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(54) METHOD AND SYSTEM FOR REDUCING POLLUTANT EMISSIONS OF A POWER SYSTEM

(76) Inventors: **James Joshua Driscoll**, Dunlap, IL (US); **John Thomas Vachon**, Peoria, IL (US); **Darrin A. Johnston**, Washington, IL (US)

Correspondence Address:
FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER LLP
901 NEW YORK AVENUE, NW
WASHINGTON, DC 20001-4413 (US)

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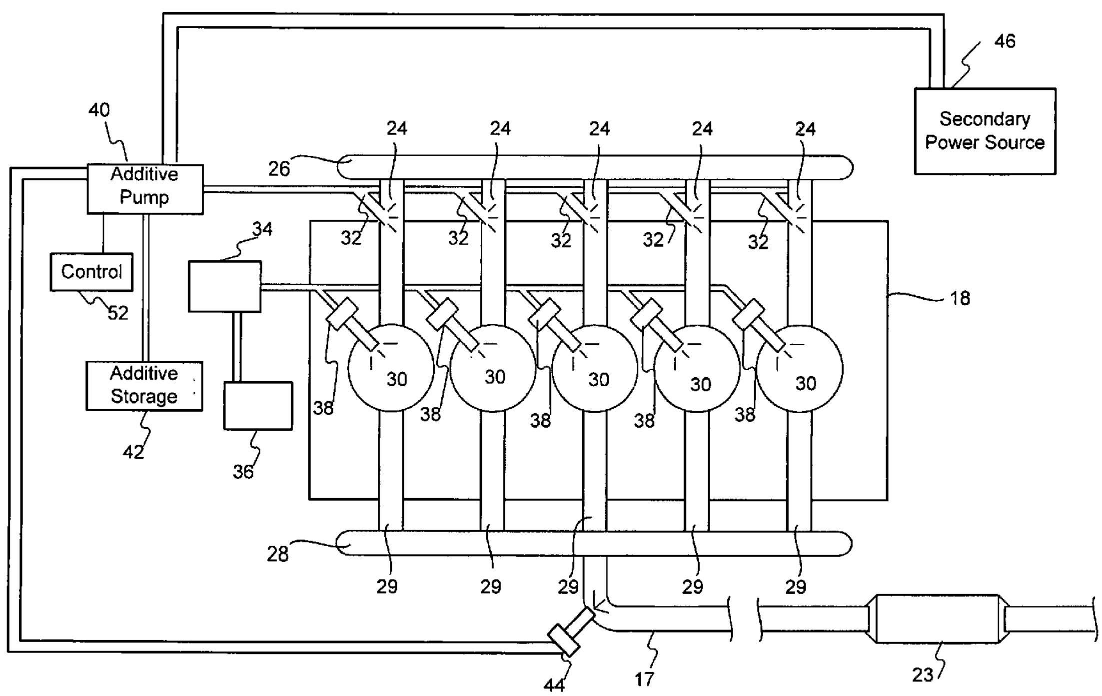
(57) **ABSTRACT**

A method for reducing pollutant emissions of a power system may include the steps of providing a first portion of an ethanol additive to a first power source, wherein the first power source includes a combustion chamber. The method may also include supplying a second portion of the ethanol additive to a second power source and providing a primary fuel to the combustion chamber. The method may further include the steps of combusting at least a portion of primary fuel and at least some of the first portion of ethanol additive in the combustion chamber, wherein the combustion results in formation of an exhaust-gas stream, providing a third portion of ethanol additive to the exhaust-gas stream, and exposing the exhaust-gas stream to a selective catalytic reduction system catalyst.



