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NON-PROVISIONAL U.S. PATENT APPLICATION

ENTITLED:

ANCILLARY OXYGEN-FIRED COMBUSTION WITH ELECTROCHEMICAL CELLS FOR CARBON DIOXIDE SEPARATION

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STATEMENT OF GOVERNMENTAL SUPPORT

The United States Government has certain rights in this invention as the inventors are employees of the U.S. Government.

RELATED APPLICATIONS

This U.S. non-provisional application is related to and claims priority of U.S. provisional application 60/885,703 filed January 19, 2007, which is hereby fully incorporated by reference in its entirety.

FIELD OF INVENTION

The present invention relates to carbon capture/separation. More specifically, one preferred embodiment of the invention relates to a system whereby carbon dioxide and oxygen from a one or more first combustors is extracted by an electrochemical cell and used in one or more oxyfired combustors producing a carbon dioxide rich effluent, which can be permanently stored or used in manufacturing.

BACKGROUND OF INVENTION/SUMMARY OF INVENTION

Recently, there have been concerns about the effects of the massive amount of carbon dioxide, a greenhouse gas, produced by the consumption of fossil fuels. With a rising concern about global warming, there is a demand for an efficient means to reduce carbon dioxide emissions in order to mitigate the effects of the consumption of fossil fuels. One technique for reducing carbon dioxide emissions is carbon sequestration, a two-step process whereby carbon dioxide is captured/separated from a point source and then permanently stored/sequestered. Pulverized coal-fired based power generation is an example of a point source that produces a significant amount of carbon dioxide in its flue gas. Unfortunately, carbon sequestration has thus far been an unviable option due to the expense of capturing carbon dioxide from a flue gas.

Current techniques used to capture carbon dioxide (CO_2) from a flue gas include liquid-based techniques, such as amine scrubbing, or solid sorbent processes.

Unfortunately such techniques prove energy intensive and expensive. Furthermore, these methods require the continuous placement and removal of liquids or solids into the flue gas followed by regeneration of the particular material.

There has been research investigating the use of electrochemical cells to separate the carbon dioxide from a flue gas stream. Walke et al., Gas Sep Pur, vol 2, pp 72-76, 1988, hereby fully incorporated by reference is one example of the use of an electrochemical cell to separate carbon dioxide. Walke describes the use of a molten carbonate electrolyte operating at 650° C to extract carbon dioxide from a flue gas. Walke envisions using the extracted carbon dioxide and water vapor for chemical processes or for enhanced oil recovery. Unfortunately, sulfur oxides, nitrogen oxides and other contaminants poison the molten carbonate cells requiring the periodic shutdown of the system to clean the molten carbonate electrolytes. Although useful for the generation of carbon dioxide from a flue gas, the method described by Walke is unfortunately, inefficient, and requires periodic system shutdown and is therefore unsuitable for efficient carbon capture/separation, especially in large scale energy production. Furthermore, the output of the method described in Walke is rich in oxygen, which may be unsuitable for long-term storage and use in chemical processing and would require a further costly separation step to obtain pure carbon dioxide.

Other efforts have been made using electrochemical cells known to separate carbon dioxide from a flue gas, however these efforts have thus far been economically unviable, since the amount of energy required to power the electrochemical cell can consume a significant amount of the total energy produced by the power plant.

Oxyfired combustors have also been investigated as a means to sequester carbon. In typical oxygen-fired combustion, the fuel (for example, coal) is fired with oxygen, rather than air, and the dilution effect of nitrogen in the combustion air is eliminated, producing a stream of primarally CO_2 and H_2O. Therefore, unlike after conventional combustion, nitrogen is not the primary component of the resulting effluent. Examples of oxyfired combustors are described in Herzog, H., E. Drake, J. Tester, R. *Rosenthal, A Research Needs Assessment for the Capture, Utilization, and Disposal of Carbon Dioxide from Fossil Fuel-Fired Power Plants*, Final Report DOE Contract No. DE-FG02-92ER30194, MIT Energy Laboratory, Cambridge, MA, 1993; and Smith, I.M. *CO2 Reduction – Prospects for Coal*, ISBN 92-9029-336-5, December 1999, hereby fully incorporated by reference. Some CO_2 and possibly moisture must be recycled back to the furnace to control the flame temperature. Unfortunately, oxyfiring requires pure oxygen, a very expensive commodity.

