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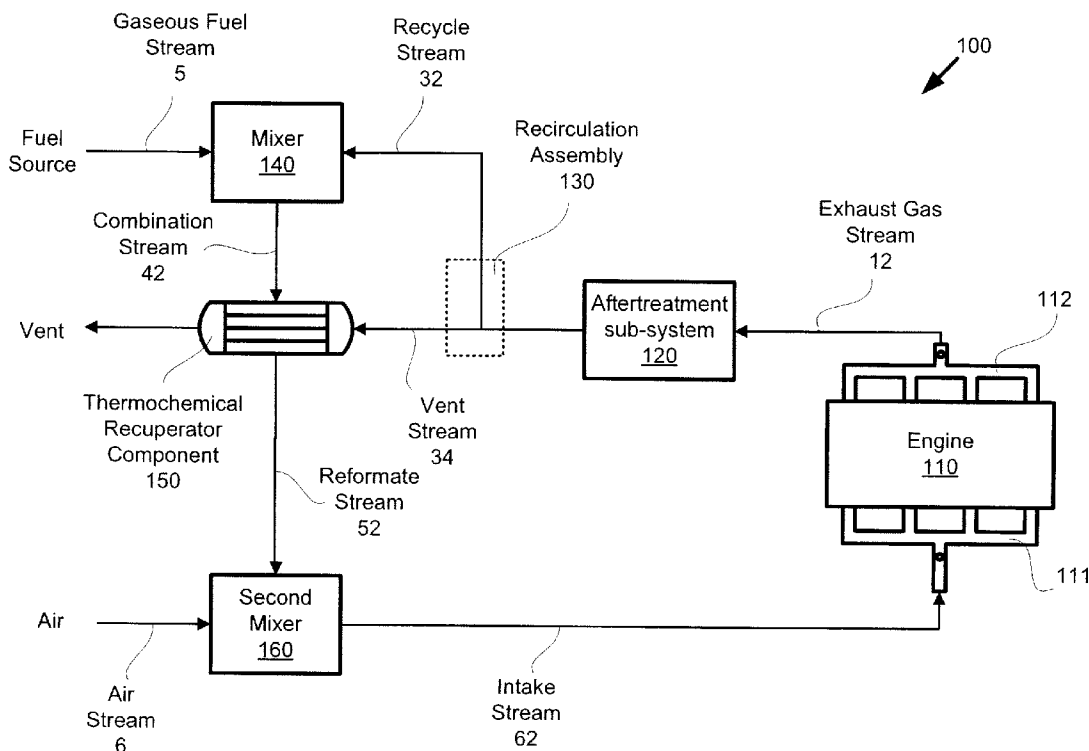
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LaPointe et al.(10) **Pub. No.: US 2014/0260203 A1**(43) **Pub. Date: Sep. 18, 2014**(54) **GASEOUS FUEL SPARK-IGNITED
INTERNAL COMBUSTION ENGINE SYSTEM****Publication Classification**

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Ashish Gupta, Columbus, IN (US)(73) Assignee: **Cummins IP, Inc.**, Columbus, IN (US)(21) Appl. No.: **14/211,072**(22) Filed: **Mar. 14, 2014****Related U.S. Application Data**(60) Provisional application No. 61/784,726, filed on Mar.
14, 2013.(57) **ABSTRACT**

A system and method for reforming a portion of an exhaust gas stream in an internal combustion engine system. An exhaust gas recirculation assembly divides the exhaust gas stream into a recycle stream and a vent stream. A mixer in fluid receiving communication with the recycle stream forms a combination stream by mixing a gaseous fuel stream with the recycle stream. A thermochemical recuperator component fluidly connects to the mixer and includes a first flow path and a second flow path. The first flow path has a catalyst through which the combination stream flows to create a reformate stream, and the second flow path has a heat transfer area for transferring heat from the vent stream to the combination stream.



