



(51) International Patent Classification:

F02C 3/34 (2006.01)

(21) International Application Number:

PCT/US2014/015138

(22) International Filing Date:

6 February 2014 (06.02.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/761,671 6 February 2013 (06.02.2013) US
 14/173,683 5 February 2014 (05.02.2014) US

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(81) Designated States (unless otherwise indicated, for every

kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every

kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: SYSTEM AND METHOD FOR CATALYST HEAT UTILIZATION FOR GAS TURBINE WITH EXHAUST GAS RE-CIRCULATION

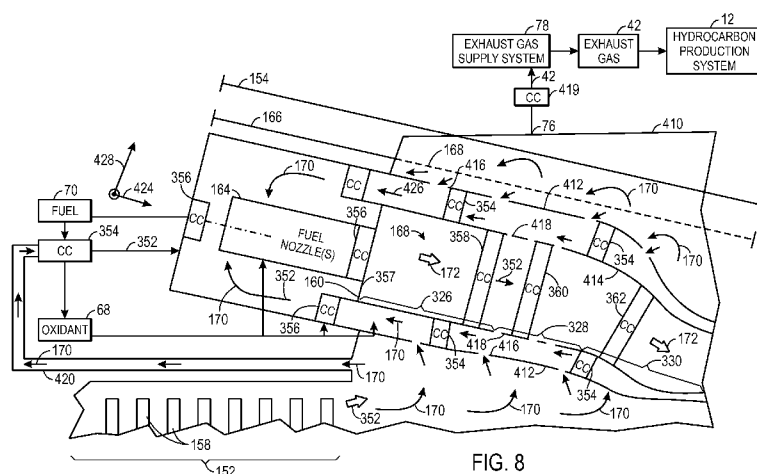


FIG. 8

(57) Abstract: A system includes a turbine combustor, a turbine, an exhaust gas compressor, a flow path, and at least one catalytic converter. The turbine is driven by combustion products from the turbine combustor. The exhaust compressor is configured to compress and route an exhaust gas from the turbine to the turbine combustor. The flow path leads from the exhaust gas compressor, through turbine combustor, and into the turbine. The catalytic converter is disposed along the flow path.

SYSTEM AND METHOD FOR CATALYST HEAT
UTILIZATION FOR GAS TURBINE WITH EXHAUST GAS
RECIRCULATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and benefit of U.S. Provisional Patent Application No. 61/761,671, entitled “SYSTEM AND METHOD FOR CATALYST HEAT UTILIZATION FOR GAS TURBINE WITH EXHAUST GAS RECIRCULATION,” filed on February 6, 2013, which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND OF THE INVENTION

[0002] The subject matter disclosed herein relates to gas turbines, and more specifically, to gas turbines with exhaust gas recirculation.

[0003] A gas turbine engine combusts a mixture of fuel and oxidant to generate hot exhaust gases, which in turn drive one or more turbine stages. In particular, the hot exhaust gases force turbine blades to rotate, thereby driving a shaft to rotate one or more loads. The exhaust gas is generally at an elevated temperature, and thus represents a source of waste heat not used by the gas turbine engine. As a result, the waste heat represents a loss of energy or efficiency of the gas turbine engine. Although the waste heat may be used in other systems, such as a heat recovery steam generator (HRSG), this use of the waste heat does not increase the energy recovery or efficiency of the gas turbine engine itself.

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 combustor, a turbine, an exhaust gas compressor, a flow path, and at least one catalytic converter. The turbine is driven by combustion products from the turbine combustor. The exhaust compressor is configured to compress and route an exhaust gas from the turbine to the turbine combustor. The flow path leads from the exhaust gas compressor, through turbine combustor, and into the turbine. The catalytic converter is disposed along the flow path.

[0006] In a second embodiment, a system includes a turbine combustion section configured to mount between an exhaust gas compressor and a turbine. The turbine combustion section includes at least one catalytic converter disposed along a flow path from the exhaust gas compressor into the turbine, through the turbine combustion section.

[0007] In a third embodiment, a method includes driving a turbine with combustion products from a turbine combustor and compressing an exhaust gas from the turbine in an exhaust gas compressor. The method also includes routing the exhaust gas along a flow path from the exhaust gas compressor, through the turbine combustor, and into the turbine. The method also includes catalytically converting a fluid flow along the flow path with at least one catalytic converter. The fluid flow includes the exhaust gas.

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 illustrates an embodiment of a method for catalytically converting exhaust gas recirculated along a catalytic flow path between a compressor section and a turbine section of a gas turbine engine;

[0014] FIG. 6 illustrates a block diagram of an embodiment of a gas turbine system with exhaust gas recirculation (EGR), illustrating with one or more catalytic converters along a catalytic flow path between a compressor section and a turbine section;

[0015] FIG. 7 is a schematic of an embodiment of a catalytic converter along a catalytic flow path;

[0016] FIG. 8 is a schematic of an embodiment of a gas turbine system, illustrating a compressor section and combustor section with one or more catalytic converters;

[0017] FIG. 9 is a block diagram of an embodiment of a gas turbine system, illustrating a system for catalytic partial oxidation combustion of an EGR flow between a compressor section and a turbine section; and

[0018] FIG. 10 is block diagram of an embodiment of a turbine-based service system with catalytic converters arranged along a catalytic flow path between a compressor section and a turbine section.

DETAILED DESCRIPTION OF THE INVENTION

[0019] 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.

[0020] 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.

[0021] 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 (CO₂) in the exhaust gas, which can then be post treated to separate and purify the CO₂ and nitrogen (N₂) 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

CO₂, 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 CO₂. 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 CO₂ production. Possible target systems include pipelines, storage tanks, carbon sequestration systems, and hydrocarbon production systems, such as enhanced oil recovery (EOR) systems.

[0022] FIG. 1 is a diagram of an embodiment of a system 10 having a 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.

[0023] 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.

[0024] 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 ϕ (Φ), 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_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), 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_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), 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_x , CO, SO_x , O_2 , N_2 , H_2 , 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).

[0025] 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.

[0026] 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.

[0027] 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_x emissions, such as nitrogen monoxide (NO) and nitrogen dioxide (NO₂). 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.

[0028] 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 CO₂, N₂, etc.).

[0029] 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 (N₂) 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 CO₂ rich, N₂ 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 CO₂, N₂ stream). The third stream 98 may have a third composition that is lean in carbon dioxide and/or rich in nitrogen (e.g., a CO₂ lean, N₂ 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 CO₂ rich, N₂ lean stream 96 may have a CO₂ purity or concentration level of greater than approximately 70, 75, 80, 85, 90, 95, 96, 97, 98, or 99 percent by volume, and a N₂ 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 CO₂ lean, N₂ rich stream 98 may have a CO₂ purity or concentration level of less than approximately 1, 2, 3, 4, 5, 10, 15, 20, 25, or 30 percent by volume, and a N₂ 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 CO₂, N₂ stream 97 may have a CO₂ purity or concentration level and/or a N₂ 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 CO₂ rich, N₂ lean stream 96 and the CO₂ lean, N₂ 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 CO₂ 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 CO₂ rich, N₂ lean streams 96, one or more CO₂ lean, N₂ rich streams 98, one or more intermediate concentration CO₂, N₂ streams 97, and one or more untreated exhaust gas 42 streams (i.e., bypassing the EG treatment system 82).

[0030] 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.

[0031] 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_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), 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_x), carbon monoxide (CO), sulfur oxides (e.g., SO_x), hydrogen, and other products of incomplete combustion. Thus, the exhaust gas 42 is particularly well suited for use with the EOR system 18.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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.

[0040] 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_x sensors), carbon oxides (e.g., CO sensors and CO₂ sensors), sulfur oxides (e.g., SO_x sensors), hydrogen (e.g., H₂ sensors), oxygen (e.g., O₂ sensors), unburnt hydrocarbons (e.g., HC sensors), or other products of incomplete combustion, or any combination thereof.

[0041] 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 CO₂, 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.

[0042] 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_x) 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_x) 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.

[0043] 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.

[0044] 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.

[0045] 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 CO₂ rich, N₂ lean stream 96, the intermediate concentration CO₂, N₂ stream 97, and the CO₂ lean, N₂ 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.

[0046] 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 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.

[0047] 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_x (e.g., NO and NO₂). 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.

[0048] 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_x 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_x emissions) produced by the diffusion flame.

[0049] 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.

[0050] 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).

[0051] 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.

[0052] 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.

106A	106B	106C	106D	106E	106F
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	LP MOC	GEN		

	STGN				
MOC	GEN	DRV			
MOC	DRV	GEN			
DRV	MOC	GEN			
DRV	CLU	MOC	GEN		
DRV	CLU	MOC	GBX	GEN	

TABLE 1

[0053] 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.

[0054] 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.

[0055] 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 CO₂ rich, N₂ lean stream 96,

the intermediate concentration CO₂, N₂ stream 97, and the CO₂ lean, N₂ 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).

[0056] 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

[0057] 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 INNER, 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.

[0058] 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).

[0059] 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.

[0060] 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.

[0061] 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 by the one or more diffusion flames, premix flames, or a combination of diffusion and premix flames. 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.

[0062] 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.

[0063] 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.

[0064] The compressed exhaust gas 170 circulates from the compressor section 152 (e.g., exhaust gas compressor) to the turbine section 156 through the combustor section 154 (e.g., turbine combustor) along a catalytic flow path. The exhaust gas 170 may flow along the catalytic flow path in the steps indicated by blocks 238, 228, 230, and 232. FIG. 5 illustrates a method 300 of directing the exhaust gas flow 170 along the catalytic flow path. The catalytic flow path directs at least the compressed exhaust gas 170 through one or more catalytic converters to react with products of incomplete combustion in the compressed exhaust gas 170. For example, the catalytic flow path may direct the exhaust gas 170 through one or more catalytic converters

with an oxidation catalyst, a carbon monoxide catalyst, or other type of catalyst. The one or more catalytic converters may react with at least some of the products of incomplete combustion in the compressed exhaust gas 170 (e.g., nitrogen oxides, carbon monoxide, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products). The one or more catalytic converters may also react with oxidant 68 or fuel 70 with the compressed exhaust gas 170. The catalytic converter may react with oxidant 68 (e.g., oxygen), carbon monoxide, and/or nitrogen oxides. Accordingly, the catalytic converter may convert carbon monoxide to carbon dioxide, reduce nitrogen oxides, reduce free oxygen (e.g., O₂) concentrations, or any combination thereof. The one or more catalytic converters described herein may increase the concentration and/or increase the purity of carbon dioxide in an exhaust gas flow utilized for enhanced oil recovery. FIG. 5 illustrates multiple catalytic conversion blocks 302 along the catalytic flow path at which a catalytic converter reacts with the compressed exhaust gas 170. The catalytic reaction may be exothermic and warm the compressed exhaust gas 170, thereby adding heat to the combustion reaction occurring in the combustors 160. The added heat may help improve the stability and efficiency of combustion, and provide more energy to be extracted via the turbine section. The method 300 of directing the compressed exhaust gas flow 170 along the catalytic flow path may include one or more of the catalytic conversion blocks 302.