Therefore, there is a need in the art for an efficient, cost-effective system for separating carbon dioxide from a gas stream. Furthermore, there is a need in the art for a solution capable of processing an effluent from fossil fuel combustion, particularly from conventional pulverized coal-firing for power generation to efficiently produce a carbon dioxide pure stream.

BRIEF SUMMARY

A system having a first fuel supply means supplying a fuel and a first air supply means supplying air connected to one or more first combustors. The one or more first combustors combust the first fuel in the supplied air and produces a first combustors effluent (e.g. flue gas), which is transferred to each cathode of one or more electrochemical cells or cell stacks each having a cathode, electrolyte, and an anode.

An electrical potential is supplied across the anode and cathode of each electrochemical cell or cell stack. The electrical potential supplied to each one or more electrochemical cells or cell stacks causes carbon dioxide (CO_2) and oxygen (O_2) to migrate from the cathode across the electrolyte to the anode of each electrochemical cell creating an anode effluent, which is transferred to one or more oxyfired combustors for further combustion. A second fuel supply supplies a second fuel to the one or more oxyfired combustors, which burns the fuel with the anode effluent, rich in carbon dioxide and oxygen. Therefore, the one or more oxyfired combustors produces an effluent rich in carbon dioxide, which is preferably captured and stored for long term storage or used in manufacturing.

Any water (H_2O) in the oxyfired combustors effluent is preferably removed. In one embodiment, the outlet of the one or more oxyfired combustors is partially recycled to the inlet of the one or more oxyfired combustors to aid in oxyfired combustion. Preferably, contaminants to the one or more electrochemical cells or cell stacks, for example sulfur oxides and nitrogen oxides, are removed before they are exposed to the one or more electrochemical cells or cell stack. More preferably, the electrochemical cells or cell stacks are resistant to sulfur oxides and nitrogen oxides.

An advantage of one embodiment of the present invention, which includes integration of the electrochemical separation with oxyfiring of a fossil fuel is having no moving parts in the separation of CO_2 from the initial flue gas resulting in reliable long-term operation and negligible maintenance. Due to this unique design, oxygen is provided by the electrochemical cell and does not have to be generated by other costly means, such as the cryogenic separation of oxygen from air. In a preferred embodiment, the primary combustor product stream is cleaned of CO_2 and the resulting stream from the oxyfired combustor is a nearly pure stream of CO_2, which is eventually stored.

DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide.

FIG. 2 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a recycling means.

FIG. 3 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a water condenser for the removal of water.

FIG. 4 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a means for removing contaminants to the one or more electrochemical cells or cell stacks.

FIG. 5 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a means for removing contaminants to the one or more electrochemical cells or cell stacks, a water condenser for the removal of water, and a means for optimizing the one or more oxyfired combustors output.

FIG. 6 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a means for removing contaminants to the one or more electrochemical cells or cell stacks, a water condenser for the removal of water, a recycling means, and a second air supply means.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A system having a first fuel supply means supplying a fuel and a first air supply means supplying air connected to one or more first combustors. The one or more first combustors combust the first fuel in the supplied air and produces a first combustors effluent (e.g. flue gas), which is transferred each cathode of one or more electrochemical cells or cell stacks each having a cathode, electrolyte, and an anode.

An electrical potential is supplied across the anode and cathode of each electrochemical cell or cell stack. The electrical potential supplied to each one or more electrochemical cells or cell stacks causes carbon dioxide (CO_2) and oxygen (O_2) to migrate from the cathode across the electrolyte to the anode of each electrochemical cell creating an anode effluent, which is transferred to one or more oxyfired combustors for further combustion. A second fuel supply supplies a second fuel to the one or more oxyfired combustors, which burns the fuel with the anode effluent, rich in carbon dioxide and oxygen. Therefore, the one or more oxyfired combustors produces an effluent rich in carbon dioxide, which is preferably captured and stored for long term storage or used in manufacturing.

Any water (H_2O) in the oxyfired combustors effluent is preferably removed. In one embodiment, the outlet of the one or more oxyfired combustors is partially recycled to the inlet of the one or more oxyfired combustors to aid in oxyfired combustion. Preferably, contaminants to the one or more electrochemical cells or cell stacks, for example sulfur oxides and nitrogen oxides, are removed before they are exposed to the one or more electrochemical cells or cell stack. More preferably, the electrochemical cells or cell stacks are resistant to sulfur oxides and nitrogen oxides.

