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**Declarations under Rule 4.17:**

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR REHEAT IN GAS TURBINE WITH EXHAUST GAS RECIRCULATION

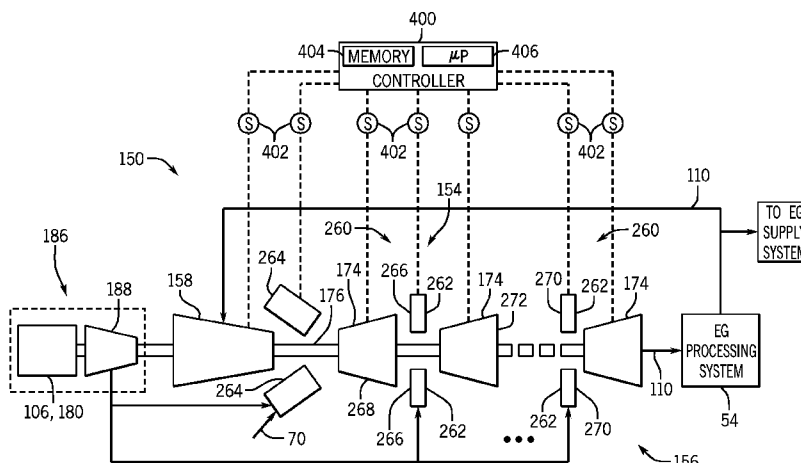


FIG. 5

(57) Abstract: A system includes a turbine having an exhaust flow path through a plurality of turbine stages, wherein the plurality of turbine stages is driven by combustion products flowing through the exhaust flow path, at least one main combustor disposed upstream from the turbine, wherein the at least one main combustor is configured to combust a fuel with a first oxidant and an exhaust gas to generate the combustion products, at least one reheat combustor disposed in or between turbine stages of the turbine, wherein the at least one reheat combustor is configured to reheat the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products, and an exhaust gas compressor, wherein the exhaust gas compressor is configured to compress and route the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path.

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SYSTEM AND METHOD FOR REHEAT IN GAS TURBINE  
WITH EXHAUST GAS RECIRCULATION

CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims priority to and benefit of U.S. Non-Provisional Patent Application No. 14/067,844, entitled "SYSTEM AND METHOD FOR REHEAT IN GAS TURBINE WITH EXHAUST GAS RECIRCULATION," filed on October 30, 2013, U.S. Provisional Patent Application No. 61/747,210, entitled "SYSTEM AND METHOD FOR REHEAT IN GAS TURBINE WITH EXHAUST GAS RECIRCULATION," filed on December 28, 2012, U.S. Provisional Patent Application No. 61/722,118, entitled "SYSTEM AND METHOD FOR DIFFUSION COMBUSTION IN A STOICHIOMETRIC EXHAUST GAS RECIRCULATION GAS TURBINE SYSTEM," filed on November 2, 2012, U.S. Provisional Patent Application No. 61/722,115, entitled "SYSTEM AND METHOD FOR DIFFUSION COMBUSTION WITH FUEL-DILUENT MIXING IN A STOICHIOMETRIC EXHAUST GAS RECIRCULATION GAS TURBINE SYSTEM," filed on November 2, 2012, U.S. Provisional Patent Application No. 61/722,114, entitled "SYSTEM AND METHOD FOR DIFFUSION COMBUSTION WITH OXIDANT-DILUENT MIXING IN A STOICHIOMETRIC EXHAUST GAS RECIRCULATION GAS TURBINE SYSTEM," filed on November 2, 2012, and U.S. Provisional Patent Application No. 61/722,111, entitled "SYSTEM AND METHOD FOR LOAD CONTROL WITH DIFFUSION COMBUSTION IN A STOICHIOMETRIC EXHAUST GAS RECIRCULATION GAS TURBINE SYSTEM," filed on November 2, 2012, all of which are herein incorporated by reference in their entirety for all purposes.

BACKGROUND OF THE INVENTION

**[0002]** The subject matter disclosed herein relates to gas turbine engines.

**[0003]** Gas turbine engines are used in a wide variety of applications, such as power generation, aircraft, and various machinery. Gas turbine engine generally combust a fuel with an oxidant (e.g., air) in a combustor section to generate hot

combustion products, which then drive one or more turbine stages of a turbine section. In turn, the turbine section drives one or more compressor stages of a compressor section, thereby compressing oxidant for intake into the combustor section along with the fuel. Again, the fuel and oxidant mix in the combustor section, and then combust to produce the hot combustion products. Unfortunately, the fuel and oxidant may not entirely combust, thereby resulting in residual oxygen and/or unburnt fuel in the hot combustion products. As a result, the incomplete combustion represents a loss of efficiency and useful energy in the gas turbine engine. The residual oxygen and/or unburned fuel may also be undesirable for downstream equipment. Furthermore, gas turbine engines typically consume a vast amount of air as the oxidant, and output a considerable amount of exhaust gas into the atmosphere. In other words, the exhaust gas is typically wasted as a byproduct of the gas turbine operation.

#### BRIEF DESCRIPTION OF THE INVENTION

**[0004]** Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

**[0005]** In a first embodiment, a system includes a turbine having an exhaust flow path through a plurality of turbine stages, wherein the plurality of turbine stages is driven by combustion products flowing through the exhaust flow path, at least one main combustor disposed upstream from the turbine, wherein the at least one main combustor is configured to combust a fuel with a first oxidant and an exhaust gas to generate the combustion products, at least one reheat combustor disposed in or between turbine stages of the turbine, wherein the at least one reheat combustor is configured to reheat the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products, and an exhaust gas compressor, wherein the

exhaust gas compressor is configured to compress and route the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path.

**[0006]** In a second embodiment, a method includes driving a turbine with combustion products flowing along an exhaust flow path through a plurality of turbine stages, combusting a fuel with a first oxidant and an exhaust gas to generate the combustion products in at least one main combustor disposed upstream from the turbine, reheating the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products via at least one reheat combustor disposed in or between turbine stages of the turbine, and compressing and routing the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path via an exhaust gas compressor.

**[0007]** In a third embodiment, a system includes a main combustor configured to combust a first fuel flow with a first oxidant flow to produce combustion products and an unburned fuel flow and a turbine section configured to receive the combustion products and the unburned fuel flow. The turbine section includes a first turbine stage, a first reheat combustor positioned downstream of the first turbine stage, comprising a first flame holding mechanism, a second turbine stage positioned downstream of the first reheat combustor, and a second reheat combustor positioned downstream of the second turbine stage, comprising a second flame holding mechanism.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0008]** These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

**[0009]** FIG. 1 is a diagram of an embodiment of a system having a turbine-based service system coupled to a hydrocarbon production system;

**[0010]** FIG. 2 is a diagram of an embodiment of the system of FIG. 1, further illustrating a control system and a combined cycle system;

[0011] FIG. 3 is a diagram of an embodiment of the system of FIGS. 1 and 2, further illustrating details of a gas turbine engine, exhaust gas supply system, and exhaust gas processing system;

[0012] FIG. 4 is a flow chart of an embodiment of a process for operating the system of FIGS. 1-3;

[0013] FIG. 5 is a schematic diagram of an embodiment of the gas turbine engine;

[0014] FIG. 6 is a schematic diagram an embodiment of a turbine section of the gas turbine engine;

[0015] FIG. 7 is a schematic diagram an embodiment of a turbine section of the gas turbine engine; and

[0016] FIG. 8 is a schematic diagram an embodiment of a turbine section of the gas turbine engine.

#### DETAILED DESCRIPTION OF THE INVENTION

[0017] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0018] When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are

intended to be inclusive and mean that there may be additional elements other than the listed elements.

**[0019]** As discussed in detail below, the disclosed embodiments relate generally to gas turbine systems with exhaust gas recirculation (EGR), and particularly stoichiometric operation of the gas turbine systems using EGR. For example, the gas turbine systems may be configured to recirculate the exhaust gas along an exhaust recirculation path, stoichiometrically combust fuel and oxidant along with at least some of the recirculated exhaust gas, and capture the exhaust gas for use in various target systems. The recirculation of the exhaust gas along with stoichiometric combustion may help to increase the concentration level of carbon dioxide (CO<sub>2</sub>) in the exhaust gas, which can then be post treated to separate and purify the CO<sub>2</sub> and nitrogen (N<sub>2</sub>) for use in various target systems. The gas turbine systems also may employ various exhaust gas processing (e.g., heat recovery, catalyst reactions, etc.) along the exhaust recirculation path, thereby increasing the concentration level of CO<sub>2</sub>, reducing concentration levels of other emissions (e.g., carbon monoxide, nitrogen oxides, and unburnt hydrocarbons), and increasing energy recovery (e.g., with heat recovery units). Furthermore, the gas turbine engines may be configured to combust the fuel and oxidant with one or more diffusion flames (e.g., using diffusion fuel nozzles), premix flames (e.g., using premix fuel nozzles), or any combination thereof. In certain embodiments, the diffusion flames may help to maintain stability and operation within certain limits for stoichiometric combustion, which in turn helps to increase production of CO<sub>2</sub>. For example, a gas turbine system operating with diffusion flames may enable a greater quantity of EGR, as compared to a gas turbine system operating with premix flames. In turn, the increased quantity of EGR helps to increase CO<sub>2</sub> production. Possible target systems include pipelines, storage tanks, carbon sequestration systems, and hydrocarbon production systems, such as enhanced oil recovery (EOR) systems.

**[0020]** Embodiments of the present disclosure are directed toward a gas turbine engine having a plurality of reheat stages. More specifically, a turbine section of the gas turbine engine includes reheat combustors that are configured to introduce oxidant into the hot gas path of the turbine section to combust unburned fuel within the hot

gas path. In certain embodiments, main combustors of the gas turbine engine operate in a fuel-rich mode, thereby introducing fuel into the main combustors at a greater than stoichiometric oxidant to fuel ratio. As a result, unburned fuel may remain in the hot gas path (e.g., in the products of combustion) after first stage combustion at the main combustors. The unburned fuel may be further combusted by the reheat combustors positioned downstream within the turbine section. In this manner, oxidant within the hot gas path may be substantially or completely consumed, thereby limiting the amount of oxidant in the products of combustion, and the products of combustion may be reheated in downstream sections of the gas turbine engine.

**[0021]** FIG. 1 is a diagram of an embodiment of a system 10 having an hydrocarbon production system 12 associated with a turbine-based service system 14. As discussed in further detail below, various embodiments of the turbine-based service system 14 are configured to provide various services, such as electrical power, mechanical power, and fluids (e.g., exhaust gas), to the hydrocarbon production system 12 to facilitate the production or retrieval of oil and/or gas. In the illustrated embodiment, the hydrocarbon production system 12 includes an oil/gas extraction system 16 and an enhanced oil recovery (EOR) system 18, which are coupled to a subterranean reservoir 20 (e.g., an oil, gas, or hydrocarbon reservoir). The oil/gas extraction system 16 includes a variety of surface equipment 22, such as a Christmas tree or production tree 24, coupled to an oil/gas well 26. Furthermore, the well 26 may include one or more tubulars 28 extending through a drilled bore 30 in the earth 32 to the subterranean reservoir 20. The tree 24 includes one or more valves, chokes, isolation sleeves, blowout preventers, and various flow control devices, which regulate pressures and control flows to and from the subterranean reservoir 20. While the tree 24 is generally used to control the flow of the production fluid (e.g., oil or gas) out of the subterranean reservoir 20, the EOR system 18 may increase the production of oil or gas by injecting one or more fluids into the subterranean reservoir 20.

**[0022]** Accordingly, the EOR system 18 may include a fluid injection system 34, which has one or more tubulars 36 extending through a bore 38 in the earth 32 to the subterranean reservoir 20. For example, the EOR system 18 may route one or more



fluids 40, such as gas, steam, water, chemicals, or any combination thereof, into the fluid injection system 34. For example, as discussed in further detail below, the EOR system 18 may be coupled to the turbine-based service system 14, such that the system 14 routes an exhaust gas 42 (e.g., substantially or entirely free of oxygen) to the EOR system 18 for use as the injection fluid 40. The fluid injection system 34 routes the fluid 40 (e.g., the exhaust gas 42) through the one or more tubulars 36 into the subterranean reservoir 20, as indicated by arrows 44. The injection fluid 40 enters the subterranean reservoir 20 through the tubular 36 at an offset distance 46 away from the tubular 28 of the oil/gas well 26. Accordingly, the injection fluid 40 displaces the oil/gas 48 disposed in the subterranean reservoir 20, and drives the oil/gas 48 up through the one or more tubulars 28 of the hydrocarbon production system 12, as indicated by arrows 50. As discussed in further detail below, the injection fluid 40 may include the exhaust gas 42 originating from the turbine-based service system 14, which is able to generate the exhaust gas 42 on-site as needed by the hydrocarbon production system 12. In other words, the turbine-based system 14 may simultaneously generate one or more services (e.g., electrical power, mechanical power, steam, water (e.g., desalinated water), and exhaust gas (e.g., substantially free of oxygen)) for use by the hydrocarbon production system 12, thereby reducing or eliminating the reliance on external sources of such services.

**[0023]** In the illustrated embodiment, the turbine-based service system 14 includes a stoichiometric exhaust gas recirculation (SEGR) gas turbine system 52 and an exhaust gas (EG) processing system 54. The gas turbine system 52 may be configured to operate in a stoichiometric combustion mode of operation (e.g., a stoichiometric control mode) and a non-stoichiometric combustion mode of operation (e.g., a non-stoichiometric control mode), such as a fuel-lean control mode or a fuel-rich control mode. In the stoichiometric control mode, the combustion generally occurs in a substantially stoichiometric ratio of a fuel and oxidant, thereby resulting in substantially stoichiometric combustion. In particular, stoichiometric combustion generally involves consuming substantially all of the fuel and oxidant in the combustion reaction, such that the products of combustion are substantially or entirely free of unburnt fuel and oxidant. One measure of stoichiometric combustion is the

equivalence ratio, or phi ( $\phi$ ), which is the ratio of the actual fuel/oxidant ratio relative to the stoichiometric fuel/oxidant ratio. An equivalence ratio of greater than 1.0 results in a fuel-rich combustion of the fuel and oxidant, whereas an equivalence ratio of less than 1.0 results in a fuel-lean combustion of the fuel and oxidant. In contrast, an equivalence ratio of 1.0 results in combustion that is neither fuel-rich nor fuel-lean, thereby substantially consuming all of the fuel and oxidant in the combustion reaction. In context of the disclosed embodiments, the term stoichiometric or substantially stoichiometric may refer to an equivalence ratio of approximately 0.95 to approximately 1.05. However, the disclosed embodiments may also include an equivalence ratio of 1.0 plus or minus 0.01, 0.02, 0.03, 0.04, 0.05, or more. Again, the stoichiometric combustion of fuel and oxidant in the turbine-based service system 14 may result in products of combustion or exhaust gas (e.g., 42) with substantially no unburnt fuel or oxidant remaining. For example, the exhaust gas 42 may have less than 1, 2, 3, 4, or 5 percent by volume of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO<sub>x</sub>), carbon monoxide (CO), sulfur oxides (e.g., SO<sub>x</sub>), hydrogen, and other products of incomplete combustion. By further example, the exhaust gas 42 may have less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO<sub>x</sub>), carbon monoxide (CO), sulfur oxides (e.g., SO<sub>x</sub>), hydrogen, and other products of incomplete combustion. However, the disclosed embodiments also may produce other ranges of residual fuel, oxidant, and other emissions levels in the exhaust gas 42. As used herein, the terms emissions, emissions levels, and emissions targets may refer to concentration levels of certain products of combustion (e.g., NO<sub>x</sub>, CO, SO<sub>x</sub>, O<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>, HCs, etc.), which may be present in recirculated gas streams, vented gas streams (e.g., exhausted into the atmosphere), and gas streams used in various target systems (e.g., the hydrocarbon production system 12).

