(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 August 2014 (21.08.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/126595 A1

(51) International Patent Classification:
H01M 8/24 (2006.01) *H01M 8/04* (2006.01)

(21) International Application Number:
PCT/US2013/032664

(22) International Filing Date:
15 March 2013 (15.03.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/765,906 18 February 2013 (18.02.2013) US

(71) Applicants: **PARKER-HANNIFIN CORPORATION** [US/US]; 6035 Parkland Boulevard, Cleveland, OH 44124-4141 (US). **WATT FUEL CELL CORP.** [US/US]; 27 Seaview Boulevard, Port Washington, NY 11050 (US).

(72) Inventors: **KNIGHT, Steven, Robert**; 7 Bethke Road, Killingworth, CT 06419 (US). **FINNERTY, Caine**; 85 Willowdale Avenue, Port Washington, NY 11050 (US). **DEWALD, Paul**; 26 Nassau Avenue, Apt. 2, Glen Cove, NY 11542 (US).

(74) Agent: **CARRION, Luis A.**; Renner, Otto, Boisselle & Sklar, LLP, 1621 Euclid Ave., 19th Floor, Cleveland, OH 44115 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: MODULAR FUEL CELL SYSTEM

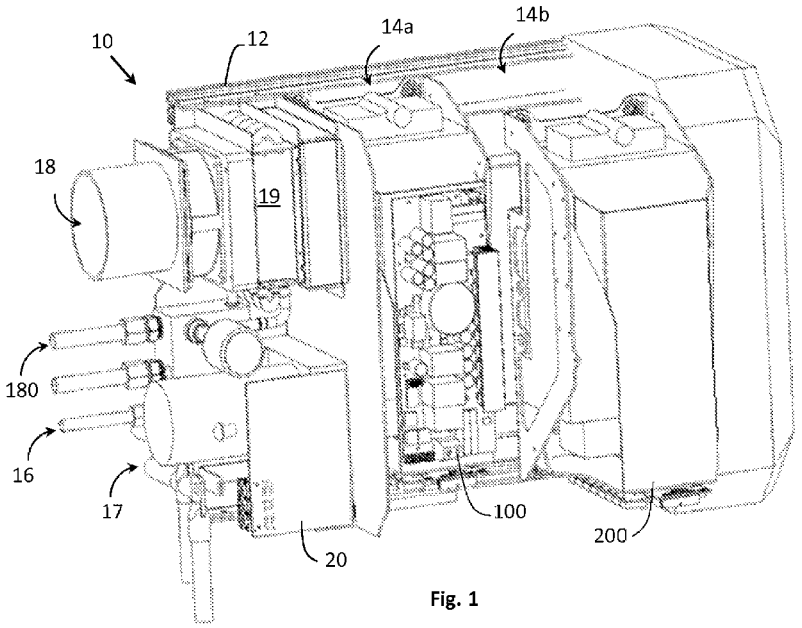


Fig. 1

(57) Abstract: A fuel cell module includes a fuel cell stack configured to produce an electrical output, power electronics circuitry configured to convert the electrical output of the fuel cell stack into a regulated output of the fuel cell module, module control electronics circuitry configured for communications within the fuel cell module and further configured for communications with master control electronics circuitry external to the fuel cell module, and a structure configured to connect together the fuel cell stack, the power electronics circuitry and the module control electronics circuitry as part of the fuel cell module that is unitary, and further configured for the unitary fuel cell module to be insertable as a unit into a multi-module system chassis.

WO 2014/126595 A1

MODULAR FUEL CELL SYSTEM

Field of Invention

The present disclosure relates generally to fuel cells and particularly to a modular fuel cell system.

Background

Conventional fuel cell systems generally lack expandability and thus, for the most part, systems are manufactured and sold in specific size (e.g., electrical power rating, heat output rating, etc.) units that are designed and manufactured for that specific size only. For example, a 1000W system is typically designed and manufactured specifically as a 1000W system. This creates issues at the manufacturing floor of lack of commonality of parts, stocking of non-common components, warehousing of specific size systems, etc. Moreover, once built, these systems will operate only up to their maximum capacity without the possibility of expanding.

From a marketing point of view, conventional systems' lack of expandability is a challenge because it is difficult for such systems to adapt to consumers' rapidly changing demands for power output, form factor, and continuous improvement. Conventional systems generally do not have the ability to be upgraded in power rating or other features without the introduction of entirely new designs. This, of course, creates additional issues including issues of design certification and validation (e.g., safety certification), system testing, etc. The undesirable results for the consumer and the manufacturer include longer times to market, increased costs and increased consumption of limited engineering resources.

Fuel cells are often used in combination heat and power (CHP) systems that provide, not only the electrical output of the fuel cell, but also garner heat produced by the fuel cell to provide a heat output. In conventional CHP systems, the heat output depends directly on the electrical output load of the fuel cell. This is a limitation, particularly in applications where a consistent heat output is desired.

Summary of Invention

The present disclosure provides fuel cell systems that are modular. The modular nature of the systems allows the manufacturer to design, test, certify and manufacture a single or reduced number of modules. The manufacturer may then use this reduced number of modules as common building blocks for a complete line of fuel cell systems of varying ratings and features. This allows for relatively short time to market and reduced costs on a new system of additional power rating or different features because the common building block is not required to be designed, tested or certified anew.

Also, the fuel cell systems disclosed herein may be operated as combination heat and power (CHP) systems where, not only are the fuel cell components modular, but a heater module is provided to break the dependence of the heat output of the CHP system from the electrical output. Modules, including fuel cell and heater modules, may be operated independently via a user interface to produce heat output only at a desired output level, electrical power with no additional heat output, or electrical output with additional heat output at a desired output level.

The modules may be provided to be self-sufficient in all aspects relating to power output (i.e., they include all pumps, blowers, valves, power and control electronics, etc.) and specifically tailored for the rated power output with no wasted capacity. The modules may also be provided to be plug and play to the larger fuel cell system.

According to one aspect of the invention, a fuel cell module includes a fuel cell stack configured to produce an electrical output, power electronics circuitry configured to convert the electrical output of the fuel cell stack into a regulated output of the fuel cell module, module control electronics circuitry configured for communications within the fuel cell module and further configured for communications with master control electronics circuitry external to the fuel cell module, and a structure configured to connect together the fuel cell stack, the power electronics circuitry and the module control electronics circuitry as part of the fuel cell module that is unitary, and further configured for the unitary fuel cell module to be insertable as a unit into a multi-module system chassis.

In one embodiment, the fuel cell module includes a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack, and a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack and to exhaust the fluid carrying heat from the fuel cell stack to a system exhaust configured to receive the fluid carrying heat from the fuel cell stack and fluid carrying heat from other modules inserted in the multi-module system chassis.

In another embodiment, the fuel cell module includes a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack, an afterburner configured to cause consumption of remnant gases from the fuel cell stack and to output a fluid carrying heat, and a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack and at least some of the fluid carrying heat from the afterburner to exhaust the fluids to a system exhaust configured to receive the fluids from the fuel cell module and fluids from other modules inserted in the multi-module system chassis.

In yet another embodiment, the fuel cell module includes an interface configured to connect the fuel cell stack to a fuel source transport, the module control electronics circuitry to the master control electronics circuitry, and the heat exhaust to the system exhaust.

In one embodiment, dimensions of the fuel cell stack, the power electronics circuitry, the module control electronics circuitry, and the balance of plant each conform to an envelope for the unitary fuel cell module to be insertable as a unit into the multi-module system chassis.

In another aspect of the present invention, a fuel cell module includes functional blocks arranged stacked as a unit. The functional blocks include a fuel cell stack block configured to produce an electrical output, a power electronics block configured to convert the electrical output of the fuel cell stack into a regulated output of the fuel cell module, and a structure configured to connect together the fuel cell stack block and the power electronics block for the fuel cell module to be insertable into a multi-module system chassis.

