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(54) **Title:** SYSTEMS FOR AND METHODS OF PROVIDING PRIMARY, AUXILIARY OR BACKUP POWER TO ONE OR MORE LOADS

(57) **Abstract:** A fuel cell system is described for providing primary, auxiliary, or backup power to one or more loads upon or after the occurrence of a power demand or outage condition. A controller senses the power demand or outage condition, and, responsive there to, operatively engages one or more fuel cells to provide power to the one or more loads.

# SYSTEMS FOR AND METHODS OF PROVIDING PRIMARY, AUXILIARY OR BACKUP POWER TO ONE OR MORE LOADS

## 1. Field of the Invention.

This invention relates generally to uninterruptible power supplies and fuel cell systems, and more specifically, to fuel cell systems for providing primary, auxiliary or backup power to one or more loads upon, after, or during power demand conditions or outages.

## 2. Related Art.

A great deal of electronic equipment in the modern world relies upon high-quality, reliable electrical power. Such equipment, each a load, includes, for example and without limitation, telecommunications equipment, Internet servers, corporate mail servers, routers, power supplies, computers, test and industrial process control equipment, alarm and security equipment, many other types of electrical devices, equipment for which a power source is necessary or desirable to enable the equipment to function for its intended purpose, and the like, and suitable combinations of any two or more thereof. Over the past decade, as the digital age has taken hold, there has been an explosive growth in the deployment of such equipment.

For many applications of such equipment, power outages can lead to losses of data, equipment damage, missed deadlines, and/or lost productivity, and therefore must be avoided. At the same time, the reliability of the traditional power generation, transmission, and distribution network has fallen in some countries due in part to the increased demands which have been placed on this network throughout the world. The result is that uninterruptible power supplies (UPS) have emerged as a means for providing primary or backup power to such equipment in the event of a power demand condition or outage.

Traditionally, UPSs use lead-acid batteries as the energy source. Such UPSs typically provide up to about 20 minutes of power, which is usually enough time to allow users to shut down their equipment in an orderly fashion, but not enough time to allow the equipment to operate through all power demand conditions or outages. Power demand or backup times much longer than this are usually not considered feasible as the required UPSs would be too heavy and bulky.

Even if power demand or backup times much beyond 20 minutes were even feasible, another problem that often has to be addressed is the heat generated by the consumption of the power by the electrical equipment. In a typical scenario, such heat is generally dissipated into a "computer room" or "communications closet" in which the equipment is housed. Under normal conditions, such areas are typically cooled with an electrical air conditioning system. However, during a power demand condition or outage, the electrical air conditioning system servicing such areas is typically down. Moreover, backup generators located outside the building and running on diesel fuel, propane, or natural gas are often not feasible for purposes of providing backup power to the air conditioning system because they tend to be expensive, bulky, have adverse environmental impacts, and frequently do not service power demand conditions or outages that occur internal to a building and affect only parts of it.

Hydrogen fuel cells have also been proposed as the energy source for a UPS. Compared to lead/acid batteries, hydrogen fuel cells are capable of providing primary or backup power over longer time durations. However, hydrogen fuel cells are fueled with hydrogen, which is flammable, explosive, and requires high pressure to store. Consequently, the hydrogen fuel cell can be unsuitable for many office environments. For additional information on hydrogen fuel cells, the reader is referred to U.S. Patent Nos. 6,117,267; 5,980,726; 6,168,705; and 6,099,716; each of which is incorporated herein by this reference.

## SUMMARY

A fuel cell system is described for providing primary, auxiliary or backup power to one or more loads upon the occurrence of a power demand or outage condition. In one embodiment, the system comprises one or more fuel cells and a controller that, upon or after sensing the occurrence of a power demand or outage condition, operatively

engages the one or more fuel cells to provide power to the one or more loads. In one configuration, the one or more fuel cells are metal fuel cells. In one example, the one or more fuel cells are zinc fuel cells.

In one implementation, one or more of the loads powered by the one or more fuel cells upon or after the occurrence of the power outage or demand condition is a cooling unit configured to (a) cool the one or more loads and/or the one or more fuel cells, or (b) remove from the vicinity of the system heat generated by the one or more loads and/or the one or more fuel cells.

A method is also described of providing primary, auxiliary, or backup power to one or more loads upon or after the occurrence of a power outage or demand condition. In one embodiment, the method comprises, upon or after sensing the occurrence of the power outage or demand condition, operatively engaging the one or more fuel cells to provide power to the one or more loads. In one implementation, this step occurs automatically, such as by a controller. In another implementation, this step occurs manually. In one configuration, the one or more fuel cells are metal fuel cells. In one example, the one or more fuel cells are zinc fuel cells.

In one example, one or more of the loads powered by the one or more fuel cells upon or after the occurrence of the power outage or demand condition is a cooling unit configured to (a) cool the one or more loads and/or the one or more fuel cells, or (b) remove from the vicinity of the system heat generated by the one or more loads and/or the one or more fuel cells.

Other systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

## Brief Description of the Drawings

The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. 1A is a block diagram of one embodiment of a fuel cell.

FIG. 1B is a block diagram of an alternate embodiment of a fuel cell.

FIG. 2A is a block diagram of an embodiment of a fuel cell system including a controller for operatively engaging one or more fuel cells to provide power to one or more loads upon the occurrence of a power outage condition.

FIG. 2B is a block diagram of one implementation of a fuel cell system in which the cooling fluid is air.

FIG. 2C is a side view of the embodiment illustrated in FIG. 2B.

FIG. 3 is a front view of an embodiment of a fuel cell system in which the cooling fluid is air cooled by a liquid coolant provided from an open loop system.

FIG. 4 is a side view of the embodiment illustrated in FIG. 3.

FIG. 5 is a front view of an embodiment of a fuel cell system in which the cooling fluid is air cooled by a liquid coolant provided from a closed loop system.

FIG. 6A is a side view of the embodiment illustrated in FIG. 5.

FIG. 6B is a side view of an embodiment of a fuel cell system in which the cooling fluid is circulated through the fuel storage unit and/or reaction product storage unit of the fuel cell.

FIG. 7 is a block diagram of a metal fuel cell system for providing backup power to one or more loads.

FIG. 8 is one implementation of the system of FIG. 7.

FIG. 9 illustrates an embodiment of a fuel cell system for providing primary, auxiliary or backup power to one or more loads upon the occurrence of a power demand or outage condition.

FIG. 10 illustrates an embodiment of a portable fuel cell system.

FIGs. 11A-11D illustrate configurations of fuel cell system for providing primary, auxiliary or backup power to one or more loads upon the occurrence of a power demand or outage condition.

FIG. 12 is a block diagram of a fuel cell system for providing primary, auxiliary or backup power to one or more loads upon the occurrence of a power demand or outage condition.

FIG. 13 illustrates an implementation of the system of FIG. 12.

FIG. 14 illustrates an implementation example of the system of FIG. 12.

FIG. 15 is a flowchart of an embodiment of a method of providing backup power to one or more loads, including cooling means, upon the occurrence of a power outage condition.

FIG. 16 is a flowchart of an embodiment of a method of utilizing one or more metal fuel cells to provide backup power to one or more loads upon the occurrence of a power outage condition.

FIG. 17 is a flowchart of an embodiment of a method of providing primary, backup, or auxiliary power to one or more loads upon the occurrence of a power demand or outage condition.

## DETAILED DESCRIPTION

Introduction to Fuel Cells and Fuel Cell Systems

A block diagram of a fuel cell is illustrated in Figure 1A. As illustrated, the fuel cell comprises a power source 20, an optional reaction product storage unit 22, an optional regeneration unit 24, a fuel storage unit 26, and an optional second reactant storage unit 28. The power source 20 in turn comprises one or more cells each having a cell body defining a cell cavity, with an anode and cathode situated in each cell cavity. The cells can be coupled in parallel or series. In one implementation, they are coupled in series to form a cell stack.

The anodes within the cell cavities in power source 20 comprise the fuel stored in fuel storage unit 26. Within the cell cavities of power source 20, an electrochemical reaction takes place whereby the anode releases electrons, and forms one or more reaction products. Through this process, the anodes are gradually consumed.

The released electrons flow through a load to the cathode, where they react with one or more second reactants from an optional second reactant storage unit 28 or from some other source. The flow of electrons through the load gives rise to a voltage for the cells. When the cells are combined in series, the sum of the voltages for the cells forms the output of the power source.

The one or more reaction products can then be provided to optional reaction product storage unit 22 or to some other destination. The one or more reaction products, from unit 22 or some other source, can then be provided to optional regeneration unit 24, which regenerates fuel and/or one or more of the second reactants from the one or more reaction products. The regenerated fuel can then be provided to fuel storage unit 26, and/or the regenerated one or more second reactants can then be provided to optional second reactant storage unit 28 or to some other destination. As an alternative to regenerating the fuel from the reaction product using the optional regeneration unit 24, the fuel can be inserted into the system from an external source and the reaction product can be withdrawn from the system.

The optional reaction product storage unit 22 comprises a unit that can store the reaction product. Exemplary reaction product storage units include without limitation one or more tanks, one or more sponges, one or more containers, one or more vats, one or more barrels, one or more vessels, and the like, and suitable combinations of any two or more thereof. Optionally, the optional reaction product storage unit 22 is detachably attached to the system.

The optional regeneration unit 24 comprises a unit that can electrolyze the reaction product(s) back into fuel (e.g., hydrogen, metal particles and/or metal-coated particles, and the like) and/or second reactant (e.g., air, oxygen, hydrogen peroxide, other oxidizing agents, and the like, and suitable combinations of any two or more thereof). Exemplary regeneration units include without limitation water electrolyzers (which regenerate an exemplary second reactant (oxygen) and/or fuel (hydrogen) by electrolyzing water), metal (e.g., zinc) electrolyzers (which regenerate a fuel (e.g., zinc) and a second reactant (e.g., oxygen) by electrolyzing a reaction product (e.g., zinc oxide (ZnO)), and the like. Exemplary metal electrolyzers include without limitation fluidized bed electrolyzers, spouted bed electrolyzers, and the like, and suitable combinations of two or more thereof. The power source 20 can optionally function as the optional regeneration unit 24 by operating in reverse, thereby foregoing the need for a regeneration unit 24 separate from the power source 20. Optionally, the optional regeneration unit 24 is detachably attached to the system.

The fuel storage unit 26 comprises a unit that can store the fuel (e.g., for metal fuel cells, metal (or metal-coated) particles or liquid born metal (or metal-coated) particles or suitable combinations thereof; for hydrogen fuel cells, hydrogen or hydrogen containing compounds that can be reformed into a usable fuel prior to consumption). Exemplary fuel storage units include without limitation one or more tanks (for example, without limitation, a high-pressure tank for gaseous fuel (e.g., hydrogen gas), a cryogenic tank for liquid fuel which is a gas at operating temperature (e.g., room temperature) (e.g., liquid hydrogen), a metal-hydride-filled tank for holding hydrogen, a carbon-nanotube-filled tank for storing hydrogen, a plastic tank for holding potassium hydroxide (KOH) and metal (e.g., zinc (Zn), other metals, and the like) particles, and the like), one or more sponges, one or more containers (e.g., a plastic container for holding dry metal (e.g., zinc (Zn), other metals, and the like) particles, and the like), one or more vats, one or more barrels, one or more vessels, and the like, and suitable combinations of any two or more thereof. Optionally, the fuel storage unit 26 is detachably attached to the system.

The optional second reactant storage unit 28 comprises a unit that can store the second reactant. Exemplary second reactant storage units include without limitation one or more tanks (for example, without limitation, a high-pressure tank for gaseous second reactant (e.g., oxygen gas), a cryogenic tank for liquid second reactant (e.g., liquid oxygen) which is a gas at operating temperature (e.g., room temperature), a tank for a second reactant which is a liquid or solid at operating temperature (e.g., room temperature), and the like), one or more sponges, one or more containers, one or more vats, one or more barrels, one or more vessels, and the like, and suitable combinations of any two or more thereof. Optionally, the optional second reactant storage unit 28 is detachably attached to the system.

Figure. 1B is a block diagram of an alternative embodiment of a fuel cell in which, compared to Figure 1B, like elements are referenced with like identifying numerals. Dashed lines are flow paths for the re-circulating anode fluid when the optional regeneration unit is present and running. Solid lines are flow paths for the re-circulating anode fluid when the fuel cell system is running in idle or discharge mode. As illustrated, in this embodiment, when the system is operating in the discharge mode, optional regeneration unit 24 need not be in the flow path represented by the solid lines.

In one embodiment, the fuel cell is a metal fuel cell. The fuel of a metal fuel cell is a metal that can be in a form to facilitate entry into the cell cavities of the power source 20. For example, the fuel can be in the form of metal (or metal-coated) particles or liquid born metal (or metal-coated) particles or suitable combinations thereof. Exemplary metals for the metal (or metal-coated) particles include without limitation zinc, aluminum, lithium, magnesium, iron, and the like.

In this embodiment, when the fuel is optionally already present in the anode of the cell cavities in power source 20 prior to activating the fuel cell, the fuel cell is pre-charged, and can start-up significantly faster than when there is no fuel in the cell cavities and/or can run for a time in the range(s) from about 0.001 minutes to about 100 minutes without additional fuel being moved into the cell cavities. The amount of time which the fuel cell can run on a pre-charge of fuel within the cell cavities can vary with, among other factors, the pressurization of the fuel within the cell cavities, and alternative embodiments of this aspect of the invention permit such amount of time to be in the range(s) from about 1 second to about 100 minutes or more, and in the range(s) from about 30 seconds to about 100 minutes or more.

Moreover, the second reactant optionally can be present in the fuel cell and pre-pressurized to any pressure in the range(s) from about 0.01 psi gauge pressure to about 200 psi gauge pressure prior to a power outage or demand sense time after the controller sensing the power demand or outage condition to facilitate the fuel cell's start-up in a timeframe significantly faster than when there is no second reactant present and no pre-pressurization in the fuel cell prior to the optional controller sensing the power demand or outage condition. Optionally, the one or more second reactants are present in the power source 20 at a time prior to an outage sense time, which outage sense time is in the range(s) from about 10 microseconds to about 10 seconds after the controller has sensed the power outage or demand condition. Optionally, this time is also after the controller has sensed the power outage or demand condition.

Moreover, in this embodiment, one optional aspect provides that the volumes of one or both of the fuel storage unit 26 and the optional second reactant storage unit 28 can be independently changed as required to independently vary the energy of the system from its power, in view of the requirements of the system. Suitable such volumes can be calculated by utilizing, among other factors, the energy density of the system, the energy requirements of the one or more loads of the system, and the time requirements for the one or more loads of the system. In one embodiment, these volumes can vary in the range(s) from about 0.001 liters to about 1,000,000 liters.

In one aspect of this embodiment, at least one of, and optionally all of, the metal fuel cell(s) is a zinc fuel cell in which the fuel is in the form of fluid borne zinc particles immersed in a potassium hydroxide (KOH) electrolytic reaction solution, and the anodes within the cell cavities are particulate anodes formed of the zinc particles. In this embodiment, the reaction products can be the zincate ion, $Zn(OH)_4^{2-}$, or zinc oxide, ZnO, and the one or more second reactants can be an oxidant (for example, oxygen (taken alone, or in any organic or aqueous (e.g., water-containing) fluid (for example and without limitation, liquid or gas (e.g., air)), hydrogen peroxide, and the like, and suitable combinations of any two or more thereof). When the second reactant is oxygen, the oxygen can be provided from the ambient air (in which case the optional second reactant storage unit 28 can be excluded), or from the second reactant storage unit 28. Similarly, when the second reactant is oxygen in water, the water can be provided from the second reactant storage unit 28, or from some other source, e.g., tap water (in which case the optional second reactant storage unit 28 can be excluded).