**[0024]** Although the SEGR gas turbine system 52 and the EG processing system 54 may include a variety of components in different embodiments, the illustrated EG processing system 54 includes a heat recovery steam generator (HRSG) 56 and an

exhaust gas recirculation (EGR) system 58, which receive and process an exhaust gas 60 originating from the SEGR gas turbine system 52. The HRSG 56 may include one or more heat exchangers, condensers, and various heat recovery equipment, which collectively function to transfer heat from the exhaust gas 60 to a stream of water, thereby generating steam 62. The steam 62 may be used in one or more steam turbines, the EOR system 18, or any other portion of the hydrocarbon production system 12. For example, the HRSG 56 may generate low pressure, medium pressure, and/or high pressure steam 62, which may be selectively applied to low, medium, and high pressure steam turbine stages, or different applications of the EOR system 18. In addition to the steam 62, a treated water 64, such as a desalinated water, may be generated by the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 or the SEGR gas turbine system 52. The treated water 64 (e.g., desalinated water) may be particularly useful in areas with water shortages, such as inland or desert regions. The treated water 64 may be generated, at least in part, due to the large volume of air driving combustion of fuel within the SEGR gas turbine system 52. While the on-site generation of steam 62 and water 64 may be beneficial in many applications (including the hydrocarbon production system 12), the on-site generation of exhaust gas 42, 60 may be particularly beneficial for the EOR system 18, due to its low oxygen content, high pressure, and heat derived from the SEGR gas turbine system 52. Accordingly, the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 may output or recirculate an exhaust gas 66 into the SEGR gas turbine system 52, while also routing the exhaust gas 42 to the EOR system 18 for use with the hydrocarbon production system 12. Likewise, the exhaust gas 42 may be extracted directly from the SEGR gas turbine system 52 (i.e., without passing through the EG processing system 54) for use in the EOR system 18 of the hydrocarbon production system 12.

**[0025]** The exhaust gas recirculation is handled by the EGR system 58 of the EG processing system 54. For example, the EGR system 58 includes one or more conduits, valves, blowers, exhaust gas treatment systems (e.g., filters, particulate removal units, gas separation units, gas purification units, heat exchangers, heat recovery units, moisture removal units, catalyst units, chemical injection units, or any

combination thereof), and controls to recirculate the exhaust gas along an exhaust gas circulation path from an output (e.g., discharged exhaust gas 60) to an input (e.g., intake exhaust gas 66) of the SEGR gas turbine system 52. In the illustrated embodiment, the SEGR gas turbine system 52 intakes the exhaust gas 66 into a compressor section having one or more compressors, thereby compressing the exhaust gas 66 for use in a combustor section along with an intake of an oxidant 68 and one or more fuels 70. The oxidant 68 may include ambient air, pure oxygen, oxygen-enriched air, oxygen-reduced air, oxygen-nitrogen mixtures, or any suitable oxidant that facilitates combustion of the fuel 70. The fuel 70 may include one or more gas fuels, liquid fuels, or any combination thereof. For example, the fuel 70 may include natural gas, liquefied natural gas (LNG), syngas, methane, ethane, propane, butane, naphtha, kerosene, diesel fuel, ethanol, methanol, biofuel, or any combination thereof.

**[0026]** The SEGR gas turbine system 52 mixes and combusts the exhaust gas 66, the oxidant 68, and the fuel 70 in the combustor section, thereby generating hot combustion gases or exhaust gas 60 to drive one or more turbine stages in a turbine section. In certain embodiments, each combustor in the combustor section includes one or more premix fuel nozzles, one or more diffusion fuel nozzles, or any combination thereof. For example, each premix fuel nozzle may be configured to mix the oxidant 68 and the fuel 70 internally within the fuel nozzle and/or partially upstream of the fuel nozzle, thereby injecting an oxidant-fuel mixture from the fuel nozzle into the combustion zone for a premixed combustion (e.g., a premixed flame). By further example, each diffusion fuel nozzle may be configured to isolate the flows of oxidant 68 and fuel 70 within the fuel nozzle, thereby separately injecting the oxidant 68 and the fuel 70 from the fuel nozzle into the combustion zone for diffusion combustion (e.g., a diffusion flame). In particular, the diffusion combustion provided by the diffusion fuel nozzles delays mixing of the oxidant 68 and the fuel 70 until the point of initial combustion, i.e., the flame region. In embodiments employing the diffusion fuel nozzles, the diffusion flame may provide increased flame stability, because the diffusion flame generally forms at the point of stoichiometry between the separate streams of oxidant 68 and fuel 70 (i.e., as the oxidant 68 and fuel 70 are mixing). In certain embodiments, one or more diluents (e.g., the exhaust gas 60,

steam, nitrogen, or another inert gas) may be pre-mixed with the oxidant 68, the fuel 70, or both, in either the diffusion fuel nozzle or the premix fuel nozzle. In addition, one or more diluents (e.g., the exhaust gas 60, steam, nitrogen, or another inert gas) may be injected into the combustor at or downstream from the point of combustion within each combustor. The use of these diluents may help temper the flame (e.g., premix flame or diffusion flame), thereby helping to reduce NO<sub>x</sub> emissions, such as nitrogen monoxide (NO) and nitrogen dioxide (NO<sub>2</sub>). Regardless of the type of flame, the combustion produces hot combustion gases or exhaust gas 60 to drive one or more turbine stages. As each turbine stage is driven by the exhaust gas 60, the SEGR gas turbine system 52 generates a mechanical power 72 and/or an electrical power 74 (e.g., via an electrical generator). The system 52 also outputs the exhaust gas 60, and may further output water 64. Again, the water 64 may be a treated water, such as a desalinated water, which may be useful in a variety of applications on-site or off-site.

**[0027]** Exhaust extraction is also provided by the SEGR gas turbine system 52 using one or more extraction points 76. For example, the illustrated embodiment includes an exhaust gas (EG) supply system 78 having an exhaust gas (EG) extraction system 80 and an exhaust gas (EG) treatment system 82, which receive exhaust gas 42 from the extraction points 76, treat the exhaust gas 42, and then supply or distribute the exhaust gas 42 to various target systems. The target systems may include the EOR system 18 and/or other systems, such as a pipeline 86, a storage tank 88, or a carbon sequestration system 90. The EG extraction system 80 may include one or more conduits, valves, controls, and flow separations, which facilitate isolation of the exhaust gas 42 from the oxidant 68, the fuel 70, and other contaminants, while also controlling the temperature, pressure, and flow rate of the extracted exhaust gas 42. The EG treatment system 82 may include one or more heat exchangers (e.g., heat recovery units such as heat recovery steam generators, condensers, coolers, or heaters), catalyst systems (e.g., oxidation catalyst systems), particulate and/or water removal systems (e.g., gas dehydration units, inertial separators, coalescing filters, water impermeable filters, and other filters), chemical injection systems, solvent based treatment systems (e.g., absorbers, flash tanks, etc.), carbon capture systems,

gas separation systems, gas purification systems, and/or a solvent based treatment system, exhaust gas compressors, any combination thereof. These subsystems of the EG treatment system 82 enable control of the temperature, pressure, flow rate, moisture content (e.g., amount of water removal), particulate content (e.g., amount of particulate removal), and gas composition (e.g., percentage of CO<sub>2</sub>, N<sub>2</sub>, etc.).

**[0028]** The extracted exhaust gas 42 is treated by one or more subsystems of the EG treatment system 82, depending on the target system. For example, the EG treatment system 82 may direct all or part of the exhaust gas 42 through a carbon capture system, a gas separation system, a gas purification system, and/or a solvent based treatment system, which is controlled to separate and purify a carbonaceous gas (e.g., carbon dioxide) 92 and/or nitrogen (N<sub>2</sub>) 94 for use in the various target systems. For example, embodiments of the EG treatment system 82 may perform gas separation and purification to produce a plurality of different streams 95 of exhaust gas 42, such as a first stream 96, a second stream 97, and a third stream 98. The first stream 96 may have a first composition that is rich in carbon dioxide and/or lean in nitrogen (e.g., a CO<sub>2</sub> rich, N<sub>2</sub> lean stream). The second stream 97 may have a second composition that has intermediate concentration levels of carbon dioxide and/or nitrogen (e.g., intermediate concentration CO<sub>2</sub>, N<sub>2</sub> stream). The third stream 98 may have a third composition that is lean in carbon dioxide and/or rich in nitrogen (e.g., a CO<sub>2</sub> lean, N<sub>2</sub> rich stream). Each stream 95 (e.g., 96, 97, and 98) may include a gas dehydration unit, a filter, a gas compressor, or any combination thereof, to facilitate delivery of the stream 95 to a target system. In certain embodiments, the CO<sub>2</sub> rich, N<sub>2</sub> lean stream 96 may have a CO<sub>2</sub> purity or concentration level of greater than approximately 70, 75, 80, 85, 90, 95, 96, 97, 98, or 99 percent by volume, and a N<sub>2</sub> purity or concentration level of less than approximately 1, 2, 3, 4, 5, 10, 15, 20, 25, or 30 percent by volume. In contrast, the CO<sub>2</sub> lean, N<sub>2</sub> rich stream 98 may have a CO<sub>2</sub> purity or concentration level of less than approximately 1, 2, 3, 4, 5, 10, 15, 20, 25, or 30 percent by volume, and a N<sub>2</sub> purity or concentration level of greater than approximately 70, 75, 80, 85, 90, 95, 96, 97, 98, or 99 percent by volume. The intermediate concentration CO<sub>2</sub>, N<sub>2</sub> stream 97 may have a CO<sub>2</sub> purity or concentration level and/or a N<sub>2</sub> purity or concentration level of between approximately 30 to 70, 35

to 65, 40 to 60, or 45 to 55 percent by volume. Although the foregoing ranges are merely non-limiting examples, the CO<sub>2</sub> rich, N<sub>2</sub> lean stream 96 and the CO<sub>2</sub> lean, N<sub>2</sub> rich stream 98 may be particularly well suited for use with the EOR system 18 and the other systems 84. However, any of these rich, lean, or intermediate concentration CO<sub>2</sub> streams 95 may be used, alone or in various combinations, with the EOR system 18 and the other systems 84. For example, the EOR system 18 and the other systems 84 (e.g., the pipeline 86, storage tank 88, and the carbon sequestration system 90) each may receive one or more CO<sub>2</sub> rich, N<sub>2</sub> lean streams 96, one or more CO<sub>2</sub> lean, N<sub>2</sub> rich streams 98, one or more intermediate concentration CO<sub>2</sub>, N<sub>2</sub> streams 97, and one or more untreated exhaust gas 42 streams (i.e., bypassing the EG treatment system 82).

**[0029]** The EG extraction system 80 extracts the exhaust gas 42 at one or more extraction points 76 along the compressor section, the combustor section, and/or the turbine section, such that the exhaust gas 42 may be used in the EOR system 18 and other systems 84 at suitable temperatures and pressures. The EG extraction system 80 and/or the EG treatment system 82 also may circulate fluid flows (e.g., exhaust gas 42) to and from the EG processing system 54. For example, a portion of the exhaust gas 42 passing through the EG processing system 54 may be extracted by the EG extraction system 80 for use in the EOR system 18 and the other systems 84. In certain embodiments, the EG supply system 78 and the EG processing system 54 may be independent or integral with one another, and thus may use independent or common subsystems. For example, the EG treatment system 82 may be used by both the EG supply system 78 and the EG processing system 54. Exhaust gas 42 extracted from the EG processing system 54 may undergo multiple stages of gas treatment, such as one or more stages of gas treatment in the EG processing system 54 followed by one or more additional stages of gas treatment in the EG treatment system 82.

**[0030]** At each extraction point 76, the extracted exhaust gas 42 may be substantially free of oxidant 68 and fuel 70 (e.g., unburnt fuel or hydrocarbons) due to substantially stoichiometric combustion and/or gas treatment in the EG processing system 54. Furthermore, depending on the target system, the extracted exhaust gas 42 may undergo further treatment in the EG treatment system 82 of the EG supply

system 78, thereby further reducing any residual oxidant 68, fuel 70, or other undesirable products of combustion. For example, either before or after treatment in the EG treatment system 82, the extracted exhaust gas 42 may have less than 1, 2, 3, 4, or 5 percent by volume of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO<sub>x</sub>), carbon monoxide (CO), sulfur oxides (e.g., SO<sub>x</sub>), hydrogen, and other products of incomplete combustion. By further example, either before or after treatment in the EG treatment system 82, the extracted exhaust gas 42 may have less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) of oxidant (e.g., oxygen), unburnt fuel or hydrocarbons (e.g., HCs), nitrogen oxides (e.g., NO<sub>x</sub>), carbon monoxide (CO), sulfur oxides (e.g., SO<sub>x</sub>), hydrogen, and other products of incomplete combustion. Thus, the exhaust gas 42 is particularly well suited for use with the EOR system 18.

**[0031]** The EGR operation of the turbine system 52 specifically enables the exhaust extraction at a multitude of locations 76. For example, the compressor section of the system 52 may be used to compress the exhaust gas 66 without any oxidant 68 (i.e., only compression of the exhaust gas 66), such that a substantially oxygen-free exhaust gas 42 may be extracted from the compressor section and/or the combustor section prior to entry of the oxidant 68 and the fuel 70. The extraction points 76 may be located at interstage ports between adjacent compressor stages, at ports along the compressor discharge casing, at ports along each combustor in the combustor section, or any combination thereof. In certain embodiments, the exhaust gas 66 may not mix with the oxidant 68 and fuel 70 until it reaches the head end portion and/or fuel nozzles of each combustor in the combustor section. Furthermore, one or more flow separators (e.g., walls, dividers, baffles, or the like) may be used to isolate the oxidant 68 and the fuel 70 from the extraction points 76. With these flow separators, the extraction points 76 may be disposed directly along a wall of each combustor in the combustor section.

**[0032]** Once the exhaust gas 66, oxidant 68, and fuel 70 flow through the head end portion (e.g., through fuel nozzles) into the combustion portion (e.g., combustion chamber) of each combustor, the SEGR gas turbine system 52 is controlled to provide



a substantially stoichiometric combustion of the exhaust gas 66, oxidant 68, and fuel 70. For example, the system 52 may maintain an equivalence ratio of approximately 0.95 to approximately 1.05. As a result, the products of combustion of the mixture of exhaust gas 66, oxidant 68, and fuel 70 in each combustor is substantially free of oxygen and unburnt fuel. Thus, the products of combustion (or exhaust gas) may be extracted from the turbine section of the SEGR gas turbine system 52 for use as the exhaust gas 42 routed to the EOR system 18. Along the turbine section, the extraction points 76 may be located at any turbine stage, such as interstage ports between adjacent turbine stages. Thus, using any of the foregoing extraction points 76, the turbine-based service system 14 may generate, extract, and deliver the exhaust gas 42 to the hydrocarbon production system 12 (e.g., the EOR system 18) for use in the production of oil/gas 48 from the subterranean reservoir 20.

**[0033]** FIG. 2 is a diagram of an embodiment of the system 10 of FIG. 1, illustrating a control system 100 coupled to the turbine-based service system 14 and the hydrocarbon production system 12. In the illustrated embodiment, the turbine-based service system 14 includes a combined cycle system 102, which includes the SEGR gas turbine system 52 as a topping cycle, a steam turbine 104 as a bottoming cycle, and the HRSG 56 to recover heat from the exhaust gas 60 to generate the steam 62 for driving the steam turbine 104. Again, the SEGR gas turbine system 52 receives, mixes, and stoichiometrically combusts the exhaust gas 66, the oxidant 68, and the fuel 70 (e.g., premix and/or diffusion flames), thereby producing the exhaust gas 60, the mechanical power 72, the electrical power 74, and/or the water 64. For example, the SEGR gas turbine system 52 may drive one or more loads or machinery 106, such as an electrical generator, an oxidant compressor (e.g., a main air compressor), a gear box, a pump, equipment of the hydrocarbon production system 12, or any combination thereof. In some embodiments, the machinery 106 may include other drives, such as electrical motors or steam turbines (e.g., the steam turbine 104), in tandem with the SEGR gas turbine system 52. Accordingly, an output of the machinery 106 driven by the SEGR gas turbines system 52 (and any additional drives) may include the mechanical power 72 and the electrical power 74. The mechanical power 72 and/or the electrical power 74 may be used on-site for

powering the hydrocarbon production system 12, the electrical power 74 may be distributed to the power grid, or any combination thereof. The output of the machinery 106 also may include a compressed fluid, such as a compressed oxidant 68 (e.g., air or oxygen), for intake into the combustion section of the SEGR gas turbine system 52. Each of these outputs (e.g., the exhaust gas 60, the mechanical power 72, the electrical power 74, and/or the water 64) may be considered a service of the turbine-based service system 14.

