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(54) CARBON DIOXIDE CAPTURE SYSTEMS AND METHODS

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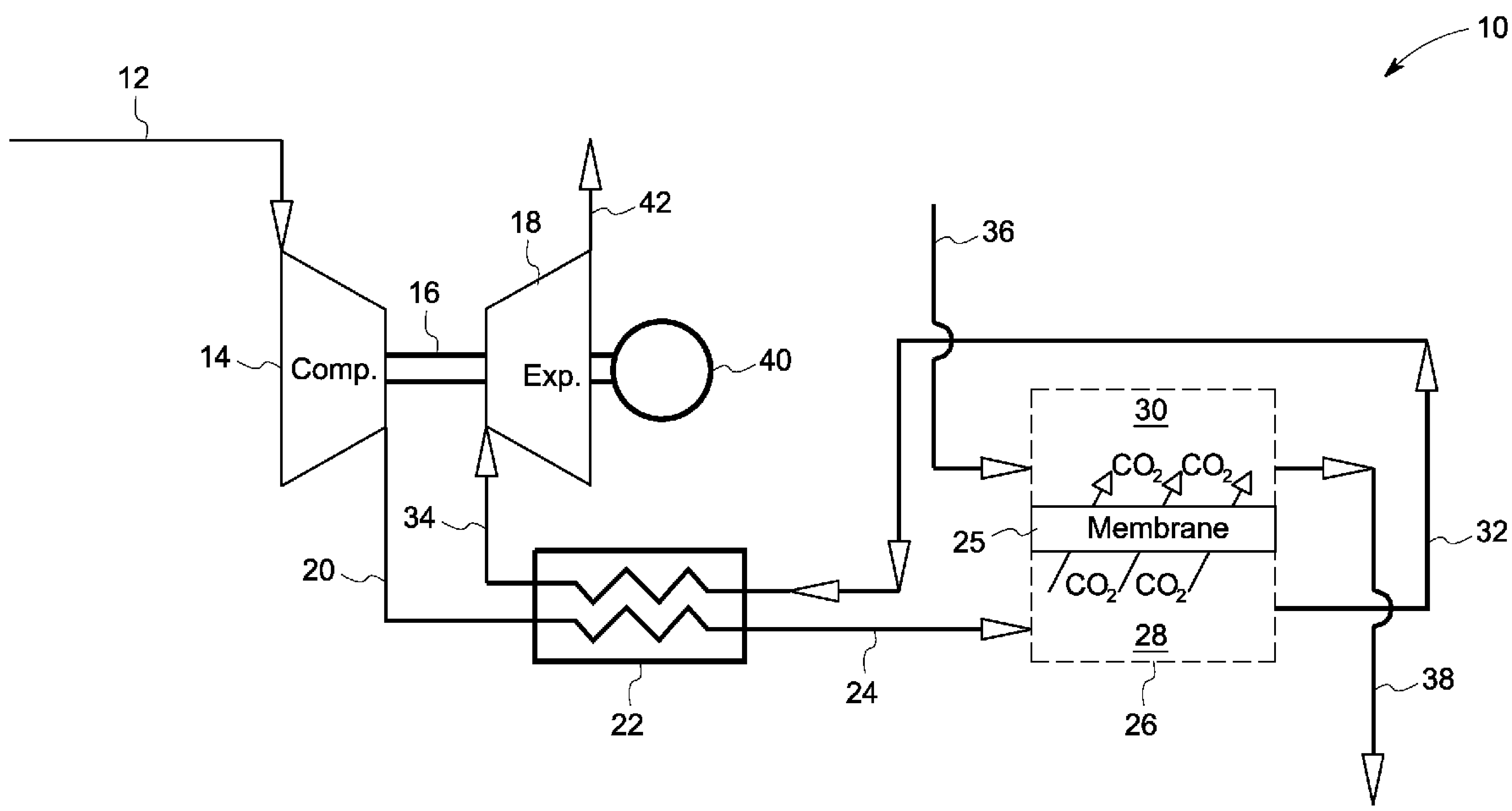
(57) **ABSTRACT**

A carbon dioxide separation system includes a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas and a separator configured to receive the compressed exhaust gas and generate a CO_2 lean stream. The separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough, and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The system further includes an expander coupled to the compressor for receiving and expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream.