[0065] As described above, the compressor section 152 compresses the exhaust gas at block 228. In some embodiments, the compressed exhaust gas 170 is directed from the compressor section 152 directly to a catalytic converter to react with the compressed exhaust gas 170, as indicated at block 304. The method 300 of FIG. 5 illustrates non-limiting examples of catalytic flow routes 306, 307, and 308 by which the compressed exhaust gas 170 may leave the compressor section 152. The first catalytic flow route 306 mixes the compressed exhaust gas 170 with fuel 70 at block 310, then mixes the compressed exhaust gas 170 and fuel 70 with the oxidant 68 at block 312. The first catalytic flow route 306 may include catalytic conversion of the compressed exhaust gas 170 as indicated by blocks 314 and 316. Accordingly, the compressed exhaust gas 170 may be catalytically converted after mixing with the fuel

70 or the oxidant 68. The second catalytic flow route 308 mixes the compressed exhaust gas 170 with the oxidant 68 at block 318, then mixes the compressed exhaust gas 170 and oxidant 68 with fuel 70 at block 320. The second catalytic flow route 308 may include catalytic conversion of the compressed exhaust gas 170 as indicated by blocks 322 and 324. The first and second catalytic flow routes 306, 308 may direct the compressed exhaust gas 170, fuel 70, and oxidant 68 to one or more premix fuel nozzles 164. Accordingly, the compressed exhaust gas 170 may be catalytically converted after mixing with the oxidant 68 or fuel 70. In some embodiments, the method 300 may direct the compressed exhaust gas 170 along the first catalytic flow routes 306 and/or the second catalytic flow routes 308 based at least in part on the composition of the compressed exhaust gas 170. For example, the catalytic conversion at block 314 with a first catalyst material may react better with a compressed exhaust gas 170 that has more unburnt fuel than the catalytic conversion at block 322 with a different second catalyst material. Moreover, in some embodiments, the method 300 mixes the compressed exhaust gas 170 with the oxidant 68 and the fuel 70 into a mixture approximately simultaneously, or the oxidant 68 and the fuel 70 may be premixed before mixing with the compressed exhaust gas 170. Blocks 306 to 324 of FIG. 5 may occur within the fuel nozzles 164 and/or head end portion 166 of the combustor 160. Additionally, at least some of blocks 306 to 324 may be sub-steps of blocks 224, 226, and 228 shown in FIG. 4.

[0066] In some embodiments, the compressed exhaust gas 170 may leave the compressor section 152 along the third catalytic flow route 307, such as for a diffusion flame within the combustor 160. The compressed exhaust gas 170 may mix the fuel 70 (block 310) separately from mixing with the oxidant 68 (block 318). The compressed exhaust gas 170 may dilute the fuel 70 at block 310 and/or dilute the oxidant 68 at block 318. The fuel 70 and any compressed exhaust gas 170 may be isolated from the oxidant 68 and any compressed exhaust gas 170 at block 325. In some embodiments, the fuel mixture and oxidant mixture are separated at block 325 and injected into the combustor 160 separately via one or more diffusion flame

nozzles 164. Accordingly, the oxidant 68, fuel 70, and compressed exhaust gas 170 may mix approximately at the diffusion flame within the combustor 160.

[0067] The compressed exhaust gas 170, oxidant 68, and fuel 70 may be combusted in the combustor 160 as indicated by block 230 of FIGS. 4 and 5. As discussed above, the compressed exhaust gas 170, oxidant 68, and fuel 70 may be mixed prior to injection into the combustor 160 via one or more premix fuel nozzles, mixed in the combustion chamber 160 via one or more diffusion flame nozzles, or any combination thereof. The composition of the mixture changes along the catalytic flow path through the combustor 160 as the mixture combusts. For example, the oxidant 68 and the fuel 70 may combust initially in a reaction zone 326. The combustion releases heat and breaks down the fuel 70 with the oxidant 68 and compressed exhaust gas 170 into the combustion gases 172. Compressed exhaust gas 170, compressed oxidant 68, and/or another diluent (e.g., steam, water, etc.) may enter the combustor 160 in a dilution zone 328, at least in part to cool the combustor 160 and/or combustion gas 172 downstream of the reaction zone 236. Gases entering the dilution zone 328 may reduce the formation and/or concentrations of nitrogen oxides by reducing the temperature within the combustor 160. In particular, some diffusion flame nozzles may improve stoichiometric combustion, resulting in higher flame temperatures. Dilution gases may cool the combustor 160 and/or flame to reduce the formation of nitrogen oxides.

[0068] The catalytic flow path passes through a transition piece 330 of the combustor section 154 prior to entering the turbine section 156. In the turbine section 156, the hot combustion gas 172 may drive the turbine stages 174 as indicated at block 332. In some embodiments, one or more catalytic converters in the combustor section 154 convert the compressed exhaust gas 170 and/or combustion gas 172 along the catalytic flow path prior to the turbine section 156. For example, some of the combustion mixture may undergo catalytic conversion at block 334, which may be located at or between the reaction zone 326 and the dilution zone 328. In some embodiments, the compressed exhaust gas 170 and/or combustion gas 172 may undergo catalytic conversion at block 336 after entering the dilution zone 328. In

some embodiments, the combustion gas 172 may undergo catalytic conversion at block 338 after entering the transition piece 330. The method 300 of directing the compressed exhaust gas 170 from the compressor section 152 to the turbine section 156 may include catalytic conversion with any combination of one or more blocks 302 as shown in FIG. 5.

[0069] FIG. 6 is a schematic illustrating some of the locations within the gas turbine system 52 where the catalytic conversion may occur in one or more catalytic converters 350. As described above with FIG. 3, the combustion gas 172 enters the turbine section 156 from the combustor section 154. The turbine section 156 outputs the exhaust gas 60 to recirculate along the exhaust recirculation path 110 from the exhaust outlet 182 to the exhaust inlet 184 into the compressor section 152. The compressor section 152 compresses the exhaust gas 66 and directs the compressed exhaust gas 170 along the catalytic flow path 352. Accordingly, fluids (e.g., exhaust gas 66) may flow along the catalytic flow path 352 and the exhaust recirculation path 110 in a loop until extracted into an exhaust gas supply system 78 and/or vented. The one or more catalytic converters 350 react with at least some of the products (e.g., nitrogen oxides, carbon monoxide, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products) of incomplete combustion in the fluid flows along the catalytic flow path 352. The one or more catalytic converters 350 may be arranged within the SEGR gas turbine system 52 to increase the concentration of carbon dioxide in the compressed exhaust gas 170 for use in enhanced oil recovery, to increase the heat added to the combustion mixture prior to expansion in the turbine section 156 for improved energy efficiency or energy attraction, or to affect the stoichiometry of the combustion, or any combination thereof. In some embodiments, the one or more catalytic converters 350 may aid diffusion flame combustion by reacting with residual materials along a flow route. For example, compressed exhaust gas 170 may be added to a fuel flow path to reduce the concentration of oxidant 68 in the fuel flow path prior to entering the combustor via the diffusion flame nozzle 164. In some embodiments, compressed exhaust gas 170 may be added to an oxidant flow

path to reduce the concentration of fuel 70 in the oxidant flow path prior to entering the combustor via the diffusion flame nozzle 164.

[0070] The catalytic converters 350 are numbered below for ease of reference as to the arrangement relative to the SEGR gas turbine system 52. Presently contemplated embodiments of the SEGR gas turbine system 52 are not limited to the locations or quantity of the catalytic converters 350 described below. Embodiments of the SEGR gas turbine system 52 may include any one or more of the catalytic converters 354, 356, 358, 360, and 362, or any combination thereof. For example, an embodiment of the SEGR gas turbine system 52 may include a first catalytic converter 354 and a second catalytic converter 356, but not a third catalytic converter 358, a fourth catalytic converter 360, or a fifth catalytic converter 362. Another embodiment of the SEGR gas turbine system 52 may include a second catalytic converter 356 and a fifth catalytic converter 362. Another embodiment may include only a first catalytic converter 354. In some embodiments, the SEGR gas turbine system 52 may include approximately 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or more catalytic converters 350 positioned along the catalytic flow path 352 between the compressor section 152 and the turbine section 156. The catalytic converters 350 may include compositions of an oxidation catalyst, a carbon monoxide 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 any combination thereof. In some embodiments, the catalyst compositions may react to convert carbon monoxide to carbon dioxide, to reduce oxygen (O_2) concentrations, to convert nitrogen oxides into nitrogen (N_2) and water (H_2O), or any combination thereof. In some embodiments, each of the catalytic converters 350 has substantially the same catalyst composition. In some embodiments, the catalytic converters 350 have different catalyst compositions based at least in part on the location of the catalytic converter 350. For example, a catalytic converter 350 proximate to the compressor section 152 may include a catalyst with a relatively strong and/or fast reaction to unburnt hydrocarbons, whereas a catalytic converter 350 proximate to the turbine section 156 may include a catalyst with a

relatively strong and/or fast reaction to oxides (e.g., nitrogen oxides, carbon monoxide, and/or sulfur oxides).

[0071] Some catalytic converters 350 may primarily react with only the compressed exhaust gas 170, only the fuel 70, or only the oxidant 68. The catalytic converters 350 may react with compressed exhaust gas 170, the fuel 70, or the oxidant 68, or any combination thereof. Reactions within the catalytic converters 350 may release additional energy in the form of heat to the compressed exhaust gas 170, the fuel 70, and/or the oxidant 68. The released heat from the catalytic converter 350 reduces the heat consumption of the HRSG 56 and increases the efficiency of the SEGR gas turbine system 52. Warmed constituents of the air/fuel mixture (e.g., for a premix flame and diffusion flame) may enable the control system 100 to reduce the intake of the fuel 70 and/or the oxidant 68 for combustion. That is, the released heat from the catalytic converter 350 enables less fuel 70 and/or less oxidant 68 to be combusted without substantially affecting the temperature (or energy) of the combustion gases 172 directed to the turbine section 156. Furthermore, heat added to the SEGR gas turbine system 52 may enable the energy from the additional heat to be extracted in the topping cycle (e.g., gas turbine system) rather than in a bottoming cycle (e.g., steam turbine system). In some embodiments, one or more catalytic converters 350 may increase a net efficiency of the SEGR gas turbine system 52 by more than approximately 0.1, 0.2, 0.3, 0.5, 1.0, 1.5, 2.0, or 2.5%,

[0072] The SEGR gas turbine system 52 may include the first catalytic converter 354 arranged between the compressor section 152 and the one or more fuel nozzles 164. The first catalytic converter 354 also receives and reacts with the compressed exhaust gas 170. The first catalytic converter 354 may receive and react with the oxidant 68 and/or the fuel 70. In some embodiments with diffusion fuel nozzles, first catalytic converter 354 may receive and react with one of the oxidant 68 and the fuel 70 separately to isolate the other of the oxidant 68 and the fuel 70 prior to the mixing in the combustor 160. The first catalytic converter 354 may be arranged internal or external to the gas turbine system (e.g., compressor section 152, combustor section 154, and turbine section 156).