FIG. 1

FIG. 1 illustrates one embodiment having one or more first combustors **5** having a first inlet, a second inlet and an outlet. A first fuel supply means **1** for supplying fuel is connected to the first inlet of the one or more first combustors **5** by one or more tubes **45**. A first air supply means **3** is connected to the second inlet of the one or more first combustors **5** by the one or more tubes **45**. The outlet of the one or more first combustors **5** is connected to one or more electrochemical cells or cell stacks **7** by one or more tubes **47**.

Each electrochemical cell in the one or more electrochemical cells or cell stacks **7** has a cathode **9**, an electrolyte **11** and an anode **13**. Each cathode **9** has an inlet and an outlet. Each anode **13** has an outlet. The inlet of each cathode **9** is connected to the outlet of the one or more first combustors **5** by one or more tubes **47**. Each cathode **9** and anode **13** are separated by an electrolyte **11**. A voltage source **23** is connected to each cathode **9** and a corresponding anode **13** by one or more wires **49**. The voltage source **23** supplies a voltage potential across the cathode **9** and anode **13** of each one or more electrochemical cells or cell stacks **7**. Although only one electrochemical cell or cell stack is shown in FIG. 1, as known in the art, any number of electrochemical cells can be used and arranged in various configurations.

The one or more first combustors **5** combust the fuel and air creating a first combustors effluent, which is transferred to the inlet of each cathode **9** of each one or more electrochemical cells or cell stacks **7**. The voltage potential supplied by the voltage source **23** causes carbon dioxide and oxygen to migrate across the cathode **9** and electrolyte **11** and into the anode **13** of each one or more electrochemical cells or cell stacks **7**. Gaseous components at each cathode **9**, other than the carbon dioxide and oxygen migrating to the anodes **13**, are exhausted as a cathode effluent **15** at the cathode outlet.

The outlet of each anode **13** is connected to the one or more oxyfired combustors **17** by one or more tubes **51**. The one or more oxyfired combustors **17** each have a first inlet, a second inlet and an outlet. The first inlet of the one or more oxyfired combustors **17** is connected to the anode **13** of each one or more electrochemical cells or cell stacks **7** by one or more tubes **51**. The second inlet of the one or more oxyfired combustors **17** is connected to a second fuel supply means **19** by one or more tubes **53**, which supplies a second fuel to the one or more oxyfired combustors **17**. The migrated carbon dioxide and oxygen and the second fuel are therefore transferred to the one or more oxyfired combustors **17**, which combust the second fuel in an oxygen, carbon dioxide rich environment creating an oxyfired combustors effluent **21** rich in carbon dioxide and water (H_2O) at the outlet of the one or more oxyfired combustors **17**.

<u>The First Fuel Supply Means 1 and the Second Fuel Supply Means 19</u>

The first fuel supply means **1** supplies a carbon based fuel combustible with the air supplied by the first air supply means **3** by the one or more first combustors **5**. Likewise, the second fuel supply means **19** supplies any fuel combustible, with the carbon dioxide, oxygen rich effluent produced by the one or more electrochemical cell or stacks **7,** by the one or more oxyfired combustors **17**. Preferably, the first fuel supply means **1** and the second fuel supply means **19** both provides a hydrogen, carbon, or a combination thereof based fuel. Preferably, a carbon containing fuel is used by both the first fuel supply means **1** and the second fuel supply means **19**, more preferably a fossil fuel (organic hydrocarbon) is used. Preferably, the first fuel supply means **1** and the second fuel supply means **19** both provide the same fuel. Preferably first fuel supply means **1** and the second fuel supply means **19** supplies any fuel including, but not limited to coal, oil, natural gas, coal-derived synthesis gas, other synthetic fuel gases, biomass, various solid wastes, and combinations thereof. In a preferred embodiment, the first fuel supply means **1** and the second fuel supply means **19** both supply coal, preferably pulverized.

First air supply means **3**

The first air supply means **3** supplies any gas combustible with the fuel supplied by the first fuel supply means **1**, by the one or more first combustors **5**. Preferably, the first air supply means **3** provides ambient air. In the alternative, the first air supply means **3** may provide processed air, for example the supplied air may be filtered for various elements or contaminants. In a preferred embodiment, the first air supply means **3** is one or more openings in the one or more first combustors **5** allowing ambient air to enter the one or more first combustors **5**.

