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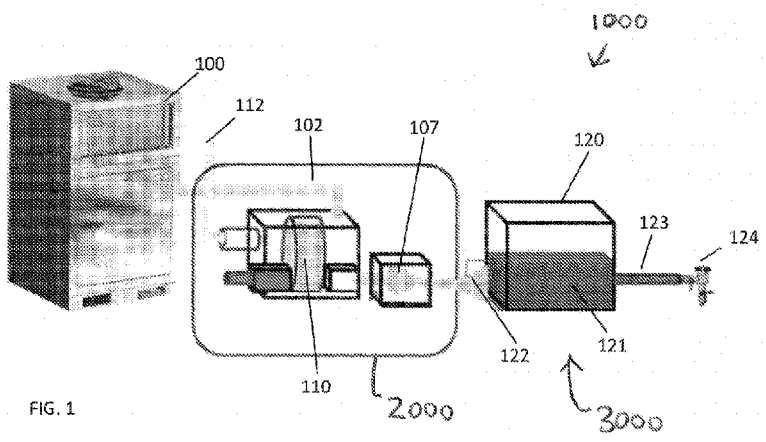

FIG. 1

(57) Abstract: A combined power conversion and carbon capture and recycling subsystem including a fossil fueled oxidation unit, a physical adsorbent C02 capture medium, rotor, motor, heater, C02 compressor, diffuser and water storage tank. Exhaust gas from fossil fuel oxidation is scrubbed of C02 via passage across a physical adsorbent and then released from the adsorbent via fuel oxidation waste heat. High C02 concentration scrubber exhaust air is then compressed and fed to a diffuser which facilitates dissociation of the C02 into water where it is temporarily stored for use in watering plants. Carbon from fossil fuel is recycled back into the environment and permanently stored as biomass by natural means of photosynthesis.

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CARBON CAPTURE SYSTEM, APPARATUS, AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[001] The present application claims the benefit of United States Provisional Patent Application No. 62/397,910, filed on September 21, 2016 (pending), the entirety of which is incorporated herein by reference for all purposes and made a part of the present disclosure.

FIELD

[002] The present disclosure relates generally to a system, apparatus, and method of capturing and\or sequestration, or otherwise managing, handling or manipulating carbon. More specifically, the present disclosure relates to a system, apparatus, and method of capturing or sequestering carbon from fossil fuel residue or fossil fuel plant exhaust gases. In some aspects, the present disclosure relates to a power generating system or apparatus or method of power generating that includes a carbon management component, system, or apparatus. In some aspects, the present disclosure relates to a system, apparatus, and method of providing carbonated water to plant life.

BACKGROUND

[003] Concern over environmental effects of green house gasses has resulted in significant effort to reduce overall atmospheric CO_2 including reforesting, increased use of renewable energy sources, and the carbon capture and storage (CCS, also referred to as carbon capture and sequestration) of carbon from fossil fuel plant exhaust gasses. CCS is now mandated internationally by many advisory and regulatory agencies with both EU and US Department of Energy directives requiring greater 90% recovery rates. This has led to a vast array of CCS technologies, such as those disclosed in U.S. Patent Nos 8,114,367,B2; 5,779,464; and 4,595,465, most of which, in one form or another, typically employ post-production scrubbing of combustion flue gasses of CO_2 using a solvating agent which reacts with and sequesters carbon.

[004] Although many such technologies, such as that disclosed in U.S. Patent Publication No. 2008/0121105, utilize metal-organics, which are highly effective, CCS technology remains a challenge due to its inherent expense and resulting reduction in fuel efficiency. Capital, operating, and energy costs may result in efficiency penalties ranging from 10% for natural gas (NG) production to 25% for petroleum based power plants. These expenses are divided into two main components, including: (1) the energy cost of the scrubbing process itself, and (2) the cost of carbon transport and storage. The latter is typically handled via geo-

sequestration by: (1) pumping CO_2 directly into geological formations, such as oil and gas fields, abandoned coal mines and saline formations; (2) storing CO_2 in a solid state as carbonates; or (3) dumping CO_2 into the ocean. No matter the method, the results are costly. The first method requires the construction of piping networks and pumping stations, as well as the dumping of caprock to ensure containment. The second method requires additional energy to heat the sequestering mineral source to achieve practical conversion rates, with added transport costs if it is not stored at the site of conversion. The last method is largely unworkable due to the potential of oceanic acidification, such that the practice has been deemed illegal by most governing agencies.

[005] While the mechanics of carbon capture is a chemical process with inherent limitations and costs independent of the location or application, sequestration is a highly variable expense, being roughly proportional to production size and accessibility, making it a particularly high expense for large isolated plants used in distributed power production.

SUMMARY

[006] Various aspects described herein or otherwise contemplated by the present disclosure seek to expand the use of CCS technology by providing a simple and cost effective carbon capture process while eliminating both the transport and sequestration phases, making said process available for a wide range of applications.

[007] Further, such exemplary systems or methods also reduce general atmospheric CO_2 by enhancing plant photosynthesis at the site of energy production. This is achieved using a fossil fueled powered energy conversion unit, such as a combined heating and power (CHP) or combined cooling, heating and power (CCHP) system, a water heater or gas powered clothes dryer equipped with a physical adsorbent based carbon capture system with an integrated aqueous dissociation unit for storing captured carbon as carbonated water, which may be used to irrigate local vegetation. Thus, such exemplary systems or methods afford disposal of captured carbon directly at the site of production via photosynthesis, eliminating transport and storage costs as well as the risk of potential leakage or environmental damage, while operating at high energy efficiencies characteristic of local power generation by providing a zero to even negative carbon footprint.

[008] In accordance with certain aspects, a system or method may be composed of a natural gas fueled oxidation unit combined with a reversible adsorbing carbon capture unit and a water storage tank with a diffuser to facilitate tank water carbonation. As opposed to common liquid amine scrubbing, the carbon capture unit used here is a solid adsorbent, such as an

alkali mineral oxide or zeolite, *e.g.*, magnesium, potassium, and lithium silicates, in which carbon affinity is temperature dependent, as described in U.S. Patent No. 6,521,026 B1, the entirety of which is incorporated herein and made a part of the present disclosure. Cycling is achieved by convection of combustion exhaust gas across the solid adsorbent, which is fixed to a continuously revolving rotor mounted such that the rotor axis is parallel to a divider separating two thermally isolated chambers maintained at temperatures designed to accept and reject carbon adherence, respectively. Thus, raw engine exhaust gas is first funneled through a lower temperature scrubber chamber in which carbon within the CO_2 adheres to the solid adsorbent forming an adsorbent-carbon complex, and is then carried out of the lower temperature scrubber chamber (*i.e.*, the adsorbing chamber) via the revolving rotor into a higher temperature scrubber chamber (*i.e.*, the releasing chamber). With the releasing chamber, the rotor and adsorbent-carbon complex is heated to release the captured carbon from the adsorbent and into a carbon carrier air for discharge to a sequestration unit. Cleansed engine exhaust (*i.e.*, engine exhaust from which carbon has been adsorbed from) is ejected from the exhaust of the adsorbing chamber. Rotor timing is synchronized with engine exhaust load and carbon content, such that the majority of trapped carbon is released upon a single revolution with adsorbent regenerated to accept a new carbon load upon reentering into the adsorbing chamber. Once discharged, the high carbon content exhaust in the releasing chamber is passed through a compressor for compression, and then is injected under pressure through a diffuser, such as a jet, porous ceramic atomizer to facilitate dissociation of the carbon into the water within a holding tank. Finally, the resulting carbonated water may then be used to irrigate local vegetation, providing a natural way to return carbon to the environment via the earth's biochemical carbon cycle.

[009] Further, various design options are noted, which enhance feasibility and optimize performance. Firstly, local energy conversion and waste carbon utilization allow the use of combustion waste heat to directly drive the carbon capture process, while also avoiding the complexities and cost of carbon transfer and storage, greatly increasing the fuel efficiency and lowering overall costs which plague centralized energy production. Secondly, although chemical absorption affords high yields, true chemical bonding combined with low absorption density require high-throughput and high-energy penalties. This, combined with the overall added complexity of the stripping process, solvent degradation, equipment corrosion and higher capital investment, makes physical adsorption a more feasible choice for small-scale commercial applications. It is also noted that, while pressure cycling generally produces higher rates, yields and purities with adsorption methods, temperature cycling is, in

some aspects, employed due to its relative simplicity and the ready availability of engine waste heat.

[0010] It is also noted that, aside from reducing carbon emissions with higher efficiency and lowered operating costs than possible with central power production and disposing of said carbon in an environmentally friendly manner, the systems, apparatus, and methods disclosed herein also serve to enhance vegetation growth via carbon enriched irrigation, which further helps to reduce atmospheric CO_2 through increased rates of photosynthesis, while also increasing biomass yields.

[0011] One aspect of the present disclosure includes a micro carbon capture system, including a fossil fuel oxidation unit that oxidizes fossil fuel to convert fossil fuel chemical energy into thermal energy, mechanical energy, electrical energy, or combinations thereof. The system includes a carbon capture unit positioned to receive exhaust gas of the fossil fuel oxidation unit. The carbon capture unit includes a regeneratable physical adsorbent and a cycling mechanism (*e.g.*, rotor driven by a motor) configured to cycle the regeneratable physical adsorbent between a first position (*e.g.*, within an absorbing chamber) and a second position (*e.g.*, within a releasing chamber). In the first position the physical adsorbent is positioned to adsorb CO_2 from the exhaust gas and, in the second position the physical adsorbent is positioned to release the CO_2.

[0012] Another aspect of the present disclosure includes a carbon capture system, including a fossil fuel oxidation unit, a carbon capture unit, and a storage unit in which carbon is stored as a biomass. The fossil fuel oxidation unit is configured to oxidize fossil fuel and convert the fossil fuel chemical energy into an alternate form of energy.

[0013] Another aspect of the present disclosure includes to a carbon capture apparatus including a carbon capture component for sequestering carbon from exhaust gases. The apparatus may include a power generating system including an exhaust. The carbon capture unit may be configured to capture exhaust gases from the exhaust.

[0014] Another aspect of the present disclosure includes to a method of capturing carbon from a fossil fuel exhaust gases. The method includes sequestering carbon from fossil fuel exhaust gases, including oxidizing fossil fuel and converting the fossil fuel into an alternate form of energy.

[0015] Another aspect of the present disclosure includes a method of capturing carbon. The method includes directing exhaust from a fossil fuel oxidation unit into a carbon capture unit, adsorbing CO_2 from with the exhaust onto a physical adsorbent within the carbon capture unit, deadsorbing the CO_2 from the physical adsorbent within the carbon capture unit, and

releasing the deadsorbed CO_2 from the carbon capture unit. The method may be implemented using any of the systems and/or apparatus described herein.

