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COMPLETE SPECIFICATION

Fuel Cell Batteries

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to fuel cell batteries. Individual fuel cells have been the result of intensive investigation in the last several years. Many types of different fuel cells have been tested and, to a limited degree, used in actual batteries. While some of these batteries have been functional for a period of time, they have, in general, had various shortcomings. A significant shortcoming has been that fuel cell batteries of the prior art have had relatively low power outputs for the space they occupy. In the vocabulary of the art, this is referred to as low power density.

Another significant shortcoming of the prior art has been the cumbersome arrangements required to provide conducting paths from the electrodes of opposite polarity within a fuel cell, or battery, as the case may be, leading to a suitable location external of the cell to provide external terminals for hookup of an external load.

Yet another shortcoming of the prior art has been the difficulty of providing satisfactorily sealed fuel cells that will effectively contain electrolyte without elaborate, complex, and expensive provision being made for sealing.

Still other shortcomings in the prior art include the complexity and expense of parts required, the multiplicity of dissimilar parts required, and the difficulties of assembly of parts into a fuel cell battery.

[Price 4s. 6d.]

Another shortcoming of the prior art has been inadequate provision to supply additional electrolyte as needed, to cells, particularly to those operating on molten electrolyte at high temperature.

It is the object of this invention to provide for a fuel cell battery of simple, economical, yet effective design and construction which has a highly efficient and simple conductive path to the exterior of the cell. The fuel cell battery includes an electrically conductive fuel supply plenum, an electrically conductive spent fuel exhaust plenum spaced from said fuel supply plenum, and a pair of spaced runs of fuel cells connected in parallel between the two plenums, the space between the runs defining a fuel passage, each run containing at least two fuel cells connected in series, each fuel cell including a pair of spaced porous first and second electrodes and an electrolyte disposed therebetween, the first electrode of one fuel cell in each run being electrically connected to one of the plenums and the second electrode of another fuel cell in each run being electrically connected to the other plenum, the second electrode of the said one fuel cell in each run being insulated from the said one plenum and electrically connected to the first electrode of an adjacent fuel cell, and the first electrode of the said another fuel cell being insulated from the said other plenum and electrically connected to the second electrode of an adjacent fuel cell, whereby the plenums serve as opposite polarity terminal busses for the fuel cell battery.

The invention will now be described in greater detail with reference to the accompanying drawings in which:—

FIGURE 1 is a perspective view of a fuel cell battery unit in accordance with a preferred embodiment of the instant invention;

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FIGURE 2 is a side view of the unit of FIGURE 1;

FIGURE 3 is a sectional view taken along 3—3 of FIGURE 2,

5 FIGURE 4 is a sectional view taken along 4—4 of FIGURE 2;

FIGURE 5 is a sectional view taken along 5—5 of FIGURE 2;

10 FIGURE 6 is a partial sectional view of an alternative embodiment as it would be seen taken along a section analogous to 4—4 of FIGURE 2, but pertaining to the modified form showing only the lower portions of the section;

15 FIGURE 7 is a partial sectional view taken along 7—7 of FIGURE 6;

FIGURE 8 is a sectional view of the modified embodiment of FIGURE 9, taken along 8—8 of FIGURE 9;

20 FIGURE 9 is a top view of a modified embodiment;

FIGURE 10 is a transverse sectional view through a line of fuel cells assembled so as to be a part of a preferred embodiment, a partial view of a three-cell series arrangement being illustrated;

30 FIGURE 11 is a perspective view, partially cut-away, illustrating a large fuel cell battery made in accordance with an embodiment of the present invention;

FIGURE 11a is a transverse sectional view through a part of the structure of the fuel cell battery of FIGURE 11, illustrating the electrolyte feed system thereof;

35 FIGURE 12 is a sectional view through a modified form of the present invention, taken along a section line analogous to 4—4 on the form of FIGURE 2, but pertaining to the modified form, and illustrating a feature which involves a secondary electrode;

40 FIGURE 13 is a section taken along 13—13 of FIGURE 12;

45 FIGURE 14 is a transverse section illustrating a modified embodiment of an electrode arrangement supported by a vertical insulated spacer and joined to a conducting bar, the view being transverse to the electrode and other structure illustrated, the electrode arrangement may be used in an embodiment of the invention;

50 FIGURE 15 is a perspective view of another embodiment of an electrode arrangement including a secondary electrode which may form a part of a preferred embodiment of the invention;

55 FIGURE 16 is a side view of the structure of FIGURE 15;

60 FIGURE 17 is a perspective view of an alternate embodiment of an electrode arrangement including a secondary electrode which may form a part of a preferred embodiment of the invention;

FIGURE 18 is a side view of the embodiment of FIGURE 17;

65 FIGURE 19 is an other alternate embodi-

ment of an electrode arrangement which may form a part of a preferred embodiment of the invention;

FIGURE 20 is a side view of the embodiment of FIGURE 19;

70 FIGURE 21 represents a preferred embodiment of an electrode arrangement which may form a part of a preferred embodiment of the present invention, and

75 FIGURE 22 is a side view of the preferred embodiment of FIGURE 21.

Attention is now directed to the perspective view of FIGURE 1. Therein is illustrated generally at 11 a fuel cell battery unit which utilizes a preferred embodiment of this invention. Battery unit 11 is made up of two parallel series arrays of two cells each. Such a configuration is sometimes referred to as a "two-by-two" arrangement.

80 It will be noted that a striking characteristic of the overall appearance of the unit of FIGURE 1 is its general configuration as a rectangular solid. As will be appreciated after the structure of unit 11 is explained, along with other aspects of the present invention, the compact, rectangular type configuration to which battery construction in accordance with concepts of the preferred embodiments of the instant invention logically leads is quite advantageous since a relatively simple system of high power density can be so constructed. By a system of high power density is meant one occupying a comparatively small amount of space for a comparatively large power output.

85 Considering the structure of unit 11, visible in Figure 1, this box-like unit has as one end the metallic conducting fuel inlet plenum 13. Its opposite end is provided by the metallic conducting fuel outlet plenum 15, which is the same in external appearance as plenum 13. The top of the box-like structure is provided by the upper insulating cell support 17, and the bottom by the lower insulating cell support 19. Both of these cell supports are of a good dielectric material, alumina and lava being satisfactory for this purpose, along with other insulating materials that possess considerable structural strength.

90 It is thus seen that the opposite metallic conducting plenums 13 and 15, and the opposite upper and lower insulating cell supports 17 and 19, define a rectangular structural frame having parallel-spaced metallic conducting members separated by, and interconnected by, spaced upper and lower parallel non-conductors.

95 Further referring to Figure 1, a fuel inlet tube 21 extends outwardly from the plenum 13. To it is securely engaged the annular electrical terminal 22. A fuel outlet tube 23 extends outwardly from the plenum 15. It has securely engaged to it the electric outlet terminal 24, which is similar in configuration

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to outlet terminal 22. Electric wires lead from each of the outlet terminals 22 and 24.

The detail of the structure carried by the rectangular frame work of the plenums and the insulated cell supports is best understood by referring to FIGURES 2—5, which all relate to the unit 11. Structure defining four fuel cells is contained within the framework of unit 11. This includes structure for the fuel cells 25, 27, 29 and 31. The general configuration and arrangement of these fuel cells is such that 25 and 27 extend with end portions in alignment so that a substantially vertical wall is provided by these two cells. Moreover, in similar manner, fuel cells 29 and 31 define a similar wall-like structure which is parallel and spaced from that defined by fuel cells 25 and 27. These walls effectively provide opposite sides to the general box-like structure of unit 11.