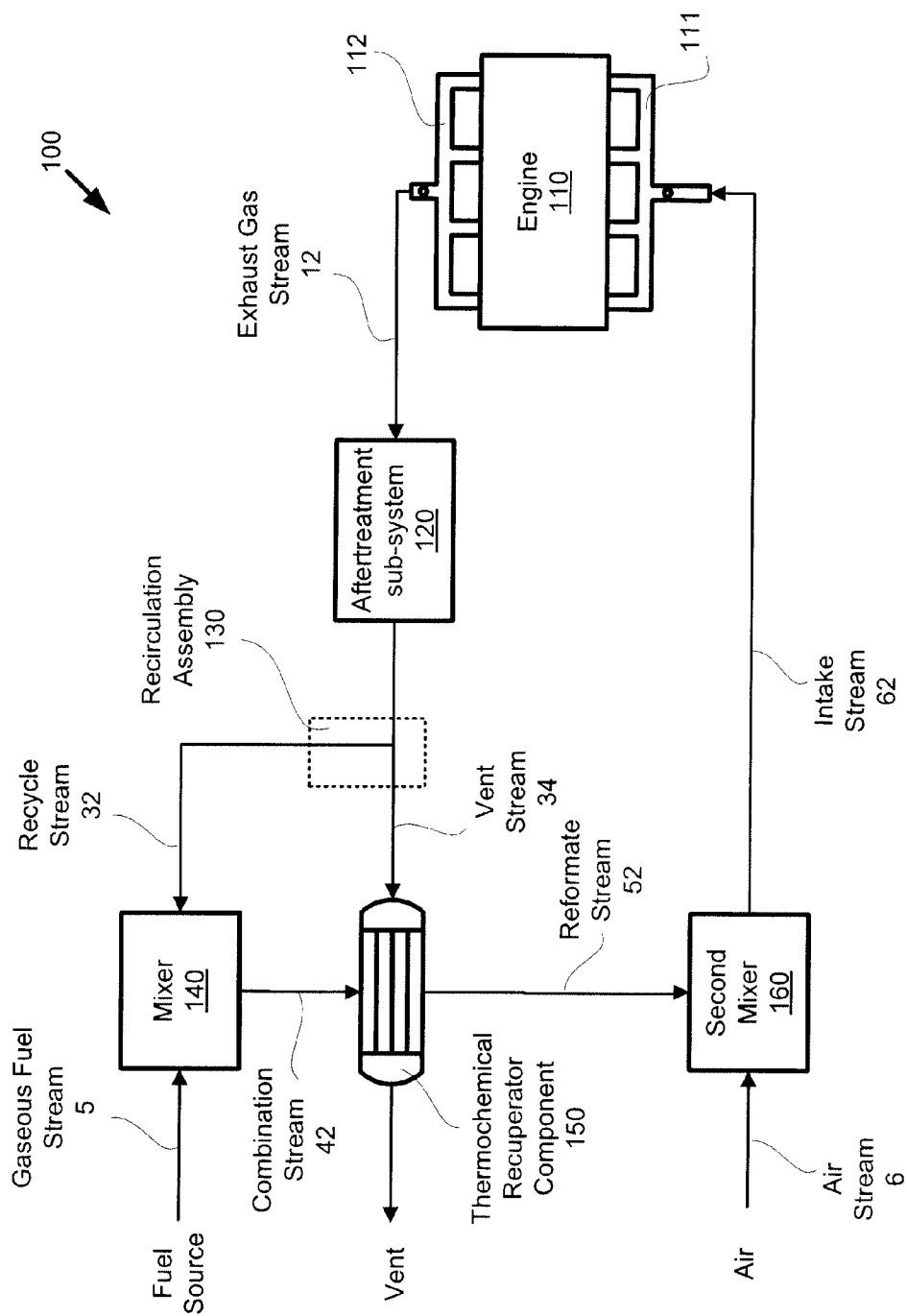


FIG. 1

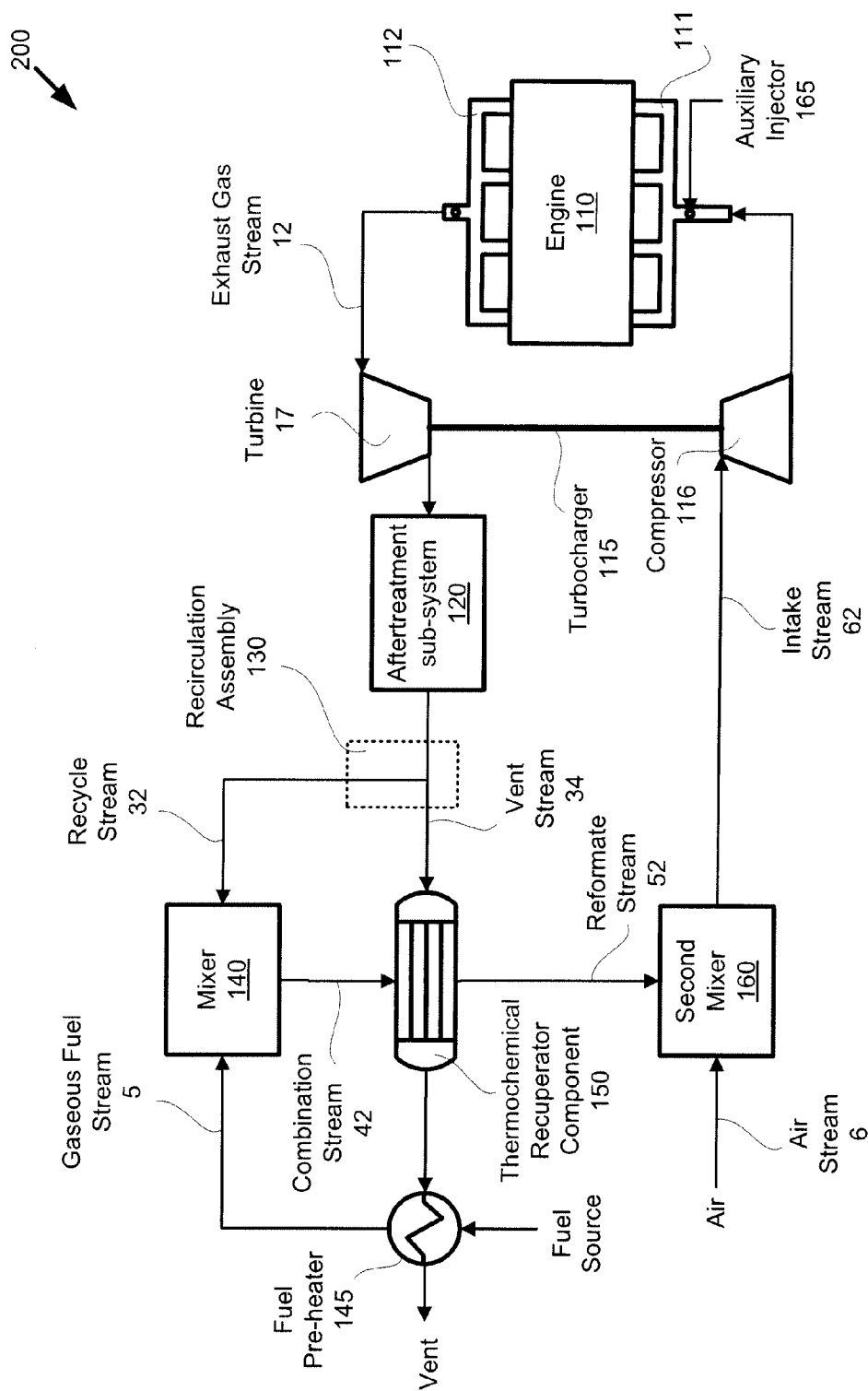


FIG. 2

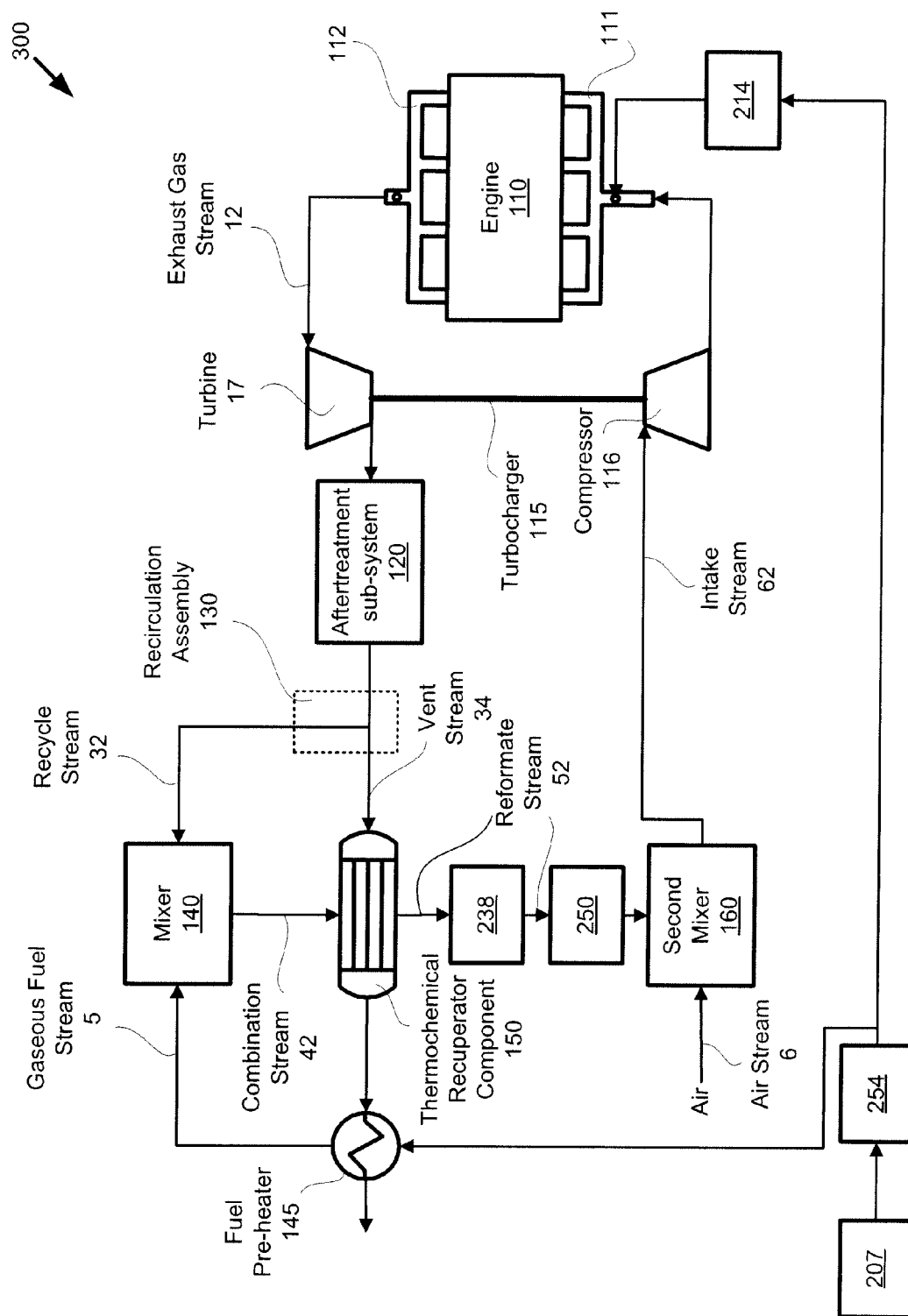


FIG. 3

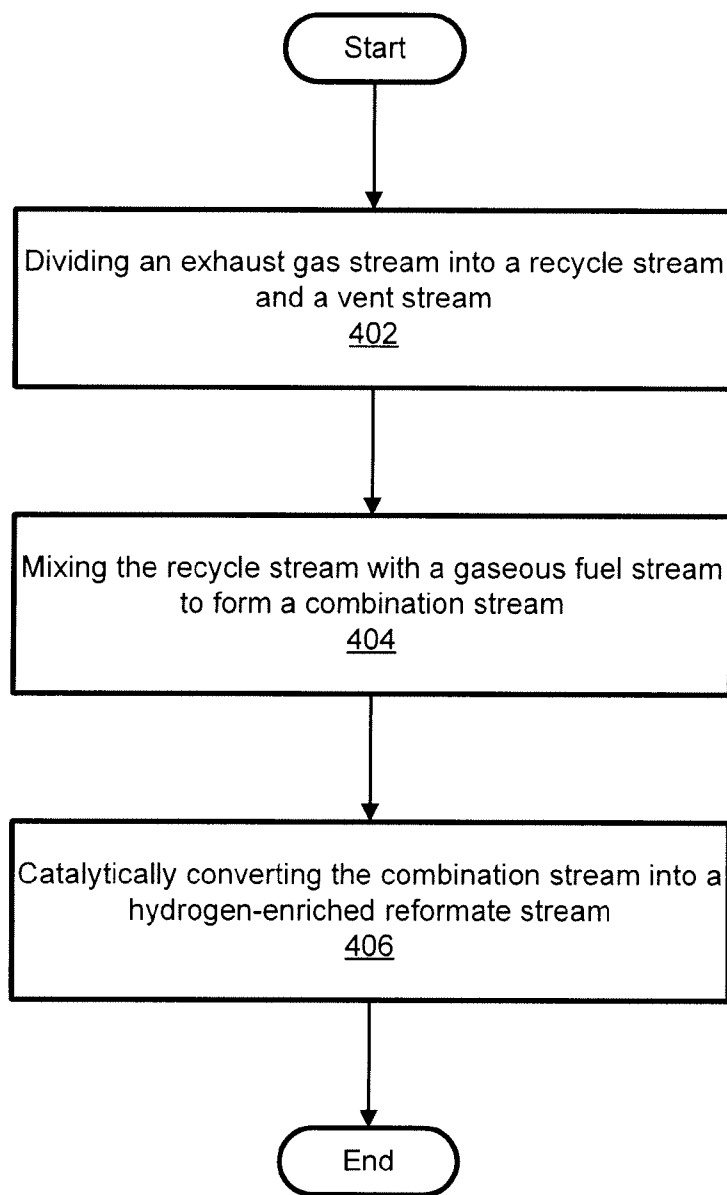
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FIG. 4

GASEOUS FUEL SPARK-IGNITED INTERNAL COMBUSTION ENGINE SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/784,726 entitled "GASEOUS FUEL SPARK-IGNITED INTERNAL COMBUSTION ENGINE SYSTEM" and filed on Mar. 14, 2013 the contents of which incorporated herein by reference in their entirety.

FIELD

[0002] This disclosure relates to gaseous fuel engine systems, and more particularly relates to reforming a recycled portion of an exhaust gas stream.