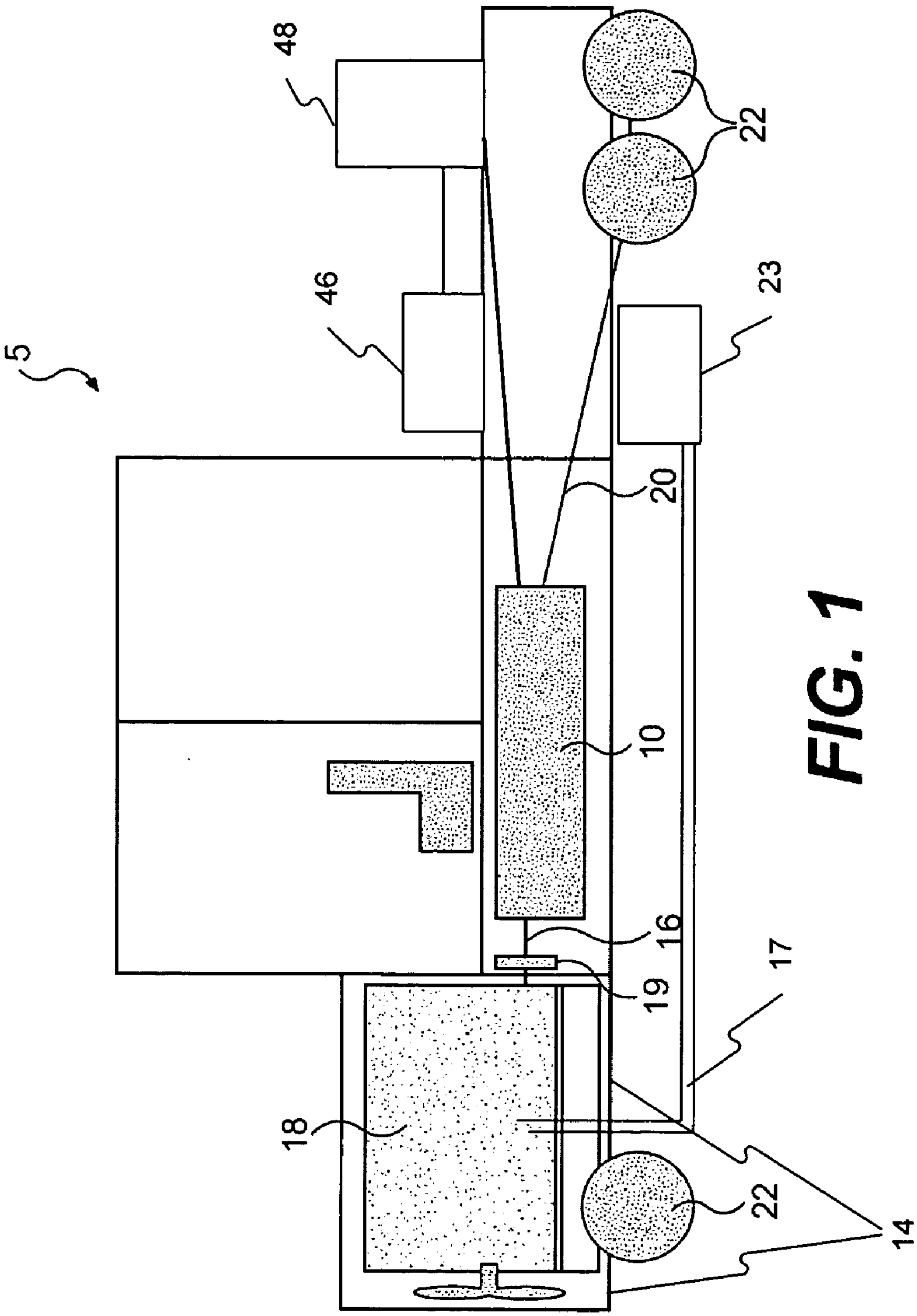
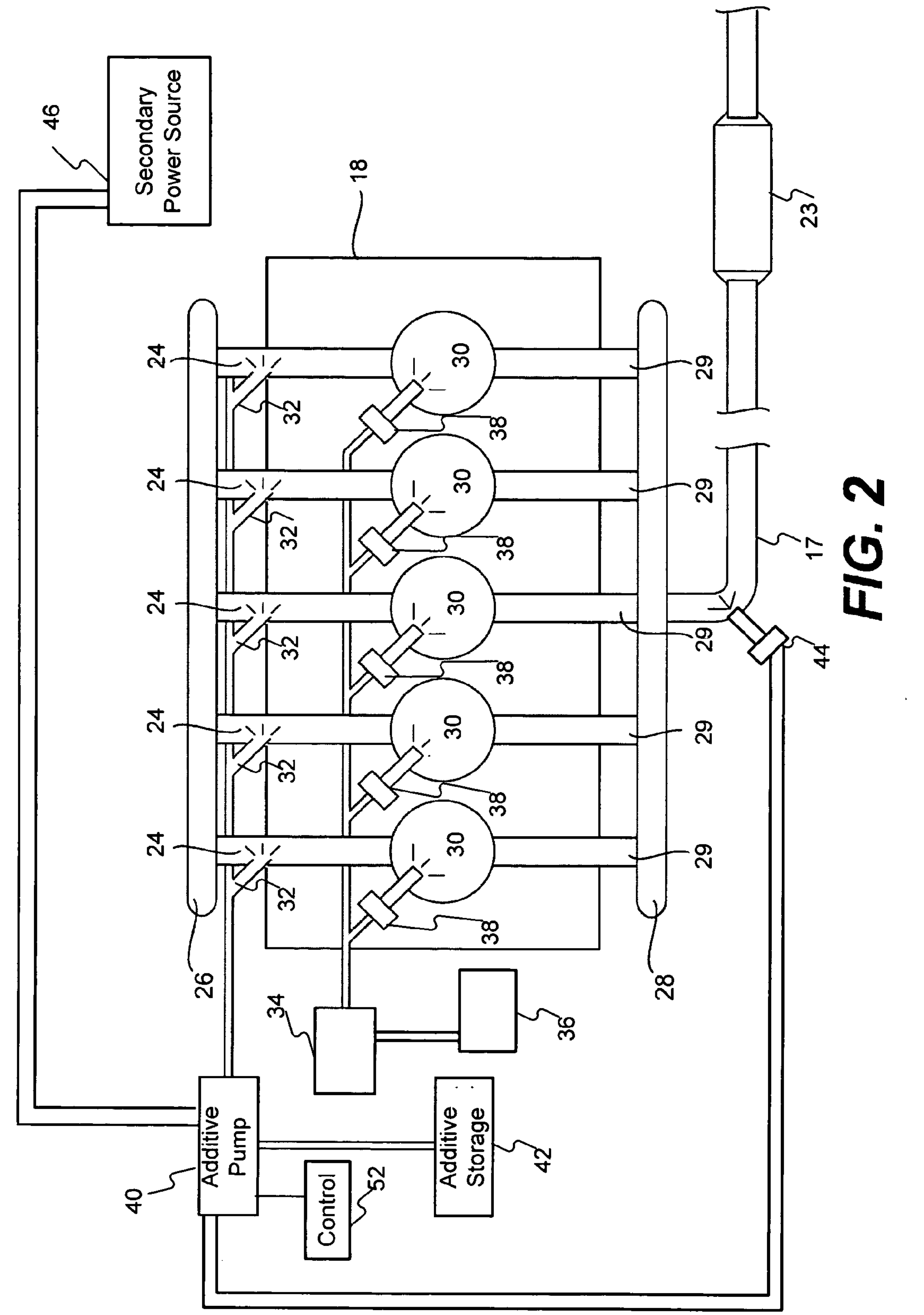


FIG. 1



Secondary Power Source
46
18
23
24
32
30
38
29
17
44
26
28
34
36
Additive Pump
40
Additive Storage
42
Control
52