Fuel cell 25 has an inner electrode 33, and an outer electrode 35. These electrodes are rectangular, porous plate-like members. They are of an electronically conducting material since they must function as electrodes. Various metals such as silver, nickel, and iron are examples of suitable materials of construction for these electrodes. Electrodes 33 and 35 are disposed in vertical planes and they are parallel. The space between them is occupied by an electrolyte. The electrolyte may be a free liquid electrolyte or it may be supported in a rigid structural matrix having a multiplicity of pores, for example, a sintered porous plate of magnesium oxide. If a rigid porous matrix is used, preferably the electrodes 33 and 35 will be joined to opposite faces of this matrix by a flame spray technique, a process known in the art.

Unit 11, however, preferably does not utilize either a free electrolyte or one within a rigid structural matrix. Rather, its preferred electrolyte system consists of a liquid electrolyte supported by the capillary action of and dispersed throughout a multiplicity of loose, finely powdered porous particles. In accordance with this concept, magnesium oxide powder of small grain size and high porosity is dispersed between the electrodes 33 and 35. Carried between these electrodes by the particles of magnesium oxide is the electrolyte, which in this preferred embodiment is a eutectic mixture of sodium and lithium carbonate, for example 50% molar sodium carbonate and 50% molar lithium carbonate. This system of finely divided porous magnesium oxide particles and electrolyte is hereinafter referred to as the electrolyte slurry. It should be borne in mind that this invention should in no sense be construed as limited to this specific electrolyte system, since a variety of others may be used.

The electrolyte slurry is indicated by the reference character 37 throughout its appear-

ance in unit 11, including within each of the cells 25, 27, 29 and 31.

Fuel cell 27 of unit 11 has the same basic configuration as fuel cell 25, with an inner rectangular porous electrode 39 and an outer porous electrode 41 of the same configuration. Electrode 39 is in vertical, end-to-end, but spaced alignment with electrode 33. Likewise, electrode 41 is in vertical, end-to-end, but spaced, alignment with electrode 35. Spacing between and support for electrodes 33 and 35 is provided, in part, by the insulating grooved spacer 43. This member is of a good dielectric material, yet it has considerable structural strength. Lava and alumina are examples of suitable material. Insulating grooved spacer 43 is a vertical member having a regular cross section throughout most of its length, which is generally rectangular in shape, but which includes a groove 44 on one of its edges which receives the end of electrode 35. The width of this groove is such that good lateral support is provided to the received portion of electrode 35, sufficient clearance being present to permit only a tight, sliding engagement of the received portion of the electrode with respect to the groove. The groove has a substantial depth clearance with the extremity of the received portion of the electrode. As will be pointed out in more detail hereinafter this feature is of importance in permitting the necessary differential expansions to occur, which will be encountered with temperature changes experienced by the unlike materials of unit 11.

Insulated grooved spacer 45 is vertically oriented and has the same configuration as insulating grooved spacer 43. However, it is oppositely oriented in direction so that its grooved portion receives the end of electrode 33, opposite to that end of electrode 35 received by insulating grooved spacer 43. With the insulated grooved spacers 43 and 45 so oriented, it will be observed that congruent sides of each lie against side portions of the opposite respective electrode. Note that the spacers 43 and 45 cooperate to space the electrodes 33 and 35 apart in generally parallel fashion.

Insulated grooved spacers 47 and 49 receive and space electrodes 41 and 39, respectively, in analogous manner to that described above for spacers 45 and 43, with respect to electrodes 33 and 35.

Attention is now directed to the manner in which the adjacent sets of opposed electrodes 33 and 35, and 39 and 41, are offset. This can best be understood by reference to FIGURE 3. With the directions taken as they appear on viewing that figure, note that electrode 33 is disposed further to the left than its opposed electrode 35. Moreover, note electrode 39 is disposed further to the left than its opposed electrode 41. Since the length of these electrodes from end to end is the

same in each instance, the result is an overlap between the outer electrode 35 of the cell 25 and the inner electrode 39 of the cell 27. Also note that inner electrode 33 of cell 25 necessarily extends to the left beyond the end of opposed electrode 35 and that outer electrode 41 of cell 27 extends to the right beyond the end of opposed electrode 39.

The metallic vertically elongated conducting bar 51 is joined to the opposite inner faces of each of the overlapping portions of electrodes 35 and 39, as by welding. Metallic conducting bar 51 is rectangular in cross section and its height coincides generally with the height of electrodes 35 and 39. As illustrated in FIGURE 3, it is preferred that the end of the overlapping portion of electrode 35 be flush with the right face of conducting bar 51 and that the end of overlapping portion of electrode 39 be flush with the left face of the conducting bar 51. Since conducting bar 51 is made of a good electronically conducting metal, since it is securely engaged to electrodes 35 and 39 throughout its length, and since its width is comparatively small, very good electronic conduction is provided between the two electrodes 35 and 39 along the short, low resistance path via conducting bar 51.

As will readily be appreciated from FIGURES 3 and 4, the configuration of fuel cells 29 and 31 is exactly the same in all respects to the configuration of fuel cells 25 and 27, except that the latter are disposed as the mirror image of the former. All of the parts of cells 25 and 27 discussed above (the electrodes, the insulating grooved spacers, and the conducting bar, are symmetrical, except for the insulating grooved spacers, and each of them is shaped so that it can be rotated lengthwise to obtain the mirror image position required. In view of the complete analogy, except for the mirror image aspect, like parts for fuel cells 29 and 31 to those employed in fuel cells 25 and 27 are designated by those same numerals employed in connection with 25 and 27, except that those numerals used for fuel cells 29 and 31 are primed.

It is pointed out in connection with the reversibility of analogous parts possible between the two sets of series cells, that, indeed, all analogous parts throughout the cell structure of the various cells are identical and interchangeable. Thus all electrodes are identical as are all insulating grooved spacers and each of the conducting bars.

The fuel cells 25, 27, 29 and 31 are supported between the plenums 13 and 15. Note that the extending portions of electrodes 33 and 33' are welded to the opposite inner faces of spaced vertical bus parts 61 and 63. These spaced vertical bus parts are rectangular projections which extend from the vertical face 65 of plenum body 67. The bus parts are

so dimensioned that the extending ends of electrodes 33 and 33' are substantially flush with vertical face 65, while the spacers 43 and 43' on the ends of electrodes 35 and 35' bear against the outer faces of bus parts 61 and 63, respectively. The bus parts 61 and 63, respectively, are preferably welded to the abutting end portions of electrodes 33 and 33'.

In like manner, plenum 15 is joined to the extending end portions of electrodes 41 and 41' by means of spaced vertical bus parts 71 and 73, extending from face 75 of generally rectangular plenum body 77. The bus parts 71 and 73 are preferably welded to the extending end portions of electrodes 41 and 41'.

Referring to FIGURES 2 and 4, the upper insulating cell support 17 is provided with channels 81 and 83, which are parallel and run the length of insulating cell support 17 from end to end. These channels are of rectangular cross section and open on the bottom face of the respective support member i.e., the face adjoining the upper portions of cells 25, 27, 29 and 31. These channels are just enough wider than the distance across the electrodes of each cell to provide for a tight but sliding fit of each electrode therein. The channels 81 and 83 are transversely spaced apart to match the transverse spacing between the aligned fuel cells 25 and 27 and the aligned fuel cells 29 and 31.