BRIEF DESCRIPTION OF DRAWINGS

[0016] So that the manner in which the features and advantages of aspects of the present disclosure may be understood in more detail, a more particular description of the briefly summarized aspects above may be had by reference to the aspects which are illustrated in the appended drawings that form a part of this specification. It is to be noted, however, that the drawings illustrate only various exemplary aspects, and are therefore not to be considered limiting of the scope of this disclosure, as it may include other effective aspects as well.

[0017] FIG. 1 depicts a micro-carbon capture system, according to one aspect of the present disclosure;

[0018] FIG. 2 depicts a micro-carbon capture system and components thereof, according to one aspect of the present disclosure;

[0019] FIG. 3 depicts a physical adsorbent carbon capture unit, according to one aspect of the present disclosure;

[0020] FIG. 4A depicts an exemplary micro-pore matrix CO_2 diffuser, according to one aspect of the present disclosure;

[0021] FIG. 4B depicts an exemplary reactor CO_2 diffuser, according to one aspect of the present disclosure;

[0022] FIG. 4C depicts an exemplary bell cap CO_2 diffuser, according to one aspect of the present disclosure;

[0023] FIG. 5A depicts a gas powered water heater with an integrated micro-carbon capture system, according to one aspect of the present disclosure;

[0024] FIG. 5B depicts a gas powered clothes dryer with an integrated micro-carbon capture system, according to one aspect of the present disclosure;

[0025] FIG. 6A depicts a micro-carbon capture system with a recycled carrier gas, according to one aspect of the present disclosure;

[0026] FIG. 6B depicts a micro-carbon capture system with a recycled carrier gas, according to one aspect of the present disclosure;

[0027] FIG. 7A depicts a micro-carbon capture system with soil and alkylation, according to one aspect of the present disclosure;

[0028] FIG. 7B depicts a micro-carbon capture system with soil and alkylation, according to one aspect of the present disclosure;

[0029] FIG. 7C depicts a portion of the micro-carbon capture system of FIG. 7B, according to one aspect of the present disclosure;

[0030] FIG. 8 depicts a soil filtering unit with automated control, according to one aspect of the present disclosure;

[0031] FIG. 9 depicts a soil filtering unit with a bioreactor, according to one aspect of the present disclosure; and

[0032] FIG. 10 depicts a schematic of an mCHP carbon capture and repurposing system, according to one aspect of the present disclosure.

DETAILED DESCRIPTION

[0033] Aspects of the present disclosure will now be described more fully with reference to the accompanying drawings, which illustrate various exemplary aspects. The disclosed concepts may, however, be embodied in many different forms and should not be construed as being limited by the illustrated aspects set forth herein. Rather, these aspects are provided so that this disclosure will be thorough as well as complete and will fully convey the scope to those skilled in the art and modes of practicing the aspects.

[0034] In one aspect, as shown in FIGS. 1 and 2, a system 1000 according to the present disclosure includes a micro CHP/CCHP system including internal combustion engine (ICE) 100, a physical adsorbent carbon capture unit 2000 coupled with ICE 100 and configured to receive exhaust therefrom, and carbonated water sequestration unit 3000 coupled with physical adsorbent carbon capture unit 2000 and configured to receive carbon (*e.g.*, CO2) therefrom.

[0035] Internal Combustion Engine

[0036] The operation of ICE 100 is well known to those skilled in the art, and will only be briefly discussed herein. Crankshaft 106 is operatively coupled to ICE 100, such that ICE 100 drives crankshaft 106. Belt 105 is operatively coupled to crankshaft 106, such that crankshaft 106 drives belt 105. Generator 104 is driven by ICE 100 via belt 105. As is known to those skilled in the art, ICE 100 may be used to provide mechanical and/or electrical power to any of various equipment, for example compressor 107. Exhaust manifold 101 is configured to receive exhaust of ICE 100, and exhaust pipe 102 is configured to receive exhaust from exhaust manifold 101.

[0037] With reference to FIGS. 1-4C, physical adsorbent carbon capture unit 2000 includes physical adsorbent carbon scrubber 117 with adsorbent rotor 110 and motor 116, a carbon rich inlet (*i.e.*, exhaust pipe 102), clean air outlet 112, clean air inlet 113, and carbon outlet 115. Carbonated water sequestration unit 3000 includes water tank 120 containing water

121, carbon diffuser 122, water cooler 127, air compressor 107, and water tank inlet 126. Carbonated water sequestration unit 3000 is operatively coupled with irrigation system 4000 and configured to provide irrigation system 4000 with carbonated water from water tank 120. Irrigation system 4000 includes piping 123 and 125, with valve 124 (*e.g.*, irrigation relieve valve) coupled therebetween. In operation, carbonated water from water tank 120 may be provided to vegetation 130.

[0038] Physical Adsorbent

[0039] Before describing overall system operation, it is perhaps most instructive to first provide an operational summary of certain CCS handling elements of system 1000, including physical adsorbent carbon scrubber 117 and carbon diffuser 122. It should be noted, as there are commercially available physical scrubbers, the description provided herein is general, provided solely for illustration. The physical adsorbent carbon scrubber 117 and carbon diffuser 122 are not limited to the examples provided herein. U.S. Patent No. 6,521,026 B1, incorporated by reference above, provides relevant background and description of scrubber operation.

[0040] In some aspects, physical adsorbent carbon scrubber 117 includes a housing divided into two sections, including low-temperature adsorbing chamber 111 and high-temperature releasing chamber 114 separated by barrier 200. Barrier 200 may be an air-tight barrier. Barrier may be constructed of a thermal insulating material, such as ceramic or glass wool, serving to minimize thermal loss between chambers 111 and 114. Barrier 200 may be centrally placed, bisecting physical adsorbent carbon scrubber 117 and spanning both chambers 111 and 114.

[0041] In some aspects, rotor 110 contains wheels or discs carrying a physical adsorbent. The physical adsorbent may be, for example and without limitation, a porous adsorbent matrix (*e.g.*, molecular sieve), such as a metal oxide or zeolite compound. Rotor 110 is driven by motor 116. As described in U.S. Patent No. 6,521,026 B1, the physical adsorbent may be permanently embedded within rotor wheels, as depicted in FIG. 3, or may be held within baskets housed by the rotor wheels for easy replacement. For example and without limitation, rotor 110 with physical adsorbent may be a carbon white or zeolite based desiccant wheel separator. In some aspects, the physical adsorbent includes an organic–inorganic hybrid or metal-organic framework. In some aspects, the physical adsorbent includes, calcium oxide, silicate, activated carbon, amine-modified activated carbon, mesoporous silicas, or hydrotalcite.

[0042] As engine exhaust gas enters physical adsorbent carbon scrubber 117 via exhaust pipe 102, the exhaust is drawn into low-temperature adsorbing chamber 111 and across rotor 110 and the physical adsorbent. In some aspects, exhaust fan 201, which may be positioned within clean air outlet 112, draws the exhaust into low-temperature adsorbing chamber 111. When passing through absorbing chamber 111, CO_2 within the exhaust adsorbs onto the physical adsorbent via van der Waals forces, forming an adsorbent-CO_2 complex and forming scrubbed clean air having an eliminated or reduced CO_2 content relative to the CO_2 content of the exhaust entering low-temperature adsorbing chamber 111. The scrubbed clean air may exit low-temperature adsorbing chamber 111 via clean air outlet 112. The low-temperature adsorbing chamber 111 may be maintained within a temperature range suitable for adsorption of CO_2 onto the physical adsorbent. The temperature of low-temperature adsorbing chamber 111 may be equal to, greater than, or less than ambient temperature. The temperature of low-temperature adsorbing chamber 111 may be equal to, greater than, or less than the temperature of the exhaust from ICE 100.

[0043] As rotor 110 rotates, it carries the adsorbent-CO_2 complex into the adjacent high-temperature releasing chamber 114. The adjacent high-temperature releasing chamber 114 may be maintained within a temperature range suitable for release of CO_2 from the physical adsorbent. The temperature of adjacent high-temperature releasing chamber 114 is greater than the temperature within low-temperature adsorbing chamber 111. Within high-temperature releasing chamber 114, heater 103 is used to raise and/or maintain the temperature of releasing chamber 114 within a range that is sufficient to free the CO_2 from adsorption onto physical adsorbent. Heater 103 may be thermally coupled with a refrigerant flow, such as via refrigerant inlet 403a and refrigerant outlet 403b.

[0044] In some aspects, low-temperature adsorbing chamber 111 is maintained at a temperature of equal to or less than 200°C, equal to or less than 120°C, equal to or less than 60°C, or equal to or less than 30°C. In some aspects, low-temperature adsorbing chamber 111 is maintained at a temperature of equal to or greater than 5°C, equal to or greater than 25°C, equal to or greater than 30°C, or equal to or greater than 60°C. In some aspects, low-temperature adsorbing chamber 111 is maintained at a temperature ranging from 5°C to 200°C, or from 5°C to 120°C, or from 5°C to 60°C, or from 5°C to 30°C, or from 25°C to 60°C. High-temperature releasing chamber 114 is maintained at a temperature that is greater than that of low-temperature adsorbing chamber 111. In some aspects, high-temperature releasing chamber 114 is maintained at a temperature that is equal to or greater than 5°C, equal to or greater than 10°C, equal to or greater than 15°C, equal to or greater than 20°C,

equal to or greater than 25°C, or equal to or greater than 30°C higher than the temperature within low-temperature adsorbing chamber 111. In some aspects, high-temperature releasing chamber 114 is maintained at a temperature that is equal from 15°C to 20°C higher than the temperature within low-temperature adsorbing chamber 111.

[0045] In some aspects, the pressure of both low-temperature adsorbing chamber 111 and high-temperature releasing chamber 114 is maintained at ambient and/or standard atmospheric pressure.

[0046] While the adsorption and deadsorption is described as varying with temperature, one skilled in the art would understand that adsorption and deadsorption may vary with other parameters, such as pressure or electrical conductivity. For example, regeneration of the physical adsorbent may be achieved via: temperature cycling using a temperature sensitive physical adsorbent; pressure cycling using a pressure sensitive physical adsorbent; or current cycling using an electrical charge sensitive physical adsorbent. In some such aspects, a heat source is provided by a heat exchanger utilizing engine waste heat, either directly via conduction through unit hardware or indirectly via a transfer medium such as refrigerant, to provide the temperature cycling, or the heat source is provided by an electrical heater powered by either a CHP/CCHP generator or an external power source. In other aspects, a pressure source is provided by a compressor powered either mechanically, by a CHP/CCHP crankshaft or electrically by a CHP/CCHP generator or by an external power supply, to provide the pressure cycling. In other aspects, a current source is provided, by either a generator of a CHP/CCHP system or an external power supply, to provide the current cycling.