In one embodiment, the fuel cell module includes a module control electronics block configured to communicate within the fuel cell module and further configured for communications with master control electronics circuitry disposed external to the fuel cell module but within the multi-module system chassis.

In another embodiment, dimensions of each of the functional blocks conform to an envelope defined in part by the structure such that the fuel cell module is insertable as a unit into the multi-module system chassis.

In yet another embodiment, the fuel cell module includes a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack block, and a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack block and to exhaust the fluid carrying heat from the fuel cell stack block to a system exhaust configured to receive the fluid carrying heat from the fuel cell stack block and fluid carrying heat from other modules inserted in the multi-module system chassis.

In one embodiment, the fuel cell module includes a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack block, an afterburner configured to cause consumption of remnant gases from the fuel cell stack block and to output a fluid carrying heat, and a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack block and at least some of the fluid carrying heat from the afterburner to exhaust the fluids to a system exhaust configured to receive the fluids from the fuel cell module and fluids from other modules inserted in the multi-module system chassis.

In another embodiment, the fuel cell module includes a module control electronics block configured to communicate within the fuel cell module, wherein the module control electronics block is configured to communicate with a heater module connected to the multi-module system chassis and the system exhaust for a heat output of the heater module to be controlled such that a heat output of the system exhaust is regulated to a predetermined setting.

In yet another embodiment, the fuel cell module includes an interface configured to connect the fuel cell stack block to a fuel source, the module control electronics block to the master control electronics circuitry, and the heat exhaust to the system exhaust.

In yet another aspect of the present invention, a combined heat and power system includes a fuel cell module configured to produce an electric output and a fuel cell heat output, a heater module configured to produce a heater heat output, and a multi-module system chassis including multiple module receiving locations each of which is configured to non-simultaneously receive the fuel cell module and the heater module, the multi-module system chassis also including a system exhaust configured to combine at least some of the fuel cell heat output and at least some of the heater heat output into a system heat output.

In one embodiment, the combined heat and power system includes a master control configured to communicate with the fuel cell module and the heater module and further configured to control the heater module for the heater heat output to be modified taking into account the fuel cell heat output.

In another embodiment, the combined heat and power system includes a master control configured to communicate with the fuel cell module and the heater module and further configured to control the heater module for the heater heat output to be controlled such that the system heat output including at least some of the fuel cell heat output is regulated to a predetermined setting.

In yet another embodiment, the combined heat and power system includes a second fuel cell module configured to produce a second electric output and a second fuel cell heat output. Each of the multiple module receiving locations is configured to receive the second fuel cell module and the system exhaust is configured to combine at least some of the fuel cell heat output, at least some of the heater heat output, and at least some of the second fuel cell heat output into the system heat output.

In one embodiment, the combined heat and power system includes a second heater module configured to produce a second heater heat output. Each

of the multiple module receiving locations is configured to receive the second heater module and the system exhaust is configured to combine at least some of the fuel cell heat output, at least some of the heater heat output, and at least some of the second heater heat output into the system heat output.

In another embodiment, the combined heat and power system includes a master control configured to communicate with the fuel cell module, the heater module and the second heater module, and further configured to control at least one of the heater module and the second heater module for at least one of the heater heat output and the second heater heat output to be modified taking into account the fuel cell heat output.

In yet another embodiment, the combined heat and power system includes a master control configured to communicate with the fuel cell module, the heater module and the second heater module, and further configured to control at least one of the heater module and the second heater module for at least one of the heater heat output and the second heater heat output to be controlled such that the system heat output including at least some of the fuel cell heat output is regulated to a predetermined setting.

In one embodiment, the combined heat and power system includes an interface configured to connect the fuel cell module and the heater module to a fuel source, and the fuel cell heat output and the heater heat output to the system exhaust.

The foregoing and other features of the invention are hereinafter described in greater detail with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 illustrates a perspective view of an exemplary modular fuel cell system.

Figs. 2A and 2B illustrate perspective and side views of an exemplary fuel cell module.

Figs. 3A and 3B illustrate perspective and side views of an exemplary heater module.

Fig. 4 illustrates a block diagram of an exemplary modular fuel cell system.

Fig. 5A illustrates an exemplary fuel cell modular system that accommodates up to one module.

Fig. 5B illustrates an exemplary fuel cell modular system that accommodates up to two modules.

Fig. 5C illustrates an exemplary fuel cell modular system that accommodates up to three modules.

Fig. 5D illustrates an exemplary fuel cell modular system that accommodates up to four modules in series.

Fig. 5E illustrates an exemplary fuel cell modular system that accommodates up to four modules with two groups of series modules disposed back to back.

Detailed Description

Fig. 1 illustrates an exemplary modular fuel cell system 10 that includes a chassis 12. The chassis 12 is a multi-module system chassis that includes multiple module receiving locations 14a and 14b. Although in the illustrated embodiment the chassis 12 is shown including two module receiving locations 14, as described below, the chassis 12 may include more than two module receiving locations 14. The system 10 is shown in Fig. 1 with portions of the enclosure removed for ease of illustration. The system 10 is shown fully enclosed in Fig. 5B.

In the illustrated embodiment, the system 10 includes a fuel cell module 100 and a heater module 200. The fuel cell module 100 and heater module 200 are described in more detail below. But, in general, the fuel cell module 100 is a device in which an electrochemical reaction takes place between fuel, such as gas containing hydrogen, and oxidizer gas, such as gas containing oxygen, in an electrolyte to extract an electrical output. The electrochemical reaction in the fuel cell module 100 also produces a heat output. In general, the heater module 200 is a device that produces a heat output.

The illustrated embodiment shows the fuel cell module 100 installed or connected to the chassis 12 while, for purposes of illustration, the heater module 200 is shown removed from or about to be installed or connected to the chassis 12. Although in the illustrated embodiment one fuel cell or power module 100 and one heater module 200 are shown, the module receiving locations 14a and 14b are each configured to non-simultaneously receive fuel cell modules 100 and heater modules 200. This means that each of the module receiving locations such as 14a or 14b can receive a fuel cell module 100 and each of the module receiving locations can also receive a heater module 200. Thus a chassis such as chassis 12 that has two module receiving locations may receive up to two fuel cell modules 100, up to two heater modules 200, or up to one fuel cell module 100 and one heater module 200.

The system 10 receives fuel via a fuel transport 16 that receives the fuel from a fuel source and transports the fuel to the modules 100 and 200.

The system 10 also includes a system electrical output 17 that combines and outputs the electrical outputs of the fuel cell modules installed in the chassis 12. In the illustrated embodiment, the system electrical output 17 outputs the electrical output of the lone fuel cell module 100. But, in embodiments where the system 10 includes more than one fuel cell module 100, the system 10 combines the electrical output of all the fuel cell modules 100 via, for example, bus bars connected to the electrical output 17.

The system 10 also includes a system exhaust 18 that combines and exhausts at least some of the heat output of the modules installed in the chassis 12. In the illustrated embodiment, the system exhaust 18 exhausts heat from the fuel cell module 100 and the heater module 200. In the illustrated embodiment, the system 10 includes a heat exchanger / circulation pump 19. The heat exchanger transfers heat from fluid exhausted from the modules 100 and 200 to fluid to be exhausted by the system exhaust 18. The circulation pump circulates liquid that is heated by the heat removed from the fluid exhausted from the modules 100 and 200. The heated liquid exits the system 10 via the circulation output 180. In another embodiment, the system 10 does not include a heat exchanger, circulation output or circulation pump.

In the illustrated embodiment, the system 10 further includes a master electronics circuitry 20 that may include a user interface, safety shut-off controls, a remote communication hub and other measurement and control functions. The master electronics circuitry 20 may communicate with the modules 100 and 200. In another embodiment, as discussed below, the system 10 does not include a master electronics circuitry 20.