The lower insulated cell support 19 has the same general shape as the upper one, and on its upper face, i.e., the one adjoining the lower portion of the cells 25, 27, 29 and 31, a pair of channels 85 and 87 are formed. These channels have the same configuration and spacing as the channels 81 and 83 in the upper insulated cell support 17.

The upper portions of cells 25 and 27 and 29 and 31, respectively, are supported throughout their length within the channels 81 and 83, respectively. In similar manner, the lower portions of the cells 25 and 27, and 29 and 31, respectively, will be supported within channels 85 and 87, respectively. The bus parts 61 and 63 extending from plenum 13 have the same height as the electrodes. Accordingly, each bus part rides in a respective channel along with the electrode assembly to which it is welded. The upper and lower insulated cell supports 17 and 19 are held in assembled position in respect to the plenums by means of bolts 89. As is seen in FIGURE 1, provision is made in the exposed face of the insulated cell support 17 to receive the end of a bolt 89 and permit its engagement with a nut. This provision consists of a recess 91 in member 17. Similar provision is made for each bolt 89.

The plenum 13 has in its body a rectangular fuel cavity 103 (FIGURE 3) which extends vertically from the level of the top

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of the lower insulated cell support 19 to the level of the bottom of the upper insulated cell support 17. End cover 105 of the plenum 13 is fastened thereto, as by welding. End cover 105 has an aperture through its mid portion coincident with its intersection with the inner bore of the fuel feed line 21. Thus, communication is provided with inlet 21 into the cavity 103. An elongated slot 107 is formed in wall 65 of the plenum that lies next to the electrode assembly. This slot runs substantially the length of the cavity 103 and is oriented to communicate with the fuel corridor 109, which is the space in between the facing walls defined by inner electrodes of fuel cells 25 and 27 on the one hand and the inner electrodes of fuel cells 29 and 31 on the other.

Referring to FIGURE 5, it will be noted that the slot 107 is graduated into increasing width as it progresses upwardly and downwardly from its center. Thus, it is comparatively narrow along its central portion 107a; it is expanded in width along portions 107b extending from either end of portion 107a; and finally, it becomes comparatively wide at the end most slot portions 107c. This slot configuration permits a more even distribution of gases entering fuel corridor 109 from cavity 103.

The plenum 15 has an end cover 111 (FIGURE 3) comparable to the end cover 105 of plenum 13. It encloses the rectangular elongated cavity 113 formed within plenum body 77. Wall 75 of the plenum body 77 is slotted to permit communication between the fuel corridor 109 and the plenum body cavity 113. An aperture leading through cover plate 111 communicates with fuel exhaust tube 23. This permits spent fuel to exit from the plenum body cavity 113. It is thus seen that passage is provided for fuel gas from its entrance way via tube 21, past the inner faces of the fuel cells while traversing corridor 109, and finally out through the fuel exhaust tube 23.

As is best illustrated in FIGURES 2 and 4, parallel transverse bores 121 and 123 extend from an outer side of lower insulating cell support 19 to a small distance beyond a point lying below the most distant electrode plate. Bore 121 is disposed in lower insulating cell support 19 below cells 25 and 29. Bore 123 is disposed in lower insulating cell support 19 below cells 27 and 31. These parallel transverse bores 121 and 123 are vertically positioned so that their transverse paths through the insulating support 19 have a common volume of intersection with respect to the lower most portions of the channels 85 and 87. Thus, the extension of the bores above the bottom of the respective channels defines intersections therewith and accordingly, form slots in the bottom of the channels with a length dependent upon the extent of the

overlap of intersection. Such slots permit communication between the bores, hereinafter called electrolyte cavities, and the compartments between the electrodes in which the electrolyte must reside for cell function.

Cups 125 and 127 extend from the side of the lower insulating cell support 19 on which the electrolyte cavities 121 and 123 open. Each of said cups has an aperture, such as 129 in cup 125 (FIGURE 1), that extends through its side which abuts the side of the insulated cell support 19. The aperture is oriented to communicate with the outer opening in the respective electrolyte cavity. Joinder between the cup and bore may be made by a nipple such as nipple 131, which joins cup 127 to lower insulated cell support 19.

To further explain the electrolyte system, fine magnesium oxide powder is disposed in each of the four cavities defined between the electrode plates of each cell, in the bores 121 and 123, and in the cups 125 and 127. Electrolyte is provided by filling the respective cups therewith. As the cup is filled, capillary action commences. Capillary action then continues until the electrodes have electrolyte disposed therebetween to an elevation determined by the porous characteristics of the magnesium oxide and the effective level of liquid in the cup. Note that small vertical apertures extend from the channels 81 and 83 all the way through the upper insulated cell support 17. These apertures, 133, 135, 137 and 139, permit communication with the upper portion of the cells 25, 27, 29 and 31, respectively. This assures that atmospheric pressure will prevail in the cells and allow capillary action to continue to its fullest extent.

The pore size associated with the magnesium oxide particles can be varied while the rest of the system remains substantially constant. Consider the equation

$$\gamma = \frac{1}{2} h g d r$$

where γ equals surface tension of the liquid; h equals height of the column of the liquid above the lower liquid level; g equals acceleration due to gravity; d equals density of the liquid; and r equals radius of the capillary tube. By rearrangement of the equation, it can be seen that the capillary pore radius is directly proportional to the surface tension of the liquid and inversely proportional to the height of the column, the gravitational acceleration and the liquid density. Consequently, with proper sizing of magnesium oxide particles, the desired amount of capillarity can be obtained for a given electrolyte. The liquid level in the cups 125 and 127 can also be varied somewhat to adjust the elevation of the electrolyte within the cells.

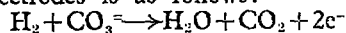
As an example, in a unit 11 where about a seven inch capillary action electrolyte level is desired, magnesium oxide particles having an approximate diameter of 0.005 inches

have been satisfactorily used. This provides an effective pore diameter of approximately 0.005 inches.

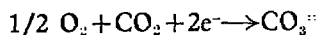
Attention is now turned away from the structure of the preferred embodiment of FIGURES 1—5 and directed to the function of that embodiment in operation and to an explanation of the electrical and electrochemical relationships involved.

The unit 11 must be placed within a suitable environment providing a reactant to contact the exposed surfaces of its electrodes 35, 41, 35' and 41'. If fuel is to be fed into the unit 11 to flow through the fuel corridor 109 separating the inner electrodes 33, 39, 33' and 39', then the inner electrodes will serve as fuel electrodes. Hence, the environment for the outer electrode should be that of an oxidizer. The unit 11 will function with various reactants, but the preferred system is hydrogen gas as a fuel feed and a mixture of oxygen and carbon dioxide as an oxidizer feed. The hydrogen may either be pure or may be mixed along with various other gases for example nitrogen, carbon dioxide, carbon monoxide, light hydrocarbons and water vapor. The oxygen may either be pure or may be supplied as air. This system may effectively use various carbonates as electrolyte; but a preferred electrolyte is the eutectic mixture of sodium carbonate and lithium carbonate. Such a mixture, 50% molar sodium carbonate and 50% molar lithium carbonate, has a melting point of about 500°C. It is therefore necessary that the cells be maintained at no less than this temperature. Preferably the gases are introduced hot for reaction at the electrodes. A preferred operating temperature would be in the vicinity of 600°C., and this is a suitable temperature at which to introduce the reactant gases.