In an alternate embodiment, the air supply means **3** supplies diluted air to the one or more first combustors **5** in order to optimize the reaction within the one or more first combustors **5** and to minimize the generation of contaminants to the one or more electrochemical cells or cell stacks **7,** for example sulfur oxides and nitrogen oxides.

One or More First Combustors **5**

The one or more first combustors **5** combust the fuel supplied by the first fuel supply means **1** with air supplied by the first air supply means **3**. Each combustor from the one or more first combustors **5** burns the first fuel producing heat and creating a first combustors effluent having carbon dioxide and other gas byproducts from the combustion of the first fuel. Products of combustion in the first combustors effluent preferably comprise nitrogen, unburned oxygen, carbon dioxide, water vapor and possible minor compounds, such as sulfur dioxide and nitric oxides, as well as others depending on the first fuel and air, as known in the art.

<u>One or More Electrochemical cells or cell stacks 7</u>

The one or more electrochemical cells or cell stacks **7**; each have a cathode **9**, an anode **13**, and an electrolyte **11** sandwiched in between the cathode **9** and anode **13**; each cathode **9** having an inlet and an outlet; each anode **13** having an outlet.

The one or more electrochemical cells or cell stacks **7** each comprise an electrolyte **11**, between and connected to a cathode **9** and anode **13** Preferably, the electrolyte **11** is sandwiched between the cathode **9** and anode **13**. The electrolyte **11** comprises an ion conducting material that allows the migration of carbon dioxide across it and more preferably enhances the migration of carbon dioxide across it. The first combustors effluent enters the cathode **9** inlet of the one or more electrochemical cells or cell stacks **7** through the one or more tubes **47**.

As the first combustors effluent enters the cathode **9** inlet carbon dioxide is absorbed from the first combustors effluent onto the cathode **9**. A voltage field is applied across the cathode **9** and anode **13** of each electrochemical cell or stack by the voltage source **23**, causing a charge transfer at the cathode/electrolyte interface forming carbonate ions. The carbonate anions migrate across the electrolyte **11** under the influence of the voltage field and form carbon dioxide gas and oxygen at the anode **13**. The overall anode reaction at the one or more electrochemical cells or stacks **7** can be written as:

$$CO_3^{2-} \Leftrightarrow CO_2 + \frac{1}{2} O_2 + 2e-$$

After flowing past the cathode **9** of each said one or more electrochemical cells or cell stacks **7** the cathode effluent **15**, without the carbon dioxide and oxygen collected by the electrochemical cells, exits the outlet of the cathode **9** as a cathode effluent **15**. Preferably, the system is used in a power plant and the cathode effluent **15** eventually exits through a stack, entering the atmosphere.

Each electrolyte **11** of the one or more electrochemical cells or cell stacks **7** comprises an ion conducting material that allows the migration of carbon dioxide across it and more preferably enhances the migration of carbon dioxide across it. Suitable electrolyte materials comprise but are not limited to carbonate containing alkali and/or alkaline earth metals, ionic liquids, and certain organic species. One preferred embodiment of the present invention uses a polymer electrolyte membrane (e.g. SELEMION®) that can transport carbonate ions as the electrolyte. Another preferred embodiment of the present invention uses molten carbonate as the electrolyte **11**.

The cathode **9** and anode **13** may comprise any electrically conducting material including but not limited to metals, metal oxides, ceramics, carbons, and electrically conducting polymers. Some preferred metals for the cathode and anode are platinum or nickel. The cathode **9** and anode **13** must be porous to allow gas to diffuse through and more preferably the cathode **9** and anode **13** must efficiently absorb and desorb carbon dioxide and oxygen so as to not limit the rate of carbon dioxide transport across the electrolyte.

An anode **13** of each said one or more electrochemical cells or cell stacks **7** produce an anode effluent, comprising an enriched stream of carbon dioxide and oxygen. The anode effluent is preferably forced through the anode outlet and into the one or more tubes **51** by a means for generating the flow of the enriched gas stream (as shown in FIG. 5 and FIG. 6).

<u>Voltage Source **23**</u>

The voltage source **23** provides a voltage field across the cathode **9** and anode **13** of each electrochemical cell or stack from the one or more electrochemical cells or cell stacks 7. Preferably, the voltage field applied by the voltage source **23** is a direct current (DC) voltage between about 0 and 1000 volts, more preferably between about 0 to 2 volts. The voltage field is preferably supplied by power generated from the one or more first combustors **5,** the one or more oxyfired combustors **17**, or a combination thereof.