In this embodiment, the particulate anodes are gradually consumed through electrochemical dissolution. In order to replenish the anodes, to deliver KOH to the anodes, and to facilitate ion exchange between the anodes and cathodes, a re-circulating flow of the fuel borne zinc particles can be maintained through the cell cavities. This flow can be maintained through one or more pumps (not shown) or through some other means. As the potassium hydroxide contacts the zinc anodes, the following reaction takes place at the anodes:

$$Zn + 4OH^- \rightarrow Zn(OH)_4^{2-} + 2e^- \qquad (1)$$

The two released electrons flow through a load to the cathode where the following reaction takes place:

$$\frac{1}{2}O_2 + 2e^- + H_2O \rightarrow 2OH^- \qquad (2)$$

The reaction product is the zincate ion, $Zn(OH)_4^{2-}$, which is soluble in the reaction solution KOH. The overall reaction which occurs in the cell cavities is the combination of the two reactions (1) and (2). This combined reaction can be expressed as follows:

$$Zn + 2OH^- + \frac{1}{2}O_2 + H_2O \rightarrow Zn(OH)_4^{2-} \qquad (3)$$

Alternatively, the zincate ion, $Zn(OH)_4^{2-}$, can be allowed to precipitate to zinc oxide, ZnO, a second reaction product, in accordance with the following reaction:

$$Zn(OH)_4^{2-} \rightarrow ZnO + H_2O + 2OH^- \qquad (4)$$

In this case, the overall reaction which occurs in the cell cavities is the combination of the three reactions (1), (2), and (4). This overall reaction can be expressed as follows:

$$Zn + \frac{1}{2}O_2 \rightarrow ZnO \qquad (5)$$

Under real world conditions, the reactions (4) or (5) yield an open-circuit voltage potential of about 1.4V. For additional information on this embodiment of a zinc/air battery, the reader is referred to U.S. Patent Nos. 5,952,117; 6,153,329; and 6,162,555, which are hereby incorporated by reference herein as though set forth in full.

The reaction product $Zn(OH)_4^{2-}$, and also possibly ZnO, can be provided to reaction product storage unit 22. Optional regeneration unit 24 can then reprocess these reaction products to yield oxygen, which can be released to the ambient air or stored in second reactant storage unit 28, and zinc particles, which are provided to fuel storage unit 26. In addition, the optional regeneration unit 24 can yield water, which can be discharged through a drain or stored in second reactant storage unit 28. It can also regenerate hydroxide, $OH^-$, which can be discharged or combined with potassium to yield the potassium hydroxide reaction solution.

The regeneration of the zincate ion, $Zn(OH)_4^{2-}$, into zinc, and one or more second reactants can occur according to the following overall reaction:

$$Zn(OH)_4^{2-} \rightarrow Zn + 2OH^- + H_2O + \frac{1}{2}O_2 \qquad (6)$$

The regeneration of zinc oxide, ZnO, into zinc, and one or more second reactants can occur according to the following overall reaction:

$$ZnO \rightarrow Zn + \frac{1}{2}O_2 \qquad (7)$$

It should be appreciated that embodiments of metal fuel cells other than zinc fuel cells or the particular form of zinc fuel cell described above are possible. For example, aluminum fuel cells, lithium fuel cells, magnesium fuel cells, iron fuel cells, and the like are possible, as are metal fuel cells where the fuel is not in particulate form but in another form such as sheets or ribbons or strings or slabs or plates. Embodiments are also possible in which the fuel is not fluid borne or continuously re-circulated through the cell cavities (e.g., porous plates of fuel, ribbons of fuel being cycled past a reaction zone, and the like). It is also possible to avoid an electrolytic reaction solution altogether or at least employ reaction solutions besides potassium hydroxide, for example, without limitation, sodium hydroxide, inorganic alkalis, alkali or alkaline earth metal hydroxides. See, for example, U.S. Patent No. 5,958,210, the entire contents of which are incorporated herein by this reference. It is also possible to employ metal fuel cells that output AC power rather than DC power using an inverter, a voltage converter, and the like.

In a second embodiment of a fuel cell, the fuel used in the electrochemical reaction that occurs within the cells is hydrogen, the second reactant is oxygen, and the reaction product is water. In one aspect, the hydrogen fuel is maintained in the fuel storage unit 26, but the second reactant storage unit 28 can be omitted and the oxygen used in the electrochemical reaction within the cells can be taken from the ambient air. In another aspect, the hydrogen fuel is maintained in the fuel storage unit 26, and the oxygen is maintained in the second reactant storage unit 28. In addition, the optional reaction product storage unit 22 can be included or omitted, and the water resulting from discharge of the unit simply discarded or stored in the reaction product storage unit 22 (if present), respectively. Later, the optional regeneration unit 24 can regenerate water from another source, such as tap water, or from the reaction product storage unit 22 (if present) into hydrogen and oxygen. The hydrogen can then be stored in fuel storage unit 22, and the oxygen simply released into the ambient air or maintained in the second reactant storage unit 28.

An advantage of fuel cells relative to traditional power sources such as lead acid batteries is that they can provide longer term primary, auxiliary or backup power more efficiently and compactly. This advantage stems from the ability to continuously refuel the fuel cells using fuel stored with the fuel cell, from some other source, and/or regenerated from reaction products by the optional regeneration unit 24. In the case of the zinc fuel cell, for example, the duration of time over which energy can be provided is limited only by the amount of fuel which is initially provided in the fuel storage unit, which is fed into the system during replacement of a fuel storage unit 26, and/or which can be regenerated from the reaction products that are produced. Thus, the system, comprising at least one fuel cell including an optional regeneration unit 24 and/or a replaceable fuel storage unit 26, can provide backup power to the one or more loads for a time in the range(s) from about 0.01 hours to about 10000 hours, or even more. In one aspect of this embodiment, the system can provide back-up power to the one or more loads for a time in the range(s) from about 0.5 hours to about 650 hours, or even more.

Moreover, the fuel cell system in accordance optionally can be configured to expel substantially no reaction product(s) outside of the system (e.g., into the environment).

Embodiments of Systems According to the Invention

Figure 2A illustrates an embodiment of a fuel cell system according to the invention in which one or more fuel cells 30 provide backup power to one or more loads 38 upon the occurrence of a power outage condition, i.e., a disruption or discontinuance of primary power to the one or more loads from a primary power source. An optional controller 34, upon sensing the occurrence of a power outage condition, operatively engages the one or more fuel cells 30 to provide power (i.e., backup power) to the one or more loads 38. When there is a resumption of primary power to the one or more loads 38, the controller 34 senses this condition, and disengages the one or more fuel cells 30 from powering the one or more loads 38. Optionally the controller 34 sensing the resumption of delivery of primary power to the one or more loads 38 then engages the primary power 32 to provide power to the one or more regeneration units (if present) in the one or more fuel cells 30 so as to regenerate the reaction products stored in the fuel cells 30 back into fuel for reuse. Further, the controller 34 optionally can be configured to engage flow of the one or more second reactants into the power source responsive to sensing the outage of primary power to the one or more loads 38. Suitable controllers include without limitation human operator(s), mechanical sensing device(s), computer-operated sensing device(s), robotic sensing device(s), electrical sensing device(s), solid state electronic switch(es), electromechanical switch(es), and the like, and suitable combinations of any two or more thereof, including software and hardware combinations.

An optional power conversion unit 36 can also be provided as a component of the system, depending on the nature and characteristics of the one or more loads 38, and the one or more fuel cells 30. The optional power conversion unit 36 comprises a unit that can convert power from one form (e.g., direct current, or DC, form; alternating current, or AC, form; and the like) to another form. Exemplary power conversion units include one or more voltage converter(s), one or more inverter(s), one or more DC to DC converter(s), and the like, and suitable combinations of any two or more thereof. The optional power conversion unit 36 functions to convert the power output from the fuel cell 30 to another form or, optionally, in the case of supply of power from the primary source 32 to the optional regeneration unit, power from the primary source 32 to another form for regeneration purposes. In one embodiment, the optional power conversion unit 36 operates to convert the DC power provided by the one or more fuel cells 30 to AC power. In another embodiment, the optional power conversion unit 36 operates to convert the DC power provided by the one or more fuel cells to another form of DC power.

The fuel cell system further comprises a cooling unit (not shown) that is powered by the one or more fuel cells upon the occurrence of a power outage condition. This cooling unit is configured to cool the one or more other loads and/or the one or more fuel cells, and/or remove from the vicinity of the system heat generated by the one or more loads (including without limitation the cooling unit) and/or the one or more fuel cells, optionally via utilization of one or more cooling fluids. Exemplary cooling units include without limitation heat exchangers, fans, absorption chillers, phase-change coolers, air conditioners, heat sinks, other passive and active units that function to remove heat, means for cooling loads, and the like, and suitable combinations of any two or more thereof. Cooling fluids include without limitation gases, liquids, and suitable combinations thereof that can absorb and release heat, as required, under suitable operating conditions to assist in the operation of the cooling unit to remove from the vicinity of the system heat generated by the one or more loads (including without limitation the cooling unit) and/or the one or more fuel cells.

In one implementation, the system further optionally comprises means for physically supporting the one or more fuel cells, and at least one of the one or more loads. Optionally, the means for supporting can be configured to support one or more of the remaining components of the system, including without limitation the remainder of the one or more loads, the optional controller, and/or the optional power conversion stage. Such means for supporting include, without limitation, one or more rack(s), one or more shelf(ves), one or more stands, one or more tables, one or more apparatus that can support one or more components of the system of the invention, and the like, and suitable combinations of any two or more thereof.

In another implementation, the system further optionally comprises means for routing a cooling fluid, whether gas, liquid, or both gas and liquid, past the one or more fuel cells and/or the one or more loads. Such means for routing include, without limitation, one or more conduits, one or more pipes, one or more pumps, one or more exhaust vents, one or more reservoirs, one or more storage tanks, one or more ducts, one or more plenums, one or more openings, one or more channels, one or more tubes, and the like, and suitable combinations of any two or more thereof.

Each of these two means, as well as each of the other components of the system, can be separate from, or integral with, one or more of the other components of the system.

A front view of a second embodiment of a system according to the invention is illustrated in Figure 2B. The system comprises one or more fuel cells 2 that are configured to provide backup power to one or more loads 4a, 4b, 4c, 4d in the event of a power outage condition.

A cooling unit 6 is powered by the one or more fuel cells 2 upon the occurrence of a power outage condition. The cooling unit 6 in this embodiment is a fan or other suitable means which intakes cooling fluid (e.g., cool air), identified in Figure 2B with numerals 8a and 8b, and blows it past the one or more fuel cells 2 and the one or more loads 4a, 4b, 4c, 4d. The cooling fluid (e.g., cool air) blows past these devices and cools them in the process. The resulting exhausted cooling fluid (e.g., warm exhaust air), identified with numeral 10, exits the system through an exhaust hose 16. In an alternative embodiment, the cooling unit 6 can draw cooling fluid (e.g., cool air) from outside of the enclosed space occupied by the fuel cells 2 and the one or more loads 4a, 4b, 4c, 4d (e.g., through an open door, vent, other exit or the like), through at least part of the system past these devices, and back to the outside of the enclosed space (e.g., through an open door, vent, other exit or the like).

In one implementation, the one or more fuel cells 2 and at least one of the one or more loads 4a, 4b, 4c, and 4d, and optionally the remainder of the one or more loads 4a, 4b, 4c, and 4d and the cooling unit 6, can be physically supported by a suitable means for physically supporting such components. In this implementation, the illustrated means is a rack, identified in the figure with numeral 18. In this implementation, the system can be located in a room, and the cooling means 6 can be configured to draw the cooling fluid (e.g., cool air) 8a and 8b from the room into the system through intake 19. The exhaust hose 16 in this implementation can extend through a ceiling or plenum 12 so that the resulting exhausted cooling fluid (e.g., warm exhaust air) 10 is allowed to exit the room.

A side view of this embodiment is illustration in Figure 2C. As illustrated, cooling fluid (e.g., cool air) 8a, 8b is drawn into the system through intake 19. Some of this cooling fluid (e.g., cool air) is directed upwards past the one or more loads 4a, 4b, 4c, 4d. The resulting exhausted cooling fluid (e.g., warm exhaust air) from the one or more loads 4a, 4b, 4c, 4d, identified with numerals 10a(1), 10a(2), and 10a(3), exits the system and room through portion 16a of the exhaust hose. The remaining portion of the incoming cooling fluid (e.g., cool air) is directed past the one or more fuel cells 2. The resulting exhausted cooling fluid (e.g., warm exhaust air) from the one or more loads 4a, 4b, 4c, 4d, identified with numerals 10b(1), 10b(2), and 10b(3), is directed into chamber 17, whereupon it is directed upwards, and exits the system and room through portion 16b of the exhaust hose.

A front view of another embodiment of a system according to the invention is illustrated in Figure 3. A side view is illustrated in Figure 4. In this embodiment, a first cooling fluid (e.g., cool air) 8a, 8b is again drawn into the system through intake 19 by means of a cooling unit (e.g., fan 6 or other equivalent means). The first cooling fluid (e.g., cool air) is directed past the one or more fuel cells 2. The resulting exhausted first cooling fluid (e.g., warm exhaust air) is then directed past a second cooling unit (e.g., heat exchanger 306). A second cooling fluid (e.g., liquid coolant) from a source (not shown) external to the system is pumped by means of pump 300 through conduit 304, and then through the second cooling unit (e.g., heat exchanger 306). The second cooling fluid (e.g., liquid coolant) is then directed from the second cooling unit (e.g., heat exchanger 306) through conduit 302 to a destination (not shown) external to the system. This process cools the exhausted first cooling fluid (e.g., warm exhaust air) as it passes through second cooling unit (e.g., heat exchanger 306). The regenerated first cooling fluid (e.g., cooled air), which is identified in the figure with numerals 310a, 310b, 310c, and 310d, is then directed past the one or more loads 4a, 4b, 4c, 4d. This process cools the loads and again results in exhausted first cooling fluid (e.g., warm exhaust air), which is directed out of the system through exhaust tube 16.

In one implementation of this embodiment, a means 18 for physically supporting the loads 4a, 4b, 4c, 4d, the one or more fuel cells 2, and the cooling unit 6 is also provided. In one example, this physical support means is a rack, but it should be appreciated that other examples are possible.

Also, the exhaust tube 16 can pass through a ceiling or plenum 12 of the room in which the system is present so that the exhausted first cooling fluid (e.g., warm exhaust air) 310a, 310b, 310c, 310d is directed out of the room.

In this embodiment, the system for passing the second cooling fluid (e.g., liquid coolant) through the second cooling unit (e.g., heat exchanger 306) can be open loop, meaning that the external source from which the second cooling fluid (e.g., liquid coolant) is derived can be different from the destination of the second cooling fluid (e.g., liquid coolant). For example and without limitation, the second cooling fluid (e.g., liquid coolant) can be tap water from a faucet or the like, and the destination for the second cooling fluid (e.g., liquid coolant, such as tap water from a faucet or the like), after it has passed through the second cooling unit (e.g., heat exchanger 306), can be a drain.

A front view of yet another embodiment of a system according to the invention is illustrated in Figure 5. A side view of this embodiment is illustrated in Figure 6A. This embodiment is similar to the previous embodiment, except that the system for passing second cooling fluid (e.g., liquid coolant) through second cooling unit (e.g., heat exchanger 306) is a closed loop system where the source and destination of the second cooling fluid (e.g., liquid coolant) is reservoir or storage tank 500. In one example, the liquid coolant is water. In another example, it is ethylene glycol.

A further embodiment of a system according to the invention is illustrated in Figure 6B. This embodiment is similar to the previous two embodiments, except that in this system, the second cooling fluid (e.g., gaseous or liquid coolant) is circulated through a tube 308 routed through the fuel storage unit 26 and/or the reaction product unit 28 so as to remove heat from the reaction product(s), the fuel, and/or the fluid carrying the fuel (e.g., the electrolyte in the case of a zinc fuel cell). The second cooling fluid (e.g., gaseous or liquid coolant) is then discarded or passed to a second cooling unit (e.g., heat exchanger 306) or reservoir external to the system.

Figure 7 illustrates an embodiment 700 of a system according to the invention which comprises one or more metal fuel cells 701 for providing backup power to one or more loads 706 upon the occurrence of a power outage condition, defined to include a disruption or discontinuation in the delivery of primary power (i.e., power from the primary source 708) to one or more loads 706. A further component comprising the system, a controller 702, senses the power outage condition and, responsive thereto, operatively engages the one or more metal fuel cells 701 to provide power (i.e., backup power) to the one or more loads 706. When there is a resumption of primary power to the one or more loads 706, the controller 702 optionally can be configured to sense this condition, and disengages the one or more fuel cells 701 from powering the one or more loads 706. Optionally the controller 202 sensing the resumption of delivery of primary power to the one or more loads 706 then engages the primary power to provide power to the one or more regeneration units in the one or more fuel cells 701 so as to regenerate the reaction products stored in the fuel cells 701 back into fuel for reuse. Further, the controller 702 optionally can be configured to engage flow of the one or more second reactants into the power source 702 responsive to sensing the outage of primary power to the one or more loads 706.