[0047] Compressor

[0048] The CO_2 released from the physical adsorbent mixes with incoming air from clean air inlet 113 to produce a high CO_2 concentration air. The high CO_2 concentration air is then drawn out of releasing chamber 114 via outlet 115, such as via inlet fan 202. The high CO_2 concentration air is drawn into compressor 107 by the pressure differential created by both inlet fan 202 and the suction of compressor 107. Release of the CO_2 from the physical adsorbent regenerates adsorbent, such that the physical adsorbent may again to adsorb additional CO_2. Rotor 110 rotates such that the regenerated physical adsorbent is again positioned within adsorbing chamber 111, where the regenerated physical adsorbent adsorbs CO_2 from exhaust gas flowing through adsorbing chamber 111, and the CO_2 adsorbing-releasing process repeats. It is noted that, although not essential for scrubber operation in general, the exhaust from ICE 100 may first be passed through a pre-cooler, such as double

tube heat exchanger 209 via inlet 208 to increase CO_2 density and/or reduce temperatures for use with low-temperature physical adsorbents, prior to entering adsorbing chamber 111. The pre-cooler may use any type of refrigerant, which may be circulated through coolant inlet 207 and coolant outlet 210. For example, the refrigerant of pre-cooler may be vapor compression/heat pump refrigerant, water for use with a CCHP or water heater applications. The temperature of the exhaust of ICE 100 may be, for example 80°C. In such an aspects, double tube heat exchanger 209 allows the exhaust to be cooled to, for example, 5-25°C, such as for use with a zeolite physical adsorbent. One skilled in the art would understand that other adsorbents operate at higher or lower temperatures. Thus, in some aspects, cooling of exhaust is not necessary or cooling of the exhaust to a different temperature than 5-25°C is performed.

[0049] It is also noted that, in some aspects, motor 116, compressor 107 and heater 103 are powered directly from the CHP/CCHP system, with motor 116 being driven by generator 104, compressor 107 being driven by engine crankshaft 106 and belt 105, and heater 103 receiving thermal energy provided by ICE 100 waste heat. Heater 103 may receive waste heat directly or by conduction with exhaust manifold 101 and/or associated piping matrix or via a thermal medium, such as a coolant or refrigerant system for convenience and to ensure optimal system efficiency. However, system 1000 is not limited to this particular arrangement, and, in practice, any source of power may be used for each component of system 1000 including external electrical power, such as the grid or local renewable energy sources such as solar or wind power.

[0050] Automated Control System

[0051] In some aspects, to ensure optimal carbon capture rates, system 1000 is equipped with an automated control system including but not limited to master controller 203, such as a microcontroller, programmed logic controller (PLC) or remote control system. Master controller 203 may be in electrical, operative, and/or data communication (*e.g.*, for sending control signals to and/or receiving data signals from) with: (1) air flow detectors 204a and 204b positioned at the engine exhaust input into adsorbing chamber 111 and carbon outlet 115, respectively; (2) CO_2 sensor 205 positioned at carbon outlet 115; (3) temperature sensors for both the adsorption chamber 111 and releasing chamber 114; (4) inlet and exhaust fans 201 and 202; (5) rotor motor 116; (6) throttle valve 206; or combinations thereof. For example, master controller 203 may receive air flow data from detectors 204a and 204b; receive CO_2 content data from CO_2 sensor 205; receive temperature measurement data from temperature sensors; control the speed of both inlet and exhaust fans 201 and 202 and of rotor

motor 116; control the throttle valve 206 for metering refrigerant flow through heater 103; or combinations thereof. With proper control algorithms for master controller 203, master controller 203 may continuously monitor and control unit temperatures to automatically accommodate real-time changes in engine performance and carbon load rates to optimize carbon recovery via: (1) metering of refrigerant using throttle valve 206; (2) controlling convection flow rates through control of fans 201 and 202; (3) controlling the adsorption/regeneration cycle times by controlling rotor motor 116; or combinations thereof. It should noted that system 1000 is not limited to the particular arrangement of sensors and control mechanisms shown in the Figures, and that various other combinations of such sensors and control mechanisms may be used, such as temperature monitoring and control only or rotor speed monitoring and control only depending upon the application and required performance. In some aspects, no monitoring or control is performed.

[0052] Carbon Diffuser

[0053] The second CCS element is carbon diffuser 122, which serves to disperse and/or atomize the CO_2 exiting compressor 107 within the water 121 in a manner that maximizes CO_2 carbon dissociation with water 121. Carbonated air exits compressor 107 under high pressure via compressor outlet 126, and enters carbon diffuser 122. In some aspects, water 121 within tank 120 is at a pressure of greater than ambient pressure. For example, the pressure of water 121 within tank 120 may be from 50 to 200psi, form 75 to 150 psi, or 100 psi. The particular type of diffuser may vary depending upon required performance and budget from a single jet to more complex designs, as long as carbon diffuser 122 is effective in achieving dispersion and/or atomization. FIGS. 4A-4C depict three exemplary diffuser designs, receptively. FIG. 4A depicts carbon diffuser 122a, a microporous diffuser. FIG. 4B depicts carbon diffuser 122b, a reactor diffuser. FIG. 4C depicts carbon diffuser 122c, a bell cover diffuser. Carbon diffuser 122a is a simple, ceramic or glass media with a matrix of fine micropores 301 connected to a positive pressure CO_2 supply 300 of sufficient strength to overcome the micropore channel resistance and tank water pressure to force the CO_2 into small bubbles totaling a large surface area, affording enhanced dissociation. Carbon diffuser 122a may operate to break pressurized CO_2 into micro sized bubbles. Carbon diffuser 122b is, in some aspects, nearly 100% effective at diffusion and/or atomization, but is more expensive and requires power to function. In carbon diffuser 122b, water 121 is re-circulated under positive pressure via a pump or filter to inlet 302, while pressurized CO_2 is fed to inlet 303, forcing both water 121 and the pressurized CO_2 into mixing chamber 304. Within mixing chamber 304, rising CO_2 contacts downward moving tank water 121. With proper

pressure and flow rate adjustment, a turbulent interchange is created in which the CO_2 is agitated, helping to further break the CO_2 into ever smaller bubbles 305. In some aspects, carbon cannot escape mixing chamber 304, such that all or virtually all of the CO_2 that enters mixing chamber 304 is eventually dissolved within water 121. Carbon diffuser 122b may function to trap and agitate pressurized CO_2 within tank water 121. In carbon diffuser 122c, CO_2 enters via inlet 306 into cap 307 and is trapped via cap 307. As with the reactor of carbon diffuser 122b, virtually all the CO_2 that enters cap 307 eventually dissociates. However, the disassociation is relatively slow, as carbon diffuser 122c lacks a mechanism to atomize the CO_2. Carbon diffuser 122c may function to trap CO_2 carbon at the water surface. Due to its high performance characteristics, the reactor design of FIG. 4B (carbon diffuser 122b) is preferred in some aspects. In some aspects, diffuser 122 is a jet with one or more nozzles.

[0054] In some aspects, the amount CO_2 dissolved into water 121 after dispersion ranges from 3 to 15 SCF/bbl, or from 5-10 SCF/bbl at temperatures ranging from 0-60°C.

[0055] General Operation

[0056] In operation, exhaust gas from internal combustion engine 100 enters adsorbing chamber 111 of scrubber 117 via exhaust pipe 102, which may or may not be assisted by an exhaust fan 201 depending on the application. CO_2 then adsorbs to the physical adsorbent attached to rotor 110, as described above. After adsorption, the CO_2 is transferred via cycling of rotor 110 using motor 116 into releasing chamber 114. Within releasing chamber 114, high temperatures from heat exchanger 103, which may be powered by combustion waste heat from ICE 100, liberate the adsorbed CO_2. The liberated CO_2 is picked up by carrier air entering the releasing chamber 114 via a vacuum or pressure differential created by compressor 107 suction and/or inlet fan 202. The carbonated air then exits the scrubber 117 via carbon outlet 115, where it is compressed by compressor 107 (*e.g.*, an internal combustion powered compressor) and fed under high pressure via outlet 126 to carbon diffuser 122. Within tank 120, the carbon (*i.e.*, CO_2) is at least temporarily sequestered as carbonated water 121. In some aspects, tank cooler 127, which may be externally powered or may use the vapor compression cooling system of the CCHP, is used to cool water 121, further enhancing carbonation. Tank cooler 127 may be thermally coupled to water tank 120.

[0057] After temporary sequestration, the carbonated water 121 may then be used to irrigate local vegetation 130 by flowing carbonated water 121 through piping 123 and 125 to local vegetation 130. The flow of carbonated water 121 may be controlled via valve 124. Without being bound by theory, it is believed that positive effect in plant growth in hyper-carbonated

environments results from both the direct injection of CO_2 into surrounding air and irrigation with carbonated water. Irrigation is believed to have a higher impact on soil respiration and root structure remodeling. Irrigation with CO2 temporarily lowers soil pH to levels more favorable to soil respiration, which not only enhances carbon intake but also general nutritional intake and nitrification via enhanced soil respiration and root remodeling with increased and more efficient subsurface biomass. Thus, aspects of the systems and methods disclosed herein provide effectively achieve a zero to negative carbon footprint operation by removing CO_2 from combustion gases, discarding of the gases in an economically and environmentally friendly way, and further helping to reduce atmospheric CO_2 via the stimulation of photosynthesis and natural sequestration via biomass.

[0058] Water Heater & Dryer

[0059] Aside from the use of a CHP/CCHP, as described above, aspects of the system and method disclosed herein may also be applicable to any fossil fuel based power conversion device for which carbon capture may be feasible or required to accommodate environmental protocols. Typical examples of possible devices include common household appliances, such as a gas powered water heater or clothes dryer, as is shown in FIGS. 5A and 5B. Water heater 500 of FIG. 5A contains typical heater components, such as burner 513, gas inlet 512, cold water inlet 506, hot water outlet 504, burner exhaust 502, and thermostat 508. Additionally, water heater 500 includes physical adsorbent carbon capture unit 503, compressor 501, CO_2 output 507, water tank 510, carbon diffuser 509, carbonated water outlet 511, and control unit 505. Dryer 526 of FIG. 5B may include standard dryer components, such as burner 523, heat exchanger 525, burner exhaust 515, natural gas inlet 524, and control unit 514. Additionally, dryer 526 may include physical adsorbent carbon capture unit 520, water inlet 519, compressor 516 with CO_2 outlet 517, water tank 518, carbon diffuser 522, and carbonated water outlet 521. It is noted all CCS components of both water heater 500 and dryer 526 work in the manner as described for the CHP/CCHP aspects of FIGS. 1-4C, with component sizes, geometries and locations adjusted to conform to application architecture and performance specifications.