The maximum voltage provided by the voltage source **23** is preferably determined by the decomposition potential of the electrolyte **11**. This is found from the thermodynamic stability of the material. More stable electrolytes can be subjected to higher applied voltages. Preferably, a 1-2 volt potential is applied for ceramic electrolytes. Therefore, the rate of carbonate ion transport is limited by both conductivity (resistance) and stability of the electrolyte.

The one or more wires **49** are any means to electrically connect the voltage source **23** to each cathode **9** and a corresponding anode **13**. Preferably, the one or more wires **49** is a first wire connected to the voltage source **23** and each cathode **9**; and a second wire connected to the voltage source **23** and each anode **13**. Each wire of the one or more wires **49** is electrically conductive, and preferably made of metal.

<u>One or more Oxyfired Combustors 17</u>

The anode **13** effluent enters the inlet of the one or more oxyfired combustors **17**. The second fuel supply means **19** supplies a second fuel into the one or more oxyfired combustors **17** by one or more tubes **53**. Combustion is sustained in the one or more oxyfired combustors **17** by the oxygen enriched anode **13** effluent from the one or more tubes **51**. In one preferred embodiment, the reactants in the one or more oxyfired combustors **17** are oxygen and carbon dioxide from the anode **13** effluent and a fossil fuel (organic hydrocarbon) from the second fuel supply source **19**. If a fossil fuel is burned close to stoichiometry, the resultant gas mixture contains essentially carbon dioxide and water (H_2O).

Preferably, a molar ratio of carbon dioxide to oxygen of about 2 to about 4 is supplied to the one or more oxyfired combustors **17**. More preferably, a molar ratio of carbon dioxide to oxygen is about 2.6 supplied to the one or more oxyfired combustors **17**. In one embodiment, a molar ratio of (CO_2 + H_2O) to O_2 of about 3.3 is supplied to the one or more oxyfired combustors **17**. An exemplary oxyfired combustor is described in U.S. Patent number 6,935,251 (2005) issued to Marin et al., hereby fully incorporated by reference. Preferably, the oxygen combusted in the one or more oxyfired combustors **17** is entirely comprised of oxygen produced at the anode **13** of the one or more electrochemical cells or cell stacks **7**.

Any number of one or more oxyfired combustors may be used, as known in the art. For example, a plurality of oxyfired combustors may be connected in parallel, whereby each oxyfired combustors is connected to the one or more anode **13** from the one or more electrochemical cells or cell stacks **7**. A plurality of oxyfired combustors connected in parallel may be desirable for redundancy or in situations where it is more efficient to have a plurality of smaller one or more oxyfired combustors as opposed to one larger combustor.

One or more Tubes

The various one or more tubes (**45**, **47**, **51**, and **53**) are any means known in the art to transfer the corresponding effluent to the corresponding components for example, tubes, pipes, channels, other transfer means, or combinations thereof. Preferably, metal, plastic, ceramic tubing or channels may be used to transfer the various effluents.

FIG. 2

FIG. 2 illustrates an embodiment identical to FIG. 1 with the addition of a recycling means **25**. The recycling means **25** has an inlet, a first outlet and a second outlet. The inlet of the recycling means **25** is connected to the outlet of the one or more oxyfired combustors **17** by one or more tubes **55**. The first outlet of the recycling means **25** is connected to the first inlet of the one or more oxyfired combustors **17** by one or more tubes **57**. The recycling means **25** recycles a portion of the oxyfired combustors effluent **21** at the outlet of the one or more oxyfired combustors **17** back into the first inlet of the one or more oxyfired combustors **17**. The oxyfired combustors effluent **21**, primarily water and carbon dioxide, is preferably recycled back into the one or more oxyfired combustors **17** by the recycling means **25** to maintain and control temperature within the oxyfired combustor **17**. The second output of the recycling means **25** produces a recycling effluent **27** rich in carbon dioxide

Recycling Means **25**

A recycling means **25** recycles a portion of the oxyfired combustors effluent **21** back into the first inlet of the one or more oxyfired combustors **17** preferably to maintaining adequate temperature control in the oxyfired combustor **17**. The combustion reaction in the one or more oxyfired combustors **17** is preferably maintained near stoichiometry and at appropriate temperatures. Preferably a portion of the carbon dioxide and water from the oxyfired combustors effluent **21** is continuously recycled. Preferably the molar ratio of CO_2 and H_2O to O_2 of about 3.3 is maintained in the one or more oxyfired combustors **17** by the recycling means **25**. In the alternative others devices, such as the Optimizing Means **37** shown in FIG. 5 may be used as a Recycling Means **25**.