Hydrogen gas is passed in through tube 21 and it flows through the fuel cell unit via corridor. 109. As it passes through corridor 109, it reacts with electrolyte in contact with electrodes 33, 33', 39 and 39'. Spent fuel leaves through tube 23. The reaction occurring at the fuel electrodes is as follows:



Oxygen and carbon dioxide are passed adjacent the exposed surfaces of electrodes 35, 35', 41 and 41'. At these electrodes, referred to normally as the "air electrodes", the following reaction takes place:



In connection with such operation of unit 11, it will be appreciated that a supply of oxygen and carbon dioxide must be provided for the "air electrodes". For test purposes, placing the unit within an oven which is provided with such a gaseous supply of oxygen and carbon dioxide, or air and carbon dioxide, will suffice, thus providing an outer casing to

contain the supplied gas. In practice, such operation would seldom be practical, and therefore other provisions are discussed and illustrated hereinafter whereby unit 11 may be equipped so that a supply of oxygen and carbon dioxide may be received, properly directed, and discharged. The discussion and illustration of such provisions will be deferred until after the electrical function of unit 11 is pointed out.

Both plenums 13 and 15 are made of electronically conductive material. They are separated by dielectrics. Plenum 13 is interconnected with the fuel electrodes 33 by means of bus parts 61, and to electrode 33' by means of bus part 63. On the other hand, outer electrodes 35 and 35', are insulated and spaced from their opposite electrode 33 and 33', respectively, by means of insulated grooved spacers 43 and 43' and by insulating grooved spacers 45 and 45'. Insulating grooved spacers 43 and 43' also insulate and separate the bus parts 61 and 63 from electrodes 35 and 35', respectively. Thus, the only path between the opposite electrodes of each of cells 25 and 29 is the path offered by intervening electrolyte 37.

Outer electrode 35 is structurally and electrically connected to inner electrode 39 of the adjacent cell 27 by means of interconnecting electronically conducting bar 51. Similarly, outer electrode 35' is structurally and electrically connected to inner electrode 39' of the cell 31 adjacent it via the conducting path provided by conducting bar 51'. Note that insulating grooved spacers 45 and 45' prevent adjacent inner electrodes 33 and 39, and 33' and 39', respectively, from having conductive contact. For cells 27 and 31, the insulating grooved spacers 47 and 47' assist in preventing an electronic conductive path between the opposed electrode pairs 39 and 41, and 39' and 41', respectively, of each cell. The path between these opposite electrodes of each cell must be through the electrolyte.

The insulating grooved spacers 49 and 49' assist in separating and insulating electrodes 39 from 41 and 39' from 41', respectively. In addition they space and insulate electrodes 39 and 39' from the bus parts 71 and 73, respectively. The extending end portion of the opposite air electrodes 41 and 41' are welded to the plenum bus parts 71 and 73, respectively. Thus, a path is provided from the air electrodes to the metal plenum 15.

The electrolyte 37 is contained within the structure provided by each cell, and is quite effectively separated from the adjacent cell by means of the integrally connecting conducting bars 51 and 51', assisted by the adjacent insulated spacers 45 and 45' and 47 and 47'. Note that the electrolyte provided to cells 25 and 29 has the common source of electrolyte bore 121. However, this system

is in no way interconnected with the common electrolyte supply provided in cells 27 and 31, via interconnecting bore 123.

In summary, it will be observed that a series hook-up of fuel cells has been provided with fuel cells 25 and 27 in series. Moreover, it will be observed that a second series hook-up of cells has been provided with cells 29 and 31 in series. And, finally, it will be observed that these two arrays of series-connected cells have been placed in parallel. Thus, a highly compact and efficient two-by-two fuel cell battery configuration is obtained. The electrical connections of the unit 11 with an external load may be made directly with the opposite polarity plenums 13 and 15, as by connection with any suitable means, such as terminals 22 and 24.

In some instances, it is desirable to provide auxiliary support in between the opposing electrodes of each cell. If magnesium oxide particles are employed, as was preferred in unit 11, it partially serves this function. In addition, the insulating grooved spacers taken in combination with the integral relationship between adjacent, opposite electrodes of opposite polarity provides considerable support. Auxiliary support may still be desirable in some instances, and can be obtained by providing ridges intermediate each of the channels in the insulated cell supports. Such ridges need not be continuous, but can be broken at strategic intervals, particularly at intervals that will permit the insulated grooved spacer ends by the bus bar to ride in the channels. FIGURE 6 shows a partial section taken through a lower insulated cell support portion of a unit along the same line which section 3—3 was cut, but is applicable to a unit having those changes discussed in the preceding sentence. Thus, referring to FIGURE 6, and to FIGURE 7, it will be seen that a spacing ridge 151 extends axially and centrally along channel 85' and divides that channel into two spaced channels which will receive the respective ones of the lower portions of electrodes 39 and 41. The width of the dividing ridge 151 is such that the plates are received to provide a close sliding fit. A similar ridge 153 in channel 87' provides an analogous function to that of spacing ridge 151. Note that the ridges 151 and 153 do not traverse certain intervals in the path along the respective channels 85' and 87'. Thus, referring to FIGURE 7, it will be noted that in the area of 155 and 157, ridges 151 and 153 are omitted. Within this area of omission, 155, for example, the insulated grooved spacers 45 and 47 and the conducting bar 51 ride on the bottom of the channel 85'. Note that each insulated grooved spacer has its outer portion notched off on either end so that it will fit into the respective channel to receive it. The termination of the outer portion of insulated grooved spacer

47 near its slot inserted end portion is illustrated at shoulder 159, visible behind the sectioned parts in the view of FIGURE 6.

The structure of the embodiment of FIGURE 6 has an electrolyte slurry (with magnesium oxide) 37' only between the electrode plates. The small solid particles of the slurry are held in position by ridges 151 and 153. Electrolyte liquid is provided in the electrolyte cavity 123' by the intercommunicating electrolyte cup (not illustrated, but exactly like cup 127 of FIGURES 1, 2, and 4) which is maintained to a level so that liquid contacts the lower portion 161 and 163 of the electrodes 39 and 41 that extend into the electrolyte cavity 123. Since these electrodes are porous, the extending portions 161 and 163 provide capillary action to raise electrolyte upward and into the magnesium oxide containing cavity between the electrodes. Thus the electrolyte slurry 37' is properly maintained.

Unit 201 of FIGURES 8 and 9 is quite similar to unit 11, however, an outer casing of a ceramic material is provided to receive and direct air and carbon dioxide. The upper insulated cell support 203 has channels 204 and 205 which receive the upper portions of fuel cells 207 and 208, respectively. In addition, outer channels 209 and 211 are provided to receive and support the upper edges of side casing wall 213 and 215. The lower insulated cell support 217 has channels 219 and 221 supporting the lower portions of fuel cells 207 and 208, and, in addition has outer channels 222 and 223 which receive and support the lower portions of casing walls 213 and 215. The plenums of fuel cell battery unit 201 are similar to the plenums of unit 11, but they each have spaced apart vertical grooves close to opposite edge portions. These grooves are positioned to receive and support the forward and rear edges of side casing walls 213 and 215. For example, see groove 224 in plenum 225 of FIGURE 9.

Casing walls 213 and 215 are of suitable dielectric material, for example, alumina or lava. Casing walls 213 and 215 have a plurality of openings therethrough to permit intercommunication with the cavity defined between the inner face of the casing walls and the air electrodes and the air manifold system, including air inlet tube 233, which curves downward at its lower end portion as seen in FIGURE 9 to intersect the portion of the "U" shaped manifold header 235 with which it is connected to convey air therethrough to the manifold connections 237. The fuel outlet 239 (FIGURE 9) also interconnects with the header 235. The respective pressure relationships between the gases are such that the exhaust fuel joins the entering air and both pass through the manifold header and then adjacent the air electrodes of cells 207 and 208, so as to provide reactive contact

therewith, and then finally out through vertical exhaust bores 241 and 243 in upper cell support 203. Note that spent fuel provides the necessary carbon dioxide for the air electrode.