[0073] The second catalytic converter 356 may be arranged with the one or more fuel nozzles 164 at the head-end portion 166 in the combustor section 154. The second catalytic converter 356 receives the compressed exhaust gas 170, and may receive the oxidant 68 and/or the fuel 70 as described with the first catalytic converter 354. In some embodiments, each of the one or more fuel nozzles 164 may have a second catalytic converter 356. In other embodiments, only some of the fuel nozzles 164 may have a second catalytic converter 356, such as approximately 10, 20, 25, 50, or 75% of the fuel nozzles 164. The second catalytic converters 356 may be arranged upstream of the one or more fuel nozzles 164, within the one or more fuel nozzles 164, or at a downstream end of the one or more fuel nozzles 164 adjacent to a combustion chamber 168.

[0074] The first catalytic converter 354 and/or the second catalytic converter 356 may affect the equivalence ratio of the stoichiometric combustion of the oxidant/fuel/exhaust gas mixture. The catalytic converters 350 may improve the efficiency of the stoichiometric combustion and reduce the concentrations of products of incomplete combustion of the combustion gas 172. As a result, overall combustion efficiency and net cycle efficiency may be improved. For example, the catalytic converter 350 may reduce the amount of carbon monoxide and increase the amount of carbon dioxide by converting the carbon monoxide to carbon dioxide. The carbon dioxide may be used to increase the effectiveness of the exhaust gas 170 for enhanced oil recovery. In some embodiments, the catalytic converters 350 may reduce the concentrations of carbon monoxide by approximately 90, 95, 96, 97, 98, or 99%. The first catalytic converter 354 and/or the second catalytic converter 356 may warm the compressed exhaust gas 170 through the catalytic reaction. The released heat energy may reduce exergetic losses due to temperature differences between the compressed exhaust gas 170 and the oxidant 68. In some embodiments, one or more of the first catalytic converter 354 or second catalytic converter 356 may increase the temperature (e.g., compressor discharge temperature) of the compressed exhaust gas 170 by approximately 8°C (15°F), 14°C (25°F), 28°C (50°F), 56°C, (100°F), or 112°C (200°F). For example, the first catalytic converter 354 may increase the compressor

discharge temperature of the compressed exhaust gas 170 from approximately 427°C (800°F) to approximately 449°C (840°F), or from approximately 427°C (800°F) to approximately 493°C (920°F).

[0075] The third catalytic converter 358 may be arranged within the reaction zone 326 of the combustor 160. The third catalytic converter 358 may affect the equivalence ratio of the stoichiometric combustion of the oxidant 68 and fuel 70 with the recirculated compressed exhaust gas 170. The fourth catalytic converter 360 may be arranged within the dilution zone 328 of the combustor section 154. The fourth catalytic converter 360 may react with the combustion gas 172 within the combustor 160. The fourth catalytic converter 360 may react with the compressed exhaust gas 170 or other diluent (e.g., water, steam, etc.) used to dilute the combustion gas 172 and to cool components of the combustor 160. The fifth catalytic converter 362 may be arranged within the transition piece 332 of the combustor section 154. The fifth catalytic converter 362 may react with the combustion gas 172 to reduce the amount and concentration of undesirable combustion products (e.g., hydrogen, oxygen, sulfur) while adding heat prior to entering the turbine section 156. Reducing the amount and concentration of some of the undesirable combustion products may increase the service life and/or reduce corrosion of components in the turbine section 156, such as the turbine blades. Adding heat to the combustion gas 172 may increase the efficiency and available energy to extract through the turbine section 156. The third, fourth, and fifth catalytic converters 358, 360, and 362 may increase the temperature of the combustion gases 172 by approximately 8°C (15°F), 14°C (25°F), 28°C (50°F), 56°C (100°F), or 112°C (200°F).

[0076] FIG. 7 illustrates an embodiment of a catalytic converter 350. The catalytic converter 350 may be positioned so that at least a first portion 380 of a fluid flow 382 along the catalytic flow path 352 flows through the catalytic converter 350. The fluid flow 382 along the catalytic flow path 352 includes at least compressed exhaust gas 170, and may include fuel 70, oxidant 68, and/or combustion gas 172. In some embodiments, the catalytic converter 350 is positioned such that substantially the entire fluid flow 382 flows through the catalytic converter 350. In other

embodiments, the catalytic converter 350 is positioned such that a first portion 380 flows through the catalytic converter 350, and a second portion 384 bypasses the catalytic converter 350. A controller 383 may monitor the fluid flow 382 via one or more sensors 385 in a first wall 392 and control the split between the first portion 380 and the second portion 384 based on sensor feedback 130 regarding concentrations of oxidant 68, fuel 70, carbon dioxide, carbon monoxide, nitrogen oxides, combustion products, or other components. The controller 383 may control the split between the first portion 380 and the second portion 384 to control the heat, nitrogen oxide concentration of the fluid flow 382, carbon dioxide concentration of the fluid flow 382, stoichiometric combustion of the fluid flow 382, or any combination thereof.

[0077] In some embodiments, the catalytic converter 350 may include one or more layers 386 with a catalyst material 388. The one or more layers 386 may be arranged in an interior volume 390 between a first wall 392 and a second wall 394. In some embodiments, the first wall 392 is a portion of combustor liner 414 about the combustor 160, and the second wall 394 is a portion of a flow sleeve 412. In some embodiments, the first and second walls 392, 394 are walls of a passage or interior volume between components of the SEGR gas turbine system 52, such as between the compressor section 152 and the combustor section 154.

[0078] A layer 386 may be a porous catalytic membrane, filter, or film with an impregnated or coated catalyst material 388. In some embodiments, a layer 386 may be a ceramic bed with a fixed or loose catalyst material 388. The catalyst material 388 may be an oxidation catalyst that causes oxidation of nitrogen oxides and/or sulfur oxides. In some embodiments, the catalyst material 388 is a carbon monoxide catalyst that oxidizes with carbon monoxide to form carbon dioxide. The catalyst material 388 may include, but is not limited to, one or more of the following components: 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. The layers 386 may be arranged in series or in parallel. The layers 386 of a catalytic converter 350 may include the same or different catalyst materials 388. In some embodiments, the catalytic converter 350 may be a coating, film, or passageway on a

wall of a component along the catalytic flow path between the compressor section 152 and the combustor section 154. A portion of the combustor liner 414, flow sleeve 412, head end wall, fuel nozzles 164, may be coated with the material of the catalytic converter 350. For example, the first and second walls 392, 394 may be one wall that extends about the fluid flow 382.

[0079] The catalytic converter 350 may include one or more layers 386, including, but not limited to, 1, 2, 3, 4, 5, 10, 15, 20, or more layers. The embodiment of FIG. 7 illustrates four layers 386 with the different catalyst materials 388. For example, the catalyst material 388 of a first layer 396 may react primarily with nitrogen oxides, the catalyst material 388 of a second layer 398 may react primarily with carbon monoxide, and the catalyst material 388 of a third layer 400 may react primarily with unburnt hydrocarbons in the first portion 380 of the fluid flow 382. In some embodiments, each layer 386 has substantially the same catalyst material 388. The catalyst material 388 may vary between catalytic converters 350 based at least in part on the position of the catalytic converter 350. The portion 380 of the fluid flow 382 exiting the catalytic converter 350 along the catalytic flow path 352 may be warmer than the portion 380 of the fluid flow 382 entering the catalytic converter 350. The portion 380 of the fluid flow 382 exiting the catalytic converter 350 may have a reduced concentration of carbon monoxide, nitrogen oxides, sulfur oxides, and/or unburnt fuel than the portion 380 entering the catalytic converter 350.

[0080] FIG. 8 illustrates a schematic of a compressor section 152 and combustor section 154 with one or more catalytic converters 350. As described above in FIG. 6, the one or more catalytic converters 350 may be arranged at various positions along the catalytic flow path 352 between the compressor section 152 and the turbine section 156. The compressor section 152 directs the compressed exhaust gas 170 from the compressor stages 158 into a compressor discharge casing 410, which encloses at least part of the combustor 160 of the combustor section 154 (e.g., the combustion chamber 168) surrounded by a combustor liner 414 and a flow sleeve 412. The flow sleeve 412 may direct the compressed exhaust gas 170 to the head end portion 166. In some embodiments, the flow sleeve 412 also receives the oxidant 68.

Gas (e.g., oxidant 68 and/or compressed exhaust gas 170) within the flow sleeve 412 may cool the combustor liner 414 that encloses the combustion chamber 168. The compressed exhaust gas 170 in the compressor discharge casing 410 may enter the flow sleeve 412 through passages 416. Some of the compressed exhaust gas 170, other diluent (e.g., steam, water), or oxidant 68 may enter the combustion chamber 168 through dilution holes 418 in the combustor liner 414. The dilution holes 418 may direct the compressed exhaust gas 170 and/or oxidant 68 into the dilution zone 328. As discussed above, some of the compressed exhaust gas 170 may be extracted through an extraction point 76 to the exhaust gas supply system 78 external to the compressor discharge casing 410. In some embodiments, a catalytic converter 419 may be at or near the extraction point 76 of the compressor discharge casing 410. The exhaust gas supply system 78 may treat and supply the exhaust gas 42 to the hydrocarbon production system 12, such as for enhanced oil recovery.

[0081] In some embodiments, one or more first catalytic converters 354 may be arranged internally within the compressor discharge casing 410, such as between the flow sleeve 412 and the combustor liner 414. In some embodiments, an external passage 420 from the compressor discharge casing 410 may direct the compressed exhaust gas 170 to a first catalytic converter 354 external to the discharge casing 410. As described above, one or more second catalytic converters 356 may be arranged within the head end portion 166 of the combustor section 154. In some embodiments, the second catalytic converters 356 are arranged upstream of the fuel nozzles 164 relative to the flow of the compressed exhaust gas 170 through the combustor section 154. A cap 357 divides the combustor 160 into the head end portion 166 and the combustion portion 168. The fuel nozzles 164 are positioned in the head end portion 166, and flames, if any, from combustion occur within the combustion portion 168. In some embodiments, the second catalytic converters 356 are arranged within the one or more fuel nozzles 164. The second catalytic converters 356 described above may be defined to be arranged internal to the SEGR gas turbine system 52 and the combustor section 154. The first catalytic converters 354 described above may be arranged either internal or external to the SEGR gas turbine system 52.

[0082] Some embodiments of the combustor 160 may include a third catalytic converter 358 in the combustion zone 326, a fourth catalytic converter 360 in the dilution zone 328, and/or a fifth catalytic converter 362 in the transition piece 330. The third, fourth, and/or fifth catalytic converters 358, 360, and 362 may enable substantially complete catalytic combustion of the oxidant 68, fuel 70, and compressed exhaust gas 170 mixture. Catalytic combustion may enable the release of energy from the fuel 70 substantially without a flame inside the combustor by catalytic reaction with the oxidant 68 and the fuel 70. In some embodiments of catalytic combustion, the SEGR gas turbine system 52 may release energy from the fuel 70 without a flame utilizing only catalytic converters 350 within the combustor 160 (e.g., third, fourth, and/or fifth catalytic converters 358, 360, and 362). Substantially complete catalytic combustion may be combustion with an equivalence ratio between approximately 0.90 to 1.10, such that the combustion gases 172 have reduced concentration levels of products of incomplete combustion. Catalytic combustion may reduce concentration levels of nitrogen oxides, carbon monoxide, sulfur oxides, hydrogen, oxygen, unburnt hydrocarbons, and other products of incomplete combustion. Catalytic combustion may enable reduced concentration levels of such products and/or low temperature combustion gas 172 relative to conventional combustion with a flame. Catalytic combustion may increase the production of carbon dioxide by converting carbon monoxide to carbon dioxide, and by reacting the oxidant 68 and the fuel 70 without a flame. The carbon dioxide may be utilized for enhanced oil recovery and other applications if extracted from the SEGR gas turbine system 52.

