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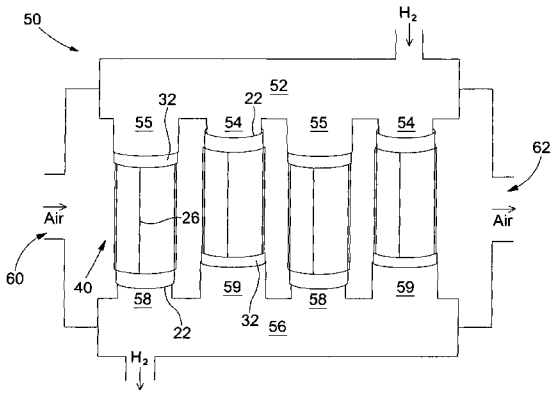

Figure 4

(57) Abstract: The present invention relates to a membrane electrode assembly for connection in a fuel cell. It comprises a tubular proton exchange membrane; inner and outer catalytic electrode layers located on the inner and outer surfaces respectively of the tubular membrane; a first electrically-conductive collar located on, and in electrical communication with, the inner electrode layer at a first end of the tubular membrane; and a second electrically-conductive collar located on, and in electrical communication with, the outer electrode layer at a second end of the tubular membrane opposite the first end. At least one of the first and second collars has an opening therethrough to permit the passage of gas through the interior of the tubular membrane.

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Fuel Cell Electrode Assembly

The invention relates to a membrane electrode assembly for connection in a fuel cell. Such assemblies may find use, for example, in fuel cells powered by hydrogen gas, particularly those for use in automobiles.

Fuel cells have been well known for some time. The general principle is that a fuel gas is supplied to an anode, with an oxidant being supplied to a cathode. The fuel and oxidant are separated by an 'electrolyte', which prevents direct mixing and also forces electrons produced at the anode to travel via an external circuit to the cathode, but which allows the movement of certain ions between the anode and cathode to generate the required chemical reactions. Common choices of fuel include small molecules such as hydrogen, methane, and methanol, with oxygen (typically from the atmosphere) being used as the oxidant. In particular, the combination of hydrogen and oxygen is favoured, since the only resulting waste product is water.

Several designs of fuel cell are well known, typically defined by the type of electrolyte used, and the operating conditions. One of the more common designs uses a proton exchange membrane (PEM) to separate the anode and the cathode. The fuel gas, such as hydrogen, is oxidised at the anode to release protons, typically through the use of a catalytic coating on the anode. The protons travel through the membrane to the cathode, where they react with the oxidant (typically atmospheric oxygen) to produce water as a by-product. Typically, several electrode pairs are stacked to form a fuel cell, with membrane sheets interleaved with single 'bipolar plates' (BPPs) which form the required electrodes. One surface of the BPP acts as anode for the assembly including the adjacent membrane, whilst the other surface of the BPP acts as cathode for the corresponding adjacent membrane assembly. Channels (known as flow field channels) are typically provided in the respective surfaces of the BPP to allow the supply of fuel gas and oxidant, and, in the case of the cathode surface, to allow water by-product to drain away.

In solid oxide fuel cells (SOFC), the electrodes are separated by an electrolyte which allows the passage of oxygen ions, typically made from doped zirconia. In this design, the oxidant (typically oxygen) reacts catalytically at the cathode to generate oxygen ions, which migrate through the electrolyte to the anode, where they react with the fuel gas. Similarly, in molten carbonate fuel cells (MCFC) the electrolyte consists of a

molten carbonate salt. The carbonate ions act as the means of transporting the oxygen to the anode, where it reacts with the fuel gas. The carbonate must be continually replenished at the cathode, usually by supplying carbon dioxide in addition to the oxidant. Both SOFC and MCFC designs typically operate at temperatures in excess of 700 °C, and offer the advantage that they do not suffer from catalyst poisoning by carbon monoxide and/or sulfide compounds (unlike the PEM designs, which commonly use expensive platinum catalysts).

By contrast, PEM fuel cell designs are able to run at typical outdoor temperatures, and thus are a popular choice for use in automotive applications. However, the dependency on the bipolar plates for functionality of the fuel cell has a number of disadvantages. The channels provided in the BPPs to allow the provision of fuel gas and oxidant do not allow the gases to react evenly over the whole area of the electrode, so that the physical space requirements of the fuel cell are higher than desired. Furthermore, sub-optimal electrical conductivity of the BPPs can lead to energy losses within the fuel cell. The permeability of the BPPs to the fuel and oxidant gases can increase over time, leading to direct mixing and reaction. This generates heat, which can damage the fuel cell apparatus, and reduces efficiency. Finally, in order to repair or replace any individual component in the fuel cell stack, it is necessary to disassemble the entire stack of BPPs and membranes. This is costly and time-consuming, and increases the possibility of further components being accidentally damaged.

The present invention has been conceived with the above issues in mind.

According to a first aspect of the invention, there is provided a membrane electrode assembly for connection in a fuel cell, comprising

a tubular proton exchange membrane;

inner and outer catalytic electrode layers located on the inner and outer surfaces respectively of the tubular membrane;

a first electrically-conductive collar located on, and in electrical communication with, the inner electrode layer at a first end of the tubular membrane; and

a second electrically-conductive collar located on, and in electrical communication with, the outer electrode layer at a second end of the tubular membrane opposite the first end;

wherein at least one of the first and second collars has an opening therethrough to permit the passage of gas through the interior of the tubular membrane.