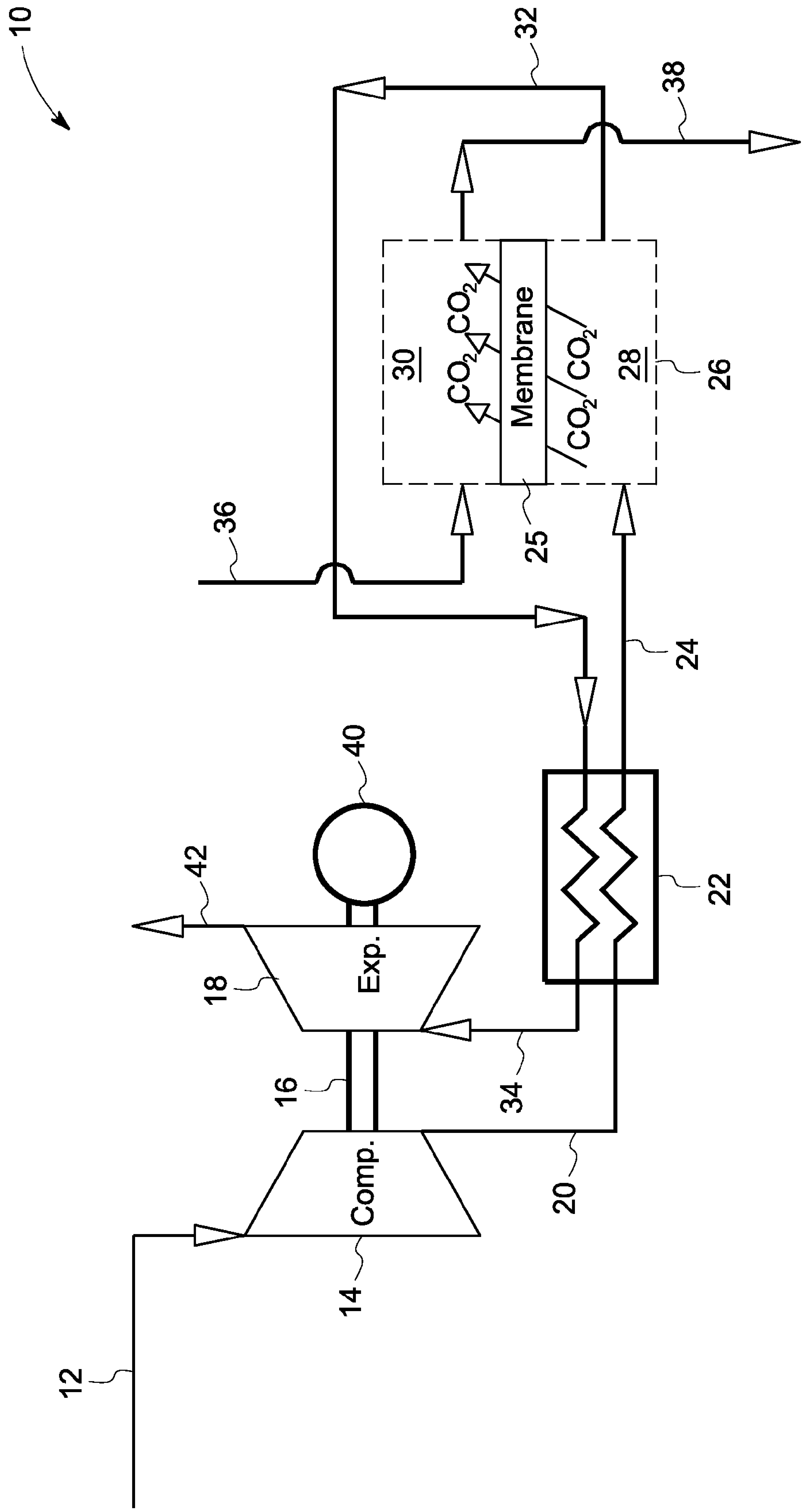

10
12
14
Comp.
16
18
Exp.
20
22
24
25
26
28
30
32
34
36
38
40
42
Membrane
CO_2
CO_2
CO_2
CO_2
CO_2
CO_2

