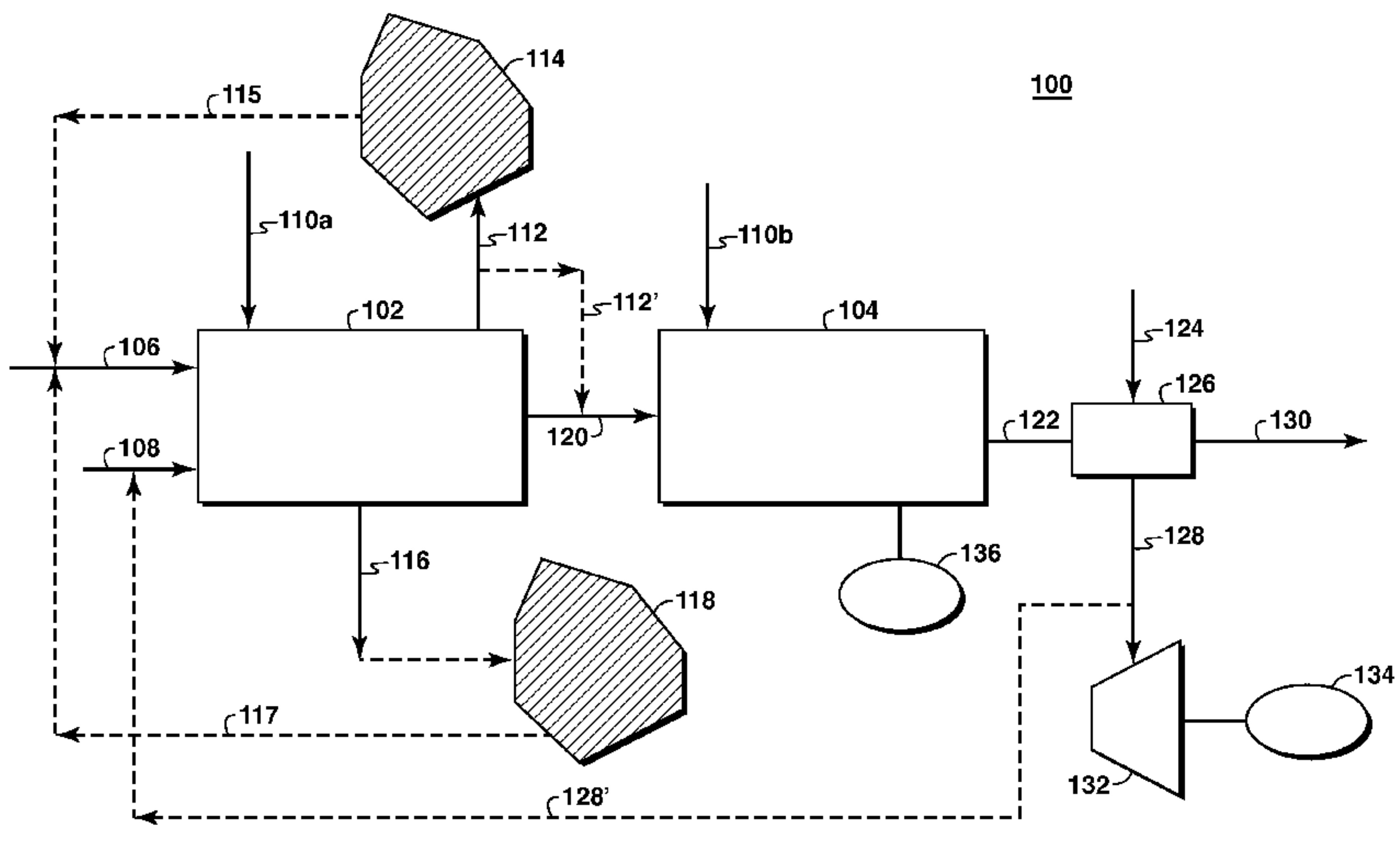

FIG. 1

(57) **Abstract**: Methods and systems for low emission power generation in hydrocarbon recovery processes are provided. One system includes integrated pressure maintenance and miscible flood systems with low emission power generation. The system may also include integration of a pressure swing reformer (PSR), air-blown auto-thermal reformer (ATR), or oxygen- blown ATR with a gas power turbine system, preferably a combined cycle gas power turbine system. Such systems may be employed to capture and utilize greenhouse gases (GHG) and generate power for use in hydrocarbon recovery operations.

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LOW EMISSION POWER GENERATION AND HYDROCARBON RECOVERY SYSTEMS AND METHODS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application 61/072,292 filed 28 March 2008 entitled LOW EMISSION POWER GENERATION AND HYDROCARBON RECOVERY SYSTEMS AND METHODS and U.S. Provisional Patent Application 61/153,508 filed 18 February 2009 entitled LOW EMISSION POWER GENERATION AND HYDROCARBON RECOVERY SYSTEMS AND METHODS and U.S. Provisional Patent Application 61/154,675 filed 23 February 2009 entitled LOW EMISSION POWER GENERATION AND HYDROCARBON RECOVERY SYSTEMS AND METHODS, the entirety of which is incorporated by reference herein.

FIELD OF THE INVENTION

[0002] Embodiments of the invention relate to low emission power generation in hydrocarbon recovery processes. More particularly, embodiments of the invention relate to methods and apparatuses for utilizing nitrogen, oxygen, carbon dioxide, and hydrocarbon fuel with reformer technology to generate power in very low emission hydrocarbon recovery processes.

BACKGROUND OF THE INVENTION

[0003] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present invention. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present invention. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] Many enhanced hydrocarbon recovery operations can be classified as one of the following types: pressure maintenance and miscible flooding. In a pressure maintenance operation, inert gasses such as nitrogen are injected into a primarily gaseous reservoir to maintain at least a minimal pressure in the reservoir to prevent retrograde condensation and improve total recovery. In a miscible flooding operation, miscible gasses such as carbon dioxide are injected into a primarily liquidous reservoir to mix with the liquids, lowering their viscosity and increasing pressure to improve the recovery rate.

[0005] Many oil producing countries are experiencing strong domestic growth in power demand and have an interest in enhanced oil recovery (EOR) to improve oil recovery from their reservoirs. Two common EOR techniques include nitrogen (N_2) injection for reservoir pressure maintenance and carbon dioxide (CO_2) injection for miscible flooding for EOR. There is also a global concern regarding green house gas (GHG) emissions. This concern combined with the implementation of cap-and-trade or carbon tax policies in many countries make reducing CO_2 emissions a priority for these and other countries as well as the companies that operate hydrocarbon production systems therein. Efficiently producing hydrocarbons while reducing GHG emissions is one of the world's toughest energy challenges.

[0006] Some approaches to lower CO_2 emissions include fuel de-carbonization or post-combustion capture. However, both of these solutions are expensive and reduce power generation efficiency, resulting in lower power production, increased fuel demand and increased cost of electricity to meet domestic power demand. Another approach is an oxyfuel gas turbine in a combined cycle (e.g. where exhaust heat from the gas turbine Brayton cycle is captured to make steam and produce additional power in a Rankin cycle). However, there are no commercially available gas turbines that can operate in such a cycle and the power required to produce high purity oxygen significantly reduces the overall efficiency of the process.

[0007] One proposed approach utilizes an autothermal reformer unit (ATR) to produce hydrogen fuel and carbon dioxide for capture and/or injection. Such systems are disclosed in many publications, including, for example International Patent Application Number WO2008/074980 (the '980 application) and Ertesvåg, Ivar S., et al., "Exergy Analysis of a Gas-Turbine Combined-Cycle Power Plant With Precombustion CO_2 Capture," Elsivier (2004) (the Ertesvag reference), the relevant portions of which are hereby incorporated by reference. The '980 application and Ertesvag references disclose systems for reforming natural gas in an auto-thermal reformer (ATR) to form a syngas, then separating the CO_2 from the syngas and sending the hydrogen-rich fuel to a conventional combined-cycle (CC) process.

[0008] As such, there is still a substantial need for a low emission, high efficiency hydrocarbon recovery process.

SUMMARY OF THE INVENTION

[0009] One embodiment of the present disclosure includes integrated systems. The integrated systems include a pressure swing reformer unit configured to utilize an air stream, a natural gas stream, and a steam stream to produce a regeneration stream comprising substantially nitrogen and a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen; and a pressure maintenance reservoir to receive at least a portion of the regeneration stream comprising substantially nitrogen. The integrated system may also include a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide; a separation unit configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream; and an enhanced oil recovery reservoir to receive at least a portion of the carbon dioxide stream. Additionally, some embodiments of the system may include a gas turbine configured to utilize the hydrogen stream to generate power and a gaseous exhaust stream.

[0010] Another embodiment of the present disclosure includes methods of producing hydrocarbons. The methods include producing a regeneration stream comprising substantially nitrogen and a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen in a pressure swing reformer; injecting at least a portion of the regeneration stream comprising substantially nitrogen into a pressure maintenance reservoir; and producing hydrocarbons from the pressure maintenance reservoir. Other embodiments of the methods may include converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor; separating the syngas stream into a carbon dioxide stream and a hydrogen stream; generating power in a gas turbine, wherein the gas turbine is configured to utilize at least a portion of the hydrogen stream as fuel; injecting at least a portion of the carbon dioxide stream into an enhanced oil recovery reservoir; and producing hydrocarbons from the enhanced oil recovery reservoir. Further embodiments may include recycling at least a portion of the hydrocarbons produced from the enhanced oil recovery reservoir to the pressure swing reformer; and recycling at least a portion of the hydrocarbons produced from the pressure maintenance reservoir to the pressure swing reformer.

[0011] In a third embodiment of the present disclosure, alternative integrated systems are provided. The integrated systems include a reactor unit configured to utilize an air stream, a hydrocarbon fuel stream, and a steam stream to produce a syngas stream comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen; a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide to form a shifted stream;

a first separation unit configured to separate the carbon dioxide stream from the shifted stream to produce a substantially carbon dioxide stream and a mixed products stream comprising substantially nitrogen and hydrogen; a gas turbine configured to utilize the mixed products stream to generate power and a gaseous exhaust stream comprising nitrogen and steam; a second separation unit configured to separate the nitrogen from the steam to produce at least a gaseous nitrogen stream; and a pressure maintenance reservoir to receive at least a portion of the gaseous nitrogen stream.

[0012] In a fourth embodiment of the disclosure, alternative methods for producing hydrocarbons are disclosed. The methods include producing a syngas stream comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen utilizing a reactor unit; converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor to form a shifted stream; separating the carbon dioxide from the shifted stream to produce a substantially carbon dioxide stream and a mixed products stream comprising substantially nitrogen and hydrogen; generating power and a gaseous exhaust stream comprising nitrogen and steam in a gas turbine, wherein the gas turbine is configured to utilize the mixed products stream comprising substantially nitrogen and hydrogen as fuel; separating the nitrogen from the steam to produce at least a gaseous nitrogen stream; injecting at least a portion of the gaseous nitrogen stream into a pressure maintenance reservoir; and producing hydrocarbons from the pressure maintenance reservoir.

[0013] In a fifth embodiment of the present disclosure, yet another alternative embodiment of integrated systems is provided. The systems include an air separation unit configured to generate a substantially nitrogen stream and a substantially oxygen stream; a reactor unit configured to utilize the substantially oxygen stream, a hydrocarbon fuel stream, and a steam stream to produce a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen; a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide; a separation unit configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream; and an enhanced oil recovery reservoir to receive at least a portion of the separated carbon dioxide stream.

[0014] In a sixth embodiment of the present disclosure, additional alternative methods of producing oil are provided. The methods include separating air in an air separation unit configured to generate a substantially nitrogen stream and a substantially oxygen stream; producing a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen using a reactor unit configured to utilize the substantially oxygen stream, a hydrocarbon fuel stream, and a steam stream; converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor to form a shifted stream; separating the shifted stream into a carbon dioxide stream and a hydrogen stream; injecting at least a portion of the separated carbon dioxide stream into an enhanced oil recovery reservoir; and producing hydrocarbons from the enhanced oil recovery reservoir.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The foregoing and other advantages of the present invention may become apparent upon reviewing the following detailed description and drawings of non-limiting examples of embodiments in which:

[0016] FIG. 1 illustrates an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit;

[0017] FIG. 2 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit like that shown in FIG. 1.

[0018] FIG. 3 is an exemplary flow chart of a method of operating an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit like those shown in FIGs. 1-2;

[0019] FIG. 4 is an illustration of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit;

[0020] FIG. 5 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like that shown in FIG. 4;

[0021] FIG. 6 is an exemplary flow chart of a method of operating an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like those shown in FIGs. 4-5;

[0022] FIG. 7 is an illustration of an alternative embodiment of the integrated system for low emission power generation and hydrocarbon recovery using a reactor unit similar to that shown in FIGs. 4-5;

[0023] FIG. 8 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like that shown in FIG. 7; and

[0024] FIG. 9 is an exemplary flow chart of an alternative method of operating an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like those shown in FIGs. 7-8.