As used herein, the term 'tubular' is intended to refer to a generally longitudinally-extending body having a substantially constant cross-section and a central aperture extending longitudinally through the entire length. It is not necessary that the body should have a circular cross-section, or that the aperture should be located at the longitudinal axis of the body. For example, the body may have a substantially triangular, square, pentagonal, hexagonal or other polygonal cross-section, a substantially elliptical cross-section, or an irregular cross-section. However, in some embodiments, the body has a substantially circular cross-section. This provides for ease of manufacture and adds strength to the body. In some embodiments, the central aperture is located at the axis of the body, such that the tubular membrane has a substantially constant thickness. This ensures that reaction takes place equally across the surface of the membrane.

The tubular membrane electrode assemblies described herein are believed to offer greater electrode surface to volume ratio than the bipolar plates found in prior art designs, and hence greater current for a given weight of fuel cell. The tubular design also facilitates sealing of the separate fuel and oxidant compartments, and gives greater flexibility in fuel cell design than planar prior art arrangements.

The provision of the first and second collars acts to provide structural strength to the membrane electrode assembly, helping to prevent the tubular membrane from being deformed. The collars also facilitate connection of the electrodes to the electrical circuitry of a fuel cell, and connection of a gas supply to the interior of the tubular membrane. In this way, the membrane electrode assembly may be rapidly and easily attached to, or detached from, a fuel cell apparatus.

In use, the membrane electrode assembly may be attached to a fuel gas manifold in a fuel cell by inserting a nozzle from the manifold into the open end of a collar. The second collar may be connected in a similar manner to a fuel cell pipe or a socket in a second manifold. Fuel gas may then be passed through the membrane electrode assembly. Preferably, the same nozzles/sockets are used to form electrical connections with the collars, and hence with the electrode layers of the membrane

electrode assembly. In this way, fitting of a membrane electrode assembly is a simple matter of fitting the membrane electrode assembly on the appropriate nozzles/sockets, without any need for soldering or other form of permanent connection. If, for any reason, the membrane electrode assembly stops functioning correctly, it is therefore a simple matter to remove it from the fuel cell and replace it with a new part. All other (functioning) membrane electrode assemblies within the fuel cell can be left in place during this procedure, thereby minimising the downtime of the fuel cell and the cost of repair.

In some embodiments, the membrane electrode assembly further comprises a first current collector in electrical communication with both the inner electrode layer and the first collar.

In some embodiments, the membrane electrode assembly further comprises a second current collector in electrical communication with both the outer electrode layer and the second collar.

The first and/or second current collector(s) may be made from any electrically-conductive material. It will be understood that the or each current collector must be sufficiently porous to allow gaseous fuels to access the relevant electrode layers. In some embodiments, the or each current collector is made from a corrosion-resistant metal. Exemplary metals include gold, silver, platinum and titanium. In some embodiments, the or each current collector is in the form of a wire mesh. Such meshes contribute to improving the structural strength of the membrane electrode assembly, whilst also retaining a high degree of porosity to allow fuel gases to access the electrode layers.

The membrane electrode assembly may optionally further comprise a gas diffusion layer on one or both of the inner and outer surfaces. Such gas diffusion layers are well known in prior art planar membrane electrode assemblies, where they aid in distributing the gases evenly onto the catalyst layers and soak up water at the cathode. However, it is believed that the membrane electrode assemblies of the present invention reduce the need for such gas diffusion layers, as the required functionality is provided by the design of the membrane electrode assembly. Thus, in some

embodiments, the membrane electrode assembly does not contain any gas diffusion layers.

Where one or both gas diffusion layers are present, it will be understood that they must be sufficiently flexible to be capable of adhering to the respective catalytic electrode layers. Woven materials, such as the known carbon cloth, may be particularly suitable in this regard.

According to a second aspect of the invention there is provided a method for making a membrane electrode assembly according to the first aspect of the invention, comprising

providing a proton exchange membrane sheet having catalytic electrode layers on both surfaces thereof;

forming the proton exchange membrane sheet into a tubular proton exchange membrane, having a first electrically-conductive collar located in a first end thereof; and

inserting a second end of the tubular membrane into a second electrically-conductive collar.

In some embodiments, providing the proton exchange membrane sheet having catalytic electrode layers on both surfaces thereof comprises applying catalytic electrode layers to one or both surfaces of a proton exchange membrane sheet. For example, the catalytic electrode layers may be applied to the polymer sheet by printing, such as for example by screen printing, or by any other suitable method.

In some further embodiments, providing the electrode layer-coated proton exchange membrane sheet further comprises applying a current collector to one or both sides of the membrane sheet. The or each current collector may be applied directly to the proton exchange membrane sheet, with the corresponding catalytic electrode layer being applied on top. Alternatively, the catalytic electrode layer may be applied directly to the proton exchange membrane sheet, with the current collector being applied on top. The or each current collector may be made from any electrically-conductive material. It will be understood that the or each current collector must be sufficiently porous to allow gaseous fuels to access the relevant electrode layers (in the case where the current collector is applied on top of the electrode layer), or to allow the relevant ions (typically protons, in the case of a hydrogen fuel cell) to travel between the electrode layer and the proton exchange membrane (where the electrode layer is

applied on top of the current collector). In some embodiments, the or each current collector is made from a corrosion-resistant metal. Exemplary metals include gold, silver, platinum and titanium. In some embodiments, the or each current collector is in the form of a wire mesh. The current collectors may be applied to the proton exchange membrane (generally prior to application of the catalytic electrode layers) by printing, such as for example by screen printing, or by any other suitable method.