An optional power conversion unit 704 can also be provided as a component of the system, depending on the nature and characteristics of the one or more loads 706, and the one or more metal fuel cells 701. The optional power conversion unit 704 comprises a unit that can convert power from one form (e.g., direct current, or DC, form; alternating current, or AC, form; and the like) to another form. Exemplary power conversion units 704 include one or more voltage converter(s), one or more inverter(s), one or more DC to DC converter(s), and the like, and suitable combinations of any two or more thereof. The optional power conversion unit 704 functions to convert the power output from the fuel cell to another form or, optionally, in the case of supply of power from the primary source to the regeneration unit, power from the primary source to another form for regeneration purposes. In one embodiment, the optional power conversion unit 704 operates to convert the DC power provided by the one or more fuel cells 701 to AC power. In another embodiment, the optional power conversion unit 704 operates to convert the DC power provided by the one or more fuel cells 701 to another form of DC power.

Referring to Figure 8, an implementation 800 of a system according to the invention includes a means 802, as described above, for physically supporting the one or more fuel cells 701, optionally the controller 702, optionally the optional power conversion unit 704, and at least one of the one or more loads 706a, 706b, optionally in an integral fashion. Alternatively, the fuel cells 701, controller 702, and the optional power conversion unit 704 can be packaged together within a means for physically supporting them, optionally in an integral fashion, and mounted separately from the loads 706a and 706b. Such means for supporting include, without limitation, one or more rack(s), one or more shelf(ves), one or more stands, one or more tables, one or more apparatus that can support one or more components of the system of the invention, and the like, and suitable combinations of any two or more thereof.

In yet another embodiment of a system according to the invention, a metal fuel cell system provides backup power to one or more loads (including without limitation a cooling unit) upon the occurrence of a power outage or demand condition. Such a system is characterized in that it has one, or any suitable combination of two or more, of the following properties: the system optionally can be configured to not utilize or produce significant quantities of flammable fuel or product, respectively; the system can provide backup power to the one or more loads for an amount of time limited only by the amount of fuel present (e.g., in the range(s) from about 0.01 hours to about 10,000 hours or more, and in the range(s) from about 0.5 hours to about 650 hours, or more); the system optionally can be configured to have an energy density in the range(s) from about 35 Watt-hours per kilogram of combined fuel and electrolyte added to about 400 Watt-hours per kilogram of combined fuel and electrolyte added; the system optionally can further comprise an energy requirement and can be configured such that the combined volume of fuel and electrolyte added to the system is in the range(s) from about 0.0028 L per Watt-hour of the system's energy requirement to about 0.025 L per Watt-hour of the system's energy requirement, and this energy requirement can be calculated in view of, among other factors, the energy requirement(s) of the one or more load(s) comprising the system (In one embodiment, the energy requirement of the system can be in the range(s) from 50 Watt-hours to about 500,000 Watt-hours, whereas in another embodiment, the energy requirement of the system can be in the range(s) from 5 Watt-hours to about 50,000,000 Watt-hours); the system optionally can be configured to have a fuel storage unit that can store fuel at an internal pressure in the range(s) from about – 5 pounds per square inch (psi) gauge pressure to about 200 psi gauge pressure.

Figure 9 illustrates an embodiment of a power generation system for providing backup, auxiliary or primary power to one or more loads upon the occurrence of a power outage or demand condition. The system comprises one or more stacks 902 of zinc fuel cells, a battery 906, a zinc fuel tank 908, a heat exchanger 910, one or more pumps 912, a zinc regenerator 914, optional power conversion module 916, battery 906, and front panel electronics 918. An optional larger fuel tank 904 may also be provided. In one example, the one or more stacks 902 comprises two stacks, each comprising 12 zinc fuel cells. In one implementation, the system is configured to be rack-mounted.

The DC power output of the one or more stacks is input to power conversion module 916. Optional power conversion module 916 provides DC-DC conversion or DC-AC conversion to the output of the one or more stacks 902. The output of the power conversion module 916 forms the power output of the system.

Fuel for the one or more stacks is provided by tank 908 or tank 904. Heat exchanger 910 dissipates heat generated by the one or more stacks 902. One of the pumps 912 pumps KOH electrolyte containing zinc pellets from tank 904 or 908 to heat exchanger 910. Also, one of the pumps 912 pumps KOH electrolyte containing zincate or zinc oxide reaction product to regenerator 914. Regenerator 914 regenerates zinc fuel from this material, and provides it to either tank 908 or tank 904 as the case may be. Battery 906 powers the one or more pumps 912, the zinc regenerator 914, and the optional power conversion module 916.

Figure 10 illustrates an embodiment of a portable power generation system based on fuel cells which is configured to provide primary, auxiliary, or backup power to one or more loads upon or after the occurrence of a power outage or demand condition. In one application, the system includes one or more stacks of zinc fuel cells to produce 1-2 kW of output power. In one example, the system includes two stacks of 20 fuel cells each coupled in series. In this example, the system also includes a power converter to provide 120 VAC power from the 22 VDC output of the fuel cell. This system may be used to provide backup, auxiliary or primary power in emergency situations, or in field environments.

Figure 11A is a flow diagram of one embodiment of a power generation system which produces 1-2 kW of output power, and which may be used to provide backup, auxiliary or primary power a variety of loads, such as computers, peripheral equipment, and telecommunications equipment, including base stations. The power output of the system is provided by one or more stacks 1102 of zinc fuel cells. Optionally, a power conversion unit (not shown) provides DC-DC conversion, or DC-AC inversion, of the output of the one or more stacks 1102. Fluid-borne fuel in the form of zinc pellets immersed in KOH solution is maintained in refillable tank 1104. The fuel is provided to the individual cells of the one or more stacks 1102 through pump 1106. A heat exchange pump 1108 circulates the fluid-borne fuel through heat exchanger 1110 to dissipate heat. Blower 1112 blows air past the one or more stacks 1102 to provide additional cooling. The air blown past the one or more stacks 1102 forms an air exhaust 1114 which exits the system. In this particular embodiment, a zinc regeneration unit is avoided.

Figure 11B is an electrical diagram of the embodiment of Figure 11A. In this particular embodiment, one or more stacks 1102 comprises two cell stacks 1102a and 1102b coupled in series. In one example, each of the stacks 1102a, 1102b comprises 20 fuel cells. Also, a power converter 1118 is explicitly shown. This device may function as a DC-DC converter, or a DC-AC inverter depending on the application. The heat exchange pump 1108, discharge pump 1108, blower 1112, and power converter 1116 are all powered by auxiliary power device 1118 in this embodiment.

Figure 11C is a flow diagram of a second embodiment of a power generation system for providing backup or primary power to one or more loads. In this particular embodiment, the power output of the system is provided by one or more stacks 1120 of zinc fuel cells. Optionally, a power conversion unit (not shown) provides DC-DC conversion, or DC-AC inversion, of the output of the one or more stacks 1120. Fluid-borne fuel in the form a zinc pellets immersed in KOH solution is maintained in refillable tank 1122. The fuel is provided to the individual cells of the one or more stacks 1120 through pump 1124. A heat exchange pump 1128 circulates the fluid-borne fuel through heat exchanger 1130 to dissipate heat. Blower 1134 blows air past the one or more stacks 1120 to provide additional cooling. The air blown past the one or more stacks 1120 forms an air exhaust 1136 which exits the system. Regeneration unit 1126 receives spent KOH electrolyte from the cells of the one or more stacks 1120, i.e., KOH electrolyte containing zincate and/or zinc oxide reaction products, by means of regeneration pump 1132. The regeneration unit 1126 regenerates zinc fuel from this material, and provides the same to tank 1122. In one example, the zinc fuel is provided to the tank 1122 in the from of fluid borne zinc pellets, i.e., zinc pellets immersed in fresh or regenerated KOH electrolyte.

Figure 11D is an electrical diagram of the embodiment of Figure 11C. In this particular embodiment, one or more stacks 1120 comprises two cell stacks 1120a and 1120b coupled in series. In one example, each of the stacks 1120a, 1120b comprises 20 fuel cells. Also, a power converter 1138 is explicitly shown. This device may function as a DC-DC converter, or a DC-AC inverter depending on the application. The heat exchange pump 1128, blower 1134, and power converter 1138, are all powered by auxiliary power device 1140 in this embodiment. Moreover, regeneration pump 1132 is powered by AC input 1144. In one example, the system is configured to provide 6kWh, 100A discharge and 30-hour recharge cycles.

Referring to Figure 12, an embodiment 1200 of a system according to the invention comprises one or more fuel cells 1201 for providing primary and/or auxiliary/backup power to one or more loads 1206 selected from the group comprising: lawn & garden equipment; radios; telephone; targeting equipment; battery rechargers; laptops; communications devices; sensors; night vision equipment; camping equipment (including without limitation, stoves, lanterns, lights, and the like); lights; vehicles (including without limitation, cars, recreational vehicles, trucks, boats, ferries, motorcycles, motorized scooters, forklifts, golf carts, lawnmowers, industrial carts, passenger carts (airport), luggage handling equipment (airports), airplanes, lighter than air crafts (e.g., blimps, dirigibles, and the like), hovercrafts, trains (e.g., locomotives, and the like), and submarines (manned and unmanned); torpedoes; security systems; electrical energy storage devices for renewable energy sources (e.g., solar-based, tidal-based, hydro-based, wind-based, and the like); many other types of electrical devices, equipment for which a primary and/or backup power source is necessary or desirable to enable the equipment to function for its intended purpose, military-usable variants of above, and the like; and suitable combinations of any two or more thereof.

The system can provide primary power to the one or more load(s) upon sensing a demand for power from such load(s), and can provide primary and/or auxiliary/backup power to the one or more loads upon the occurrence of a power outage condition, defined to include a disruption or discontinuation in the delivery of system-external primary power (i.e., power from the primary source 1208 external to the system) to one or more loads 1206. A further component comprising the system, a controller 1202, senses the power demand condition and/or the power outage condition, as applicable, and, responsive thereto, operatively engages the one or more fuel cells 1201 to provide power (i.e., primary or auxiliary/backup power, as applicable) to the one or more loads 1206. When there is a cessation of demand for primary power by, and/or a resumption of primary power to, the one or more loads 1206, the controller 1202 optionally can be configured to sense either or both of these conditions, and disengage the one or more fuel cells 1201 from powering the one or more loads 1206. Optionally the controller 1202 sensing the resumption of delivery of primary power to the one or more loads 1206 then engages the primary power to provide power to the one or more regeneration units in the one or more fuel cells 1201 so as to regenerate the reaction products stored in the fuel cells 1201 back into fuel for reuse. Further, the controller 1202 optionally can be configured to engage flow of the one or more second reactants into the one or more fuel cells 1201 responsive to sensing the demand of primary power from, or the outage of system-external primary power to, the one or more loads 1206. Suitable controllers include without limitation human operator(s), mechanical sensing device(s), computer-operated sensing device(s), robotic sensing device(s), electrical sensing device(s), solid state electronic switch(es), electromechanical switch(es), and the like, and suitable combinations of any two or more thereof, including hardware and software conditions.

An optional power conversion unit 1204 can also be provided as a component of the system, depending on the nature and characteristics of the one or more loads 1206, and the one or more fuel cells 1201. The optional power conversion unit 1204 comprises a unit that can convert power from one form (e.g., direct current, or DC, form; alternating current, or AC, form; and the like) to another form. Exemplary power conversion units 1204 include one or more voltage converter(s), one or more inverter(s), one or more DC to DC converter(s), and the like, and suitable combinations of any two or more thereof. The optional power conversion unit 1204 functions to convert the power output from the fuel cell to another form or, optionally, in the case of supply of power from the primary source to the regeneration unit, power from the primary source to another form for regeneration purposes. In one embodiment, the optional power conversion unit 1204 operates to convert the DC power provided by the one or more fuel cells 1201 to AC power. In another embodiment, the optional power conversion unit 1204 operates to convert the DC power provided by the one or more fuel cells 1201 to another form of DC power.

Referring to Figure 13, an implementation 1300 of the system of Figure 12 includes a means 1302, as described above, for physically supporting the one or more fuel cells 1201, optionally the controller 1202, optionally the optional power conversion unit 1204, and at least one of the one or more loads 1206a, 1206b, optionally in an integral fashion. Alternatively, the fuel cells 1201, controller 1202, and the optional power conversion unit 1204 can be packaged together within a means for physically supporting them, optionally in an integral fashion, and mounted separately from the loads 1206a and 1206b. Such means for supporting include, without limitation, one or more rack(s), one or more shelf(ves), one or more stands, one or more tables, one or more apparatus that can support one or more components of the system of the invention, and the like, and suitable combinations of any two or more thereof.

## EXAMPLES

Example 1 – Fuel Cell System For Powering a Lawnmower

An exemplary fuel cell system suitable for use in powering a lawnmower can comprise two fuel cell stacks, a tank for zinc fuel and electrolyte, a pump for circulating zinc fuel pellets and KOH electrolyte between the fuel cell stacks and the zinc/electrolyte tank, an air blower for each cell stack, a heat exchanger for each cell stack, and electronics for electrical current control.

Each fuel cell stack can comprise twenty cells connected electrically in series, where fuel and electrolyte can be continuously recirculated through the pump, the cell stacks and the electrolyte tank. The maximum combined output power of an exemplary set of such stacks can be about 5.3 kW. Zinc fuel pellets and KOH electrolyte can be stored in the electrolyte tank that is mounted under the fuel cell stacks. The tank capacity of an illustrative electrolyte tank can be about 45 litres and can contain sufficient zinc to produce about 7 kWh of electricity.

Atmospheric air under low pressure from about 0.1 to 10 atmospheres can be fed into each cell of the cell stacks from the air blower, while oxygen depleted air can be evacuated back into the atmosphere. When the fuel cell has achieved an exemplary optimum operating temperature (e.g., about 55 C), another pump can circulate the electrolyte from the tank through an air cooled heat exchangers.

The electronics systems can be used to initially draw power from a lead-acid battery to provide initial power for the electrolyte circulation pump. After a few seconds the power from the auxiliary lead acid battery can be switched off and all power for the pumps and air blowers can be provided by the zinc air fuel cell.

The electrical energy that can be generated by the fuel cell can be fed into a voltage booster device the output of which provides electrical current at constant voltage. This electrical energy can be then in turn fed to the electric motors and circuits that operate the lawnmower.

Example 2 – Fuel Cell System For Powering a Personal Power Source

An exemplary fuel cell system suitable for use in powering a personal power source (e.g., a power source suitable for powering a variety of loads can comprise a fuel stack, a tank for zinc fuel and electrolyte, a pump for circulating zinc fuel pellets and KOH electrolyte between the fuel cell stacks and the electrolyte tank, an air blower, a heat exchanger, and electronics for electrical current control.

Each fuel cell stack can comprise twenty cells connected electrically in series, where fuel and electrolyte can be continuously recirculated through the pump, the cell stacks and the electrolyte tank. The maximum combined output power of an exemplary set of such stacks can be about 2.6 kW. Zinc fuel pellets and KOH electrolyte can be stored in the electrolyte tank that is mounted under the fuel cell stacks. The tank capacity of an illustrative electrolyte tank can be about 5.5 litres and can contain sufficient zinc to produce about 1.0 kWh of electricity.

Atmospheric air under low pressure from about 0.1 to about 10 atmospheres can be fed into each cell of the cell stacks from the air blower, while oxygen depleted air can be evacuated back into the atmosphere. When the fuel cell has achieved an exemplary optimum operating temperature (e.g., 55 C), another pump can circulate the electrolyte from the tank through an air cooled heat exchangers.

The electronics systems can be used to initially draw power from a lead-acid battery to provide initial power for the electrolyte circulation pump. After a few seconds the power from the auxiliary lead acid battery can be switched off and all power for the pumps and air blowers can be provided by the zinc air fuel cell.

The electrical energy that can be generated by the fuel cell can be fed into a voltage booster device the output of which provides electrical current at constant voltage. This electrical energy can be then in turn fed to the electric motors and circuits that operate the lawnmower.