FIG. 2

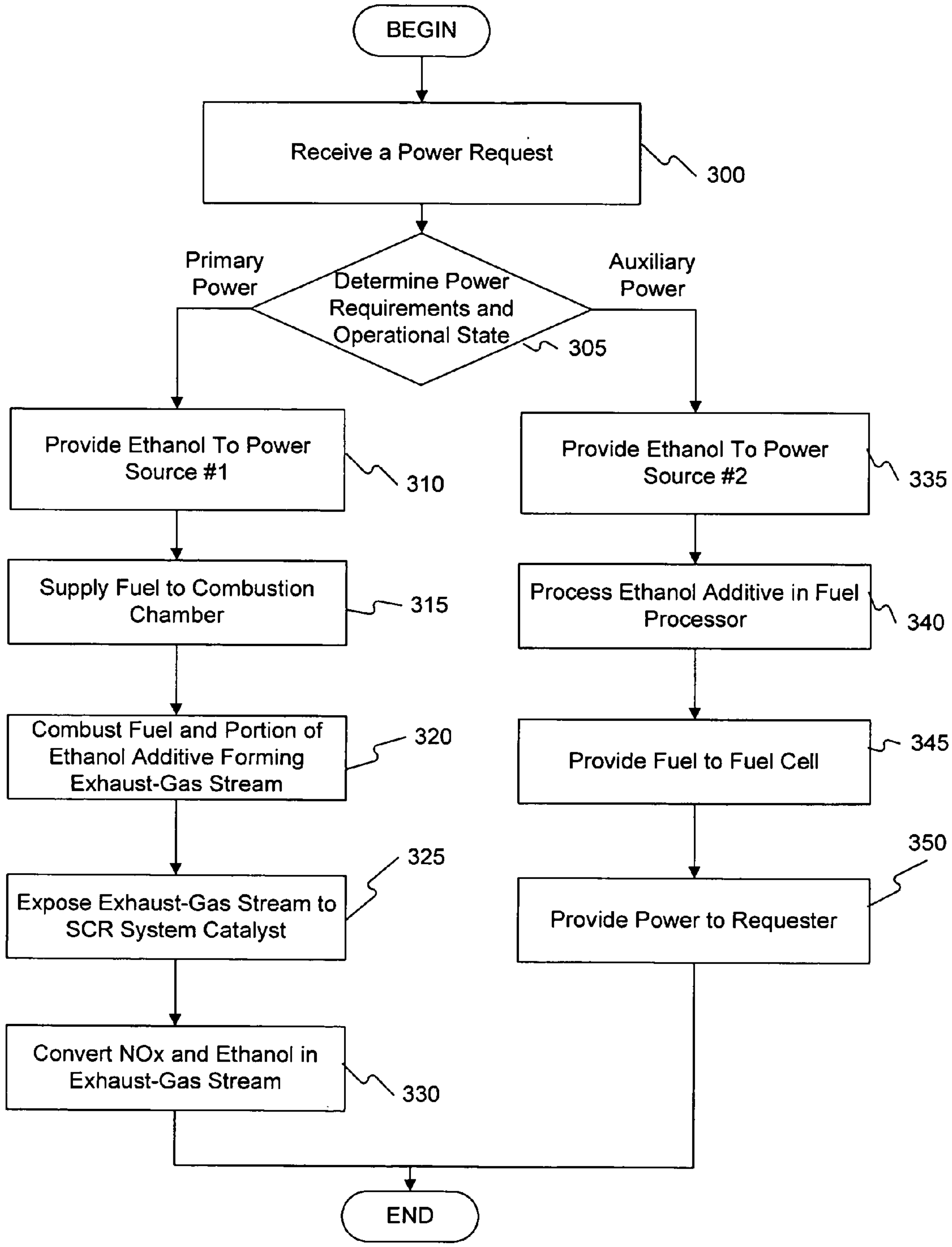

BEGIN
Receive a Power Request
300
Primary Power
Determine Power Requirements and Operational State
Auxiliary Power
305
Provide Ethanol To Power Source #1
310
Supply Fuel to Combustion Chamber
315
Combust Fuel and Portion of Ethanol Additive Forming Exhaust-Gas Stream
320
Expose Exhaust-Gas Stream to SCR System Catalyst
325
Convert NOx and Ethanol in Exhaust-Gas Stream
330
Provide Ethanol To Power Source #2
335
Process Ethanol Additive in Fuel Processor
340
Provide Fuel to Fuel Cell
345
Provide Power to Requester
350
END

FIG. 3

METHOD AND SYSTEM FOR REDUCING POLLUTANT EMISSIONS OF A POWER SYSTEM

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 11/410,258, entitled "SYSTEM FOR INCREASING EFFICIENCY OF AN SCR CATALYST," and filed Apr. 25, 2006, which is expressly incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure pertains generally to reduction of pollutant emissions and, more particularly, to use of an ethanol additive for reducing both petroleum based fuel use and overall power source emissions.

BACKGROUND

[0003] Government standards associated with combustion engine emissions have increased the burden on manufacturers to reduce the amount of nitrogen oxides (NOx) and other pollutants that may be exhausted from their engines. Along with this burden is the manufacturer's commitment to their customers to produce powerful yet fuel efficient engines. However, the sometimes inverse relationship between fuel economy/power and reduced emissions tends to make the task of reducing pollutants while meeting customer needs a daunting one.

[0004] NOx emission levels may be affected by engine combustion temperatures and air to fuel ratio, among other things. When the temperature inside combustion chambers exceeds 1300 degrees C., nitrogen may combine with oxygen to form oxides of nitrogen, or NOx. Because lean mixtures in a power source typically lead to higher combustion temperatures, lean burn engines may produce more NOx than other richer burning power sources. Lean burn engines create less NOx than richer burning engines (e.g. stoichiometric gasoline), but stoichiometric engines can use a 3-way catalyst. Some engines rely on methods such as exhaust gas recirculation, for example, to lower combustion chamber temperatures and reduce NOx formation. These methods may be insufficient to meet standards promulgated by government agencies limiting NOx emissions.

[0005] Selective catalytic reduction (SCR) provides a method for removing NOx emissions from fossil fuel powered systems for engines, factories, and power plants. During typical SCR, a catalyst may facilitate a reaction between exhaust gas NOx and a reductant, for example, ethanol, to produce nitrogen gas and byproduct substances such as water and nitrogen thereby removing NOx from the exhaust gas.

[0006] Hydrocarbon reductants used in an SCR system have previously been injected into the exhaust-gas stream upstream of a catalyst and mixed with the exhaust gas to facilitate a reaction in the presence of the catalyst. Thorough mixing of the reductant in the exhaust-gas stream may improve the reaction between the reductant and NOx, thereby further reducing NOx emissions and limiting the release of highly-reactive species into the atmosphere. The performance of a lean-NOx catalyst to reduce NOx may depend upon many other factors, such as catalyst formulation, the size of the catalyst, exhaust gas temperature, the reductant compound, and reductant dosing rate. The result has been to somewhat reduce atmospheric output of NOx, but reduction has fallen short of governmental requirements.

[0007] Anhydrous fuel-grade ethanol has been used with some success as a reductant in SCR systems through injection into an exhaust-gas stream upstream of an SCR system catalyst. In such a system, NOx in the exhaust-gas stream may react with the injected ethanol in the presence of the catalyst which may result in formation of nitrogen, water, and other byproducts. However, anhydrous fuel-grade ethanol is a flammable liquid. Further, injection of the ethanol into the exhaust stream is a waste of energy that could otherwise be extracted from the ethanol.

[0008] Fuel-grade ethanol has also been emulsified within diesel fuel for combustion in quantities up to approximately 15% ethanol by volume as a means for increasing consumption of renewable type fuels and reducing some pollutant emissions. This emulsification, typically referred to as e-diesel, has been accomplished using proprietary emulsifying agents to maintain some stability in the emulsion and reduce reactivity. However, emulsified ethanol is still highly corrosive and lacks the lubricating qualities of petroleum based fuels. This may result in long-term damage to injection pumps and fuel injectors designed to receive petroleum based fuels exclusively. Further, emulsions of ethanol within petroleum fuels greater than 15% ethanol by volume, create unstable, reactive emulsions that are impractical for storage or use in an engine. Further, because the anhydrous fuel-grade ethanol is emulsified in low concentrations and designed for combustion, a majority of the emulsified ethanol is combusted in the combustion chamber, resulting in little if any remaining ethanol to be used as a reductant in the exhaust-gas stream.

[0009] One system for using fuel-grade anhydrous ethanol as a reductant in a lean-NOx SCR system is disclosed in the publication *Selective Catalytic Reduction of Diesel Engine NOx Emissions Using Ethanol as a Reductant*, U.S. Department of Energy 9th Diesel Emissions Reduction Conference (Aug. 24-28, 2003) by Kass et al. (hereinafter "the Kass publication"). The system of the Kass publication includes an injector for spraying ethanol, which is either extracted from e-diesel or stored separately in a fuel-grade anhydrous form, directly into a bent region of the exhaust pipe to facilitate mixing of the ethanol with the exhaust-gas stream. The system further includes a system for extracting a portion of fuel-grade ethanol from e-diesel which may be stored in a fuel storage tank. An ethanol injector is placed upstream of an alumina-supported silver lean-NOx catalyst such that conversion of NOx is facilitated as the mixture contacts the lean-NOx catalyst.