BACKGROUND

[0003] Emissions regulations for internal combustion engines have become more stringent over recent years. Environmental concerns have motivated the implementation of stricter emission requirements for internal combustion engines throughout much of the world. Governmental agencies, such as the Environmental Protection Agency (EPA) in the United States, carefully monitor the emission quality of engines and set acceptable emission standards, to which all engines must comply. Generally, emission requirements vary according to engine type. Emission tests for spark-ignited gasoline (e.g., non-gaseous) engines typically monitor the release of carbon monoxide, nitrogen oxides (NO_x), and unburned hydrocarbons (UHC). Catalytic converters (e.g., oxidation catalysts) implemented in an exhaust gas aftertreatment system have been used to eliminate many of the regulated pollutants present in exhaust gas generated from gasoline powered engines. For example, some known three-way catalysts include carefully selected catalytic material formulations to specifically oxidize carbon monoxide and unburned hydrocarbons, and reduce nitrogen oxides to less harmful components, present in the exhaust gas. Conventional three-way catalysts are designed to oxidize or reduce such pollutants more efficiently for engines running above the stoichiometric air-to-fuel ratio (i.e., rich conditions).

[0004] Recently, due at least in part to high crude oil prices, environmental concerns, and future fuel availability, many internal combustion engine designers have looked to at least partially replace crude oil fossil fuels, e.g., gasoline and diesel, with so-called alternative fuels for powering internal combustion engines. Desirably, by replacing or reducing the use of fossil fuels with alternative fuels, the cost of fueling internal combustion engines is decreased, harmful environmental pollutants are decreased, and/or the future availability of fuels is increased. Known alternative fuels include gaseous fuels or fuels with gaseous hydrocarbons, such as, for example, natural gas, petroleum gas (propane), and hydrogen. The combustion byproducts present in exhaust gas generated by spark-ignited gaseous-powered engines are similar to those present in exhaust gas generated by spark-ignited non-gaseous-powered engines. Accordingly, conventional gaseous-powered engine systems utilize the same oxidation catalysts found in non-gaseous-powered engine systems to oxidize the regulated pollutants generated by gaseous-powered engines.

[0005] Traditionally, gaseous-powered engines are operated at rich air-to-fuel ratios (e.g., richer than stoichiometric) in order to reduce oxygen concentrations within the exhaust gas, and thus reduce the formation of carbon monoxide and nitrogen oxides. However, operating a gaseous-powered engine under stoichiometric or richer air-to-fuel ratios results in a relatively low brake thermal efficiency of the engine. Moreover, operating at such air-to-fuel ratios causes high combustion temperatures, which result in high component temperatures in the engine, and the necessity to reduce output power to avoid component failure. However, in view of the premium placed on satisfying exhaust emissions regulations, conventional gaseous-powered engines are designed to meet exhaust emissions regulations at the expense of thermal efficiency and power density.

SUMMARY

[0006] The subject matter of the present application has been developed in response to the present state of the art, and in particular, in response to the problems and needs in the art of gaseous-fuel-powered internal combustion engine systems that have not yet been fully solved by currently available systems. Accordingly, in certain embodiments, a gaseous-fuel-powered internal combustion engine system is disclosed herein that improves the thermal efficiency and power density of the engine while meeting stringent exhaust emissions regulations. In other words, the control system and method described in the present disclosure overcomes many of the shortcomings of the prior art.

[0007] The present disclosure relates to an engine system that includes an exhaust gas aftertreatment sub-system that is fluidly connected to an exhaust manifold of an internal combustion engine for receiving an exhaust gas stream. The system further includes an exhaust gas recirculation assembly fluidly connected to the exhaust gas aftertreatment sub-system. The exhaust gas recirculation assembly divides the exhaust gas stream into a recycle stream and a vent stream. The system also includes a mixer in fluid receiving communication with the recycle stream that forms a combination stream by mixing a gaseous fuel stream with the recycle stream. The system further includes a thermochemical recuperator component fluidly connected to the mixer. The thermochemical recuperator component includes a first flow path that has a catalyst through which the combination stream flows to create a reformat stream. The thermochemical recuperator component further includes a second flow path comprising a heat transfer area for transferring heat from the vent stream to the combination stream.

[0008] In one embodiment, the reformat stream may be a hydrogen enriched gaseous stream. The exhaust gas aftertreatment sub-system may be a three-way catalyst. Also, in one embodiment, the exhaust gas stream may have, at most, trace amounts of oxygen. The gaseous fuel stream may be natural gas and the system may further include a sulfur scrubber upstream of the thermochemical recuperator component. The system may further include a fuel pre-heater that transfers heat from the vent stream to the gaseous fuel stream. The system may also include a reformat stream cooler and a second mixer to form an intake stream by combining the reformat stream with an air stream. In one implementation, the system may include a filter disposed in the reformat stream and may also include a turbocharger with a turbine upstream of the exhaust gas recirculation assembly.

[0009] In one specific example of an implementation of the system of the present disclosure, the engine system includes a natural gas engine comprising an intake manifold and an exhaust manifold. The specific system includes an exhaust gas aftertreatment sub-system that is fluidly connected to the exhaust manifold for receiving an exhaust gas stream. This exhaust gas aftertreatment sub-system includes a three-way catalyst. The specific system further includes an exhaust gas recirculation assembly fluidly connected to the exhaust gas aftertreatment sub-system for dividing the exhaust gas stream into a recycle stream and a vent stream. Also included is a fuel pre-heater in fluid receiving communication with the vent stream so that heat from the vent stream is transferred to a gaseous fuel stream. Also, a mixer is included in the specific implementation of the system for forming a combination stream by mixing the gaseous fuel stream with the recycle stream. The specific system also includes a thermochemical recuperator component fluidly connected to the mixer, wherein the thermochemical recuperator has a first flow path that has a catalyst through which the combination stream flows to create a hydrogen-enriched reformat stream. The thermochemical recuperator component further has a second flow path with a heat transfer area for transferring heat from the vent stream to the combination stream. Finally, the specific system includes a second mixer in fluid receiving communication with the reformat stream that forms an intake stream by combining the reformat stream with an air stream.