Example 3 – Zinc/Air Fuel Cell System

With reference to Figure 14, zinc pellets and KOH electrolyte can be contained within the fuel tank (electrolyte + zinc) 1402. These particles can be initially at rest until such time as they are picked up in the stream of flowing KOH electrolyte, Q1, identified with numeral 1404. The stream of KOH electrolyte and zinc pellets can be sucked from the tank and into the fuel delivery pump 1406. From the fuel delivery pump 1406, the stream can enter a pipe that directs them toward the fuel cell stack 1408 through flow path 1407. On entering the fuel cell stack 1408, the electrolyte and pellets flow stream can first encounter a flow distribution manifold that can distribute electrolyte and zinc pellets substantially uniformly to each of the plurality of individual cells. Some zinc pellets can drop into the fuel cell anode cavity (not illustrated) and remain there until they dissolve and some pellets remain in the flow stream and exit the cell via a flow path Q3, which is identified with numeral 1210. The flow can be returned to the electrolyte tank via the flow path Q3. Although some zinc pellets that fall into the fuel cell anode cavity can be completely dissolved, a few of the pellets can be only partially dissolved; because of their small size, these partially dissolved pellets can exit the anode cavity and enter the flow stream from the cell and pass back to the electrolyte tank, via flow path Q2 (not shown in Figure 14, but in parallel with flow path Q3).

Atmospheric air can be sucked into a blower 1412 and then can be passed through a carbon dioxide scrubber 1414. From there, the air flow can enter a pipe 1416 which directs air into a manifold (not illustrated) where it is split evenly into a plurality of flows streams, one for each cell. The air can pass down the back of the cathodes and can become somewhat or substantially completely depleted in oxygen. This air can exit the cell stack via another manifold and can then pass into an exhaust pipe 1418. The exhaust air flows can be then passed through a demisting device 1420 to remove any small particles of electrolyte and can be then evacuated into the atmosphere.

Electrical current can pass through the fuel cell stack and into a voltage booster 1422. This voltage booster provides variable output power of constant voltage but of varying current. From the voltage booster, the electrical power can be passed to the electrical load 1424.

An embodiment of a method of operation according to the invention is illustrated in Figure 15. As illustrated, the method is performed upon or after the occurrence of and optionally occurs throughout the duration of a power outage condition. The method begins with step 1500, where, upon the occurrence of the power outage condition, one or more fuel cells are operatively engaged to provide backup power to one or more loads. Step 1502 is then performed. In step 1502, again upon or after the occurrence of a power outage condition, the one or more fuel cells are engaged to power up a cooling means. Step 1504 is then performed. In optional step 1504, for the substantial duration of the power outage condition, the cooling unit is engaged to cool both the one or more loads and the one or more fuel cells sufficiently to allow both to dissipate heat and function.

Figure 16 is a flowchart of an embodiment 1600 of a method of operating a system according to the invention. The method is performed upon the occurrence of a power outage condition, and begins with step 1602, in which the power outage condition is sensed. The method then proceeds to step 1604, in which, upon (e.g., at or after, or the like) the time of the sensing of a power outage condition, one or more metal fuel cells are operatively engaged to provide power to one or more loads. Optional step 1606 can also be performed during this time of operative engagement. In optional step 1606, depending on the nature and characteristics of the one or more fuel cells and the one or more loads, the power from the one or more fuel cells can be converted to another form. In one example, the power from the one or more fuels is in the form of DC power, and this step converts the DC power into AC power.

The one or more fuel cells can continue to provide power to the one or more loads for the substantial duration of the power outage condition. At some point, the power outage condition ceases and delivery of primary power to the loads is resumed. In step 1608, this event is sensed, and, upon or after the time of sensing this event, step 1610 is performed. In step 1610, the one or more metal fuel cells are operatively disengaged from providing power to the one or more loads. In optional step 1612, the primary power source is operatively engaged to provide power to the one or more regeneration units within the fuel cells so as to regenerate the reaction products stored in the fuel cells back into fuel for reuse.

Figure 17 is a flowchart of an embodiment 1700 of a method of operating a system according to the invention. The method is performed upon or after the occurrence of a power demand condition or a power outage condition, and begins with step 1702, in which the power demand condition or the power outage condition is sensed. The method then proceeds to step 1704, in which, upon (e.g., at or after, or the like) the time of the sensing of a power demand condition or the power outage condition, one or more fuel cells are operatively engaged to provide power to one or more loads selected from the group comprising: lawn & garden equipment; radios; telephone; targeting equipment; battery rechargers; laptops; communications devices; sensors; night vision equipment; camping equipment (including without limitation, stoves, lanterns, lights, and the like); lights; vehicles (including without limitation, cars, recreational vehicles, trucks, boats, ferries, motorcycles, motorized scooters, forklifts, golf carts, lawnmowers, industrial carts, passenger carts (airport), luggage handling equipment (airports), airplanes, lighter than air crafts (e.g., blimps, dirigibles, and the like), hovercrafts, trains (e.g., locomotives, and the like), and submarines (manned and unmanned); torpedoes; security systems; electrical energy storage devices for renewable energy sources (e.g., solar-based, tidal-based, hydro-based, wind-based, and the like); many other types of electrical devices, equipment for which a primary and/or backup power source is necessary or desirable to enable the equipment to function for its intended purpose, military-usable variants of above, and the like; and suitable combinations of any two or more thereof.

Optional step 1706 can also be performed during this time of operative engagement. In optional step 1706, depending on the nature and characteristics of the one or more fuel cells and the one or more loads, the power from the one or more fuel cells can be converted to another form. In one example, the power from the one or more fuels is in the form of DC power, and this step converts the DC power into AC power.

The one or more fuel cells can continue to provide power to the one or more loads for the substantial duration of the power demand condition or the power outage condition. At some point, the power demand condition or the power outage condition ceases. In step 1708, this event is sensed, and, upon or after the time of sensing this event, step 1710 is performed. In step 1710, the one or more fuel cells are operatively disengaged from providing power to the one or more loads. In optional step 1712, the system-external primary power is operatively engaged to provide power to the one or more regeneration units within the fuel cells so as to regenerate the reaction products stored in the fuel cells back into fuel for reuse.

In a further embodiment, the invention provides methods of pre-charging a fuel cell system for providing backup power to one or more loads (including without limitation a cooling unit). Such methods comprise placing an amount of fuel in cell cavities of a power source of a fuel cell system prior to operative engagement of the fuel cell system. This amount of fuel can be sufficient to operatively engage the fuel cell system for a time in the range(s) from about 0.001 minutes to about 100 minutes without additional fuel being added thereto. Optionally, the fuel is kept in the cell cavities for a time prior to operative engagement of the fuel cell system in the range(s) from about 0.001 minutes to about 10 years or more.

In another embodiment, the invention provides methods of utilizing a pre-charged fuel cell system for providing backup power to one or more loads (including without limitation a cooling unit). Such methods comprise operatively engaging a fuel cell system, containing fuel in cell cavities of a power source of the fuel cell system prior to its operative engagement, for a time in the range(s) from about 0.001 minutes to about 100 minutes without adding additional fuel thereto.

As utilized herein, the term "about" comprises any deviation upward or downward from the value modified by "about" by up to 20% of such value.

As employed herein, the term "in the range(s)" comprises the range defined by the values listed after the term "in the range(s)", as well as any and all subranges contained within such range, where each such subrange is defined as having as a first endpoint any value in such range, and as a second endpoint any value in such range that is greater than the first endpoint and that is in such range.

As utilized herein, the term “significantly faster” comprises any increase in the time value modified by “significantly faster” that is in the range(s) greater than 10% of such time value.

While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention. Accordingly, the invention is not to be restricted, except in light of the appended claims and equivalents thereto.

## CLAIMS

What is claimed is:

1. A fuel cell system for providing primary, auxiliary or backup power to one or more loads comprising:

one or more fuel cells; and

a controller for operatively engaging the one or more fuel cells to provide primary, auxiliary or backup power to the one or more loads upon or after the occurrence of a power demand or outage condition.

2. The system of claim 1 further comprising a cooling unit that is powered by the one or more fuel cells upon or after the occurrence of a power demand or outage condition.

3. The system of claim 1 wherein each of the one or more fuel cells is selected from metal fuel cells and hydrogen fuel cells.

4. The system of claim 1 wherein each of the one or more fuel cells is a metal fuel cell.

5. The system of claim 4 wherein each of the one or more fuel cells is selected from zinc fuel cells, aluminum fuel cells, lithium fuel cells, magnesium fuel cells, and iron fuel cells.

6. The system of claim 5 wherein at least one of the one or more fuel cells is a zinc fuel cell.

7. The system of claim 1 wherein at least one of the one or more fuel cells comprises a regeneration unit.

8. The system of claim 1 wherein at least one of one or more fuel cells comprises a power source.

9. The system of claim 8 wherein the power source is configured to function as a regeneration unit.

10. The system of claim 1 further comprising one or more fuel storage units.

11. The system of claim 1 further comprising one or more reaction product storage units.

**12.** The system of claim 1 further comprising one or more second reactant storage units.

**13.** The system of claim 1 further comprising a power conversion unit for converting the power output from the one or more fuel cells into another form.

**14.** The system of claim 13 wherein the power conversion unit is configured to convert DC power from the one or more fuel cells into AC power.

**15.** The system of claim 13 wherein the power conversion unit is configured to convert DC power from the one or more fuel cells into another form of DC power.

**16.** The system of claim 2 wherein the controller is configured to sense outage of primary power to the one or more loads, and, responsive thereto, operatively engage the one or more fuel cells to provide power to the one or more loads and the cooling unit.

**17.** The system of claim 2 wherein the controller is configured to sense resumption of primary power to the one or more loads, and, responsive thereto, disengage the one or more fuel cells from providing power to the one or more loads and the cooling unit.

**18.** The system of claim 8 or 9 wherein the controller is configured to sense resumption of delivery of primary power from a source to the one or more loads, and, responsive thereto, engage the primary power source to provide power to one or more of the regeneration units in the one or more fuel cells.

**19.** The system of claim 4 wherein the system is configured to avoid utilizing or producing significant quantities of flammable fuel or reactant product.

**20.** The system of claim 1 wherein the system is configured to provide backup power to the one or more loads for a time period in the range from about 0.01 hours to about 10,000 hours.

**21.** The system of claim 20 wherein the system is configured to provide backup power to the one or more loads for a time period in the range from about 0.5 hours to about 650 hours.

**22.** The system of claim 4 wherein the system is configured to have an energy density in the range from about 35 Watt-hours per kilogram of combined fuel and electrolyte added to the system to about 400 Watt-hours per kilogram of combined fuel and electrolyte added to the system.

**23.** The system of claim 4 wherein the system further comprises an energy requirement, and wherein the system is configured such that the combined volume of fuel and electrolyte added to the system is in the range from about 0.0028 L per Watt-hour of the system's energy requirement to about 0.025 L per Watt-hour of the system's energy requirement.

**24.** The system of claim 23 wherein the energy requirement is in the range from about 50 Watt-hours to about 500,000 Watt-hours.

**25.** The system of claim 23, wherein the energy requirement is in the range from about 5 Watt-hours to about 5,000,000 Watt-hours.

**26.** The system of claim 10, wherein the fuel storage unit is configured to store fuel at a pressure in the range from about –5 psi to about 200 psi.

**27.** The system of claim 8, wherein the power source has one or more cell cavities which contain fuel prior to the controller sensing the power demand or outage condition.

**28.** The system of claim 27, wherein the amount of fuel present in the cell cavities of the power source prior to the controller sensing the power outage or demand condition is sufficient to permit operative engagement of the one or more fuel cells by the controller to provide power to the one or more loads at a rate at least ten percent faster than when there is substantially no fuel present in the cell cavities of the power source prior to the controller sensing the power outage or demand condition.

**29.** The system of claim 27, wherein the amount of fuel present in the cell cavities of the power source prior to the controller sensing the power outage or demand condition is sufficient to permit operative engagement of the one or more fuel cells by the controller for a time in the range of about 0.001 minutes to about 100 minutes or more without additional fuel being added.

**30.** The system of claim 8, wherein one or more second reactants are present in the power source at a pressure in the range from about 0.01 psi gauge pressure to about 200 psi gauge pressure prior to operative engagement of the one or more fuel cells by the controller to provide power to the one or more loads.

**31.** The system of claim 30, wherein the one or more second reactants are present in the power source at the pressure at a time prior to a demand or outage sense time, which demand or outage sense time is in the range from about 10 microseconds to about 10 seconds after the controller has sensed the power demand or outage condition.

**32.** The system of claim 31, wherein the time is also after the controller has sensed the power outage or demand condition.

**33.** The system of claim 1, wherein the system is configured to expel substantially no reaction products outside of the system.

**34.** The system of claim 1 further comprising a fuel storage unit and a second reactant storage unit which have an independently selected volume in the range from about 0.001 liters to about 10,000 liters.

**35.** The system of claim 2, wherein the cooling unit is configured to remove from the vicinity of the system heat generated by the one or more loads and/or the one or more fuel cells.

**36.** The system of claim 35, wherein the cooling unit is configured to circulate cooling fluid past the one or more fuel cells and/or the one or more loads.

**37.** The system of claim 35, wherein the cooling unit comprises an open loop system configured to cool a first cooling fluid by circulating a second cooling fluid through a heat exchange, and to then circulate the cooled first cooling fluid past the one or more fuel cells and/or the one or more loads.

**38.** The system of claim 35, wherein the cooling unit comprises a closed loop system configured to cool a first cooling fluid by circulating a second cooling fluid from a reservoir through a heat exchanger and then back to the reservoir, and to then circulate the cooled first cooling fluid past the one or more fuel cells and/or the one or more loads

**39.** The system of claim 1 further comprising means for physically supporting the one or more fuel cells, and at least one of the one or more loads.

**40.** The system of claim 39 wherein the system further comprises a power conversion unit, and a regeneration unit, and the means for physically supporting the one or more fuel cells and at least one of the one or more loads further comprises means for physically supporting the controller, the power conversion unit, the regeneration unit, and the remainder of the one or more loads, and wherein the means integrally supports the system.

**41.** The system of any of claims 39 or 40 wherein the means is a rack.

**42.** The system of claim 1 further comprising means for routing a cooling fluid past the one or more fuel cells and/or the one or more loads.

**43.** A method of providing primary, auxiliary, or backup power to one or more loads upon or after the occurrence of a power demand or outage condition, the method comprising, upon or after the occurrence of the power demand or outage condition, operatively engaging one or more fuel cells to provide power to the one or more loads.

**44.** The method of claim 43 further comprising engaging the one or more fuel cells to provide power to the one or more loads throughout the duration of the power outage or demand condition.

**45.** The method of claim 43 further comprising engaging the one or more fuel cells to provide primary, auxiliary or backup power to a cooling unit upon or after the occurrence of the power outage or demand condition.

**46.** The method of claim 45 wherein the one or more fuel cells provide power to the cooling unit before, after or during providing power to the one or more loads.

**47.** The method of claim 45, further comprising, for the substantial duration of the power demand or outage condition, engaging the cooling unit to cool both the one or more loads and/or the one or more fuel cells sufficiently to allow both to dissipate heat and to continue functioning.

**48.** The method of claim 45, wherein the cooling unit comprises a means for cooling one or more loads.

**49.** The method of claim 43 further comprising disengaging the one or more fuel cells from providing power to the one or more loads and/or the cooling unit upon or after the cessation of the power demand or outage condition.

**50.** The method of claim 40 further comprising engaging a primary power source to provide primary power to the one or more loads upon or after sensing cessation of a primary power outage condition.

**51.** The method of claim 50 further comprising engaging the primary power source to provide primary power to one or more regeneration units upon or after sensing cessation of a power outage condition.

**52.** The method of claim 43 wherein the one or more fuel cells are metal fuel cells.

**53.** The method of claim 43 wherein one or more of the fuel cells have a power source having cell cavities, the method further comprising containing an amount of fuel in the cell cavities of the power source prior to operative engagement of the fuel cell system.

**54.** The method of claim 53, wherein the amount of fuel is sufficient to operatively engage the one or more fuel cells for a time in the range from about 0.001 minutes to about 100 minutes without additional fuel being added thereto.

**55.** The method of claim 53, wherein the fuel is kept in the cell cavities for a time prior to operative engagement of the one or more fuel cells in the range from about 0.001 minutes to about 10 years.

**56.** The method of claim 53 further comprising containing fuel in the cell cavities of the power source prior to operative engagement, for a time in the range from about 0.001 minutes to about 100 minutes without adding additional fuel thereto.

**57.** The method of claim 52 wherein the one or more fuel cells are zinc fuel cells.

**58.** The method of claim 43 wherein the one or more fuel cells have a power output, and the method further comprises converting the power output of the one or more fuel cells to another form.

**59.** The method of claim 58, wherein the power output from the one or more fuel cells is DC power, and the other form is AC power.