[0083] It may be appreciated that the combustion portion 154 may be arranged about an axis 422 with the combustor liner 414 and flow sleeve 412 extending circumferentially about the axis 422. The combustion gases 172 flow through the combustion chamber 168 primarily in a downstream direction 424 toward the turbine section 156. The compressed exhaust gas 170 and/or the oxidant 68 may flow toward the head end portion 166 from the compressor section 152 in an upstream direction 426 relative to the combustion gases 172 through the flow sleeve 412. The one or

more first and second catalytic converters 354, 356 may be arranged within the combustor section 154 spaced in a radial direction 428 from the axis 422.

[0084] FIG. 9 illustrates an embodiment of the SEGR gas turbine system 52 with a catalytic converter 350 that may be used in catalytic partial oxidation (CPOX) combustion. The exhaust recirculation path 110, compressor section 152, and turbine section 156 of FIG. 9 may operate substantially similar as described above with FIGS. 3 and 6. The sixth catalytic converter 440 may have several components, such as a reformer 442, a shift reactor 444, and a separation unit 446. The reformer 442 may receive the fuel 70 and at least some of the compressed exhaust gas 170 and/or compressed oxidant 68 from the oxidant compressor 188. The reformer 442 may convert (i.e., reform) the fuel 70 to a syngas 448 (e.g., hydrogen (H_2) and carbon monoxide) by partial oxidation and/or steam reforming. The compressed exhaust gas 170 may improve the partial oxidation of the fuel 70 into the syngas 448. The shift reactor 444 receives the syngas 448, compressed exhaust gas 170, and oxidant 68, and then converts (i.e., shifts) the syngas 448 into carbon dioxide 92 (CO_2) and hydrogen 450 (H_2). The shift reactor may convert the syngas 445 by a water-gas shift reaction. The separation unit 446 may separate the carbon dioxide 92 from the hydrogen 450, and direct the hydrogen 450 to the one or more fuel nozzles 164. The carbon dioxide 92 may be directed to a storage tank 88 or to a carbon sequestration system 90. The separated carbon dioxide 92 may be utilized as a diluent gas and/or for enhanced oil recovery as described above. The hydrogen 450, oxidant 68, and compressed exhaust gas 170 may undergo stoichiometric combustion in the combustor section 154. The stoichiometric combustion may be conventional combustion (e.g., with a flame) utilizing one or more premix fuel nozzles and/or one or more diffusion fuel nozzles. In some embodiments, stoichiometric combustion may be catalytic combustion (e.g., without a flame). Some embodiments of the combustor section 154 may have one or more catalytic converters 350 in addition to the sixth catalytic converter 440.

[0085] FIG. 10 illustrates an embodiment of the system 10 with catalytic converters 350 along the catalytic flow path 352 between the compressor section 152 and the turbine section 156 of the SEGR gas turbine system 52. As described above

with reference to FIGS. 4-8, one or more catalytic converters 350 may be arranged at any point along the catalytic flow path 352 to react with the compressed exhaust gas 170 and to reduce the concentration of products of incomplete combustion from the combustion gas 172. The combustion gas 172 flows along the exhaust recirculation path 110 from the turbine section 156 into the HRSG 56 of the exhaust gas processing system 54. In the HRSG 56, heat is extracted in the bottoming cycle to produce steam 62. In some embodiments, the steam 62 is directed to the combined cycle system 102 with a steam turbine 104 to extract energy from the steam 62, such as by driving machinery 106 (e.g., generator), to produce electricity. In some embodiments, the heat from the HRSG 56 may be used in a fuel desulfurization system 460 and/or a fuel heating system 462 to treat the fuel 70 supplied to the one or more fuel nozzles 164 in the combustors 160. A catalytic converter 350 may be arranged along the catalytic flow path 352 and another catalytic converter 350 may be arranged along the exhaust recirculation path 110, such as within the HRSG 56 or the EGR system 58. The catalytic converters 350 in the exhaust gas processing system 54 may reduce the concentrations of the oxidant 68, unburnt fuel 70, or other component materials. The catalytic converters 350 may convert carbon monoxide to carbon dioxide, thus increasing the concentration of carbon dioxide that may be used for enhanced oil recovery.

[0086] The exhaust gas 62 that exits the HRSG 56 may pass through the EGR system 54, or vice versa, along the exhaust recirculation path 110 before recirculating to the compressor section 152. In some embodiments, the compressor section 152 compresses the exhaust gas 66 separate from the oxidant compressor 188 (e.g., main air compressor). The compressor section 152 and/or the oxidant compressor 188 may be driven by the turbine section 156 and/or the steam turbine 104. The oxidant 68 from the oxidant compressor 188 may mix with the compressed exhaust gas 170 and fuel 70 in the combustor 160 or the catalytic converter 350. In some embodiments, compressed nitrogen oxides, oxidant 68, or other gases from the main air compressor 188 may be directed through a first valve 464 to mix with compressed exhaust gas 170 in the exhaust gas supply system 78. The gases from the main air compressor

188 may react be used to reduce the concentrations of carbon monoxide in the compressed exhaust gas 170. The exhaust gas supply system 78 may mix the main air compressor gases and the compressed exhaust gas 170 into a mixture 466 at a second valve 468 and cool the mixture 466 in a purge cooler 470. In some embodiments, the main air compressor gases may dilute the carbon monoxide concentrations in the mixture 466. In some embodiments, a catalytic converter 350 within the purge cooler 470 may reduce the concentration levels of products of incomplete combustion (e.g., carbon monoxide, nitrous oxides, etc.) in the mixture 466 by reacting with the oxidant 68 in the mixture 466. The exhaust gas 42 may exit the exhaust gas supply system 78 as one or more streams 95 (e.g., first stream 96, second stream 97, third stream 98) with differing concentration levels of nitrogen (N_2) and carbon dioxide 92 (CO_2).

[0087] The SEGR gas turbine systems 52 described above may utilize one or more catalytic converters 350 between the compressor section 152 and the turbine section 156. In some embodiments, one or more catalytic converters 350 may be arranged along an exhaust recirculation path 110 to reduce the concentrations of residual fuel 70 and/or oxidant 68 in the exhaust gas 66. For example, a combustor section 154 having one or more diffuser fuel nozzles 164 may separate the oxidant 68 and the fuel 70 until injection into the combustor 160 where the oxidant 68 and fuel 70 mix at the diffusion flame. The one or more catalytic converters 350 of the SEGR gas turbine system 52 may include compositions of an oxidation catalyst, a carbon monoxide 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 any combination thereof.

[0088] Gases with high concentrations of carbon dioxide may be utilized in enhanced oil recovery systems 18. The gases used for EOR may have low concentrations (e.g., substantially zero) of oxidant 68, fuel 70, and/or other components (e.g., nitrogen oxides, water). The catalytic converters 350 may increase the concentrations of carbon dioxide in the exhaust gas 42 by converting carbon monoxide to carbon dioxide and by bringing the equivalence ratio to approximately 1.0 (e.g., between 0.95 and 1.05). The catalytic converters 350 described above may

reduce the concentrations of oxidant 68 and fuel 70 in compressed exhaust gas 170 between the compressor section 152 and the turbine section 156. The added heat from the catalytic converters between the compressor section 152 and the turbine section 156 may improve the flame stability and energy extraction from the SEGR gas turbine system 52. In some embodiments, the catalyst compositions may react to convert carbon monoxide to carbon dioxide, to reduce oxygen (O₂) concentrations, to convert nitrogen oxides into nitrogen (N₂) and water (H₂O), or any combination thereof. The exhaust gas, or the carbon dioxide extracted from the exhaust gas, may be utilized by a fluid injection system 36 for enhanced oil recovery.

[0089] 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.

ADDITIONAL DESCRIPTION

[0090] The present embodiments provide a system and method for utilizing heat from catalytic reactions within an exhaust gas recirculation gas turbine system. 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:

[0091] Embodiment 1. A system, having: a turbine combustor, a turbine driven by combustion products from the turbine combustor, and an exhaust gas compressor, wherein the exhaust gas compressor is configured to compress and supply an exhaust gas to the turbine combustor. The system also includes a flow path and at least one

catalytic converter disposed along the flow path. The flow path is from the exhaust compressor, through the turbine combustor, and into the turbine.

[0092] Embodiment 2. The system of embodiment 1, wherein the at least one catalytic converter includes an oxidation catalyst, a carbon monoxide 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.

[0093] Embodiment 3. The system of any preceding embodiment, wherein the at least one catalytic converter includes a shift reactor.

[0094] Embodiment 4. The system of embodiment 3, wherein the at least one catalytic converter includes a reformer disposed upstream from the shift reactor.

[0095] Embodiment 5. The system of embodiment 3, wherein the at least one catalytic converter includes a carbon sequestration system disposed downstream from the shift reactor.

[0096] Embodiment 6. The system of any preceding embodiment, wherein the at least one catalytic converter includes one or more catalytic membranes.

[0097] Embodiment 7. The system of any preceding embodiment, wherein the system includes a gas turbine engine having the turbine combustor, the turbine, and the exhaust gas compressor.

[0098] Embodiment 8. The system of embodiment 7, wherein the at least one catalytic converter is disposed external to the gas turbine engine.

[0099] Embodiment 9. The system of embodiment 7, wherein the at least one catalytic converter is disposed internal to the gas turbine engine.

[00100] Embodiment 10. The system of embodiment 7, wherein the system includes an exhaust gas supply system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas supply system.

[00101] Embodiment 11. The system of embodiment 7, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.

[00102] Embodiment 12. The system of any preceding embodiment, wherein the at least one catalytic converter is disposed inside a compressor discharge casing.

[00103] Embodiment 13. The system of any preceding embodiment, wherein the at least one catalytic converter is coupled to the turbine combustor.

[00104] Embodiment 14. The system of embodiment 13, wherein the turbine combustor includes a first wall disposed about an interior volume, and a second wall disposed about the first wall. The at least one catalytic converter is disposed between the first and the second walls.

[00105] Embodiment 15. The system of embodiment 13, wherein the turbine combustor includes at least one wall disposed about an interior volume, a cap dividing the interior volume into a head end portion and a combustion portion, and at least one fuel nozzle disposed in the head end portion. The at least one catalytic converter is disposed within the head end portion.

[00106] Embodiment 16. The system of embodiment 13, wherein the turbine combustor includes at least one wall disposed about an interior volume, a cap dividing the interior volume into a head end portion and a combustion portion, and at least one fuel nozzle disposed in the head end portion. The at least one catalytic converter is disposed within the combustion portion.

[00107] Embodiment 17. The system of embodiments 13, wherein the at least one catalytic converter is coupled to a fuel nozzle within the turbine combustor.