**[0034]** The SEGR gas turbine system 52 produces the exhaust gas 42, 60, which may be substantially free of oxygen, and routes this exhaust gas 42, 60 to the EG processing system 54 and/or the EG supply system 78. The EG supply system 78 may treat and delivery the exhaust gas 42 (e.g., streams 95) to the hydrocarbon production system 12 and/or the other systems 84. As discussed above, the EG processing system 54 may include the HRSG 56 and the EGR system 58. The HRSG 56 may include one or more heat exchangers, condensers, and various heat recovery equipment, which may be used to recover or transfer heat from the exhaust gas 60 to water 108 to generate the steam 62 for driving the steam turbine 104. Similar to the SEGR gas turbine system 52, the steam turbine 104 may drive one or more loads or machinery 106, thereby generating the mechanical power 72 and the electrical power 74. In the illustrated embodiment, the SEGR gas turbine system 52 and the steam turbine 104 are arranged in tandem to drive the same machinery 106. However, in other embodiments, the SEGR gas turbine system 52 and the steam turbine 104 may separately drive different machinery 106 to independently generate mechanical power 72 and/or electrical power 74. As the steam turbine 104 is driven by the steam 62 from the HRSG 56, the steam 62 gradually decreases in temperature and pressure. Accordingly, the steam turbine 104 recirculates the used steam 62 and/or water 108 back into the HRSG 56 for additional steam generation via heat recovery from the exhaust gas 60. In addition to steam generation, the HRSG 56, the EGR system 58, and/or another portion of the EG processing system 54 may produce the water 64, the exhaust gas 42 for use with the hydrocarbon production system 12, and the exhaust gas 66 for use as an input into the SEGR gas turbine system 52. For example, the water 64 may be a treated water 64, such as a desalinated water for use in other

applications. The desalinated water may be particularly useful in regions of low water availability. Regarding the exhaust gas 60, embodiments of the EG processing system 54 may be configured to recirculate the exhaust gas 60 through the EGR system 58 with or without passing the exhaust gas 60 through the HRSG 56.

**[0035]** In the illustrated embodiment, the SEGR gas turbine system 52 has an exhaust recirculation path 110, which extends from an exhaust outlet to an exhaust inlet of the system 52. Along the path 110, the exhaust gas 60 passes through the EG processing system 54, which includes the HRSG 56 and the EGR system 58 in the illustrated embodiment. The EGR system 58 may include one or more conduits, valves, blowers, gas treatment systems (e.g., filters, particulate removal units, gas separation units, gas purification units, heat exchangers, heat recovery units such as heat recovery steam generators, moisture removal units, catalyst units, chemical injection units, or any combination thereof) in series and/or parallel arrangements along the path 110. In other words, the EGR system 58 may include any flow control components, pressure control components, temperature control components, moisture control components, and gas composition control components along the exhaust recirculation path 110 between the exhaust outlet and the exhaust inlet of the system 52. Accordingly, in embodiments with the HRSG 56 along the path 110, the HRSG 56 may be considered a component of the EGR system 58. However, in certain embodiments, the HRSG 56 may be disposed along an exhaust path independent from the exhaust recirculation path 110. Regardless of whether the HRSG 56 is along a separate path or a common path with the EGR system 58, the HRSG 56 and the EGR system 58 intake the exhaust gas 60 and output either the recirculated exhaust gas 66, the exhaust gas 42 for use with the EG supply system 78 (e.g., for the hydrocarbon production system 12 and/or other systems 84), or another output of exhaust gas. Again, the SEGR gas turbine system 52 intakes, mixes, and stoichiometrically combusts the exhaust gas 66, the oxidant 68, and the fuel 70 (e.g., premixed and/or diffusion flames) to produce a substantially oxygen-free and fuel-free exhaust gas 60 for distribution to the EG processing system 54, the hydrocarbon production system 12, or other systems 84.

[0036] As noted above with reference to FIG. 1, the hydrocarbon production system 12 may include a variety of equipment to facilitate the recovery or production of oil/gas 48 from a subterranean reservoir 20 through an oil/gas well 26. For example, the hydrocarbon production system 12 may include the EOR system 18 having the fluid injection system 34. In the illustrated embodiment, the fluid injection system 34 includes an exhaust gas injection EOR system 112 and a steam injection EOR system 114. Although the fluid injection system 34 may receive fluids from a variety of sources, the illustrated embodiment may receive the exhaust gas 42 and the steam 62 from the turbine-based service system 14. The exhaust gas 42 and/or the steam 62 produced by the turbine-based service system 14 also may be routed to the hydrocarbon production system 12 for use in other oil/gas systems 116.

[0037] The quantity, quality, and flow of the exhaust gas 42 and/or the steam 62 may be controlled by the control system 100. The control system 100 may be dedicated entirely to the turbine-based service system 14, or the control system 100 may optionally also provide control (or at least some data to facilitate control) for the hydrocarbon production system 12 and/or other systems 84. In the illustrated embodiment, the control system 100 includes a controller 118 having a processor 120, a memory 122, a steam turbine control 124, a SEGR gas turbine system control 126, and a machinery control 128. The processor 120 may include a single processor or two or more redundant processors, such as triple redundant processors for control of the turbine-based service system 14. The memory 122 may include volatile and/or non-volatile memory. For example, the memory 122 may include one or more hard drives, flash memory, read-only memory, random access memory, or any combination thereof. The controls 124, 126, and 128 may include software and/or hardware controls. For example, the controls 124, 126, and 128 may include various instructions or code stored on the memory 122 and executable by the processor 120. The control 124 is configured to control operation of the steam turbine 104, the SEGR gas turbine system control 126 is configured to control the system 52, and the machinery control 128 is configured to control the machinery 106. Thus, the controller 118 (e.g., controls 124, 126, and 128) may be configured to coordinate

various sub-systems of the turbine-based service system 14 to provide a suitable stream of the exhaust gas 42 to the hydrocarbon production system 12.

**[0038]** In certain embodiments of the control system 100, each element (e.g., system, subsystem, and component) illustrated in the drawings or described herein includes (e.g., directly within, upstream, or downstream of such element) one or more industrial control features, such as sensors and control devices, which are communicatively coupled with one another over an industrial control network along with the controller 118. For example, the control devices associated with each element may include a dedicated device controller (e.g., including a processor, memory, and control instructions), one or more actuators, valves, switches, and industrial control equipment, which enable control based on sensor feedback 130, control signals from the controller 118, control signals from a user, or any combination thereof. Thus, any of the control functionality described herein may be implemented with control instructions stored and/or executable by the controller 118, dedicated device controllers associated with each element, or a combination thereof.

**[0039]** In order to facilitate such control functionality, the control system 100 includes one or more sensors distributed throughout the system 10 to obtain the sensor feedback 130 for use in execution of the various controls, e.g., the controls 124, 126, and 128. For example, the sensor feedback 130 may be obtained from sensors distributed throughout the SEGR gas turbine system 52, the machinery 106, the EG processing system 54, the steam turbine 104, the hydrocarbon production system 12, or any other components throughout the turbine-based service system 14 or the hydrocarbon production system 12. For example, the sensor feedback 130 may include temperature feedback, pressure feedback, flow rate feedback, flame temperature feedback, combustion dynamics feedback, intake oxidant composition feedback, intake fuel composition feedback, exhaust composition feedback, the output level of mechanical power 72, the output level of electrical power 74, the output quantity of the exhaust gas 42, 60, the output quantity or quality of the water 64, or any combination thereof. For example, the sensor feedback 130 may include a composition of the exhaust gas 42, 60 to facilitate stoichiometric combustion in the SEGR gas turbine system 52. For example, the sensor feedback 130 may include

feedback from one or more intake oxidant sensors along an oxidant supply path of the oxidant 68, one or more intake fuel sensors along a fuel supply path of the fuel 70, and one or more exhaust emissions sensors disposed along the exhaust recirculation path 110 and/or within the SEGR gas turbine system 52. The intake oxidant sensors, intake fuel sensors, and exhaust emissions sensors may include temperature sensors, pressure sensors, flow rate sensors, and composition sensors. The emissions sensors may include sensors for nitrogen oxides (e.g., NO<sub>x</sub> sensors), carbon oxides (e.g., CO sensors and CO<sub>2</sub> sensors), sulfur oxides (e.g., SO<sub>x</sub> sensors), hydrogen (e.g., H<sub>2</sub> sensors), oxygen (e.g., O<sub>2</sub> sensors), unburnt hydrocarbons (e.g., HC sensors), or other products of incomplete combustion, or any combination thereof.

**[0040]** Using this feedback 130, the control system 100 may adjust (e.g., increase, decrease, or maintain) the intake flow of exhaust gas 66, oxidant 68, and/or fuel 70 into the SEGR gas turbine system 52 (among other operational parameters) to maintain the equivalence ratio within a suitable range, e.g., between approximately 0.95 to approximately 1.05, between approximately 0.95 to approximately 1.0, between approximately 1.0 to approximately 1.05, or substantially at 1.0. For example, the control system 100 may analyze the feedback 130 to monitor the exhaust emissions (e.g., concentration levels of nitrogen oxides, carbon oxides such as CO and CO<sub>2</sub>, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products of incomplete combustion) and/or determine the equivalence ratio, and then control one or more components to adjust the exhaust emissions (e.g., concentration levels in the exhaust gas 42) and/or the equivalence ratio. The controlled components may include any of the components illustrated and described with reference to the drawings, including but not limited to, valves along the supply paths for the oxidant 68, the fuel 70, and the exhaust gas 66; an oxidant compressor, a fuel pump, or any components in the EG processing system 54; any components of the SEGR gas turbine system 52, or any combination thereof. The controlled components may adjust (e.g., increase, decrease, or maintain) the flow rates, temperatures, pressures, or percentages (e.g., equivalence ratio) of the oxidant 68, the fuel 70, and the exhaust gas 66 that combust within the SEGR gas turbine system 52. The controlled components also may include one or more gas treatment systems, such as catalyst units (e.g., oxidation catalyst

units), supplies for the catalyst units (e.g., oxidation fuel, heat, electricity, etc.), gas purification and/or separation units (e.g., solvent based separators, absorbers, flash tanks, etc.), and filtration units. The gas treatment systems may help reduce various exhaust emissions along the exhaust recirculation path 110, a vent path (e.g., exhausted into the atmosphere), or an extraction path to the EG supply system 78.

**[0041]** In certain embodiments, the control system 100 may analyze the feedback 130 and control one or more components to maintain or reduce emissions levels (e.g., concentration levels in the exhaust gas 42, 60, 95) to a target range, such as less than approximately 10, 20, 30, 40, 50, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, 5000, or 10000 parts per million by volume (ppmv). These target ranges may be the same or different for each of the exhaust emissions, e.g., concentration levels of nitrogen oxides, carbon monoxide, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products of incomplete combustion. For example, depending on the equivalence ratio, the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 250, 500, 750, or 1000 ppmv; carbon monoxide (CO) within a target range of less than approximately 20, 50, 100, 200, 500, 1000, 2500, or 5000 ppmv; and nitrogen oxides (NO<sub>x</sub>) within a target range of less than approximately 50, 100, 200, 300, 400, or 500 ppmv. In certain embodiments operating with a substantially stoichiometric equivalence ratio, the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 ppmv; and carbon monoxide (CO) within a target range of less than approximately 500, 1000, 2000, 3000, 4000, or 5000 ppmv. In certain embodiments operating with a fuel-lean equivalence ratio (e.g., between approximately 0.95 to 1.0), the control system 100 may selectively control exhaust emissions (e.g., concentration levels) of oxidant (e.g., oxygen) within a target range of less than approximately 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, or 1500 ppmv; carbon monoxide (CO) within a target range of less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, or 200 ppmv; and nitrogen oxides (e.g., NO<sub>x</sub>) within a target range of less than approximately 50, 100, 150, 200, 250, 300,

350, or 400 ppmv. The foregoing target ranges are merely examples, and are not intended to limit the scope of the disclosed embodiments.

**[0042]** The control system 100 also may be coupled to a local interface 132 and a remote interface 134. For example, the local interface 132 may include a computer workstation disposed on-site at the turbine-based service system 14 and/or the hydrocarbon production system 12. In contrast, the remote interface 134 may include a computer workstation disposed off-site from the turbine-based service system 14 and the hydrocarbon production system 12, such as through an internet connection. These interfaces 132 and 134 facilitate monitoring and control of the turbine-based service system 14, such as through one or more graphical displays of sensor feedback 130, operational parameters, and so forth.

**[0043]** Again, as noted above, the controller 118 includes a variety of controls 124, 126, and 128 to facilitate control of the turbine-based service system 14. The steam turbine control 124 may receive the sensor feedback 130 and output control commands to facilitate operation of the steam turbine 104. For example, the steam turbine control 124 may receive the sensor feedback 130 from the HRSG 56, the machinery 106, temperature and pressure sensors along a path of the steam 62, temperature and pressure sensors along a path of the water 108, and various sensors indicative of the mechanical power 72 and the electrical power 74. Likewise, the SEGR gas turbine system control 126 may receive sensor feedback 130 from one or more sensors disposed along the SEGR gas turbine system 52, the machinery 106, the EG processing system 54, or any combination thereof. For example, the sensor feedback 130 may be obtained from temperature sensors, pressure sensors, clearance sensors, vibration sensors, flame sensors, fuel composition sensors, exhaust gas composition sensors, or any combination thereof, disposed within or external to the SEGR gas turbine system 52. Finally, the machinery control 128 may receive sensor feedback 130 from various sensors associated with the mechanical power 72 and the electrical power 74, as well as sensors disposed within the machinery 106. Each of these controls 124, 126, and 128 uses the sensor feedback 130 to improve operation of the turbine-based service system 14.



[0044] In the illustrated embodiment, the SEGR gas turbine system control 126 may execute instructions to control the quantity and quality of the exhaust gas 42, 60, 95 in the EG processing system 54, the EG supply system 78, the hydrocarbon production system 12, and/or the other systems 84. For example, the SEGR gas turbine system control 126 may maintain a level of oxidant (e.g., oxygen) and/or unburnt fuel in the exhaust gas 60 below a threshold suitable for use with the exhaust gas injection EOR system 112. In certain embodiments, the threshold levels may be less than 1, 2, 3, 4, or 5 percent of oxidant (e.g., oxygen) and/or unburnt fuel by volume of the exhaust gas 42, 60; or the threshold levels of oxidant (e.g., oxygen) and/or unburnt fuel (and other exhaust emissions) may be less than approximately 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 1000, 2000, 3000, 4000, or 5000 parts per million by volume (ppmv) in the exhaust gas 42, 60. By further example, in order to achieve these low levels of oxidant (e.g., oxygen) and/or unburnt fuel, the SEGR gas turbine system control 126 may maintain an equivalence ratio for combustion in the SEGR gas turbine system 52 between approximately 0.95 and approximately 1.05. The SEGR gas turbine system control 126 also may control the EG extraction system 80 and the EG treatment system 82 to maintain the temperature, pressure, flow rate, and gas composition of the exhaust gas 42, 60, 95 within suitable ranges for the exhaust gas injection EOR system 112, the pipeline 86, the storage tank 88, and the carbon sequestration system 90. As discussed above, the EG treatment system 82 may be controlled to purify and/or separate the exhaust gas 42 into one or more gas streams 95, such as the CO<sub>2</sub> rich, N<sub>2</sub> lean stream 96, the intermediate concentration CO<sub>2</sub>, N<sub>2</sub> stream 97, and the CO<sub>2</sub> lean, N<sub>2</sub> rich stream 98. In addition to controls for the exhaust gas 42, 60, and 95, the controls 124, 126, and 128 may execute one or more instructions to maintain the mechanical power 72 within a suitable power range, or maintain the electrical power 74 within a suitable frequency and power range.

[0045] FIG. 3 is a diagram of embodiment of the system 10, further illustrating details of the SEGR gas turbine system 52 for use with the hydrocarbon production system 12 and/or other systems 84. In the illustrated embodiment, the SEGR gas turbine system 52 includes a gas turbine engine 150 coupled to the EG processing

system 54. The illustrated gas turbine engine 150 includes a compressor section 152, a combustor section 154, and an expander section or turbine section 156. The compressor section 152 includes one or more exhaust gas compressors or compressor stages 158, such as 1 to 20 stages of rotary compressor blades disposed in a series arrangement. Likewise, the combustor section 154 includes one or more combustors 160, such as 1 to 20 combustors 160 distributed circumferentially about and/or axially along a rotational axis 162 of the SEGR gas turbine system 52. Furthermore, each combustor 160 may include one or more fuel nozzles 164 configured to inject the exhaust gas 66, the oxidant 68, and/or the fuel 70. For example, a head end portion 166 of each combustor 160 may house 1, 2, 3, 4, 5, 6, or more fuel nozzles 164, which may inject streams or mixtures of the exhaust gas 66, the oxidant 68, and/or the fuel 70 into a combustion portion 168 (e.g., combustion chamber) of the combustor 160.