**60.** The system of claim 1 wherein the one or more loads are selected from the group comprising: lawn & garden equipment; radios; telephone; targeting equipment; battery rechargers; laptops; communications devices; sensors; night vision equipment; camping equipment; stoves; lanterns; lights; vehicles; cars; recreational vehicles; trucks; boats; ferries; motorcycles; motorized scooters; forklifts; golf carts; lawnmowers; industrial carts; passenger carts (airport); luggage handling equipment (airports); airplanes; lighter than air crafts; blimps; dirigibles; hovercrafts; trains;

locomotives; submarines (manned and unmanned); torpedoes; security systems; electrical energy storage devices for solar-based, tidal-based, hydro-based, wind-based, and other renewable energy source; equipment for which a primary and/or backup power source is necessary or desirable to enable the equipment to function for its intended purpose, military-usable variants of above, and suitable combinations of any two or more thereof.

**61.** The method of claim 43, wherein the one or more loads are selected from the group comprising: lawn & garden equipment; radios; telephone; targeting equipment; battery rechargers; laptops; communications devices; sensors; night vision equipment; camping equipment; stoves; lanterns; lights; vehicles; cars; recreational vehicles; trucks; boats; ferries; motorcycles; motorized scooters; forklifts; golf carts; lawnmowers; industrial carts; passenger carts (airport); luggage handling equipment (airports); airplanes; lighter than air crafts; blimps; dirigibles; hovercrafts; trains; locomotives; submarines (manned and unmanned); torpedoes; security systems; electrical energy storage devices for solar-based, tidal-based, hydro-based, wind-based, and other renewable energy source; equipment for which a primary and/or backup power source is necessary or desirable to enable the equipment to function for its intended purpose, military-usable variants of above, and suitable combinations of any two or more thereof.