[0010] While the system of the Kass publication may result in some NOx reduction through ethanol introduced in the exhaust stream, both e-diesel and fuel-grade ethanol can be more difficult to store and manage because of their reactive characteristics. As a result, added cost may be incurred when using e-diesel and/or fuel-grade ethanol as a reductant injected into an exhaust stream.

[0011] In addition, injection of ethanol into an exhaust stream, as taught in the Kass publication, may not result in adequate mixing of the ethanol with the exhaust-gas stream, and, consequently, may result in discharge of unreacted fuel-grade ethanol. Moreover, injection of ethanol into the exhaust stream may deprive the engine of valuable energy stored within the ethanol, thereby eliminating any benefit to brake specific fuel consumption or use as a fuel for an alternative power source (e.g., a fuel cell).

[0012] The present disclosure is directed at overcoming one or more of the problems or disadvantages in the prior art power systems.

SUMMARY OF THE INVENTION

[0013] In one embodiment, the present disclosure is directed to a method for reducing pollutant emissions of a power system. The method may include the steps of providing a first portion of an ethanol additive to a first power source, wherein the first power source includes a combustion chamber, supplying a second portion of the ethanol additive to a second power source, and providing a primary fuel to the combustion chamber. The method may further include the steps of combusting at least a portion of primary fuel and at least some of the first portion of ethanol additive in the combustion chamber, wherein the combustion results in formation of an exhaust-gas stream, providing a third portion of ethanol additive to the exhaust-gas stream, and exposing the exhaust-gas stream to a selective catalytic reduction system catalyst.

[0014] In another embodiment, the present disclosure is directed to a system for reducing emissions. The system may include a first power source, including a combustion chamber and an exhaust system, a second power source configured to receive an ethanol additive, and a controller operatively connected to the first power source and the second power source. The controller may be configured to receive a request for power, determine a first operational state associated with the first power source and a second operational state associated with the second power source, and, based on the request and the determination of the first and second states, cause an ethanol additive to be provided to at least one of the first power source, the second power source, or the exhaust system.

[0015] In yet another embodiment, the present disclosure is directed to a machine, including a frame, a traction device, and a first power source operatively connected to the frame and the traction device. The first power source may include at least one combustion chamber an exhaust system fluidly connected to the at least one combustion chamber and configured to receive an exhaust-gas stream a fuel source configured to supply a primary fuel to the at least one combustion chamber an additive supply device configured to supply a first portion of an ethanol additive to the at least one combustion chamber a secondary additive supply device configured to supply a second portion of the ethanol additive to the exhaust system, and a selective reduction catalyst system catalyst fluidly connected to the exhaust system and configured to receive the exhaust gas stream. The machine may also include a second power source configured to receive a third portion of the ethanol additive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** provides a pictorial representation of a machine according to an exemplary disclosed embodiment;

[0017] FIG. **2** schematically illustrates first and second power sources, according to an exemplary disclosed embodiment; and

[0018] FIG. **3** is a flow chart illustrating an exemplary disclosed method of reducing pollutant emissions of a power system.

DETAILED DESCRIPTION

[0019] FIG. **1** provides a pictorial representation of an exemplary machine **5** having multiple systems and components that may cooperate to accomplish a task. Machine **5** may include a system for reducing pollutant emissions. Machine **5** may embody a fixed or mobile machine that performs some type of operation associated with an industry such as mining, construction, farming, transportation, or any other industry known in the art. For example, machine **5** may be an earth moving machine such as an excavator, a dozer, a loader, a backhoe, a motor grader, a dump truck, or any other earth moving machine. Additionally, machine **5** may include on-highway vehicles such as tractors, passenger cars, heavy and light trucks, and other similar vehicles. Machine **5** may include a first power source **18**, a second power source **46**, auxiliary devices **48**, and an input member **16** connecting a transmission assembly **10** to power source **18** via a torque converter **19**. Machine **5** may also include a frame **14** and an output member **20** connecting the transmission assembly **10** to one or more traction devices **22** operatively connected to frame **14**. Power source **18** may be operatively connected to frame **14** and may further be fluidly connected to an exhaust system **17**, which may in turn be fluidly connected to an SCR system catalyst **23**. Second power source **46** may be designed to provide power to auxiliary devices **48**.

[0020] FIG. **2** schematically illustrates a power system capable of implementing the disclosed systems and methods for reducing pollutant emissions of a power system. In an exemplary pollutant emission reduction system, first power source **18** and second power source **46** may be present. First power source **18** may include an internal combustion engine, e.g., a diesel engine, a gasoline engine, a gaseous fuel-powered engine, and the like, or any other lean-burn engine apparent to one skilled in the art. Alternatively, first power source **18** may be another source of power, such as a furnace, gas-turbine, or another suitable source of power for a powered system (e.g., a factory or power plant) designed to operate with an excess of oxygen. First power source **18** may include, for example, an intake manifold **26**, intake passages **24**, exhaust ports **29**, an exhaust manifold **28**, combustion chambers **30**, additive supply devices **32**, and fuel sources **38**. First power source **18** may further include a fuel pump **34**, fuel storage **36**, additive pump **40**, additive controller **52**, and additive storage **42**, among other things.

[0021] Combustion chambers **30** may be configured to receive and combust materials including fuel and air. Additionally, each combustion chamber **30** may be configured to receive at least one additive material including, for example, an ethanol additive and/or a hydrous ethanol additive. Hydrous ethanol will be understood to mean any combination of ethanol and water in any proportion appropriate for addition to a combustion chamber. The term ethanol additive, as referred to throughout this specification, will be understood to mean any substance or mixture containing ethanol in amounts greater than 15 percent by volume, including fuel-grade ethanol, denatured ethanol, and hydrous ethanol. For example, an ethanol additive may include between 30 percent ethanol by volume and 80 percent ethanol by volume. In one embodiment, the ethanol additive is a hydrous ethanol and includes approximately 40 percent ethanol by volume and 60 percent water by volume. A hydrous ethanol additive may be similar to vodka or other distilled spirits, or the hydrous ethanol additive may be denatured. Hydrous denatured ethanol may be less expensive than pure ethanol and may be substantially more stable for easier storage and transport. One of ordinary skill in the art will recognize that the ethanol additive compositions described herein are exemplary only, and numerous variations of ethanol additives may be used without departing from the scope of the disclosed systems and methods.

[0022] Combustion chambers **30** may be configured for compression ignition (CI), spark ignition (SI), homogeneous charge compression ignition (HCCI), or any other type of combustion ignition. For example, a diesel engine may initiate combustion as a piston (not shown) within combustion chamber **30** nears top-dead-center and critical temperature and pressure are reached.

[0023] Combustion chambers **30** may be configured to receive a supply of fuel from fuel sources **38**. Fuel sources **38** may include injectors or atomizers configured to inject fuel directly into combustion chambers **30**. Alternatively, fuel sources **38** may be configured to supply fuel to intake manifold **26** or intake passages **24**. Fuel sources **38** may be configured to supply fuel at a specific time (timed injection) or, alternatively, may be configured to introduce fuel continuously or at random intervals. Configuration of fuel sources **38** may depend upon the combustion configuration of combustion chambers **30** (e.g., CI, SI, or HCCI).