**[0046]** The fuel nozzles 164 may include any combination of premix fuel nozzles 164 (e.g., configured to premix the oxidant 68 and fuel 70 for generation of an oxidant/fuel premix flame) and/or diffusion fuel nozzles 164 (e.g., configured to inject separate flows of the oxidant 68 and fuel 70 for generation of an oxidant/fuel diffusion flame). Embodiments of the premix fuel nozzles 164 may include swirl vanes, mixing chambers, or other features to internally mix the oxidant 68 and fuel 70 within the nozzles 164, prior to injection and combustion in the combustion chamber 168. The premix fuel nozzles 164 also may receive at least some partially mixed oxidant 68 and fuel 70. In certain embodiments, each diffusion fuel nozzle 164 may isolate flows of the oxidant 68 and the fuel 70 until the point of injection, while also isolating flows of one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) until the point of injection. In other embodiments, each diffusion fuel nozzle 164 may isolate flows of the oxidant 68 and the fuel 70 until the point of injection, while partially mixing one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) with the oxidant 68 and/or the fuel 70 prior to the point of injection. In addition, one or more diluents (e.g., the exhaust gas 66, steam, nitrogen, or another inert gas) may be injected into the combustor (e.g., into the hot products of combustion) either at or downstream from the combustion zone, thereby helping to reduce the temperature of the hot products of combustion and reduce

emissions of NO<sub>x</sub> (e.g., NO and NO<sub>2</sub>). Regardless of the type of fuel nozzle 164, the SEGR gas turbine system 52 may be controlled to provide substantially stoichiometric combustion of the oxidant 68 and fuel 70.

**[0047]** In diffusion combustion embodiments using the diffusion fuel nozzles 164, the fuel 70 and oxidant 68 generally do not mix upstream from the diffusion flame, but rather the fuel 70 and oxidant 68 mix and react directly at the flame surface and/or the flame surface exists at the location of mixing between the fuel 70 and oxidant 68. In particular, the fuel 70 and oxidant 68 separately approach the flame surface (or diffusion boundary/interface), and then diffuse (e.g., via molecular and viscous diffusion) along the flame surface (or diffusion boundary/interface) to generate the diffusion flame. It is noteworthy that the fuel 70 and oxidant 68 may be at a substantially stoichiometric ratio along this flame surface (or diffusion boundary/interface), which may result in a greater flame temperature (e.g., a peak flame temperature) along this flame surface. The stoichiometric fuel/oxidant ratio generally results in a greater flame temperature (e.g., a peak flame temperature), as compared with a fuel-lean or fuel-rich fuel/oxidant ratio. As a result, the diffusion flame may be substantially more stable than a premix flame, because the diffusion of fuel 70 and oxidant 68 helps to maintain a stoichiometric ratio (and greater temperature) along the flame surface. Although greater flame temperatures can also lead to greater exhaust emissions, such as NO<sub>x</sub> emissions, the disclosed embodiments use one or more diluents to help control the temperature and emissions while still avoiding any premixing of the fuel 70 and oxidant 68. For example, the disclosed embodiments may introduce one or more diluents separate from the fuel 70 and oxidant 68 (e.g., after the point of combustion and/or downstream from the diffusion flame), thereby helping to reduce the temperature and reduce the emissions (e.g., NO<sub>x</sub> emissions) produced by the diffusion flame.

**[0048]** In operation, as illustrated, the compressor section 152 receives and compresses the exhaust gas 66 from the EG processing system 54, and outputs a compressed exhaust gas 170 to each of the combustors 160 in the combustor section 154. Upon combustion of the fuel 60, oxidant 68, and exhaust gas 170 within each combustor 160, additional exhaust gas or products of combustion 172 (i.e.,

combustion gas) is routed into the turbine section 156. Similar to the compressor section 152, the turbine section 156 includes one or more turbines or turbine stages 174, which may include a series of rotary turbine blades. These turbine blades are then driven by the products of combustion 172 generated in the combustor section 154, thereby driving rotation of a shaft 176 coupled to the machinery 106. Again, the machinery 106 may include a variety of equipment coupled to either end of the SEGR gas turbine system 52, such as machinery 106, 178 coupled to the turbine section 156 and/or machinery 106, 180 coupled to the compressor section 152. In certain embodiments, the machinery 106, 178, 180 may include one or more electrical generators, oxidant compressors for the oxidant 68, fuel pumps for the fuel 70, gear boxes, or additional drives (e.g. steam turbine 104, electrical motor, etc.) coupled to the SEGR gas turbine system 52. Non-limiting examples are discussed in further detail below with reference to TABLE 1. As illustrated, the turbine section 156 outputs the exhaust gas 60 to recirculate along the exhaust recirculation path 110 from an exhaust outlet 182 of the turbine section 156 to an exhaust inlet 184 into the compressor section 152. Along the exhaust recirculation path 110, the exhaust gas 60 passes through the EG processing system 54 (e.g., the HRSG 56 and/or the EGR system 58) as discussed in detail above.

**[0049]** Again, each combustor 160 in the combustor section 154 receives, mixes, and stoichiometrically combusts the compressed exhaust gas 170, the oxidant 68, and the fuel 70 to produce the additional exhaust gas or products of combustion 172 to drive the turbine section 156. In certain embodiments, the oxidant 68 is compressed by an oxidant compression system 186, such as a main oxidant compression (MOC) system (e.g., a main air compression (MAC) system) having one or more oxidant compressors (MOCs). The oxidant compression system 186 includes an oxidant compressor 188 coupled to a drive 190. For example, the drive 190 may include an electric motor, a combustion engine, or any combination thereof. In certain embodiments, the drive 190 may be a turbine engine, such as the gas turbine engine 150. Accordingly, the oxidant compression system 186 may be an integral part of the machinery 106. In other words, the compressor 188 may be directly or indirectly driven by the mechanical power 72 supplied by the shaft 176 of the gas turbine engine

150. In such an embodiment, the drive 190 may be excluded, because the compressor 188 relies on the power output from the turbine engine 150. However, in certain embodiments employing more than one oxidant compressor is employed, a first oxidant compressor (e.g., a low pressure (LP) oxidant compressor) may be driven by the drive 190 while the shaft 176 drives a second oxidant compressor (e.g., a high pressure (HP) oxidant compressor), or vice versa. For example, in another embodiment, the HP MOC is driven by the drive 190 and the LP oxidant compressor is driven by the shaft 176. In the illustrated embodiment, the oxidant compression system 186 is separate from the machinery 106. In each of these embodiments, the compression system 186 compresses and supplies the oxidant 68 to the fuel nozzles 164 and the combustors 160. Accordingly, some or all of the machinery 106, 178, 180 may be configured to increase the operational efficiency of the compression system 186 (e.g., the compressor 188 and/or additional compressors).

**[0050]** The variety of components of the machinery 106, indicated by element numbers 106A, 106B, 106C, 106D, 106E, and 106F, may be disposed along the line of the shaft 176 and/or parallel to the line of the shaft 176 in one or more series arrangements, parallel arrangements, or any combination of series and parallel arrangements. For example, the machinery 106, 178, 180 (e.g., 106A through 106F) may include any series and/or parallel arrangement, in any order, of: one or more gearboxes (e.g., parallel shaft, epicyclic gearboxes), one or more compressors (e.g., oxidant compressors, booster compressors such as EG booster compressors), one or more power generation units (e.g., electrical generators), one or more drives (e.g., steam turbine engines, electrical motors), heat exchange units (e.g., direct or indirect heat exchangers), clutches, or any combination thereof. The compressors may include axial compressors, radial or centrifugal compressors, or any combination thereof, each having one or more compression stages. Regarding the heat exchangers, direct heat exchangers may include spray coolers (e.g., spray intercoolers), which inject a liquid spray into a gas flow (e.g., oxidant flow) for direct cooling of the gas flow. Indirect heat exchangers may include at least one wall (e.g., a shell and tube heat exchanger) separating first and second flows, such as a fluid flow (e.g., oxidant flow) separated from a coolant flow (e.g., water, air, refrigerant, or any other liquid or gas coolant),

wherein the coolant flow transfers heat from the fluid flow without any direct contact. Examples of indirect heat exchangers include intercooler heat exchangers and heat recovery units, such as heat recovery steam generators. The heat exchangers also may include heaters. As discussed in further detail below, each of these machinery components may be used in various combinations as indicated by the non-limiting examples set forth in TABLE 1.

**[0051]** Generally, the machinery 106, 178, 180 may be configured to increase the efficiency of the compression system 186 by, for example, adjusting operational speeds of one or more oxidant compressors in the system 186, facilitating compression of the oxidant 68 through cooling, and/or extraction of surplus power. The disclosed embodiments are intended to include any and all permutations of the foregoing components in the machinery 106, 178, 180 in series and parallel arrangements, wherein one, more than one, all, or none of the components derive power from the shaft 176. As illustrated below, TABLE 1 depicts some non-limiting examples of arrangements of the machinery 106, 178, 180 disposed proximate and/or coupled to the compressor and turbine sections 152, 156.

<b>106A</b>	<b>106B</b>	<b>106C</b>	<b>106D</b>	<b>106E</b>	<b>106F</b>
MOC	GEN				
MOC	GBX	GEN			
LP MOC	HP MOC	GEN			
HP MOC	GBX	LP MOC	GEN		
MOC MOC	GBX	GEN			
HP MOC	GBX	GEN	LP MOC		
MOC MOC	GBX GBX	GEN DRV			
DRV	GBX	LP MOC	HP MOC	GBX	GEN
DRV	GBX	HP MOC	LP MOC	GEN	
HP MOC	GBX CLR	LP MOC	GEN		
HP MOC	GBX CLR	LP MOC	GBX	GEN	
HP MOC	GBX HTR STGN	LP MOC	GEN		
MOC	GEN	DRV			
MOC	DRV	GEN			
DRV	MOC	GEN			
DRV	CLU	MOC	GEN		
DRV	CLU	MOC	GBX	GEN	

**TABLE 1**

**[0052]** As illustrated above in TABLE 1, a cooling unit is represented as CLR, a clutch is represented as CLU, a drive is represented by DRV, a gearbox is represented as GBX, a generator is represented by GEN, a heating unit is represented by HTR, a main oxidant compressor unit is represented by MOC, with low pressure and high pressure variants being represented as LP MOC and HP MOC, respectively, and a steam generator unit is represented as STGN. Although TABLE 1 illustrates the machinery 106, 178, 180 in sequence toward the compressor section 152 or the turbine section 156, TABLE 1 is also intended to cover the reverse sequence of the machinery 106, 178, 180. In TABLE 1, any cell including two or more components is intended to cover a parallel arrangement of the components. TABLE 1 is not intended to exclude any non-illustrated permutations of the machinery 106, 178, 180. These components of the machinery 106, 178, 180 may enable feedback control of temperature, pressure, and flow rate of the oxidant 68 sent to the gas turbine engine 150. As discussed in further detail below, the oxidant 68 and the fuel 70 may be supplied to the gas turbine engine 150 at locations specifically selected to facilitate isolation and extraction of the compressed exhaust gas 170 without any oxidant 68 or fuel 70 degrading the quality of the exhaust gas 170.

**[0053]** The EG supply system 78, as illustrated in FIG. 3, is disposed between the gas turbine engine 150 and the target systems (e.g., the hydrocarbon production system 12 and the other systems 84). In particular, the EG supply system 78, e.g., the EG extraction system (EGES) 80, may be coupled to the gas turbine engine 150 at one or more extraction points 76 along the compressor section 152, the combustor section 154, and/or the turbine section 156. For example, the extraction points 76 may be located between adjacent compressor stages, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 interstage extraction points 76 between compressor stages. Each of these interstage extraction points 76 provides a different temperature and pressure of the extracted exhaust gas 42. Similarly, the extraction points 76 may be located between adjacent turbine stages, such as 2, 3, 4, 5, 6, 7, 8, 9, or 10 interstage extraction points 76 between turbine stages. Each of these interstage extraction points 76 provides a different temperature and pressure of the extracted exhaust gas 42. By further example, the extraction points 76 may be located at a multitude of locations



throughout the combustor section 154, which may provide different temperatures, pressures, flow rates, and gas compositions. Each of these extraction points 76 may include an EG extraction conduit, one or more valves, sensors, and controls, which may be used to selectively control the flow of the extracted exhaust gas 42 to the EG supply system 78.

**[0054]** The extracted exhaust gas 42, which is distributed by the EG supply system 78, has a controlled composition suitable for the target systems (e.g., the hydrocarbon production system 12 and the other systems 84). For example, at each of these extraction points 76, the exhaust gas 170 may be substantially isolated from injection points (or flows) of the oxidant 68 and the fuel 70. In other words, the EG supply system 78 may be specifically designed to extract the exhaust gas 170 from the gas turbine engine 150 without any added oxidant 68 or fuel 70. Furthermore, in view of the stoichiometric combustion in each of the combustors 160, the extracted exhaust gas 42 may be substantially free of oxygen and fuel. The EG supply system 78 may route the extracted exhaust gas 42 directly or indirectly to the hydrocarbon production system 12 and/or other systems 84 for use in various processes, such as enhanced oil recovery, carbon sequestration, storage, or transport to an offsite location. However, in certain embodiments, the EG supply system 78 includes the EG treatment system (EGTS) 82 for further treatment of the exhaust gas 42, prior to use with the target systems. For example, the EG treatment system 82 may purify and/or separate the exhaust gas 42 into one or more streams 95, such as the CO<sub>2</sub> rich, N<sub>2</sub> lean stream 96, the intermediate concentration CO<sub>2</sub>, N<sub>2</sub> stream 97, and the CO<sub>2</sub> lean, N<sub>2</sub> rich stream 98. These treated exhaust gas streams 95 may be used individually, or in any combination, with the hydrocarbon production system 12 and the other systems 84 (e.g., the pipeline 86, the storage tank 88, and the carbon sequestration system 90).

**[0055]** Similar to the exhaust gas treatments performed in the EG supply system 78, the EG processing system 54 may include a plurality of exhaust gas (EG) treatment components 192, such as indicated by element numbers 194, 196, 198, 200, 202, 204, 206, 208, and 210. These EG treatment components 192 (e.g., 194 through 210) may be disposed along the exhaust recirculation path 110 in one or more series arrangements, parallel arrangements, or any combination of series and parallel

arrangements. For example, the EG treatment components 192 (e.g., 194 through 210) may include any series and/or parallel arrangement, in any order, of: one or more heat exchangers (e.g., heat recovery units such as heat recovery steam generators, condensers, coolers, or heaters), catalyst systems (e.g., oxidation catalyst systems), particulate and/or water removal systems (e.g., inertial separators, coalescing filters, water impermeable filters, and other filters), chemical injection systems, solvent based treatment systems (e.g., absorbers, flash tanks, etc.), carbon capture systems, gas separation systems, gas purification systems, and/or a solvent based treatment system, or any combination thereof. In certain embodiments, the catalyst systems may include an oxidation catalyst, a carbon monoxide reduction catalyst, a nitrogen oxides reduction catalyst, an aluminum oxide, a zirconium oxide, a silicone oxide, a titanium oxide, a platinum oxide, a palladium oxide, a cobalt oxide, or a mixed metal oxide, or a combination thereof. The disclosed embodiments are intended to include any and all permutations of the foregoing components 192 in series and parallel arrangements. As illustrated below, TABLE 2 depicts some non-limiting examples of arrangements of the components 192 along the exhaust recirculation path 110.