[0010] Also disclosed in the present disclosure is a method for reforming a portion of an exhaust gas stream. The method includes dividing an exhaust gas stream from an engine into a recycle stream and a vent stream. The method further includes mixing the recycle stream with a gaseous fuel stream to form a combination stream. Finally, the method includes catalytically converting the combination stream into a hydrogen-enriched reformat stream. In one implementation, catalytically converting the combination stream into a hydrogen-enriched reformat stream involves flowing the combination stream through a first flow path of a thermochemical recuperator component and flowing the vent stream through a second flow path of the thermochemical recuperator component. The first flow path has a catalyst for reacting the combination stream and the second flow path has a heat transfer area for transferring heat from the vent stream to the combination stream. In one implementation, the method may further include removing oxygen from the exhaust gas stream before catalytically converting the combination stream into a hydrogen-enriched reformat stream. For example, oxygen may be removed by operating the engine at an air/fuel ratio that is stoichiometric or fuel rich or by implementing a three-way catalyst in an exhaust gas aftertreatment sub-system to remove the oxygen.

[0011] Reference throughout this specification to features, advantages, or similar language does not imply that all of the features and advantages that may be realized with the present disclosure should be or are in any single embodiment of the invention. Rather, language referring to the features and advantages is understood to mean that a specific feature, advantage, or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed herein. Thus, discussion of the features and advantages, and similar language, throughout this specification may, but do not necessarily, refer to the same embodiment.

[0012] Furthermore, the described features, advantages, and characteristics of the disclosure may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize that the subject matter of the present application may be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the disclosure. Further, in some instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the subject matter of the present disclosure. These features and advantages of the present disclosure will become more fully apparent from the following description and appended claims, or may be learned by the practice of the disclosure as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In order that the advantages of the disclosure will be readily understood, a more particular description of the disclosure briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the disclosure and are not therefore to be considered to be limiting of its scope, the subject matter of the present application will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

[0014] FIG. 1 is a schematic block diagram of a system for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to one embodiment;

[0015] FIG. 2 is a schematic block diagram of a system for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to another embodiment;

[0016] FIG. 3 is a schematic block diagram of a system for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to yet another embodiment; and

[0017] FIG. 4 is a schematic flow chart diagram of a method for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to one embodiment.

DETAILED DESCRIPTION

[0018] Reference throughout this specification to “one embodiment,” “an embodiment,” or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present disclosure. Appearances of the phrases “in one embodiment,” “in an embodiment,” and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment. Similarly, the use of the term “implementation” means an implementation having a particular feature, structure, or characteristic described in connection with one or more embodiments of the present disclosure, however, absent an express correlation to indicate otherwise, an implementation may be associated with one or more embodiments.

[0019] FIG. 1 is a schematic block diagram of a system **100** for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to one embodiment. The system **100** includes an internal combustion engine **110**, an exhaust gas aftertreatment sub-system **120**, an exhaust gas recirculation assembly **130**, a mixer **140**, a thermochemical

recuperator component **150**, and a second mixer **160**. Generally, the system **100** is configured so that an exhaust gas stream **12** exiting the exhaust manifold **112** of an internal combustion engine **110** flows into an exhaust gas aftertreatment sub-system **120**. As described below in greater detail, the exhaust gas aftertreatment sub-system **120** may include various components, such as a hydrocarbon oxidation catalyst, a particulate filter, and/or a nitrogen oxide reduction catalyst, among others. The exhaust gas stream **12** is then divided into two separate streams **32**, **34** by an exhaust gas recirculation assembly **130**. The two streams **32**, **34** are a recycle stream **32** and a vent stream **34**. The exhaust gas recirculation assembly **130** may include a piping manifold and/or various valves to divide the exhaust gas stream **12** into a recirculating portion (recycle stream **32**) and a portion that vents to the atmosphere (vent stream **34**).

[0020] In the depicted embodiment of the system **100**, the recycle stream **32** flows into a mixer **140** where it is combined and mixed with a gaseous fuel stream **5**. In one embodiment, the mixer **140** may be a portion of tubing/piping. In another embodiment, the mixer **140** may include a chamber where the gaseous fuel stream **5** and the recycle stream **32** are combined. In yet another embodiment, the mixer **140** may include mixing elements, such as baffles or actuators, which promote the mixing of the two gaseous streams into a combination stream **42**. The combination stream **42** then flows into a thermochemical recuperator component **150**. The thermochemical recuperator component **150** has two separate flow paths, a first flow path with a catalyst and a second flow path with a heat transfer area. The combination stream **42** flows through the first flow path and a portion of the molecules adsorb onto the surface of the catalyst and react to convert the combination stream into a hydrogen-enriched reformat stream **52** (further details are included below regarding the catalyst). The vent stream **34** from the exhaust gas recirculation assembly **130** flows through the second flow path and transfers heat across the heat transfer area to the combination stream **42**. In one embodiment, the combination stream **42** and/or the catalyst in the first flow path of the thermochemical recuperator component **150** must be at a certain temperature in order to effectively and efficiently react.

[0021] The reformat stream **52** then flows to a second mixer **160** to be combined with an air stream **6** in order to form an intake stream **62**. In one embodiment, the second mixer **160** may be a portion of tubing/piping. In another embodiment, the second mixer **160** may include a chamber where the reformat stream **52** and the air stream **6** are combined. In yet another embodiment, the second mixer **160** may include mixing elements, such as baffles or actuators, which promote the mixing of the two gaseous streams in order to form the intake stream **62**.

[0022] FIG. 2 is a schematic block diagram of a system **200** for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to another embodiment. According to one specific embodiment of the internal combustion engine system **200** shown schematically in FIG. 2, the system **200** includes an internal combustion engine **110** that has an intake manifold **111** and an exhaust manifold **112**. The engine **110** may be a spark-ignited engine fueled by gaseous hydrocarbons, such as natural gas, petroleum gas (propane), and hydrogen, and operated under stoichiometric conditions. As defined herein, gaseous fuels, as opposed to non-gaseous fuels (e.g., gasoline and diesel), are those that are introduced and managed within the engine in a gaseous state, as opposed

to, a liquid or solid state. In FIG. 2, the depicted engine **110** is a spark-ignited engine fueled by natural gas. Spark-ignited gaseous fuel engines are configured and calibrated differently than spark-ignited non-gaseous fuel engines. Gaseous fuel engines introduce considerations not present with non-gaseous engines. For example, non-gaseous engines do not produce significant amounts of certain combustion byproducts produced by gaseous engines. Gaseous fuel engines typically produce large amounts of methane when the gaseous fuel itself contains a large amount of methane, which is normal with natural gas and a wide variety of other gaseous fuels.