Figs. 2A and 2B illustrate perspective and side views of an exemplary fuel cell module 100. In general, the fuel cell module 100 includes in a single modular entity all or most of the power and controls systems needed to support its rated output. In that sense, the module 100 is by itself a fully operational fuel cell system. However, in general, the module 100 does not include components outside of systems needed to support its rated output and any systems needed to interact within the system 10. Thus the module 100 generally does not include components that are better provided at the system 10 to avoid unnecessary redundancy among modules.

Specifically, the module 100 includes a fuel cell stack 110 in which the electrochemical reaction discussed above takes place to produce the electrical output. As a result of the electrochemical reaction, the fuel cell stack 110 also produces the heat output. The ratio of electrical to heat output is a function of the efficiency of the fuel cell stack 110. For example, in a fuel cell stack that is 50% efficient, approximately half of the energy derived from the fuel is converted to the electrical output while the other half is converted to heat.

Examples of fuel that the fuel cell stack 110 may use include hydrogen, which can be in the form of hydrogen gas. However, alternative hydrogen-rich fuels such as, for example, propane, natural gas, diesel, gasoline, jet fuel and biofuels may be used. The use of alternative fuels may require that the fuel be reformed for the hydrogen gas to be separated from other constituents of the fuel. In one embodiment, the fuel cell module 100 includes a reformer to reform the fuel. In another embodiment, the reformer is included in the system 10, but external to the module 100. For example, the reformer may take the form of a module, similar to the modules 100 and 200, that is insertable in the chassis 12. In another embodiment, the reformer is included in the system 10 external to the

module 100, but not as a module. In yet another embodiment, the reformer is provided external to the system 10.

The module 100 also includes power electronics circuitry 120 that converts the electrical output of the fuel cell stack 110 to a regulated output of the fuel cell module 100. The module 100 further includes module control electronics circuitry 130 that may communicate with the master electronics circuitry 20 of the system 10. The module control electronics circuitry 130 also communicates within the fuel cell module 100 to, for example, set maximum power output limits, etc.

In the illustrated embodiment, the module 100 further includes a balance of plant 140. The balance of plant 140 may include valves, blowers, fans or other devices that are complementary to the fuel cell stack 110 and that allow or assist the fuel cell stack 110 or other components of the module 100 to perform to their rating. For example, the balance of power 140 include a device (e.g., fan, blower, etc.) that exhaust a fluid (e.g., air, water vapor, etc.) carrying heat (i.e., the heat output) from the fuel cell stack 110.

The module 100 also includes a heat exhaust 150 that receives at least some of the fluid carrying the heat removed from the fuel cell stack 110 and exhausts the fluid to the system exhaust 18. As discussed above, the system exhaust 18 receives the fluid carrying heat from the module 100 and fluid carrying heat from other modules in the multi-module system chassis 12.

In one embodiment (not shown), the module 100 also includes an afterburner that causes consumption (e.g., combustion, oxidation, etc.) of remnant fluid (e.g., hydrogen) from the fuel cell stack 110 and outputs a fluid (e.g., water vapor) carrying heat. In this embodiment, the heat exhaust 150 receives the combination of at least some of the fluid carrying heat from the fuel cell stack 110 and at least some of the fluid carrying heat from the afterburner. The system exhaust receives this combination of fluids from the fuel cell module 100 and fluid from other modules in the multi-module system 10.

In one embodiment, the heat output of the fuel cell module 100 may be increased by diverging some of the fuel input into the fuel cell module 100 to the

afterburner to increase the heat output of the afterburner. In another embodiment, the fuel cell stack 110 and the afterburner reside within one common enclosure.

The module 100 also includes a structure 160. The structure 160 directly or indirectly connects components of the fuel cell module 100 so that together these components form the fuel cell module 100. For example, in the illustrated embodiment, the structure 160 connects the fuel cell stack 110, the power electronics circuitry 120, the module control electronics circuitry 130, the balance of plant 140 and the exhaust 150. In some embodiments, the structure 160 connects fewer components than those illustrated, while in other embodiments the structure 160 connects more components than those illustrated. Connection provided by the structure 160 makes the fuel cell module 100 a unitary fuel cell module that is held together and insertable in the system chassis 12 as a unit.

The fuel cell module 100 interfaces with the system 10 to receive fuel via the fuel transport 16, to communicate via the module control electronics circuitry 130 to the master electronics circuitry 20, to exhaust heat via the heat exhaust 150 to the system exhaust 18, and so on.

Figs. 3A and 3B illustrate perspective and side views of an exemplary heater module 200. In general, the heater module 200 includes in a single modular entity all or most of the power and controls systems to support its rated output. In that sense, the module 200 is by itself a fully operational heating system. However, in general, the module 200 does not include components outside of systems needed to support its rated output and any systems needed to interact within the system 10. Thus, similar to the fuel cell module 100, the heater module 200 generally does not include components that are better provided at the system 10 to avoid unnecessary redundancy.

Specifically, the heater module 200 includes a heater 210 that produces a heat output. For example, the heater 210 may produce a heat output by combustion, oxidation, interaction of fuel with an electric element, or by any other method. The module 200 also includes module control electronics circuitry 230 that may communicate with the master electronics circuitry 20 of the system 10 or with module control electronics circuitry 130 or 230 of other modules in the

system 10. The module control electronics circuitry 230 also communicates within the heater module 200 to, for example, set maximum heat output limits, etc.

In the illustrated embodiment, the module 200 further includes a balance of plant 240. The balance of plant 240 may include valves, blowers, fans or other devices that are complementary to the heater 210 and that allow or assist the heater 210 or other components of the module 200 to perform to their rating. For example, the balance of power 240 may include a device (e.g., fan, blower, etc.) that exhaust a fluid (e.g., air, water vapor, etc.) carrying heat from the heater 210.

The module 200 also includes a heat exhaust 250 that receives at least some of the fluid carrying the heat from the heater 210 and exhausts the fluid to the system exhaust 18. As discussed above, the system exhaust 18 receives the fluid carrying heat from the heater module 200 and fluid carrying heat from other modules in the multi-module system chassis 12.

The module 200 also includes a structure 260. The structure 260 directly or indirectly connects components of the heater module 200 so that together these components form the heater module 200. For example, in the illustrated embodiment, the structure 260 connects the heater 210, the module control electronics circuitry 230, the balance of plant 240 and the exhaust 250. In some embodiments, the structure 260 connects fewer components than those illustrated, while in other embodiments the structure 260 connects more components than those illustrated. Connection provided by the structure 260 makes the heater module 200 a unitary heater module that is held together and insertable in the system chassis 12 as a unit.

The heater module 200 interfaces with the system 10 to receive fuel via the fuel transport 16, to communicate via the module control electronics circuitry 230 to the master electronics circuitry 20, to exhaust heat via the heat exhaust 250 to the system exhaust 18, and so on.

The fuel cell module 100 and the heater module 200 have dimensions that allow for the modules to be insertable as a unit into the system chassis 12.

Therefore, in the fuel cell module 100, for example, dimensions of the fuel cell stack 110, the power electronics circuitry 120, the module control electronics circuitry 130, and the balance of plant 140 each conform to an envelope for the unitary fuel cell module 100 to be insertable as a unit into the multi-module system chassis 12. Similarly, in the heater module 200, dimensions of the heater 210, the module control electronics circuitry 230, and the balance of plant 240 may each conform to an envelope for the unitary heater module 200 to be insertable as a unit into the multi-module system chassis 12.

In one embodiment, the fuel cell module 100 and the heater module 200 may be conceptualized as a series of functional blocks that are arranged stacked as a unit. Therefore, in the fuel cell module 100, for example, the functional blocks include the fuel cell stack 110 (i.e., a fuel cell stack block), the power electronics circuitry 120 (i.e., a power electronics block), etc. The structure 160 connects the blocks together for the fuel cell module 100 to be insertable into the multi-module system chassis 12 as a unit.