[00108] Embodiment 18. A system includes a turbine combustion section configured to mount between an exhaust gas compressor and a turbine. The turbine combustion section includes at least one catalytic converter disposed along a flow path from the exhaust gas compressor, through the turbine combustion section, and into the turbine.

[00109] Embodiment 19. The system of embodiment 18, wherein the at least one catalytic converter includes an oxidation catalyst, a carbon monoxide 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.

[00110] Embodiment 20. The system of embodiments 18 or 19, wherein the at least one catalytic converter includes a shift reactor.

[00111] Embodiment 21. The system of embodiments 18, 19, or 20, wherein the turbine combustion section includes a turbine combustor, wherein the at least one catalytic converter is coupled to the turbine combustor.

[00112] Embodiment 22. The system of embodiment 21, wherein the turbine combustor includes a combustion zone, wherein the at least one catalytic converter is disposed within the combustion zone.

[00113] Embodiment 23. The system of embodiments 18, 19, 20, or 21, wherein the turbine combustion section includes a fuel nozzle, wherein the at least one catalytic converter is coupled to the fuel nozzle.

[00114] Embodiment 24. The system of embodiments 18, 19, 20, 21, 22, or 23, wherein the turbine combustion section includes a transition piece. The at least one catalytic converter is coupled to the transition piece.

[00115] Embodiment 25. A method, including driving a turbine with combustion products from a turbine combustor, compressing an exhaust gas from the turbine in an exhaust gas compressor, and routing the exhaust gas along a flow path from the exhaust gas compressor through the turbine combustor, and into the turbine. The method also includes catalytically converting a fluid flow along the flow path with at least one catalytic converter, wherein the fluid flow includes the exhaust gas.

[00116] Embodiment 26. The method of embodiment 25, including combusting a mixture of the exhaust gas and a fuel within the turbine combustor.

[00117] Embodiment 27. The method of embodiment 26, wherein the mixture is combusted stoichiometrically.

[00118] Embodiment 28. The method of embodiments 25, 26, or 27, including extracting a portion of the exhaust gas and routing the portion of the exhaust gas to a hydrocarbon production system.

[00119] Embodiment 29. The system of embodiments 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, or 17, wherein the turbine combustor is configured to combust a mixture of a fuel and an oxidant with an equivalence ratio of approximately 0.95 to approximately 1.05.

[00120] Embodiment 30. The system of embodiments 21, 22, 23, or 24, wherein the turbine combustor is configured to combust a mixture of a fuel and an oxidant with an equivalence ratio of approximately 0.95 to approximately 1.05.

[00121] Embodiment 31. The method of embodiments 26, 27, or 28, wherein the mixture has an equivalence ratio of approximately 0.95 to approximately 1.05.

CLAIMS:

1. A system, comprising:
 - a turbine combustor;
 - a turbine driven by combustion products from the turbine combustor;
 - an exhaust gas compressor, wherein the exhaust gas compressor is configured to compress and route an exhaust gas from the turbine to the turbine combustor;
 - a flow path from the exhaust gas compressor, through the turbine combustor, and into the turbine; and
 - at least one catalytic converter disposed along the flow path.
2. The system of claim 1, wherein the at least one catalytic converter comprises an oxidation catalyst, a carbon monoxide 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.
3. The system of claim 1, wherein the at least one catalytic converter comprises a shift reactor.
4. The system of claim 3, wherein the at least one catalytic converter comprises a reformer disposed upstream from the shift reactor, a carbon sequestration system disposed downstream from the shift reactor, or any combination thereof.
5. The system of claim 1, wherein the at least one catalytic converter comprises one or more catalytic membranes.
6. The system of claim 1, comprising a gas turbine engine having the turbine combustor, the turbine, and the exhaust gas compressor.
7. The system of claim 6, wherein the at least one catalytic converter is disposed external to the gas turbine engine.

8. The system of claim 6, wherein the at least one catalytic converter is disposed internal to the gas turbine engine.
9. The system of claim 6, comprising an exhaust gas supply system coupled to the gas turbine engine, and a hydrocarbon production system coupled to the exhaust gas supply system.
10. The system of claim 6, wherein the gas turbine engine is a stoichiometric exhaust gas recirculation (SEGR) gas turbine engine.
11. The system of claim 1, wherein the at least one catalytic converter is disposed inside a compressor discharge casing.
12. The system of claim 1, wherein the at least one catalytic converter is coupled to the turbine combustor.
13. The system of claim 12, wherein the turbine combustor comprises a first wall disposed about an interior volume, and a second wall disposed about the first wall, wherein the at least one catalytic converter is disposed between the first wall and the second wall.
14. The system of claim 12, wherein the turbine combustor comprises at least one wall disposed about an interior volume, a cap dividing the interior volume into a head end portion and a combustion portion, and at least one fuel nozzle disposed in the head end portion, wherein the at least one catalytic converter is disposed within the head end portion, within the combustion portion, or any combination thereof.
15. The system of claim 12, wherein the at least one catalytic converter is coupled to a fuel nozzle within the turbine combustor.

16. A system, comprising:
a turbine combustion section configured to mount between an exhaust gas compressor and a turbine, wherein the turbine combustion section comprises at least one catalytic converter disposed along a flow path from the exhaust gas compressor, through the turbine combustion section, and into the turbine.
17. The system of claim 16, wherein the at least one catalytic converter comprises an oxidation catalyst, a carbon monoxide 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.
18. The system of claim 16, wherein the turbine combustion section comprises a turbine combustor, wherein the at least one catalytic converter is coupled to the turbine combustor.
19. The system of claim 18, wherein the turbine combustor comprises a combustion zone, wherein the at least one catalytic converter is disposed within the combustion zone.
20. The system of claim 16, wherein the turbine combustion section comprises a fuel nozzle, wherein the at least one catalytic converter is coupled to the fuel nozzle.
21. The system of claim 16, wherein the turbine combustion section comprises a transition piece, wherein the at least one catalytic converter is coupled to the transition piece.
22. A method, comprising:
driving a turbine with combustion products from a turbine combustor;
compressing an exhaust gas from the turbine in an exhaust gas compressor;
routing the exhaust gas along a flow path from the exhaust gas compressor, through the turbine combustor, and into the turbine; and

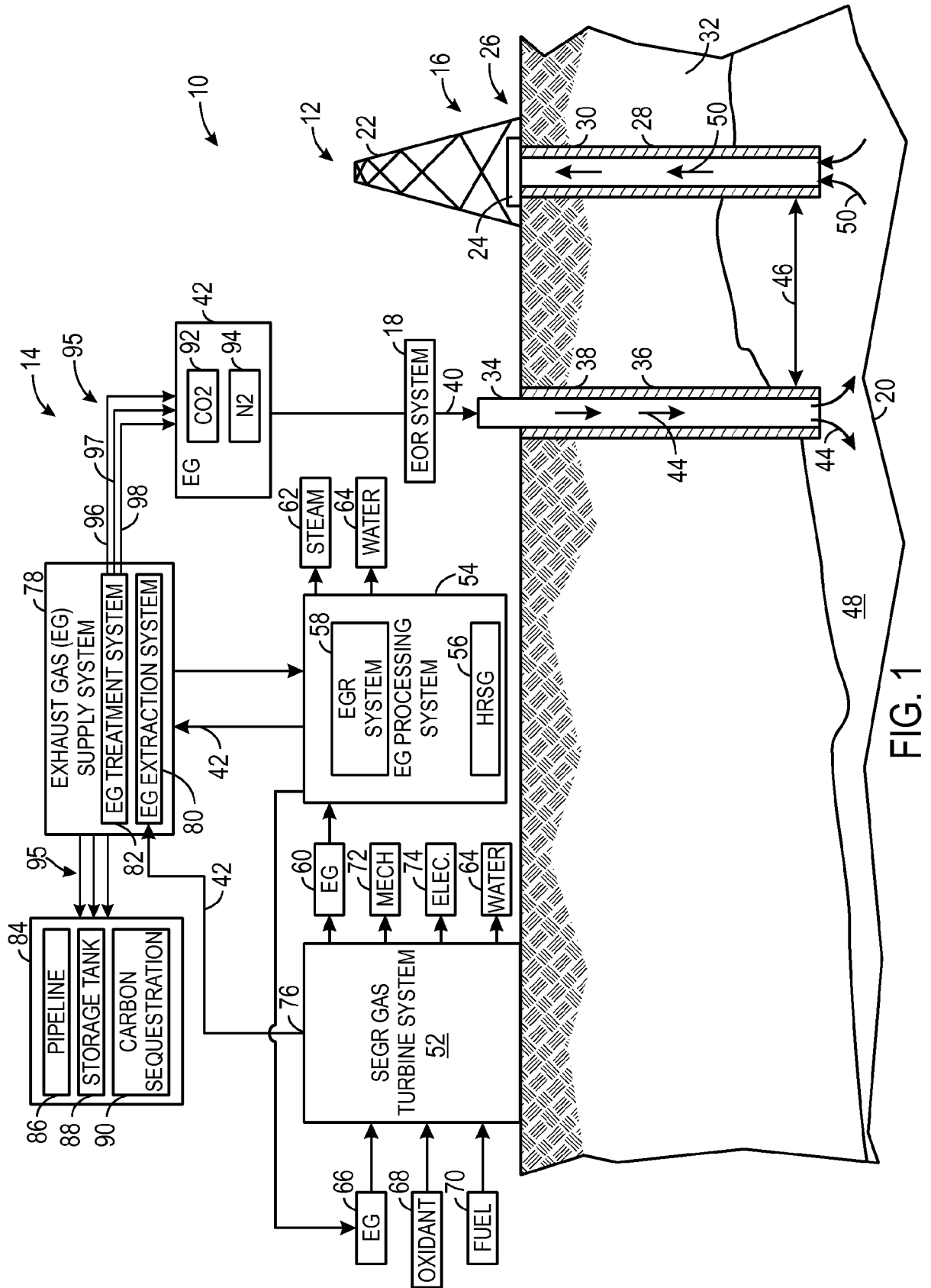
catalytically converting a fluid flow along the flow path with at least one catalytic converter, wherein the fluid flow comprises the exhaust gas.

23. The method of claim 22, comprising combusting a mixture of the exhaust gas and a fuel within the turbine combustor.

24. The method of claim 23, wherein the mixture is combusted stoichiometrically.

25. The method of claim 22, comprising extracting a portion of the exhaust gas, and routing the portion of the exhaust gas to a hydrocarbon production system.