In some embodiments, forming the proton exchange membrane sheet into a tubular proton exchange membrane having a first electrically-conductive collar located in a first end thereof comprises wrapping one edge of the proton exchange membrane sheet around a first electrically-conductive collar.

In some further embodiments, the first electrically-conductive collar is connected to a tubular current collector, such that wrapping one edge of the proton exchange membrane sheet around the first electrically-conductive collar causes the proton exchange membrane sheet to be wrapped around the circumference of the tubular current collector.

In some alternative embodiments, forming the proton exchange membrane sheet into a tubular proton exchange membrane having a first electrically-conductive collar located in a first end thereof comprises forming the proton exchange membrane sheet into a tube, and inserting a first electrically-conductive collar into a first end of the tube.

In some further embodiments, the first electrically-conductive collar is connected to an inner tubular current collector, such that inserting the first electrically-conductive collar into a first end of the tube further comprises inserting the inner tubular current collector into the interior of the tube.

In some embodiments, the second electrically-conductive collar is connected to an outer tubular current collector, such that inserting the second end of the tubular membrane into the second electrically-conductive collar comprises inserting the tubular membrane into the second tubular current collector.

The inner and/or outer tubular current collector(s) may be made from any electrically-conductive material. It will be understood that the or each current collector must be

sufficiently porous to allow gaseous fuels to access the relevant electrode layers. In some embodiments, the or each current collector is made from a corrosion-resistant metal. Exemplary metals include gold, silver, platinum and titanium. In some embodiments, the or each current collector is in the form of a wire mesh.

According to a third aspect of the present invention, there is provided a fuel cell comprising at least one membrane electrode assembly according to the first aspect of the invention.

The use of the membrane electrode assembly according to the first aspect of the invention allows for rapid removal and replacement in the event of failure of the electrode assembly. The downtime of the fuel cell is therefore minimised. Furthermore, since there is no requirement for the individual electrode assemblies to be directly linked (unlike the prior art designs in which each BPP acted as an electrode for both adjacent assemblies), the risk of damage to other membrane electrode assemblies when replacing a failed item is reduced.

In some embodiments, the fuel cell comprises between 2 and 20, or between 4 and 12 such membrane electrode assemblies. The presence of several membrane electrode assemblies within a single fuel cell increases the total voltage and/or current that can be obtained from the fuel cell, and improves efficiency by sharing resources such as a fuel supply. However, as the number of membrane electrode assemblies within a single fuel cell increases, so does the risk of the entire fuel cell needing to be shut down due to failure of a membrane electrode assembly.

In some embodiments, the fuel cell comprises means for supplying one of a fuel gas and an oxidant to the interior of each such membrane electrode assembly, and the other of a fuel gas and an oxidant to the exterior of each such membrane electrode assembly. In some further embodiments, the exteriors of all such membrane electrode assemblies are linked to form a common space.

In particular, fuel gas may be supplied to the interior of each membrane electrode assembly, and oxidant supplied to the exteriors of the membrane electrode assemblies. The exterior surfaces of the membrane electrode assemblies can be accessed relatively easily, so this arrangement ensures that a plentiful supply of oxidant is

available, and that water produced by the cell is easily removed. In particular, since the membrane electrode assemblies described herein do not use dipolar plates, the supply of oxidant to the cathode is not restricted to limited channels, but rather can access substantially the whole of the cathode surface. This is particularly beneficial with the use of air to supply the oxidant (as atmospheric oxygen); since air is freely available, the main restriction is in physical access to the cathode, rather than any concerns over cost. Furthermore, since oxygen constitutes only approximately 21% of air, it is useful to have a significant throughput of air through the fuel cell, to ensure that the oxygen does not become depleted. Finally, a steady throughput of air can help to remove water in the form of vapour.

The supply of gas to the interior of the membrane electrode assemblies may be achieved via a manifold connected to the inputs of the assemblies (i.e. the collar at one end of each assembly). A similar manifold may be connected to the outputs of the membrane electrode assemblies (i.e. the collar at the other end of each assembly) where it is desired to collect the gas exiting the membrane electrode assembly. In particular, where the fuel gas is supplied to the interior of the membrane electrode assemblies, any unreacted fuel may be collected from the outputs of the assemblies and recycled to the inputs. This is particularly useful where the fuel gas is hydrogen, as there are no by-products to the catalytic oxidation, so the unreacted fuel collected from the outputs is just as pure as the fuel supplied to the inputs.

In some embodiments, the fuel cell further comprises a housing enclosing the membrane electrode assembly (or assemblies). It will be understood that the housing should ordinarily provide electrical connections for obtaining electrical power from the fuel cell, and at least inlets for the fuel and oxidant. In some embodiments, the housing has a removable portion which allows access to the interior and particularly to each membrane electrode assembly. In some further embodiments, the electrical connections and inlets for the fuel and oxidant are all located on the removable portion. Thus, maintenance of the fuel cell is facilitated by simply removing the removable portion of the housing, which thereby disconnects the remainder of the housing from the electrical connections and inlets for the fuel and oxidant. This allows the remainder of the housing to be relocated for maintenance, or replaced with an equivalent part, without the need to disconnect the electrical connections, fuel supply and oxidant supply from the removable part of the housing.

According to a fourth aspect of the invention, there is provided a fuel cell comprising at least two membrane electrode assemblies, each membrane electrode assembly comprising an anode, a cathode, and a proton exchange membrane, wherein the membrane electrode assemblies are independently removable from the fuel cell.