FIG. 1

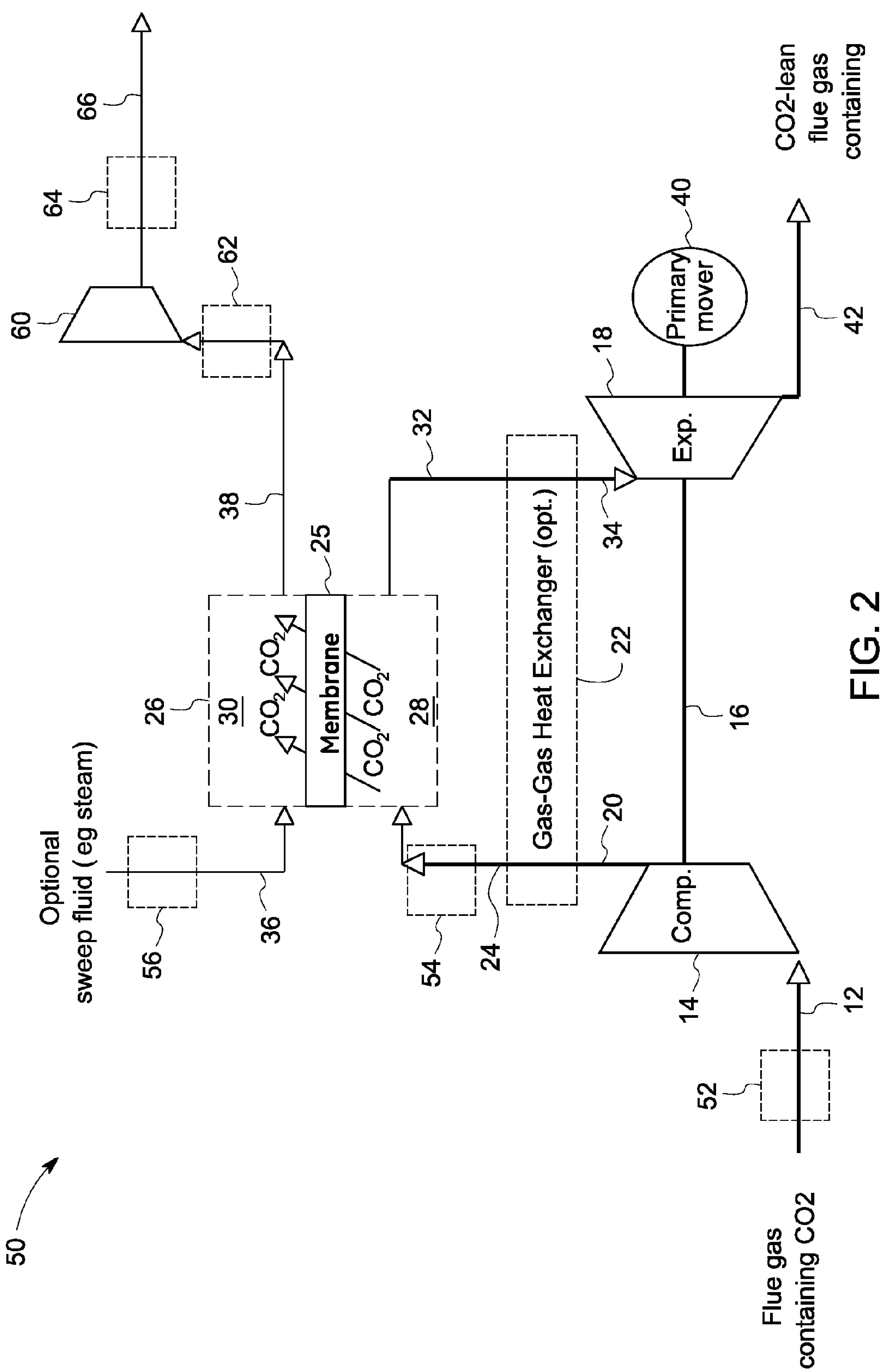

50
Optional sweep fluid (eg steam)
56
36
26
30
Membrane
25
28
38
32
60
62
64
66
54
24
20
22
Gas-Gas Heat Exchanger (opt.)
34
16
Comp.
14
Exp.
18
Primary mover
40
42
12
52
Flue gas containing CO2
CO2-lean flue gas containing

FIG. 2

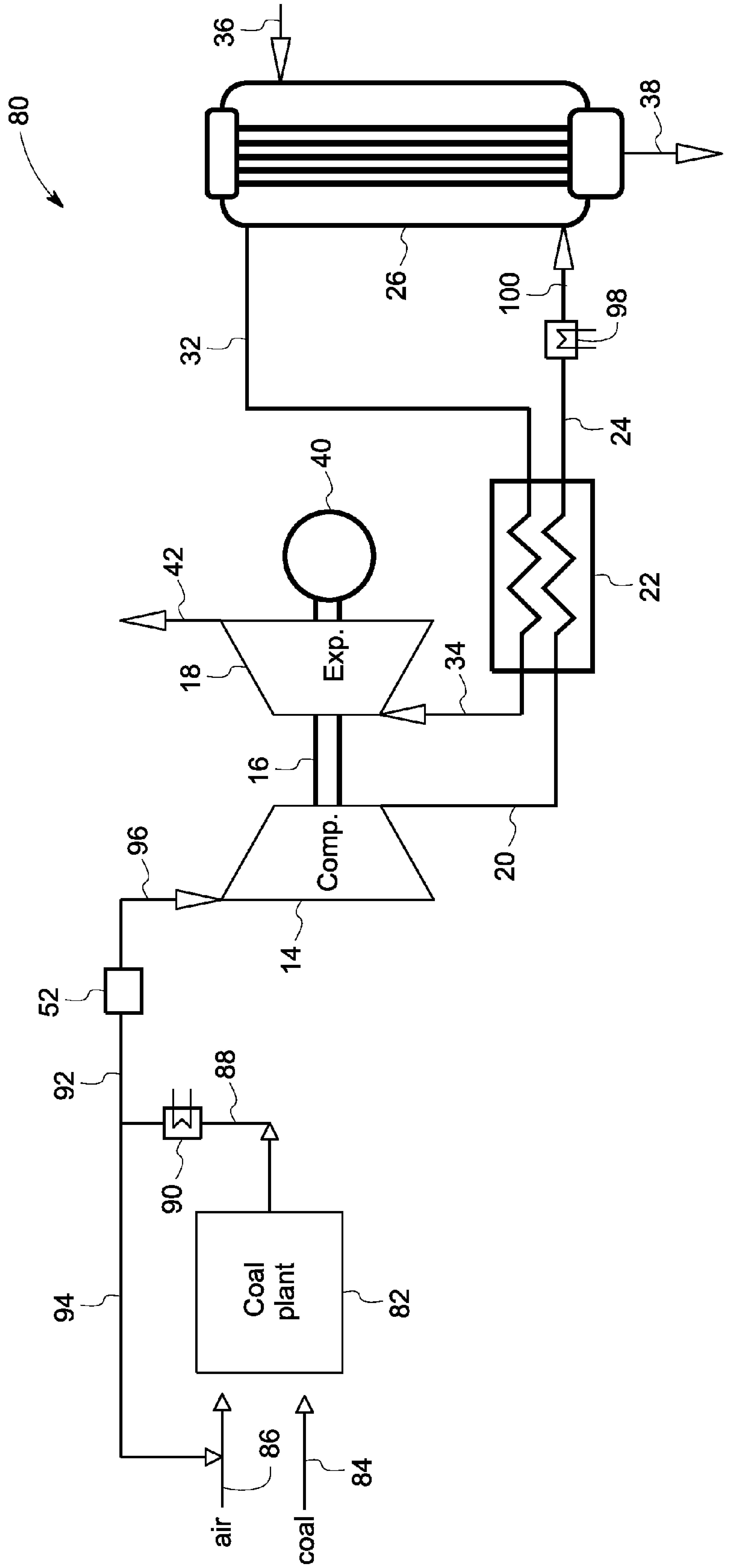

80
36
38
26
100
98
32
24
40
42
Exp.
18
34
22
16
Comp.
96
20
14
52
92
88
90
Coal
plant
82
94
86
air
coal
84