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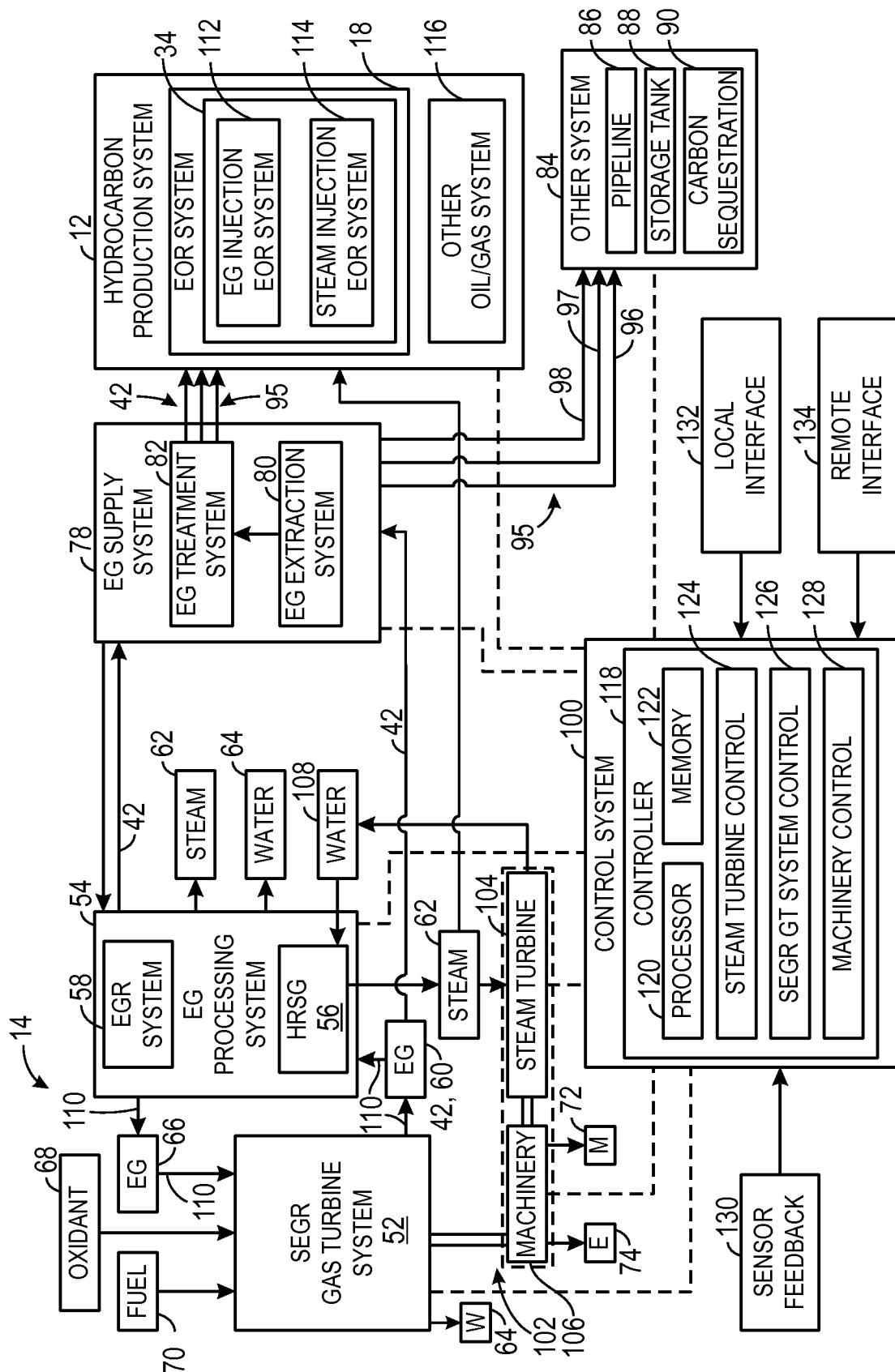