[0060] Recycled CO_2 Carrier Gas

[0061] In system 1000 depicted in FIG. 2, air is used as a carrier or purge gas source. Without being bound by theory, it is believed that solid adsorbents, including mono layer chemisorption and multi layer physisorption phenotypes, saturate or enhance adsorption effectiveness with increasing partial pressure for a given isotherm. Thus, while the relative low CO_2 component of standard temperature and pressure (STP) air assures high

deadsorption rates, and therefore high capture efficiency, it also limits the resulting partial pressure and CO_2 purity of the captured product. Therefore, in some aspects, as shown in FIG. 6A, captured CO_2 is stored in tank 120, and is recycled via return piping 1142 and compressor 107. In some such aspects, recycling CO_2 for use as the carrier gas lessens the amount of free binding sites and thus lowers the capture capacity, but increases the resulting CO_2 purity of the captured gas. Thus, while the use of air typically results in greater carbon capture rates from exhaust gas, the use of recycled CO_2 affords increased partial pressure for higher solubility of carbonated water and/or CO_2 available for direct repurposing as biomass.

[0062] In some aspects, as shown in FIG. 6B, CO_2 is recycled via return through compressor 240 and heat exchanger 242 to regenerative input 113b. Heat exchangers 242 and 244 serve a dual purpose in both cooling inlet combustion exhaust, while also heating the CO_2 recirculation stream to temperatures sufficient for regenerating the physical adsorbent. Typically, silica and zeolite physical adsorbents operate to adsorb CO_2 at temperatures ranging from 5°C to 200°C, while combustion exhausts may be at a temperature ranging from 250°C to 400°C. Thus, heat exchangers 242 and 244 serve to cool exhaust to temperatures acceptable for adsorption of CO_2. CO_2 liberated in chamber 114 is then added to the effluent of chamber 114, which is again heated and recycled to further increase the CO_2 content. Finally, regulator 245 maintains the effluent output of chamber 114 at a pressure level sufficient to maintain flow rates for a given temperature and compressor output, which optimizes regeneration of the physical adsorbent. CO_2 levels above this value are then automatically released as a high CO_2 content effluent for input into compressor 107 for delivery to, *e.g.*, water tank 120.

[0063] Soil and Alkylation Filters

[0064] In some aspects, as shown in FIGS. 7A-7C, system 1000 includes soil and alkylation filter unit 132 for use in directly repurposing and/or sequestering the captured carbon as biomass or solid carbonate. Soil and alkylation filter unit 132 includes a series of vertical drawers 144 with mesh or semi permeable bottoms and separators 131 allowing passage of gas through drawers 144 while affording containment of particulate contents of drawers 144. Soil and alkylation filter unit 132 is configured to allow high content CO_2 influent 133 to flow sequentially up through drawers 144 to exhaust port 136. The high content CO_2 influent 133 is drawn through soil and alkylation filter unit 132 via fan 139, either directly via line 137 or from containment tank 120, then through piping 133, depending upon the setting of 3-way valve 138. As the influent gas is derived, in whole or in part, via combustion exhaust, influent 133 is high in CO_2 content as well as traces of inorganic combustion products such as

H_2S, SO_2, NH_3 and NO_x. Such gas is then passed upward within filtering unit 126 through at least one soil or compost filter 135 and/or at least one alkylation filter 134. Filters 135 contain either soil and/or compost with or without plants 140 contained therein. Without being bound by theory, it is believed that research has demonstrated that the combined effect of sequestration by soil particulates, the catalyst activity of micro organisms, and plant respiration effectively reform combustion products as biomass. As shown in Fig. 7B, drawers 144 may be removed for periodic servicing to add or remove soil, compost and formed lime stone, manage plants and add water as needed.

[0065] It is noted that the piping configuration shown is presented for illustrative purposes, and that one skilled in the art would understand that any number of piping configurations may be implemented. In some aspects, system 1000 includes only carbonated water tank 120 without filtering unit 126, only filtering unit 126 without water tank 120, or both filtering unit 126 and water tank 120.

[0066] Soil Filtering Unit with Automated Control

[0067] Without being bound by theory, it is believed that, for the portion of exhaust gas carbon dioxide captured as soil organic carbon (SOC) in living systems such as plants, microbes and fungus, research has shown that carbon capture rates are optimized within defined ranges of water and CO_2 levels. Specifically, 20-40% water by weight of soil mass and 400 to 2000 ppm of carbon dioxide. Thus, in some aspects, it is advantageous to automate system of FIGS. 7A-7C, as is shown in the automated system of FIG. 8. Watering within filtering unit 126 is automated via external water source 142, pump 141, sprinkler jets 147, humidity sensors 143, and control unit 149. For example and without limitation, control unit 149 may be a PLC that is programmed with logic instructions to control pump 141 to initiate watering within filtering unit 126 when the humidity sensors 143 detect a humidity that is below a preset limit. CO_2 influent is regulated via pump 139b, CO_2 sensors 152, and control unit 149. Control unit 149 may be programmed with logic instructions to control pump 139b to initiate and/or cease input of CO_2 into filtering unit 126 based upon CO_2 measurements taken by CO_2 sensors 152. Control unit 149 may be in data communication with pump 141, pump 139b, CO_2 sensors 152, pH sensors 145, and humidity sensors 143 for monitoring and/or control thereof. Additional control via soil temperature and pH sensors 145 may provide for optimal growth rates for plants, while stabilizing microbe and fungus populations to regulate decomposition so as to optimize trapped organic carbon, such as humus. In some aspects, activated carbon filter 148 is positioned at the outlet of filtering unit 126 as a final filter stage to trap hydrocarbons and inorganic and malodorous gases before

release to the atmosphere. In some aspects, drip pan 150 is positioned to collect soil drainage within filtering unit 126. Exhaust vents 146 (*e.g.*, louvered vents) may be positioned at least one, or all sides, at a top of filtering unit to allow exhaust to escape without allowing, *e.g.*, rain water to enter.

[0068] In some aspects, alkylation filters 134 contain alkylating agents, such as calcium hydroxide, which serve to reduce CO_2 in a reaction, such as:

[0069] $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$ (Reaction 1)

[0070] Reaction 1, above, forms calcium carbonate, which may be harvested as an ingredient for building materials such as concrete, or left within drawers 144 where it may be used as an alkylating agent to neutralize acidic compounds produced from hydration of inorganic gases within the soil filters according Reactions 2 and 3:

[0071] $CaCO_3 + H_2SO_4 \rightarrow H_2O + CO_2 + CaSO_4$ (Reaction 2)

[0072] $CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_20 + CO_2$ (Reaction 3)

[0073] Reactions 2 and 3 produce water, carbon dioxide, calcium nitrate, and sulfate salts. Carbon dioxide may again be sequestered as biomass by soil filers 135. Calcium nitrate is commonly used as a fertilizer and in wastewater treatment to limit organic production of hydrogen sulfide. Calcium sulfate precipitates as an insoluble hydrate.

[0074] In some aspects, sensors, such as temperature, CO_2, carbonic acid, carbonated water, and soil pH sensors may be added and connected to controller 203 in a feedback loop to track and adjust adsorption/deadsorption, soil temperatures, rotation speeds of motor 116, and soil water supplies to optimize CO_2 capture and repurposing yields and rates.

[0075] Soil Filtering Unit with Bioreactor

[0076] In some aspects, as shown in FIG. 9, system 1000 includes bioreactor 154, which repurposes biomass 156 produced by filtering unit 132 (*i.e.*, biomass generator) and/or sewage 158 into methane. The methane thus produced may be recycled, such as via 3-way valve 162 through piping 159 and 164 to supplement a main natural gas supply 160 as a fuel source for the micro CHP (mCHP) engine 100. Fuel enters ICE 100 via fuel inlet port 166.

[0077] Bioreactor 154 may contain a number of anaerobic bacteria and/or protozoa that serve to decompose biomass 156 and/or sewage 158 with the aid of a water supply 157 in a two-step process involving biohydrogen generation and biomethanation. It is noted that biogeneration of methane is a natural and beneficial partner for carbon capture, as methanogenesis is a natural final stage of organic decay as fine organic matter affording breakdown to the simplest organic elements when oxygen has been depleted and H_2 and CO_2 accumulate. First, organic matter 156 from filtering unit 132 soil containers 134, which may

be in the form of plants 140, fungus, bacteria and/or humus, is harvested and placed into bioreactor 154 (an air-tight tank). Within bioreactor 154, organic matter 156, optionally mixed with sewage 158 from an external source, is hydrated via external water supply 157 to provide a nurturing anoxic environment for anaerobic digestion.

[0078] Although a number of chemical processes take place during digestion, biohyrodgenesis carried out by microbes such as Clostridium, Desulfovibrio, and Ralstonia typically converts glucose to acetic acid, CO_2 and hydrogen in accordance with Reaction 4:

[0079] $C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3CO_2H + 2CO_2 + 4H_2$ (Reaction 4)

[0080] It is noted that the fermentation occurring within bioreactor 154 is a dark fermentation process not requiring light energy, and is exergonic, which is highly beneficial for bioreactor applications requiring lower energy input while affording continuous operation (*e.g.*, 24 hour operation).

[0081] Next, methanogen microbes further digest the acetic acid and hydrogen according to dual Reactions 5 and 6:

[0082] $CH_3COOH \rightarrow CH_4 + CO_2$ (Reaction 5)

[0083] $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Reaction 6)

[0084] In Reactions 5 and 6, methane, water and carbon dioxide are produced. It is noted that, by controlling the ratio of acetotrophic and hydrogenotrophic microbe yields, it is possible to obtain combinations such that a large percentage of harvested organic matter 156 is converted to methane. Such microbes may include any number of some fifty known species containing molecular markers for methogenesis proteins such as Methanobacterium bryantii and Methanobrevibacter arboriphilicus.

[0085] mCHP Caron Capture and Repurposing System

[0086] FIG. 10 is a simplified schematic of system 1000, showing the subcomponent relationships. It is noted that, although carbon purity introduced into water tank 120, filtering unit 132 and bioreactor 154 is enhanced via the carbon capture process of the solid, physical adsorption scrubber 117, all of these systems may function using raw exhaust as denoted by the dashed arrow resulting in a number of possible carbon source and sink permutations. First, carbon is returned directly to the soil for absorption as carbonated water via water tank 120 as shown in FIG. 2. Second, carbon is fixated as biomass such as plants, fungus or humus within the soil containers 134 of filtering unit 132, either via photosynthesis by plant life or chemosynthesis via autotrophic organisms such as fungi, bacteria and protozoa as shown in FIGS. 7A-8. The resulting accumulated biomass may then be transferred directly back to the soil of an external environment for natural sequestration or to bioreactor 154 for further

bacterial digestion. Lastly, bioreactor 154 performs a final, high-level decomposition similar to that carried out during enteric fermentation in ruminants and generation of marsh gases. Thus, the system serves to either capture and return combustion released carbon back to the environment in a natural form, or to recycle carbon for reuse as a fuel source using natural processes and no or few supporting chemicals.