Fig. 4 illustrates a block diagram of an exemplary modular fuel cell system 30. As discussed above, a modular fuel cell system such as system 30 may include fuel cell modules 100. In the illustrated embodiment, the system 30 includes two fuel cell modules 100a and 100b. The system 30 may also include heater modules 200. In the illustrated embodiment, the system 30 includes one heater module 200.

The system 30 receives fuel via a fuel transport 16 that receives the fuel from a fuel source and transports the fuel to the modules 100 and 200. The system 30 also includes a system electrical output 17 (e.g., electrical bus) that combines and outputs the electrical outputs of the fuel cell modules 100. The system electrical output 17 may connect to devices powered or charged by the electrical output 17 including a battery.

The system 30 further includes a system exhaust 18 that combines and exhausts at least some of the heat output of the fuel cell modules 100 and the heater modules 200. The system 30 also includes a circulation output 180 that transports liquid heated by heat from the fuel cell modules 100 and the heater modules 200.

The system 30 further includes a master electronics circuitry 20 that may include a user interface, safety shut-off controls, a remote communication hub and other measurement and control functional blocks. The master electronics circuitry 20 communicates with the modules 100 and 200.

The fuel cell modules 100a and 100b include the fuel cell stacks 110 that produce an electrical output and a heat output. The modules 100 also include power electronics circuitry 120 that converts the electrical output of the fuel cell stack 110 into the regulated output of the fuel cell modules 100. The modules 100 further include module control electronics circuitry 130 that communicates with the master electronics circuitry 20 of the system 30. The module control electronics circuitry 130 also communicates within the fuel cell module 100 to, for example, set maximum power output limits, etc.

The fuel cell module 100 further includes the balance of plant 140 that includes, for example, a device (e.g., fan, blower, etc.) that exhausts fluid (e.g., air) carrying heat from the fuel cell stack 110 for at least some of the heat output to be transferred by the heat exchanger / circulation pump 19 to fluid to be exhausted to the system exhaust 18.

In the illustrated embodiment, the modules 100 include afterburners 170 that cause consumption (e.g., combustion, oxidation, etc.) of remnant fluid (e.g., hydrogen) from the fuel cell stack 110 and output a fluid (e.g., water vapor) carrying heat. The heat exchanger / circulation pump 19 exchanges the combination of at least some of the fluid carrying heat from the fuel cell stack 110 and at least some of the fluid carrying heat from the afterburner 170 to fluid that is transferred to the system exhaust 18. The circulation pump causes transfer of some of the heat from the fuel cell stack 110 and at least some of the fluid carrying heat from the afterburner 170 to liquid that is circulated via the circulation output 180.

The heater module 200 includes a heater 210 that produces a heat output as described above. The module 200 also includes module control electronics circuitry 230 that communicates with the master electronics circuitry 20 of the system 30 or with module control electronics circuitry 130 or 230 of other modules in the system 30. The module control electronics circuitry 230 also

communicates within the heater module 200 to, for example, set maximum heat output limits, etc.

The heater module 200 further includes the balance of plant 240 that includes, for example, a device (e.g., fan, blower, etc.) that exhausts a fluid (e.g., air) carrying heat from the heater 210. The module 200 exhausts the fluid carrying the heat from the heater 210 to be transferred by the heat exchanger / circulation pump 19 to fluid to be exhausted to the system exhaust 18 or liquid to be circulated via the circulation output 180..

The fuel cell modules 100 and the heater module 200 interface with the system 30 at least to receive fuel via the fuel transport 16, to communicate via the module control electronics circuitry 130 and 230, respectively, to the master electronics circuitry 20 and to exhaust heat via the heat exhausts 150 and 250, respectively, to the system exhaust 18. In addition, the fuel cell modules 100 interface with the system 30 to deliver their electrical output via the system electrical output 17.

The module control electronics circuitry 130 and 230 and the master electronics circuitry 20 may be daisy chained for communication. This means that the master electronics circuitry 20 connects to the first module 100a, which in turn connects to the second module 200, and the second module 200 to the third module 100b. In one embodiment, the module control electronics circuitry 130 and 230 communicate via a CAN (controller area network) bus. Alternatively, the module control electronics circuitry 130 and 230 may communicate with the master electronics circuitry 20 in a discreet fashion, so that each module control electronics circuitry 130 and 230 communicates individually with the master electronics circuitry 20.

In one embodiment where at least one fuel cell module 100 and at least one heater module 200 are installed, the master electronics circuitry 20 communicates with the module electronics circuitry 130 and 230 of the fuel cell module 100 and the heater module 200, respectively. The master electronics circuitry 20 controls the heat output of the heater module 200 taking into account the heat output of the fuel cell 100.

For example, a system 10 including a single 500 W fuel cell module 100 and a single 2,500 BTU/hr heater module 200 may be installed in an application where 500 W of electrical power and 2,000 BTU/hr of heat are required. The fuel cell module 100 alone can provide the 500 W of electrical output and may be able to provide approximately 1,600 BTU/hr heat output while delivering the 500W of electrical output. To make up for the difference in heat output (i.e., 2,000 BTU/hr – 1,600 BTU/hr = 400 BTU/hr) the master electronics circuitry 20 may communicate with the module electronics circuitry 230 of the heater module 200 to command a heater output of 400 BTU/hr.

Thus, in this embodiment, the master electronics circuitry 20 communicates with the heater module 200. The heat output of the heater module 200 is controlled such that the heat output of the system 30, including at least some heat from the fuel cell module 100 and some heat from the heater module 200, is regulated to a predetermined setting. Therefore, the system including the fuel cell module 100 and the heater module 200 may be operated as a combination heat and power (CHP) system that breaks the dependence of the heat output from the electrical output. The fuel cell module 100 and the heater module 200 may be operated to produce heat output only at a predetermined setting, electrical power with no additional heat output, or electrical output with additional heat output at a predetermined setting.

In another embodiment, the system 30 does not include a master electronics circuitry 20 and instead uses a master module / slave module arrangement. In this embodiment, one of the modules acts as the master and the remaining modules act as the slaves. The module electronics circuitry 130 or 230 of the master module acts similar to the master control electronics 20. The remaining modules are connected to (e.g., daisy chained together) and controlled by the master module.

In one embodiment where at least one fuel cell module 100 and at least one heater module 200 are installed, the module electronics circuitry 130 or 230 of the master module acting as the master control electronics 20 communicates within its corresponding module and with the module electronics circuitry 130 and 230 of other fuel cell modules 100 or heater modules 200, respectively. The

module electronics circuitry 130 or 230 of the master module acting as the master control electronics 20 controls the heat output of the heater module 200 taking into account the heat output of the fuel cell 100. This way the heat output at the system exhaust 18 is regulated to a predetermined setting as discussed above.

In the embodiments of Figs. 1 and 4, the fuel cell modules 100 may be 500W modules and the heater modules 200 may be 10,000BTU/hr modules. However, different sized fuel cell modules 100 (e.g., 100W, 500W, 1000W, etc.) and different sized heater modules 200 (e.g., 2,500BTU/hr, 5,000BTU/hr, 10,000BTU/hr, etc.) may be used, including, for example combinations of different fuel cell modules 100 and different heater modules 200 within the same system.

Figs. 5A-5E illustrate exemplary fuel cell modular systems 5, 10, 30, 40 and 50, respectively. The embodiments of Figs. 5A-5E seek to illustrate exemplary sizes for modular fuel cell systems. In the illustrated embodiments, the systems 5, 10, 30, 40 and 50 are illustrated fully enclosed. The main differences between systems are the physical size of the chassis 12 and the number of module receiving locations. Otherwise, the systems are almost identical. The modularity of these systems creates a very flexible fuel cell system platform.