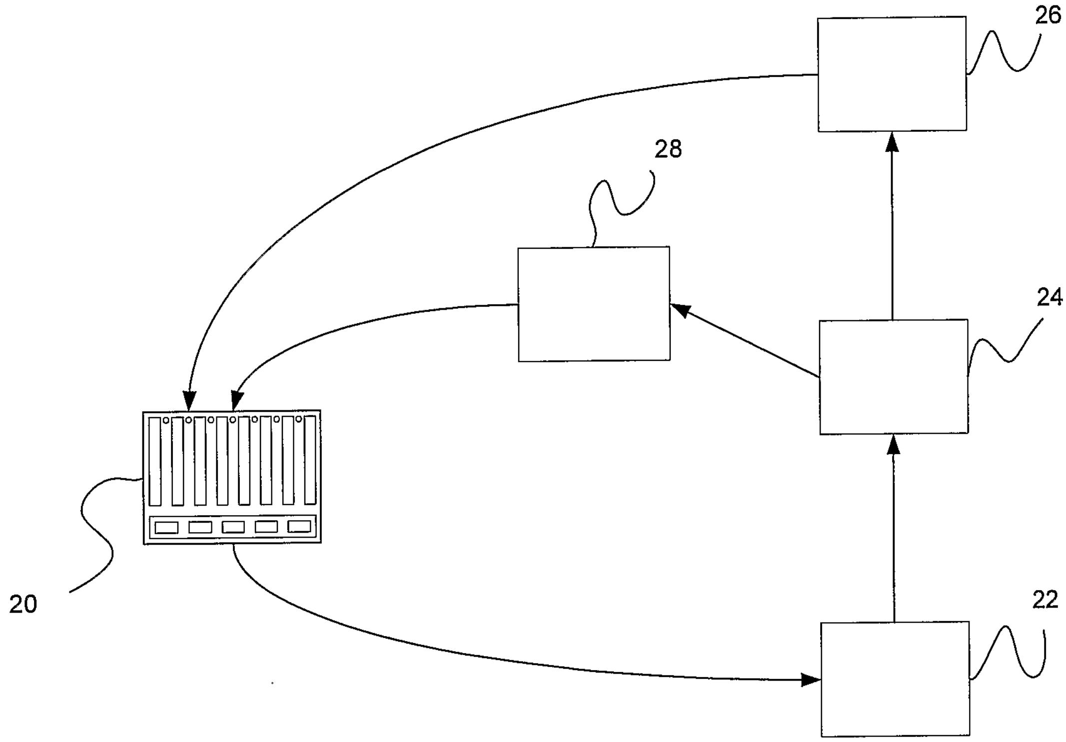



FIGURE 1A

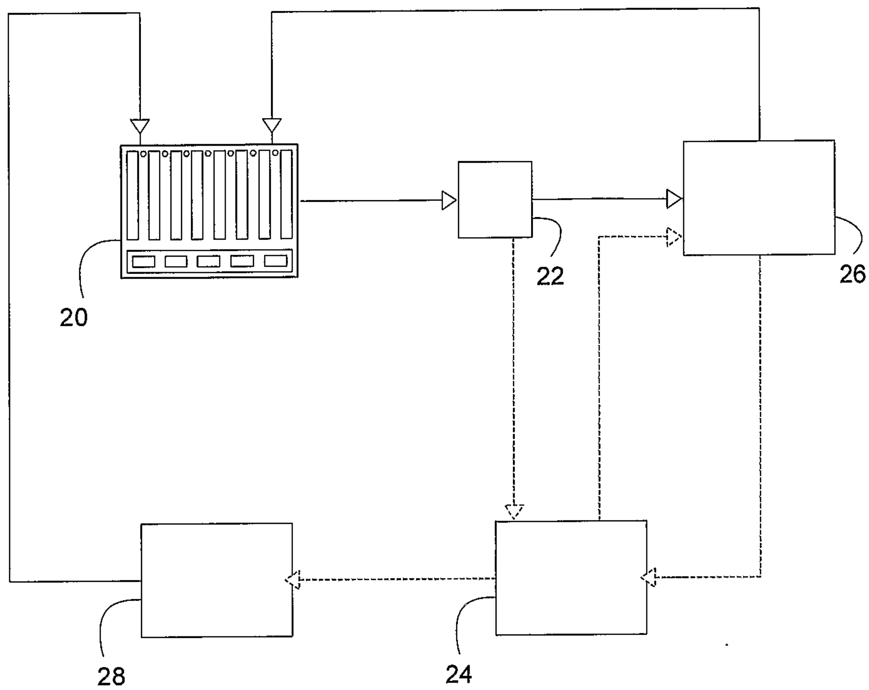



FIGURE 1B

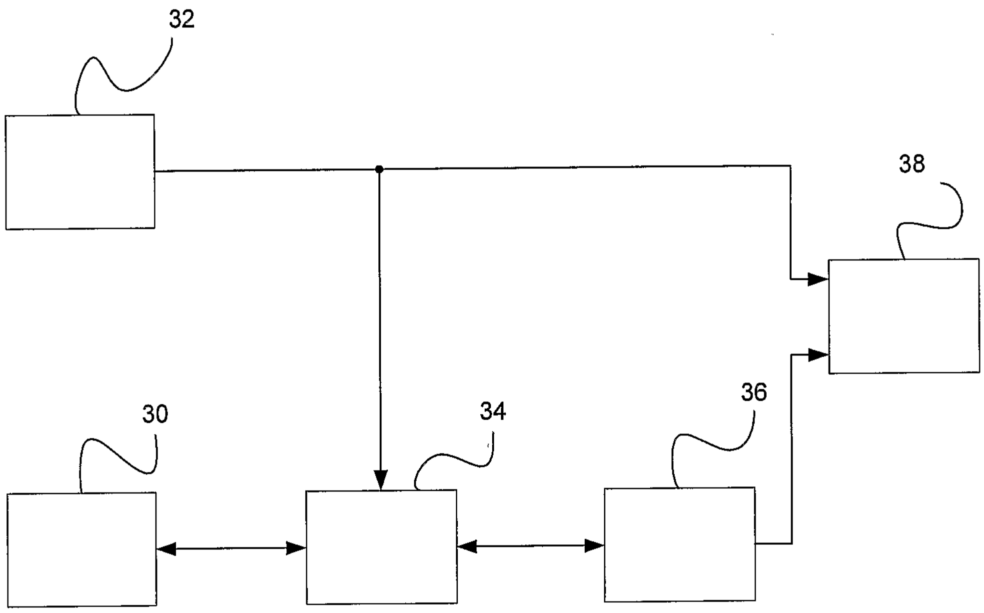



FIGURE 2A

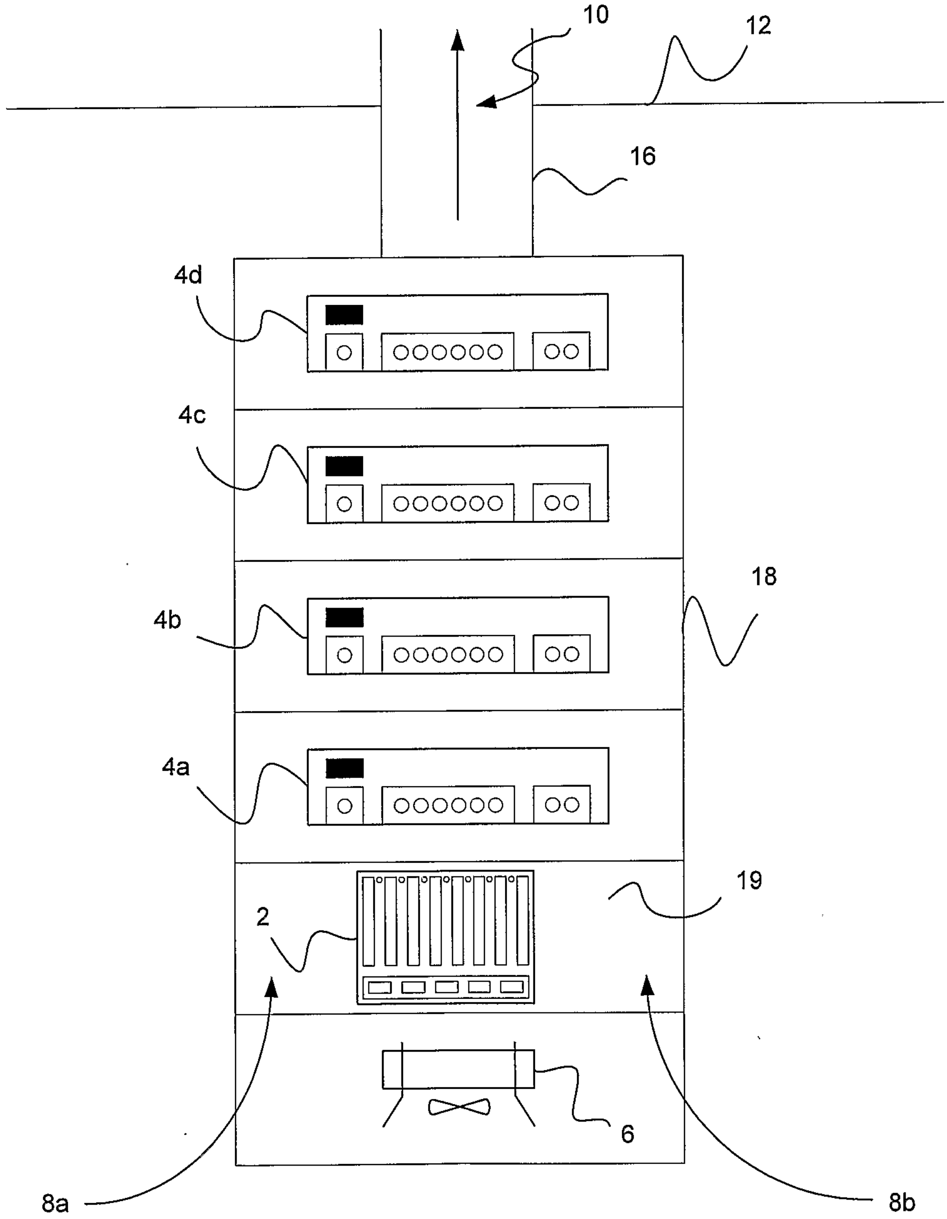



FIGURE 2B

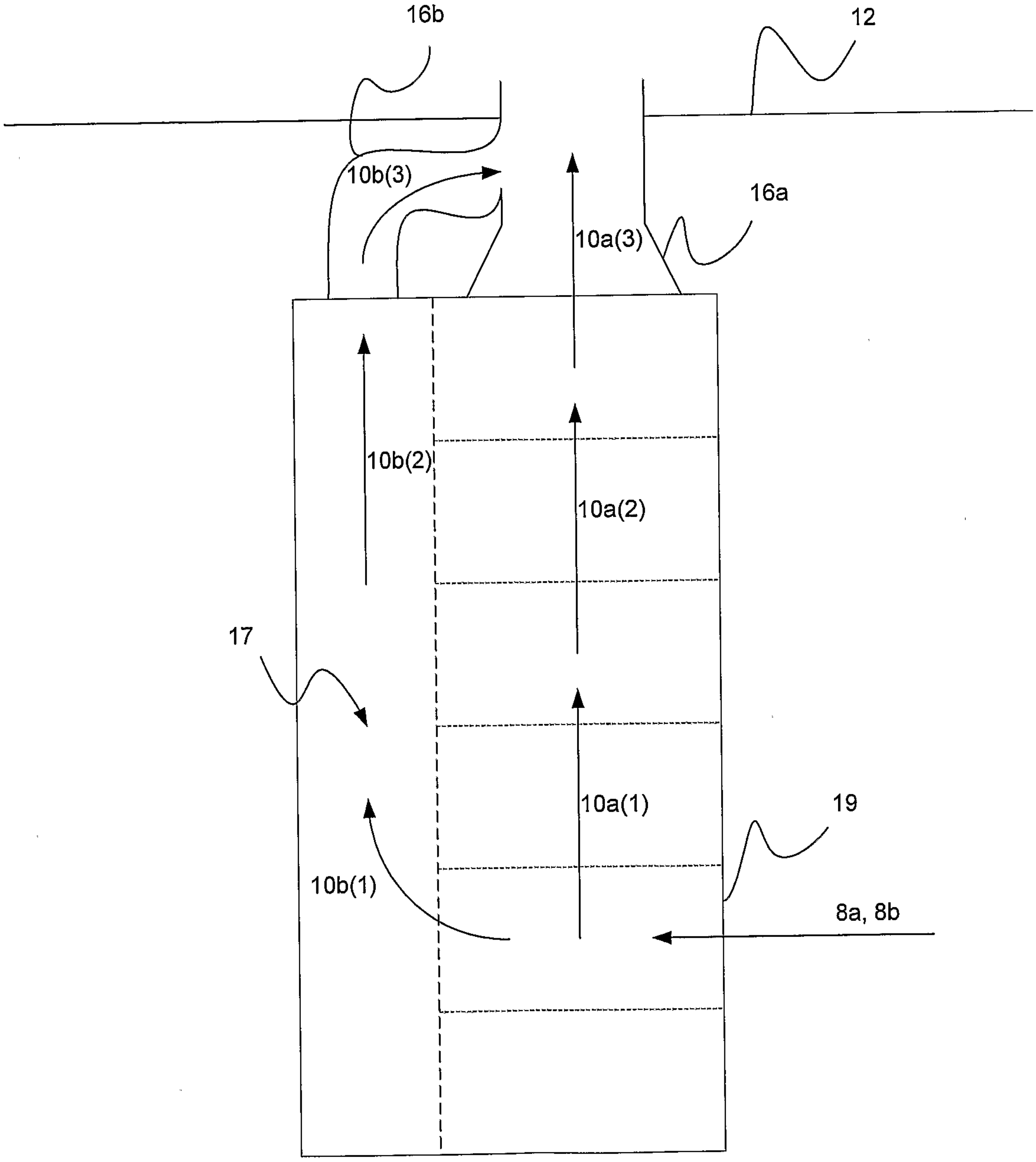



FIGURE 2C

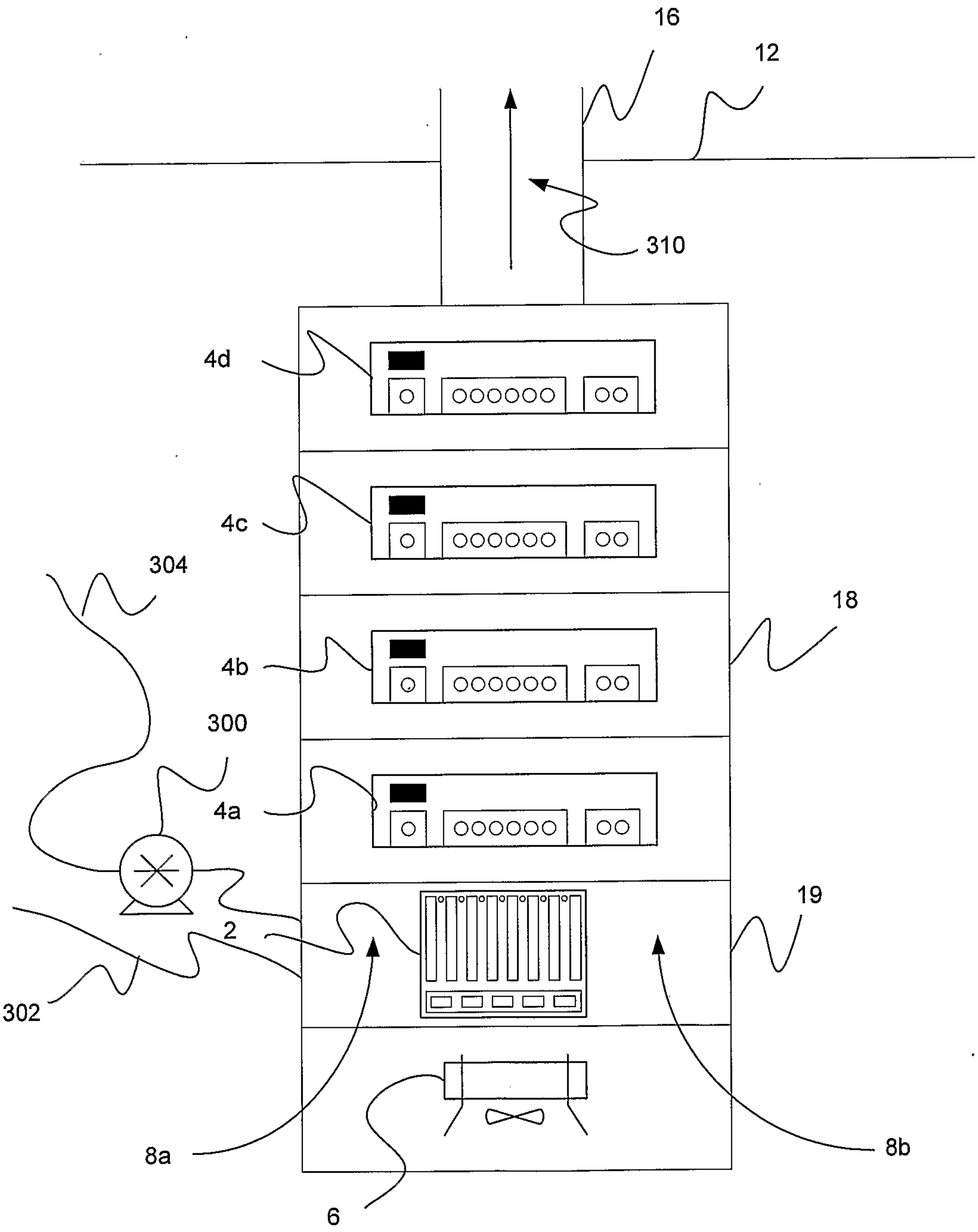



FIGURE 3

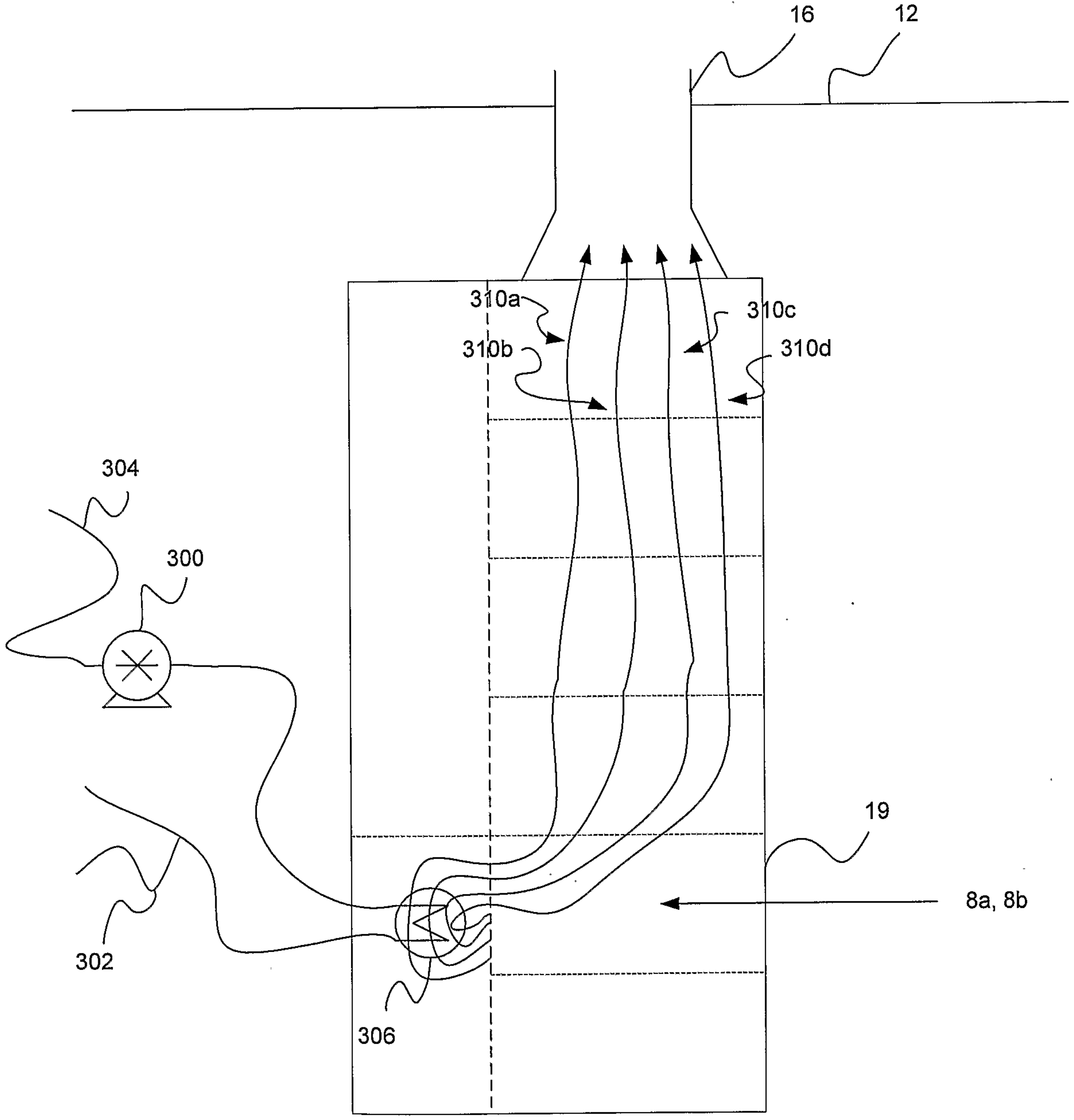



**FIGURE 4**

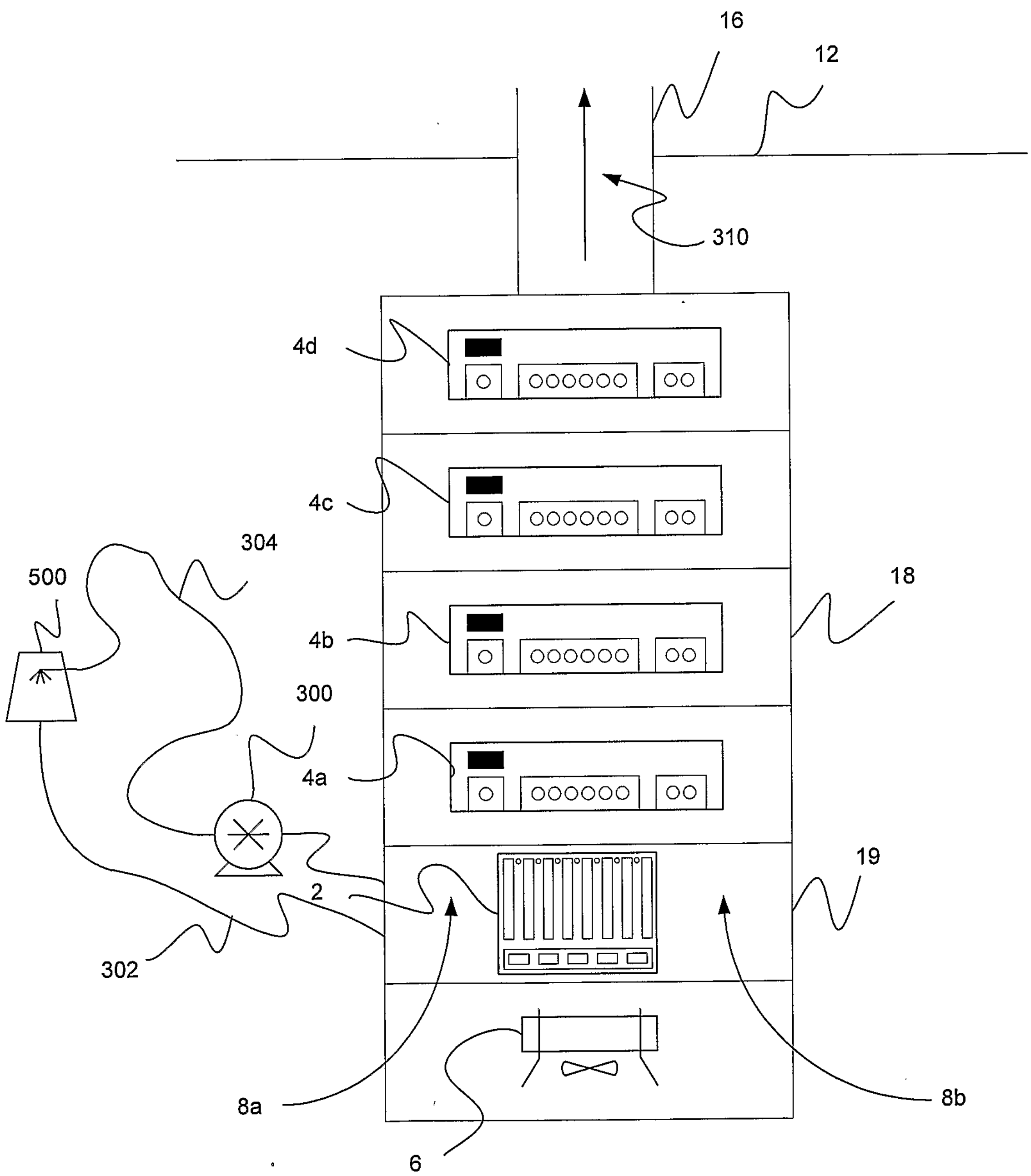



FIGURE 5