[0087] It should be noted and understood that many of the specific features or combination of features illustrated in or introduced above (or described in the claims submitted below), and\or discussed in accompanying descriptions, may be combined with or incorporated with or other feature(s) described or illustrated in any other Figure provided herein. Moreover, the following claims serve also to describe and illustrate some (but not all) aspects of the present disclosure. The claims serve therefore as an integral part of the present disclosure.

[0088] The foregoing description has been presented for purposes of illustration and description of preferred aspects. This description is not intended to limit associated concepts to the various systems, apparatus, structures, processes, and methods specifically described herein. For example, aspects of the processes and equipment illustrated by the Figures and discussed above may be employed or prove suitable for use with other systems and apparatus. The aspects described and illustrated herein are further intended to explain the best modes for practicing the system and methods, and to enable others skilled in the art to utilize same and other aspects and with various modifications required by the particular applications or uses of the present disclosure.

CLAIMS

What is claimed is:

1. A micro carbon capture system comprising:

a fossil fuel oxidation unit that oxidizes fossil fuel to convert fossil fuel chemical energy into thermal energy, mechanical energy, electrical energy, or combinations thereof;

a carbon capture unit positioned to receive exhaust gas of the fossil fuel oxidation unit, the carbon capture unit including a regeneratable physical adsorbent and a cycling mechanism configured to cycle the regeneratable physical adsorbent between a first position and a second position;

wherein, in the first position, the physical adsorbent is positioned to adsorb CO_2 from the exhaust gas and, in the second position, the physical adsorbent is positioned to release the CO_2.

2. The micro carbon capture system of claim 1, further comprising:

a water tank positioned to receive the CO_2 released from the physical adsorbent, wherein the water tank contains water, wherein the CO_2 is stored as carbonated water within the storage tank;

a soil filtering unit positioned to receive the CO_2 released from the physical adsorbent, the soil filtering including at least one soil or compost filter, at least one alkylation filter, or combinations thereof positioned such that the CO_2 filters through the at least one soil or compost filter, at least one alkylation filter, or combinations thereof; or

combinations thereof.

3. The micro carbon capture system of claim 2, wherein the system comprises the water tank.

4. The micro carbon capture system of claim 3, further comprising a tank cooler thermally coupled to the water tank and configured to cool the water within the water tank.

5. The micro carbon capture system of claim 3, further comprising a compressor and a carbon diffuser, wherein the compressor is in fluid communication between the carbon capture unit and the water tank, and wherein the carbon diffuser is positioned to disperse, atomize, or combinations thereof the released CO_2 into the water within the water tank.

6. The micro carbon capture system of claim 5, wherein the compressor is driven by the fossil fuel oxidation unit, or is powered by an external power source.

7. The micro carbon capture system of claim 5, wherein the carbon diffuser is a microporous diffuser, a reactor diffuser, or a bell cover diffuser.

8. The micro carbon capture system of claim 3, further comprising an irrigation system in fluid communication with the water tank, the irrigation system positioned to receive the carbonated water from the water tank and deliver the carbonated water to vegetation.

9. The micro carbon capture system of claim 1, wherein the cycling mechanism includes a rotor operatively coupled to a motor, wherein the physical adsorbent is positioned on the rotor, and wherein the motor is configured to rotate the rotor to move the physical adsorbent between the first position and the second position.

10. The micro carbon capture system of claim 9, wherein the motor is driven directly from the fossil fuel oxidation unit, or is powered by an external power source.

11. The micro carbon capture system of claim 9, wherein the carbon capture unit includes a housing, the housing including an adsorbing chamber positioned to receive the exhaust and a releasing chamber positioned to receive the released CO_2.

12. The micro carbon capture system of claim 11, wherein the housing is divided into two sections, including the adsorbing chamber and the releasing chamber, by a barrier.

13. The micro carbon capture system of claim 11, wherein the adsorbing chamber is maintained within a temperature range suitable for adsorption of CO_2 onto the physical adsorbent, and wherein the releasing chamber is maintained within a temperature range suitable for deadsorption of CO_2 from the physical adsorbent, wherein the temperature within the releasing chamber is higher than the temperature within the adsorbing chamber.

14. The micro carbon capture system of claim 13, further comprising a heater, the heater thermally coupled with the releasing chamber.

15. The micro carbon capture system of claim 14, wherein the heater is powered directly from the fossil fuel oxidation unit via receipt of waste heat therefrom, or is powered by an external power source.

16. The micro carbon capture system of claim 13, wherein the adsorbing chamber is maintained at a temperature of equal to or less than 200°C equal to or greater than 5°C, and wherein the releasing chamber is maintained at a temperature that is equal to or greater than 5°C, higher than the temperature within the adsorbing chamber.

17. The micro carbon capture system of claim 9, wherein the rotor includes wheels or discs carrying the physical adsorbent.

18. The micro carbon capture system of claim 1, wherein the physical adsorbent is a molecular sieve.

19. The micro carbon capture system of claim 1, wherein the physical adsorbent includes an organic–inorganic hybrid or metal-organic framework.

20. The micro carbon capture system of claim 1, wherein the physical adsorbent is a metal oxide.

21. The micro carbon capture system of claim 1, wherein the physical adsorbent includes zeolite, calcium oxide, silicate, activated carbon, amine-modified activated carbon, mesoporous silicas, or hydrotalcite.

22. The micro carbon capture system of claim 1, wherein the physical adsorbent adsorbs CO_2 from the exhaust via van der Waals forces, forming an adsorbent-CO_2 complex and forming scrubbed air clean having an eliminated or reduced CO_2 relative to the CO_2 content of the exhaust.

23. The micro carbon capture system of claim 2, wherein the system includes the soil filtering unit adapted to repurpose, sequester, or combinations thereof the CO_2 as biomass or solid carbonate.

24. The micro carbon capture system of claim 23, wherein the soil filtering unit includes a series of vertical drawers with mesh or semi permeable bottoms and separators configured to allow passage of CO_2 through the drawers while containing particulate contents of the drawers.

25. The micro carbon capture system of claim 24, wherein the soil filtering unit is configured to allow high content CO_2 influent to flow sequentially up through the drawers to an exhaust port.

26. The micro carbon capture system of claim 25, wherein the high content CO_2 influent contains H_2S, SO_2, NH_3, NO_x, or combinations thereof.

27. The micro carbon capture system of claim 23, wherein the soil or compost filters contain plants.

28. The micro carbon capture system of claim 23, wherein, within the soil filtering unit, sequestration of CO_2 by soil particulates, catalyst activity on CO_2 by micro organisms, and plant respiration of CO_2 reforms combustion products as biomass.

29. The micro carbon capture system of claim 23, wherein a portion of the CO_2 is captured as soil organic carbon (SOC) in plants, microbes, fungus, or combinations thereof within the soil filtering unit.

30. The micro carbon capture system of claim 23, wherein the soil filtering unit includes an automated watering and monitoring system.

31. The micro carbon capture system of claim 30, wherein the automated watering and monitoring system includes a control unit, an external water source, and one or more sensors.

32. The micro carbon capture system of claim 31, wherein the control unit is configured to receive data signals from the one or more sensors and control release of water from the external water source into the soil filtering unit based upon the data signals.

33. The micro carbon capture system of claim 31, wherein the external water source includes a pump and sprinkler jets.

34. The micro carbon capture system of claim 33, wherein the one or more sensors include at least one humidity sensor, and wherein the control unit is a PLC that is programmed with logic instructions to control the pump to initiate watering within the soil filtering unit when the humidity sensors detect a humidity that is below a preset limit.

35. The micro carbon capture system of claim 31, wherein the automated watering and monitoring system includes CO_2 influent regulator pump, one or more CO_2 sensors, and wherein the control unit is a PLC programmed with logic instructions to control the CO_2 influent regulator pump to initiate and/or cease input of CO_2 into the soil filtering unit based upon CO_2 measurements taken by the CO_2 sensors.

36. The micro carbon capture system of claim 31, wherein the one or more sensors include pH sensors.

37. The micro carbon capture system of claim 23, further comprising an activated carbon filter positioned at an exhaust outlet of the soil filtering unit, a drip pan positioned to collect soil drainage within the soil filtering unit, exhaust vents positioned at a top of the soil filtering unit, or combinations thereof.

38. The micro carbon capture system of claim 23, wherein the alkylation filters contain alkylating agents.

39. The micro carbon capture system of claim 23, further comprising a bioreactor in fluid communication with a water supply, wherein the bioreactor receives biomass produced in the soil filtering unit, the bioreactor containing anaerobic bacteria, protozoa, or combinations thereof that decompose the biomass in the presence of water from the water supply in a two-step process involving biohydrogen generation and biomethanation.

40. The micro carbon capture system of claim 39, wherein the bioreactor in fluid communication with a sewage source.

41. The micro carbon capture system of claim 39, wherein organic matter from the soil filtering unit, optionally mixed with sewage, is formed into methane, wherein the bioreactor is in fluid communication with the fossil fuel oxidization unit for providing the methane thereto as fuel.

42. The micro carbon capture system of claim 1, further comprising a pre-cooler in fluid communication between the fossil fuel oxidation unit and the carbon capture unit, the pre-cooler positioned and configured to cool exhaust from the fossil fuel oxidation unit prior to the exhaust entering the carbon capture unit.

43. The micro carbon capture system of claim 1, wherein the fossil fuel oxidation unit is CHP/CCHP.

44. The micro carbon capture system of claim 1, wherein the fossil fuel oxidation unit is an internal combustion engine, a water heater, or a clothing dryer.

45. The micro carbon capture system of claim 1, further comprising an automated control system including a master controller in electrical, operative, and/or data communication with: air flow detectors positioned at inputs and outputs of the carbon capture unit; a CO_2 sensor positioned at an outlet of the carbon capture unit; temperature sensors positioned within the carbon capture unit; inlet and exhaust fans of the carbon capture unit; a rotor motor of the cycling mechanism of the carbon capture unit; a throttle valve of a heater of the carbon capture unit; or combinations thereof.

46. The micro carbon capture system of claim 2, wherein air is used as a carrier or purge gas source for the carbon capture unit, or wherein captured CO_2 stored in the water tank is recycled into the carbon capture unit as the carrier or purge gas.

47. The micro carbon capture system of claim 46, wherein the captured CO_2 stored in the water tank is recycled via return through a compressor and heat exchanger into a releasing chamber of the carbon capture unit.