194	196	198	200	202	204	206	208	210
CU	HRU	BB	MRU	PRU				
CU	HRU	HRU	BB	MRU	PRU	DIL		
CU	HRSG	HRSG	BB	MRU	PRU			
OCU	HRU	OCU	HRU	OCU	BB	MRU	PRU	
HRU CU	HRU CU	BB	MRU	PRU				
HRSG OCU	HRSG OCU	BB	MRU	PRU	DIL			
OCU	HRSG OCU	OCU	HRSG OCU	OCU	BB	MRU	PRU	DIL
OCU	HRSG ST	HRSG ST	BB	COND	INER	WFIL	CFIL	DIL
OCU HRSG ST	OCU HRSG ST	BB	COND	INER	FIL	DIL		
OCU	HRSG ST	HRSG ST	OCU	BB	MRU HE COND	MRU WFIL	PRU INER	PRU FIL CFIL
CU	HRU COND	HRU COND	HRU COND	BB	MRU HE COND WFIL	PRU INER	PRU FIL CFIL	DIL

**TABLE 2**

[0056] As illustrated above in TABLE 2, a catalyst unit is represented by CU, an oxidation catalyst unit is represented by OCU, a booster blower is represented by BB, a heat exchanger is represented by HX, a heat recovery unit is represented by HRU, a heat recovery steam generator is represented by HRSG, a condenser is represented by COND, a steam turbine is represented by ST, a particulate removal unit is represented by PRU, a moisture removal unit is represented by MRU, a filter is represented by

FIL, a coalescing filter is represented by CFIL, a water impermeable filter is represented by WFIL, an inertial separator is represented by INER, and a diluent supply system (e.g., steam, nitrogen, or other inert gas) is represented by DIL. Although TABLE 2 illustrates the components 192 in sequence from the exhaust outlet 182 of the turbine section 156 toward the exhaust inlet 184 of the compressor section 152, TABLE 2 is also intended to cover the reverse sequence of the illustrated components 192. In TABLE 2, any cell including two or more components is intended to cover an integrated unit with the components, a parallel arrangement of the components, or any combination thereof. Furthermore, in context of TABLE 2, the HRU, the HRSG, and the COND are examples of the HE; the HRSG is an example of the HRU; the COND, WFIL, and CFIL are examples of the WRU; the INER, FIL, WFIL, and CFIL are examples of the PRU; and the WFIL and CFIL are examples of the FIL. Again, TABLE 2 is not intended to exclude any non-illustrated permutations of the components 192. In certain embodiments, the illustrated components 192 (e.g., 194 through 210) may be partially or completely integrated within the HRSG 56, the EGR system 58, or any combination thereof. These EG treatment components 192 may enable feedback control of temperature, pressure, flow rate, and gas composition, while also removing moisture and particulates from the exhaust gas 60. Furthermore, the treated exhaust gas 60 may be extracted at one or more extraction points 76 for use in the EG supply system 78 and/or recirculated to the exhaust inlet 184 of the compressor section 152.

[0057] As the treated, recirculated exhaust gas 66 passes through the compressor section 152, the SEGR gas turbine system 52 may bleed off a portion of the compressed exhaust gas along one or more lines 212 (e.g., bleed conduits or bypass conduits). Each line 212 may route the exhaust gas into one or more heat exchangers 214 (e.g., cooling units), thereby cooling the exhaust gas for recirculation back into the SEGR gas turbine system 52. For example, after passing through the heat exchanger 214, a portion of the cooled exhaust gas may be routed to the turbine section 156 along line 212 for cooling and/or sealing of the turbine casing, turbine shrouds, bearings, and other components. In such an embodiment, the SEGR gas turbine system 52 does not route any oxidant 68 (or other potential contaminants)

through the turbine section 156 for cooling and/or sealing purposes, and thus any leakage of the cooled exhaust gas will not contaminate the hot products of combustion (e.g., working exhaust gas) flowing through and driving the turbine stages of the turbine section 156. By further example, after passing through the heat exchanger 214, a portion of the cooled exhaust gas may be routed along line 216 (e.g., return conduit) to an upstream compressor stage of the compressor section 152, thereby improving the efficiency of compression by the compressor section 152. In such an embodiment, the heat exchanger 214 may be configured as an interstage cooling unit for the compressor section 152. In this manner, the cooled exhaust gas helps to increase the operational efficiency of the SEGR gas turbine system 52, while simultaneously helping to maintain the purity of the exhaust gas (e.g., substantially free of oxidant and fuel).

**[0058]** FIG. 4 is a flow chart of an embodiment of an operational process 220 of the system 10 illustrated in FIGS 1-3. In certain embodiments, the process 220 may be a computer implemented process, which accesses one or more instructions stored on the memory 122 and executes the instructions on the processor 120 of the controller 118 shown in FIG. 2. For example, each step in the process 220 may include instructions executable by the controller 118 of the control system 100 described with reference to FIG. 2.

**[0059]** The process 220 may begin by initiating a startup mode of the SEGR gas turbine system 52 of FIGS. 1-3, as indicated by block 222. For example, the startup mode may involve a gradual ramp up of the SEGR gas turbine system 52 to maintain thermal gradients, vibration, and clearance (e.g., between rotating and stationary parts) within acceptable thresholds. For example, during the startup mode 222, the process 220 may begin to supply a compressed oxidant 68 to the combustors 160 and the fuel nozzles 164 of the combustor section 154, as indicated by block 224. In certain embodiments, the compressed oxidant may include a compressed air, oxygen, oxygen-enriched air, oxygen-reduced air, oxygen-nitrogen mixtures, or any combination thereof. For example, the oxidant 68 may be compressed by the oxidant compression system 186 illustrated in FIG. 3. The process 220 also may begin to supply fuel to the combustors 160 and the fuel nozzles 164 during the startup mode

222, as indicated by block 226. During the startup mode 222, the process 220 also may begin to supply exhaust gas (as available) to the combustors 160 and the fuel nozzles 164, as indicated by block 228. For example, the fuel nozzles 164 may produce one or more diffusion flames, premix flames, or a combination of diffusion and premix flames. During the startup mode 222, the exhaust gas 60 being generated by the gas turbine engine 156 may be insufficient or unstable in quantity and/or quality. Accordingly, during the startup mode, the process 220 may supply the exhaust gas 66 from one or more storage units (e.g., storage tank 88), the pipeline 86, other SEGR gas turbine systems 52, or other exhaust gas sources.

**[0060]** The process 220 may then combust a mixture of the compressed oxidant, fuel, and exhaust gas in the combustors 160 to produce hot combustion gas 172, as indicated by block 230. In particular, the process 220 may be controlled by the control system 100 of FIG. 2 to facilitate stoichiometric combustion (e.g., stoichiometric diffusion combustion, premix combustion, or both) of the mixture in the combustors 160 of the combustor section 154. However, during the startup mode 222, it may be particularly difficult to maintain stoichiometric combustion of the mixture (and thus low levels of oxidant and unburnt fuel may be present in the hot combustion gas 172). As a result, in the startup mode 222, the hot combustion gas 172 may have greater amounts of residual oxidant 68 and/or fuel 70 than during a steady state mode as discussed in further detail below. For this reason, the process 220 may execute one or more control instructions to reduce or eliminate the residual oxidant 68 and/or fuel 70 in the hot combustion gas 172 during the startup mode.

**[0061]** The process 220 then drives the turbine section 156 with the hot combustion gas 172, as indicated by block 232. For example, the hot combustion gas 172 may drive one or more turbine stages 174 disposed within the turbine section 156. Downstream of the turbine section 156, the process 220 may treat the exhaust gas 60 from the final turbine stage 174, as indicated by block 234. For example, the exhaust gas treatment 234 may include filtration, catalytic reaction of any residual oxidant 68 and/or fuel 70, chemical treatment, heat recovery with the HRSG 56, and so forth. The process 220 may also recirculate at least some of the exhaust gas 60 back to the compressor section 152 of the SEGR gas turbine system 52, as indicated by block

236. For example, the exhaust gas recirculation 236 may involve passage through the exhaust recirculation path 110 having the EG processing system 54 as illustrated in FIGS. 1-3.

**[0062]** In turn, the recirculated exhaust gas 66 may be compressed in the compressor section 152, as indicated by block 238. For example, the SEGR gas turbine system 52 may sequentially compress the recirculated exhaust gas 66 in one or more compressor stages 158 of the compressor section 152. Subsequently, the compressed exhaust gas 170 may be supplied to the combustors 160 and fuel nozzles 164, as indicated by block 228. Steps 230, 232, 234, 236, and 238 may then repeat, until the process 220 eventually transitions to a steady state mode, as indicated by block 240. Upon the transition 240, the process 220 may continue to perform the steps 224 through 238, but may also begin to extract the exhaust gas 42 via the EG supply system 78, as indicated by block 242. For example, the exhaust gas 42 may be extracted from one or more extraction points 76 along the compressor section 152, the combustor section 154, and the turbine section 156 as indicated in FIG. 3. In turn, the process 220 may supply the extracted exhaust gas 42 from the EG supply system 78 to the hydrocarbon production system 12, as indicated by block 244. The hydrocarbon production system 12 may then inject the exhaust gas 42 into the earth 32 for enhanced oil recovery, as indicated by block 246. For example, the extracted exhaust gas 42 may be used by the exhaust gas injection EOR system 112 of the EOR system 18 illustrated in FIGS. 1-3.

**[0063]** FIG. 5 is a schematic illustrating an embodiment of the gas turbine engine 150 described above with respect to FIG. 3. In the illustrated embodiment, the combustor section 154 of the gas turbine engine 150 includes a plurality of reheat stages 260. More specifically, each reheat stage 260 includes one or more reheat combustors 262. As described below, the reheat stages 260 may be spaced across multiple turbine stages within the turbine section 156, wherein each turbine stage has a plurality of turbine blades disposed circumferentially about the rotational axis of the gas turbine engine 150. In this manner, unburned fuel 70 may remain in the hot gas path beyond a first combustion stage and may be combusted at a subsequent

combustion stage, thereby enabling reheat of the combustion products within the turbine section 156.

**[0064]** As described above, the oxidant compressor 188 compresses oxidant 68 that is supplied to the combustor section 154. In the illustrated embodiment, the combustor section 154 includes main combustors 264, which each receive the compressed oxidant 68, fuel 70, and recirculated exhaust gas 66. In certain embodiments, the main combustors 264 may be operated in a fuel-rich mode. That is, the main combustors 264 may be operated at a fuel-rich equivalence ratio such that unburnt fuel 70 may remain in the hot gas path of the gas turbine engine 150, while all oxidant 70 in the main combustors 264 may be generally consumed. As similarly described above, products of combustion 172 produced in the main combustors 264 travel downstream to the turbine section 156. More specifically, the products of combustion 172 drive the turbines 174 (e.g., stages) of the turbine section 156, thereby rotating the shaft 176, before exiting the gas turbine engine 150 as the exhaust gas 60.

**[0065]** As mentioned above, the gas turbine system 150 includes a plurality of reheat combustors 262. The reheat combustors 262 are in fluid communication the oxidant compressor 188, and thus receive a flow of oxidant 68. However, for reasons discussed below, certain embodiments of the reheat combustors 262 generally may not be configured to receive a flow of fuel 70. As shown in the illustrated embodiment, the reheat combustors 262 may be positioned between various stages 174 of the turbine section 156. For example, first reheat combustors 266 are positioned downstream of a first stage 268 (or a first set of 1, 2, 3, or more turbine stages) of the turbine section 156. Similarly, second reheat combustors 270 are positioned after a second stage 272 (or a second set of 1, 2, 3, or more turbine stages) of the turbine section 156. In other embodiments any number of the reheat combustors 262 may be used with any number of stages 174 in the turbine section 156. As mentioned above, each of the reheat combustors 262 may be configured to receive oxidant 68 from the oxidant compressor 188. In the manner described below, the reheat combustors 262 may combust fuel 70 flowing within the products of combustion 172. In other words, the products of combustion 172 flowing within the



turbine section 156 may include uncombusted fuel 70, and the reheat combustors 262 may combust this fuel 70 with additional oxidant 68, thereby reheating the products of combustion 172.

**[0066]** For example, in operation, the main combustors 264 may operate in a fuel-rich mode. In other words, the main combustors 264 may receive more fuel 70 than a stoichiometric oxidant 68 to fuel 70 ratio. As such, after combustion within the main combustors 264, an amount of fuel 70 may remain in the hot gas path (e.g., within the products of combustion 172) beyond the first combustion stage (e.g., the combustion stage at the main combustors 264). Thereafter, the unburned or uncombusted fuel 70 may be combusted downstream at one or more of the reheat stages 260. As will be appreciated, the introduction of fuel 70 at a higher than stoichiometric oxidant 68 to fuel 70 ratio may cause the oxidant 68 within the hot gas path to be consumed more completely, thereby reducing the presence of oxidant 68 in the products of combustion 172, and therefore the exhaust gas 60. Moreover, the reheat combustors 262 described herein may have significantly reduced hardware as compared to the main combustors 264, while also providing a cooling airflow therein. That is, the oxidant 68 flowing through the reheat combustors 262 may also be used to cool various components of the turbine section 156 and the gas turbine engine 150. For example, the reheat combustors 262 may include oxidant 68 flow paths but may not include fuel 70 flow paths. As mentioned above, the oxidant 68 may be combusted by the reheat combustors 262 with fuel 70 already in the hot gas path of the gas turbine engine 150 (e.g., fuel 70 left over from combustion in the main combustors 264 upstream). As a result, the gas turbine system 52 described herein may provide improved cycle efficiencies with reduced emissions of oxidant 68.

**[0067]** Furthermore, the gas turbine engine 150 may include a controller 400 configured to regulate various operations of the gas turbine engine 150. For example, the controller 400 may be configured to regulate a flow rate of oxidant 68 to one or more of the reheat combustors 262 via valves or other flow regulating devices. The controller 400 may also regulate other operations, such as operation of flame holding mechanisms of the reheat combustors 262, operation of the main combustors 264 (e.g., flow rate of fuel 70 and/or oxidant 68 to the main combustors 264), and so forth.

Moreover, the controller 400 may be configured to regulate operation of various components of the gas turbine engine 150 based feedback (e.g., measured feedback) of various operating parameters of the gas turbine engine 150. For example, the gas turbine engine 150 may include one or more sensors 402 configured to measure one or more operating parameters, such as a flow rate of oxidant 68, a temperature of the products of combustion 172, a flow rate of the products of combustion 172 in the turbine section 156, amount of fuel 70 in the products of combustion 172 at various points or stages in the turbine section 156, rotational speed of various stages of the turbine section 156, an amount of oxidant 68 in the products of combustion 172, a ratio of fuel 70 to oxidant 68 in the products of combustion 172, a ratio of fuel 70 to oxidant 68 flowing to the main combustors 264, and so forth. The controller 400 may further include memory 404 and a microprocessor 406. For example, the memory 404 may include a tangible, machine-readable medium configured to store software, code, or other instructions, and the microprocessor 406 may be configured to execute the instructions, software, or code stored in the memory 404. While FIGS. 6-8 described below do not show the controller 400 and sensors 402, it will be appreciated that the embodiments described below may include the controller 400 and sensors 402.

**[0068]** FIG. 6 is a schematic diagram illustrating the reheat combustors 262 distributed in various stages 174 of the turbine section 156. In the description below, reference may be made to first, second, and third elements (e.g., nozzles, turbine blades, etc.). Any reference to such elements may include embodiments in which such elements are in consecutive order or embodiments in which there are other components (e.g., nozzle, turbine blades, etc.) upstream, downstream, and/or in between such elements.

**[0069]** As described above, the turbine section 156 is positioned downstream of the main combustors 264. In the illustrated embodiment, the turbine section 156 includes the first stage 268 (or set of one or more turbine blades or stages 296), the second stage 272 (or set of one or more turbine blades or stages 296), and a third stage 280 (or set of one or more turbine blades or stages 296). However, as mentioned above, the turbine section 156 may include any suitable number of stages 174. The

turbine section 156 further includes the first reheat combustor 266 positioned downstream of the first stage 268 and the second reheat combustor 270 positioned downstream of the second stage 272. As shown, the third stage 280 of the turbine section 156 is positioned downstream of the second reheat combustor 270.

**[0070]** The first reheat combustor 266 includes a nozzle flow path 282 extending through a nozzle 284 (e.g., a turbine nozzle). The nozzle 284 extends into the hot gas path of the second stage 272 of the turbine section 156 and may include a variety of configurations and/or structures. Furthermore, as the oxidant 68 from the oxidant compressor 188 flows through the nozzle flow path 282, the oxidant 68 flow may cool the nozzle 284. As shown, the nozzle flow path 282 exits the nozzle 284 at a trailing end 286 thereof via a number of film cooling holes 288. As such, the oxidant 68 may cool the nozzle 284 or other components of the turbine section 156 as the oxidant 68 flows into the hot gas path (e.g., represented by arrows 298). As described below, the oxidant 68 exits into the hot gas path of the turbine section 156 for reheat combustion of the unburned fuel 70. Additionally, the first, second, and third stages 268, 272, and 280 may also include additional nozzles 284 which are stationary and/or do not include nozzle flow paths 282.

**[0071]** The first reheat combustor 266 also includes a flame holding mechanism 290 positioned downstream of the trailing end 286 of the nozzle 284, so as to reduce the pressure loss therein. Additionally, the flame holding mechanism 290 is positioned adjacent to a combustion zone 292 for a stage of reheat. Specifically, the flame holding mechanism 290 may maintain the combustion zone 292 at a consistent location in the hot gas path, so as to maintain combustion therein. The flame holding mechanism 290 may include a bluff body, a swirl, a jet, or other similar structure that may generate and/or provide a flame to combust the oxidant 68 and the unburned fuel 70 in the hot gas path. Additionally, any number of the flame holding mechanisms 290 may be included in the first reheat combustor 266. Similarly, the second reheat combustor 290 may have a similar configuration to that of the first reheat combustor 266. In other words, the second reheat combustor 290 may include the nozzle 284 having the nozzle flow path 282 configured to flow the oxidant 68 and the flame holding mechanism 290 positioned adjacent to the combustion zone 292.