FIG. 3

FIG. 3 illustrates an embodiment identical to FIG. 1 with the addition of condenser **29** having an inlet, a first outlet and a second outlet. The inlet of the condenser **29** is connected to the outlet of the one or more oxyfired combustors **17** by one or more tubes **59**, whereby the oxyfired combustors effluent **21** is transferred to the condenser **29**. The condenser **29** removes water (H_2O) from the oxyfired combustors effluent **21** at the inlet of the condenser **29** and generates the first outlet and the second outlet. A condenser effluent **31** is generated at the first outlet of the condenser **29**. The condenser effluent **31** has a substantial reduction in water compared to the oxyfired combustors effluent **21** as the water is discharged as a water effluent **33** at the second outlet of the condenser **29**. Preferably, the water effluent **33** is reused, but alternatively may be discarded.

<u>Condenser **29**</u>

The condenser **29** receives the oxyfired combustors effluent **21** exiting the one or more oxyfired combustors **17** and produces a condenser effluent **31** having a substantial reduction in water. The captured water is released at the second outlet of the condenser **29** as a water effluent **33**. The water vapor is condensed and separated in the condenser **29** and a more purified stream of carbon dioxide exits the condenser **29** as a condenser effluent **31**. Preferably the condenser **29** is a water condenser, TEG glycol dehydration unit, or other devices known in the art.

In the alternative, any means for removing water from the oxyfired combustors effluent **21** may be used, including but not limited to gas-to-liquid heat exchangers and chillers.

<u>FIG. 4</u>

FIG. 4 illustrates an embodiment identical to FIG. 1 with the addition of a means for removing contaminants **35** between the one or more first combustors **5** and the one or more electrochemical cells or cell stacks **7**. The means for removing contaminants **35** comprises an inlet and an outlet. The inlet of the means for removing contaminants **35** is connected to the outlet of the one or more first combustors **5** by one or more tubes **63**. The outlet of the means for removing contaminants **35** is connected to the cathode **9** of each one or more electrochemical cells or cell stacks **7** by one or more tubes **65**.

Contaminants of the electrochemical cells or cell stacks are anything that causes any degradation in the carbon dioxide capture of the electrochemical cells or cell stacks **7**. Degradation in the performance of the electrochemical cells or cell stacks **7** depends on various factors such as the first fuel, electrochemical cells or cell stacks type, and operating conditions (temperature, air, fuel quality, etc.), as well as other factors known in the art. Examples of contaminants include, but are not limited to sulfur dioxides and nitrogen dioxides.

In one embodiment, the one or more first combustors **5** effluent passes through one or more of the following before reaching each cathode **9** of the one or more electrochemical cells or cell stacks **7**: a wet scrubber for acid gas and sulfur oxides removal, a means of selective catalytic reduction for nitrogen oxide control, and/or a baghouse or electrostatic precipitator for particulate capture.

FIG. 5

FIG. 5 illustrates an embodiment identical to FIG. 1 with the addition of a means for removing contaminants **35**, an anode effluent fan **71**, a condenser **29**, a means for optimizing the one or more oxyfired combustors output **37**. In this embodiment, the means for removing contaminants **35** is connected to the one or more first combustors **5** by one or more tubes **63** and to each cathode **9** of the one or more electrochemical cells or cell stacks **7** by one or more tubes **65** as in FIG. 4.

The anode effluent fan **71** is connected to each anode **13** by one or more tubes **73** and is connected to the inlet of the one or more oxyfired combustors **17** by one or more tubes **75**. The condenser **29** is connected to the outlet of the one or more oxyfired combustors **17** by one or more tubes **59** as in FIG. 3.

The means for optimizing the one or more oxyfired combustors output **37** has an inlet, a first outlet and a second outlet. The inlet of the means for optimizing the one or more oxyfired combustors output **37** is connected to the first outlet of the condenser **29**.

The means for optimizing the one or more oxyfired combustors output **37** produces an optimized effluent **41** at its second outlet and a recycled effluent **43** at its first outlet.