FIG. 2

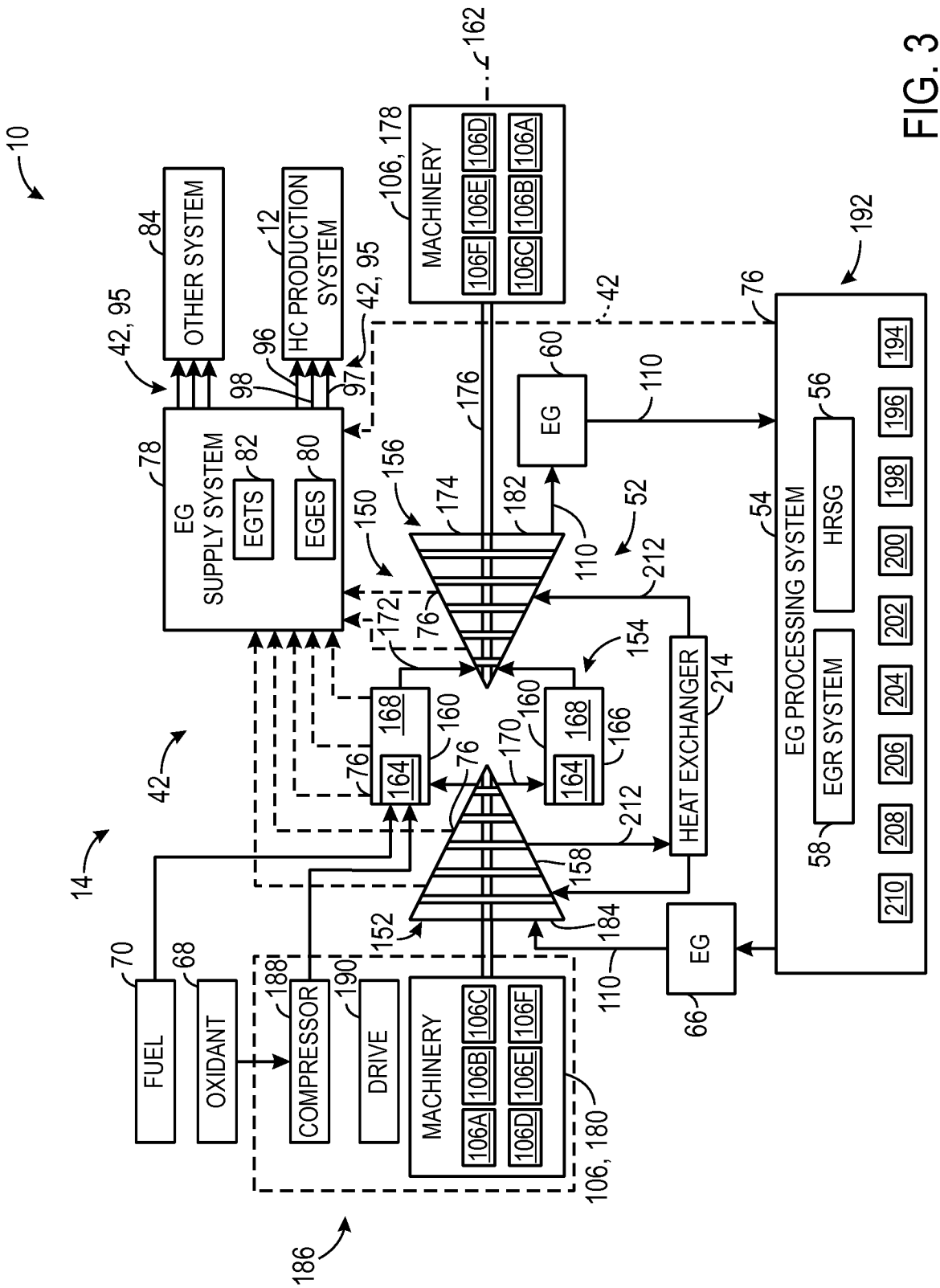


FIG. 3

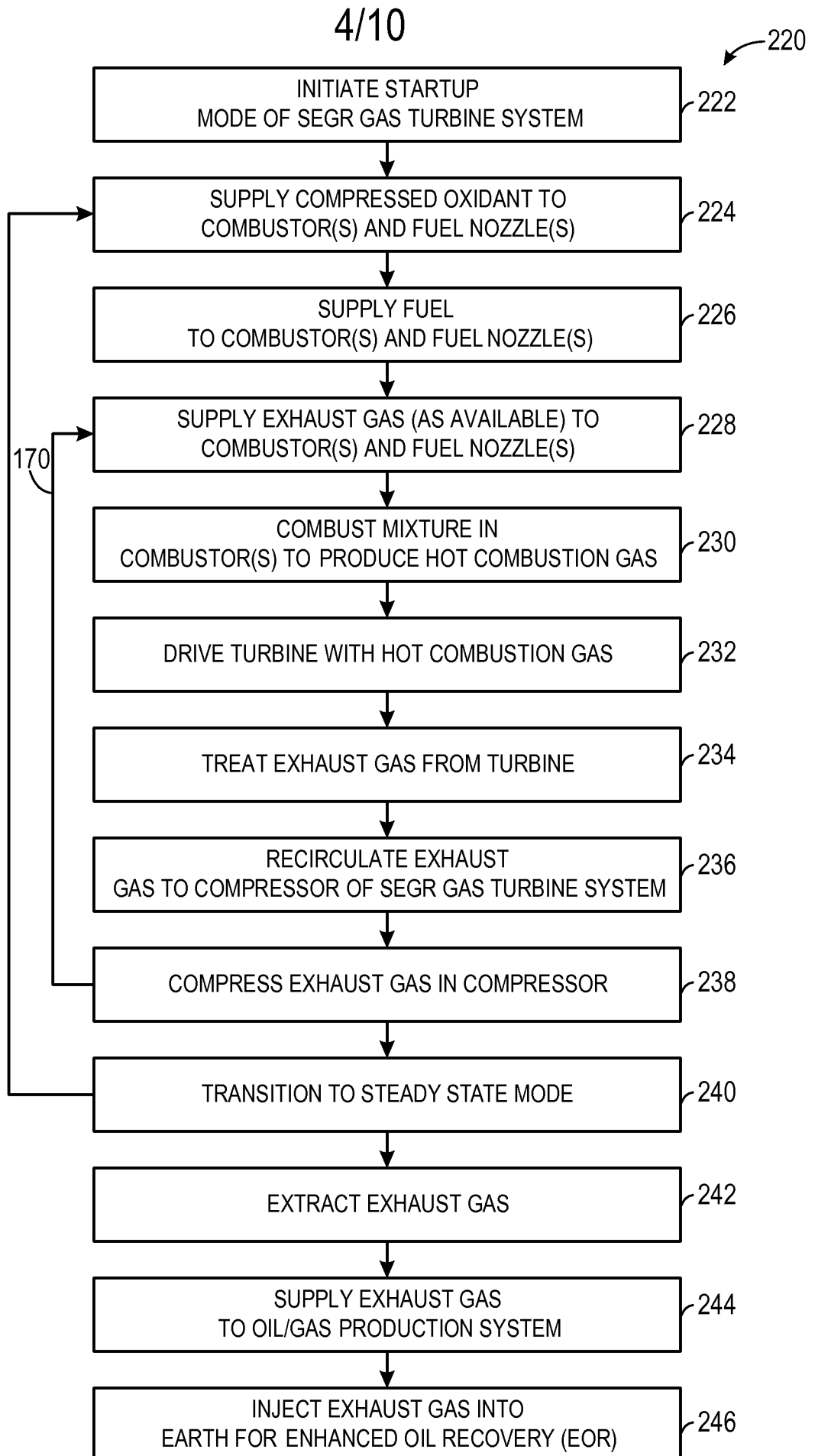


FIG. 4

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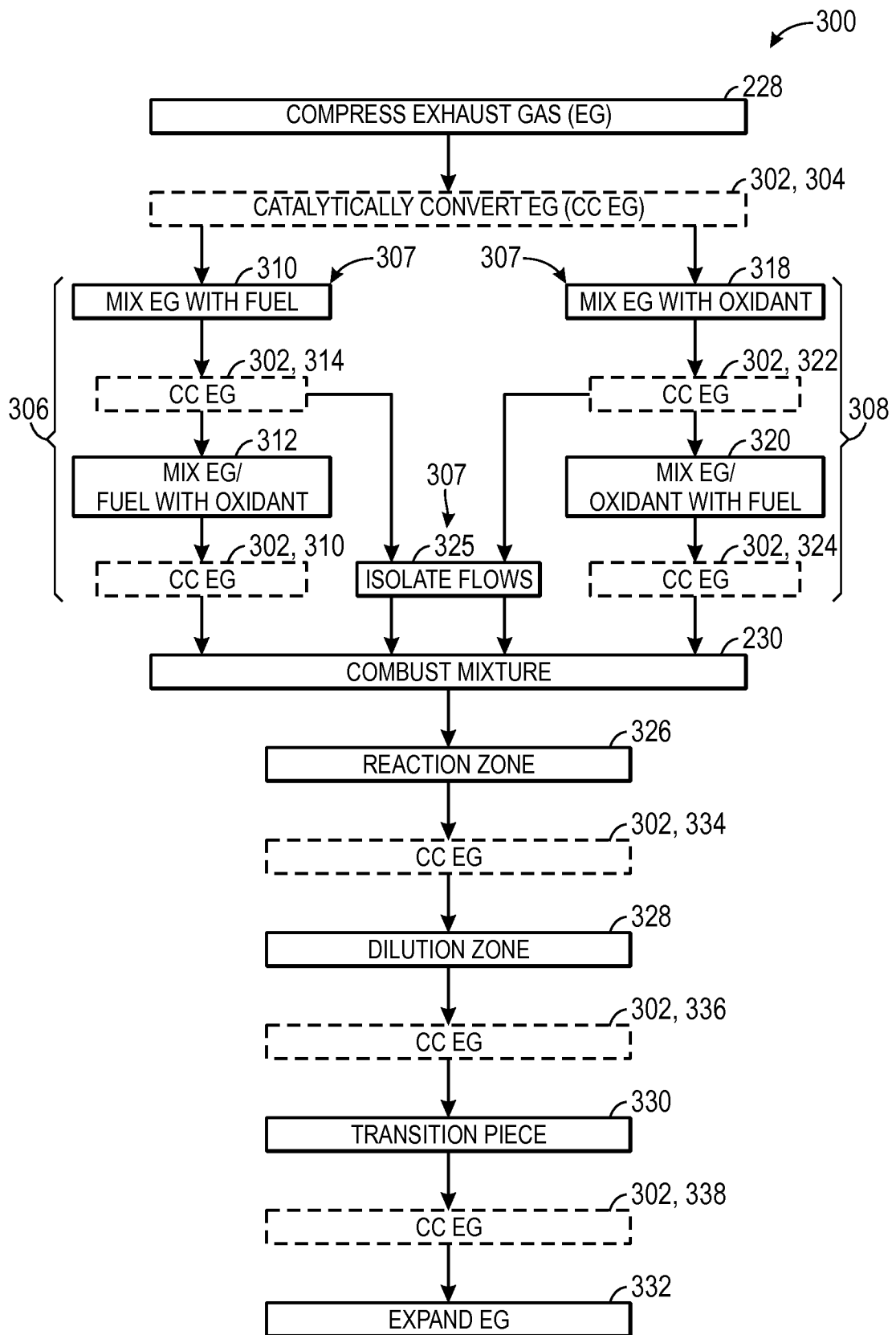


FIG. 5

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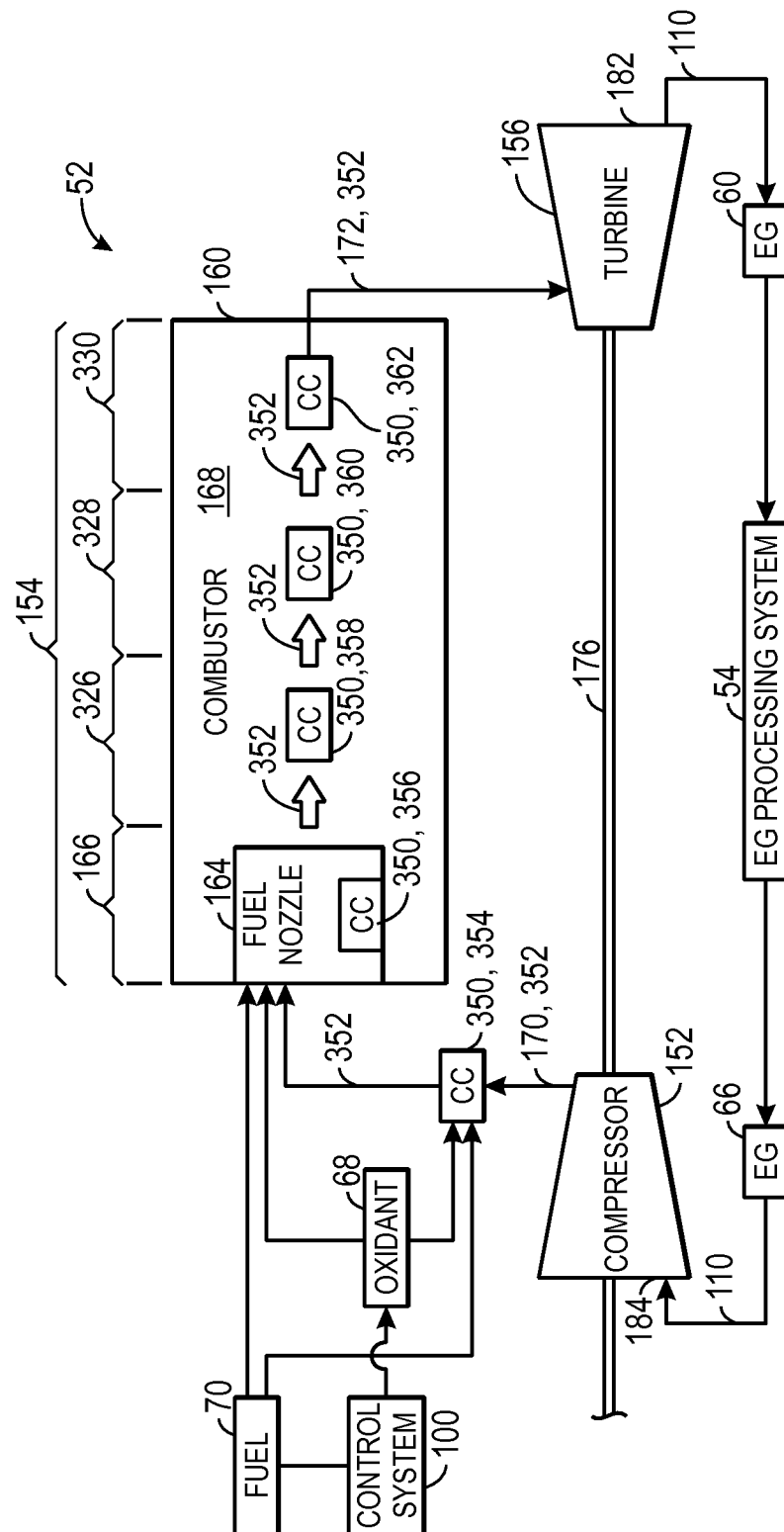


FIG. 6

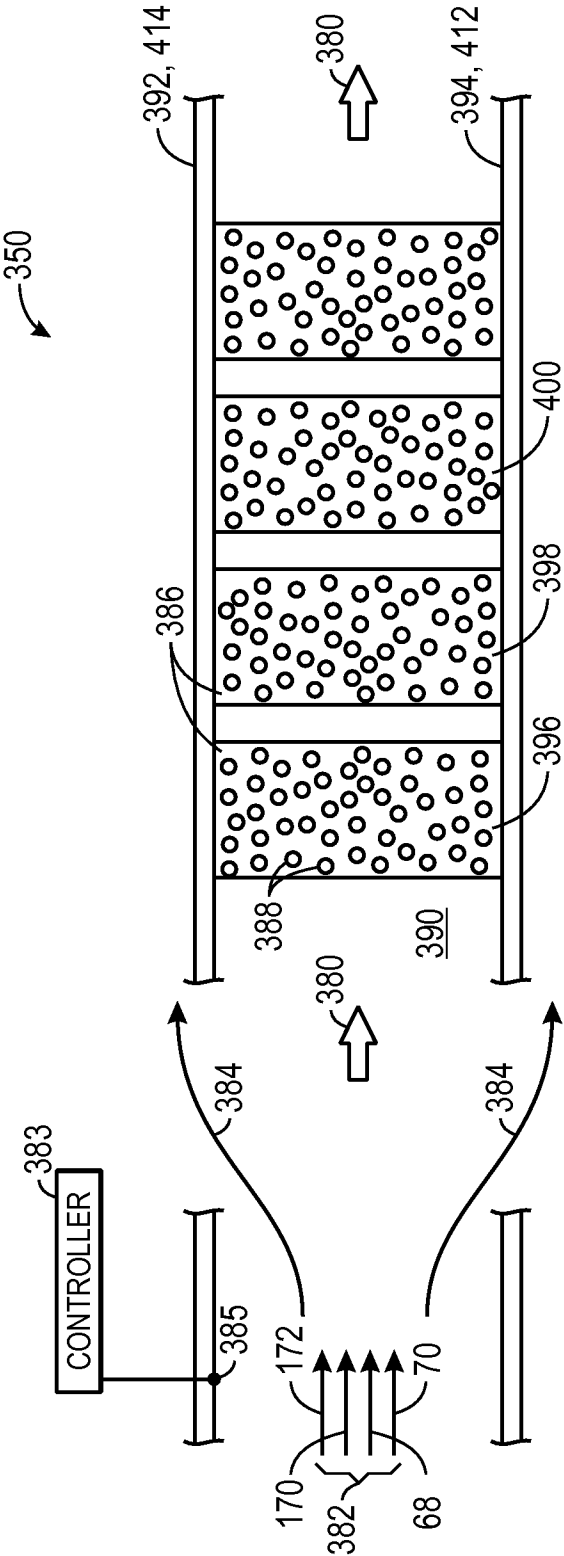
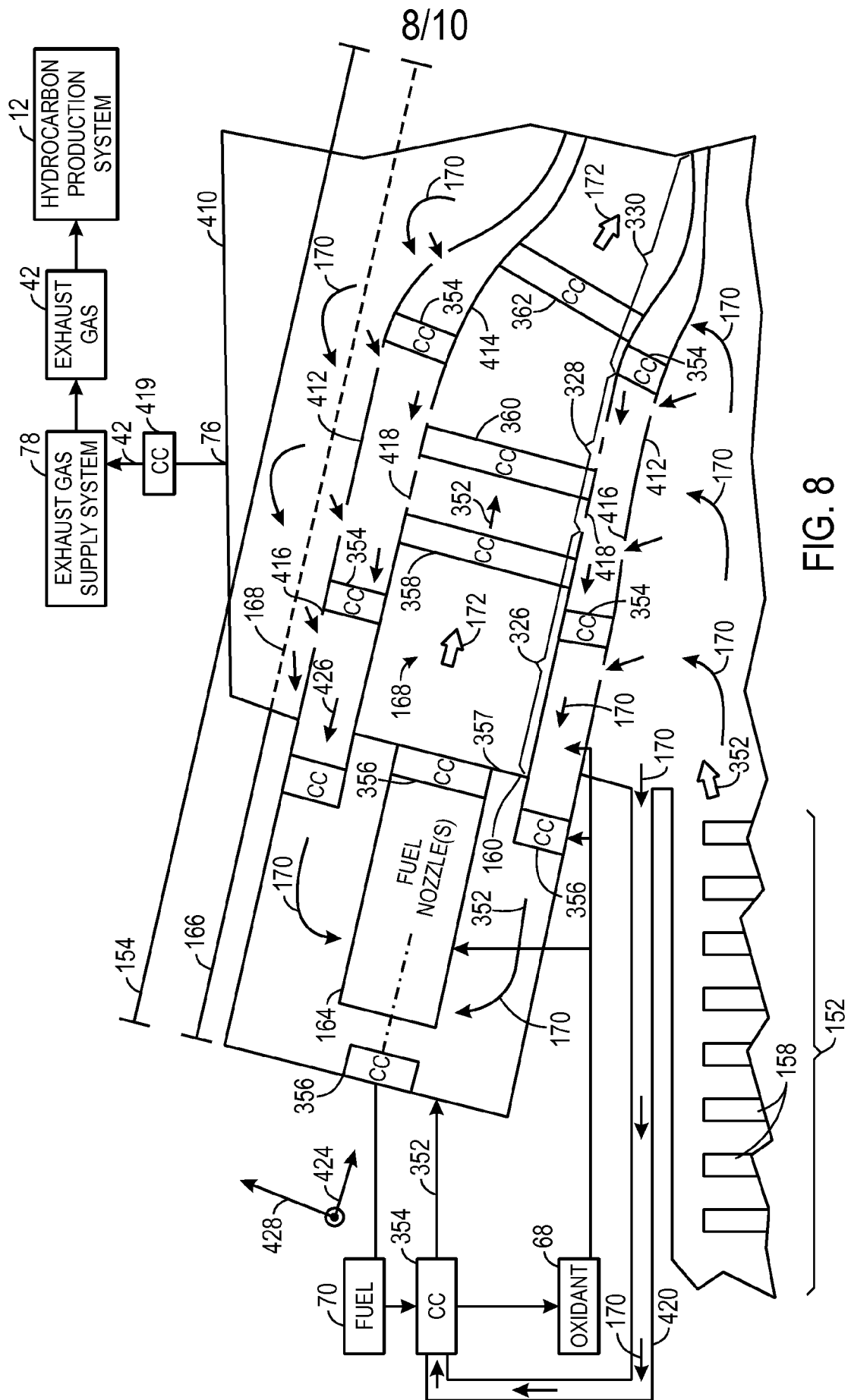