[0072] As the oxidant 68 flows past the flame holding mechanism 290 of the respective reheat combustor 262, unburned fuel 70 within the turbine section 156 may be combusted with the oxidant 68. In certain embodiments, the amount of oxidant 68 flowing into the reheat combustors 262 may be regulated (e.g., by controller 118) to enable more complete consumption of the oxidant 68 within the reheat combustion zones 292. In this manner, the amount of oxidant 68 remaining in the products of combustion 172 and the exhaust gas 60 may be substantially reduced or eliminated.

[0073] FIG. 7 is a schematic illustrating another embodiment of the turbine section 156 having reheat combustors 262. The illustrated embodiment is similar to the embodiment described above and includes similar elements and element numbers. In the illustrated embodiment, the first reheat combustor 266 includes both the nozzle flow path 282 extending through the nozzle 284 in the second stage 272 of the turbine section 156, as well as a turbine blade flow path 300 extending through a rotating turbine blade 302 of the first stage 268 of the turbine section 156. As will be appreciated, the first stage 268 of the turbine section 156 may have multiple turbine blades 302, each turbine blade 302 having a respective turbine blade flow path 300.

[0074] As shown, the turbine blade flow path 300 extends from (e.g., is fluidly coupled to) the nozzle flow path 282 to the rotating turbine blade 302 of the first stage 268 of the turbine section 156. As such, the oxidant 68 may flow through the nozzle 284 and the rotating turbine blade 302, thereby cooling each. Furthermore, as the oxidant 68 flow exits the turbine blade flow path 300 through cooling holes 304 at a trailing end 306 of the rotating turbine blade 302, the oxidant 68 passes across the flame holding mechanism 290 into the combustion zone 292 so as to provide a stage of reheat combustion. Similarly, the second reheat combustor 270 may include the nozzle flow path 282 extending through the nozzle 284 of the third stage 280 of the turbine section 156, and the nozzle flow path 282 may extend to the turbine blade flow path 300 of the rotating turbine blade 302 of the second stage 272 of the turbine section 156. As the oxidant 68 flow exits the cooling holes 304 of the rotating turbine blade 302, the oxidant 68 flow passes the flame holding mechanism 290 of the second reheat combustor 270, thereby creating the combustion zone 292 for reheat combustion. More specifically, the oxidant 68 mixes with unburned fuel 70 in the hot

gas path of the gas turbine engine 150, and the flame holding mechanism 290 causes combustion of the oxidant 68 and the unburned fuel 70, thereby providing reheat of the products of combustion 172 within the gas turbine engine 150.

**[0075]** As similarly described above, the oxidant 68 flowing through the nozzle flow path 282 and turbine blade flow path 300 may flow to the flame holding mechanism 290 to combust unburned fuel 70 within the turbine section 156. In this manner, the products of combustion 172 within the turbine section 156 may be reheated via the reaction of the unburned fuel 70 with additional oxidant 68. Additionally, the amount of oxidant 68 flowing through the reheat combustors 262 may be regulated (e.g., by controller 118) such that unburned fuel 70 is more completely consumed, while still reducing the amount of oxidant 68 left over in the products of combustion 172.

**[0076]** FIG. 8 is a schematic of another embodiment of the turbine section 156. In the illustrated embodiment, the first reheat combustor 266 includes the nozzle flow path 282 extending through the nozzle 284 in the first stage 268 of the turbine section 156 and upstream of the rotating turbine blade 302 of the first stage 268. As described above, the nozzle flow path 282 flows oxidant 68 through the body of the nozzle 270, thereby cooling the nozzle 270. As the oxidant 68 exits the trailing end 286 of the nozzle 284 through the cooling holes 288, the oxidant 68 travels across the rotating turbine blade 302 downstream of the nozzle 284 and toward the flame holding mechanism 290 positioned downstream of the rotating turbine blade 302. Specifically, in the illustrated embodiment, the flame holding mechanism 290 is positioned downstream of the rotating turbine blade 302 of the first stage 268 of the turbine section 156 and upstream of the nozzle 284 of the second stage 272 of the turbine section 156. In operation, the flame holding mechanism 290 and the oxidant 68 combust remaining fuel 70 within the hot gas path, thereby creating the combustion zone 292 and providing a stage of reheat. The second reheat combustor 270 also may be positioned adjacent to the second stage 272 of the turbine section 156. More specifically, the nozzle flow path 282 may extend through the nozzle 284 positioned upstream of the rotating turbine blade 302 of the second stage 272. As the oxidant 68 exits the nozzle flow path 282 and passes across the rotating turbine blade

302, the oxidant 68 may cross the flame holding mechanism 290, thereby creating the combustion zone 292 downstream of the second stage 272 of the turbine section 156.

[0077] Embodiments of the present disclosure are directed toward the gas turbine engine 52 having a plurality of reheat stages 260. More specifically, the turbine section 156 of the gas turbine engine 156 includes reheat combustors 266 that are configured to introduce oxidant 68 into the hot gas path of the turbine section 156 to combust unburned fuel 70 within the hot gas path. In certain embodiments, the main combustors 264 of the gas turbine engine 52 operate in a fuel-rich mode, thereby introducing fuel 70 into the main combustors 264 at a greater than stoichiometric oxidant 68 to fuel 70 ratio. As a result, unburned fuel 70 may remain in the hot gas path (e.g., in the products of combustion 172) after first stage combustion at the main combustors 264. The unburned fuel 70 may be further combusted by the reheat combustors 260 positioned downstream within the turbine section 156. For example, oxidant 68 may be introduced into the hot gas path of the turbine section 156 through the nozzle flow path 282 of the nozzle 284 and/or the turbine blade flow path 300 of the rotating turbine blade 302. Additionally, this oxidant 68 flow may further serve to cool components of the turbine section 156 (e.g., the nozzle 284 and/or the rotating turbine blade 302). As the oxidant 68 is introduced into the hot gas path, the oxidant 68 may flow past the flame holding mechanism 290, thereby creating the combustion zone 292 where unburned fuel 70 may be consumed with the oxidant 68 and the products of combustion 172 may be reheated.

#### ADDITIONAL DESCRIPTION

[0078] The present embodiments provide a system and method for reheat in a gas turbine with exhaust gas recirculation. It should be noted that any one or a combination of the features described above may be utilized in any suitable combination. Indeed, all permutations of such combinations are presently contemplated. By way of example, the following clauses are offered as further description of the present disclosure:

Embodiment 1. A system, having a turbine having an exhaust flow path through a plurality of turbine stages, wherein the plurality of turbine stages is driven by combustion products flowing through the exhaust flow path, at least one main combustor disposed upstream from the turbine, wherein the at least one main combustor is configured to combust a fuel with a first oxidant and an exhaust gas to generate the combustion products, at least one reheat combustor disposed in or between turbine stages of the turbine, wherein the at least one reheat combustor is configured to reheat the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products, and an exhaust gas compressor, wherein the exhaust gas compressor is configured to compress and route the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path.

Embodiment 2. The system of embodiment 1, comprising an oxidant compression system configured to compress and supply the first oxidant to the at least one main combustor, wherein the oxidant compression system is configured to compress and supply the second oxidant to the at least one reheat combustor.

Embodiment 3. The system of embodiment 1, wherein the at least one reheat combustor comprises a flame holder disposed in or between the turbine stages, wherein an oxidant flow path extends through at least one turbine nozzle of the turbine, at least one turbine blade of the turbine, or a combination thereof, wherein the oxidant flow path is configured to supply the second oxidant to a reheat zone adjacent the flame holder.

Embodiment 4. The system of embodiment 3, wherein the oxidant flow path extends to a plurality of openings in fluid communication with the exhaust flow path through the turbine, and the exhaust flow path is in fluid communication with the reheat zone.

Embodiment 5. The system of embodiment 3 or 4, wherein the plurality of openings comprises a plurality of film cooling holes.

Embodiment 6. The system of embodiment 1, wherein the at least one reheat combustor comprises a first reheat combustor having a first oxidant flow path through a first turbine nozzle of a first turbine stage of the plurality of turbine stages, the first turbine stage comprises a first set of rotary turbine blades downstream of the first turbine nozzle, and the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path.

Embodiment 7. The system of embodiment 6, wherein the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path directly in the first turbine stage.

Embodiment 8. The system of embodiments 6 or 7, wherein the first oxidant flow path is configured to route the second oxidant through an additional structure after passing through the first turbine nozzle.

Embodiment 9. The system of embodiments 6, 7, or 8, wherein the first oxidant flow path is configured to route the second oxidant through the additional structure upstream of the first turbine nozzle after passing through the first turbine nozzle.

Embodiment 10. The system of embodiments 6, 7, 8, or 9, wherein the additional structure comprises an additional turbine nozzle, an additional set of rotary turbine blades, or a combination thereof.

Embodiment 11. The system of any preceding embodiment, wherein the first oxidant flow path comprises a first plurality of openings disposed at a first trailing end portion of the first turbine nozzle.

Embodiment 12. The system of any preceding embodiment, wherein the first reheat combustor comprises a first flame holder disposed downstream of the first turbine nozzle and upstream of the first set of rotary turbine blades of the first turbine stage.



Embodiment 13. The system of any preceding embodiment, wherein the first turbine nozzle is disposed directly downstream of the at least one main combustor.

Embodiment 14 The system of any preceding embodiment, comprising one or more turbine stages disposed between the at least one main combustor and the first turbine nozzle.

Embodiment 15. The system of any preceding embodiment, wherein the at least one reheat combustor comprises a second reheat combustor having a second oxidant flow path through a second turbine nozzle of a second turbine stage of the plurality of turbine stages, wherein the second turbine stage comprises a second set of rotary turbine blades downstream of the second turbine nozzle, the second turbine stage is downstream of the first turbine stage, and the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path.

Embodiment 16. The system of any preceding embodiment, wherein the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path directly in the second turbine stage.

Embodiment 17. The system of embodiments 15 or 16, wherein the second oxidant flow path is configured to route the second oxidant through an additional structure after passing through the second turbine nozzle.

Embodiment 18. The system of embodiments 15, 16, or 17, wherein the second oxidant flow path is configured to route the second oxidant through the additional structure upstream of the second turbine nozzle after passing through the second turbine nozzle.

Embodiment 19. The system of embodiments 15, 16, 17, or 18, wherein the additional structure comprises an additional turbine nozzle, an additional set of rotary turbine blades, or a combination thereof.

Embodiment 20. The system of embodiments 15, 16, 17, or 18, wherein the additional structure comprises the first set of rotary turbine blades in the first turbine stage.

Embodiment 21. The system of any preceding embodiment, wherein the first oxidant flow path is configured to route the second oxidant through a set of rotary turbine blades upstream of the first turbine nozzle after passing through the first turbine nozzle, and the second oxidant flow path is configured to route the second oxidant through the first set of rotary turbine blades upstream of the second turbine nozzle after passing through the second turbine nozzle.

Embodiment 22. The system of any preceding embodiment, wherein the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path through a first set of openings in both the first turbine nozzle and the set of rotary turbine blades, or the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path through a second set of openings in the first set of rotary turbine blades, or a combination thereof.

Embodiment 23. The system of any preceding embodiment, wherein the second turbine stage is disposed directly downstream of the first turbine stage without any intermediate turbine stages.

Embodiment 24. The system of any preceding embodiment, wherein the second turbine stage is disposed downstream of the first turbine stage with one or more intermediate turbine stages, and each intermediate turbine stage has a turbine nozzle upstream from a set of rotary turbine blades.

Embodiment 25. The system of any preceding embodiment, wherein the second oxidant flow path comprises a second plurality of openings disposed at a second trailing end portion of the second turbine nozzle.

Embodiment 26. The system of any preceding embodiment, wherein the second reheat combustor comprises a second flame holder disposed downstream of the second turbine nozzle and upstream of the second set of rotary turbine blades of the second turbine stage.

Embodiment 27. The system of embodiment 1, comprising a gas turbine engine having the turbine, the at least one main combustor, the at least one reheat combustor, the exhaust gas compressor, and an exhaust gas recirculation system configured to recirculate the exhaust gas along the exhaust recirculation path from the turbine to the at least one main combustor.

Embodiment 28. The system of embodiments 1 or 27, wherein the exhaust gas recirculation system comprises a heat recovery steam generator, a catalyst unit, a moisture removal unit, a particulate removal unit, or any combination thereof.

Embodiment 29. The system of embodiments 1 or 27, comprising an exhaust gas extraction system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas extraction system.

Embodiment 30. The system of embodiments 1 or 27, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.

Embodiment 31. The system of any preceding embodiment, wherein the controller is configured to supply the second oxidant through the first and second oxidant flow paths to enable stoichiometric combustion of the unburnt fuel in the at least one reheat combustor.

Embodiment 32. A method, including driving a turbine with combustion products flowing along an exhaust flow path through a plurality of turbine stages, combusting a fuel with a first oxidant and an exhaust gas to generate the combustion products in at least one main combustor disposed upstream from the turbine, reheating the combustion products by adding a second oxidant to react with unburnt fuel in the

combustion products via at least one reheat combustor disposed in or between turbine stages of the turbine, and compressing and routing the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path via an exhaust gas compressor.

Embodiment 33. The method of embodiment 32, comprising holding a reheat flame with a flame holder of the at least one reheat combustor in or between the turbine stages.

Embodiment 34. The method of embodiment 32, comprising flowing the second oxidant along an oxidant flow path through at least one turbine nozzle of the turbine, at least one turbine blade of the turbine, or a combination thereof.

Embodiment 35. The method of embodiments 32 or 34, comprising discharging the second oxidant from the oxidant flow path into the exhaust flow path through a plurality of openings, wherein the plurality of openings is disposed in the at least one turbine nozzle, the at least one turbine blade, or a combination thereof.

Embodiment 36. The method of embodiments 32, 34, or 35, wherein the plurality of openings comprises a plurality of film cooling holes.

Embodiment 37. The method of embodiments 32 or 34, wherein flowing comprises routing the second oxidant along the oxidant flow path through both the at least one turbine nozzle and the at least one turbine blade before directing the second oxidant into the exhaust flow path.

Embodiment 38. The method of embodiments 32 or 34, wherein flowing comprises routing the second oxidant along the oxidant flow path from a first component to a second component in an upstream direction along the exhaust flow path, wherein the first component comprises the at least one turbine nozzle or the at least one turbine blade, and the second component comprises the at least one turbine nozzle or the at least one turbine blade.

Embodiment 39. The method of embodiment 32, comprising extracting the exhaust gas via an exhaust gas extraction system, treating the exhaust gas with a treatment system, and routing the exhaust gas to a hydrocarbon production system.

Embodiment 40. The method of embodiment 32, comprising stoichiometrically combusting the fuel.

Embodiment 41. A system, including a main combustor configured to combust a first fuel flow with a first oxidant flow to produce combustion products and an unburned fuel flow and a turbine section configured to receive the combustion products and the unburned fuel flow. The turbine section includes a first turbine stage, a first reheat combustor positioned downstream of the first turbine stage, comprising a first flame holding mechanism, a second turbine stage positioned downstream of the first reheat combustor, and a second reheat combustor positioned downstream of the second turbine stage, comprising a second flame holding mechanism.

Embodiment 42. The system of embodiment 41, wherein the first turbine stage comprises a first turbine nozzle configured to flow a second oxidant flow into the turbine section and toward the first flame holding mechanism, and the second turbine stage comprises a second turbine nozzle configured to flow a third oxidant flow into the turbine section and toward the second flame holding mechanism.

Embodiment 43. The system of embodiments 41 or 42, wherein the first turbine stage comprises a first rotary turbine blade disposed between the first turbine nozzle and the first flame holding mechanism, and the second turbine stage comprises a second rotary turbine blade disposed between the second turbine nozzle and the second flame holding mechanism.

Embodiments 44. The system of embodiment 41, wherein the first turbine stage comprises a first rotary turbine blade configured to flow a second oxidant flow into

the turbine section and toward the first flame holding mechanism, and the second turbine stage comprises a second rotary turbine blade configured to flow a third oxidant flow into the turbine section and toward the second flame holding mechanism.

Embodiment 45. The system of embodiment 41, comprising a controller configured to regulate flow of the first fuel flow and the first oxidant flow into the combustor such that the combustor operate in a rich mode.

Embodiment 46. The system of any preceding embodiment, wherein the controller is configured to regulate flow of the second oxidant flow to enable stoichiometric combustion of unburned fuel in the turbine section.