In some embodiments, the membrane electrode assemblies are tubular.

In some further embodiments, the membrane electrode assemblies are connected to the fuel cell by means of a push fit connection. As used herein, a push fit connection refers to a connection made by pushing two items together so that they are held by friction. A push fit connection therefore offers the advantage that connection can be made relatively quickly and simply, without the need for screws, bolts or other connecting means.

In some further embodiments, one of the anode and cathode is on the external surface of the membrane electrode assembly, and the other of the anode and cathode is on the internal surface.

In some embodiments, a single connection means forms both a mechanical and an electrical connection between the membrane electrode assembly and the fuel cell. It will be understood that the or each electrical connection should be to one of the anode and cathode, and should enable electrical communication between the anode or cathode and an electrical terminal of the fuel cell. The mechanical connection holds the membrane electrode assembly in place within the fuel cell. Again, this simplifies fitting of a membrane electrode assembly into the fuel cell, since it reduces the number of separate connections that must be made. In some embodiments, there are no mechanical connections to the membrane electrode assembly which are not also electrical connections. In some embodiments, there are no electrical connections which are not also mechanical connections.

One example of a fuel cell according to the third aspect of the invention will now be described with reference to the accompanying Figures, in which:

Figure 1 shows components of a membrane electrode assembly;

Figure 2 shows a partially assembled membrane electrode assembly;

Figure 3 shows a fully assembled membrane electrode assembly;

Figure 4 shows a schematic view of a fuel cell incorporating the membrane electrode assembly of Figure 3; and

Figure 5 shows perspective and exploded views of a fuel cell incorporating the membrane electrode assembly of Figure 3.

Referring to Figure 1, a tubular proton exchange membrane 10 is in the form of a cylinder having open ends. Both the outer 12 and inner 14 surfaces of the membrane are coated with platinum catalyst particles having a particle size in the range of 2 to 5 nm.

An inner current collector 20 consists of a cylindrical collar 22, a wire ring 24 having the same outer dimension as the collar, and located coaxial with, but spaced apart from, the collar, and a number of parallel longitudinal wires 26 joining the wire ring 24 to the collar 22. The inner current collector 20 is sized to fit snugly inside the tubular proton exchange membrane 10, so that the collar 22, ring 24 and longitudinal wires 26 are in good electrical communication with the inner surface 14 of the tubular membrane 10.

Referring to Figure 2, the inner current collector 20 is located inside the tubular proton exchange membrane 10 such that the collar 22 is positioned near to a first end 10a of the tubular membrane 10, leaving only a small band of the inner surface 14 of the tubular membrane between the collar 22 and the end 10a of the membrane. The wire ring 24 and longitudinal wires 26 of the current collector 20 are located within the tubular membrane 10 (not shown).

Referring to Figure 3, a membrane electrode assembly 40 consists of the tubular membrane 10, the inner current collector 20 and an outer current collector 30. The outer current collector 30 consists of a cylindrical collar 32, a wire ring 34 having the same internal dimension as the collar, and located coaxial with, but spaced apart from, the collar, and a number of parallel longitudinal wires 36 joining the wire ring 34 to the collar 32. The outer current collector 30 is larger than the inner current collector 20, being sized to fit snugly around the tubular proton exchange membrane 10, so that the collar 32, ring 34 and longitudinal wires 36 are in good electrical communication with the outer surface 12 of the tubular membrane 10.

The outer current collector is located around the outside of the tubular proton exchange membrane 10 such that the collar 32 is positioned near to a second end 10b of the tubular membrane 10 opposite the first end 10a, leaving only a small band of the outer surface 12 of the tubular membrane between the collar 32 and the end 10b of the membrane. The wire ring 34 and longitudinal wires 36 of the outer current collector 30 are also located around the tubular membrane 10.

It will be appreciated that the representations shown in Figures 1 to 3 are merely illustrative, and do not necessarily represent the actual proportions of the membrane electrode assembly 40. In particular, the membrane electrode assembly 40 may be significantly longer, relative to its diameter, than that shown. Nevertheless, it will be appreciated that the current collectors should extend over substantially all of the length of their respective surfaces, and that the inner 20 and outer 30 current collectors should have opposite orientations.

Although the current collectors are shown having four longitudinal wires 26, 36 each, it will be appreciated that this number is not essential and other geometries would be possible. For example, it would be possible to have the wires wound around the inner and outer circumferences of the tubular membrane 10 in a helical fashion, such as at an angle of 45° to the axial direction. The longitudinal wires must be of sufficient number, thickness and spacing to provide strength to the current collectors and good electrical communication with substantially all of the respective surfaces of the tubular current collector, whilst at the same time not significantly impeding the flow of gas (such as fuel gas or oxidant) to those surfaces.

The collars 22, 32, wire rings 24, 34, and longitudinal wire 26, 36 may be made from any suitable metal which provides good electrical conductivity and resistance to corrosion. The use of gold, or gold-plated metal is preferred. For example, the pieces may be formed from gold-plated copper of sufficient thickness to provide support for the proton exchange membrane. The gold plating is typically at a thickness of 0.2 to 5 μm. The wires and collar can be joined by any suitable method, including welding, brazing, soldering, and mechanical connectors.

The tubular membrane 10 may be formed from any suitable proton-permeable membrane, such as the well-known NAFION polymer available from DuPont. The

catalyst particles may be applied to the surfaces of the membrane by any appropriate method, such as screen printing, before the membrane is formed into the tube shown.