[0024] Fuel sources **38** may be operatively connected to fuel pump **34**. Fuel pump **34** may be configured to deliver fuel from fuel storage **36** to fuel sources **38**. Fuel pump **34** may include an injection pump of the rotary or distributor variety, or any other suitable pump, and may be driven indirectly by gears or chains from the crankshaft or by other methods (e.g., electrically). One of skill in the art will recognize that many types of pumps may function adequately and fall within the scope of the current disclosure.

[0025] The fuel supplied to combustion chambers **30** may include, for example, diesel fuel, gasoline, alcohols, propane, methane, or any other suitable fuel. The fuel may be supplied to fuel sources **38** under pressure, and/or fuel sources **38** may, themselves, be configured to further increase the pressure or velocity of the fuel. Fuel storage **36** may be configured to store fuel, among other things, and may include a tank or other similar container. Fuel may be supplied at timed intervals (e.g., based on first power source **18** rotational position), randomly, and/or continuously. Control of the fuel source **38** may be regulated by methods known by those of ordinary skill in the art and appropriate for the type of power source in operation.

[0026] Intake manifold **26** may be configured to draw air from atmosphere or from an air source (e.g., a turbocharger) and provide the air to combustion chambers **30** via intake passages **24**. For example, intake manifold **26** may be fluidly connected to a forced induction system such as the outlet of a turbocharger or supercharger. Intake manifold **26** may further be fluidly connected to at least one intake passage **24**, which in turn may be fluidly connected to a combustion chamber **30**. In one embodiment consistent with the disclosure, intake manifold **26** may also be fluidly connected to an additive supply device **32** configured to supply an ethanol additive to intake manifold **26**. It is important to note that while additive supply devices **32** are depicted in FIG. **2** as being fluidly connected to intake passages **24**, additive supply devices **32** may be located at any suitable location for providing the ethanol additive to combustion chambers **30**. For example, additive supply devices **32** may also be located at intake manifold **26**, combustion chambers **30**, a turbocharger outlet (not shown), or any other suitable location such that an ethanol additive may by provided to combustion chambers **30**. Additive supply devices **32** may include an injector or atomizer similar to that depicted by additive supply device **32** and may be installed in intake manifold **26** to cause an ethanol additive to be introduced and mixed with other substances contained therein. Fuel or other additive substances (e.g., performance boosting substances including propane) may also be supplied to intake manifold **26**.

[0027] Intake passages **24** may be configured to carry substances including, air, fuel, an ethanol additive, other substances, or any combination thereof, to combustion chambers **30**. Intake passages **24** may contain additive supply devices **32** configured to supply an ethanol additive to combustion chambers **30**. Intake passages **24** may further include devices to facilitate mixing of materials entering combustion chambers **30**. Such devices may be configured to impart rotation to the flow of materials within intake passages **24**. Intake passages **24** may be opened to combustion chambers **30** via intake valve assemblies (not shown) which may open and close, as desired, to facilitate flow of materials (e.g., air and/or ethanol additive) into combustion chambers **30**.

[0028] Additive supply devices **32** may be fluidly connected to additive pump **40** or other apparatus designed to pressurize or impart motion to fluid or gas. Additive pump **40** may be an injection pump of the rotary or distributor variety, among others, and may be driven indirectly by gears or chains from the crankshaft or by other methods (e.g., electrically). One of skill in the art will recognize that many types of pumps may function adequately and fall within the scope of the current disclosure. Additive pump **40** may further be communicatively connected to additive controller **52**. Additive pump may be configured to draw an ethanol additive from additive storage **42** and supply the ethanol additive to additive supply devices **32**, a secondary additive supply device **44**, and/or second power source **46** based on a determination by additive controller **52**. Additive pump **40** may be configured to supply ethanol additive to additive supply devices **32** under pressure, or alternatively, additive supply devices **32** may be configured to increase the pressure or velocity of the ethanol additive. Supply of an ethanol additive may occur at timed intervals, continuously, or randomly and may be based on additional determinations made by additive controller **52**. Additive storage **42** may be configured to store an ethanol additive, among other things, and may include a tank or other similar container.

[0029] Additive controller **52** may be a mechanical or an electrical based controller configured to control the flow of ethanol additive from additive pump **40**. For example, additive controller **52** may send electric signals causing valves on additive pump **40** to open and close thereby directing flow of ethanol additive to additive supply devices **32**, second power source **46**, secondary additive supply device **44**, or any other suitable location. Flow control may be based on factors including power requirements, emissions requirements, fuel availability, and other parameters. Control of the ethanol additive supply may also be regulated based on sensors present in exhaust system **17** and engine timing, among other things. For example, where a sensor present in the exhaust-gas stream indicates the presence of unacceptable levels of unburned ethanol, the ethanol additive supply rate to secondary additive supply device **44** may be modified by additive controller **52** accordingly. One of ordinary skill in the art will recognize that other methods for providing and controlling the flow of ethanol additive may be available and fall within the scope of this disclosure.

[0030] Combustion within combustion chambers **30** may result in combustion of at least a portion of the fuel and at least a portion of the ethanol present in the ethanol additive. Heat and/or power may be derived from the combustion of both the fuel and the ethanol. For example, ethanol from the ethanol additive may be combusted in amounts up to 95 percent and may produce up to 50 percent of available brake horsepower. Further, water from the hydrous ethanol additive may assist in reducing flame temperature in combustion chamber **30**, and may therefore assist in reducing NOx produced during the combustion. One of skill in the art will recognize that such effects may vary based on ethanol and water concentrations in the ethanol additive.

[0031] As a result of combustion, an exhaust-gas stream including NOx, unburned ethanol, water, and hydrocarbons (e.g., unburned fuel), among other things, may be generated. The unburned ethanol may include gas phase ethanol and may be substantially mixed with the exhaust-gas stream via the combustion process within combustion chamber **30**. Gas-phase ethanol may be present in the exhaust-gas stream in amounts between about 10 ppm by volume and about 10000 ppm by volume of the exhaust-gas stream. One of ordinary skill in the art will recognize that higher or lower concentrations of ethanol may be present in the exhaust-gas stream based on numerous conditions (e.g., temperature, water content, ethanol additive input, etc.).

[0032] Exhaust ports **29** may be fluidly connected to combustion chambers **30** and configured to receive the exhaust-gas stream generated as a result of combustion of the fuel and at least a portion of an ethanol additive within combustion chambers **30**. The fluid connection from combustion chambers **30** to exhaust ports **29** may be opened and closed using exhaust valve assemblies (not shown) to allow flow of an exhaust-gas stream from combustion chambers **30** into exhaust ports **29**. The exhaust valve assemblies may also be configured to allow such flow to occur at timed intervals. Further, exhaust ports **29** may be fluidly connected to a secondary additive supply device **44** configured to provide additional ethanol additive to the exhaust-gas stream. It is important to note that although secondary additive supply device **44** is depicted in FIG. **2** as being fluidly connected to exhaust system **17**, secondary additive supply device **44** may be located at any suitable location for providing the ethanol additive to the exhaust-gas stream. For example, secondary additive supply device **44** may also be located at exhaust manifold **28**, exhaust ports **29**, or any other suitable location for providing an ethanol additive to the exhaust gas stream.