[0023] The system **200** depicted in FIG. 2 includes various additional components that may be implemented with the present disclosure. For example, a turbocharger **115**, a fuel pre-heater **145**, and an auxiliary air/fuel injector **165**, among others, may also be included in the system **200**. The air stream **6** includes an air inlet that is at essentially atmospheric pressure, thus enabling fresh air to enter the system **200**. The fresh air is mixed with the reformat stream **52** in the second mixer **160**. Additional gaseous fuel can be added to the air/fuel mixture downstream of the second mixer **160** and compressor **116** in the form of an auxiliary fuel injector **165** for more precisely dithering the air-to-fuel ratio of the mixture prior to entering the engine **110**. Although the auxiliary injector **165** is depicted as directly injecting air/fuel into the intake manifold **111**, it is contemplated that the auxiliary injector **165** may be injected at other locations upstream of the combustion chambers of the engine **110**.

[0024] In operation, the air/fuel mixture from the second mixer **160** is compressed by the compressor **116** to increase the pressure and density of the mixture. The compressor **116** is co-rotatably driven by a turbine **117** of the turbocharger **115**, which is driven by the exhaust gas stream **12** from the engine **110**, as is known in the art. Although not depicted, the compressed air/fuel mixture may then flow into a charge air cooler, which decreases the temperature of the intake air charge for sustaining the use of a denser intake charge into the engine **110**. Following cooling, the air/fuel mixture is directed into the combustion chambers of the engine **110**. The air/fuel mixture may be ignited via a spark-ignition system, and the fuel is combusted to generate the pressure differential within the chambers for powering the engine **110** and various auxiliary devices, such as an alternator.

[0025] Combustion of the fuel produces exhaust gas that is operatively vented into the exhaust gas manifold **112**. After exiting the engine **110**, the exhaust gas drives the turbine **117** of the turbocharger **115**. The exhaust gas aftertreatment sub-system **120** can include one or more exhaust treatment components, such as, for example, three-way catalysts, oxidation catalysts, filters, adsorbers, and the like, for treating (i.e., removing pollutants from) the exhaust gas stream **12**. In particular embodiments, the exhaust gas aftertreatment sub-system **120** includes an advanced three-way catalyst. In certain implementations, the three-way catalyst is a flow-through type catalyst having a catalyst bed exposed to the exhaust gas flowing through the main exhaust line and past the bed. The catalyst bed includes a catalytic layer disposed on a washcoat or carrier layer. The carrier layer can include any of various materials (e.g., oxides) capable of suspending the catalytic layer therein. The catalyst layer is made from one or more catalytic materials selected to react with (e.g., oxidize) one or more pollutants in the exhaust gas. The catalytic materials of the three-way catalyst can include any of various materials, such as precious metals platinum, palladium, and rhodium, as

well as other materials, such as transition metals cerium, iron, manganese, and nickel. Further, the catalyst materials can have any of various ratios relative to each other for oxidizing and reducing relative amounts and types of pollutants as desired. Generally, the three-way catalyst contains catalytic materials specifically selected to react with and oxidize or reduce three specific pollutants. The three specific pollutants include carbon monoxide (CO), unburned hydrocarbons (UHC), and nitrogen oxides (NO_x). In one embodiment the three-way catalyst is a single integrated element and in another embodiment the three-way catalyst may include multiple catalysts elements at various locations in the aftertreatment sub-system 120.

[0026] The exhaust gas recirculation assembly 130 includes actuators and valves to direct exhaust gas 12 to one or more destinations. For example, the exhaust gas recirculation assembly 130 can include an EGR valve that is actuable to direct (e.g., vent) a portion of the received exhaust gas into the atmosphere as expelled exhaust (vent stream 34) and direct a portion of the received exhaust gas into an exhaust gas recirculation (EGR) line (recycle stream 32) for recirculation back into the combustion chambers of the engine 110.

[0027] The system 200 may also include a fuel pre-heater 145, thermochemical recuperator 150, a mixer 140, and a reformat cooler (not depicted). A gaseous fuel, which in the illustrated embodiment is natural gas, is supplied from a fuel source, such as a gaseous fuel compression tank, to the pre-heater 145. The pre-heater 145 can be a flow-through heat exchanger with coils in exhaust receiving communication with the vent stream 34 of the exhaust gas stream 12. The gaseous fuel stream 5, e.g., natural gas, is passed over the coils, and heat from the coils is transferred into the gaseous fuel stream 5, which increases the temperature of the fuel. From the pre-heater 145, the vent stream 34 may be expelled from the system 200 and the heated gaseous fuel stream 5 is directed into a mixer 140. The mixer 140 also receives a recycle stream 32 through an EGR line of the recirculation assembly 130. The mixer 140 combines and mixes the heated gaseous fuel stream 5 with the recycle stream 32 to form a combination stream 42.

[0028] From the mixer 145, the combination stream 42 flows into the thermochemical recuperator component 150, which also receives heat from the vent stream 34. Similar to the pre-heater 145, the thermochemical recuperator component 150 can include flow-through heat exchanger components, such as coils in exhaust receiving communication with the vent stream 34 from the recirculation assembly 130. The combination stream 42 is passed over the coils, and heat from the coils is transferred into the combination stream 42, which increases the temperature of the mixture. Unlike the pre-heater 145, the thermochemical recuperator component 150 also includes a catalyst bed coated with catalytic materials. As the combination stream 42 passes through the thermochemical recuperator component 150 and is heated, the heated mixture also passes over the catalytic materials, which effectuate chemical reactions within the combination stream 42 to form new chemical compositions.