**[0079]** This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

## CLAIMS:

1. A system, comprising:
  - a turbine having an exhaust flow path through a plurality of turbine stages, wherein the plurality of turbine stages is driven by combustion products flowing through the exhaust flow path;
  - at least one main combustor disposed upstream from the turbine, wherein the at least one main combustor is configured to combust a fuel with a first oxidant and an exhaust gas to generate the combustion products;
  - at least one reheat combustor disposed in or between turbine stages of the turbine, wherein the at least one reheat combustor is configured to reheat the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products; and
  - an exhaust gas compressor, wherein the exhaust gas compressor is configured to compress and route the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path.
2. The system of claim 1, comprising an oxidant compression system configured to compress and supply the first oxidant to the at least one main combustor, wherein the oxidant compression system is configured to compress and supply the second oxidant to the at least one reheat combustor.
3. The system of claim 1, wherein the at least one reheat combustor comprises a flame holder disposed in or between the turbine stages, wherein an oxidant flow path extends through at least one turbine nozzle of the turbine, at least one turbine blade of the turbine, or a combination thereof, wherein the oxidant flow path is configured to supply the second oxidant to a reheat zone adjacent the flame holder.
4. The system of claim 3, wherein the oxidant flow path extends to a plurality of openings in fluid communication with the exhaust flow path through the turbine, and the exhaust flow path is in fluid communication with the reheat zone.

5. The system of claim 4, wherein the plurality of openings comprises a plurality of film cooling holes.
6. The system of claim 1, wherein the at least one reheat combustor comprises a first reheat combustor having a first oxidant flow path through a first turbine nozzle of a first turbine stage of the plurality of turbine stages, the first turbine stage comprises a first set of rotary turbine blades downstream of the first turbine nozzle, and the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path.
7. The system of claim 6, wherein the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path directly in the first turbine stage.
8. The system of claim 6, wherein the first oxidant flow path is configured to route the second oxidant through an additional structure after passing through the first turbine nozzle.
9. The system of claim 8, wherein the first oxidant flow path is configured to route the second oxidant through the additional structure upstream of the first turbine nozzle after passing through the first turbine nozzle.
10. The system of claim 9, wherein the additional structure comprises an additional turbine nozzle, an additional set of rotary turbine blades, or a combination thereof.
11. The system of claim 6, wherein the first oxidant flow path comprises a first plurality of openings disposed at a first trailing end portion of the first turbine nozzle.
12. The system of claim 6, wherein the first reheat combustor comprises a first flame holder disposed downstream of the first turbine nozzle and upstream of the first set of rotary turbine blades of the first turbine stage.



13. The system of claim 6, wherein the first turbine nozzle is disposed directly downstream of the at least one main combustor.
14. The system of claim 6, comprising one or more turbine stages disposed between the at least one main combustor and the first turbine nozzle.
15. The system of claim 6, wherein the at least one reheat combustor comprises a second reheat combustor having a second oxidant flow path through a second turbine nozzle of a second turbine stage of the plurality of turbine stages, wherein the second turbine stage comprises a second set of rotary turbine blades downstream of the second turbine nozzle, the second turbine stage is downstream of the first turbine stage, and the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path.
16. The system of claim 15, wherein the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path directly in the second turbine stage.
17. The system of claim 15, wherein the second oxidant flow path is configured to route the second oxidant through an additional structure after passing through the second turbine nozzle.
18. The system of claim 17, wherein the second oxidant flow path is configured to route the second oxidant through the additional structure upstream of the second turbine nozzle after passing through the second turbine nozzle.
19. The system of claim 18, wherein the additional structure comprises an additional turbine nozzle, an additional set of rotary turbine blades, or a combination thereof.
20. The system of claim 18, wherein the additional structure comprises the first set of rotary turbine blades in the first turbine stage.

21. The system of claim 15, wherein the first oxidant flow path is configured to route the second oxidant through a set of rotary turbine blades upstream of the first turbine nozzle after passing through the first turbine nozzle, and the second oxidant flow path is configured to route the second oxidant through the first set of rotary turbine blades upstream of the second turbine nozzle after passing through the second turbine nozzle.

22. The system of claim 21, wherein the first oxidant flow path is configured to supply the second oxidant into the exhaust flow path through a first set of openings in both the first turbine nozzle and the set of rotary turbine blades, or the second oxidant flow path is configured to supply the second oxidant into the exhaust flow path through a second set of openings in the first set of rotary turbine blades, or a combination thereof.

23. The system of claim 15, wherein the second turbine stage is disposed directly downstream of the first turbine stage without any intermediate turbine stages.

24. The system of claim 15, wherein the second turbine stage is disposed downstream of the first turbine stage with one or more intermediate turbine stages, and each intermediate turbine stage has a turbine nozzle upstream from a set of rotary turbine blades.

25. The system of claim 15, wherein the second oxidant flow path comprises a second plurality of openings disposed at a second trailing end portion of the second turbine nozzle.

26. The system of claim 15, wherein the second reheat combustor comprises a second flame holder disposed downstream of the second turbine nozzle and upstream of the second set of rotary turbine blades of the second turbine stage.

27. The system of claim 1, comprising a gas turbine engine having the turbine, the at least one main combustor, the at least one reheat combustor, the exhaust gas

compressor, and an exhaust gas recirculation system configured to recirculate the exhaust gas along the exhaust recirculation path from the turbine to the at least one main combustor.

28. The system of claim 27, wherein the exhaust gas recirculation system comprises a heat recovery steam generator, a catalyst unit, a moisture removal unit, a particulate removal unit, or any combination thereof.

29. The system of claim 27, comprising an exhaust gas extraction system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas extraction system.

30. The system of claim 27, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.

31. A method, comprising:

driving a turbine with combustion products flowing along an exhaust flow path through a plurality of turbine stages;

combusting a fuel with a first oxidant and an exhaust gas to generate the combustion products in at least one main combustor disposed upstream from the turbine;

reheating the combustion products by adding a second oxidant to react with unburnt fuel in the combustion products via at least one reheat combustor disposed in or between turbine stages of the turbine; and

compressing and routing the exhaust gas from the turbine to the at least one main combustor along an exhaust recirculation path via an exhaust gas compressor.

32. The method of claim 31, comprising holding a reheat flame with a flame holder of the at least one reheat combustor in or between the turbine stages.

33. The method of claim 31, comprising flowing the second oxidant along an oxidant flow path through at least one turbine nozzle of the turbine, at least one turbine blade of the turbine, or a combination thereof.

34. The method of claim 33, comprising discharging the second oxidant from the oxidant flow path into the exhaust flow path through a plurality of openings, wherein the plurality of openings is disposed in the at least one turbine nozzle, the at least one turbine blade, or a combination thereof.

35. The method of claim 34, wherein the plurality of openings comprises a plurality of film cooling holes.

36. The method of claim 33, wherein flowing comprises routing the second oxidant along the oxidant flow path through both the at least one turbine nozzle and the at least one turbine blade before directing the second oxidant into the exhaust flow path.

37. The method of claim 33, wherein flowing comprises routing the second oxidant along the oxidant flow path from a first component to a second component in an upstream direction along the exhaust flow path, wherein the first component comprises the at least one turbine nozzle or the at least one turbine blade, and the second component comprises the at least one turbine nozzle or the at least one turbine blade.

38. The method of claim 31, comprising extracting the exhaust gas via an exhaust gas extraction system, treating the exhaust gas with a treatment system, and routing the exhaust gas to a hydrocarbon production system.

39. The method of claim 31, comprising stoichiometrically combusting the fuel.

40. A system, comprising:  
a main combustor configured to combust a first fuel flow with a first oxidant flow to produce combustion products and an unburned fuel flow;  
a turbine section configured to receive the combustion products and the unburned fuel flow, comprising:  
a first turbine stage;  
a first reheat combustor positioned downstream of the first turbine stage, comprising a first flame holding mechanism;  
a second turbine stage positioned downstream of the first reheat combustor; and  
a second reheat combustor positioned downstream of the second turbine stage, comprising a second flame holding mechanism.

41. The system of claim 40, wherein the first turbine stage comprises a first turbine nozzle configured to flow a second oxidant flow into the turbine section and toward the first flame holding mechanism, and the second turbine stage comprises a second turbine nozzle configured to flow a third oxidant flow into the turbine section and toward the second flame holding mechanism.

42. The system of claim 41, wherein the first turbine stage comprises a first rotary turbine blade disposed between the first turbine nozzle and the first flame holding mechanism, and the second turbine stage comprises a second rotary turbine blade disposed between the second turbine nozzle and the second flame holding mechanism.

43. The system of claim 40, wherein the first turbine stage comprises a first rotary turbine blade configured to flow a second oxidant flow into the turbine section and toward the first flame holding mechanism, and the second turbine stage comprises a second rotary turbine blade configured to flow a third oxidant flow into the turbine section and toward the second flame holding mechanism.

44. The system of claim 40, comprising a controller configured to regulate flow of the first fuel flow and the first oxidant flow into the combustor such that the combustor operate in a rich mode.

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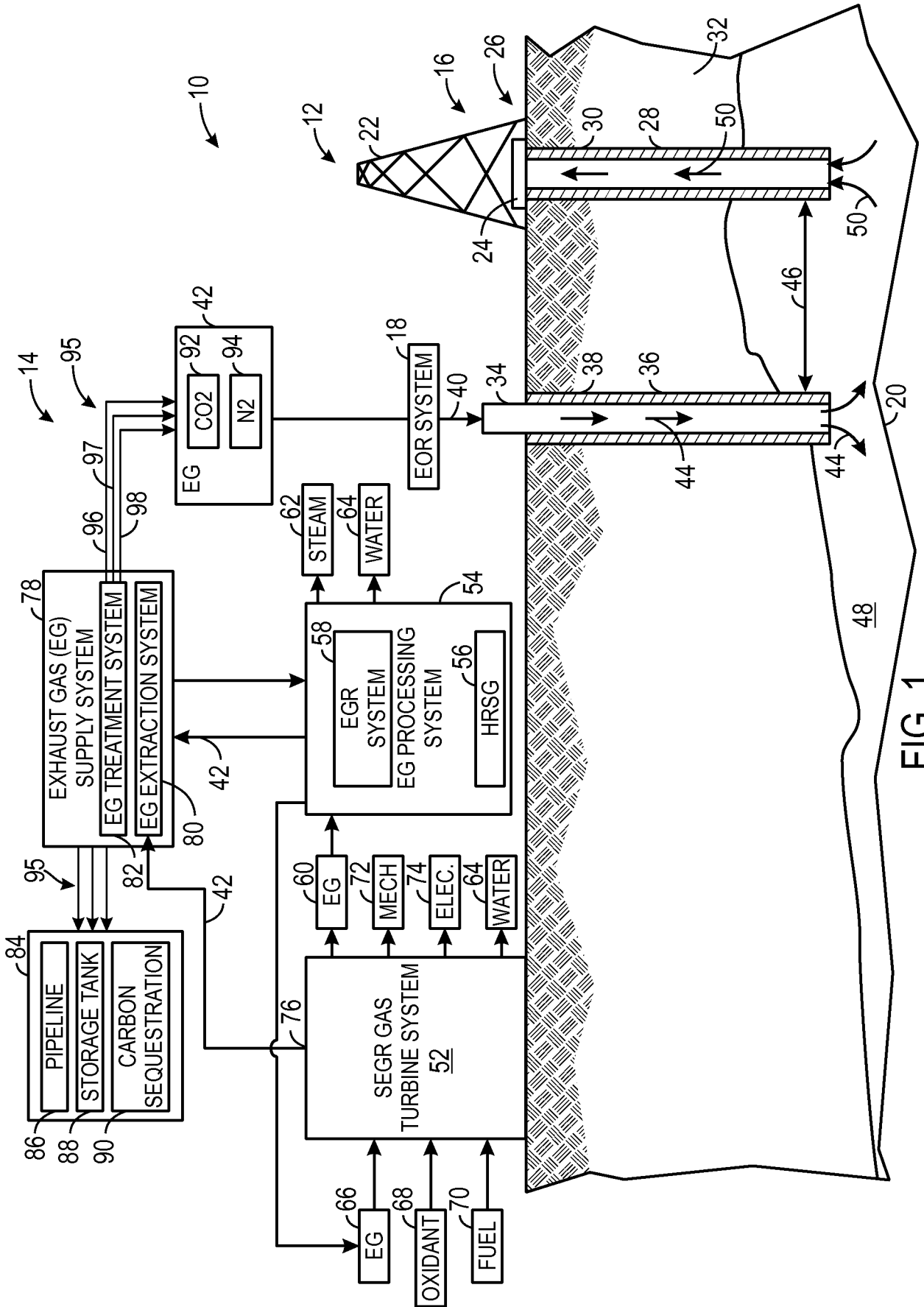


FIG. 1

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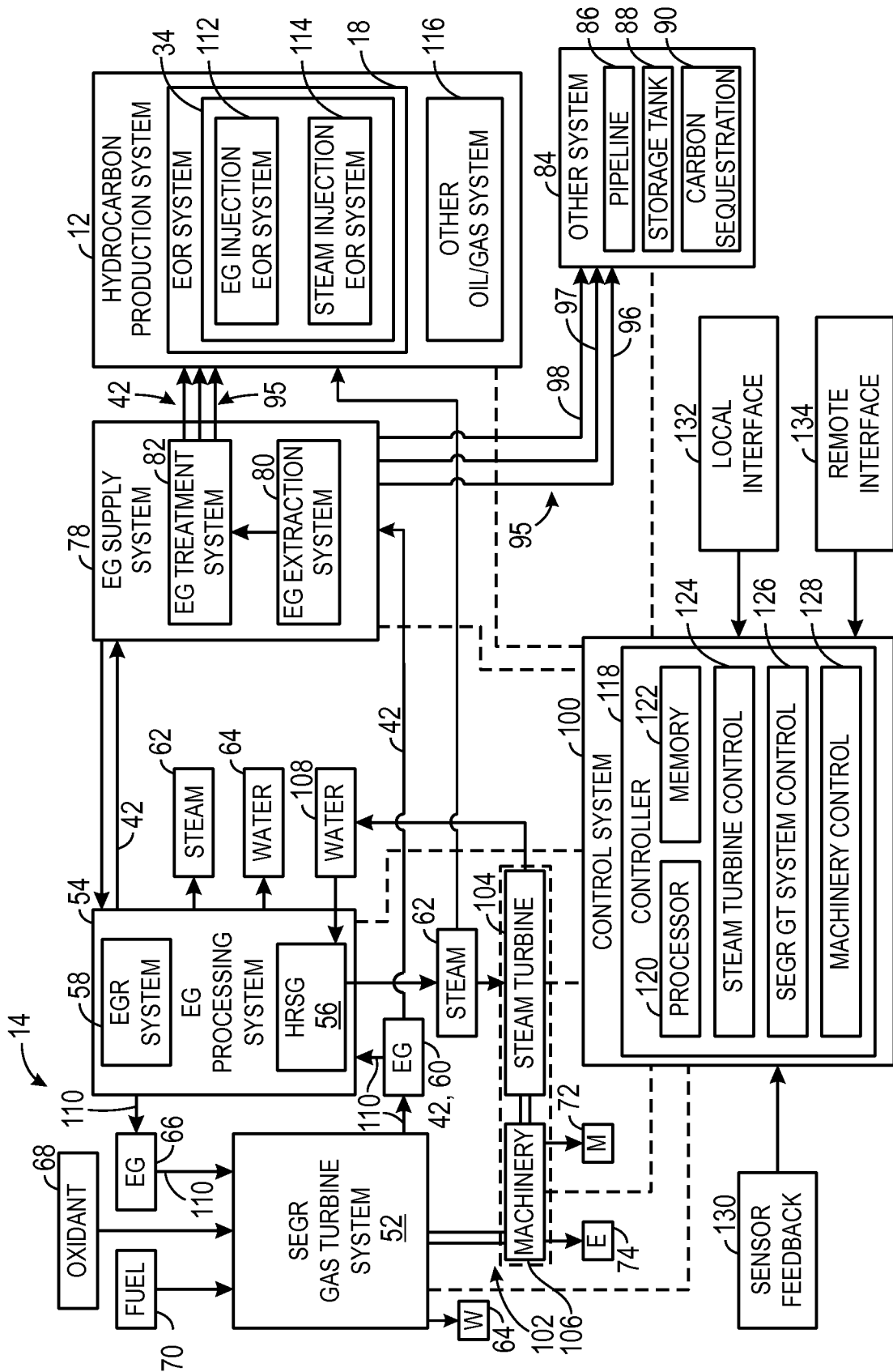