The electrical output of the membrane electrode assembly is approximately 1.1 V. Multiple electrode assemblies may be connected in series to achieve the required voltage output.

Referring to Figure 4, a fuel cell 50 contains a number of membrane electrode assemblies 40, a hydrogen input manifold 52 having a number of nozzles 54 and sockets 55 thereon, a hydrogen output manifold 56 having a number of nozzles 58 and sockets 59 thereon, an air input 60 and an air output 62. Each membrane electrode assembly is connected to the input 52 and output 54 hydrogen manifolds by pushing the internal collar 22 over a nozzle 54, 58 on one of the manifolds, and inserting the external collar 32 into a socket 55, 59 on the other manifold. The membrane electrode assemblies are therefore arranged parallel to one another between the input 52 and output 54 manifolds.

The hydrogen input manifold 52 is connected to a source of hydrogen. The nozzles 54, 58 and sockets 55, 59 of the input 52 and output 56 manifolds allow hydrogen to flow through the interior of the membrane electrode assemblies 40, and thus to contact the catalyst-coated inner surface 14 of the membrane 10, which therefore forms the anode. Any unreacted hydrogen exiting the membrane electrode assemblies 40 is collected in the hydrogen output manifold 56 and recycled to the input manifold 54.

It will be understood that each nozzle 54, 58 and socket 55, 59 on the input 52 and output 56 manifolds must either be connected to a membrane electrode assembly 40, or blocked with a plug (not shown), to prevent hydrogen from mixing freely with air. Any such mixing would be wasteful, since it would consume fuel without producing electricity, and could damage the fuel cell through heat production or explosion. Connections between the nozzles 54, 58, sockets 55, 59 and membrane electrode assemblies 40 may be sealed with an O-ring (not shown) or similar.

The air input 60 and output 62 provide a flow of air to the space around the exterior of the membrane electrode assemblies. This brings atmospheric oxygen into contact with the catalyst-coated exterior surface 12 of the membrane 10, which therefore forms the

cathode. The flow of air also helps to remove water, in the form of vapour, which is produced at the cathode as a by-product of the reaction, and also to cool the membrane electrode assemblies to prevent excess heat build-up. The air output 62 returns the used air, which is (slightly) oxygen-depleted, moistened, and warmed, to the atmosphere.

The membrane electrode assemblies 40 are connected in series to provide the required output voltage, which is supplied to external terminals (not shown) of the fuel cell 50. Thus, the internal collar 22 of one membrane electrode assembly 40 must be electrically connected to the external collar 32 of another membrane electrode assembly 40, to form a chain of such assemblies. As depicted, this may be achieved by having adjacent membrane electrode assemblies with opposite orientations, so that on each of the hydrogen manifolds 52, 56 a nozzle 54, 58 is paired with a socket 55, 59. An electrical connection (not shown) may then be simply provided between the nozzle 54, 58 and socket 54, 58 to link the internal collar 22 and external collar 32 of the adjacent membrane electrode assemblies 40.

It will be appreciated that the membrane electrode assemblies may alternatively have the same orientation. In such embodiments, one of the inlet 52 and outlet 56 manifolds will have only nozzles 54, 58, whilst the other of the inlet 52 and outlet 56 manifolds has only sockets 55, 59. Electrical connections will then need to be provided between the internal collar 22 of one membrane electrode assembly 40 and the external collar 32 of the adjacent membrane electrode assembly. Thus, whilst this alternative arrangement has the benefit that all membrane electrode assemblies are aligned in the same orientation (thus simplifying assembly), it has the disadvantage that the electrical connections required between adjacent membrane electrode assemblies are longer and more complex.

The source of hydrogen may be a storage tank, such as a tank containing liquefied hydrogen under pressure. The air input 60 and/or output 62 may be provided with one or more electric fans to ensure a steady movement of air through the fuel cell.

A drain (not shown) may be provided for removal of liquid water from the fuel cell.

Referring to Figure 5, a fuel cell 50 has a housing consisting of a generally cylindrical body 70 and two end plates 72a,b. As shown in Figure 5(b), the body 70 and end plates 72 are held together by bolts 74. Within the body, 10 membrane electrode assemblies 40 are arranged around the inner circumference, aligned axially oriented towards the same end plate 72. As shown, external collars 32 are located at the tops of the membrane electrode assemblies 40, whilst internal collars (not shown) are located at the bottom ends.

Located underneath the top end plate 72a is a hydrogen input manifold 52. An inlet 76 extends from the input manifold through the top end plate 72a for connection to a source of hydrogen. Sockets (not shown) are located on the lower side of the hydrogen input manifold 52 for receiving the external collars 32 of the membrane electrode assemblies 40, and forming a gas-tight electrical connection therewith. Similarly, a hydrogen output manifold 56 is located above the lower end plate 72b, and has an outlet (not shown) extending through the lower end plate 72b. Nozzles 58 are located on the upper side of the hydrogen output manifold for insertion into the internal collars of the membrane electrode assemblies 40.

Upper 78 and lower 80 gaskets lie adjacent to the internal faces of the input 52 and output 56 manifolds, with apertures passing around each of the membrane electrode assemblies 40, and aid in sealing the membrane electrode assemblies 40 against the manifolds 52, 26, to prevent the direct mixing of hydrogen and air. The gaskets are made from an electrically insulating polymeric material.