DETAILED DESCRIPTION OF THE INVENTION

[0025] In the following detailed description section, the specific embodiments of the present invention are described in connection with preferred embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present invention, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the invention is not limited to the specific embodiments described below, but rather, it includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0026] At least one benefit of the system is integration of two types of recovery processes to produce two types of injection gas (nitrogen and CO_2) for additional hydrocarbon recovery. One exemplary approach to produce N_2, CO_2 and power to take advantage of the catalytic combustion step within a Pressure Swing Reforming (PSR) process to reactively remove oxygen from an air stream, while simultaneously producing high pressure syngas that is readily separated into a CO_2 stream for petroleum production operations and a hydrogen (H_2) stream to be used in high-efficiency power generation. In this unexpected application of PSR systems and processes, the regeneration step may be advantageously operated at a high pressure that is similar to the reforming pressure. In one embodiment of the present invention, the reforming and regenerations steps are both operated at similar and high (e.g. 300-500 psig) pressures. In another embodiment, a small amount of the nitrogen produced in the regeneration step is used to dilute the hydrogen prior to the hydrogen's use as fuel in a gas turbine system. Pressure Swing Reforming processes have been disclosed in at least U.S. Pat. No. 7,491,250 and U.S. App. No. 2005/0201929, the latter of which is hereby incorporated by reference.

[0027] Additional embodiments of the presently disclosed systems and processes include production of N_2, CO_2, and power for petroleum production operations using an air-based Autothermal Reformer (ATR), partial oxidation reactor (POX) or other reactor unit. In the ATR, exothermic partial oxidation of methane and endothermic catalytic steam reforming produce high pressure syngas that is readily converted through the water-gas shift reaction into CO_2 and hydrogen (H_2), and separated into a CO_2 stream for petroleum production operations and a hydrogen (H_2) stream to be used in high-efficiency power generation. The

POX performs the same partial oxidation reaction as the ATR, but at a higher temperature and without a catalyst.

[0028] Further additional embodiments of the presently disclosed systems and processes include production of nitrogen (N_2), CO_2 and power through using a conventional Air Separation Unit (ASU) to produce an enriched or pure N_2 stream for N_2 substitution while simultaneously producing an enriched or pure oxygen stream as feed to an Autothermal Reformer (ATR) in which exothermic partial oxidation of methane and endothermic catalytic steam reforming produce high pressure syngas that may be readily converted through the water-gas shift reaction into CO_2 and hydrogen (H_2), and separated into a CO_2 stream for petroleum production operations and a hydrogen (H_2) stream to be used in high-efficiency power generation.

[0029] Although it is possible to produce nitrogen for reservoir pressure maintenance and carbon dioxide for EOR completely independently, embodiments of the disclosed systems and methods take advantage of the synergies that are possible when both nitrogen and carbon dioxide are produced in an integrated process to accomplish the production of these gases at a much lower cost while also producing power and /or desalinated water with ultra low emissions. Note, that if EOR utilization is not possible, the CO_2 produced by the power production can be purged from the recycle stream and sequestered or stored. This allows the various embodiments to be utilized for power production with ultra-low emissions.

[0030] In one embodiment, power may be produced from the hydrogen stream via combustion at elevated pressure, so that additional power can be produced by expanding the products of combustion across the expander of a gas turbine. The efficiency of a Brayton cycle is a function of the pressure ratio across the expander and the inlet temperature to the expander. Therefore, moving to higher-pressure ratios and higher expander inlet temperatures increases gas turbine efficiency. The inlet temperature to the expander may be limited by material considerations and cooling of the part surfaces. Using these types of fuels in a high pressure combustor and then expanding them in the expander section can result in high efficiencies and provide an economical way for utilizing such reserves. Depending on the well head pressure available, the expansion may also be stopped at an elevated pressure to reduce the cost associated with compressing nitrogen for well pressurization operations.

[0031] Referring now to the figures, FIG. 1 illustrates an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit. The system **100** comprises a pressure swing reformer unit **102** configured to utilize an air stream **110a**, a natural gas stream **106** and a steam stream **108** to produce a regeneration stream **112** comprising substantially nitrogen (N_2) a carbon dioxide (CO_2) stream **116** and a hydrogen stream **120**. The system **100** may further include an enhanced oil recovery reservoir **118** to receive the carbon dioxide stream **116** and optionally produce a hydrocarbon stream **117** and a pressure maintenance reservoir **114** to receive the regeneration stream **112** and optionally produce a hydrocarbon stream **115**. In some embodiments, a gas turbine unit **104** is also provided, which utilizes an air stream **110b** and the hydrogen stream **120** to generate power **136** and a gaseous exhaust stream **122**, which may be directed to a heat recovery unit **126** configured to utilize water **124** to cool the gaseous exhaust stream **122** to form a cooled exhaust stream **130**, produce at least one unit of steam **128** for use in steam generator **132** to produce power **134**.

[0032] In some alternative embodiments, at least a portion of the regeneration stream **112** may be redirected to combine with the hydrogen stream **120** via stream **112'**. In another alternative embodiment, at least a portion of the steam **128** may be redirected to combine with the steam stream **108** via stream **128'**. In yet another alternative embodiment, air stream **110b** may be compressed by the compressor integrated into the gas turbine **104**.

[0033] FIG. 2 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit like that shown in FIG. 1. As such, FIG. 2 may be best understood with reference to FIG. 1. The system **200** is an alternative, exemplary embodiment of the system **100** and includes an inlet air compressor **201**, a compressed inlet stream **202**, which may contain some recycled nitrogen from stream **208** via compressor **210**, wherein the inlet stream **202** is introduced into the PSR regeneration unit **204**. The PSR **102** also includes a PSR reform unit **206** for receiving the steam **108** and natural gas **106**, which produces a syngas stream **211** comprising carbon monoxide, carbon dioxide, and hydrogen, which is fed to a water-gas shift reactor **212** to convert at least a portion of the carbon monoxide to carbon dioxide, then sent to a separator **214**, which separates as much of the carbon dioxide as possible into stream **116** to produce the hydrogen stream **120**. The gas turbine **104** includes an integrated compressor **220a**, combustor **220b**, and expander **220c**. Optionally, at least a portion of the hydrogen stream **120** may be redirected to the PSR regeneration unit **204** via stream **216**, in which case hydrogen stream **120'** is fed to the combustor **220b**. Optionally, compressed air may be routed from the inlet compressor **220a** to the inlet stream **202** via stream **221**.

[0034] FIG. 3 is an exemplary flow chart of a method of operating an integrated system for low emission power generation and hydrocarbon recovery using a pressure swing reforming unit like those shown in FIGs. 1-2. As such, FIG. 3 may be best understood with reference to FIGs. 1-2. The method **300** includes the steps of producing **302** a regeneration stream **208** comprising substantially nitrogen and a syngas stream **211** comprising carbon monoxide, carbon dioxide, and hydrogen in a pressure swing reformer **102**; injecting **304** at least a portion of the regeneration stream comprising substantially nitrogen **112** into a pressure maintenance reservoir **114** (note, stream **112** is an optional portion of stream **208**, which may be divided into stream **112** sent to hydrocarbon production operations and a recycle stream that is combined with fresh air 110a to generate the PSR regeneration oxidant stream **202**); and producing hydrocarbons **306** from the pressure maintenance reservoir **114**. The process **300** may optionally further include recycling at least a portion of the produced hydrocarbons via stream **115** to a hydrocarbon feed stream **106** for use in the PSR **102**.

[0035] In one alternative embodiment, the method **300** may further include converting **308** at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor **212** to produce a shifted stream **213** comprising hydrogen and carbon dioxide; separating **310** the shifted stream **213** into a carbon dioxide stream **116** and a hydrogen stream **120**; injecting **314** at least a portion of the carbon dioxide stream **116** into an enhanced oil recovery reservoir **118**; producing hydrocarbons **316** from the enhanced oil recovery reservoir **118**; and optionally recycling **318** at least a portion of the produced hydrocarbons via stream **117** to a hydrocarbon feed stream **106** for use in the PSR **102**. Additionally, the process **300** may further include generating **312** power **136** in a gas turbine **104**, wherein the gas turbine **104** is configured to utilize at least a portion of the hydrogen stream **120** as fuel.

[0036] In one exemplary embodiment of the systems **100** and **200** and method **300**, the PSR reforming step **302** may be carried out at a pressure sufficient to supply fuel (e.g. hydrogen streams **120** or **120'**) to the gas turbine **104** (e.g. about 50 to about 200 pounds per square inch gauge (psig) above gas turbine combustion pressure). The feed **106**, **108** to the reforming step may be comprised of natural gas and steam. The product from the reforming step **302** is a syngas mixture comprising CO, H_2, CO_2, H_2O, and other components (e.g. contaminants). After optional H_2O addition, the stream is shifted **304** to convert most of the CO to CO_2 (yielding more hydrogen), and a separation is performed **306** to remove the CO_2. Separation can be via conventional acid gas scrubbing, membrane separation, physical or chemical absorption solvents, or any other effective process. The removed CO_2 **116** is conditioned as required (not shown) for petroleum production operations and transported to that use.

[0037] Hydrogen **120** that remains after the CO_2 removal step **306** is used for power generation. The hydrogen **120** may be used in any power generating cycle, but is advantageously used as feed to a gas turbine power system, more advantageously to a combined cycle gas turbine power system. Some fraction of the steam **128'** that is produced in a combined cycle gas turbine power system may be used as the reforming feed steam **108**. In one embodiment of the present disclosure, steam may be raised by cooling the regeneration flue gas **208** prior to recycle, and this steam is used as the reforming feed steam **108**. In another alternative embodiment of the present disclosure, some fraction of the produced hydrogen **216** is used as fuel in the PSR regeneration step **302**.

[0038] In one unexpected arrangement of the PSR process **300**, the regeneration unit **204** is advantageously operated at a pressure similar to the operating pressure of the reforming unit **206**. In one embodiment of the present invention, the reforming and regenerations steps are both operated at similar and high (e.g. 300-500 psig) pressures. In yet another alternative embodiment, a small amount of the nitrogen produced in the regeneration step **208** is used to dilute the hydrogen **120** prior to the hydrogen's use as fuel in a gas turbine system **104**.

[0039] One advantage of the present system is that the PSR reforming step **302** is relatively insensitive to impurities such as higher hydrocarbons, nitrogen, sulfur and CO_2. Thus, the natural gas feed **106** to the reformer **102** can be a lower-purity stream that is generated as part of the petroleum production operations (e.g. from production/recycle streams **115** or **117**). This can save substantial gas cleanup costs for the petroleum production operations.

[0040] Higher hydrocarbons normally will cause soot or coke formation in conventional reformers, but are more readily reformed by the PSR system **102**. Advantageously, nitrogen in the PSR reforming feed may pass through the reformer and end up an acceptable (even preferred) fuel diluent **112'** in the hydrogen **120** that is sent to power gas turbine **104**. Carbon dioxide in the PSR reforming feed can reduce the amount of steam **108** needed for reforming, but will shift product distribution toward CO. Some additional steam may be added to the shift reactor **212** to drive all of the CO to CO_2, but then the existing separation will capture this CO_2 for re-use in petroleum production operations. Further, the PSR **102** is substantially more tolerant of sulfur than conventional reforming processes. Sulfur at levels of 10 to 100 ppm in hydrocarbon feed can be accommodated. However, this sulfur will emerge in the

PSR products, some as SOx in the substantially nitrogen stream **208**, and some as H_2S in the CO_2 stream **116**. Thus, sulfur should be allowed to enter the PSR reformer **206** only if its emergence in streams **208** and **116** does not interfere with the petroleum production operations.

[0041] Although two reservoirs **114** and **118** are referenced, the reservoirs may be the same reservoir, be two, three, four or more different reservoirs, and may include multiple reservoirs for injection or production. Further, the content of the production streams from the reservoirs **115** and **117** will likely change over time, particularly at "break-through" where the injected gases begin to be produced.

[0042] In general, the EOR reservoir **118** is a reservoir or a portion of a reservoir that comprises substantially liquid hydrocarbons such as crude oil and is generally located over an aquifer. The liquid hydrocarbons are miscible with injected compressed carbon dioxide stream **116** at the proper temperature and pressure. High CO_2 concentrations (e.g. up to about 90 volume % or greater) are preferred in such a miscible flooding operation because the CO_2 acts as a dilute to lower the viscosity of the oil and as a solvent to remove the oil from the formation rock, and other reasons. In addition, less power is needed to pump the gas **116** into the reservoir if it properly mixes. Oxygen levels in the injection stream **116** are preferably kept very low.

[0043] In general, the pressure maintenance reservoir **114** is a reservoir or a portion of a reservoir that includes a gas cap above an oil producing formation. As the liquids are produced, the gas cap pressure and formation pressure is reduced, resulting in lower production and possibly retrograde condensation in the gas portion. The injected gas **1112** is configured to maintain the pressure in the reservoir to at least maintain recovery pressure and avoid retrograde condensation. Miscibility is not an issue in such an operation. As such, inert gasses like nitrogen are preferred. In the special, exemplary case where at least the injection reservoirs **114** and **118** are the same, the nitrogen may be injected into the gas cap of the reservoir and the carbon dioxide is used as a miscible injectant for EOR in the same reservoir.