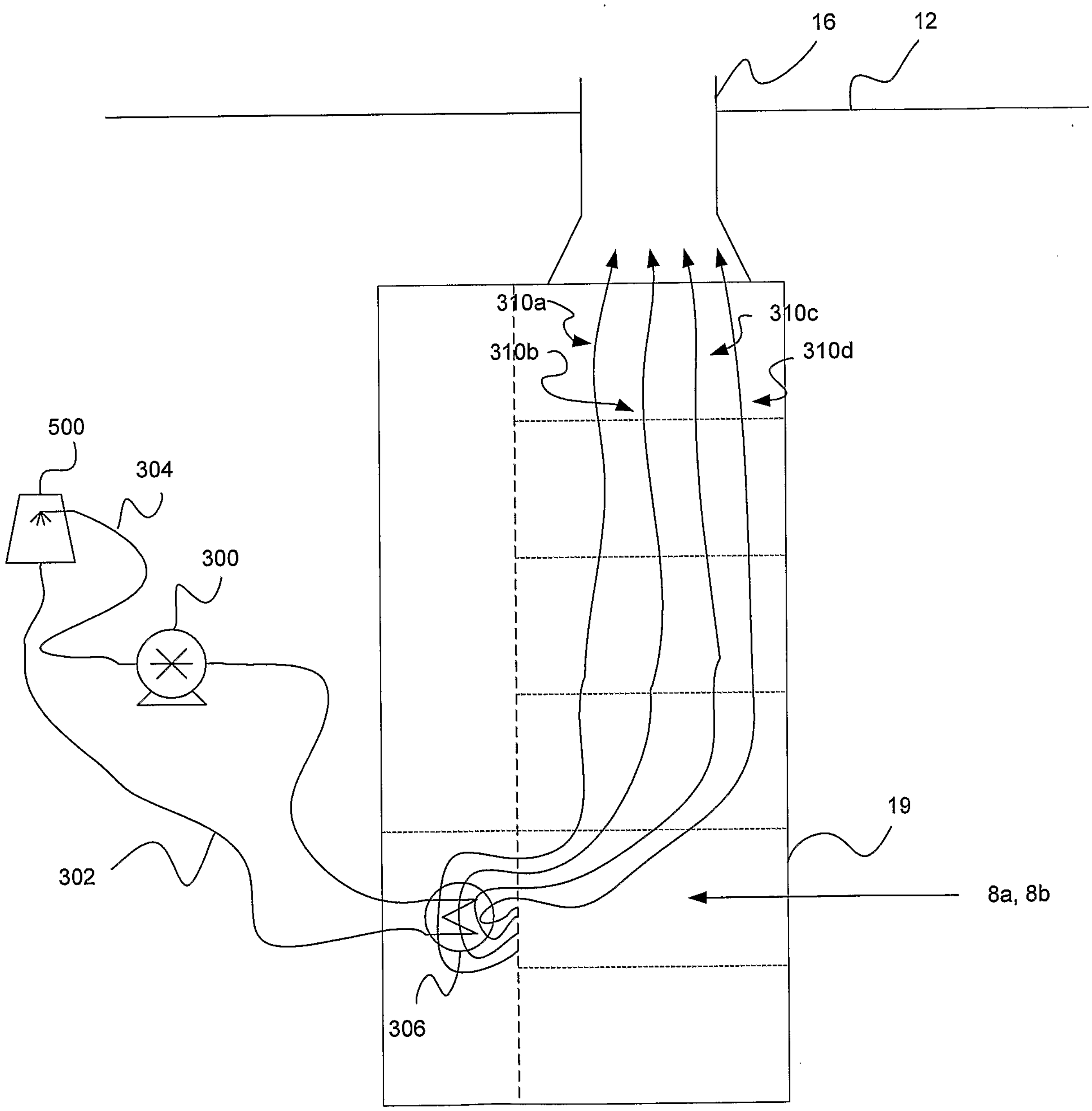



FIGURE 6A

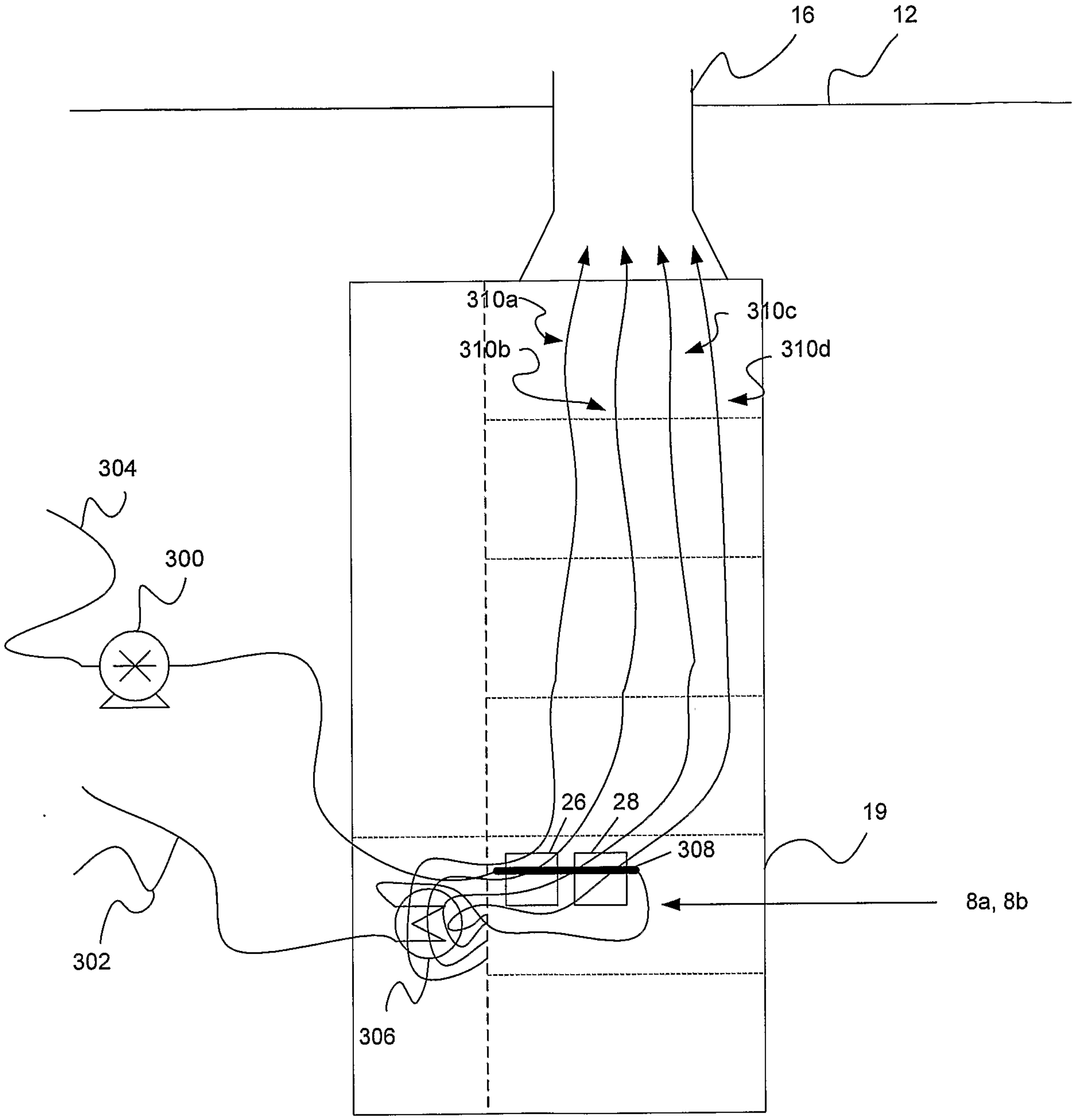



FIGURE 6B

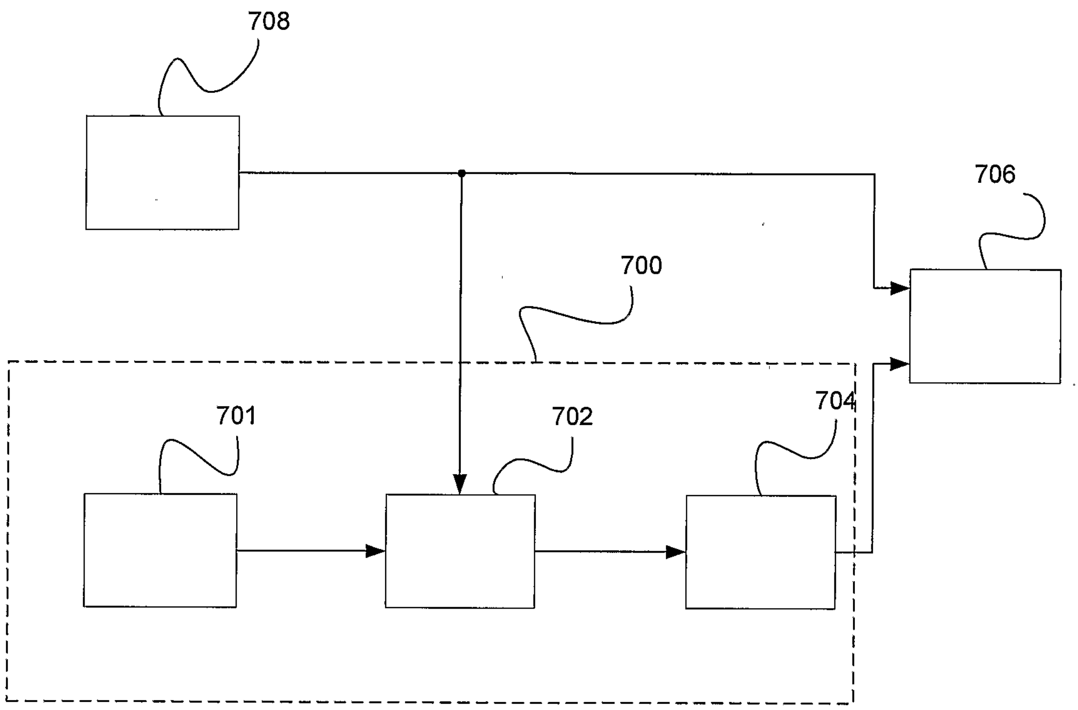



FIGURE 7

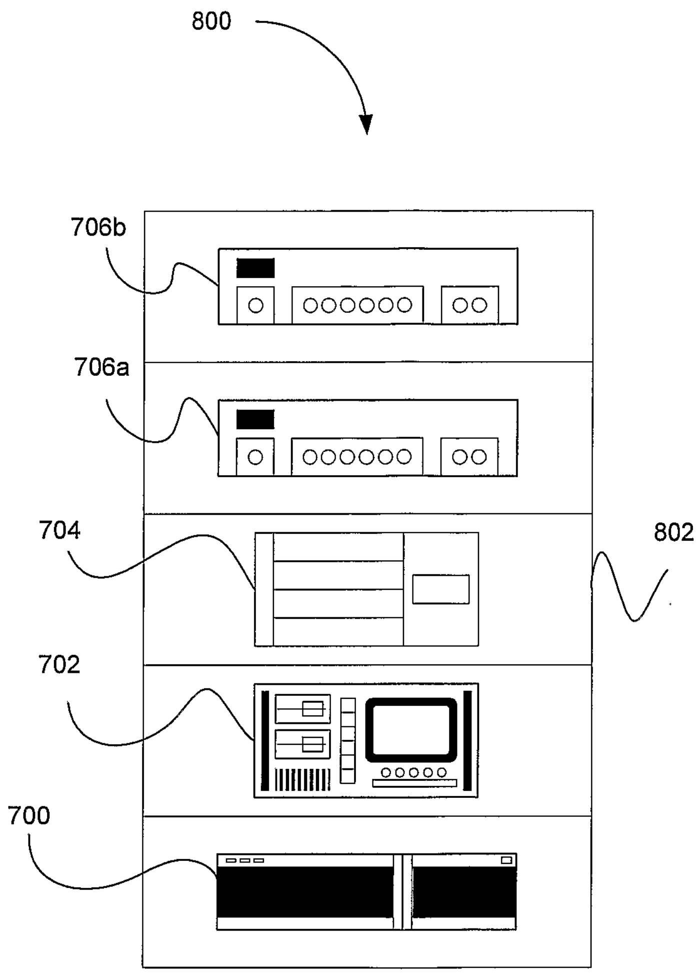



FIGURE 8

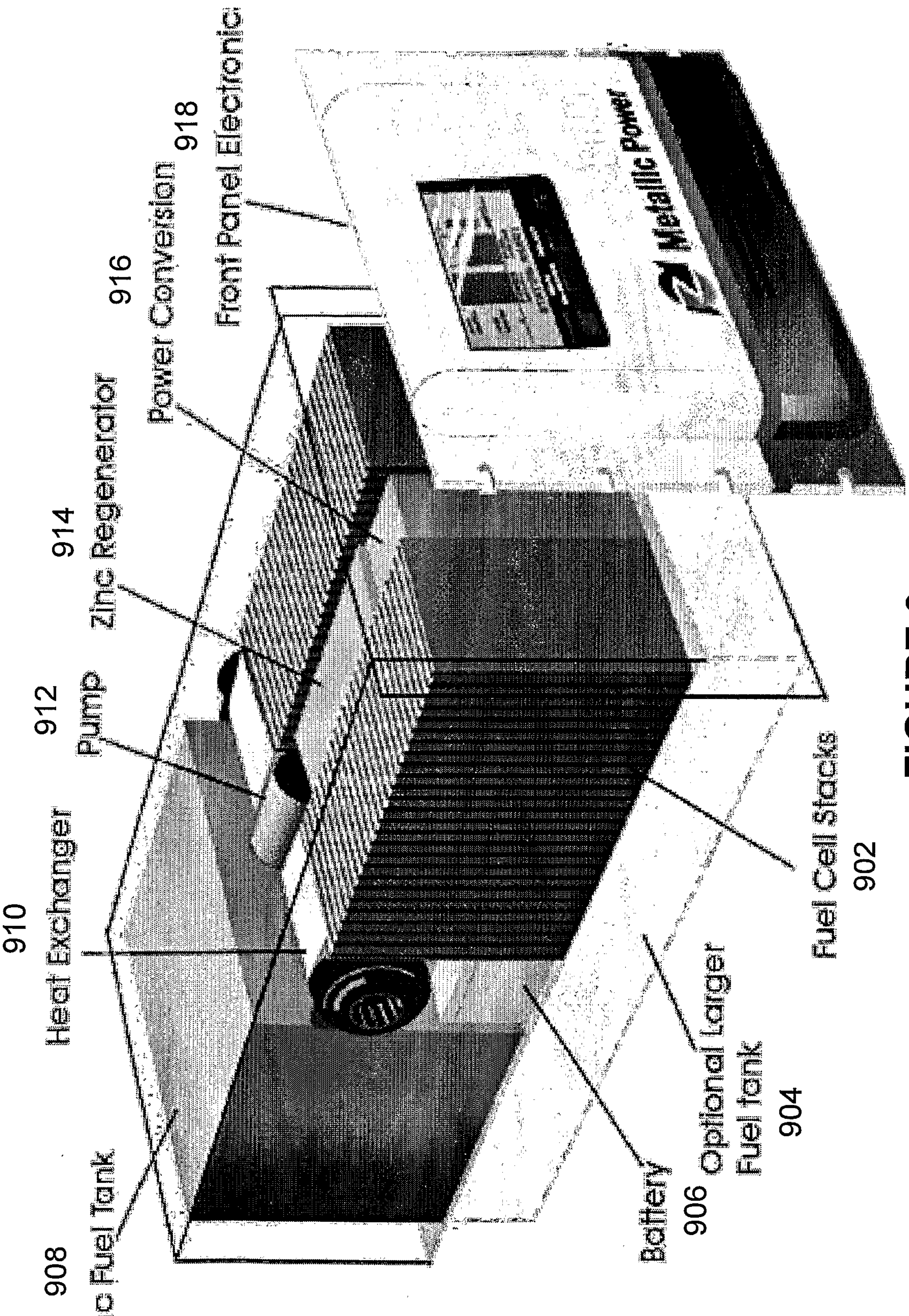

916
Power Conversion
918
Front Panel Electronic
914
Zinc Regenerator
912
Pump
910
Heat Exchanger
908
Zinc Fuel Tank
Metallic Power
Fuel Cell Stacks
902
Battery
906
Optional Larger
Fuel tank
904