[0033] Exhaust manifold **28** may be fluidly linked to at least one exhaust port **29** and may collect and receive an exhaust-gas stream from the at least one exhaust port **29**. Exhaust manifold **28** may operate to link several exhaust ports **29** together and receive the cumulative exhaust from exhaust ports **29**. Exhaust manifold **28** may further include devices for supplying other substances (e.g., urea, ethanol, etc.) for mixture in the exhaust-gas stream, or, alternatively, no such additional devices may be present. For example, exhaust manifold **28** may be fluidly connected to secondary additive supply device **44**, which may be configured to supply ethanol additive to exhaust manifold **28**. Exhaust manifold **28** may include sensors (not shown) for detecting levels of exhaust gas pollutants as well as levels of remaining ethanol and/or other substances within the exhaust-gas stream. Where the sensors indicate low levels of unburned ethanol, additional ethanol additive may be provided to exhaust manifold **28**, or other suitable location, by secondary additive supply device **44**. Exhaust manifold **28** may further include fluid connections to allow for recirculation of some exhaust gas and/or coupling of exhaust gas to the turbine of a turbocharger (not shown).

[0034] Exhaust manifold **28** may be fluidly connected to exhaust system **17**, which may be configured to receive the exhaust-gas stream from exhaust manifold **28**. Exhaust system **17** may include pipes, tubes, clamps, etc., and may direct the flow of the exhaust-gas stream in various directions. Exhaust system **17** may also be fluidly connected to secondary additive supply device **44** and configured to receive additional ethanol additive for combination with the exhaust-gas stream. Exhaust system **17** may also include sensors, mixing devices, and fluid connections to recirculation devices and turbocharger turbines (not shown), among other things.

[0035] SCR system catalyst **23** may be disposed in exhaust system **17** downstream of exhaust manifold **28**. Exhaust system **17** may direct flow of the exhaust-gas stream such that the exhaust-gas stream is received by SCR system catalyst **23** and caused to contact the SCR system catalyst.

[0036] SCR system catalyst **23** may be made from a variety of materials. SCR system catalyst **23** may include a catalyst support material and a metal promoter dispersed within the catalyst support material. The catalyst support material may include at least one of alumina, zeolite, aluminophosphates, hexyluminates, aluminosilicates, zirconates, titanosilicates, and titanates. In one embodiment, the catalyst support material may include at least one of alumina and zeolite, and the metal promoter may include silver (Ag). Combinations of these materials may be used, and the catalyst material may be chosen based on the type of fuel used, the ethanol additive used, the air to fuel-vapor ratio desired, and/or for conformity with environmental standards. One of ordinary skill in the art will recognize that numerous other catalyst compositions may be used without departing from the scope of this disclosure. Further, multiple SCR system catalysts may also be included in exhaust system **17**.

[0037] The lean-NOx catalytic reaction is a complex process including many steps. One of the reaction mechanisms, however, that may proceed in the presence of SCR system catalyst **23** can be summarized by the following reaction equations:

$$NO+O_2 \rightarrow NOx \quad (1)$$

$$HC+O_2 \rightarrow \text{oxygenated HC} \quad (2)$$

$$NOx+\text{oxygenated HC}+O_2 \rightarrow N_2+CO_2+H_2O \quad (3)$$

[0038] SCR system catalyst **23** may catalyze the reduction of NOx to N_2 gas, as shown in equation (3). Further, as shown in equation (2), a hydrocarbon reducing agent may be converted to an activated, oxygenated hydrocarbon that may interact with the NOx compounds to form organo-nitrogen containing compounds. These materials may possibly decompose to isocyanate (NCO) or cyamide groups and eventually yield nitrogen gas (N_2) through the series of reactions as summarized above. As noted, the unburned ethanol may be well mixed within the exhaust-gas stream as a result of the combustion process in combustion chamber **30**. This well-mixed, unburned ethanol, and any additional ethanol additive, may further react in the presence of other hydrocarbons (e.g., unburned fuel) in order to aid in the production of oxygenated hydrocarbons, as represented by equation (2).

[**0039**] Second power source **46** may be configured to supply power to one or more components of machine **5** or to any other suitable device. Second power source **46** may include fuel cells, fuel processors, heat exchangers, catalysts, combustion engines, and other devices known to those skilled in the art. Fuel cell, as used herein, means any fuel consuming electrochemical energy conversion device. For example, a fuel cell may include a proton exchange membrane fuel cell and/or a solid-oxide fuel cell. In one embodiment, second power source **46** may include a fuel cell or a stacked arrangement of fuel cells. Such fuel cells may be configured to react a fuel (e.g., hydrogen) with an oxidizer (e.g., air) to generate electrical energy and water.

[**0040**] A fuel processor may be fluidly connected with a fuel cell or fuel cell stack within second power source **46** and configured to provide a fuel to the fuel cell. Fuel processor, as used herein, means any device capable of converting one or more substances into a fuel for consumption within a fuel cell. For example, a fuel processor may include a steam reformer configured to convert a hydrous ethanol additive into various components including hydrogen, water, and CO_2. A steam reformer may include steam generators, catalysts, and other items known to those of skill in the art. Hydrous ethanol may be provided to the fuel processor via a fluid connection to additive supply pump **40** based on a control message sent by additive controller **52**. For example, auxiliary devices **48** may request power, causing additive controller **52** to determine whether first power source **18**, second power source **46**, or a combination thereof are available for power production (e.g., available and not overloaded). Upon making such a determination, additive controller **52** may cause valves within additive pump **40** to open and/or close thereby directing flow of ethanol additive to first power source **18**, second power source **46**, and/or secondary additive supply device **44**. In another example, a power request may indicate that auxiliary devices **48** are requesting power and first power source **18** is not available to supply auxiliary devices **48** with power (e.g., not running, disabled, or overloaded). Additive controller **52** may cause valves within additive pump **40** to open and/or close thereby directing flow of ethanol additive to second power source **46**.

[**0041**] Processing of an ethanol additive may occur in the presence of steam and a catalyst within a fuel processor similar to the following equations:

$$C_2H_5OH+H_20 \longleftrightarrow CH_4+CO_2+2H_2 \quad (4)$$

$$CH_4+H_20 \longleftrightarrow CO+3H_2 \quad (5)$$

$$CO+H_20 \longleftrightarrow CO2+H_2 \quad (6)$$

[**0042**] The ethanol additive may react in the presence of steam and one or more catalysts to form methane, carbon dioxide and hydrogen gas as shown in equation 4. The methane generated by the process may then further react in the presence of steam and one or more catalysts to produce carbon monoxide and additional hydrogen gas as shown in equation 5. The carbon monoxide may then react in the presence of additional steam and one or more catalysts to form additional carbon dioxide and hydrogen gas as shown in equation 6. The presented equations are meant to be exemplary only and other reactions may also proceed without departing from the scope of this disclosure.