FIG. 2

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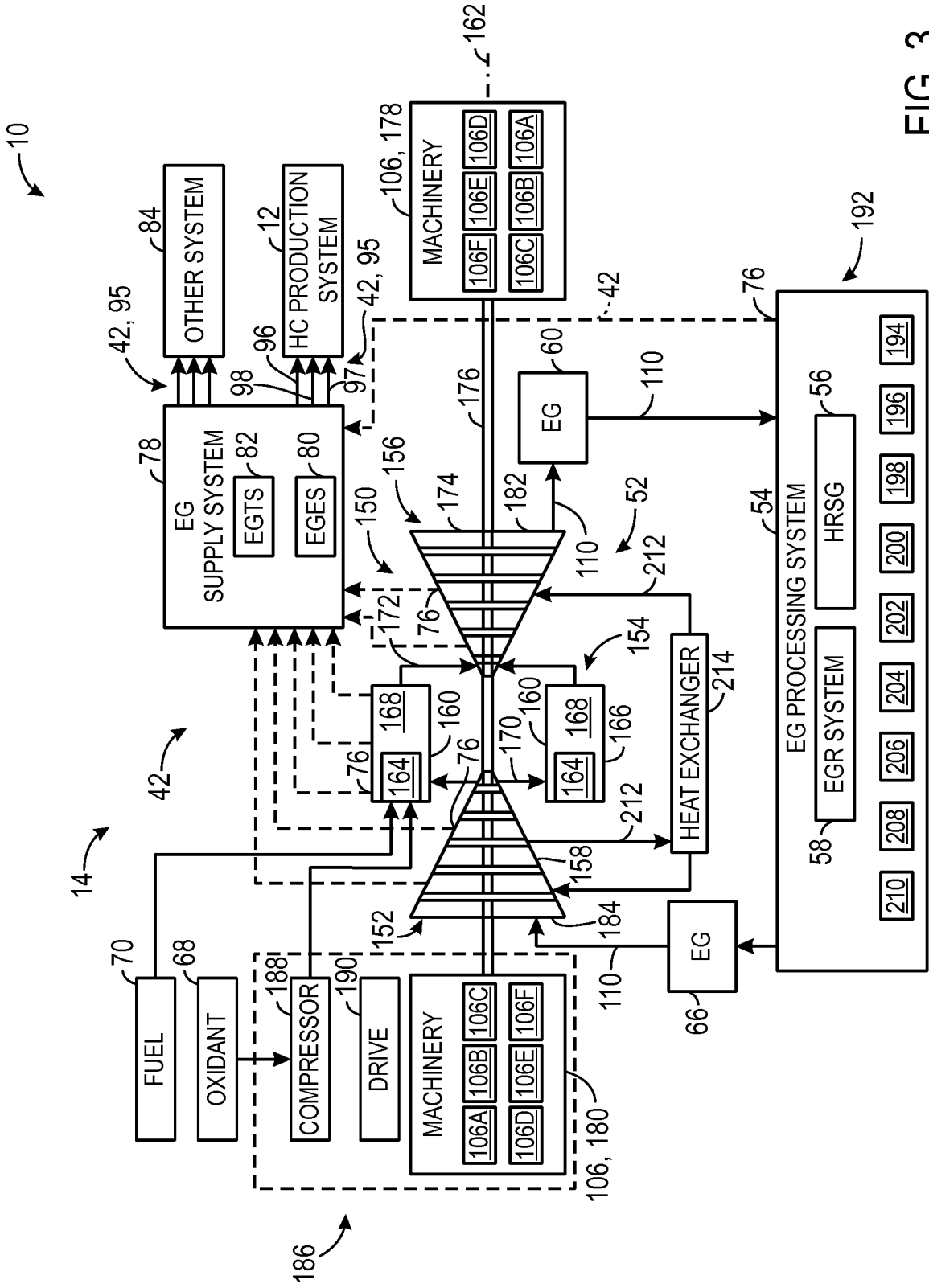


FIG. 3

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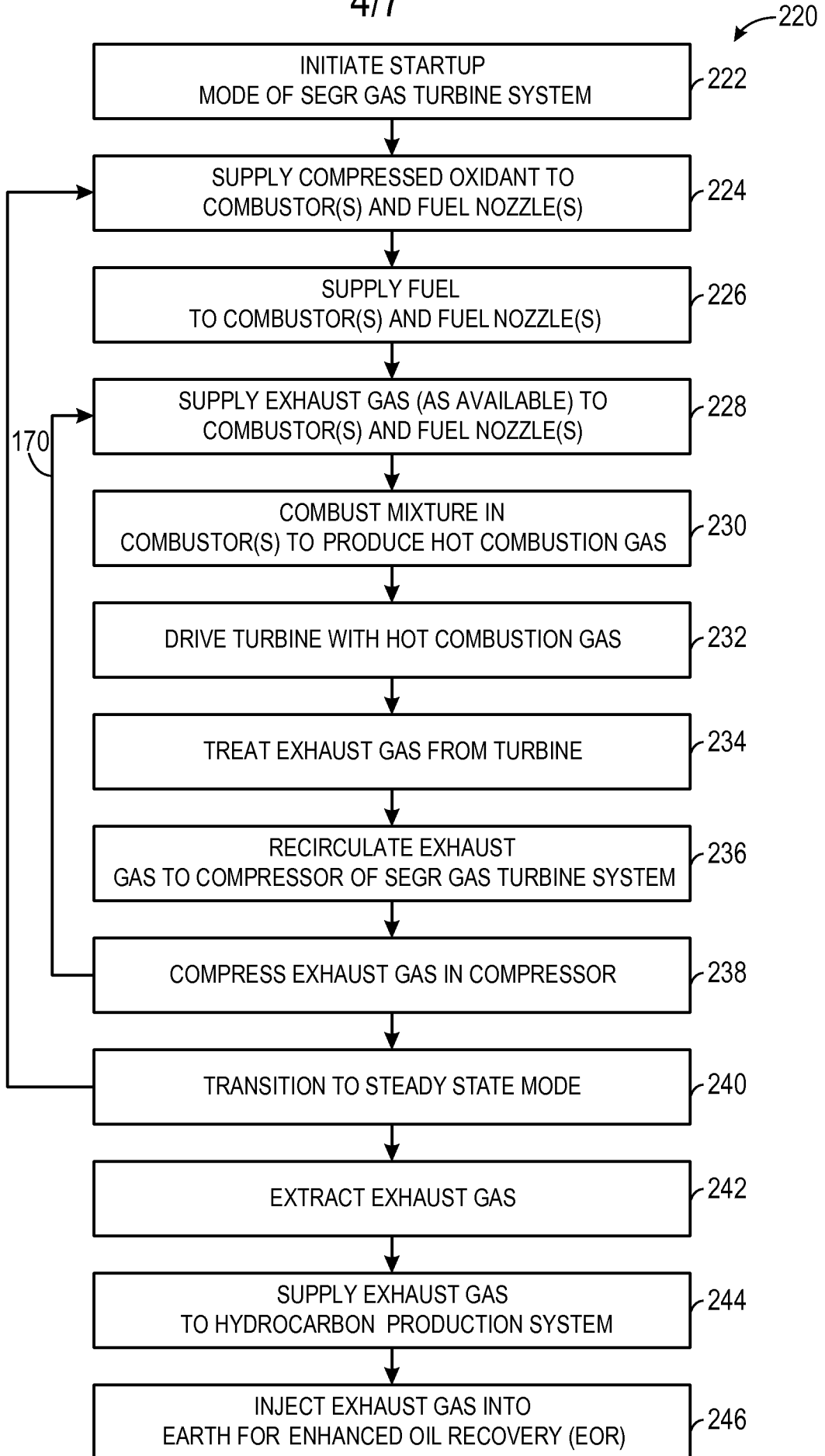


FIG. 4

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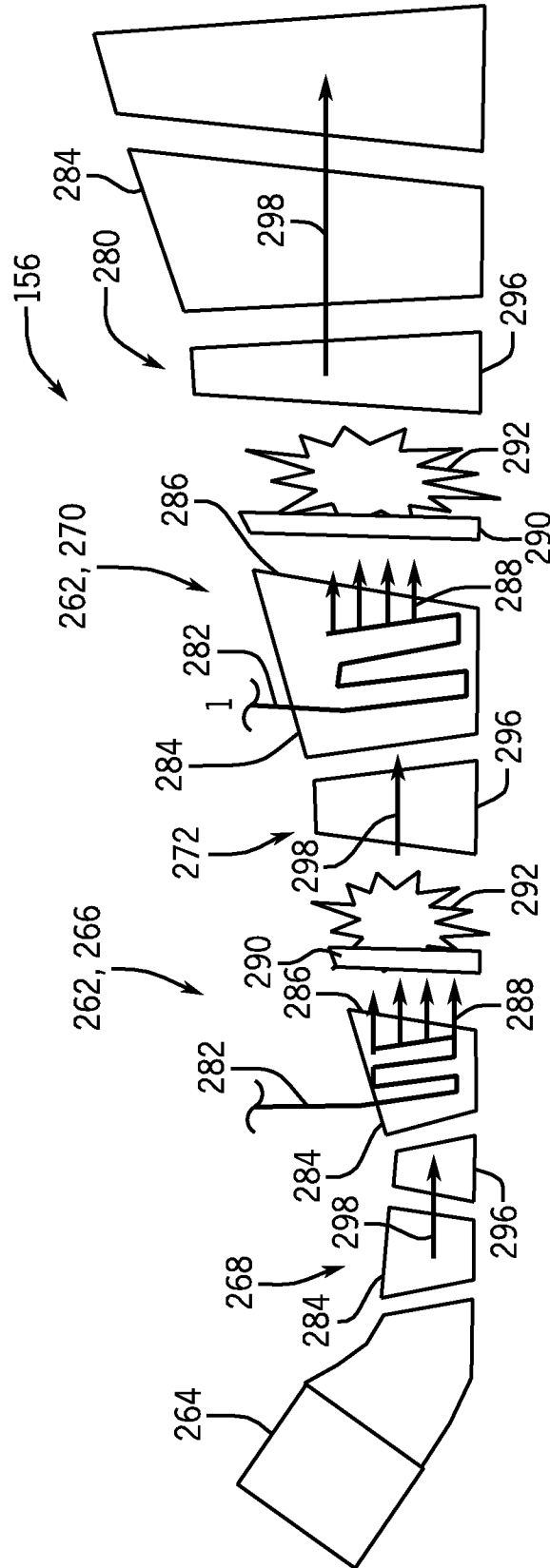
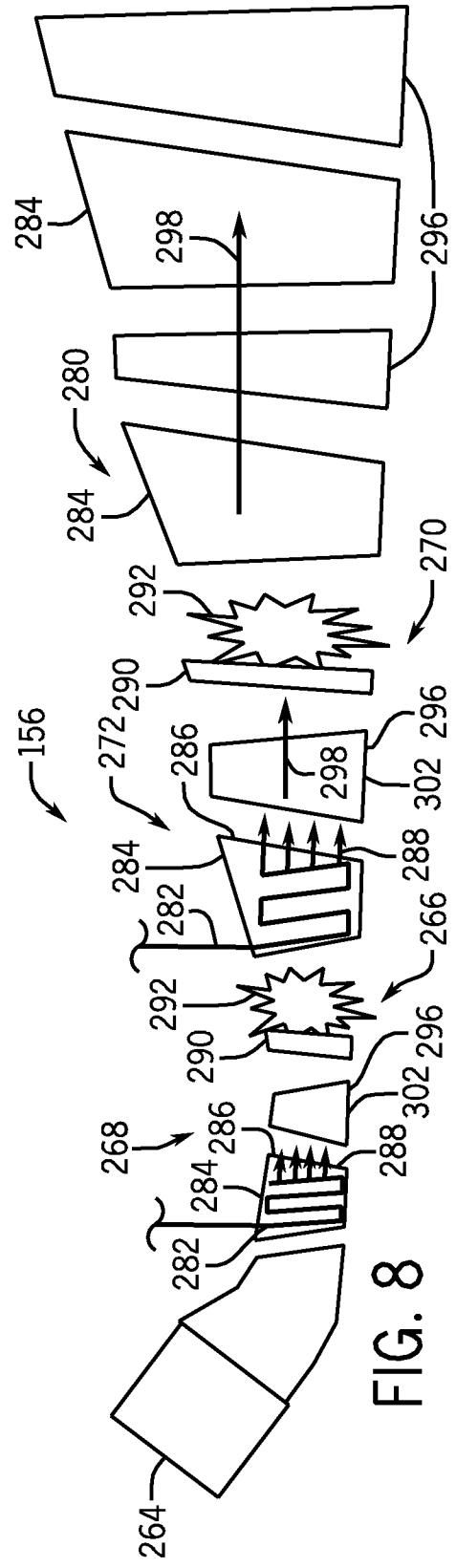
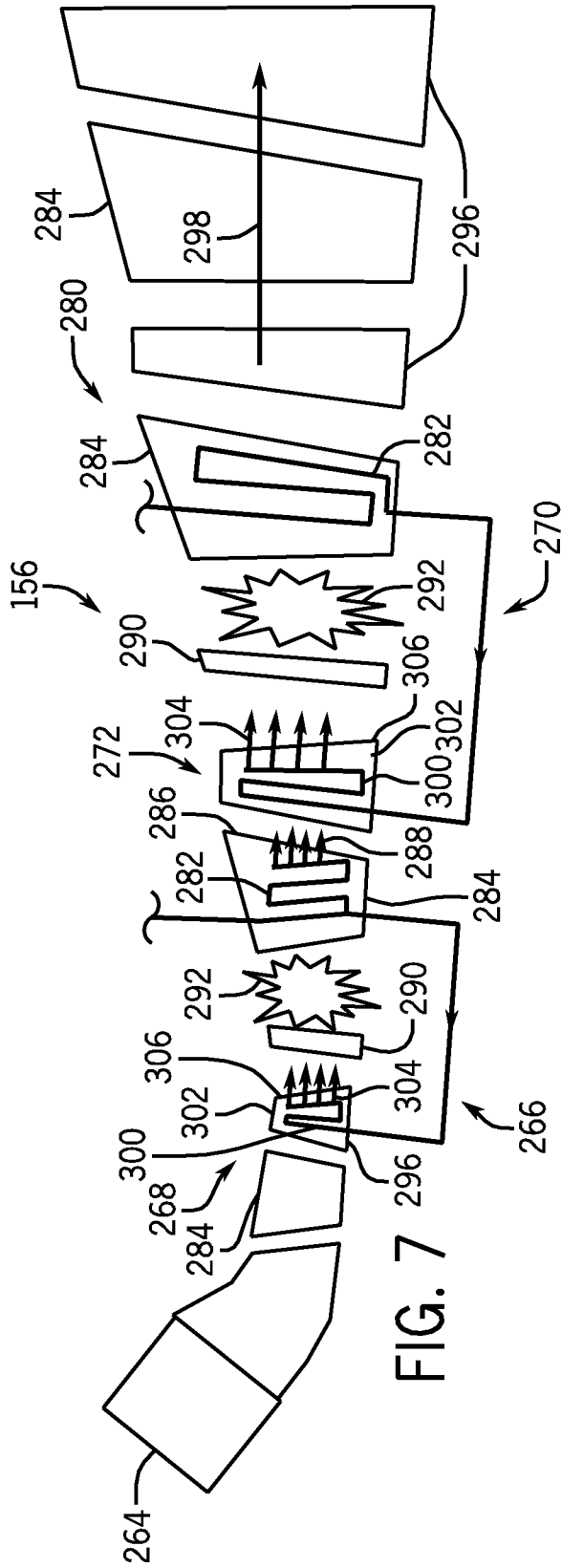


FIG. 6

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# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2013/067946

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. F02C3/34 F02C6/00 F02C7/18  
 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)  
 F02C

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, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/067056 A1 (PALMER MILES [US] ET AL) 22 March 2012 (2012-03-22)	1,2,27, 28,30, 31,39
Y	paragraphs [0045], [0046], [0049], [0050]; figure 1 -----	3-7, 11-26,32
X	US 2003/037533 A1 (CARELLI ERIC V [US] ET AL) 27 February 2003 (2003-02-27)	40-43
Y	paragraphs [0024] - [0027]; claim 1; figures 1,3,4 -----	3-7, 11-26,32
X	US 2012/090327 A1 (ROFKA STEFAN [CH] ET AL) 19 April 2012 (2012-04-19)	1,2,27, 28,30,31
Y	paragraphs [0040], [0044], [0045], [0053]; figure 4 -----	3,32
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Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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

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