FIG. 7



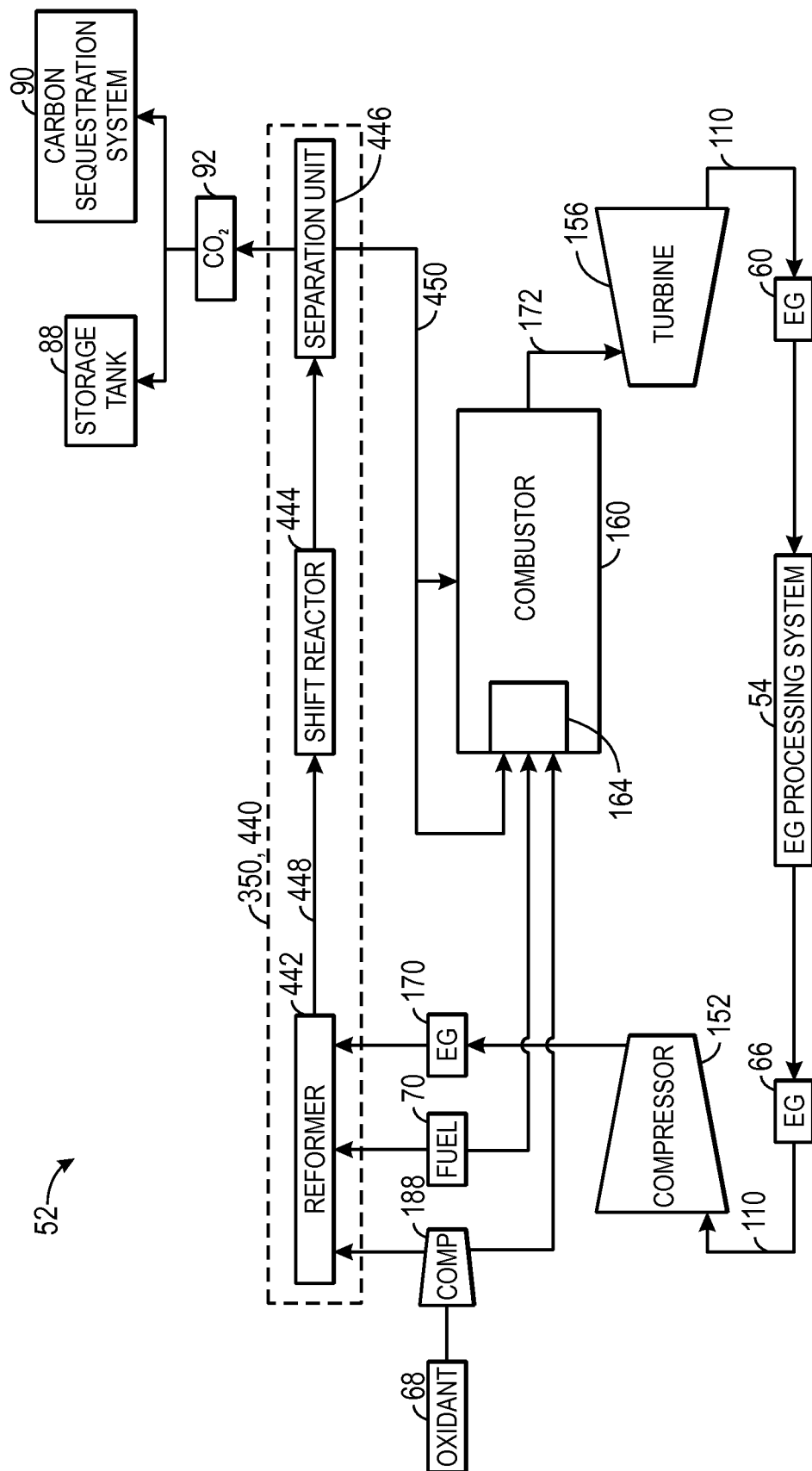


FIG. 9

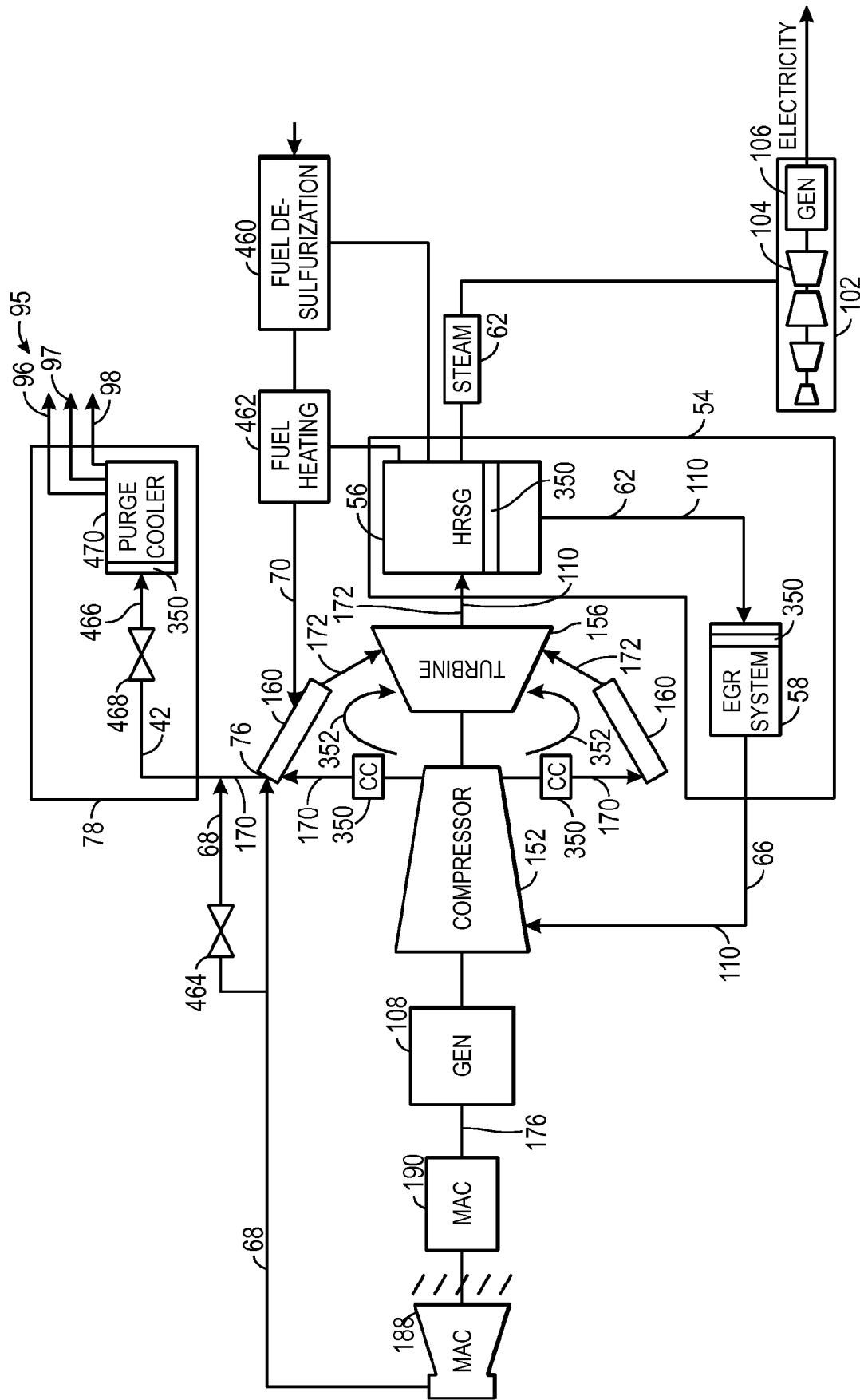


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/015138

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02C3/34
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 2012/073260 A1 (DRAPER SAMUEL DAVID [US]) 29 March 2012 (2012-03-29)	1,2, 6-11,16, 17,22-25
Y	paragraph [0016] - paragraph [0018] paragraph [0014] figure 1	3-5
X	US 2012/119512 A1 (DRAPER SAMUEL DAVID [US]) 17 May 2012 (2012-05-17) paragraph [0074] paragraph [0079] paragraph [0016]; figure 1	1,2,6-8, 16,17, 22-24
X	US 2012/098276 A1 (KRAEMER GILBERT OTTO [US] ET AL) 26 April 2012 (2012-04-26) figure 4 paragraph [0040]	1,2, 12-23
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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"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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Date of the actual completion of the international search

28 May 2014

Date of mailing of the international search report

05/06/2014

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Authorized officer

Burattini, Paolo

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/015138

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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