The system 5 accommodates a single module and thus when equipped with a 500 W fuel cell module 100, for example, the system 5 results in a 500 W fuel cell system or when equipped with a 5,000 BTU/hr heater module 200, for example, the system 5 results in a 5,000 BTU/hr heater system.

The system 10 accommodates two modules and thus when equipped with two 500 W fuel cell modules 100, for example, the system 10 results in a 1000 W fuel cell system. When equipped with two 5,000 BTU/hr heater modules 200, for example, the system 10 results in a 10,000 BTU/hr heater system. When equipped with one 500 W fuel cell module 100 and one 5,000 BTU/hr heater module 200, for example, the system 10 results in a combination 500 W electrical output and 5,000 BTU/hr heat output system.

Similarly, the system 30 accommodates three modules. The systems 40 and 50 both accommodate four modules each. The system 40 accommodates four modules disposed in series, while the system 50 accommodates four modules with two groups of two modules disposed back to back.

The systems described herein may provide a user the ability to adjust the system electrical and heat capacity by adding, removing or replacing modules or simply by shutting down modules. If, once a system has been installed, additional capacity becomes necessary, modules may be installed into any empty module receiving location or higher capacity modules may replace existing modules to increase electrical or heat output. Likewise, if once a system has been installed, less capacity is necessary, the size and number of modules also can be changed to reduce capacity.

Additionally, on a manufacturing floor, the systems allow for ease of production because their expandability requires little changeover when assembling different size units and does not require new training for assembly. Once the manufacturing line is in operation, the assembly procedure is substantially the same, regardless of the size of the fuel cell.

Although the invention has been shown and described with respect to a certain embodiment or embodiments, equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

Claims

What is claimed is:

1. A fuel cell module comprising:

a fuel cell stack configured to produce an electrical output;

power electronics circuitry configured to convert the electrical output of the fuel cell stack into a regulated output of the fuel cell module;

module control electronics circuitry configured for communications within the fuel cell module and further configured for communications with master control electronics circuitry external to the fuel cell module; and

a structure configured to connect together the fuel cell stack, the power electronics circuitry and the module control electronics circuitry as part of the fuel cell module that is unitary, and further configured for the unitary fuel cell module to be insertable as a unit into a multi-module system chassis.

2. The fuel cell module of claim 1, comprising:

a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack; and

a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack and to exhaust the fluid carrying heat from the fuel cell stack to a system exhaust configured to receive the fluid carrying heat from the fuel cell stack and fluid carrying heat from other modules inserted in the multi-module system chassis.

3. The fuel cell module of claim 1, comprising:

a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack;

an afterburner configured to cause consumption of remnant gases from the fuel cell stack and to output a fluid carrying heat; and

a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack and at least some of the fluid carrying heat from the afterburner to exhaust the fluids to a system exhaust configured to receive the fluids from the fuel cell module and fluids from other modules inserted in the multi-module system chassis.

4. The fuel cell module of any of claims 1-3, comprising:

an interface configured to connect the fuel cell stack to a fuel source transport, the module control electronics circuitry to the master control electronics circuitry, and the heat exhaust to the system exhaust.

5. The fuel cell module of any of claims 1-3, wherein dimensions of the fuel cell stack, the power electronics circuitry, the module control electronics circuitry, and the balance of plant each conform to an envelope for the unitary fuel cell module to be insertable as a unit into the multi-module system chassis.

6. A fuel cell module comprising:

functional blocks arranged stacked as a unit, the functional blocks including:

a fuel cell stack block configured to produce an electrical output;

a power electronics block configured to convert the electrical output of the fuel cell stack into a regulated output of the fuel cell module; and

a structure configured to connect together the fuel cell stack block and the power electronics block for the fuel cell module to be insertable into a multi-module system chassis.

7. The fuel cell module of claim 6, comprising:

a module control electronics block configured to communicate within the fuel cell module and further configured for communications with master control

electronics circuitry disposed external to the fuel cell module but within the multi-module system chassis.

8. The fuel cell module of any of claims 6-7, wherein dimensions of each of the functional blocks conform to an envelope defined in part by the structure such that the fuel cell module is insertable as a unit into the multi-module system chassis.

9. The fuel cell module of claim 6, comprising:

a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack block; and

a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack block and to exhaust the fluid carrying heat from the fuel cell stack block to a system exhaust configured to receive the fluid carrying heat from the fuel cell stack block and fluid carrying heat from other modules inserted in the multi-module system chassis.

10. The fuel cell module of claim 6, comprising:

a balance of plant including a device configured to exhaust a fluid carrying heat from the fuel cell stack block;

an afterburner configured to cause consumption of remnant gases from the fuel cell stack block and to output a fluid carrying heat; and

a heat exhaust configured to receive at least some of the fluid carrying heat from the fuel cell stack block and at least some of the fluid carrying heat from the afterburner to exhaust the fluids to a system exhaust configured to receive the fluids from the fuel cell module and fluids from other modules inserted in the multi-module system chassis.

11. The fuel cell module of any of claims 9-10, comprising:

a module control electronics block configured to communicate within the fuel cell module, wherein the module control electronics block is configured to communicate with a heater module connected to the multi-module system chassis and the system exhaust for a heat output of the heater module to be controlled such that a heat output of the system exhaust is regulated to a predetermined setting.

12. The fuel cell module of any of claims 6-11, comprising:

an interface configured to connect the fuel cell stack block to a fuel source, the module control electronics block to the master control electronics circuitry, and the heat exhaust to the system exhaust.

13. A combined heat and power system, comprising:

a fuel cell module configured to produce an electric output and a fuel cell heat output;

a heater module configured to produce a heater heat output; and

a multi-module system chassis including multiple module receiving locations each of which is configured to non-simultaneously receive the fuel cell module and the heater module, the multi-module system chassis also including a system exhaust configured to combine at least some of the fuel cell heat output and at least some of the heater heat output into a system heat output.

14. The combined heat and power system of claim 13, comprising:

a master control configured to communicate with the fuel cell module and the heater module and further configured to control the heater module for the heater heat output to be modified taking into account the fuel cell heat output.

15. The combined heat and power system of claim 13, comprising:

a master control configured to communicate with the fuel cell module and the heater module and further configured to control the heater module for the heater heat output to be controlled such that the system heat output including at least some of the fuel cell heat output is regulated to a predetermined setting.

16. The combined heat and power system of claim 13, comprising:

a second fuel cell module configured to produce a second electric output and a second fuel cell heat output, wherein

each of the multiple module receiving locations is configured to receive the second fuel cell module,

the system exhaust is configured to combine at least some of the fuel cell heat output, at least some of the heater heat output, and at least some of the second fuel cell heat output into the system heat output.

17. The combined heat and power system of claim 13, comprising:

a second heater module configured to produce a second heater heat output, wherein

each of the multiple module receiving locations is configured to receive the second heater module,

the system exhaust is configured to combine at least some of the fuel cell heat output, at least some of the heater heat output, and at least some of the second heater heat output into the system heat output.

18. The combined heat and power system of claim 17, comprising:

a master control configured to communicate with the fuel cell module, the heater module and the second heater module, and further configured to control at least one of the heater module and the second heater module for at least one of the heater heat output and the second heater heat output to be modified taking into account the fuel cell heat output.

19. The combined heat and power system of claim 17, comprising:

a master control configured to communicate with the fuel cell module, the heater module and the second heater module, and further configured to control at least one of the heater module and the second heater module for at least one of the heater heat output and the second heater heat output to be controlled such that the system heat output including at least some of the fuel cell heat output is regulated to a predetermined setting.

20. The combined heat and power system of claim 13, comprising:

an interface configured to connect the fuel cell module and the heater module to a fuel source, and the fuel cell heat output and the heater heat output to the system exhaust.