[0044] The production streams **115** and **117** may be the same or different or include production from multiple reservoirs and may include any variety of light and heavy liquid and gaseous hydrocarbon components as well as other non-hydrocarbon components such as carbon dioxide, hydrogen sulfide, nitrogen, carbonyl sulfide, and combination thereof. During initial or early stage production, it is expected that there will be significantly more heavy hydrocarbon components than sour or non-hydrocarbon components in the production streams **115** and **117**. After optional separation and clean-up, stream **117** may comprise from at least about 70 mol percent (%) hydrocarbons to about 99 mol % hydrocarbons, from about 1 mol % to about 5 mol % CO_2, from about 0 mol % N_2 to about 5 mol % N_2, and some other components.

[0045] As hydrocarbons are produced and particularly once gas breakthrough occurs, the compositions of streams **115** and **117** may change drastically. For example, after CO_2 breakthrough, an exemplary production stream **117** may have the following contents: about 5 mol percent (%) hydrocarbons to about 60 mol % hydrocarbons, from about 40 mol % to about 95 mol % CO_2, from about 0 mol % N_2 to about 10 mol % N_2, and some other components. After nitrogen breakthrough, an exemplary production stream **115** may have the following contents: about 5 mol percent (%) hydrocarbons to about 60 mol % hydrocarbons, from about 5 mol % to about 20 mol % CO_2, from about 40 mol % N_2 to about 95 mol % N_2, and some other components. Note that breakthrough is a transient process rather than a step-wise process resulting in a relatively fast, but gradual increase in the amount of breakthrough gas produced. For example, a reservoir may steadily produce about 5 mol % CO_2 during early production, then produce an increasing amount of CO_2 during a transition period (from a month to several years) until the CO_2 production reaches a high steady state production of about 95 mol % CO_2.

[0046] In additional embodiments, it may be desirable to keep hydrogen stream **120** at higher temperatures for mixing and combustion in the combustor **220b**. Stream **120** may be heated by cross-exchange with hot exhaust gas stream **122** or steam streams **128** or **128'**, heat generated by one of the other compressors in the system **200** (e.g. compressors **201**, **210**, or **220a**), or the HRSG **126**. A temperature sufficient to improve the efficiency of combustion in the combustor **220b** is preferred. In one embodiment, the hydrogen stream **120** may be from about 50 degrees Celsius (°C) to about 500 °C upon entering the combustor **220b**.

[0047] The combustor **220b** may be a standard combustor or may be a customized or modified combustor. Examples of applicable combustor types include a partial oxidation (POX) burner, diffusion burners, lean-premix combustors, and piloted combustors. Note that each burner type may require some modification to work with the available fuel stream. In the diffusion flame combustor (or "burner") the fuel and the oxidant mix and combustion takes place simultaneously in the primary combustion zone. Diffusion combustors generate regions of near-stoichiometric fuel/air mixtures where the temperatures are very high. In premix combustors, fuel and air are thoroughly mixed in an initial stage resulting in a uniform, lean, unburned fuel/air mixture that is delivered to a secondary stage where the combustion reaction takes place. Lean–premix combustors are now common in gas turbines due to lower flame temperatures, which produces lower NOx emissions. In the piloted combustor a hot flamed pilot ensures that the lean fuel oxidant mixture surrounding it maintains stable combustion. These piloted combustors are typically used in aircraft engines and for fuels that may not be able to maintain stable combustion on their own.

PSR EXAMPLE

[0048] To further illustrate embodiments of the PSR system **102**, some exemplary streams of the calculated heat and material balance for the embodiments shown in FIGs. 1-2 are given in Table 1 below. This exemplary pressure swing reformer system **102** is operated as two cylindrical reactors alternating between regeneration and reforming step. As shown, unit **204** reflects the reactor vessel currently in the regeneration step while unit **206** reflects reactor vessel currently in the reforming step. The reactors have internal dimensions of 11 ft (3.4M) diameter and 4 ft (1.2M) length. The reactors are positioned with cylindrical axis in a vertical orientation, and reforming is carried out as up-flow; regeneration as down-flow. The packing is composed of 400 cell/in^2 (62 cell/cm^2) honeycomb monolith having a bulk density of 50 lb/ft^3 (0.8 g/cc). The bottom 70% of the packing includes reforming catalyst. Overall cycle length is 30 seconds; 15 s for the regeneration step and 15 seconds for the reforming step. A brief steam purge is included at the end of the reforming step.

[0049] The reforming unit **206** is fed with methane **106** at the rate of 1760 kgmoles/hr, accompanied by steam **108** at a rate of 4494 kgmoles/hr, representing a reforming C1GHSV of 3,600 hr^{-1}. Syngas (reformate) **211** is produced at rates shown in Table 1, and converted in high and low temperature shift stages **212** to yield shifted product **213**. Separation is accomplished by absorption using an activated MDEA solvent system, yielding 1647 kgmoles/hr of CO_2 in purified stream **116** and hydrogen rich fuel stream **120** shown in Table 1.

[0050] Of the hydrogen-rich fuel, 26% is used in the PSR regeneration step (via stream **216**) and 74% is consumed and sent to the gas turbine **104** via stream **120'** shown on Table 1. The gas turbine **104** operates with air compression to 12.6 atm. abs. and 384°C; a heat rate of 10,100 BTU/kWh (10655 kJ/kWh); 921 lb/sec (418 kg/s) turbine flow; and 126 MW net power output **136**.

[0051] Air compressor **201** provides fresh air **110a** to the PSR regeneration system, as shown in Table 1. This air is combined with recycle flue gas compressed by compressor **210** and fed as stream **202** to the PSR regeneration step. Regeneration exhaust **208** (prior to recycle removal) is shown in Table 1. The non-recycled fraction of the PSR effluent **208** is cooled to remove water resulting in N_2 product **112** shown on Table 1.

Table 1

(PSR at 3600 hr^{-1} C1GHSV)

Stream #	**211**	**116**	**120**	**120'**	**110a**	**208**	**112**
Temperature, °C	401	65	65	65	25	427	65
Pressure, atm abs	16	2	15	15	1	12.2	12.2
stream name	Reformate	CO2 Product	H2 product	GT H2 Fuel	Fresh Air	PSR Flue	N2 Product
Kgmols/hr H2O	2,189	30	123	91	0	7,681	60
O2	0	0	0		912	24	6
N2	171	0	171	126	3,432	14,757	3,432
CO2	263	1,647	0		0	100	23
CH4	35	0	35	26	0	0	0
CO	1,458	0	73	54	0	0	0
H2	5,456	3	6,838	5,059	0	0	0
Total	9,572	1,680	7,241	5,356	4,344	22,555	3,521

[0052] FIG. 4 is an illustration of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit. The system **400** comprises a reactor unit **402** configured to utilize an air stream **410a**, a hydrocarbon fuel stream **406** and a steam stream **408** to produce a carbon dioxide (CO_2) stream **416** and a mixed products stream **420** substantially comprising hydrogen and nitrogen. The system **400** may further include an enhanced oil recovery reservoir **418** to receive the carbon dioxide stream **416** and optionally produce a hydrocarbon stream **417** and a pressure maintenance reservoir **414**, which optionally produces a hydrocarbon stream **415**. In some embodiments, a gas turbine unit **404** is also provided, which utilizes an air stream **410b** and the mixed products stream **420** to generate power **436** and a gaseous exhaust stream **422** comprising steam and nitrogen, which may be directed to a heat recovery unit **426** configured to utilize water **424** to cool the gaseous exhaust stream **422** to form a cooled exhaust stream **430** comprising substantially nitrogen, produce at least one unit of steam **428** for use in steam generator **432** to produce power **434**.

[0053] In some alternative embodiments, at least a portion of the cooled exhaust stream **430** may be further separated to increase the nitrogen concentration and the nitrogen may be redirected to the air stream **410b** for use as a diluent in the gas power turbine or sent to the pressure maintenance reservoir **414** via line **430''**. In addition, at least a portion of the steam **428** may be redirected to combine with the steam stream **408** via stream **428'**. In yet another alternative embodiment, air stream **410b** may be compressed by an air compressor integrated into the gas turbine **404**.

[0054] FIG. 5 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like that shown in FIG. 4. As such, FIG. 5 may be best understood with reference to FIG. 4. System **500** is an alternative, exemplary embodiment of the system **400** and includes an inlet air compressor **502** and a compressed inlet stream **504**, wherein the inlet stream **504** is introduced into the reactor unit **402**. The reactor unit **402** produces a syngas stream **505** comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen, which may be fed to a water-gas shift reactor **510** to convert at least a portion of the carbon monoxide to carbon dioxide to form a shifted stream **511** comprising substantially carbon dioxide, nitrogen, and hydrogen, which may be sent to a separator **512**, which separates as much of the carbon dioxide as possible into stream **416** to produce the mixed products stream having substantially hydrogen and nitrogen **420**. Separator **512** may be a solvent-based absorption/regeneration system such as an amine or physical solvent system. The gas turbine **404** includes an integrated air compressor **514a**, combustor **514b**, and expander **514c**. The mixed products stream **420** may then be mixed and combusted (pre-mixed or other arrangement, as discussed above) with the high pressure air from integrated compressor **514a** to form combustion products stream **520**, which may then be expanded via expander **514c**. Optionally, compressed air may be routed from the inlet compressor **514a** to the inlet stream **504** via stream **515**.

[0055] In one exemplary alternative embodiment, the integrated compressor **514a** is the same as the compressor **502** and a portion of the high pressure air **504** is used in the reactor unit, while the remainder is used in the combustor **514b**. In addition, the system **500** may optionally include a heat exchanger **506** configured to form an optional steam stream **508** utilizing the heat from syngas stream **505** to form slightly cooled syngas stream **507**. Optional steam stream **508** may be added to steam stream **428** or **428'** or utilized with steam stream **408**.

[0056] FIG. 6 is an exemplary flow chart of a method of operating an integrated system for low emission power generation and hydrocarbon recovery using an auto-thermal reforming unit like those shown in FIGs. 4-5. As such, FIG. 6 may be best understood with reference to FIGs. 4-5. The method **600** includes producing **602** a syngas stream **505** comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen utilizing a reactor unit **402**; converting **604** at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor **510** to form a shifted stream **511**; separating **606** the carbon dioxide from the shifted stream **511** to produce a substantially carbon dioxide stream **416** and a mixed products stream **420** comprising substantially nitrogen and hydrogen; generating **608** power **436** and a gaseous exhaust stream **422** comprising nitrogen and steam in a gas turbine **404**, wherein the gas turbine **404** is configured to utilize the mixed products stream **420** comprising substantially nitrogen and hydrogen as fuel; separating **610** the nitrogen from the steam to produce at least a gaseous nitrogen stream **430**; injecting **612** at least a portion of the gaseous nitrogen stream **430''** into a pressure maintenance reservoir **414**; and producing **614** hydrocarbons from the pressure maintenance reservoir **414** via stream **415**.

[0057] In one exemplary alternative embodiment, the method may further include injecting **616** at least a portion of the separated carbon dioxide stream **416** into an enhanced oil recovery reservoir **418**; and producing **618** hydrocarbons from the enhanced oil recovery reservoir **418** via stream **417**. Additionally, the method **600** may include recycling **619** at least a portion of the hydrocarbons produced **417** from the enhanced oil recovery reservoir **418** to the reactor unit **402**; and recycling **615** at least a portion of the hydrocarbons produced **415** from the pressure maintenance reservoir **414** to the reactor unit **402**.

[0058] Separation **606** may also separate any hydrogen sulfide (H_2S) present in stream **511** to remove it from mixed products stream **420** and thereby including H_2S in stream **416**. Stream **416** could then be further processed to convert the H_2S into sulfur or injected into a reservoir **417** for sequestration or enhanced oil recovery.

[0059] In another embodiment of the method **600**, air **410a** is compressed in a dedicated air compressor **502** (or extracted from the gas turbine air compressor **514a**) and sent to the reactor unit **402** together with methane **406** and steam **408**. The air rate is adjusted to satisfy the heat balance between the exothermic and endothermic reactions in the reactor **402**. The nitrogen in the air **504** passes through the reformer **402** (and shift reactors **510**) as an inert gas and ends up as an acceptable (even preferred) fuel diluent in the hydrogen stream **420** that is sent to power generation. Separation **606** after the shift reactor **510** is performed to remove the CO_2 **416**; the inert nitrogen is not removed and acts as a diluent for the H_2 fuel to the gas turbine **404**. The flue gas (e.g. exhaust gas **422**) from the gas turbine **404** consists of nitrogen and steam and is dried as needed and then utilized in petroleum production operations (e.g. reservoirs **414** and/or **418**). Note that reservoirs **414** and **418** may have the same or similar properties to reservoirs **114** and **118** discussed above.