- 5 The basic unit 11 is quite versatile. A multiplicity of such units may be assembled within a suitable air casing, and provided with an interconnecting manifold for fuel.
10 The result would be to place a large number of two-series cell arrays in parallel.

- Moreover, the instant invention is not limited to arrangement whereby only two cells are in series. In accordance with the concept of an interconnecting, spacing conductor bar and complementary spacer means an efficient, economical multi-cell series unit may be constructed. This concept is illustrated in FIGURE 10, which is a partial sectional view through three cells in series.
15 Cell 301 has opposing electrode plates 303 and 305 of opposite polarity. It is in series with cell 307, having opposing electrode plates 309 and 311 of opposite polarity, which in turn is in series with cell 313 having opposing electrode plates 315 and 317 of opposite polarity. Note that the opposing electrode plates, all of the same general size and configuration, are offset so that the plates represented on top as viewed in
20 FIGURE 10 extend to the right beyond their lower opposing plates in each cell. Overlapped portions are thus provided and the conducting bars 319 and 321 join such overlapped portions of adjacent cell plate of opposite polarity to provide a conductive path therebetween. Thus, cell 301 is electronically conductively joined to cell 307 via the conducting bar 319 interconnecting the
35 electrode plates 303 and 311, and the cell 307 is in turn joined to the cell 313, in series arrangement, through the electronic conductive path offered by the interconnecting conducting bar 321 between electrode plates 309 and 317. A suitable electrolyte, such as a slurry of magnesium oxide and sodium-lithium carbonate eutectic, described in connection with unit 11, is provided in the electrolyte-tight compartments of each of cells
45 301, 307, and 313. Insulated grooved spacers 325 are provided to electrically insulate and space the electrode plates in manner analogous to that described in connection with the embodiment of FIGURE 1. It is pointed out that these insulated groove spacers assist in making a good electrolyte seal in addition to the spacing and support functions they perform.

- 50 While it is not absolutely necessary that the conducting bars, such as 319 and 321, FIGURE 10, be welded or integrally joined to the electrodes they interconnect, it is highly desirable that tight contact be maintained between the overlapping plate ends and the intervening respective conducting bar lest

resistance become high or electrolyte loss be promoted through a faulty seal. Moreover, the support provided by integrally connecting plates via a conducting bar is valuable. Thus welding, or otherwise, fixedly securing the conducting bars to the electrodes they interconnect, is seen to be the best way to assure that the necessary tight contact is maintained and that structural support is amply provided.

Attention is directed, in FIGURE 10, to the spacing provided between the end of an electrode, such as 311, and the base of the slot in which it slides. The provision of such clearance, indicated at 327 for the specific electrode plate 311, is most important in instances where high temperature operation is involved, as is the case in molten carbonate cells. Over a temperature change of several hundred degrees, the differences in expansion for the ceramic type and the metallic type elements included within a system can become quite large. Accordingly, the clearance 327 permits differential expansion and eliminates the setting up of excessive stresses, and at all times, the sliding support seal type structure involved provides good lateral support and satisfactory sealing with respect to electrolyte.

The conducting bar means that interconnect adjacent cell electrodes of the opposite polarity in accordance with the instant invention has been illustrated as a separate bar, preferably joined to the electrodes interconnected by welding. In some instances, the conducting bar means and the two adjacent electrodes it interconnects may be fabricated from a single piece of material. For example, a single sintered metal piece could be fabricated in the desired shape with spaced, parallel end electrode plates and an interconnecting mid-portion.

It will be apparent that the series cell structure of FIGURE 10, whether it consists of three series units or of a multiplicity, may be joined to a conducting bus, similar to bus parts 61 and 71 of unit 11 at either end in accordance with the general conducting plenum concept of FIGURES 1-5. Moreover, it will be apparent that elongated versions of the insulating cell support means of the nature disclosed in FIGURE 1 may be provided for multi-series units.

A fuel cell battery of comparatively large power output is illustrated generally at 349 in FIGURE 11. Therein in perspective is illustrated a box-like structure, having opposite ends defined by inlet fuel plenum 351 and fuel outlet plenum 353. Fuel inlet conduit 354 interconnects a fuel supply cavity internal of inlet fuel plenum 351 with a fuel supply. A plurality of regularly spaced vertical slots 355 lead from from the rear wall of inlet fuel plenum 351. A plurality of vertical slots 357 are provided in the inner wall of the

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outlet plenum opposite the slots 355. Through these slots spent fuel leaves the fuel cells to enter the cavity of the outlet plenum and then exit through spent fuel line 359.

- 5 Only one unit 361 is shown in place in the box-like structure of FIGURE 11, in order to simplify the diagram. That unit is substantially the same as the unit 11 except the two parallel lines of series cells are extended, per the manner of the embodiment of FIGURE 10, until a total of two arrays of ten cells each in series are included within each unit. The unit 361 is thus a two-by-ten unit. Twenty units like 361 are assembled within the structure of FIGURE 11 to provide forty parallel sets of 10 cells in series.

- 10 The plenums 351 and 353 are conducting and thus serve as busses. Side 363 is a non-conducting material, such as a ceramic, as is the opposite side 365. A bottom, not illustrated, and a top 367 of non-conducting material of a similar nature are also provided. The bottom and top are disposed with a substantial clearance below and above the respective lower and upper insulated cell supports. For example, note the vertical clearance provided between the top extremity of upper insulated cell support 369 and insulated top 367, which is indicated by the vertical distance that top support groove 371, passing lengthwise along the top of plenum 353, lies above upper insulated cell support 369.

- 15 Air line 373 leads to manifold 375 in the lower portion of wall 363. Note that spent fuel line 359 joins line 373 prior to the manifold 375. Wall 363 has a suitable opening (not illustrated) which receives the gaseous mixture of air and spent fuel from manifold 375. Recall in this connection that the bottom of the fuel battery of FIGURE 11 is of an insulating material which extends downwardly a substantial distance below the cell supports to provide an air-carbon dioxide receptacle cavity.

- 20 The spacing between individual units 361 within the large battery is to provide for oxidizer gas flow up between them to allow contact of the oxidizer gas with the air electrodes.

- 25 The central top portion of side 365 in the large battery configuration of FIGURE 11 has an outlet manifold 377 which provides for the outlet of spent air-carbon dioxide from the top portion of the large battery unit to the exhaust line 379.

- 30 Each unit 361 must be provided with electrolyte for its cells. The electrolyte may be self-contained in each unit if desired; however, this makes it quite difficult to efficiently supply such make-up electrolyte as is needed. Accordingly, the fuel cell battery 359 is preferably equipped with electrolyte supply means that will provide make-up electrolyte, as required, to the various cells in a simple but efficient manner. Such supply means is based

on the principle that a common electrolyte may be supplied to all cells of like potential without disturbing the electrochemical and electrical relationships of the battery.