[**0043**] In one embodiment, steam for use in a steam reformer may be generated utilizing waste heat obtained during the operation of first power source **18**. For example, a heat exchanger (not shown) may be fluidly connected to a coolant line from first power source **18**. The heat exchanger may then extract heat from the coolant and use such heat to produce steam or preheat water for use in steam production. Additionally, waste heat generated at second power source **46** may also be utilized to produce steam or preheat water for use in steam production. Waste heat from second power source **46** may be used alone or in combination with other heat sources such as, heat derived from first power source **18**.

[**0044**] Hydrogen (H_2) produced by a fuel processor may be provided to a fuel cell or fuel cell stack within second power source **46**, or, alternatively, the hydrogen may be stored in a hydrogen storage container (not shown) for later use. A fuel cell within second power source **46** may be configured to provide electrical energy based on a process of reacting hydrogen and oxygen to form water which may be illustrated by the following equations:

$$H_2 \rightarrow 2H^+ + 2e^- \quad (7)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (8)$$

[**0045**] Reactive hydrogen gas may be stripped of electrons as shown in equation 7. Products of the reaction in equation 7 may then react in the presence of oxygen to form water and electricity (e.g., free electrons) as shown in equation 8. The electricity generated from the reaction may then be provided to other devices utilizing such power (e.g., auxiliary devices **48**), or may be used for other suitable purposes.

[**0046**] Auxiliary devices **48** may be provided with power from second power source **46**. Auxiliary devices **48** may include, motors, lights, pumps, compressors, resistance heaters, and any other device utilizing electrical or mechanical energy. For example, an electric motor may be powered by second power source **46** and may in turn be operatively connected to transmission assembly **10** or traction devices **22**. Electrical power provided by second power source **46** may thereby cause motion of machine **5**. In another example, hydraulic pressure for use with a hydraulic crane may be provided by a hydraulic pump powered by auxiliary power supply **46**. Any number of other configurations and devices may be utilized without departing from the scope of this disclosure.

INDUSTRIAL APPLICABILITY

[**0047**] The disclosed systems and methods may be applicable to any powered system that includes a power source that produces an exhaust-gas stream, such as an engine. The disclosed systems and methods may allow for reduction efficiencies of NOx from an exhaust-gas stream of greater than 90 percent, and reduction of overall pollutants by up to 100 percent when operating with an alternative power source exclusively. Operation of the disclosed systems and methods will now be explained.

[0048] Operation of combustion chambers **30** may be dependant on the ratio of air to fuel-vapor that is supplied during operation. When determining the air to fuel-vapor ratio, primary fuel as well as other combustible materials in combustion chamber **30** (e.g., ethanol additive, propane, etc.) may be included as fuel-vapor. The air to fuel-vapor ratio is often expressed as a lambda value, which is derived from the stoichiometric air to fuel-vapor ratio. The stoichiometric air to fuel-vapor ratio is the chemically correct ratio for combustion to take place. A stoichiometric air to fuel-vapor ratio may be considered to be equivalent to a lambda value of 1.0.

[0049] Combustion chambers may operate at non-stoichiometric air to fuel-vapor ratios. A combustion chamber with a lower air to fuel-vapor ratio has a lambda less than 1.0 and is said to be rich. A combustion chamber with a higher air to fuel-vapor ratio has a lambda greater than 1.0 and is said to be lean.

[0050] Lambda may affect combustion chamber NOx emissions and fuel efficiency. A lean-operating combustion chamber may have improved fuel efficiency compared to a combustion chamber operating under stoichiometric or rich conditions. However, lean operation may increase temperature and, therefore, increase NOx production, making elimination of NOx in the exhaust gas difficult.

[0051] SCR systems can provide a method for decreasing exhaust-gas NOx emissions through the use of additives such as ethanol. In an exemplary embodiment of the present disclosure, NOx and unburned ethanol generated by lean combustion (lambda greater than 1.0) in combustion chambers **30** may be converted into acetaldehyde, nitrogen, water, and other substances in the presence of an SCR system catalyst **23**.

[0052] FIG. **3** is a flowchart depicting one exemplary method for operation of the disclosed systems and methods. In one embodiment, a request for power is received by additive controller **52** (step **300**). Based on a determination of the request for power and the operational states of first power source **18** and second power source **46**, additive controller **52** may cause a supply of an ethanol additive to be directed to first power source **18** (step **305**: primary power) and/or second power source **46** (step **305**: auxiliary power). Where additive controller **52** determines that power should be provided by first power source **18**, additive controller **52** may cause ethanol additive to be provided to additive supply devices **32** which may provide an ethanol additive to combustion chambers **30** (step **310**). Once the ethanol additive has been supplied to combustion chambers **30**, along with a suitable amount of air, fuel may be supplied to combustion chambers **30** (step **315**). Following the supply of fuel, combustion of the materials within combustion chambers **30** may be initiated (step **320**). A fluid connection between exhaust manifold **28** and exhaust system **17** may then allow an exhaust-gas stream formed as a result of combustion, to be received by exhaust system **17**. Exhaust system **17** may be configured to direct the exhaust-gas stream to be received by SCR system catalyst **23** via a fluid connection (step **325**). The exhaust-gas stream may then flow through SCR system catalyst **23**, thus contacting SCR system catalyst **23** based on the design and flow pattern of SCR system catalyst **23**. SCR system catalyst **23** may facilitate reactions resulting in the reduction/conversion of NOx from the exhaust-gas stream (step **330**). The products of such conversion may include nitrogen, water, and acetaldehyde, among other things. The resulting reduction efficiencies of SCR system catalyst **23** for NOx may, therefore, be increased to greater than 90 percent. In other words, NOx within an exhaust-gas stream may be reduced by greater than 90 percent and may meet federal regulations for year 2010 NOx emissions.

[0053] Where additive controller **52** determines that power should be provided by second power source **46**, additive controller **52** may cause ethanol additive to be provided to second power source **46** (step **335**). The ethanol additive may then be processed by a fuel processor to produce hydrogen gas among other things (step **340**). Hydrogen gas produced during the processing may then be provided to the fuel cell for use as fuel (step **345**). Power generated by the fuel cell may then be provided to auxiliary devices **48** or another requesting device (step **350**). Utilizing second power source **46** in this way can eliminate harmful emissions with the only byproduct being water.

[0054] Several advantages may be associated with the disclosed systems and method for reducing pollutant emissions of a power system. For example, ethanol additives containing water (i.e., hydrous ethanol), whether denatured or not, may be substantially less reactive than pure fuel-grade ethanol. Further, pure fuel-grade ethanol may act as a desiccant drawing in water from the surrounding atmosphere, whereas hydrous ethanol additives may be stored at equilibrium. Therefore, requirements for storage and transportation of a hydrous ethanol additive may be substantially lower than for storage and transportation of pure fuel-grade ethanol. Use of hydrous ethanol additives may lead to significant cost savings over pure fuel-grade ethanol and other benefits such as, cooler combustion chamber temperatures and/or reduced combustion chamber production of NOx.