[0060] In one exemplary alternative embodiment, the reactor unit **402** may be one of an exothermic partial oxidation reactor, wherein the hydrocarbon fuel stream **406** is a carbonaceous hydrocarbon fuel stream or an endothermic steam reforming reactor, wherein the hydrocarbon fuel stream **406** is a natural gas fuel stream. In one exemplary system, an idealized equation for the partial oxidation reforming of a hydrocarbon may be:

$$C_nH_mO_p + x(O_2+3.76N_2) + (2n-2x-p)H_2O = nCO_2 + (2n-2x-p+m/2)H_2 + 3.76N_2$$

Wherein x is the oxygen-to-fuel molar ratio. This ratio may be used to determine 1) the amount of water needed to convert the carbon to carbon dioxide, 2) the hydrogen yield (in moles), 3) the concentration (in mol%) of hydrogen in the product stream, and 4) the heat of reaction. When x=0, the equation reduces to the endothermic steam reforming reaction; when x=12.5, the equation is the partial oxidation combustion reaction. The molar ratio of oxygen contained in the air feed stream **410a** to carbon (in hydrocarbon) in the fuel feed stream **406** (e.g. the value of "x") may be from about 0.45:1 to 0.85:1, or from about 0.6:1 to 0.7:1.

[0061] In one exemplary embodiment, the fuel feed stream **406** may comprise one or more additional gaseous components selected from the group consisting of heavier hydrocarbons having two or more carbon atoms (hereinafter referred to as C2+ hydrocarbons), carbon dioxide, nitrogen, and carbon monoxide.

[0062] In some examples of the disclosed systems **400** and **500** and methods **600**, the molar ratio of steam **408** to carbon (in hydrocarbons) in the hydrocarbon fuel stream **406** that is introduced to the reactor **402** is up to about 3:1, or up to about 2.5:1. For example, the molar ratio of steam **408** to carbon (in hydrocarbons) in the hydrocarbon fuel stream **406** is within the range of 0:1 to 3:1, preferably, 0.3:1to 3:1, in particular 1:1to 2.5:1. The steam to carbon molar ratio is based on the carbon in the hydrocarbons of the fuel feed stream excluding carbon in any carbon dioxide and/or carbon monoxide that is present in the fuel feed stream. Where steam is present in a process stream, mole% is based on % of total wet molar flow rate of the stream under discussion. Optionally, the air feed stream also comprises steam. For example, the amount of steam in the air feed stream **410a** is up to 10 mole%, in particular, up to 1mole%.

[0063] Optionally, the hydrocarbon fuel stream **406** that is introduced to the reactor **402** comprises hydrogen. The presence of hydrogen in the hydrocarbon fuel stream **406** may be advantageous because the hydrogen may facilitate ignition of the hydrocarbon fuel stream **406** with the oxygen contained in the air feed stream **410a**. For example, the amount of hydrogen in the fuel feed stream may be within the range of about 0 to about 20 mole%, or from about 2 to about 18 mole%.

[0064] In yet another exemplary embodiment of the disclosed systems **400** and **500** and methods **600**, the hydrocarbon fuel stream **406** is introduced to the reactor **402** at a temperature in the range of about 350 to about 700°C, or about 400 to about 650°C, or about 425 to about 620°C. The hydrocarbon fuel stream **406** may be cross-exchanged with any one or more of streams **408**, **428'**, **505**, **504**, **422**, or some other stream. However, if the hydrocarbon fuel stream **406** is introduced to the reactor at a temperature above about 600°C, it may be preferred to boost the temperature of the hydrocarbon fuel stream **406** using an external heater (not shown). The air feed stream **410a** or **504** may be similarly heated.

[0065] In some exemplary embodiments of the disclosed systems **400** and **500** and methods **600**, the hydrocarbon fuel stream **406** may be produced by passing a pre-reformer feed stream comprising a hydrocarbon feedstock and steam through a pre-reformer (not shown) that contains a pre-reforming catalyst to obtain a hydrocarbon fuel stream **406** comprising methane, hydrogen, carbon monoxide, carbon dioxide and steam. If desired, the hydrogen content of the hydrocarbon fuel stream may be increased. This may be achieved by multiple step pre-reforming, by using high pre-reformer inlet temperatures, or by recycling hydrogen to the fuel feed stream. The hydrocarbon feedstock for hydrocarbon fuel stream **406** may be selected from the group consisting of natural gas, liquefied petroleum gas (LPG) and various petroleum distillates (e.g. naphtha). Additionally, a desulfurisation unit comprising a hydrogenator and a desulfuriser may be provided upstream of the reactor **402** and pre-reformer (if present) to remove sulfur containing compounds from the hydrocarbon feedstock (e.g. natural gas, LPG, or petroleum distillate).

[0066] In embodiments of the disclosed systems **400** and **500** and methods **600**, the reactor **402** is an air driven reactor. In one exemplary embodiment, the air feed stream **410a** or **504** is compressed in a multistage air compressor **502**, for example a compressor having from 4 to 8 stages, preferably, 6 stages. Alternatively, the air may be compressed by integrated compressor **514a** and sent to a boost compressor **502** for additional compression before entering the reactor **402**. The shift converter **510** may be a single shift reactor containing a shift catalyst or it may comprise a high temperature shift reactor containing a high temperature shift catalyst and a low temperature shift reactor containing a low temperature shift catalyst.

[0067] In still further embodiments, suitable CO_2 separation units **512** include units that employ a membrane to separate the hydrogen stream from the concentrated carbon dioxide stream or units comprising a CO_2 absorber and CO_2 desorber that employ physical or chemical absorption solvents. In one exemplary embodiment, the carbon dioxide stream **416** may comprise at least about 98% CO_2 on a dry basis, the remainder being mostly hydrogen. In some cases, the mixed products stream **420** may comprise trace amount of carbon oxides (CO and CO_2) and methane, for example, less than 500 ppm on a molar basis.

[0068] In still further embodiments, the carbon dioxide stream **416** is dehydrated to reduce its water content such that the dehydrated CO_2 stream has a dew point of approximately -1°C at the transportation pressure of the carbon dioxide stream **416** thereby ensuring that liquid (water) will not condense out of the stream. For example, the carbon dioxide stream **416** may be dehydrated at a pressure of about 20 to about 60 barg. Suitably, the water content of the carbon dioxide stream **416** is reduced in a suction knock out drum. The carbon dioxide stream **416** may then be compressed and the compressed CO_2 stream is passed through at least one dehydration bed (formed from, for example, a molecular sieve or a silica gel) or through a glycol dehydration unit (for example, a triethylene glycol dehydration unit) to reduce the water content still further.

[0069] Preferably, the dehydrated carbon dioxide stream **416** is compressed and delivered to a pipeline for transfer to a reception facility of an oil or gas field where the carbon dioxide stream **416** is used as an injection gas in the oil or gas reservoir **418**. The carbon dioxide stream **416** may be further compressed to above the pressure of the enhanced recovery reservoir **418** of the oil or gas field before being injected into the reservoir. The injected CO_2 displaces the hydrocarbons towards an associated production well for enhanced recovery of hydrocarbons therefrom.

[0070] An advantage of the process of the present invention is that the synthesis gas stream **505** and hence the hydrogen stream **420** have a relatively high nitrogen content. Accordingly, the hydrogen may be sufficiently diluted with nitrogen that there is no requirement to dilute the hydrogen stream **420** with additional water in order to control the levels of NOx in the exhaust **422** from the gas turbine **404**. For example, the level of NOx in the exhaust gas may be less than about 60 ppm, or less than about 25 ppm. In another example, the hydrogen stream **420** may contain about 35 to about 65% by volume hydrogen, more preferably, 45 to 60% by volume hydrogen, for example, 48 to 52% by volume of hydrogen.

[0071] In still further exemplary embodiments of the disclosed systems **400** and **500** and methods **600**, the heat recovery unit **426** is a heat recovery and steam generator unit (HRSG) that generates and superheats additional steam for use in the steam turbine **432** and elsewhere in the systems **400** and **500**. Thus, the HRSG **426** is capable of generating high pressure (HP) steam, medium pressure (MP) steam and low pressure (LP) steam and of superheating these steam streams. The HRSG **426** may also be capable of reheating MP steam that is produced as an exhaust stream from the high pressure stage of a multistage steam turbine **432**. For example, the superheated HP steam that is produced in the HRSG **426** is at a pressure in the range of about 80 to about 200 barg and a temperature in the range of about 450 to about 600°C. The superheated MP steam may, for example, be generated in the HRSG **426** at a pressure in the range of about 25 to about 50 barg and a temperature in the range of about 300 to about 400°C. Further, the superheated LP steam may, for example, be generated in the HRSG **426** is at a pressure in the range of about 2 to about 10 barg and a temperature in the range of about 200 to about 300°C. In still another alternative embodiment, the heat recovery in the HRSG **426** may occur at elevated pressure. In such a process, the volume of the gaseous exhaust stream **422** can be significantly reduced and the water condenses out at a higher temperature; this makes the removal of the water easier to accomplish and the heat of condensation available at a higher temperature which is more valuable for power generation **434** or desalination (not shown).

[0072] In one exemplary embodiment of the present invention, the cooled exhaust gas **430** is recycled from the HRSG **426** to either or both of the inlet air stream **410b** via line **430'** and injected into the pressure maintenance reservoir **414** via line **430''**. In either case, the stream may require additional cleanup or drying similar to the processes described above with respect to carbon dioxide stream **416**. The stream **430''** may also be pressurized via a compressor prior to injection. The stream **430"** may also be treated further to remove traces of oxygen before injection.

[0073] FIG. 7 is an illustration of an alternative embodiment of the integrated system for low emission power generation and hydrocarbon recovery using a reactor unit similar to that shown in FIGs. 4-5. As such, FIG. 7 may be best understood with reference to FIGs. 4-5. The system **700** comprises an air separation unit **711** configured to generate a substantially nitrogen stream **712** and a substantially oxygen stream **713**, a reactor unit **702** configured to utilize the substantially oxygen stream **713**, a hydrocarbon fuel stream **706** and a steam stream **708** to produce a carbon dioxide (CO_2) stream **716** and a hydrogen stream **720**, wherein the carbon dioxide stream **716** may be directed to an enhanced oil recovery reservoir **718** for use in hydrocarbon recovery operations, such as production of a hydrocarbon stream **717**. The nitrogen stream **712** may be utilized to dilute the hydrogen stream **720** via line **712'** or may be directed to a pressure maintenance reservoir **714** for use in hydrocarbon recovery operations, such as production of a hydrocarbon stream **715**.

[0074] In some embodiments, a gas turbine unit **704** is also provided, which utilizes an air stream **710b** and the hydrogen stream **720** to generate power **736** and a gaseous exhaust stream **722**, which may be directed to a heat recovery unit **726** configured to utilize water **724** to cool the gaseous exhaust stream **722** to form a cooled exhaust stream **730** and produce at least one unit of steam **728** for use in steam generator **732** to produce power **734**. In additional alternative embodiments, some nitrogen may be utilized to dilute the air stream **710b** coming into the gas turbine **704** via line **712''**. In some alternative embodiments, at least a portion of the steam **728** may be redirected to combine with the steam stream **708** via stream **728'**. In yet another alternative embodiment, air stream **710b** may be compressed by the compressor integrated into the gas turbine **704**.

[0075] FIG. 8 illustrates a schematic of an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like that shown in FIG. 7. As such, FIG. 8 may be best understood with reference to FIG. 7. System **800** is an alternative, exemplary embodiment of the system **700** and includes an inlet air compressor **802** to generate compressed air stream **803** to feed the ASU **711**, and a stand-alone compressor **804** to compress the nitrogen stream **712**. The reactor unit **702** produces a syngas stream **805** comprising carbon monoxide, carbon dioxide, and hydrogen, which may be fed to a water-gas shift reactor **810** to convert at least a portion of the carbon monoxide to carbon dioxide to form a shifted stream **811** comprising substantially carbon dioxide, and hydrogen, which may be sent to a separator **812**, which separates as much of the carbon dioxide as possible into stream **716** to produce the hydrogen stream **720**. The gas turbine **704** includes an integrated compressor **814a**, combustor **814b**, and expander **814c**. The hydrogen stream **720** may then be mixed and combusted (pre-mixed or other arrangement, as discussed above) with the high pressure air from integrated compressor **814a** to form combustion products stream **820**, which may then be expanded via expander **814c**. Optionally, compressed air may be routed from the inlet compressor **814a** to the inlet stream **804** via stream **815**.

[0076] In one exemplary alternative embodiment, the integrated compressor **814a** is the same as the compressor **802** and a portion of the high pressure air **803** is used in the reactor unit **702**, while the remainder is used in the combustor **814b**. In addition, the system **800** may optionally include a heat exchanger **806** configured to form an optional steam stream **808** utilizing the heat from syngas stream **805** to form slightly cooled syngas stream **807**. Optional steam stream **808** may be added to steam stream **728** or **728'** or utilized with steam stream **708**. As with reactor **402**, the reactor **702** may be configured to operate in an exothermic partial oxidation reaction, wherein the hydrocarbon fuel stream **706** is a carbonaceous hydrocarbon or in an endothermic steam reforming reaction, wherein the hydrocarbon fuel stream **706** is a natural gas fuel stream.