FIG. 3

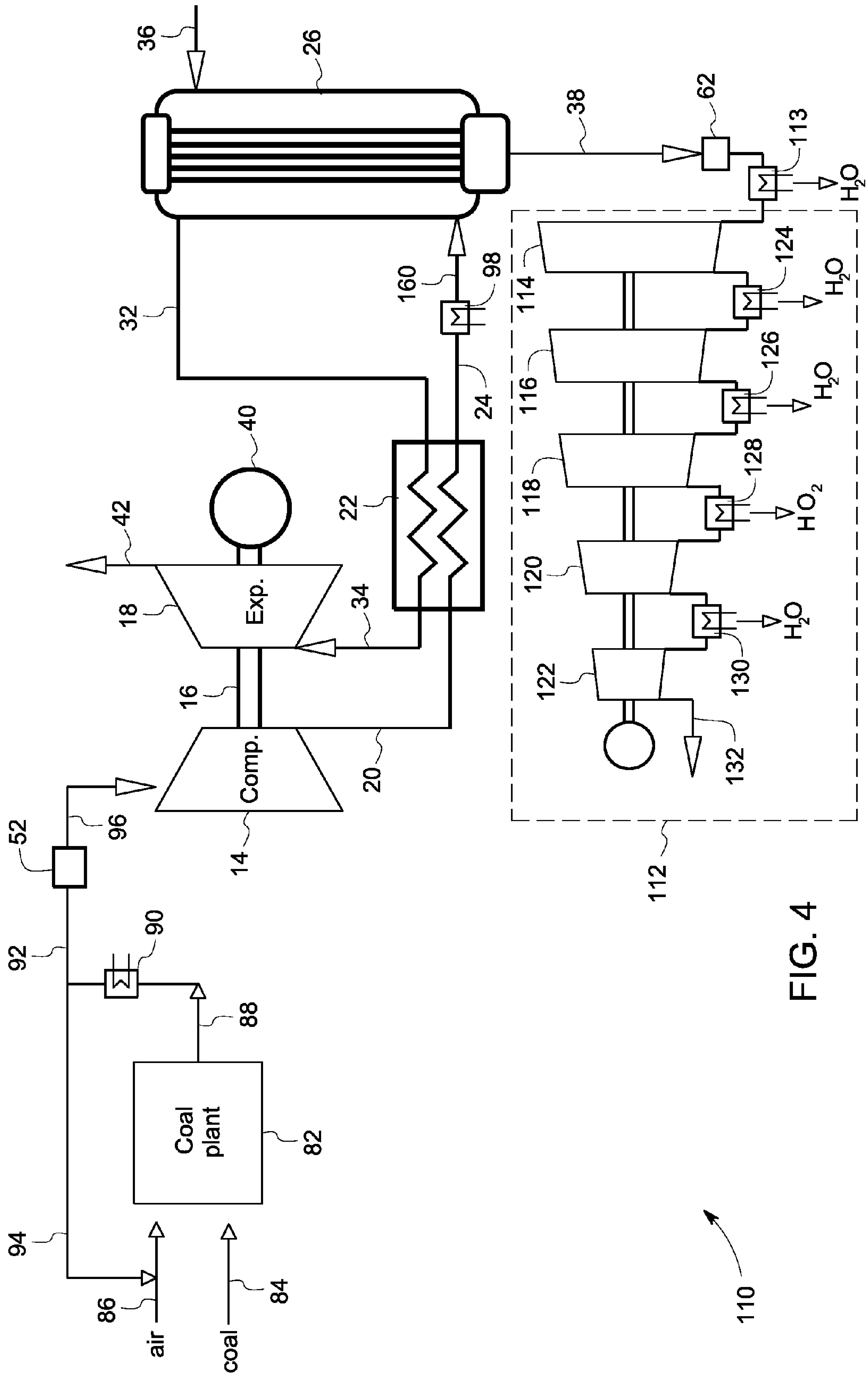


FIG. 4

CARBON DIOXIDE CAPTURE SYSTEMS AND METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-In-Part of U.S. patent application Ser. No. 11/564,912, Docket Number 207795-1, entitled "CARBON DIOXIDE CAPTURE SYSTEMS AND METHODS," filed Nov. 30, 2006, which application is herein incorporated by reference.

BACKGROUND

[0002] This invention relates generally to carbon capture and more specifically to methods and systems for capturing carbon dioxide.

[0003] Before carbon dioxide (CO_2) gas can be sequestered from power plants and other point sources, it must be captured in a relatively pure form. On a mass basis, CO_2 is the nineteenth largest commodity chemical in the United States, and CO_2 is routinely separated and captured as a byproduct of industrial processes such as synthetic ammonia production, hydrogen (H_2) production or limestone calcination.

[0004] Existing CO_2 capture technologies, however, are not cost-effective when considered in the context of sequestering CO_2 from power plants. Most power plants and other large point sources use air-fired combustors, a process that exhausts CO_2 diluted with nitrogen. For efficient carbon sequestration, the CO_2 in these exhaust gases must be separated and concentrated.

[0005] CO_2 is currently recovered from combustion exhaust by using, for example, amine absorbers and cryogenic coolers. The cost of CO_2 capture using current technology, however, can be as high as $150 per ton—much too high for carbon emissions reduction applications. Furthermore, carbon dioxide capture is generally estimated to represent three-fourths of the total cost of a carbon capture, storage, transport, and sequestration system.

[0006] Accordingly, there is a need for a new CO_2 separation system and method to make CO_2 separation and capture from power plants easier and more cost effective.

BRIEF DESCRIPTION

[0007] In one aspect, a carbon dioxide separation system includes a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas and a separator configured to receive the compressed exhaust gas and generate a CO_2 lean stream. The separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough, and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The system further includes an expander coupled to the compressor for receiving and expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream.