[0029] When the temperature within the recuperator component 150 reaches predetermined temperature thresholds (e.g., between about 600° C. and about 1,100° C. in some implementations), the catalytic materials of the thermochemical recuperator component 150 effectively increase the energy ratio/density of the combination stream 42 by promoting desirable chemical reactions. For example, the catalytic

materials may include a high nickel concentration, which promotes the combination of hydrocarbons (from the gaseous fuel stream 5) with water vapor (from the recycle stream 32) to generate a reformat stream 52 enriched with hydrogen and carbon monoxide. The combustion of gaseous fuels, such as natural gas, generates sufficient water vapor to sustain the reforming reactions. Moreover, the components in the exhaust gas aftertreatment sub-system 120 result in a processed exhaust gas stream 12 that is essentially void of oxygen and consisting mainly of water vapor, carbon dioxide, and nitrogen, according to one embodiment. In one embodiment, the presence of oxygen in the exhaust gas reduces the efficacy of the reforming reactions taking place in the thermochemical recuperator component 150. For this reason, the recirculation assembly 130 is positioned downstream of the aftertreatment sub-system 120, where the oxygen content of the exhaust gas stream has been reduced by the three-way catalyst. Further, certain exothermic processes performed by the three-way catalyst (e.g., the oxidation of carbon monoxide and unburned hydrocarbons) increases the temperature of the exhaust gas stream 12. Accordingly, positioning the thermochemical recuperator component 150 downstream of the exhaust gas aftertreatment sub-system 120 utilizes the hotter exhaust gas exiting to promote the reforming reactions within the recuperator.

[0030] This chemically-altered fuel/EGR mixture is defined as the reformat stream 52, which exits the recuperator component 150 and may flow into a variety of other processing components, such as a reformat cooler. The reformat cooler may also include coils over which the reformat stream 52 passes. Coolant may flow through the coils in order to lower the temperature of the reformat stream 52. The cooled reformat stream 52 is then combined with air in the second mixer 160 to form an intake stream 62. The intake stream 62 flows through the compressor 116 of the turbocharger 115 and then to the intake manifold 11 of the engine 110, as discussed above. Cooling the reformat stream 52 increases the density of the stream and improves the engine efficiency and power.

[0031] FIG. 3 is a schematic block diagram of a system 300 for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to yet another embodiment. The depicted system 300 includes additional features that may be included in an engine system of the present disclosure. For example, the engine system 300 includes an engine, an advanced three-way catalyst, a thermochemical recuperator 150 downstream of the catalyst, a fuel pre-heater 145, a mixer 140, and a second mixer 160, among other components. The depicted system 300 may further include a reformat cooler 238, various temperature sensors, control valves, and pressure regulators as indicated, which can be controlled by various modules of an electronic control module or controller. Additionally, the engine system 300 includes a reformat filter 250 downstream of the reformat cooler 238 to filter out particulate matter and other constituents that are potentially harmful to the engine 110. The filter 250 may include a heater to increase the temperature of the reformat above a condensation level of the reformat. The engine system 300 also includes a sulfur scrubber 254 upstream of the pre-heater 145 and upstream of a dithering fuel injector 214. Sulfur degrades the components of the recuperator 150 and the engine 110. Accordingly, the sulfur scrubber 254 reduces the sulfur content in the gaseous fuel prior to the fuel entering the recuperator 150 and engine 110.

[0032] The internal combustion engine system 300 also includes an insulation system that insulates the exhaust after-treatment sub-system 120 and the fuel delivery system. Because the efficiency of the reforming reactions within the thermochemical recuperator 150 is sensitive to the temperature of the gaseous fuel stream 5 and the recycle stream 32, the insulation system is configured to reduce heat losses from the exhaust and fuel delivery systems. The insulation system includes exhaust insulation that insulates (e.g., is wrapped around) the various components and plumping of the exhaust system, and fuel delivery insulation that insulates the various components and plumping of the fuel delivery system.

[0033] The system 300 may also include various valves, gauges, controllers, and actuators and how each of these elements may be configured in order to controllably operate the system 300. In addition, various additional components, such as air filters, sensors, pumps, throttles, etc., may also be implemented in certain embodiments of the system. It is contemplated that these additional components and elements (not depicted) fall within the scope of the present disclosure.

[0034] FIG. 4 is a schematic flow chart diagram of a method 400 for reforming a recycled portion of an exhaust gas stream to improve engine efficiency, according to one embodiment. The method 400 first includes dividing an exhaust gas stream 12 from an engine 110 into a recycle stream 32 and a vent stream 34 at 402. The method 400 then includes mixing the recycle stream 32 with a gaseous fuel stream 5 to form a combination stream 42 at 404. Further, the method 400 includes catalytically converting the combination stream 42 into a hydrogen-enriched reformat 52 stream at 406. As described above, various additional steps may be implemented with this method 400, such as removing oxygen from the exhaust gas stream 12 before catalytically converting the combination stream 42 into a hydrogen-enriched reformat stream 52. For example, the engine 110 may be operated at an air/fuel ratio that is stoichiometric or fuel rich in order to prevent excess oxygen in the exhaust gas stream 12. In other embodiments, various other processing components, such as those found in the aftertreatment sub-system 120, may actively remove/reduce oxygen.

[0035] The described features, structures, advantages, and/or characteristics of the subject matter of the present disclosure may be combined in any suitable manner in one or more embodiments and/or implementations. In the above description, numerous specific details are provided to impart a thorough understanding of embodiments of the subject matter of the present disclosure. One skilled in the relevant art will recognize that the subject matter of the present disclosure may be practiced without one or more of the specific features, details, components, materials, and/or methods of a particular embodiment or implementation. In other instances, additional features and advantages may be recognized in certain embodiments and/or implementations that may not be present in all embodiments or implementations. Further, in some instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the subject matter of the present disclosure. The features and advantages of the subject matter of the present disclosure will become more fully apparent from the above description and appended claims, or may be learned by the practice of the subject matter as set forth above.

[0036] In the above description, certain terms may be used such as “up,” “down,” “upper,” “lower,” “horizontal,” “vertical,” “left,” “right,” and the like. These terms are used, where

applicable, to provide some clarity of description when dealing with relative relationships. But, these terms are not intended to imply absolute relationships, positions, and/or orientations. For example, with respect to an object, an “upper” surface can become a “lower” surface simply by turning the object over. Nevertheless, it is still the same object. Further, the terms “including,” “comprising,” “having,” and variations thereof mean “including but not limited to” unless expressly specified otherwise. An enumerated listing of items does not imply that any or all of the items are mutually exclusive and/or mutually inclusive, unless expressly specified otherwise. The terms “a,” “an,” and “the” also refer to “one or more” unless expressly specified otherwise.

[0037] Additionally, instances in this specification where one element is “coupled” to another element can include direct and indirect coupling. Direct coupling can be defined as one element coupled to and in some contact with another element. Indirect coupling can be defined as coupling between two elements not in direct contact with each other, but having one or more additional elements between the coupled elements. Further, as used herein, securing one element to another element can include direct securing and indirect securing. Additionally, as used herein, “adjacent” does not necessarily denote contact. For example, one element can be adjacent another element without being in contact with that element.