48. The micro carbon capture system of claim 47, further comprising a regulator configured to maintain effluent output of the releasing chamber at a pressure level sufficient to maintain flow rates for a given temperature and compressor output optimized for regeneration of the physical adsorbent, wherein CO_2 levels above the pressure level is released as a high CO_2 content effluent for input into the water tank.

49. The micro carbon capture system of claim 1, wherein the cycling mechanism comprises a rotor driven by a motor for cycling the physical adsorbent between an CO_2 absorbing chamber and a CO_2 releasing chamber of the carbon capture unit, wherein rotor timing is synchronized with exhaust load and CO_2 content, such that a majority of trapped

CO_2 is released upon a single revolution with the physical adsorbent regenerated to accept a new CO_2 load upon reentering into the adsorbing chamber.

50. The micro carbon capture system of claim 1, wherein, in said carbon capture unit, regeneration of the physical adsorbent is achieved via: temperature cycling using a temperature sensitive physical adsorbent; pressure cycling using a pressure sensitive physical adsorbent; or current cycling using an electrical charge sensitive physical adsorbent.

51. The micro carbon capture system of claim 50, wherein:

a heat source is provided by a heat exchanger utilizing engine waste heat, either directly via conduction through unit hardware or indirectly via a transfer medium such as refrigerant, to provide the temperature cycling; or wherein the heat source is provided by an electrical heater powered by either a CHP/CCHP generator or an external power source; or

a pressure source is provided by a compressor powered either mechanically by a CHP/CCHP crankshaft or electrically by a CHP/CCHP generator or by an external power supply to provide the pressure cycling; or

a current source is provided by either a generator of a CHP/CCHP system or an external power supply to provide the current cycling.

52. A carbon capture system comprising:

a fossil fuel oxidation unit, a carbon capture unit, and a storage unit in which carbon is stored as a biomass, wherein said fossil fuel oxidation unit is configured to oxidize fossil fuel and convert the fossil fuel chemical energy into an alternate form of energy.

53. A carbon capture apparatus comprising a carbon capture component for sequestering carbon from exhaust gases.

54. The apparatus of claim 53, further comprising a power generating system including an exhaust, wherein said carbon capture unit is configured to capture exhaust gases from said exhaust.

55. A method of capturing carbon from a fossil fuel exhaust gases, said method comprising sequestering carbon from fossil fuel exhaust gases, including oxidizing fossil fuel and converting said fossil fuel into an alternate form of energy.

56. The method of claim 55, further comprising cycling through a regenerating physical adsorbent to capture CO_2 from exhaust gas.

57. The method of claim 56, wherein said cycling includes releasing CO_2 to a temporary storage unit.

58. The method of claim 57, wherein said temporary storage unit includes a water storage tank, said method further comprising using a CO_2 diffuser to dissociate CO_2 within said
water storage tank.

59. A method of operating any one of the systems or apparatus of claims 1-54.

60. A method of capturing carbon, the method comprising;

directing exhaust from a fossil fuel oxidation unit into a carbon capture unit;

adsorbing CO_2 from with the exhaust onto a physical adsorbent within the carbon capture unit;

deadsorbing the CO_2 from the physical adsorbent within the carbon capture unit; and

releasing the deadsorbed CO_2 from the carbon capture unit.

61. The method of claim 60, wherein the deadsorbed CO_2 is released into a water within a water tank, forming carbonated water.

62. The method of claim 61, further comprising irrigating vegetation with the carbonated water.

63. The method of claim 61, wherein a compressor directs the deadsorbed CO_2 into the water tank, and wherein a carbon diffuser disperses, atomizes, or combinations thereof the deadsorbed CO_2 within the water, forming the carbonated water.

64. The method of claim 60, wherein deadsorbing the CO_2 from the physical adsorbent includes heating the physical adsorbent, pressurizing the physical adsorbent, or applying an electrical current to the physical adsorbent.

65. The method of claim 60, wherein the carbon capture unit includes an absorbing chamber and a releasing chamber, wherein the absorbing and releasing chambers are thermally insulated from one another, wherein the exhaust is directed into the absorbing chamber, and wherein the CO_2 is deadsorbed within the releasing chamber.

66. The method of claim 65, wherein the releasing chamber is maintained at a temperature that is higher than the temperature within the absorbing chamber.

67. The method of claim 65, wherein the physical adsorbent is cycled through the absorbing and releasing chambers.

68. The method of claim 67, wherein cycling the physical adsorbent includes rotating the physical adsorbent on a rotor.

69. The method of claim 60, further comprising cooling the exhaust prior to directing the exhaust into the carbon capture unit.

70. The method of claim 65, further comprising recycling CO_2 released from the carbon capture unit back into the carbon capture unit.

71. The method of claim 60, wherein the deadsorbed CO_2 is released into a soil filtering unit, wherein the soil filtering unit repurposes, sequesters, or combinations thereof the CO_2 as biomass or solid carbonate.

72. The method of claim 71, further comprising filtering the deadsorbed CO_2 through at least one soil or compost filter, at least one alkylation filter, or combinations thereof positioned within the soil filtering unit.

73. The method of claim 71, wherein the soil or compost filters contain plants.

74. The method of claim 73, wherein, within the soil filtering unit, sequestration of CO_2 by soil particulates, catalyst activity on CO_2 by micro organisms, plant respiration of CO_2, or combinations thereof reforms combustion products as biomass.

75. The method of claim 74, wherein a portion of the CO_2 is captured as soil organic carbon (SOC) in plants, microbes, fungus, or combinations thereof within the soil filtering unit.

76. The method of claim 71, further comprising directing biomass from the soil filtering unit to a bioreactor, directing water into the bioreactor, and decomposing the biomass within the bioreactor.

77. The method of claim 76, wherein anaerobic bacteria, protozoa, or combinations thereof decompose the biomass in the presence of the water from the water supply in a two-step process including biohydrogen generation and biomethanation.

78. The method of claim 76, further comprising directing sewage into the bioreactor, wherein the sewage is decomposed.

79. The method of claim 76, wherein decomposing of the biomass within the bioreactor forms methane.

80. The method of claim 79, further comprising directing the methane into the fossil fuel oxidization unit as fuel.

81. The method of claim 60, wherein the system of any of claims 1 to 51 is used to implement the method.

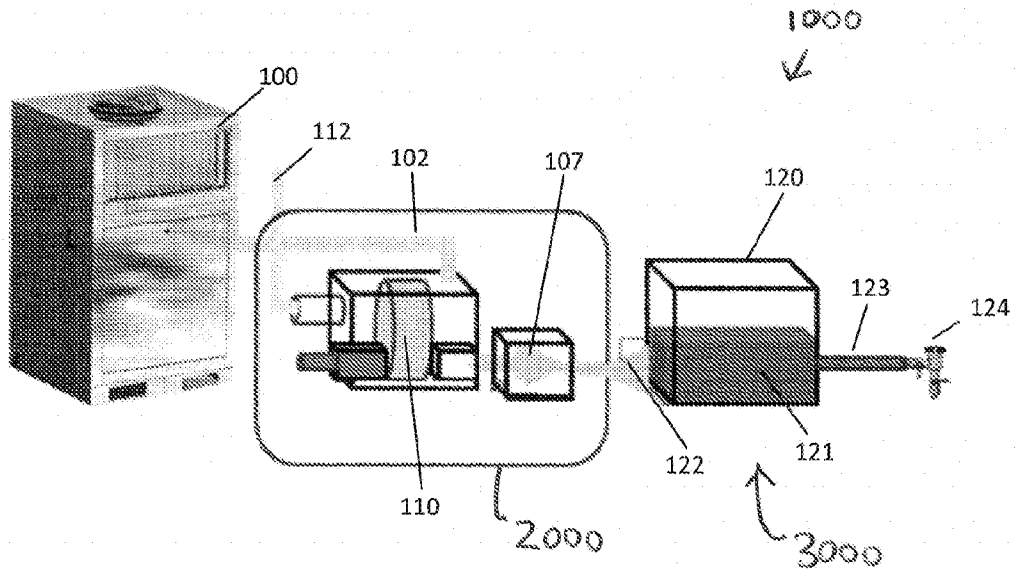
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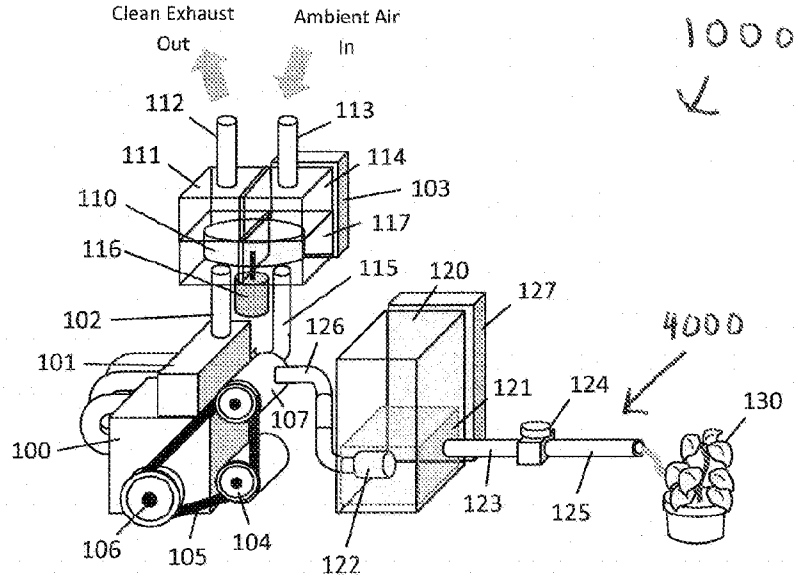
FIG. 1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Ambient Air In
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121
124
130
107
100
123
125
106
105
104
122