- 35 A means of providing electrolyte supply to cells of like potential is illustrated in FIGURES 11a, wherein a pair of adjacent units 361 from fuel cell battery 349 are shown. The unit 361 on the right, as viewed in FIGURE 11a, is the unit nearest the rear side 365 of fuel battery 349. Each unit 361 has an electrolyte bore (electrolyte cavity) 381 in its lower, insulating cell support 383, connecting the two parallel cells of like potential within the unit. The section of FIGURE 11a is taken at a location on units 361 that is analogous to the location where the section of FIGURE 4 was taken on unit 11. The only difference is that the bore 381 (FIGURE 11a), unlike the bore 123 (FIGURE 4), runs all the way through the lower insulating cell support. The bores 381 of adjacent units 361 are interconnected by nipples 385. The unit 381 next to side 365 of fuel cell battery 349 has its bore in communication with supply cup or reservoir 387 via nipple 389, which extends through a nipple receiving aperture in side 365. It is thus seen that the cup 387 provides a common electrolyte supply to the aligned, interconnecting electrolyte bores 381 in each of the twenty units within fuel cell battery 349. It will be apparent that such a common supply system can be provided for each of the ten different electrode potentials involved in the fuel cell battery 349. Thus, ten external cups, each communicating with aligned bores interconnecting a common one of the ten different potential cells of each of units 361 is needed. The general location of the line of cups 387, rearward of end 365, can be readily understood by noting the line of cup nipple apertures 391, shown in the lower part of side 365, FIGURE 11. It will be apparent that the units 361 nearest to end 363 will require a stopper means in its bore opening adjacent end 363. Alternatively, this bore opening can be connected via a nipple through end 363 with a second external cup, similar to cup 387 external of the other end 365.

- 40 It will thus be apparent that when the large battery 349, of FIGURE 11, is fed air via 373 that the air, together with the carbon dioxide provided by the spent fuel via line 359, will enter the bottom cavity below the various units and flow up between them to contact the air electrodes to permit the air electrode reaction to occur. The spent gases then flow outward through the outlet manifold 377 to exhaust line 379. Moreover, it will be apparent that fuel will pass from fuel inlet conduit 354 into the cavity within plenum 351; thence through the various parallel paths offered by the units 361 to contact the fuel electrodes in each and finally

out through the cavity of the plenum 353, to join the inlet air via line 359.

The use of electrically active secondary electrodes in conjunction with the primary electrodes is illustrated in FIGURES 12 and 13. Therein, the unit 11' is like unit 11, previously discussed, except for the additions and changes mentioned herebelow.

Secondary electrodes 401 of corrugated configuration are joined to all of the air electrodes 403 of unit 11'. These corrugated units are of an electrode material which is the same as, or quite similar to, the electrode material of the respective electrode to which the secondary electrodes attach. Thus, if the air electrodes are a sintered silver, either sintered silver or a fine mesh silver wire screen might be utilized as the secondary electrodes. Spot welding may be used to affix the secondary electrodes 401 to the respective electrodes to which they connect.

The secondary electrode on the primary air electrodes materially increase effective contact between the electrolyte and the reacting oxidizer gas. The result is increased power output for otherwise comparable situations. Moreover, the secondary air electrodes can be connected to an adjoining secondary electrode of like polarity when a system employing several units in side by side relationship is involved. This materially adds to structural support.

Perhaps of even more importance is the somewhat similar concept of attaching secondary electrodes in between parallel electrodes of like potential. In the unit 11' this takes the form of interconnection of parallel fuel electrodes. In unit 11' (Fig. 13) corrugated secondary electrodes 405 and 407 of like or similar material to the main fuel electrodes 409 and 411, are connected between opposing fuel electrodes of the same potential. Secondary electrodes 405 and 407 are affixed, as by spot welding, to the inner opposed surfaces of the parallel fuel electrodes 409 and 411, respectively. It will be noted that the corrugations are disposed at right angles to the direction of the corrugations of secondary electrodes 401 used in connection with the air electrodes and that they provide parallel channels to direct fuel adjacent to the fuel electrode surfaces in such a manner that good contact will be ensured. The interconnections of each pair of parallel "mirror-imaged" fuel electrodes by the secondary electrodes 405 and 407 effectively increases the size of the electrode means without damaging any other aspect of operation and leads to increased output. Moreover, good structural support is provided by the secondary electrodes.

When a plurality of units of the general nature of unit 11' are assembled into a large battery where an air electrode on one unit will rest beside an air electrode of like

potential, secondary electrodes extending from each may be joined to add structural support.

The unit 11' has an electrolyte bore 412 that extends transversely all the way through the lower insulated cell support. Cups 415 and 417 are provided on either side to intercommunicate with the electrolyte bore in similar manner to the provision made in connection with unit 11. Note that the cups 415 and 417 have been extended downward to provide additional electrolyte capacity. The bore, cups, and electrolyte compartments of each fuel cell are filled with magnesium oxide to provide a capillary matrix supporting the electrolyte.

FIGURE 14 illustrates a slightly different method of mounting an electrode. This method is particularly designed for fine mesh screen wire electrodes. The fine mesh screen wire electrode 421 has elongated "U" shaped metal clips 423, each with opposing sides 425 and 427 bent together to enclose an edge of screen 421. Similar metal clips (not illustrated) preferably enclose the top and bottom edges of the screen electrode 421 and effectively frame the rectangular screen electrode within the clips. One of the metal clips 423 is welded to the conducting bar 429. The opposite metal clip 423 rides in the vertical insulated spacer. Note the spacing between the end of the clip and the rear of the slot 431 to provide for expansion.

A variety of screen wire mesh sizes may be used for electrodes. For example, in a system based on the design of unit 11, an air electrode of S.A.E. 316 stainless steel, 150 wires per inch mesh wire grid screen, silver painted, and a fuel electrode of 120 wires per inch mesh pure nickel wire grid screen may be satisfactorily employed.

It is seen that the metal clips provide a support frame and a convenient mounting means for a fine mesh screen wire electrode. When used with the form of electrolyte feed illustrated in FIGURES 6 and 7, it is desirable that portions of the frame be cut away adjacent electrolyte cavities or bores to permit direct communication between the screen and the electrolyte supply.

It will be observed that the electrodes of this invention have been illustrated in the preferred embodiment as either a sintered mass of particles forming a porous electrode or fine mesh wire screen. Other methods of construction are possible as long as the end product is a porous electrode of suitable material. It is necessary that the electrode be electronically conducting. Examples of materials suitable for certain systems include silver, nickel, and iron. For the unit 11 disclosed herein, when operated with a molten carbonate electrolyte, it is preferred that the air electrode be silver or a stainless steel painted with silver and that the fuel electrode be nickel or a high nickel content alloy. The thickness

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of the electrodes of the preferred embodiments is in all cases relatively small compared to their other dimensions. Such a configuration is referred to hereinafter in the claims as "plate-like". It is to be understood that this includes screen wire electrodes as well as other varieties.

It will be seen from the foregoing that this invention provides a fuel cell battery having a high power density. This is partly made possible by the conductive, series interconnecting of adjacent cells to provide a continuous line of series connected cells with no wasted space. Moreover, such line of cells is disposed so that a partition is defined which separates the fuel and oxidizer reactants. In a preferred form, with two similar series lines of cells in parallel, it has been observed that a fuel corridor is defined between the two lines of cells. Fuel can be passed from a suitable fuel supply, such as the plenum of the embodiment described, down the fuel corridor to contact all fuel electrodes in the two lines of series connected cells.

The rectangular construction of the preferred embodiments of the instant invention is an additional factor of importance in making possible high power density fuel cell batteries of simple construction.

It will be observed that a method of interconnecting cells is provided which utilizes a conducting bar to interconnect adjacent fuel cells in series fashion. This conducting bar preferably is fixedly joined to plates of opposite polarity in adjacent cells. In a preferred form, the plates overlap and the conducting bar engages the overlapped portions. By such connection a highly efficient, low-resistance path for electronic conduction between the adjacent plates of opposite polarity is provided. Moreover, the interconnecting conducting bar assists in maintaining separation of electrolyte between the adjacent cells.