[0008] In another aspect, a carbon dioxide separation system includes a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas and a membrane separator configured to receive the compressed exhaust gas and generate a CO_2 lean stream. The membrane separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough wherein the sweep fluid is at a sub-atmospheric pressure and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The system further includes an expander coupled to the compressor for receiving and expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream.

[0009] In yet another aspect, a carbon dioxide separation system includes a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas and a facilitated transport membrane separator configured to receive the compressed exhaust gas and generate a CO_2 lean stream The facilitated transport membrane separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough, wherein the sweep fluid is at a sub-atmospheric pressure and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The system further includes an expander coupled to the compressor for receiving and expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream.

[0010] In yet another aspect, an exhaust gas treatment system includes a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas, wherein the exhaust gas is generated from a coal gasification plant or a natural gas combined cycle power plant and a membrane separator configured to receive the compressed exhaust gas and generate a CO_2 lean stream. The membrane separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough, wherein the sweep fluid is at a sub-atmospheric pressure and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The system further includes an expander coupled to the compressor for receiving and expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream and a post purification system and a compressing system to generate a high pressure CO_2 rich stream.

[0011] In another aspect, a method for separating carbon dioxide includes compressing an exhaust gas comprising CO_2 and generating a compressed exhaust gas and receiving the compressed exhaust gas in a separator and generating a CO_2 lean stream The separator includes a first flow path for receiving the compressed exhaust gas, a second flow path for directing a sweep fluid therethrough wherein the sweep fluid is at a sub-atmospheric pressure and a material with selective permeability of carbon dioxide for separating the first and the second flow paths and for promoting carbon dioxide transport therebetween. The method further includes expanding the CO_2 lean stream to generate power and an expanded CO_2 lean stream.

DRAWINGS

[0012] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0013] FIG. 1. is a schematic depiction of one embodiment of the instant invention;

[0014] FIG. 2. is another schematic depiction of one embodiment of the instant invention;

[0015] FIG. 3. is another schematic depiction of one embodiment of the instant invention; and

[0016] FIG. 4. is another schematic depiction of one embodiment of the instant invention.

DETAILED DESCRIPTION

[0017] FIG. 1 illustrates a carbon dioxide (CO_2) separation system 10 including a compressor 14 for receiving an exhaust gas 12 comprising CO_2 and generating a compressed exhaust gas 20. The separation system 10 also includes a separator 26 configured to receive the compressed exhaust gas 20 and generate a CO_2 lean stream 32. The separator 26 includes a first flow path 28 for receiving the compressed exhaust gas 20, a second flow path 30 for directing a sweep fluid 36 therethrough, and a material 25 with selective permeability of carbon dioxide for separating the first and the second flow paths 28 and 30 and for promoting carbon dioxide transport therebetween. The CO_2 separation system 10 further includes an expander 18 optionally coupled to the compressor 14 through a common shaft 16 for receiving and expanding the CO_2 lean stream 32 to generate power through generator 40 and an expanded CO_2 lean stream 42, or reduce the overall power requirement in the compressor-expander section to be provided by an external source such as a motor.

[0018] As shown in FIG. 1, in operation, the compressed exhaust gas 20 from the compressor 14 is optionally sent to a heat exchanger 22. The heat exchanger 22 is configured to receive the compressed exhaust gas 20 and the CO_2 lean stream 32 from the separator 26 to generate a cooled compressed exhaust gas 24. The heat exchanger 22 is used to utilize the heat content of the compressed exhaust gas 20 and also to cool the compressed exhaust gas 20 to a lower temperature for efficient separation of CO_2 in the separator 26. The cooled compressed exhaust gas 24 is introduced into the first flow path 28 of the separator 26. In one embodiment, the separator 26 is a membrane separation unit.

[0019] The separation systems described herein enhance the driving forces for CO_2 removal by membranes from the cooled compressed exhaust gas 24 comprising CO_2 as the cooled compressed exhaust gas 24 is at high pressure. The pressure difference across the membrane, which pressure difference is the driving force for CO_2 removal is further enhanced by operating the sweep fluid 36 at a sub-atmospheric permeate pressure. In some embodiments, the sweep fluid 36 is at a sub-atmospheric pressure of about 0.1 bar to about 0.5 bar. In one embodiment, the sweep fluid 36 is at a sub-atmospheric pressure of about 0.2 bar. Referring once again to FIG. 1, in one embodiment, the compressed exhaust gas 20 containing CO_2 is directed along the first flow path 28 and the sweep fluid 36 is directed along the second flow path 30. The separator 26 is selective to CO_2 and as the sweep flow 36 has a significantly lower CO_2 partial pressure than that of the cooled exhaust gas 24 containing CO_2, the CO_2 is drawn into the sweep fluid 36 through the CO_2 selective material 25. Accordingly, the stream flowing out of first flow path 28 is the CO_2 lean stream 32, which CO_2 lean stream 32 is heated in the heat exchanger 22. The heated CO_2 lean stream 34 is introduced into the expander 18 to generate the expanded CO_2 lean stream 42 and power. The independence of the compressor-expander system makes the separation systems described herein attractive for retrofitting into the existing power plants with CO_2 capture. In some embodiments, the power generated by expanding the CO_2 lean stream 32 may not be sufficient to run the compressor 14, in which case external power is used to run the compressor 14. In some embodiments, in contrast to heating the CO_2 lean stream 32 in the heat exchanger 22, the CO_2 lean stream 32 may be optionally cooled down (not shown) and expanded to atmospheric pressure. In this case, the cooled (at very low or even sub-zero temperatures) expanded CO_2 lean stream can be used for any cooling process in a power plant. Optionally a dehumidification device (not shown) can be added prior to the expansion of the CO_2 lean stream 32 in the expander 42 to avoid formation of ice or expander damage by droplets. In some embodiments, the exhaust gas 12 is compressed to about 5 bar before being sent to the separator 26. Since the separation system 10 described above can operate independently, it can be a retrofit option for a cost-effective and simple CO_2 separation solution from exhaust streams in existing power plants. The expanded CO_2 lean stream 42 that is released to atmosphere is substantially reduced in CO_2 by using the technique described above.