[0055] Moreover, by providing a system for supplying an ethanol additive to an intake port, intake manifold, or combustion chamber, using equipment distinct from the fuel supply system, systems designed for ethanol specific applications may be used. Ethanol may be corrosive to rubber and some metal parts and can damage parts designed for use with petroleum based products, for example, pumps, injectors, etc. By using parts designed specifically designed for ethanol (e.g., plastics), this damage can be reduced or eliminated.

[0056] Additionally, injection of an ethanol additive into an intake port prior to combustion may allow for greater mixing of any remaining ethanol within an exhaust-gas stream. Increased mixing may occur as the result of many mechanisms related to the combustion process (e.g., turbulence, compression, etc.). Complete mixing of ethanol within the exhaust-gas stream may be beneficial to increasing the reduction efficiency of an SCR system catalyst. Therefore, combining an SCR system catalyst with intake port injection of ethanol may result in substantial increased efficiency of the reaction between NOx and ethanol contained in the exhaust-gas stream, as the stream contacts the SCR system catalyst. Moreover, allowing a portion of the ethanol to be combusted in combustion chambers **30** may further result in benefits to brake specific fuel consumption, while also leaving an amount of unburned ethanol in the exhaust-gas stream. The amount of ethanol remaining in the exhaust-gas stream may be sufficient to facilitate catalytic reduction reactions and may improve the efficiency of an SCR system catalyst. But, the amount of unburned ethanol in the exhaust-gas stream may remain small enough to substantially prevent emission of reactive ethanol species into the air post catalyst.

[0057] Provisioning a portion of ethanol additive for use in an alternative fuel source may further provide the benefit of power generation with a substantial reduction in petroleum based fuel use and little or no pollutant emissions. By determining which power source is better suited to provide power for a particular request, power needs may be met while also minimizing overall pollutant output.

[0058] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed system and methods for reducing pollutant emissions of a power system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed systems and methods for reducing pollutant emissions of a power system. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A method for reducing pollutant emissions of a power system, the method comprising:

providing a first portion of an ethanol additive to a first power source, wherein the first power source includes a combustion chamber;

supplying a second portion of the ethanol additive to a second power source;

providing a primary fuel to the combustion chamber;

combusting at least a portion of primary fuel and at least some of the first portion of ethanol additive in the combustion chamber, wherein the combustion results in formation of an exhaust-gas stream;

providing a third portion of ethanol additive to the exhaust-gas stream; and

exposing the exhaust-gas stream to a selective catalytic reduction system catalyst.

2. The method of claim 1, wherein the second power source includes a fuel cell.

3. The method of claim 2, wherein the second power source further includes a fuel processor.

4. The method of claim 3, further including:

processing at least a portion of the second portion of the ethanol additive to generate at least one of hydrogen, carbon dioxide, or water; and

providing hydrogen to the fuel cell.

5. The method of claim 1, wherein the ethanol additive includes hydrous ethanol.

6. The method of claim 5, wherein the hydrous ethanol includes water in an amount between about 30 percent by volume and about 80 percent by volume.

7. The method of claim 1, wherein the selective reduction catalyst system catalyst includes a lean-NOx catalyst.

8. The method of claim 1, further including:

determining a quantity of ethanol additive in the exhaust-gas stream; and

controlling a volume of the third portion of the ethanol additive based on the determination.

9. The method of claim 1, further including:

receiving a request for power;

determining a first operational state associated with the first power source and a second operational state associated with the second power source; and

controlling, based on the request and the determination of the first and second operational states, a volume of at least one of the first portion, second portion, or third portion of the ethanol additive.

10. The method of claim 9, wherein determining the first operational state includes identifying a first existing power load on the first power source and determining the second operational state includes identifying a second existing power load on the second power source.

11. The method of claim 10, wherein determining the first operational state further includes determining whether the first power source is available for production of power and determining the second operational state includes determining whether the second power source is available for production of power.

12. The method of claim 11, wherein controlling a volume of at least one of the first portion, second portion, or third portion of the ethanol additive further includes:

if the first power source is available for production of power and the first existing power load does not exceed a predetermined threshold, supplying the first portion of ethanol additive to the first power source; and

if the second power source is available for production of power and the second existing power load does not exceed a predetermined threshold, supplying the second portion of ethanol additive to the second power source.

13. The method of claim 3, further including:

extracting heat from the first power source; and

providing the heat to the fuel processor.

14. A system for reducing emissions, the system comprising:

a first power source, including a combustion chamber and an exhaust system;

a second power source configured to receive an ethanol additive; and

a controller operatively connected to the first power source and the second power source, wherein the controller is configured to:

receive a request for power;

determine a first operational state associated with the first power source and a second operational state associated with the second power source; and

based on the request and the determination of the first and second states, cause an ethanol additive to be provided to at least one of the first power source, the second power source, or the exhaust system.

15. The system of claim 14, wherein the second power source includes a fuel cell.

16. The system of claim 14, further including a fuel processor fluidly connected to the fuel cell.

17. The system of claim 16, wherein the fuel processor is configured to process at least a portion of ethanol additive to yield at least a fuel for the fuel cell.

18. The system of claim 14, wherein the second power source is configured to provide power to at least one of the traction device and the at least one auxiliary device.

19. The system of claim 14, further including a heat exchanger configured to remove heat from the first power source and provide at least a portion of the removed heat to the second power source.

20. The system of claim 14, wherein determining the first operational state includes identifying a first existing power load on the first power source and determining the second operational state includes identifying a second existing power load on the second power source.

21. The system of claim 20, wherein determining the first operational state further includes determining whether the first power source is available for production of power and determining the second operational state includes determining whether the second power source is available for production of power.

22. The system of claim 21, wherein the ethanol additive is provided to the first power source if the first power source is available for production of power and the first existing power load does not exceed a predetermined threshold, and the ethanol additive is provided to the second power source if the second power source is available for production of power and the second existing power load does not exceed a predetermined threshold.

23. A machine, comprising:

a frame;

a traction device;

a first power source operatively connected to the frame and the traction device, wherein the first power source includes:

at least one combustion chamber;

an exhaust system fluidly connected to the at least one combustion chamber and configured to receive an exhaust-gas stream;

a fuel source configured to supply a primary fuel to the at least one combustion chamber;

an additive supply device configured to supply a first portion of an ethanol additive to the at least one combustion chamber;

a secondary additive supply device configured to supply a second portion of the ethanol additive to the exhaust system; and

a selective reduction catalyst system catalyst fluidly connected to the exhaust system and configured to receive the exhaust gas stream; and

a second power source configured to receive a third portion of the ethanol additive.

24. The machine of claim 23, wherein the second power source includes a fuel cell.

25. The machine of claim 23, further including a fuel processor.

26. The machine of claim 23, wherein the second power source provides power to at least one of the traction device and at least one auxiliary device.

27. The machine of claim 23, further including a heat exchanger configured to remove energy from the first power source and provide at least a portion of the removed energy to the second power source.

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