It can further be seen that a conducting plenum is provided which has the dual function as a terminal bus for a fuel cell battery and as a means to convey fuel into the unit. A similar conducting plenum is provided as a means of exhausting spent fuel. Thus, external bus terminals are made available for the fuel cell battery. The connections from the cells to the conducting plenum is preferably a direct connection between plates of the proper polarity and the conducting plenums themselves. In a preferred form, at least two parallel lines of cells are utilized. The space between the parallel lines of cells defines a fuel corridor and the plenums provide means to introduce and withdraw fuel and spent fuel, respectively, from this corridor. The interconnection between the parallel lines of series cells and the plenums is made directly between the plenums and plates of proper polarity. Thus parallel electrical connection is provided be-

tween series sets of cells and the plenums serve as bus terminals for the battery.

This invention also provides in a preferred embodiment a novel electrolyte system which includes an electrolyte supply cavity and a reservoir leading to this cavity. Electrolyte supply is maintained between plates in a preferred form by capillary action of the plurality of small porous particles disposed between the plates.

It will further be observed that a highly versatile system of constructing large fuel batteries from smaller units may be provided. The structure of the individual units is relatively simple and involves a small number of parts. Note that the insulating cell supports provided in an aspect of this invention are interchangeable. Further, note that electrodes are preferably of like configuration and, thus, interchangeable. Note also that the preferred conducting bars are interchangeable.

It should also be observed that the structure of a preferred embodiment of the invention makes possible a simple but efficient sealing of electrolyte within the various individual cells. Thus sealing is accomplished without special seals. It is particularly effective in molten carbonate electrolyte systems, such as the 50%—50% molar sodium-lithium carbonate eutectic, because the high surface tension of the electrolyte cooperates in making a tight seal.

While the unit 11 first illustrated herein as a preferred embodiment of the present invention involves only a two-by-two cell arrangement, it will be understood, as from FIGURES 10 and 11 and accompanying discussion, that other configurations are quite important. For example, the two-by-ten arrangement illustrated in FIGURE 11 has more practical value for many applications than does the two-by-two unit 11, of FIGURE 1. The number of cells in series in a unit may vary from two to an arbitrarily selected large number. It will also be apparent that any order of number of parallel rows can be provided in an assembled battery.

While the fuel supply has been illustrated herein as being fed to the corridor defined between facing sets of fuel electrodes, it will be understood that under some conditions it may be preferred to supply oxidizer to the corridor, in which case the facing electrodes will be oxidizer electrodes. It should be understood that such change is clearly within the scope of this invention.

Referring now to FIGURE 15, therein is illustrated in more detail a pair of generally rectangular porous plate-like electrodes 521 and 523. These electrodes are interconnected by a plurality of regularly, vertically spaced-apart rectangular horizontal plates 525.

The specific electrodes 521 and 523 are made out of sintered silver, i.e. they are fab-

ricated by sintering small particles of silver together into the desired final shape, a technique well known in the art. As a multiplicity of different electronically conducting materials are usable, it is not intended that the material of construction of the electrodes serve as any limitation since the invention is adaptable to any effective electrode material. Examples for some applications are silver, nickel, iron, stainless steel, silver-coated stainless steel and nickel-resinated stainless steel.

The horizontal plates 525 are preferably made of the same, or a very similar, material to the electrodes. This prevents unwanted electrochemical activity resulting from the junction of two dissimilar metals. Plates 525 are porous.

The plates 525 are joined to the electrodes 521 and 523 by conventional methods, such as spot welding.

It will be noted that the structure resulting from the joinder of electrodes 521 and 523 by horizontal plates 525, as illustrated in FIGURE 15 and FIGURE 16, defines a volume of void space intermediate the parallel electrode plates 521 and 523 while at the same time providing a substantial amount of surface area contiguous to such intermediate void space. With plates 521 and 523 serving as electrodes of like polarity and at like potential in two oppositely disposed separate cells, as in a fuel cell battery made up of at least two oppositely disposed cells, the flow of fuel or oxidizer, as the case may be, can be directed between the electrodes 521 and 523 to contact a film of electrolyte from the respective cells on surface areas of the porous electrodes 521 and 523. Moreover, electrolyte will transfer from the contact areas of electrodes 521 and 523 and porous plates 525 to form a film of electrolyte on the surface areas of the porous plates 525. In such application, it is seen that the plates 525 substantially increase the electrode surface area available. Since they will be in excellent contact with fuel or oxidizer moving between electrodes 521 and 523, they function quite efficiently as secondary electrodes and they augment the effect of the "primary" electrodes 521 and 523 to a considerable extent. Thus, for a given volume, the cells will produce a higher output.

The plates 525 are preferably joined to the electrodes 521 and 523 in such a manner that relatively unobstructed communication is permitted between the pore structure of each in the vicinity of the joint. This insures that good mass transfer of electrolyte will occur from the electrodes 521 and 523 to the secondary electrode.

The secondary electrodes defined by the plates 525 not only serve an electrochemically active function, to serve as secondary electrodes augmenting the primary electrodes, but in addition serve as fluid flow directors and

distributors between the primary electrodes. The spacing is so provided that it is compatible with evenly directing the flow of reactant fluid (liquid or gas, as the case may be) by means of the several channels 527 defined between the electrodes 521 and 523 by the opposite faces of each adjacent pair of plates 525. With such a configuration, the plates 525 actually assist in properly distributing the reactant material over the surface areas of the primary and secondary electrodes, i.e., electrodes 521 and 523, and plates 525, respectively.

It will further be noted that the plates 525 provide structural support for opposed plates of like polarity in "mirror-image" arranged cells.

In fuel cell batteries based on this "mirror-image" arrangement, using secondary electrodes, it is found that a higher output per unit volume can be obtained by a considerable extent than is experienced without the use of such electrodes. Thus, a relatively high power density is made possible.

If desired, the plates 521 and 523 may be fine mesh wire screens. If it is necessary to add rigidity, this can be accomplished by forming the screens, like a picture, with thin sheets of supporting material. Moreover, plates 525 may take the form of screens. If they are framed, however, it is preferable to provide a plurality of spaced openings in the framework adjacent contact with the electrodes 521 and 523 to more effectively provide for transfer of electrolyte from the electrodes 521 and 523 to the plates 525.

FIGURES 17 and 18 illustrate rectangular plate-like electrodes 531 and 533, of the same basic nature as electrodes 521 and 523, discussed above. They have a plurality of intermediate members 535 and 537 between them. These members 535 and 537 are analogous to the plates 525. Members 535 and 537 are rectangular plates of like configuration to each other, having substantially the same length as the width of electrodes 531 and 533. Members 535 and 537 are oppositely inclined at the same angle. These members are interconnected alternately in the space between electrodes 531 and 533 substantially throughout the height of these electrodes. The ends of members 535 and 537 meet adjacent their respective end intersections with electrodes 531 and 533. As viewed from the side, the interconnected members give the appearance of a vertical zig-zag arrangement, i.e. they appear as a line of adjacent contiguous "W"s that has been rotated from the horizontal to the vertical. Note the channels 539 defined between each adjoining member 535 and 537.

Another configuration of secondary electrodes between a pair of electrodes 541 and 543 is illustrated in FIGURES 19 and 20. Therein, the regular cross section of each

secondary electrode 545 is shaped as an "X". They lie one below the other with the top-most extremities of one "X" adjoining the bottom-most extremities of the one below.