[0020] The membrane in the separation systems described here may comprise any membrane material that is stable at the operating conditions and has the required CO_2 permeability and selectivity at the operating conditions. Possible membrane materials that are selective for CO_2 include certain inorganic and polymer materials, as well as combinations comprising at least one of these materials. Inorganic materials include microporous carbon, microporous silica, microporous titanosilicate, microporous mixed oxide, and zeolite materials, as well as combinations comprising at least one of these materials.

[0021] Polymeric materials known to be selective for CO_2 include, for example, certain polymer materials, such as polyethylene oxides, polyimides, and polyamides. While not to be limited by a particular theory, mechanisms for CO_2 selectivity in polymeric materials include solution-diffusion and facilitated transport. In a solution-diffusion membrane the flux of CO_2 is enhanced over the other gases in the gas stream by the virtue of CO_2 having a higher solubility in the membrane, a higher diffusivity through the membrane or a combination of both. In a facilitated transport membrane, functional groups with a chemical affinity for CO_2 are present within the membrane that allow a higher flux of CO_2 relative to the other gases. Examples of facilitated transport membranes include polyethylenimine/poly(vinyl alcohol).

[0022] In practice, the membrane often comprises a separation layer that is disposed upon a support layer. The porous support can comprise a material that is different from the separation layer. Support layers for polymeric membranes can comprise polysulfone, poly(ether sulfone), Teflon, cellulose acetate, or polyacrylonitrile. Support materials for asymmetric inorganic membranes include porous alumina, titania, cordierite, carbon, silica glass (e.g., Vycor®), and metals, as well as combinations comprising at least one of these materials. Porous metal support layers include ferrous materials, nickel materials, and combinations comprising at least one of these materials, such as stainless steel, iron-based alloys, and nickel-based alloys. In addition, polymeric membranes can be disposed on polymeric or inorganic supports. Membranes can include polymeric materials such as polyethers and polyether blends and hybrid membranes such as silanized gamma-alumina membranes. Silanes, such as 2-acetoxyethyl, 2-carbomethoxyethyl and 3-aminopropyl, can be integrated with ceramic membranes to achieve selective CO_2 transport.

[0023] Hybrid membranes that incorporate inorganic particles within a polymeric matrix can show enhanced CO_2 selectivity properties at elevated operating conditions. Mixed matrix membranes that incorporate adsorbent inorganic particles such as zeolites or carbon within polymeric matrices also show enhanced properties at elevated operating conditions. This technique is not restricted to any particular membrane material or type and encompasses any membrane comprising any material that is capable of providing suitable levels of permeance and selectivity. That includes, mixed matrix membranes, facilitated transport membranes, hollow fiber membranes, spiral wound membranes, ionic liquid membranes and polymerized ionic liquid membranes.

[0024] In one embodiment, the separator is a facilitated transport membrane. As an alternative to conventional polymeric membranes, facilitated transport membranes may be used as they have the potential of achieving both high permeability and high selectivity. Facilitated transport membranes may selectively permeate CO_2 by means of a reversible reaction of CO2 with an incorporated complexing agent (carrier) in the membrane, whereas gases such as H_2, N_2, and CH_4 will permeate exclusively by the solution-diffusion mechanism.

[0025] In one embodiment, the exhaust gas **12** is at a temperature in the range between about 30° C. to about 700° C. This system can be utilized over a wide range of systems for any exhaust gas, for example, furnace exhaust, thermal oxidizers, metal processing or any other industrial process.

[0026] In one embodiment, sweep fluid **36** is a condensable fluid, like steam for example. In another embodiment, sweep fluid **18** can be one or more of the following: refrigerants; alcohols, like ethanol; hydrocarbons like butane; fluorinated and non-fluorinated hydrocarbons, ketones, ethers, and ethers; and siloxanes. In addition, while this invention is discussed in relation to CO_2 capture systems, a material selective to other constituents within an exhaust gas steam, for example, CO, nitrous oxide (NOx), or acid gases like hydrogen sulfide (H_2S), sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) or other pollutants or species, may be utilized to capture the other constituents in a similar fashion.

[0027] FIG. **2** illustrates a membrane system **50** to separate the CO_2 content in the compressed exhaust gas **12**. As shown in FIG. **2**, separator **26** physically separates first flow path **28** and second flow path **30** and promotes carbon dioxide transport therebetween. FIG. **2** also illustrates the different locations for the purification systems. In one embodiment, a purification system **52** is provided in the flow path of the exhaust gas **12** before the exhaust **12** is introduced into the compressor **14**. In some other embodiments, a purification system **54** is provided to purify the compressed exhaust gas **24** before it enters the membrane **26**. In another embodiment, the sweep fluid **36** is treated in a purification unit **56** before being sent to the membrane **26** and the CO_2 rich stream **38** from the membrane is also treated in another purification unit **62** prior to being compressed in a compressor **60**, which compressor **60** may be a single or a multistage compressor. The compressor **60** generates a CO_2 product stream **66** at high pressure. Optionally the compressed CO_2 product **66** may also be treated in yet another purification unit **64** after compression. The purification units **52**, **54**, **56** and **64** described in this section may include cooling, drying or particle removing systems or combinations thereof.