FIG. 2

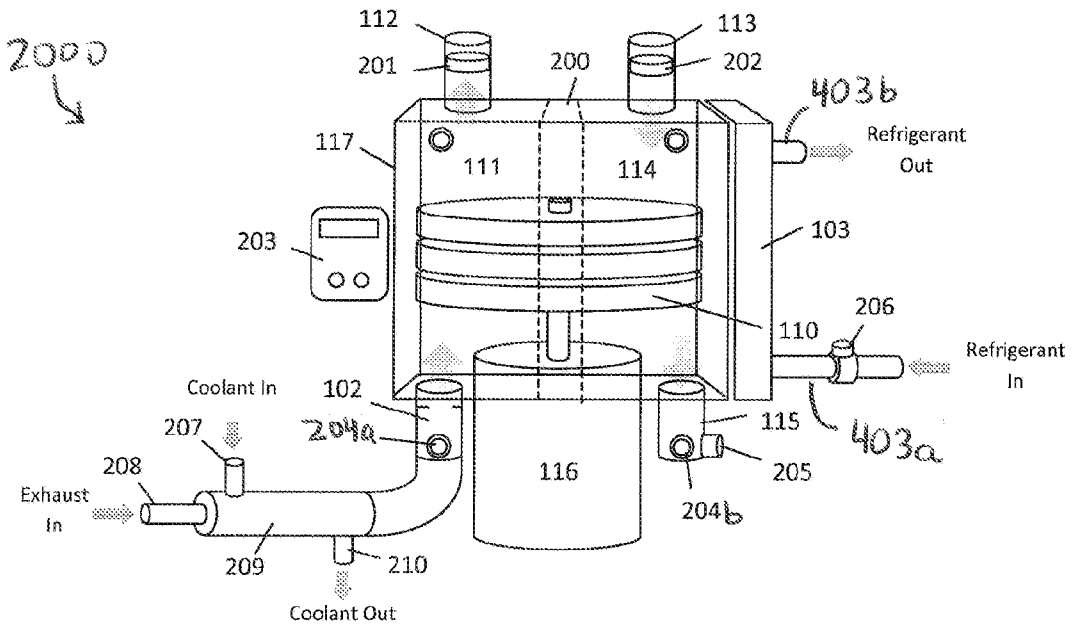

FIG. 3

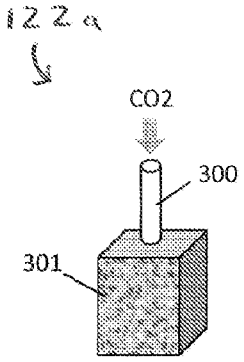

FIG. 4A

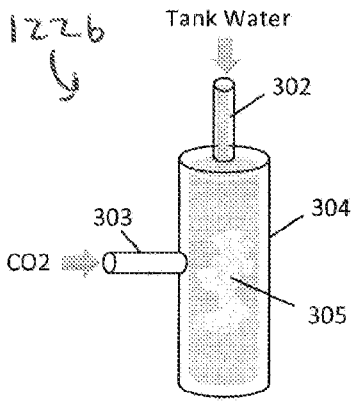

FIG. 4B

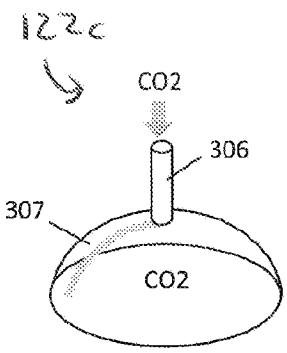

FIG. 4C

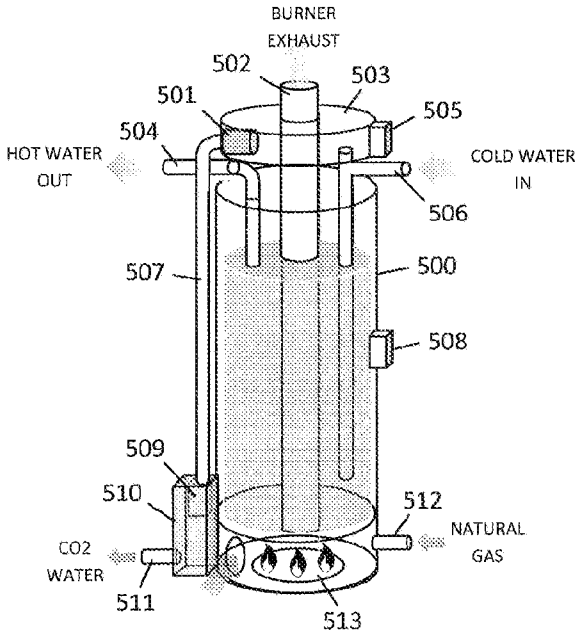
BURNER
EXHAUST
502
503
501
505
504
HOT WATER
OUT
COLD WATER
IN
506
507
500
508
509
510
512
NATURAL
GAS
CO2
WATER
511
513

FIG. 5A

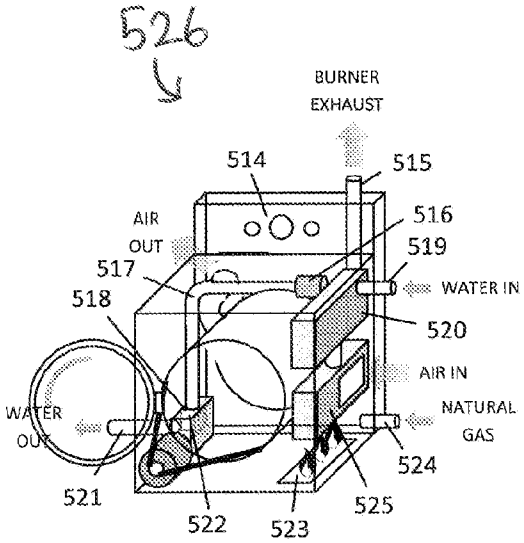
526
BURNER
EXHAUST
514
515
AIR
OUT
516
519
517
WATER IN
518
520
AIR IN
WATER
OUT
NATURAL
GAS
524
521
522
523
525

FIG. 5B

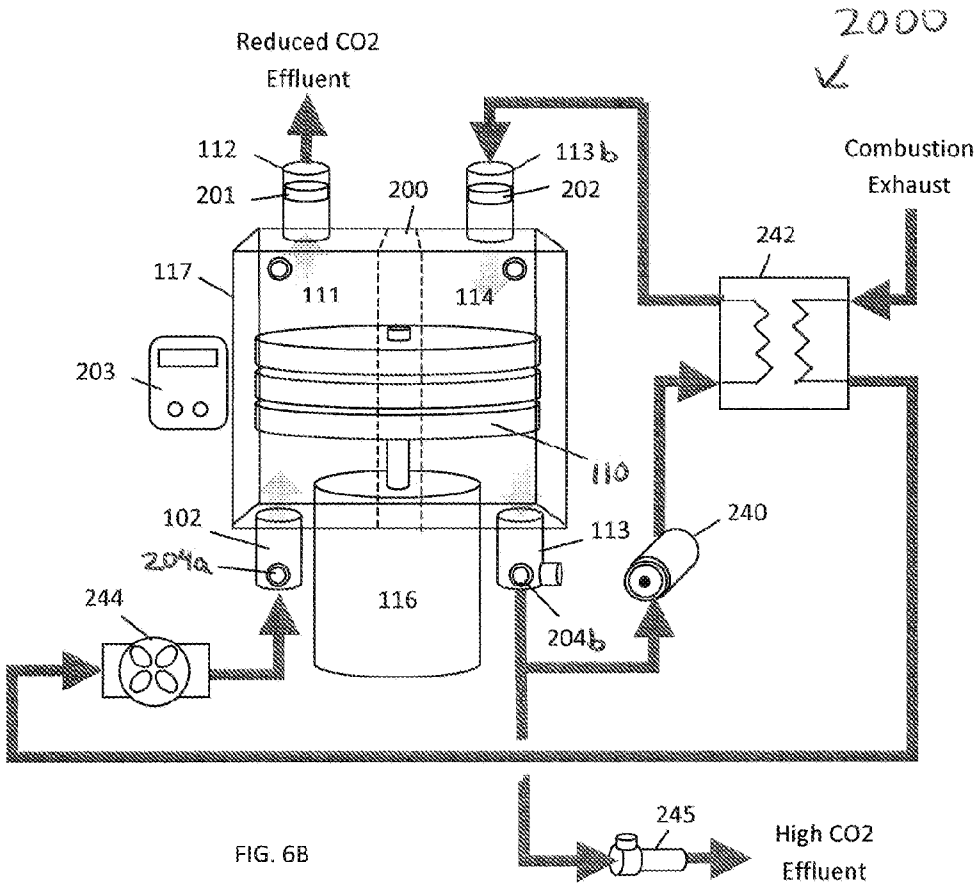
2000
Reduced CO2
Effluent
112
201
200
113b
202
Combustion
Exhaust
242
117
111
114
203
110
102
204a
113
240
244
116
204b
245
High CO2
Effluent

FIG. 6B

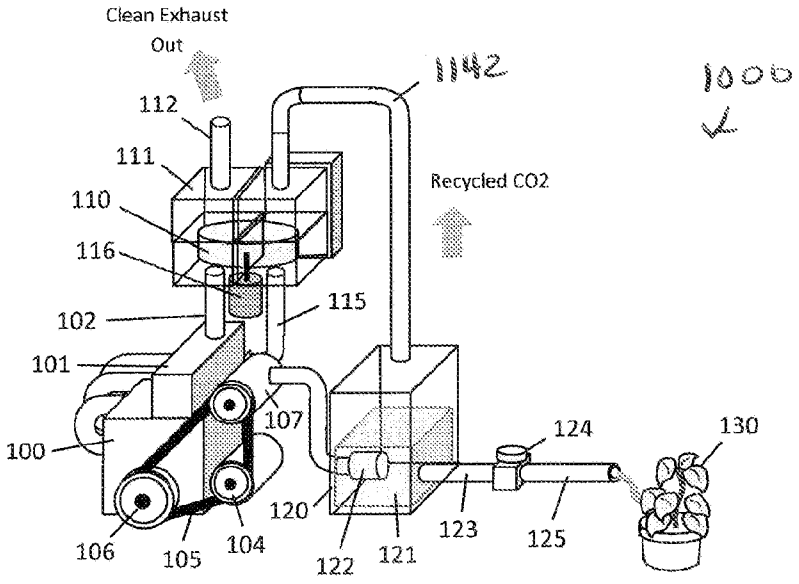
Clean Exhaust
Out
1142
1000
112
111
110
116
Recycled CO2
102
115
101
107
100
124
130
120
123
125
106
105
104
122
121