5 It will be seen, by reference to FIGURE 20, that a lattice-work of secondary electrodes is defined by the assembled structure. Note that a plurality of channels 547 in this lattice-work communicate with an adjacent electrode.

10 In FIGURES 21 and 22, a corrugated secondary electrode 549 is shown separating, but interconnecting, the electrodes 551 and 553. In cross section, the corrugated secondary electrode has the general appearance of a sine wave. This configuration has been found to be particularly suitable for fine mesh screen secondary electrodes. The corrugations add rigidity to the screen, and, moreover, such corrugated secondary screen electrodes are rather simply joined to the primary electrodes by spot welding intermittently along the intersections of the corrugations with the primary electrodes. Note the reactant flow channels 555 defined between the electrodes by the assembled structure.

The present Application has been divided from copending Application No. 1012/65 (Serial No. 1092211) as has copending Application No. 26328/67 (Serial No. 1092213). Those two copending Application also describes the fuel cell batteries described in the present Application and claim certain features of those batteries.

WHAT WE CLAIM IS:—

35 1. A fuel cell battery including an electrically conductive fuel supply plenum, an electrically conductive spent fuel exhaust plenum spaced from said fuel supply plenum, and a pair of spaced runs of fuel cells connected in parallel between the two plenums, the space between the runs defining a fuel passage, each run containing at least two fuel cells connected in series, each fuel cell including a pair of spaced porous first and second electrodes and an electrolyte disposed therebetween, the first electrode of one fuel cell in each run being electrically connected to one of the plenums and the second electrode of another fuel cell in each run being electrically connected to the other plenum, the second electrode of the said one fuel cell in each run being insulated from the said one plenum and electrically connected to the first electrode of an adjacent fuel cell, and the first electrode of the said another fuel

cell in each run being insulated from the said other plenum and electrically connected to the second electrode of an adjacent fuel cell, whereby the plenums serve as opposite polarity terminal busses for the fuel cell battery.

2. A fuel cell battery according to claim 1, including an insulating casing having an upper portion providing a top closure for the electrodes of the fuel cells and a lower portion having a pair of spaced parallel elongated channels in an upper surface thereof, the elongated channels receiving the lower edges of the electrodes of the fuel cells respectively in the runs of fuel cells, the lower portion of the casing having a plurality of cavities therein for the reception of electrolyte, which cavities extend below the lower edges of the electrodes received in the elongated channels and communicate with the channels, and the battery including means enabling the electrolyte to be drawn from the cavities and up between the pairs of electrodes of the fuel cells by capillary action.

3. A fuel cell battery according to claim 2, wherein the said means enabling said electrolyte to be drawn up between the pairs of electrodes of the fuel cells by capillary action includes a plurality of small particles of loose material forming a porous medium disposed between the pairs of electrodes of the fuel cells.

4. A fuel cell battery according to claim 3, wherein the particles are magnesium oxide.

5. A fuel cell battery according to any preceding claim, wherein each fuel cell further includes a secondary electrode adjoining at least one of the porous first and second porous electrodes thereof in effective electrolyte transfer relation from the adjoining porous electrode to the secondary electrode; the secondary electrode extending outwardly from the body of the adjoining porous electrode and substantially increasing the effective reactive surface area of that porous electrode for electrochemical reaction.

6. A fuel cell battery according to claim 1 substantially as hereinbefore described and illustrated by Figs. 1—5, or Figs. 6 and 7, or Figs. 8 and 9 or Fig. 10 or Figs. 11 and 11a of the accompanying drawings.

ABEL & IMRAY,
Chartered Patent Agents,
Quality House, Quality Court,
Chancery Lane, London, W.C.2.

secondary electrode 545 is shaped as an "X". They lie one below the other with the top-most extremities of one "X" adjoining the bottom-most extremities of the one below.

- 5 It will be seen, by reference to FIGURE 20, that a lattice-work of secondary electrodes is defined by the assembled structure. Note that a plurality of channels 547 in this lattice-work communicate with an adjacent electrode.
- 10 In FIGURES 21 and 22, a corrugated secondary electrode 549 is shown separating, but interconnecting, the electrodes 551 and 553. In cross section, the corrugated secondary electrode has the general appearance of a
- 15 sine wave. This configuration has been found to be particularly suitable for fine mesh screen secondary electrodes. The corrugations add rigidity to the screen, and, moreover, such corrugated secondary screen electrodes are
- 20 rather simply joined to the primary electrodes by spot welding intermittently along the intersections of the corrugations with the primary electrodes. Note the reactant flow channels 555 defined between the electrodes by the
- 25 assembled structure.

The present Application has been divided from copending Application No. 1012/65 (Serial No. 1092211) as has copending Application No. 26328/67 (Serial No. 1092213). Those two copending Application also describes the fuel cell batteries described in the present Application and claim certain features of those batteries.

WHAT WE CLAIM IS:—

- 35 1. A fuel cell battery including an electrically conductive fuel supply plenum, an electrically conductive spent fuel exhaust plenum spaced from said fuel supply plenum, and a pair of spaced runs of fuel cells connected in parallel between the two plenums, the space
- 40 between the runs defining a fuel passage, each run containing at least two fuel cells connected in series, each fuel cell including a pair of spaced porous first and second electrodes and an electrolyte disposed therebetween, the first
- 45 electrode of one fuel cell in each run being electrically connected to one of the plenums and the second electrode of another fuel cell in each run being electrically connected to the other plenum, the second electrode of the said
- 50 one fuel cell in each run being insulated from the said one plenum and electrically connected to the first electrode of an adjacent fuel cell, and the first electrode of the said another fuel

cell in each run being insulated from the said other plenum and electrically connected to the second electrode of an adjacent fuel cell, whereby the plenums serve as opposite polarity terminal busses for the fuel cell battery.

2. A fuel cell battery according to claim 1, including an insulating casing having an upper portion providing a top closure for the electrodes of the fuel cells and a lower portion having a pair of spaced parallel elongated channels in an upper surface thereof, the elongated channels receiving the lower edges of the electrodes of the fuel cells respectively in the runs of fuel cells, the lower portion of the casing having a plurality of cavities therein for the reception of electrolyte, which cavities extend below the lower edges of the electrodes received in the elongated channels and communicate with the channels, and the battery including means enabling the electrolyte to be drawn from the cavities and up between the pairs of electrodes of the fuel cells by capillary action.

3. A fuel cell battery according to claim 2, wherein the said means enabling said electrolyte to be drawn up between the pairs of electrodes of the fuel cells by capillary action includes a plurality of small particles of loose material forming a porous medium disposed between the pairs of electrodes of the fuel cells.

4. A fuel cell battery according to claim 3, wherein the particles are magnesium oxide.

5. A fuel cell battery according to any preceding claim, wherein each fuel cell further includes a secondary electrode adjoining at least one of the porous first and second porous electrodes thereof in effective electrolyte transfer relation from the adjoining porous electrode to the secondary electrode; the secondary electrode extending outwardly from the body of the adjoining porous electrode and substantially increasing the effective reactive surface area of that porous electrode for electrochemical reaction.

6. A fuel cell battery according to claim 1 substantially as hereinbefore described and illustrated by Figs. 1—5, or Figs. 6 and 7, or Figs. 8 and 9 or Fig. 10 or Figs. 11 and 11a of the accompanying drawings.

ABEL & IMRAY,
Chartered Patent Agents,
Quality House, Quality Court,
Chancery Lane, London, W.C.2.