[0028] FIG. **3** illustrates another exemplary separation system **80** wherein in operation, the exhaust gas **96** that is sent to the compressor **14** is generated in a power generation system **82**. As shown in FIG. **3**, an exhaust gas **88** can be generated from a coal fired power plant **82**. Typically a coal-fired power plant uses a combustion or gasification process (not shown) to burn coal **84** with air **86** to generate fuel for the turbine (not shown) or generate the exhaust stream **88**. The exhaust stream **88** from the coal-fired power plant **82** comprises carbon dioxide CO_2 in the range of about 10% to about 15%. Alternatively the exhaust stream **88** can also be generated in a natural gas power plant. An exhaust generated from a natural gas power plant comprises about 3% to about 8% CO_2. To achieve the high exhaust gas CO_2 concentrations for natural gas power plants, exhaust gas recirculation back to the gas turbine may be advantageously applied, as described later. The final exhaust **96** sent to the compressor **14** may be generated in either of these coal-fired or natural gas power plants or a combination of the exhausts generated from each of these plants. In some embodiments, a portion of the exhaust gas **94** is recycled back into the coal-fired power plant **82** to increase the concentration of CO_2 in the exhaust gas **96**. Exhaust gas recirculation around the main coal-fired power plant (or using natural gas as feed for the combustion process) is advantageously used to increase the CO_2 concentration within the working fluid, leading to an additional rise in CO_2 partial pressure in the exhaust gas **88**, and a further increase of the driving forces for CO_2 separation. In some embodiments, the exhaust gas **88** is passed through a heat exchanger **90** to cool down the exhaust gas **88** and the cooled exhaust stream **92** is introduced to a pre-treatment unit **52** to remove species including but not limited particles. The purified cooled exhaust stream **96** is introduced to the compressor **14** and the compressed exhaust stream **20** is treated in the separator **26** as described in the earlier section to generate a CO_2 rich stream **38**.

[0029] FIG. **4** illustrates yet another exemplary separation system **110**, wherein the CO_2 rich stream **38** generated from the separator **26** is treated in a post separation purification unit **62** to separate species like particles. In one embodiment, the purification unit **62** may include a condenser **113** to separate the water content in the CO_2 rich stream **38**. The sweep stream **36** as described in the earlier section is at a sub-atmospheric pressure and hence the CO_2 rich stream **38** at sub-atmospheric pressure is compressed to a high pressure in a multistage compressor **112**. As shown in FIG. **4**, the multistage compressor **112** comprises 5 stages **114**, **116**, **118**, **120** and **122** with intercoolers **124**, **126**, **128** and **130** in between to cool the compressed gas in between compression stages. The number of stages in the multistage compressor **112** is determined by the pressure ratio at which the final CO_2 product **132** has to be produced at. In one embodiment, the CO_2 product **132** is generated at about 100 bar pressure. The CO_2 product **132** can be used in any industrial application, transported and sold in merchant market or used in enhanced oil recovery.

[0030] There are several advantages for separating CO_2 from exhaust gases using techniques described in the preceding sections. Typically post combustion separation of CO_2 from any exhaust gas is not energy efficient due to lack of availability of elevated pressure in the exhaust stream. In the separation systems described herein, the exhaust gas is compressed to increase the CO_2 partial pressure, which compression process allows the use of CO_2 separation technologies such as membrane technology. The compression power required to compress the exhaust gas is partly recovered by expanding the CO_2 lean stream in an expander coupled to the compressor. As described herein, the membrane permeate side is operated at a sub-atmospheric conditions, e.g. by operating a CO_2 compression chain at sub-atmospheric inlet suction pressure (e.g. at about 0.2 bar). By this a higher pressure difference over the membrane is established at relative low compression power, as mainly the much smaller flow of the permeate side rich in CO_2 has to be compressed in contrast to the larger feed side. This leads to increased driving forces for separation, and enables the use of membrane technology for CO_2 capture. Due to the low permeate pressure (sub-atmospheric), steam at a temperature lower than 100° C. can be used for sweeping, as required by a lot of polymeric membrane materials. The separation systems described herein are easy to implement on all existing and future power plants, as no integration with the main power system is required. This separation system may also be used for CO_2 rich flue gases from any industrial processes. Optionally, still heat recovery from the main power system could be implemented, including heat recovery from the hot gas turbine exhaust gas, or a gas turbine intercooler (if available). By (optionally) using the exhaust gas recirculation (shown in FIGS. **3** and **4**) and pressurizing CO_2-rich exhaust gas, this technique raises the partial pressure of CO_2 in the power plant exhaust-gas, thus simplifying the CO_2 separation process. The compression of the exhaust gas also decreases the volume of gas to be treated in the CO_2 separator, thus reducing the associated capital and energy demands.

[0031] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

1. A carbon dioxide separation system comprising:
- a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas;
- a separator configured to receive said compressed exhaust gas and generate a CO_2 lean stream, said separator comprising;
- a first flow path for receiving said compressed exhaust gas;
- a second flow path for directing a sweep fluid therethrough; and
- a material with selective permeability of carbon dioxide for separating said first and said second flow paths and for promoting carbon dioxide transport therebetween; and
- an expander coupled to said compressor for receiving and expanding said CO_2 lean stream to generate power and an expanded CO_2 lean stream.