An aperture in the hydrogen input manifold 52 equipped with an electric fan 82 provides a supply of air to the interior of the fuel cell, where it circulates past the external surfaces of the membrane electrode assemblies 40. The fuel cell reactions take place as the hydrogen flows through the interior of the membrane electrode assemblies, and air flows into the fuel cell. Water produced as a product of the reaction is removed either as vapour in the air flow, or drains from a port at the base of the fuel cell (not shown).

In an example 5kW fuel cell of the invention 20 membrane electrode assemblies were included in the fuel cell assembly. Each membrane electrode assembly had a diameter of 4 cm and a height of 40 cm, giving an individual membrane electrode assembly

surface area of approximately 500 cm^2 and a total surface area of approximately 1 m^2. The 5 kW output makes the fuel cell ideal for application in automotive hybrid systems and portable applications. In automotive hybrid systems utilising electric motors powered by batteries charged from a suitable supply, the 5 kW fuel cell can provide sufficient charge to the batteries between charging cycles to significantly extend the range of the vehicle.

CLAIMS:

1. A membrane electrode assembly for connection in a fuel cell, comprising a tubular proton exchange membrane; inner and outer catalytic electrode layers located on the inner and outer surfaces respectively of the tubular membrane; a first electrically-conductive collar located on, and in electrical communication with, the inner electrode layer at a first end of the tubular membrane; and a second electrically-conductive collar located on, and in electrical communication with, the outer electrode layer at a second end of the tubular membrane opposite the first end; wherein at least one of the first and second collars has an opening therethrough to permit the passage of gas through the interior of the tubular membrane

2. The membrane electrode assembly as claimed in claim 1, further comprising an inner current collector in electrical communication with both the inner electrode layer and the first collar.

3. The membrane electrode assembly as claimed in claim 1 or claim 2, further comprising an outer current collector in electrical communication with both the outer electrode layer and the second collar.

4. The membrane electrode assembly as claimed in claim 2 or claim 3, wherein the inner current collector and/or outer current collector comprises a wire mesh.

5. A method for making a membrane electrode assembly according to any one of claims 1 to 4, comprising providing a proton exchange membrane sheet having catalytic electrode layers on both surfaces thereof; forming the proton exchange membrane sheet into a tubular proton exchange membrane having a first electrically-conductive collar located in a first end thereof; and inserting a second end of the tubular membrane into a second electrically-conductive collar.

6. The method as claimed in claim 5, wherein providing a proton exchange membrane sheet having catalytic electrode layers on both surfaces thereof comprises applying catalytic electrode layers to one or both surfaces of a proton exchange membrane sheet.

7. The method as claimed in claim 5 or claim 6, wherein providing the electrode layer-coated proton exchange membrane sheet further comprises applying a current collector to one or both sides of the membrane sheet.

8. The method as claimed in any one of claims 5 to 7, wherein forming the proton exchange membrane into a tubular proton exchange membrane having a first electrically-conductive collar located in a first end thereof comprises wrapping one edge of the proton exchange membrane sheet around a first electrically-conductive collar.

9. The method as claimed in claim 8, wherein the first electrically-conductive collar is connected to a tubular current collector, such that wrapping one edge of the proton exchange membrane sheet around the first electrically-conductive collar causes the proton exchange membrane sheet to be wrapped around the circumference of the tubular current collector.

10. The method as claimed in any one of claims 5 to 7, wherein forming the proton exchange membrane sheet into a tubular proton exchange membrane having a first electrically-conductive collar located in a first end thereof comprises forming the proton exchange membrane sheet into a tube, and inserting a first electrically-conductive collar into a first end of the tube.

11. The method as claimed in claim 10, wherein the first electrically-conductive collar is connected to an inner tubular current collector, such that inserting the first electrically-conductive collar into a first end of the tube further comprises inserting the inner tubular current collector into the interior of the tube.

12. The method as claimed in any one of claims 5 to 11, wherein the second electrically-conductive collar is connected to an outer tubular current collector, such that inserting the second end of the tubular membrane into the second electrically-conductive collar comprises inserting the tubular membrane into the second tubular current collector.

13. A fuel cell comprising at least one membrane electrode assembly as claimed in any one of claims 1 to 4.

14. The fuel cell as claimed in claim 13, comprising between 2 and 20 membrane electrode assemblies as claimed in any one of claims 1 to 4.

15. The fuel cell as claimed in claim 13 or claim 14, further comprising means for supplying one of a fuel gas and an oxidant to the interior of each membrane electrode assembly, and the other of a fuel gas and an oxidant to the exterior of each membrane electrode assembly.

16. The fuel cell as claimed in claim 15, wherein the exteriors of the membrane electrode assemblies are linked to form a common space.

17. A fuel cell comprising at least two membrane electrode assemblies, each membrane electrode assembly comprising an anode, a cathode and a proton exchange membrane, wherein the membrane electrode assemblies are independently removable from the fuel cell.

18. The fuel cell as claimed in claim 17, wherein the membrane electrode assemblies are tubular.

19. The fuel cell as claimed in claim 18, wherein each of the membrane electrode assemblies is connected to the fuel cell by means of a push fit connection.

20. The fuel cell as claimed in any one of claims 17 to 19, wherein a single connection forms both a mechanical and an electrical connection between each membrane electrode assembly and the fuel cell.