[0077] FIG. 9 is an exemplary flow chart of an alternative method of operating an integrated system for low emission power generation and hydrocarbon recovery using a reactor unit like those shown in FIGs. 7-8. As such, FIG. 9 may be best understood with reference to FIGs. 7-8. The method **900** includes separating air **902** in an air separation unit **711** configured to generate a substantially nitrogen stream **712** and a substantially oxygen stream **713**; producing **904** a syngas stream **805** comprising carbon monoxide, carbon dioxide, and hydrogen using a reactor unit **702** configured to utilize the substantially oxygen stream **713**, a hydrocarbon fuel stream **706**, and a steam stream **708**; converting **906** at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor **810** to form a shifted stream **811**; separating **908** the shifted stream **811** into a carbon dioxide stream **716** and a hydrogen stream **720**; injecting **910** at least a portion of the separated carbon dioxide stream into an enhanced oil recovery reservoir; and producing **912** hydrocarbons from the enhanced oil recovery reservoir **718**.

[0078] Additionally, the method **900** may optionally include generating **914** power **736** in a gas turbine **704**, wherein the gas turbine **704** is configured to utilize at least a portion of the hydrogen stream **720** as fuel; injecting **916** at least a portion of the substantially nitrogen stream **712** into a pressure maintenance reservoir **714**; and producing **916** hydrocarbons from the pressure maintenance reservoir **714**. In a further alternative embodiment, the method **900** may optionally include recycling **913** at least a portion of the hydrocarbons produced from the enhanced oil recovery reservoir **718** to the reactor unit **702** via line **717**; and recycling **919**

at least a portion of the hydrocarbons produced from the pressure maintenance reservoir **714** to the reactor unit **702** via line **715**.

[0079] In some embodiments of the disclosed systems **700** and **800** and methods **900** air **710a** is compressed to feed an Air Separation Unit (ASU) **711**, which may be a cryogenic unit. Air feed pressure may be in the range of about 6 to about 10 barg for efficient operation of the ASU **711**. The nitrogen product stream **712** may be pumped or compressed via compressor **804** to the pressure desired for the petroleum production operation for which product nitrogen is destined. The oxygen product stream **713** may be pumped or compressed to the pressure desired for injection to the reactor unit **702**. The oxygen feed rates to the reactor unit **702** are adjusted to satisfy the heat balance between the exothermic and endothermic reactions in the reactor.

[0080] Additionally and optionally, the reactor reforming step **904** is preferably carried out at a pressure needed to supply fuel to the gas turbine **704** (typically about 50 to about 200 psig above gas turbine combustion pressure). The product from the reforming step is a syngas mixture **805** comprising CO, H_2, CO_2, H_2O, and small amounts of other components. After optional heat recovery steam generation in heat exchanger **806** (which may be the same unit as HRSG **726** in some embodiments) for additional power generation in the steam turbine(s) **732** and optional H_2O addition, the stream **807** is shifted to convert most of the CO to CO_2 (yielding more hydrogen), and a separation **908** is performed to remove the CO_2. Separation can be via conventional acid gas scrubbing, or any other effective process, as discussed above. The removed CO_2 **716** is conditioned as required (as discussed above) for petroleum production operations and transported for sequestration or for injection in an enhanced oil recovery reservoir **718**.

[0081] Hydrogen stream **720** is used for power generation **736**. The hydrogen **720** may be used in any power generating cycle, but is advantageously used as feed to a gas turbine power system **704**, more advantageously to a combined cycle gas turbine power system. Some fraction of the steam **728** that is produced in the reactor heat recovery steam generator **726** or in the combined cycle gas turbine power system **704** may be used as the reactor feed steam **708**. In yet another alternative embodiment, at least a portion of the nitrogen **712'** may be used to dilute the hydrogen **720** prior to the hydrogen's use as fuel in a gas turbine system **704**.

[0082] In particular embodiments of the systems **700** and **800** and methods **900** the air separation unit(s) (ASU) **711** may be based on cryogenic separation or separation utilizing a mole sieve. At the low end of the oxygen purity spectrum for the cryogenic-based ASU is an ASU design optimized for high-purity nitrogen production, resulting in oxygen purity below about 70%. This stream may contain nitrogen levels greater than 20%. At the other end of the spectrum is an ASU design optimized for high-purity oxygen production in which even Argon is separated from the oxygen, resulting in oxygen purity close to 100%.

[0083] In some embodiments of the present disclosure, the ASU **711** is a cryogenic process for separating nitrogen **712** and oxygen **713** from air. The cost associated with the ASU **711** generally depends on the desired purity of the products. Producing 99.5% pure oxygen requires a significant increase in capital and horsepower compared to an ASU that produces 95% oxygen. Therefore, the purity of the oxygen that is used in the reactor should be limited based on the specification of the syngas stream **805**. If a high purity stream is required then high purity oxygen may be required.

[0084] Fuel contaminates should also be considered. Generally, only fuels that produce byproducts that can meet the EOR specification or fuels that are at a significantly high enough economic advantage so that the processing equipment to remove them can be justified should be considered.

[0085] Where a market exists for Argon, the additional cost, power, and complexity for its separation in the ASU **711** may be justified.

[0086] While the present invention may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown only by way of example. However, it should again be understood that the invention is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present invention includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

Claims:

What is claimed is:

1. An integrated system, comprising:

a pressure swing reformer unit configured to utilize an air stream, a natural gas stream, and a steam stream to produce a regeneration stream comprising substantially nitrogen and a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen; and

a pressure maintenance reservoir to receive at least a portion of the regeneration stream comprising substantially nitrogen.

2. The system of claim 1, further comprising:

a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide;

a separation unit configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream; and

an enhanced oil recovery reservoir to receive at least a portion of the carbon dioxide stream.

3. The system of claim 2, further comprising a gas turbine configured to utilize the hydrogen stream to generate power and a gaseous exhaust stream.

4. The system of claim 2, further comprising:

a first production stream produced from the pressure maintenance reservoir, wherein at least a portion of the first production stream is combined with the natural gas stream; and

a second production stream produced from the enhanced oil recovery reservoir, wherein at least a portion of the second production stream is combined with the natural gas stream.

5. The system of claim 3, further comprising a heat recovery unit configured to receive and cool the gaseous exhaust stream, produce at least one unit of heat energy, and generate at least a volume of water and a cooled gaseous stream, wherein the heat energy is utilized to generate steam.

6. The system of claim 5, wherein the steam is utilized in a manner selected from the group consisting of: 1) generate steam power in a steam turbine, 2) recycle to the pressure swing reformer unit, and 3) any combination thereof.

7. A method of producing hydrocarbons, comprising:

producing a regeneration stream comprising substantially nitrogen and a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen in a pressure swing reformer;

injecting at least a portion of the regeneration stream comprising substantially nitrogen into a pressure maintenance reservoir; and

producing hydrocarbons from the pressure maintenance reservoir.

8. The method of claim 7, further comprising:

converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor;

separating the syngas stream into a carbon dioxide stream and a hydrogen stream;

generating power in a gas turbine, wherein the gas turbine is configured to utilize at least a portion of the hydrogen stream as fuel;

injecting at least a portion of the carbon dioxide stream into an enhanced oil recovery reservoir; and

producing hydrocarbons from the enhanced oil recovery reservoir.

9. The method of claim 8, further comprising a step selected from the group consisting of:

a) recycling at least a portion of the hydrocarbons produced from the enhanced oil recovery reservoir to the pressure swing reformer;

b) recycling at least a portion of the hydrocarbons produced from the pressure maintenance reservoir to the pressure swing reformer; and

c) any combination thereof.

10. An integrated system, comprising:

a reactor unit configured to utilize an air stream, a hydrocarbon fuel stream, and a steam stream to produce a syngas stream comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen;

a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide to form a shifted stream;

a first separation unit configured to separate the carbon dioxide stream from the shifted stream to produce a substantially carbon dioxide stream and a mixed products stream comprising substantially nitrogen and hydrogen;

a gas turbine configured to utilize the mixed products stream to generate power and a gaseous exhaust stream comprising nitrogen and steam;

a second separation unit configured to separate the nitrogen from the steam to produce at least a gaseous nitrogen stream; and

a pressure maintenance reservoir to receive at least a portion of the gaseous nitrogen stream.

11. The system of claim 10, further comprising an enhanced oil recovery reservoir to receive at least a portion of the separated carbon dioxide stream.

12. The system of claim 11, further comprising a stream selected from the group consisting of:

a) a first production stream produced from the pressure maintenance reservoir, wherein at least a portion of the first production stream is combined with the hydrocarbon fuel stream;

b) a second production stream produced from the enhanced oil recovery reservoir, wherein at least a portion of the second production stream is combined with the hydrocarbon fuel stream; and

c) any combination thereof.

13. The system of claim 10, wherein the second separation unit is a heat recovery unit configured to receive and cool the gaseous exhaust stream, produce at least one unit of heat energy and generate at least a volume of water, wherein the heat energy is utilized to generate additional steam.

14. The system of claim 13, further comprising a heat exchanger configured to utilize heat from the mixed products stream to produce an optional steam stream.

15. The system of claim 14, wherein the steam, the additional steam, and the optional steam stream are utilized in a manner selected from the group consisting of: 1) generate steam power in a steam turbine, 2) recycle to the autothermal reformer unit, and 3) any combination thereof.

16. The system of claim 10, further comprising a nitrogen recycle stream configured to recycle at least a portion of the gaseous nitrogen stream into the gas turbine for use as a diluent.

17. The system of claim 10, wherein the reactor unit is configured to operate in a manner selected from the group consisting of:

1) an exothermic partial oxidation reactor, wherein the hydrocarbon fuel stream is a carbonaceous hydrocarbon fuel stream;

2) an endothermic steam reforming reactor, wherein the hydrocarbon fuel stream is a natural gas fuel stream; and

3) a catalytic reactor, wherein each of an endothermic partial oxidation reaction and an endothermic steam reforming reaction occur and the hydrocarbon fuel stream is a natural gas fuel stream.

18. A method of producing hydrocarbons, comprising:

producing a syngas stream comprising carbon monoxide, carbon dioxide, nitrogen, and hydrogen utilizing a reactor unit;

converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor to form a shifted stream;

separating the carbon dioxide from the shifted stream to produce a substantially carbon dioxide stream and a mixed products stream comprising substantially nitrogen and hydrogen;

generating power and a gaseous exhaust stream comprising nitrogen and steam in a gas turbine, wherein the gas turbine is configured to utilize the mixed products stream comprising substantially nitrogen and hydrogen as fuel;

separating the nitrogen from the steam to produce at least a gaseous nitrogen stream;

injecting at least a portion of the gaseous nitrogen stream into a pressure maintenance reservoir; and

producing hydrocarbons from the pressure maintenance reservoir.

19. The method of claim 18, further comprising:

injecting at least a portion of the separated carbon dioxide stream into an enhanced oil recovery reservoir; and

producing hydrocarbons from the enhanced oil recovery reservoir.

20. The method of claim 19, further comprising a step selected from the group consisting of:

a) recycling at least a portion of the hydrocarbons produced from the enhanced oil recovery reservoir to the reactor unit;

b) recycling at least a portion of the hydrocarbons produced from the pressure maintenance reservoir to the reactor unit; and

c) any combination thereof.

21. An integrated system, comprising:

an air separation unit configured to generate a substantially nitrogen stream and a substantially oxygen stream;

a reactor unit configured to utilize the substantially oxygen stream, a hydrocarbon fuel stream, and a steam stream to produce a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen;

a water-gas shift reactor configured to convert at least a portion of the carbon monoxide to carbon dioxide;

a separation unit configured to separate the syngas stream into a carbon dioxide stream and a hydrogen stream; and

an enhanced oil recovery reservoir to receive at least a portion of the separated carbon dioxide stream.

22. The system of claim 21, further comprising a pressure maintenance reservoir configured to receive at least a portion of the substantially nitrogen stream.

23. The system of claim 22, further comprising a gas turbine configured to utilize the hydrogen stream to generate power and a gaseous exhaust stream.

24. The system of claim 23, further comprising a heat recovery unit configured to receive and cool the gaseous exhaust stream, produce at least one unit of heat energy, and generate at least a volume of water and a cooled gaseous stream, wherein the heat energy is utilized to generate steam.

25. The system of claim 24, further comprising a heat exchanger configured to utilize heat from the syngas stream to produce an optional steam stream.

26. The system of claim 25, wherein the steam, the additional steam, and the optional steam stream are utilized in a manner selected from the group consisting of: 1) generate steam power in a steam turbine, 2) recycle to the autothermal reformer unit, and 3) any combination thereof.

27. The system of claim 23, further comprising a stream selected from the group consisting of:

a) a first production stream produced from the pressure maintenance reservoir, wherein at least a portion of the first production stream is combined with the hydrocarbon fuel stream;

b) a second production stream produced from the enhanced oil recovery reservoir, wherein at least a portion of the second production stream is combined with the hydrocarbon fuel stream; and

c) any combination thereof.

28. The system of claim 22, wherein the reactor unit is configured to operate in a manner selected from the group consisting of:

1) an exothermic partial oxidation reactor, wherein the hydrocarbon fuel stream is a carbonaceous hydrocarbon;

2) an endothermic steam reforming reactor, wherein the hydrocarbon fuel stream is a natural gas fuel stream; and

3) a catalytic reactor, wherein each of an endothermic partial oxidation reaction and an endothermic steam reforming reaction occur and the hydrocarbon fuel stream is a natural gas fuel stream.