2. The carbon dioxide separation system according to claim **1**, wherein said sweep fluid is at a sub-atmospheric pressure.

3. The carbon dioxide separation system according to claim **1**, wherein said exhaust gas is generated from one or more of a coal-fired power plant or a natural gas combined cycle power plant or an industrial process generating a CO_2 rich flue gas.

4. The carbon dioxide separation system according to claim **3**, wherein a portion of said exhaust gas is recycled back into said coal-fired power plant or natural gas combined cycle power plant.

5. The carbon dioxide separation system according to claim **1** further comprising a heat exchanger configured to receive said compressed exhaust gas and CO_2 lean stream to generate a cold compressed exhaust gas.

6. The carbon dioxide separation system according to claim **1** further comprising a pre-cooler to cool down said compressed exhaust gas.

7. The carbon dioxide separation system according to claim **1**, wherein said exhaust gas comprises at about 3% to about 15% CO_2 by volume.

8. The carbon dioxide separation system according to claim **1** further comprising a particle removal unit configured to remove particles from said exhaust gas.

9. The carbon dioxide separation system according to claim **1**, wherein said separator is a membrane separator configured to generate a permeate stream comprising CO_2.

10. The carbon dioxide separation system according to claim **9**, wherein said membrane separator is selected from a group consisting of mixed matrix membranes, facilitated transport membranes, hollow fiber membranes, spiral wound membranes, ionic liquid membranes and polymerized ionic liquid membranes.

11. A carbon dioxide separation system in accordance with claim **1**, wherein said exhaust gas is in the temperature range between about 150° C. to about 700° C.

12. A carbon dioxide separation system in accordance with claim **1**, wherein said sweep fluid is a condensable fluid.

13. A carbon dioxide separation system in accordance with claim **1**, wherein said sweep fluid is steam.

14. A carbon dioxide separation system in accordance with claim **1**, wherein said sweep fluid is an organic compound.

15. The carbon dioxide separation system in accordance with claim **1**, wherein said sweep fluid is selected from the group consisting of refrigerants; alcohols; fluorinated and non-fluorinated hydrocarbons, ketones, esters, and ethers; siloxanes and combinations thereof.

16. The carbon dioxide separation system in accordance with claim **1**, wherein said sweep fluid is at a pressure of about 0.1 to about 0.3 bar.

17. The carbon dioxide separation system in accordance with claim **1** further comprising a post purification system and a compressing system.

18. The carbon dioxide separation system in accordance with claim **17**, wherein said compressing system comprises a compressor with at least one stage to compressed said permeate stream to produce CO_2 rich stream at high pressure.

19. The carbon dioxide separation system in accordance with claim **1**, wherein said exhaust gas is produced from at least one of a gas turbine, a furnace, a thermal oxidizer, metal processing systems, or an industrial process.

20. A carbon dioxide separation system comprising:
- a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas;
- a membrane separator configured to receive said compressed exhaust gas and generate a CO_2 lean stream, said membrane separator comprising;
- a first flow path for receiving said compressed exhaust gas;
- a second flow path for directing a sweep fluid therethrough wherein said sweep fluid is at a sub-atmospheric pressure; and
- a material with selective permeability of carbon dioxide for separating said first and said second flow paths and for promoting carbon dioxide transport therebetween; and
- an expander coupled to said compressor for receiving and expanding said CO_2 lean stream to generate power and an expanded CO_2 lean stream.

21. A carbon dioxide separation system in accordance with claim **20**, wherein said sweep fluid is steam.

22. A carbon dioxide separation system comprising:
- a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas;

a facilitated transport membrane separator configured to receive said compressed exhaust gas and generate a CO_2 lean stream, said facilitated transport membrane separator comprising;

a first flow path for receiving said compressed exhaust gas;

a second flow path for directing a sweep fluid therethrough, wherein said sweep fluid is at a sub-atmospheric pressure; and

a material with selective permeability of carbon dioxide for separating said first and said second flow paths and for promoting carbon dioxide transport therebetween and

an expander coupled to said compressor for receiving and expanding said CO_2 lean stream to generate power and an expanded CO_2 lean stream.

23. An exhaust gas treatment system comprising:

a compressor for receiving an exhaust gas comprising CO_2 and generate a compressed exhaust gas, wherein said exhaust gas is generated from a coal gasification plant or a natural gas combined cycle power plant;

a membrane separator configured to receive said compressed exhaust gas and generate a CO_2 lean stream, said membrane separator comprising;

a first flow path for receiving said compressed exhaust gas;

a second flow path for directing a sweep fluid therethrough, wherein said sweep fluid is at a sub-atmospheric pressure; and

a material with selective permeability of carbon dioxide for separating said first and said second flow paths and for promoting carbon dioxide transport therebetween;

an expander coupled to said compressor for receiving and expanding said CO_2 lean stream to generate power and an expanded CO_2 lean stream; and

a post purification system and a compressing system to generate a high pressure CO_2 rich stream.

24. A method for separating carbon dioxide comprising:

compressing an exhaust gas comprising CO_2 and generating a compressed exhaust gas;

receiving said compressed exhaust gas in a separator and generating a CO_2 lean stream, said separator comprising;

a first flow path for receiving said compressed exhaust gas;

a second flow path for directing a sweep fluid therethrough wherein said sweep fluid is at a sub-atmospheric pressure; and

a material with selective permeability of carbon dioxide for separating said first and said second flow paths and for promoting carbon dioxide transport therebetween; and

expanding said CO_2 lean stream to generate power and an expanded CO_2 lean stream.

25. The method of claim **25**, wherein said separator is a membrane separator.

* * * * *