FIG. 6A

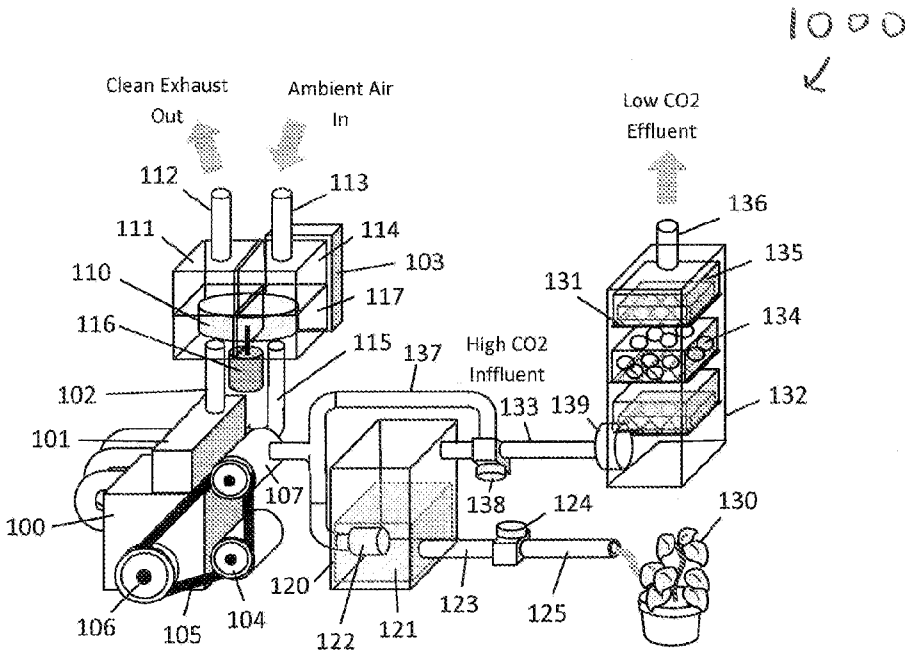

FIG. 7A

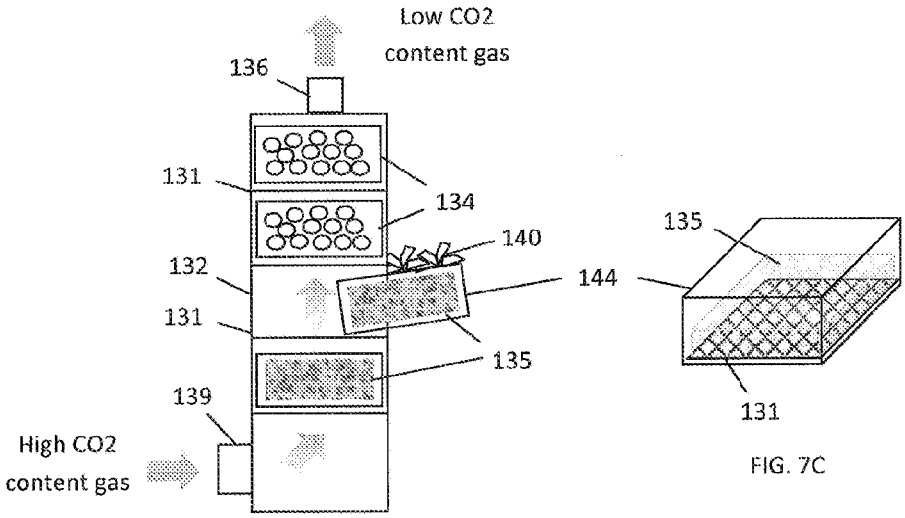

FIG. 7C

FIG. 7B

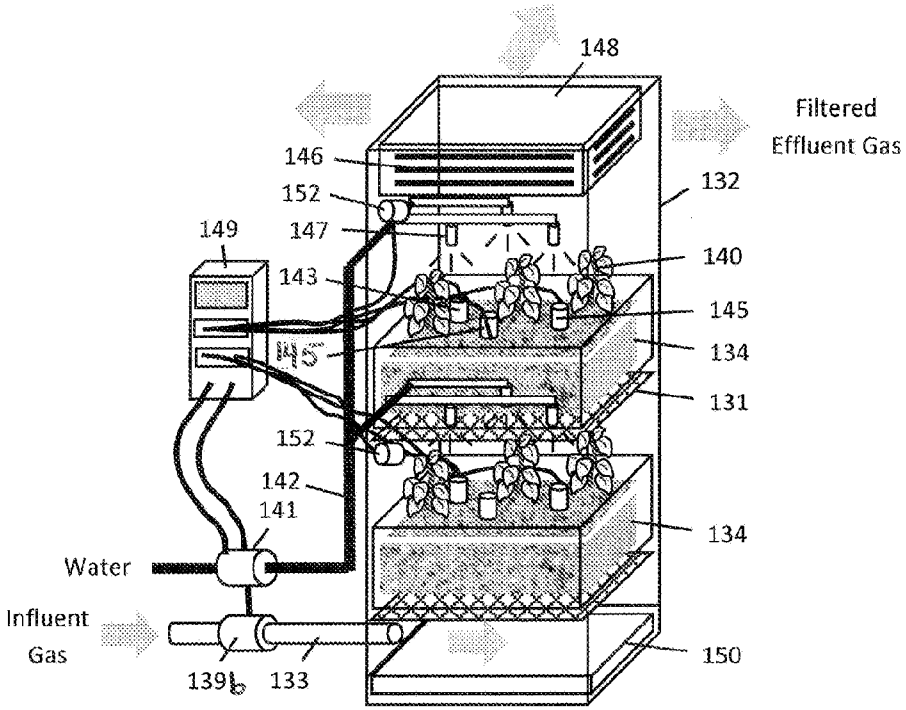
148
Filtered
Effluent Gas
146
152
132
149
147
140
143
145
134
131
152
142
141
134
Water
Influent
Gas
139
133
150

FIG. 8

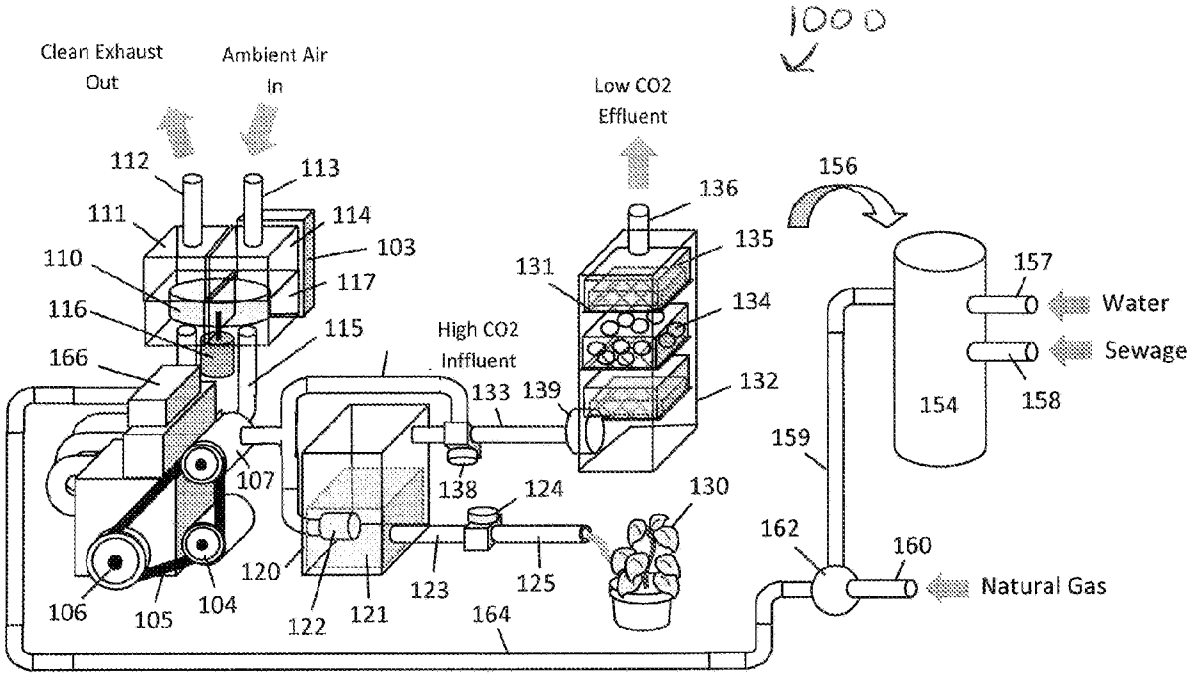
1000
Clean Exhaust Out
Ambient Air In
Low CO2 Effluent
High CO2 Inffluent
Water
Sewage
Natural Gas
112
113
111
114
103
110
117
116
115
166
107
133
139
136
135
131
134
132
156
157
154
158
159
138
124
130
162
160
120
123
125
106
105
104
122
121
164

FIG. 9

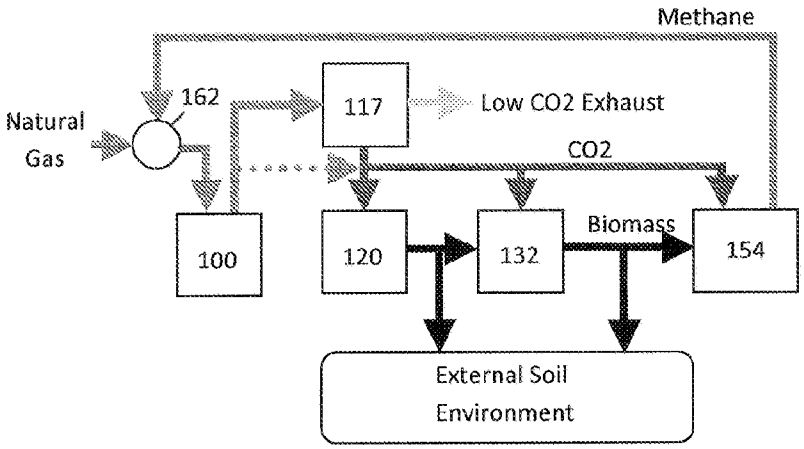
Methane
Natural Gas
162
117
Low CO2 Exhaust
CO2
100
120
132
Biomass
154
External Soil Environment

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/052778

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01N 3/08; B01D 53/62; B01D 53/06 (2018.01)

CPC - F01N 3/0857; B01D 53/62; B01D 53/0462; B01D 53/06; B01D 2257/504; B01D 2258/01 (2018.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,521,026 B1 (GOTO) 18 February 2003 (18.02.2003) entire document	1, 9, 11-18, 20, 21, 50, 51, 60, 64-68, 70
---		---
Y		10, 19, 22, 42-45, 69
X	US 2005/0252215 A1 (BEAUMONT) 17 November 2005 (17.11.2005) entire document	52
X	US 2013/0298532 A1 (SAUDI ARABIAN OIL COMPANY) 14 November 2013 (14.11.2013) entire document	53-57, 59
---		---
Y		42-45, 69
Y	US 2015/0273385 A1 (EISENBERGER et al) 01 October 2015 (01.10.2015) entire document	10
Y	US 2012/0133939 A1 (YAGHI et al) 31 May 2012 (31.05.2012) entire document	19, 22
A	US 2010/0115831 A1 (ARBOGAST) 13 May 2010 (13.05.2010) entire document	1-80
A	US 2014/0174291 A1 (EXXONMOBIL RESEARCH AND ENGINEERING COMPANY) 26 June 2014 (26.06.2014) entire document	1-80
A	US 2011/0195473 A1 (WILHELM) 11 August 2011 (11.08.2011) entire document	1-80

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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

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

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

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 January 2018	30 JAN 2018
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/052778

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 81
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.