29. A method of producing hydrocarbons, comprising:

separating air in an air separation unit configured to generate a substantially nitrogen stream and a substantially oxygen stream;

producing a syngas stream comprising carbon monoxide, carbon dioxide, and hydrogen using a reactor unit configured to utilize the substantially oxygen stream, a hydrocarbon fuel stream, and a steam stream;

converting at least a portion of the carbon monoxide to carbon dioxide in a gas-water shift reactor to form a shifted stream;

separating the shifted stream into a carbon dioxide stream and a hydrogen stream;

injecting at least a portion of the separated carbon dioxide stream into an enhanced oil recovery reservoir; and

producing hydrocarbons from the enhanced oil recovery reservoir.

30. The method of claim 29, further comprising:

generating power in a gas turbine, wherein the gas turbine is configured to utilize at least a portion of the hydrogen stream as fuel;

injecting at least a portion of the substantially nitrogen stream into a pressure maintenance reservoir; and

producing hydrocarbons from the pressure maintenance reservoir.

31. The method of claim 30, further comprising:

recycling at least a portion of the hydrocarbons produced from the enhanced oil recovery reservoir to the reactor unit; and

recycling at least a portion of the hydrocarbons produced from the pressure maintenance reservoir to the reactor unit.

32. The system of any one of claims 1, 10, and 21, wherein at least a portion of the system is located offshore.

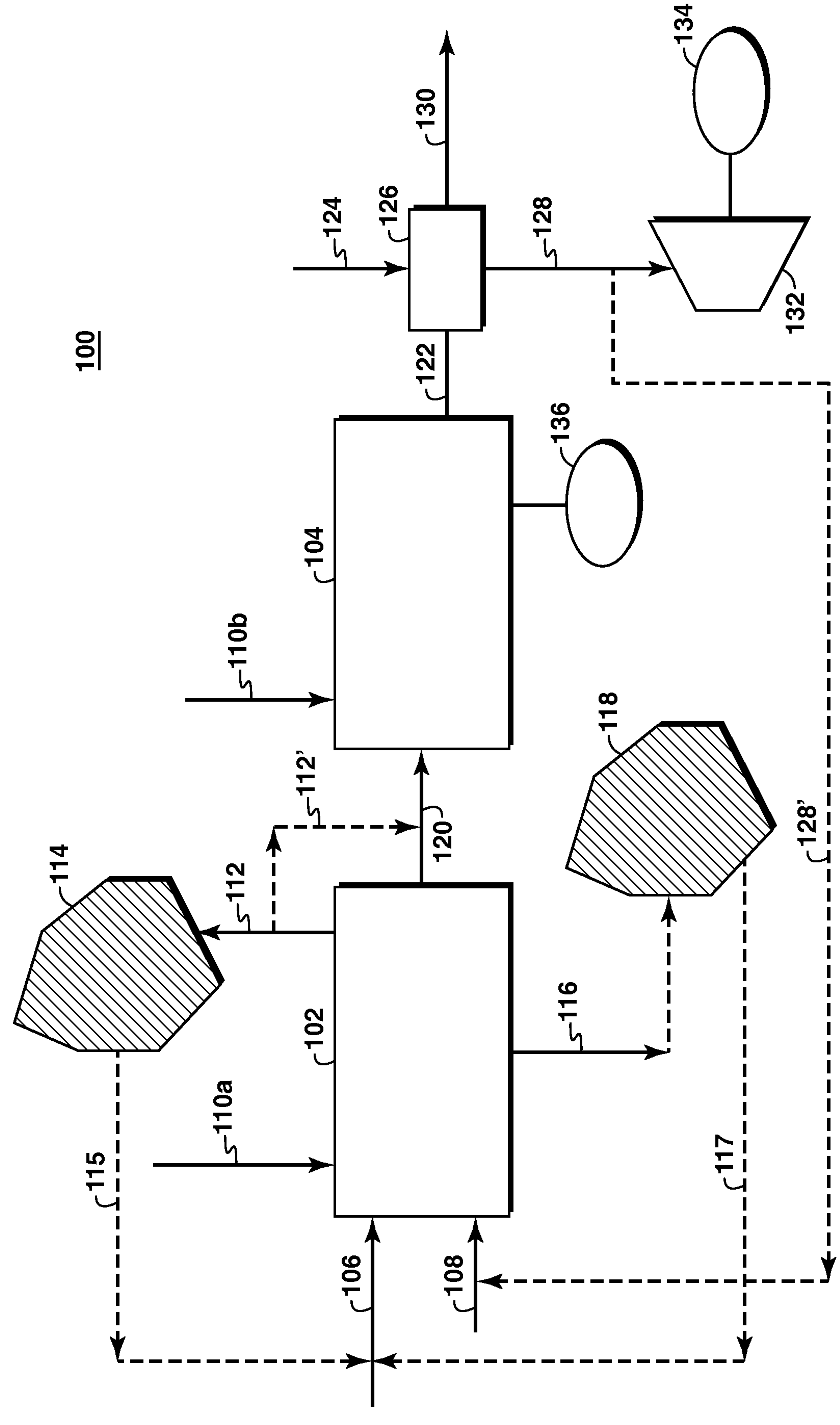
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FIG. 1

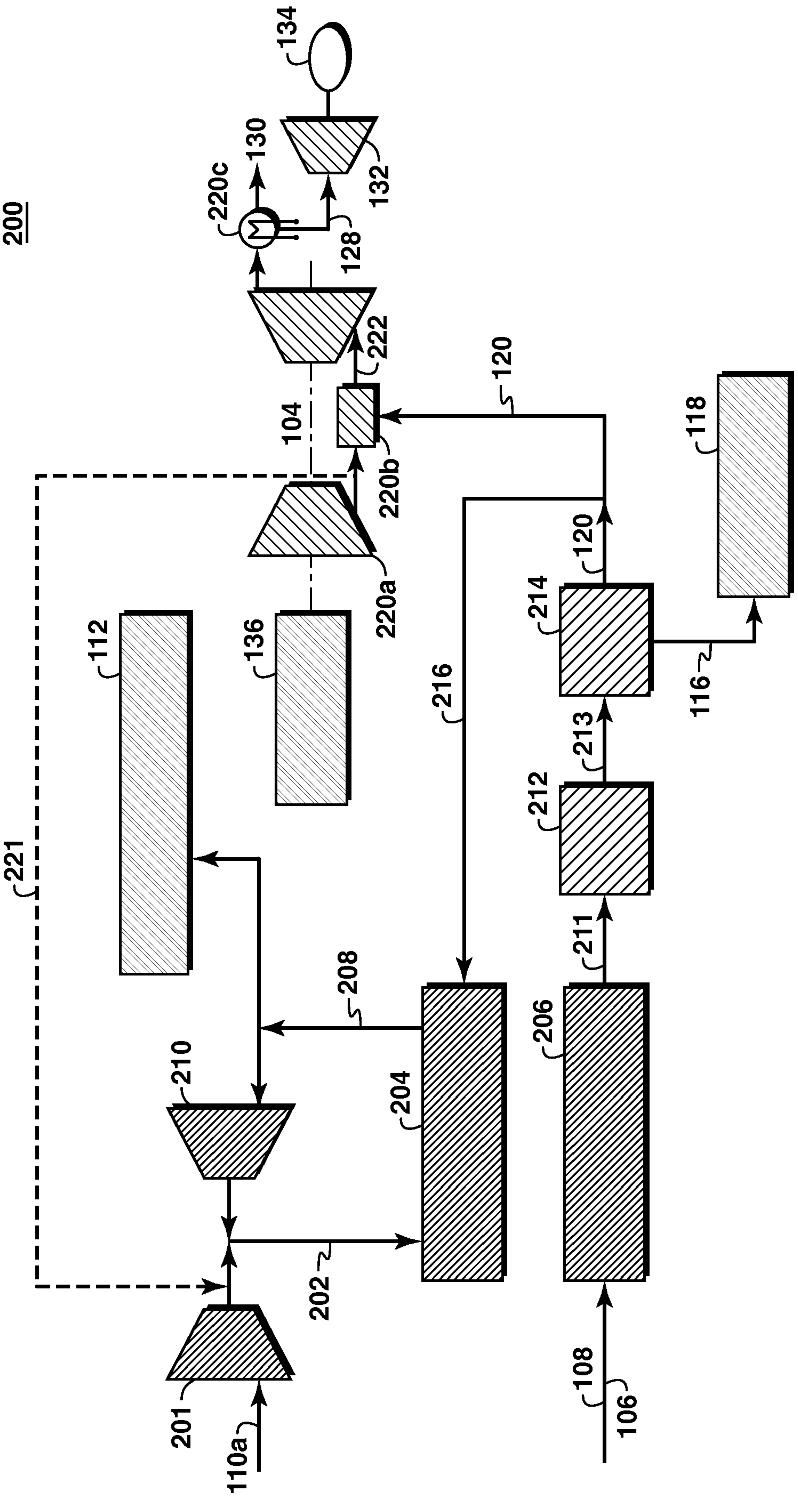
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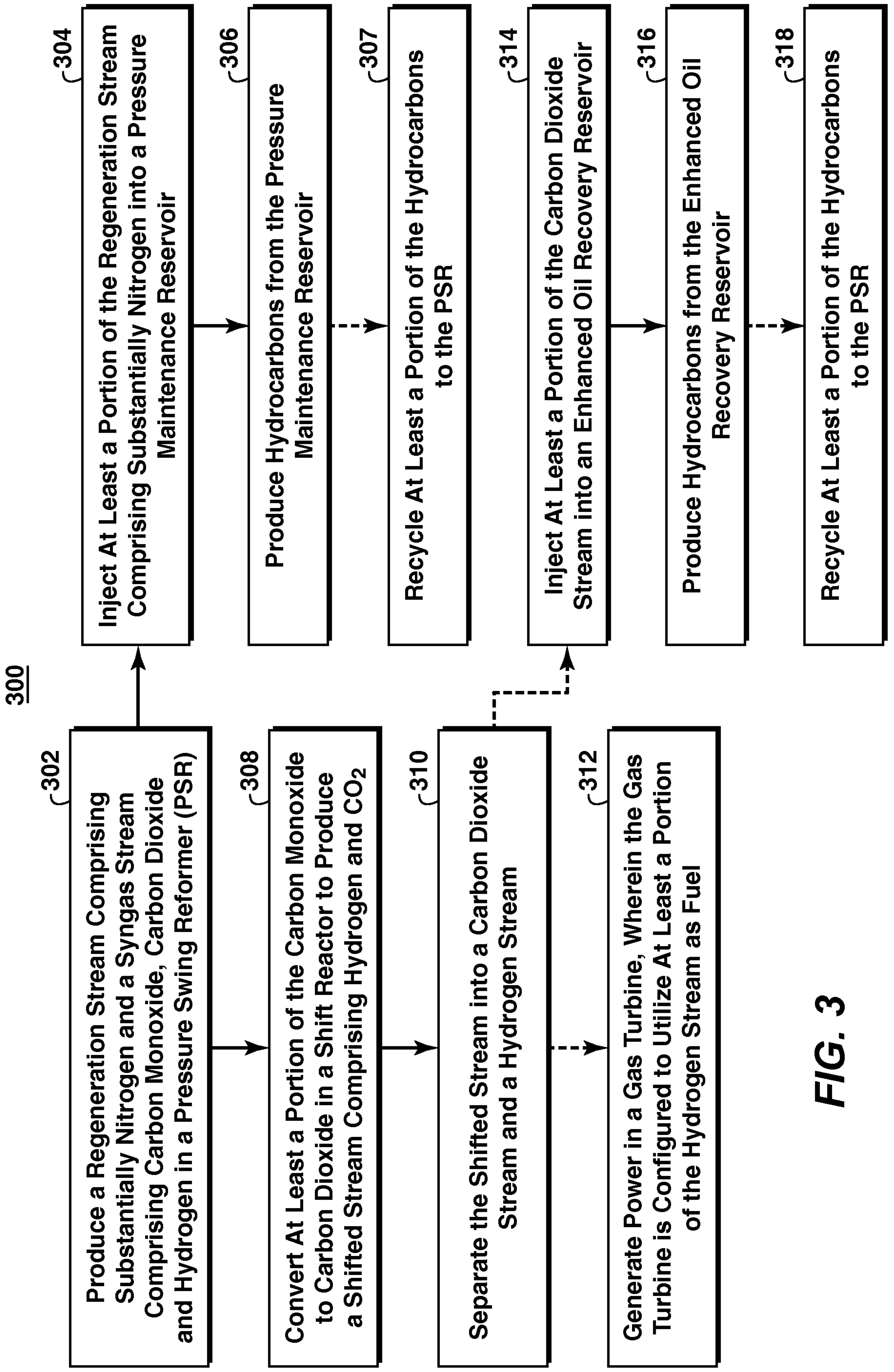
FIG. 2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302
Produce a Regeneration Stream Comprising Substantially Nitrogen and a Syngas Stream Comprising Carbon Monoxide, Carbon Dioxide and Hydrogen in a Pressure Swing Reformer (PSR)
304
Inject At Least a Portion of the Regeneration Stream Comprising Substantially Nitrogen into a Pressure Maintenance Reservoir
306
Produce Hydrocarbons from the Pressure Maintenance Reservoir
307
Recycle At Least a Portion of the Hydrocarbons to the PSR
308
Convert At Least a Portion of the Carbon Monoxide to Carbon Dioxide in a Shift Reactor to Produce a Shifted Stream Comprising Hydrogen and CO_2
310
Separate the Shifted Stream into a Carbon Dioxide Stream and a Hydrogen Stream
314
Inject At Least a Portion of the Carbon Dioxide Stream into an Enhanced Oil Recovery Reservoir
316
Produce Hydrocarbons from the Enhanced Oil Recovery Reservoir
318
Recycle At Least a Portion of the Hydrocarbons to the PSR
312
Generate Power in a Gas Turbine, Wherein the Gas Turbine is Configured to Utilize At Least a Portion of the Hydrogen Stream as Fuel