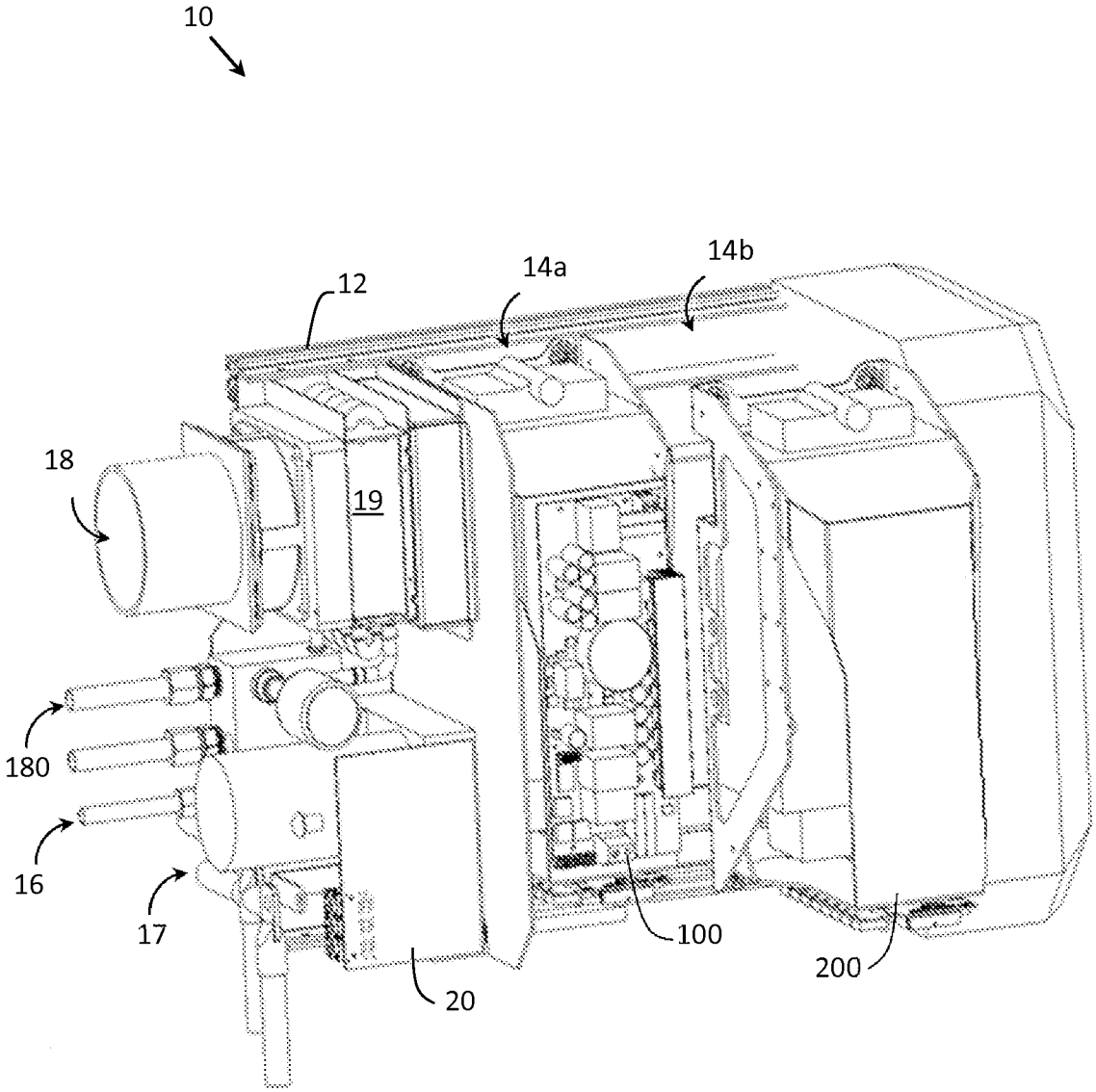


Fig. 1

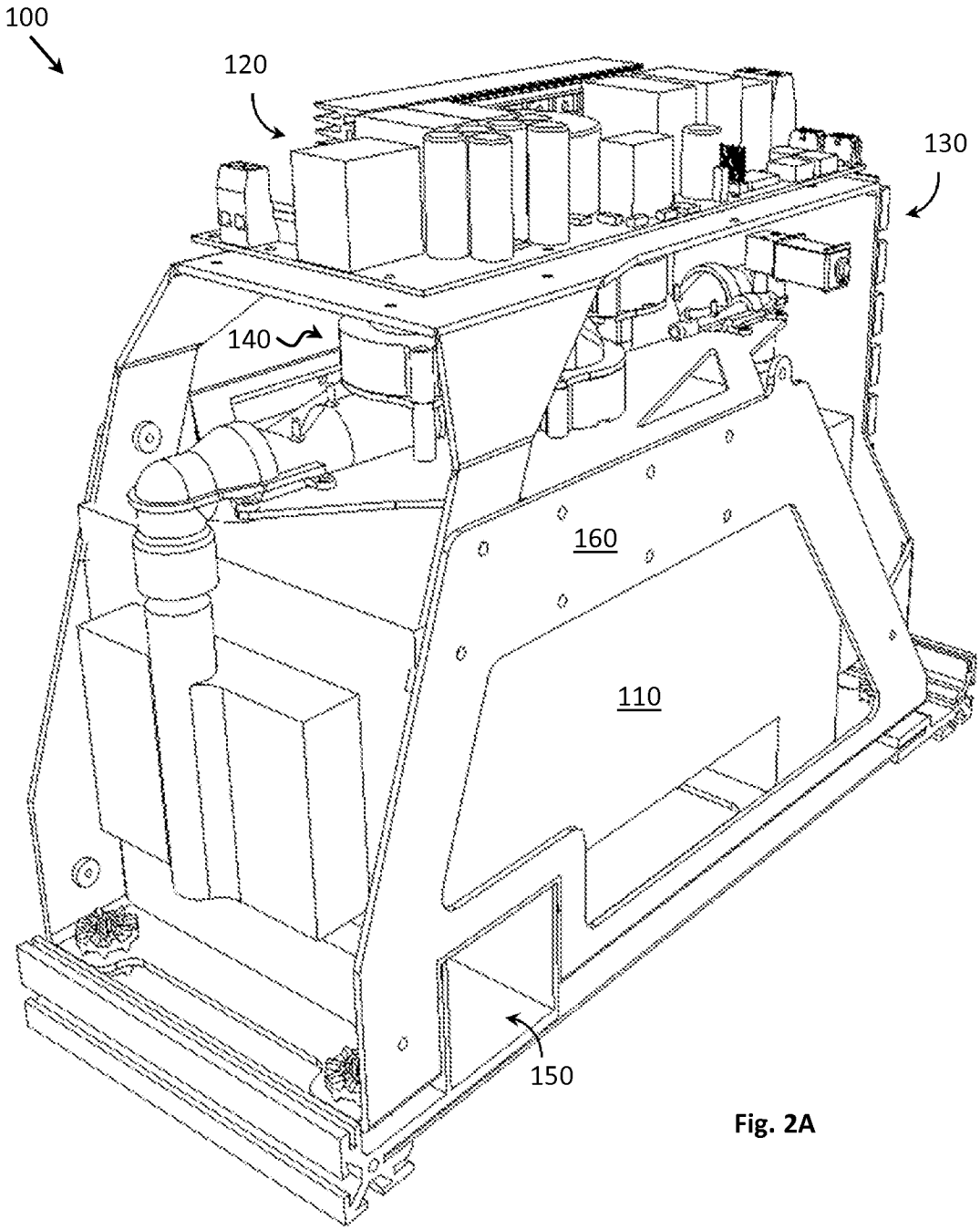


Fig. 2A

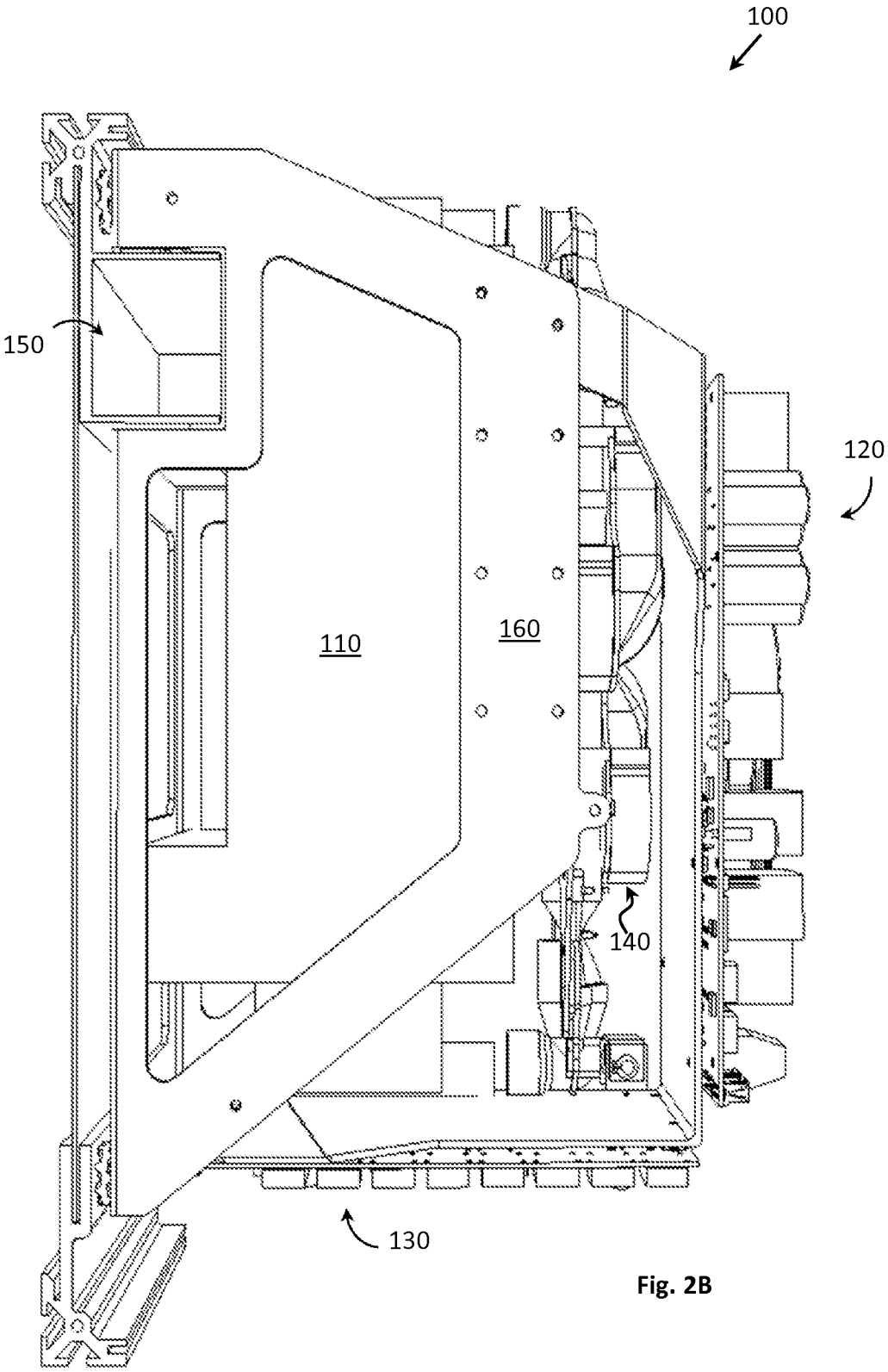


Fig. 2B

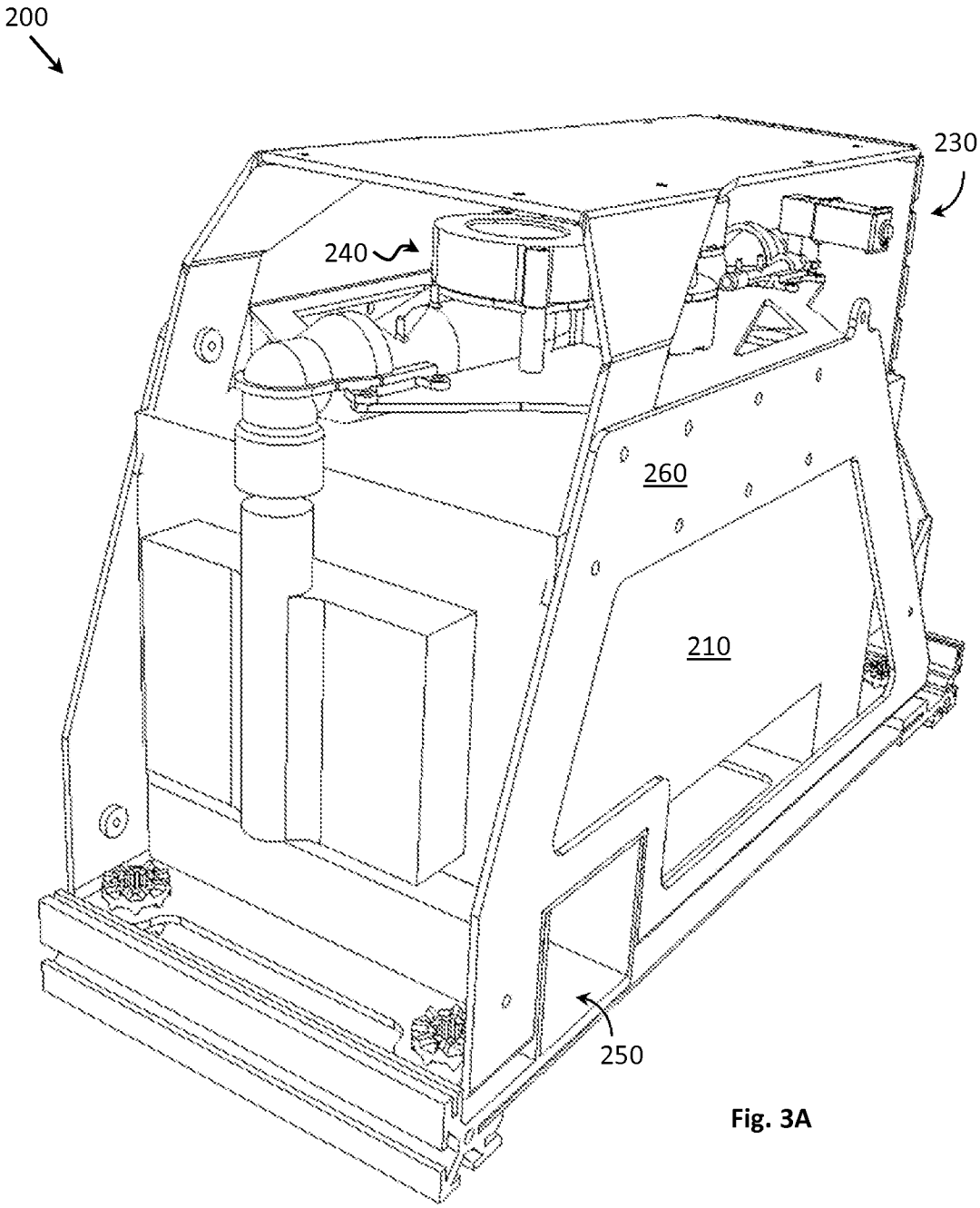