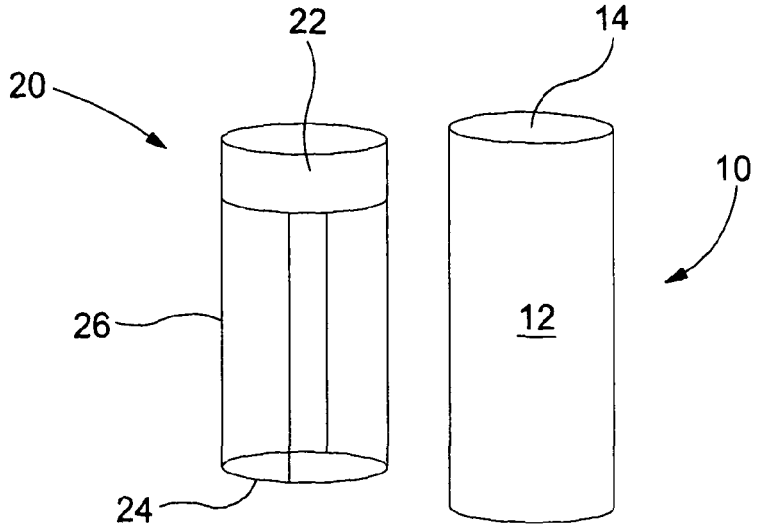

Figure 1

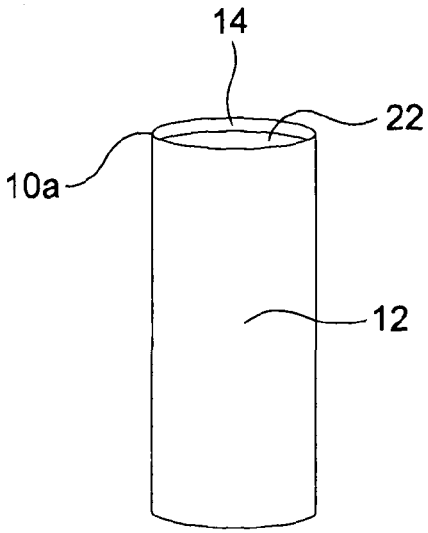

Figure 2

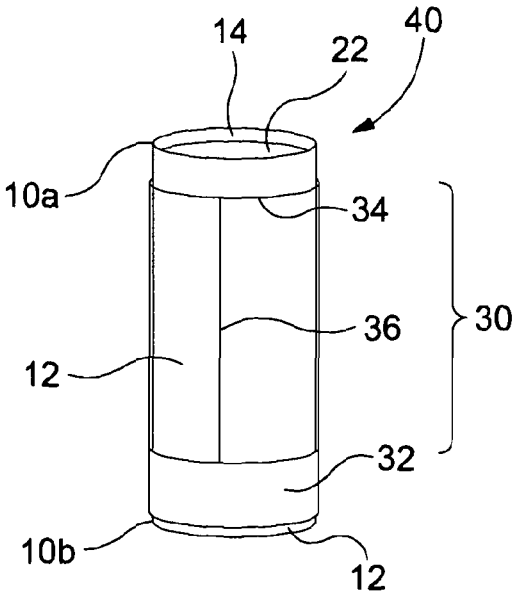

Figure 3

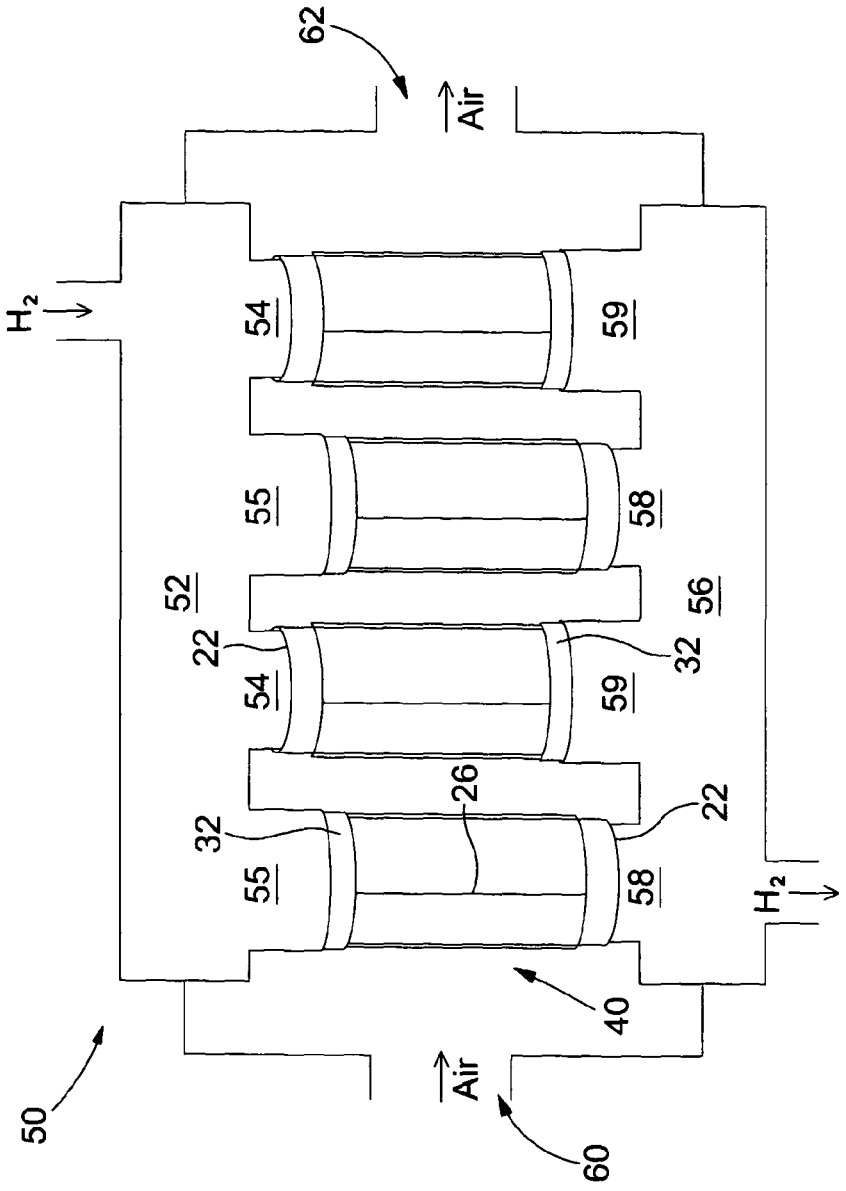

Figure 4

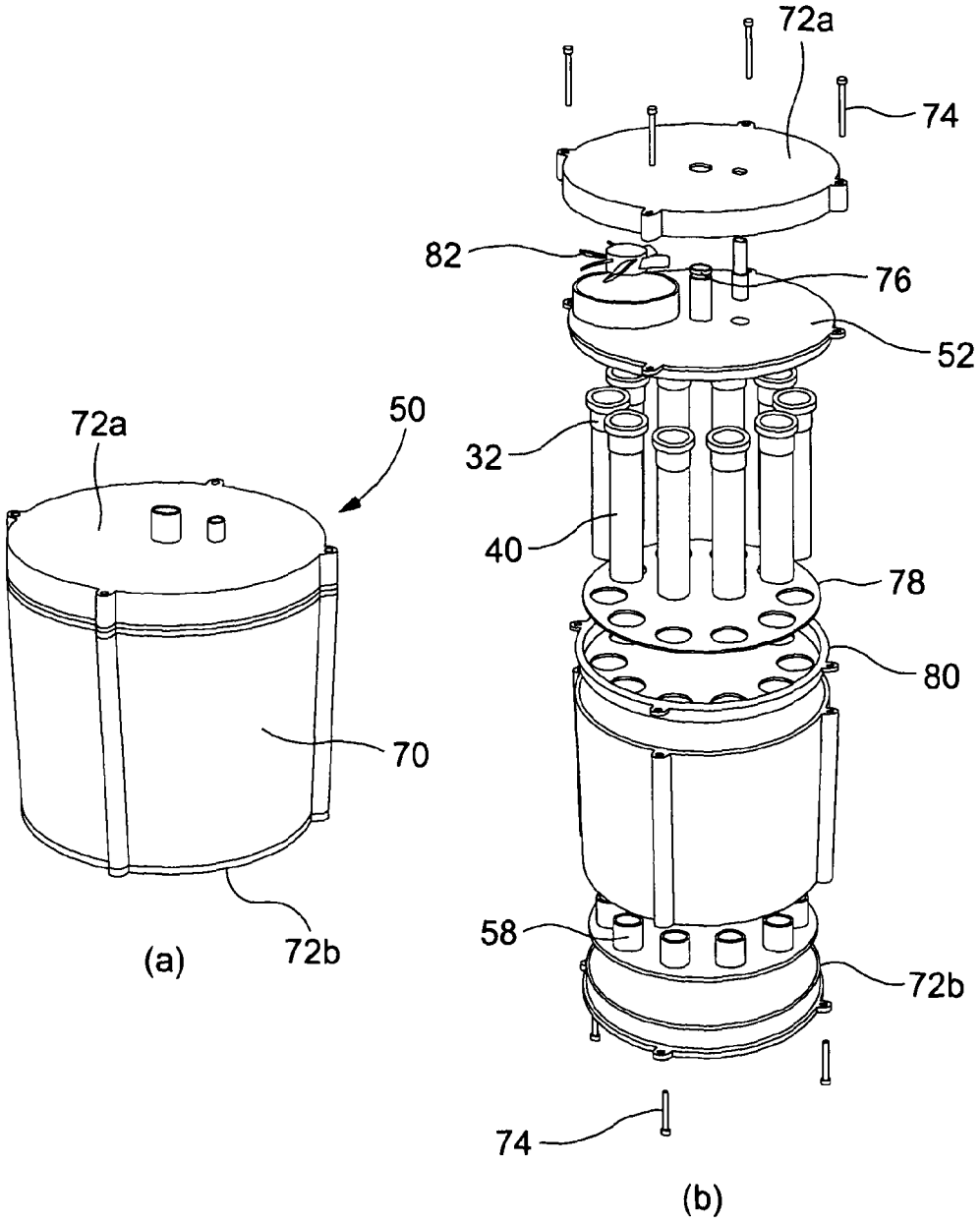

Figure 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/000052

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M8/02 H01M8/24 H01M8/00
ADD.

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)
H01M

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/166053 A1 (BADDING MICHAEL E [US] ET AL) 27 July 2006 (2006-07-27) paragraph [0016]	17-20
A	US 6 506 511 B1 (LAKEMAN JOHN B [GB] ET AL) 14 January 2003 (2003-01-14) abstract paragraph [0033] - paragraph [0038]; figures 5a-5f	1-20
A	TW 200 847 509 A ((UYNA-N) UNIV NAT TAIPEI TECHNOLOGY) 1 December 2008 (2008-12-01) abstract; figures drawing sheets 1-11	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 April 2011	28/04/2011

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2011/000052

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		KR 20080110654 A	18-12-2008
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