FIG. 3

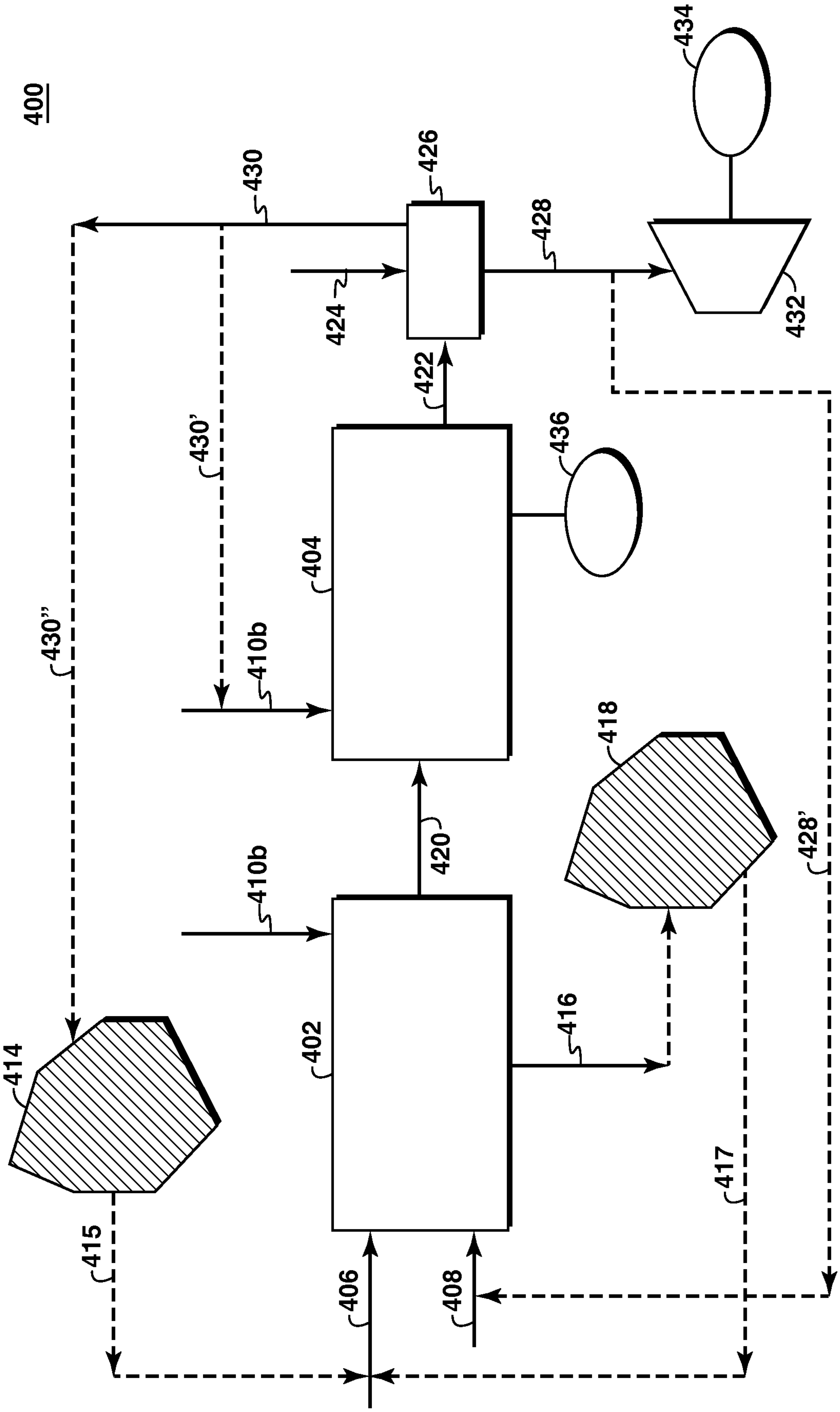
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FIG. 4

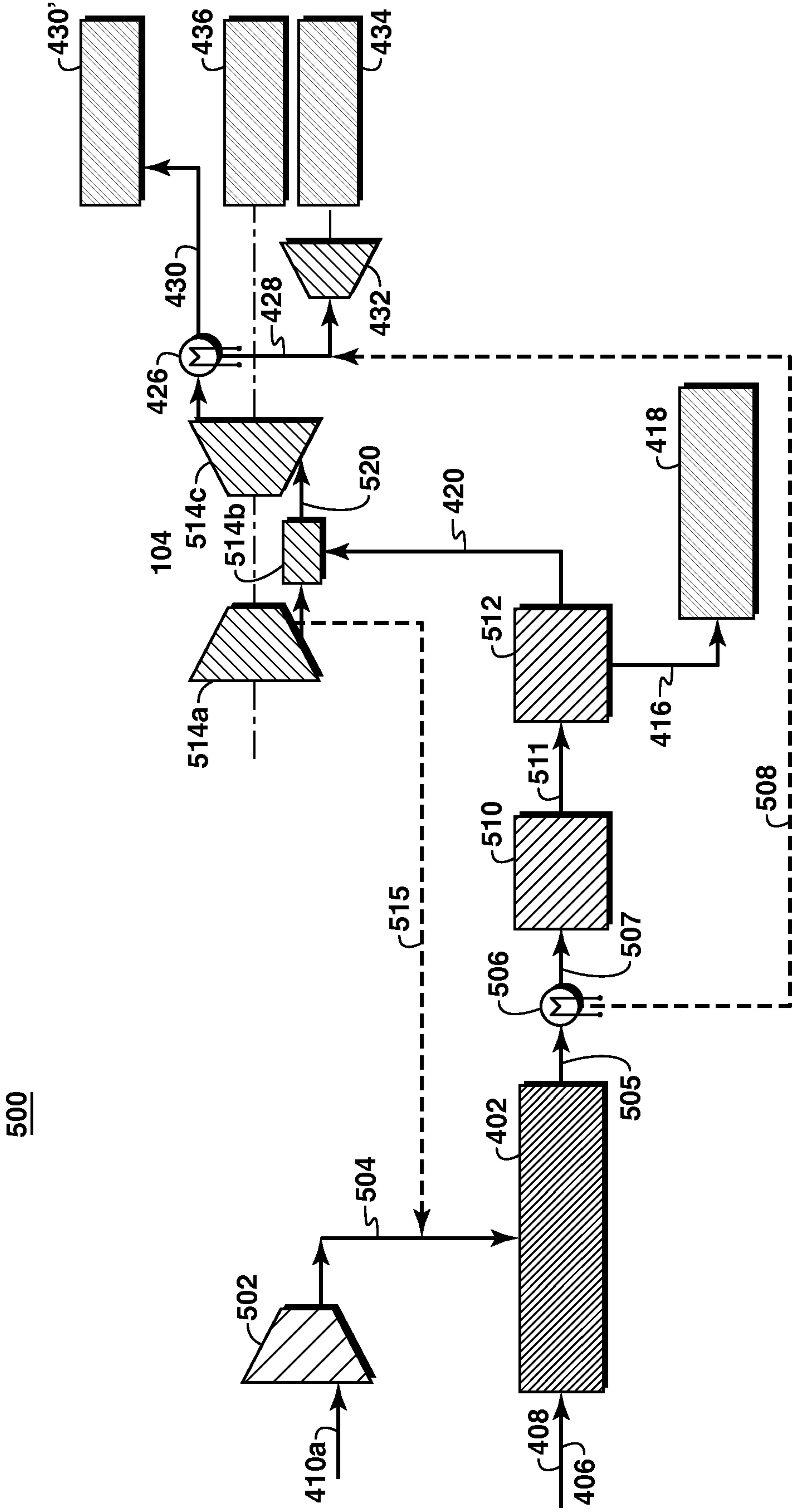
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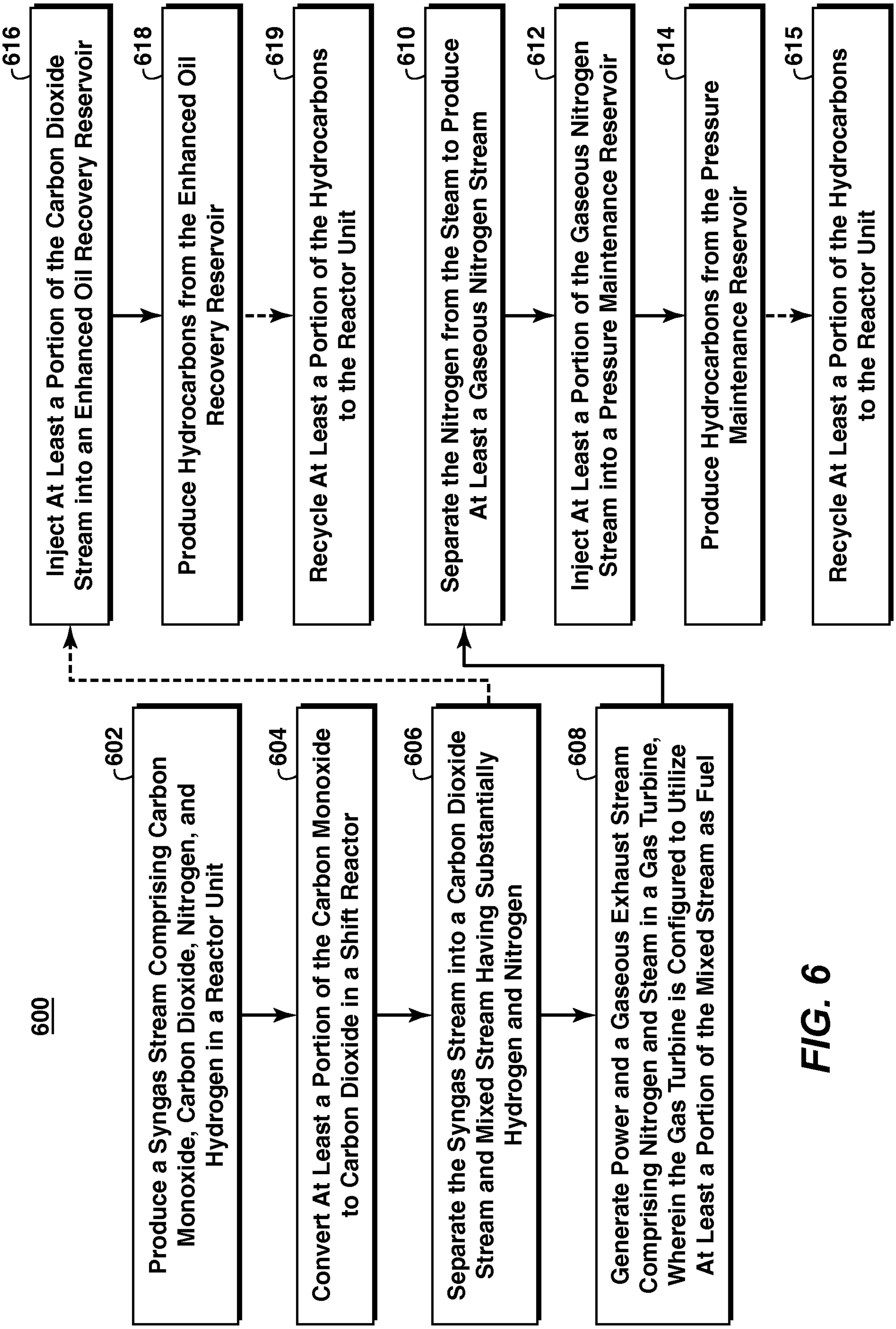
FIG. 5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602
Produce a Syngas Stream Comprising Carbon Monoxide, Carbon Dioxide, Nitrogen, and Hydrogen in a Reactor Unit
604
Convert At Least a Portion of the Carbon Monoxide to Carbon Dioxide in a Shift Reactor
606
Separate the Syngas Stream into a Carbon Dioxide Stream and Mixed Stream Having Substantially Hydrogen and Nitrogen
608
Generate Power and a Gaseous Exhaust Stream Comprising Nitrogen and Steam in a Gas Turbine, Wherein the Gas Turbine is Configured to Utilize At Least a Portion of the Mixed Stream as Fuel
610
Separate the Nitrogen from the Steam to Produce At Least a Gaseous Nitrogen Stream
612
Inject At Least a Portion of the Gaseous Nitrogen Stream into a Pressure Maintenance Reservoir
614
Produce Hydrocarbons from the Pressure Maintenance Reservoir
615
Recycle At Least a Portion of the Hydrocarbons to the Reactor Unit
616
Inject At Least a Portion of the Carbon Dioxide Stream into an Enhanced Oil Recovery Reservoir
618
Produce Hydrocarbons from the Enhanced Oil Recovery Reservoir
619
Recycle At Least a Portion of the Hydrocarbons to the Reactor Unit