[0038] The schematic flow chart diagrams and method schematic diagrams described above are generally set forth as logical flow chart diagrams. As such, the depicted order and labeled steps are indicative of representative embodiments. Other steps, orderings and methods may be conceived that are equivalent in function, logic, or effect to one or more steps, or portions thereof, of the methods illustrated in the schematic diagrams.

[0039] Additionally, the format and symbols employed are provided to explain the logical steps of the schematic diagrams and are understood not to limit the scope of the methods illustrated by the diagrams. Although various arrow types and line types may be employed in the schematic diagrams, they are understood not to limit the scope of the corresponding methods. Indeed, some arrows or other connectors may be used to indicate only the logical flow of a method. For instance, an arrow may indicate a waiting or monitoring period of unspecified duration between enumerated steps of a depicted method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown.

[0040] As used herein, the phrase “at least one of”, when used with a list of items, means different combinations of one or more of the listed items may be used and only one of the items in the list may be needed. The item may be a particular object, thing, or category. In other words, “at least one of” means any combination of items or number of items may be used from the list, but not all of the items in the list may be required. For example, “at least one of item A, item B, and item C” may mean item A; item A and item B; item B; item A, item B, and item C; or item B and item C. In some cases, “at least one of item A, item B, and item C” may mean, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; or some other suitable combination.

[0041] The present subject matter may be embodied in other specific forms without departing from its spirit or essen-

tial characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

1. An engine system, comprising:
 - an exhaust gas recirculation assembly fluidly connected to an exhaust manifold of an internal combustion engine, the exhaust gas recirculation assembly configured to divide an exhaust gas stream into a recycle stream and a vent stream;
 - a mixer in fluid receiving communication with the recycle stream, the mixer configured to form a combination stream by mixing a gaseous fuel stream with the recycle stream; and
 - a thermochemical recuperator component fluidly connected to the mixer, wherein the thermochemical recuperator including:
 - a first flow path comprising a catalyst through which the combination stream flows to create a reformat stream, and
 - a second flow path comprising a heat transfer area for transferring heat from the vent stream to the combination stream.
2. The engine system of claim 1, wherein the reformat stream comprises a hydrogen enriched gaseous stream.
3. The engine system of claim 1, further comprising an exhaust gas aftertreatment sub-system fluidly connected between the exhaust manifold of an internal combustion engine and the exhaust gas recirculation assembly.
4. The engine system of claim 3, wherein the exhaust gas aftertreatment sub-system includes a three-way catalyst.
5. The engine system of claim 1, wherein the gaseous fuel stream comprises natural gas.
6. The engine system of claim 1, further comprising a sulfur scrubber positioned upstream of the thermochemical recuperator component.
7. The engine system of claim 1, further comprising a fuel pre-heater, the pre-heater configured to transfer heat from the vent stream to the gaseous fuel stream.
8. The engine system of claim 1, further comprising a reformat stream cooler, the reformat stream cooler configured to lower the temperature of the reformat stream.
9. The engine system of claim 1, further comprising a second mixer, the second mixer configured to combine the reformat stream with an air stream so as to form an intake stream for routing to the internal combustion engine.
10. The engine system of claim 1, further comprising a filter disposed in the reformat stream, the filter configured to remove selected particulate matter from the reformat stream.
11. The engine system of claim 1, further comprising a turbocharger with a turbine upstream of the exhaust gas recirculation assembly.
12. An engine system, comprising
 - a natural gas engine including an intake manifold and an exhaust manifold;
 - an exhaust gas recirculation assembly fluidly connected to the exhaust manifold, the exhaust gas recirculation assembly configured to divide an exhaust gas stream into a recycle stream and a vent stream;

- a mixer in fluid receiving communication with the recycle stream, the mixer configured to form a combination stream by mixing the gaseous fuel stream with the recycle stream; and
 - a thermochemical recuperator component fluidly connected to the mixer, wherein the thermochemical recuperator comprises:
 - a first flow path comprising a catalyst through which the combination stream flows to create a hydrogen-enriched reformat stream, and
 - a second flow path comprising a heat transfer area for transferring heat from the vent stream to the combination stream.
13. The engine system of claim 12, further comprising a second mixer in fluid receiving communication with the reformat stream, the second mixer configured to form an intake stream by combining the reformat stream with an air stream.
 14. The engine system of claim 12, further comprising an exhaust gas aftertreatment sub-system fluidly connected between the exhaust manifold and the exhaust gas recirculation assembly.
 15. The engine system of claim 14, wherein the exhaust gas aftertreatment sub-system includes a three-way catalyst.
 16. The engine system of claim 12, further comprising a fuel pre-heater in fluid receiving communication with the vent stream and configured to transfer heat from the vent stream to a gaseous fuel stream;
 17. A method for reforming a portion of an exhaust gas stream, the method comprising:
 - dividing the exhaust gas stream from an engine into a recycle stream and a vent stream;
 - mixing the recycle stream with a gaseous fuel stream to form a combination stream; and
 - catalytically converting the combination stream into a hydrogen-enriched reformat stream.
 18. The method of claim 17, wherein catalytically converting the combination stream into a hydrogen-enriched reformat stream includes flowing the combination stream through a first flow path of a thermochemical recuperator component and flowing the vent stream through a second flow path of the thermochemical recuperator component, wherein the first flow path comprises a catalyst for reacting the combination stream and the second flow path comprises a heat transfer area for transferring heat from the vent stream to the combination stream.
 19. The method of claim 17, further comprising pre-heating the gaseous fuel stream by transferring heat from the vent stream to the gaseous fuel stream.
 20. The method of claim 17, further comprising cooling the hydrogen-enriched reformat stream.
 21. The method of claim 17, further comprising removing oxygen from the exhaust gas stream before catalytically converting the combination stream into a hydrogen-enriched reformat stream.
 22. The method of claim 21, wherein removing oxygen from the exhaust gas stream comprises operating the engine at an air/fuel ratio that is one of stoichiometric and fuel rich.
 23. The method of claim 21, wherein a three-way catalyst is used in the removing of oxygen from the exhaust gas stream

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