The recycled effluent **43** at the first outlet of the means for optimizing the one or more oxyfired combustors output **37** is connected to the first inlet of the one or more oxyfired combustors **17** for combustion by one or more tubes **69**. The optimized effluent **41** at the second outlet of the means for optimizing the one or more oxyfired combustors output **37** contains a more pure carbon dioxide stream and is preferably stored for long term storage or used in manufacturing

Anode Effluent Fan **71**

The anode effluent fan **71** provides an induced draft to aid in the transport of the anode **13** effluent into the one or more oxyfired combustors **17**. In the alternative, other means of moving or inducing carbon dioxide and oxygen off each anode **13** may be used. For example, various pumps, or gas streams may be used to help move the carbon dioxide and oxygen from each anode **13** to the one or more oxyfired combustors **17**.

Means for Optimizing the Oxyfired Combustor Output **37**

The means for optimizing the one or more oxyfired combustors output **37** continuously recycles back a determined portion of the condenser effluent **31** (the oxyfired effluent **21** after it is processed by the condenser **29**). Preferably, the amount of oxyfired combustors effluent **21** recycled back into the one or more oxyfired combustors **17** is optimized primarily for temperature control in the one or more oxyfired combustors **17**. Preferably, the means for optimizing the one or more oxyfired combustors output **37** monitors the temperature and oxygen levels of the oxyfired combustors effluent **21**, the condenser effluent **31**, the optimized effluent **41**, or a combination thereof. Preferably, the determined portion recycled is variable and continuously optimized. In a preferred embodiment the means for optimizing the one or more oxyfired combustors output **37** is computer controlled.

Although the means for optimizing the one or more oxyfired combustors output **37** is depicted as a single block in FIG. 5, any number of components may be used. For example, the recycling means in FIG. 2 may be utilized in conjunction with the means for optimizing the one or more oxyfired combustors output **37**, which may be beneficial as it may decrease the size and transfer abilities of the means for optimizing the one or more oxyfired combustors output **37**.

Furthermore, the means for removing contaminants **35**, the condenser **29**, the means for optimizing the one or more oxyfired combustors output **37**, may be omitted from FIG. 5, as known in the art. For example, in a preferred embodiment, the one or more electrochemical cells or cell stacks **7** are resistant to sulfur oxides and nitrogen oxides and therefore the means for removing contaminants **35** is preferably removed. Likewise, depending on various factors, such as the first fuel, the second fuel, the one or more oxyfired combustors **17** conditions (temperature, oxygen levels, construction, etc...), as well as others, the condenser **29** may preferably be omitted, as the water content may be acceptable for the desired use. Furthermore, the addition of water in the optimized output **41** may be acceptable or desired, depending on the use, whereby the condenser **29** can or should be omitted.

<u>FIG. 6</u>

FIG. 6 depicts one embodiment of a combustion system for the efficient capture/separation of carbon dioxide having a means for removing contaminants, a water condenser, a recycling means, and a second air supply means. This embodiment is similar to FIG. 5 except for a recycling means **25** is used in the embodiment shown in FIG 5 instead of the optimizing means **37** in FIG. 6. Furthermore, the embodiment shown in FIG. 6 uses of a second air supply means **77** connected to the cathode **9** of the one or more electrochemical cells or cell stacks **7**.

The second air supply means **77** is the same as the first air supply means **3**, except the second air supply means **77** supplies air to the cathode **9** of the one or more electrochemical cells or cell stacks **7**. Preferably, the second air supply means **77** supplies enough air whereby about a two to one carbon dioxide to oxygen ratio is established at the cathode **9** of the one or more electrochemical cells or cell stacks **7**.

Having described the basic concept of the invention, it will be apparent to those skilled in the art that the foregoing detailed disclosure is intended to be presented by way of example only, and is not limiting. Various alterations, improvements, and modifications are intended to be suggested and are within the scope and spirit of the present invention.

Additionally, the recited order of the elements or sequences, or the use of numbers, letters or other designations thereof, is not intended to limit the claimed processes to any order except as may be specified in the claims. All ranges disclosed herein also encompass any and all possible sub-ranges and combinations of sub-ranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as "up to," "at least," "greater than," "less than," and the like refer to ranges which can be subsequently broken down into sub-ranges as discussed above. Accordingly, the invention is limited only by the following claims and equivalents thereto.

All publications and patent documents cited in this application are incorporated by reference in their entirety for all purposes to the same extent as if each individual publication or patent document were so individually denoted.