FIG. 6

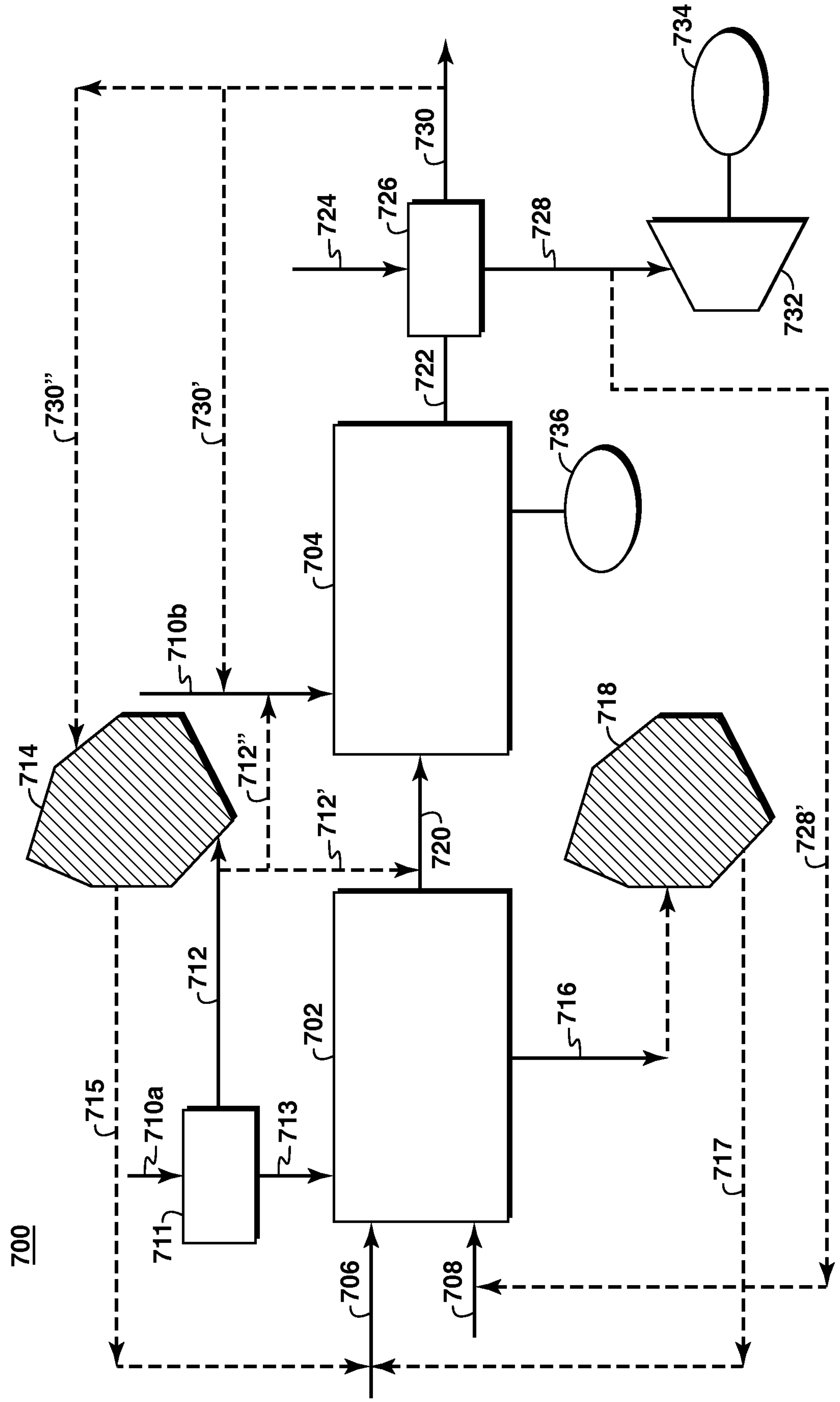
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FIG. 7

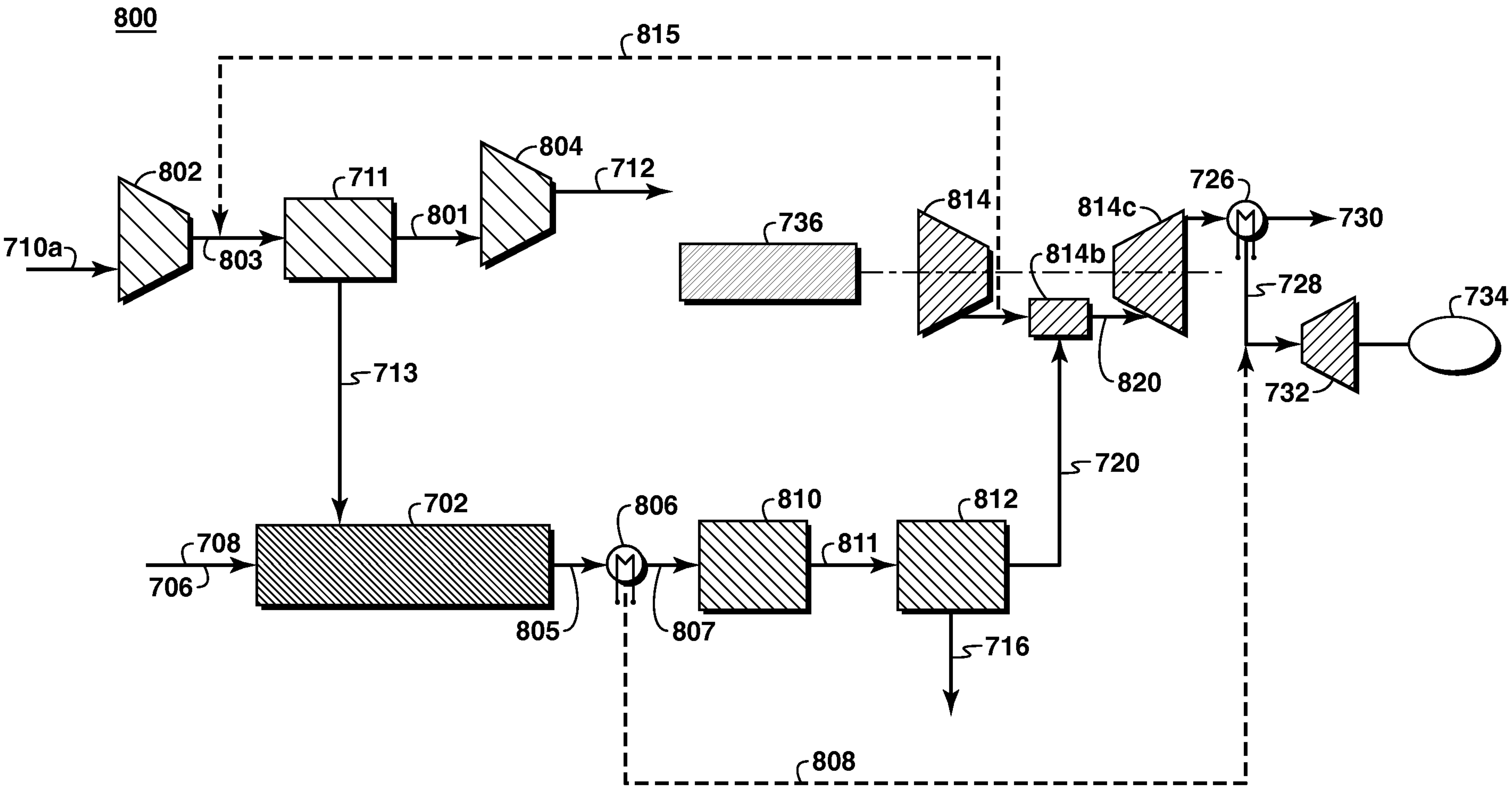
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FIG. 8

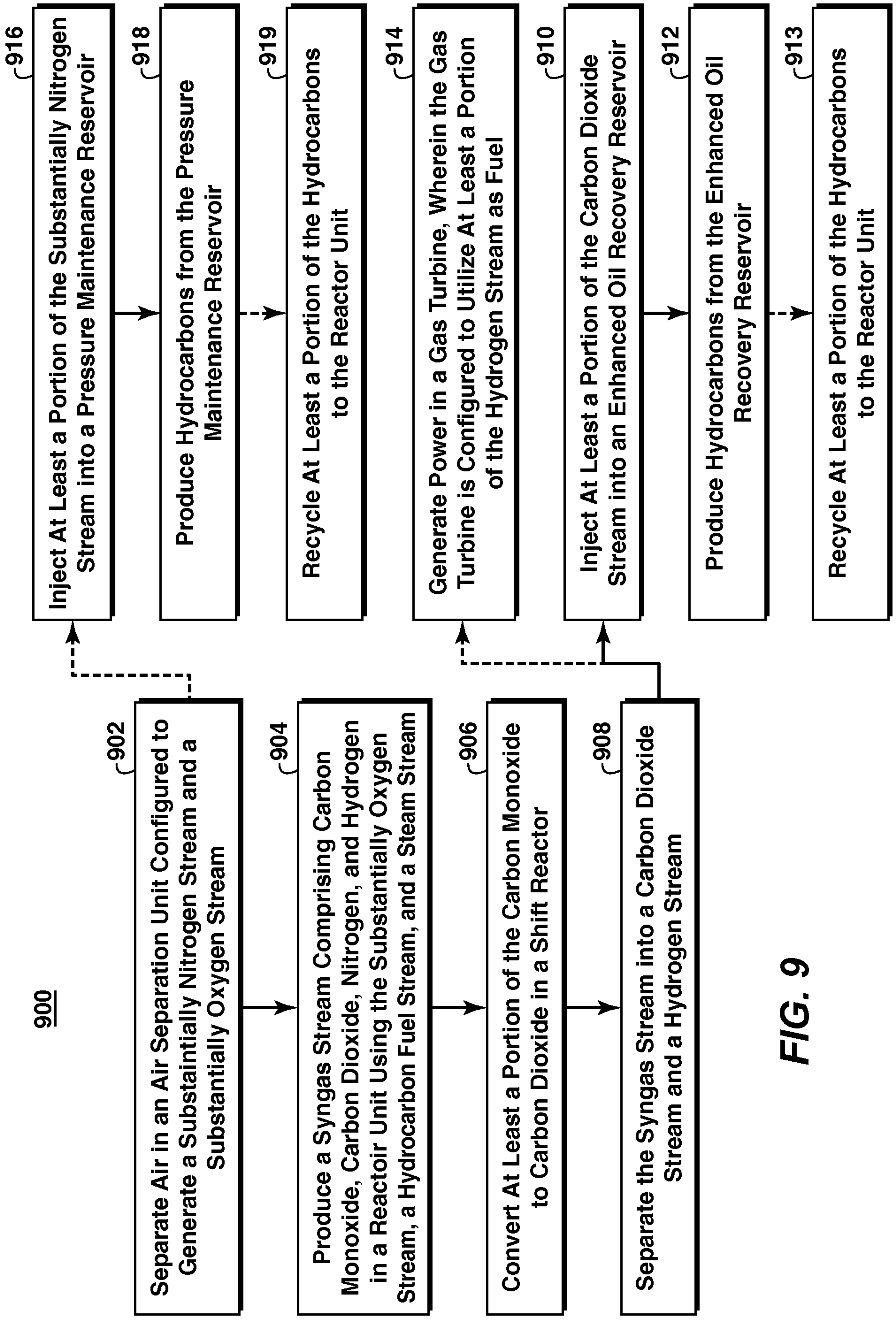
900
902
Separate Air in an Air Separation Unit Configured to Generate a Substaintially Nitrogen Stream and a Substantially Oxygen Stream
904
Produce a Syngas Stream Comprising Carbon Monoxide, Carbon Dioxide, Nitrogen, and Hydrogen in a Reactoir Unit Using the Substantially Oxygen Stream, a Hydrocarbon Fuel Stream, and a Steam Stream
906
Convert At Least a Portion of the Carbon Monoxide to Carbon Dioxide in a Shift Reactor
908
Separate the Syngas Stream into a Carbon Dioxide Stream and a Hydrogen Stream
916
Inject At Least a Portion of the Substantially Nitrogen Stream into a Pressure Maintenance Reservoir
918
Produce Hydrocarbons from the Pressure Maintenance Reservoir
919
Recycle At Least a Portion of the Hydrocarbons to the Reactor Unit
914
Generate Power in a Gas Turbine, Wherein the Gas Turbine is Configured to Utilize At Least a Portion of the Hydrogen Stream as Fuel
910
Inject At Least a Portion of the Carbon Dioxide Stream into an Enhanced Oil Recovery Reservoir
912
Produce Hydrocarbons from the Enhanced Oil Recovery Reservoir
913
Recycle At Least a Portion of the Hydrocarbons to the Reactor Unit

FIG. 9


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FIG. 1