FIGURE 9

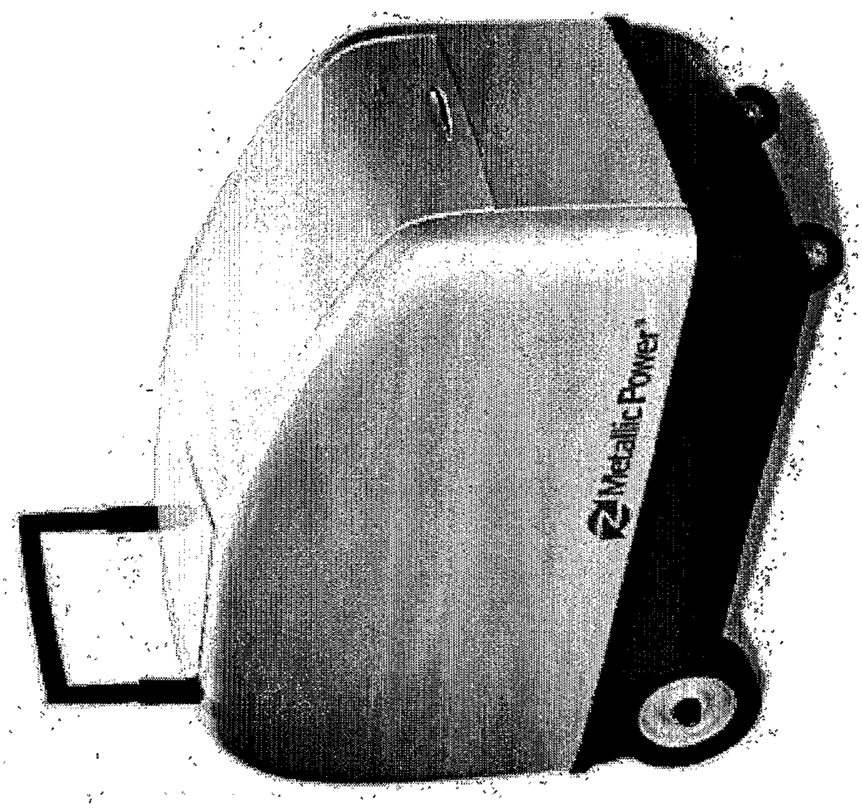



FIGURE 10

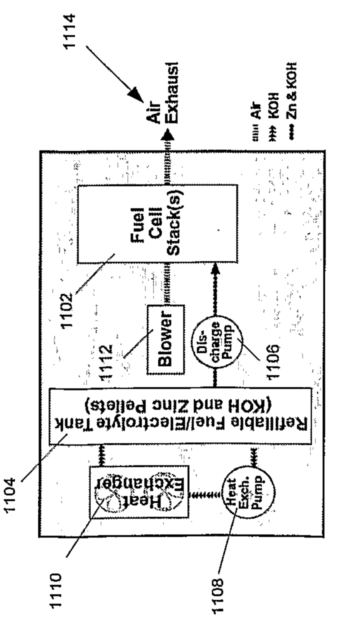



FIGURE 11A

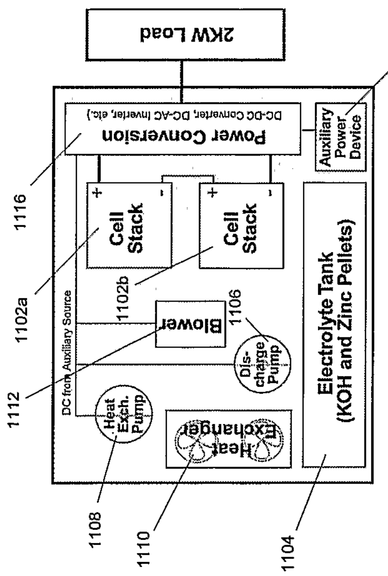



FIGURE 11B

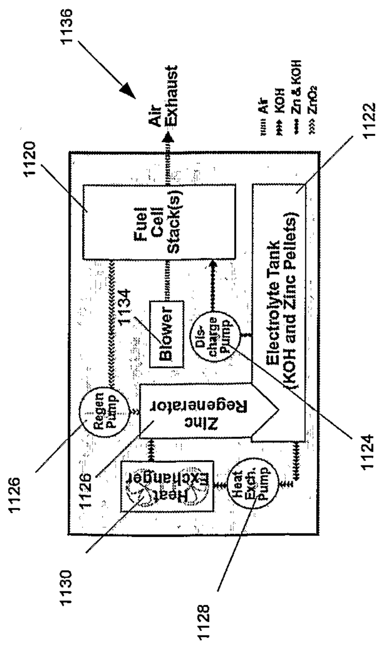



FIGURE 11C

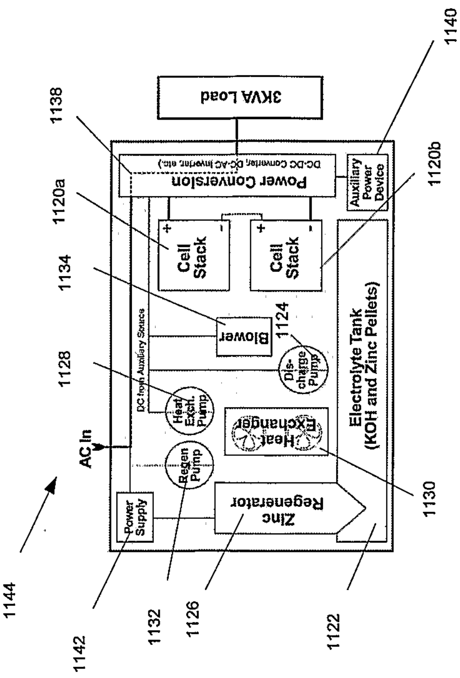



FIGURE 11D

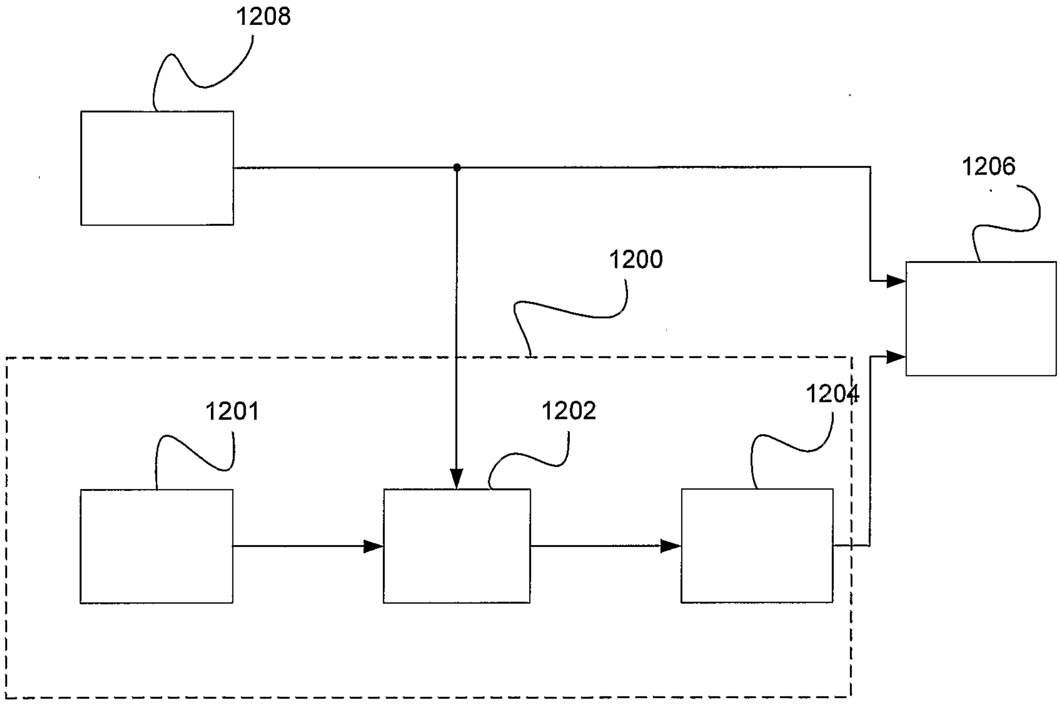



FIGURE 12

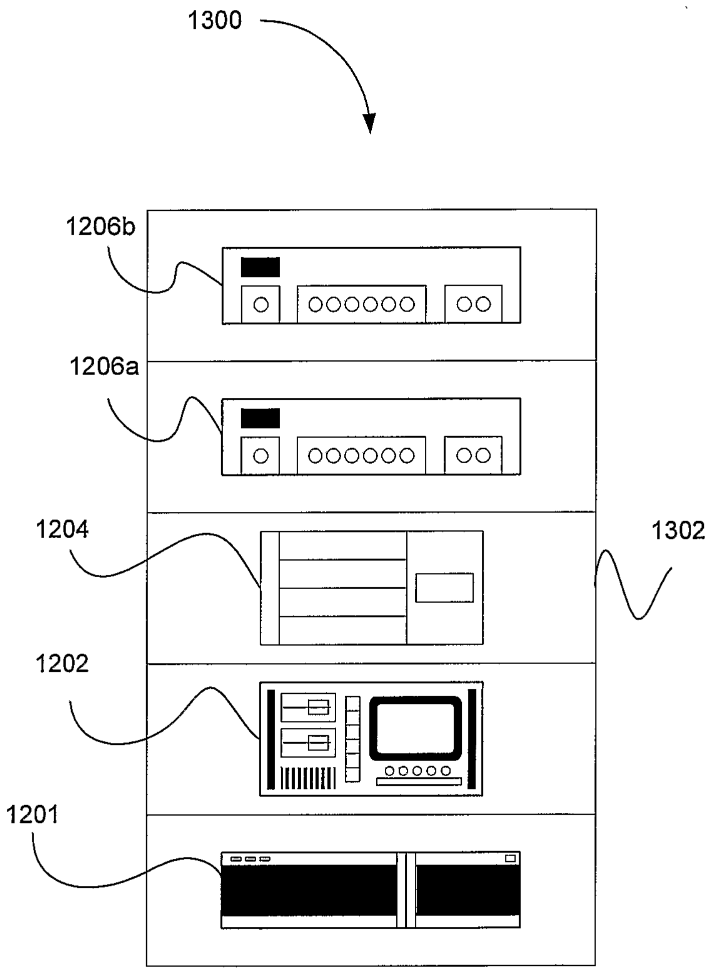
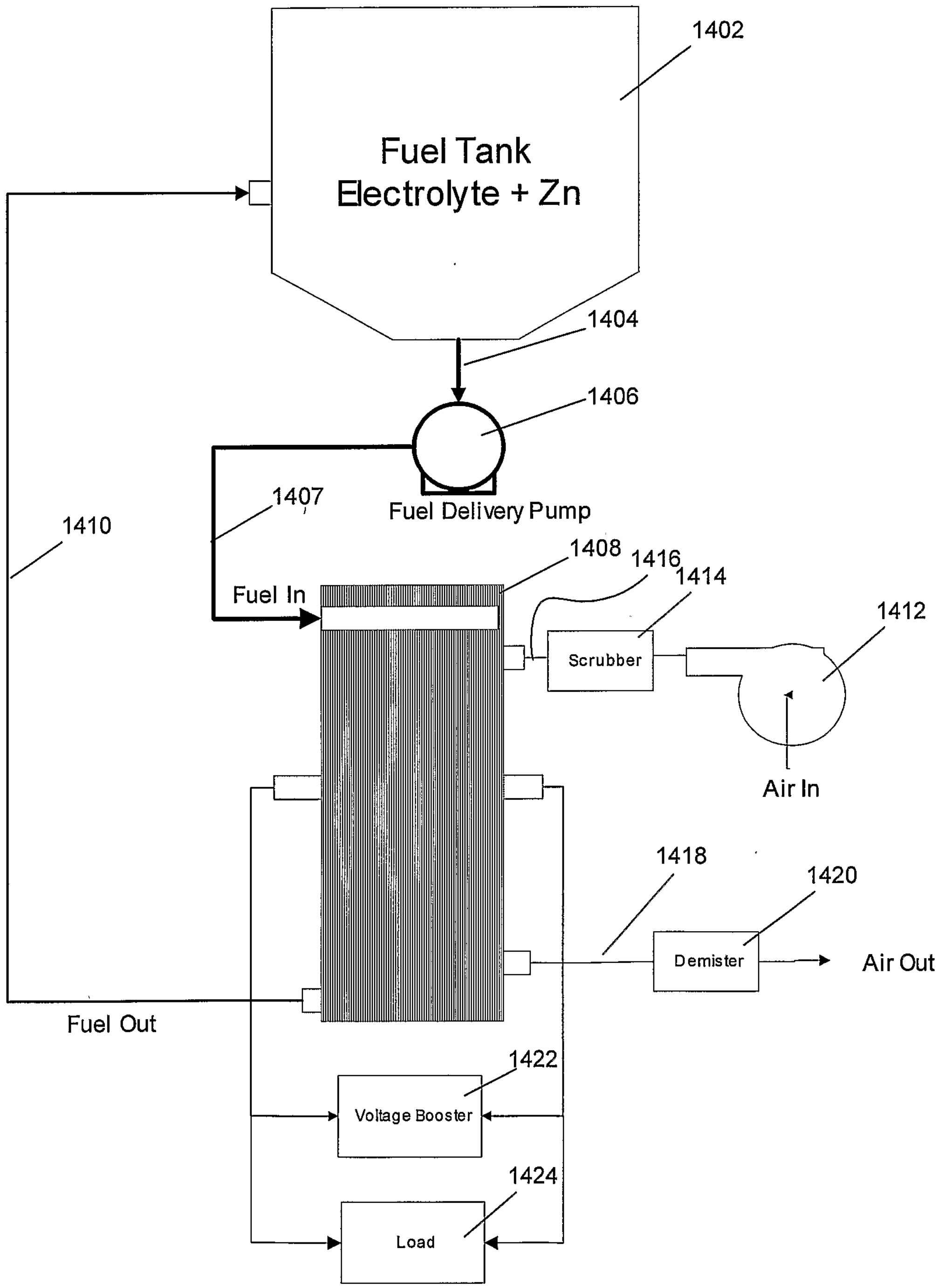



FIGURE 13

FlowSchematics of Fuel Cells and Fuel Tank




# FIGURE 14

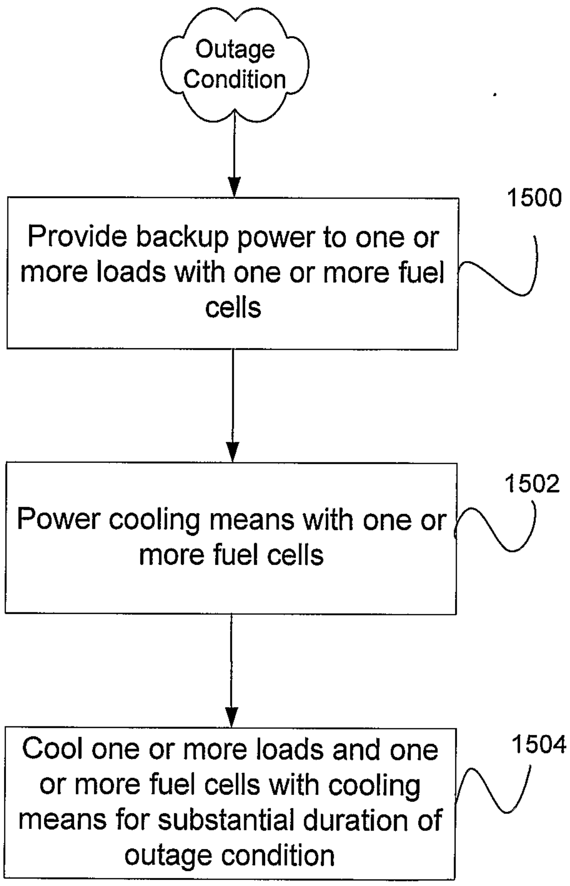

Outage Condition
Provide backup power to one or more loads with one or more fuel cells
1500
Power cooling means with one or more fuel cells
1502
Cool one or more loads and one or more fuel cells with cooling means for substantial duration of outage condition
1504

FIGURE 15

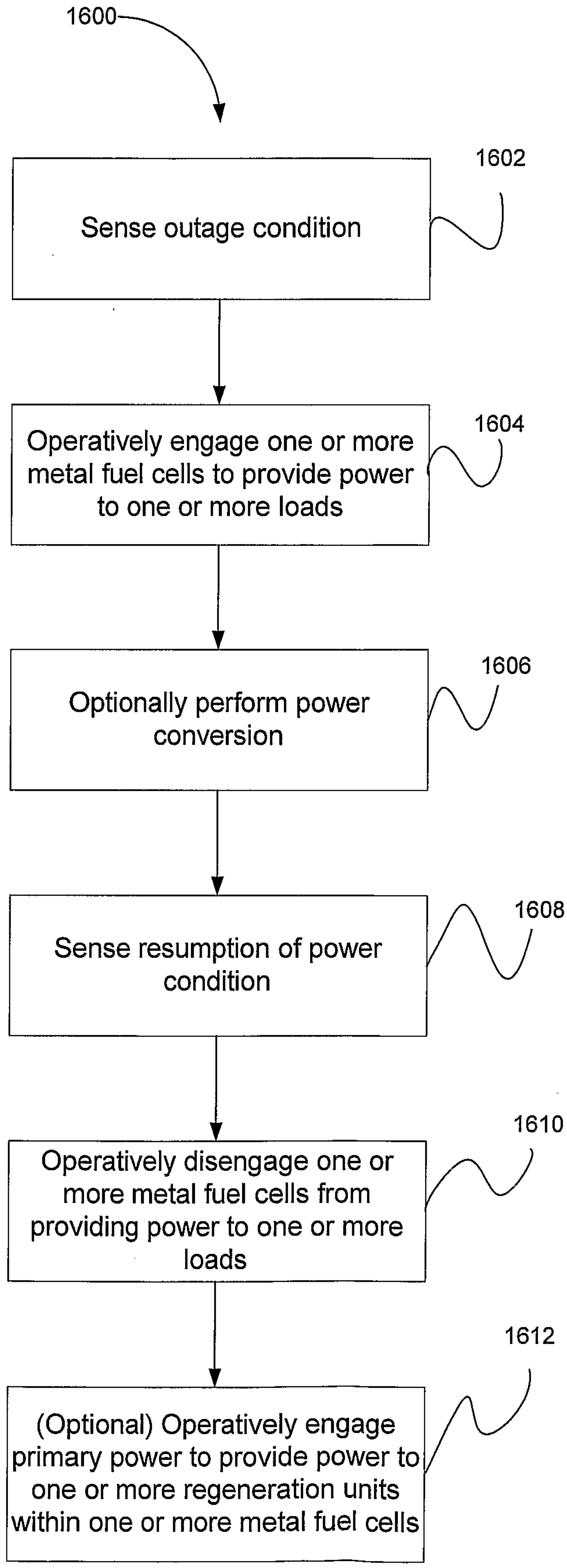

1600
Sense outage condition
1602
Operatively engage one or more metal fuel cells to provide power to one or more loads
1604
Optionally perform power conversion
1606
Sense resumption of power condition
1608
Operatively disengage one or more metal fuel cells from providing power to one or more loads
1610
(Optional) Operatively engage primary power to provide power to one or more regeneration units within one or more metal fuel cells
1612

FIGURE 16

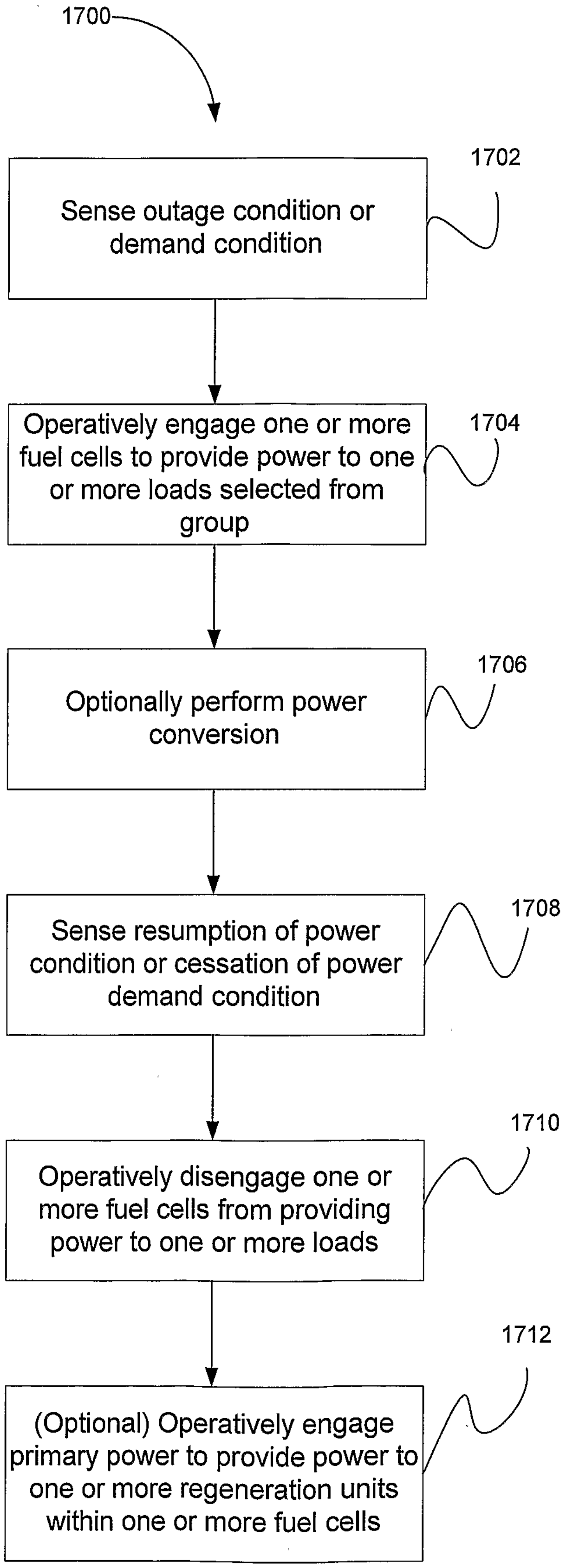

1700
Sense outage condition or demand condition
1702
Operatively engage one or more fuel cells to provide power to one or more loads selected from group
1704
Optionally perform power conversion
1706
Sense resumption of power condition or cessation of power demand condition
1708
Operatively disengage one or more fuel cells from providing power to one or more loads
1710
(Optional) Operatively engage primary power to provide power to one or more regeneration units within one or more fuel cells
1712

FIGURE 17