Fig. 3A

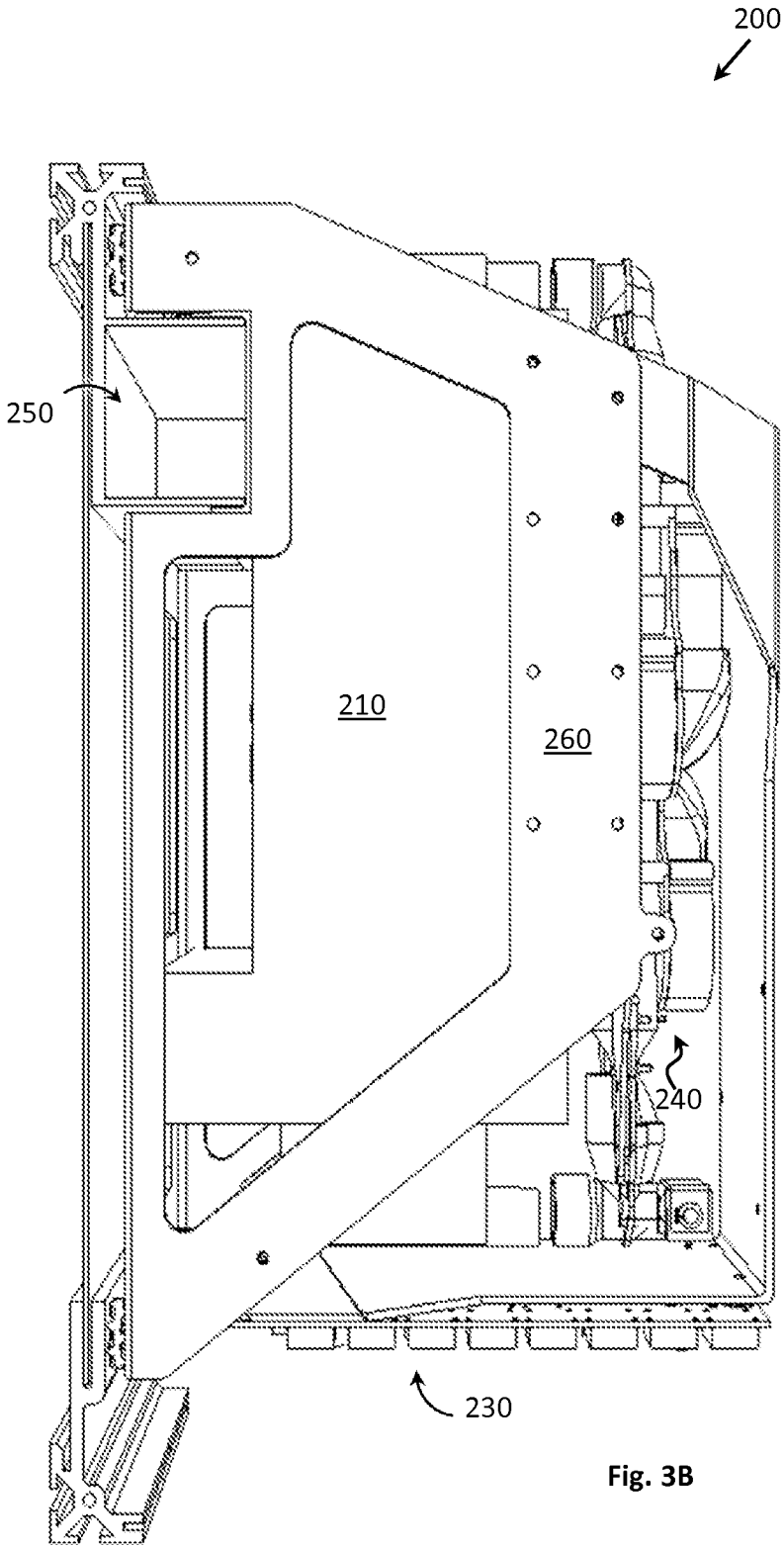


Fig. 3B

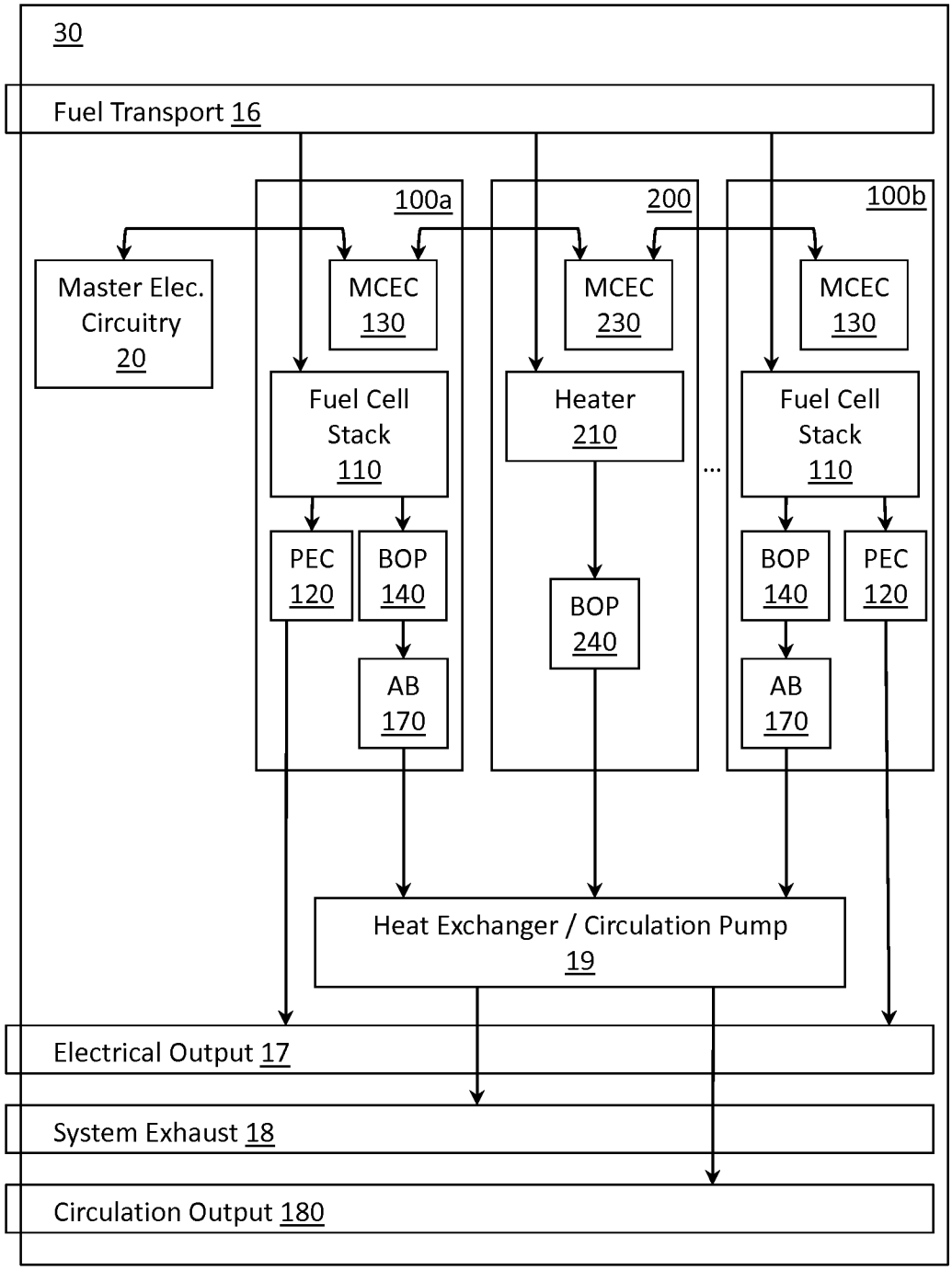

30
Fuel Transport 16
100a
200
100b
Master Elec. Circuitry 20
MCEC 130
MCEC 230
MCEC 130
Fuel Cell Stack 110
Heater 210
Fuel Cell Stack 110
PEC 120
BOP 140
BOP 240
BOP 140
PEC 120
AB 170
AB 170
Heat Exchanger / Circulation Pump 19
Electrical Output 17
System Exhaust 18
Circulation Output 180

Fig. 4

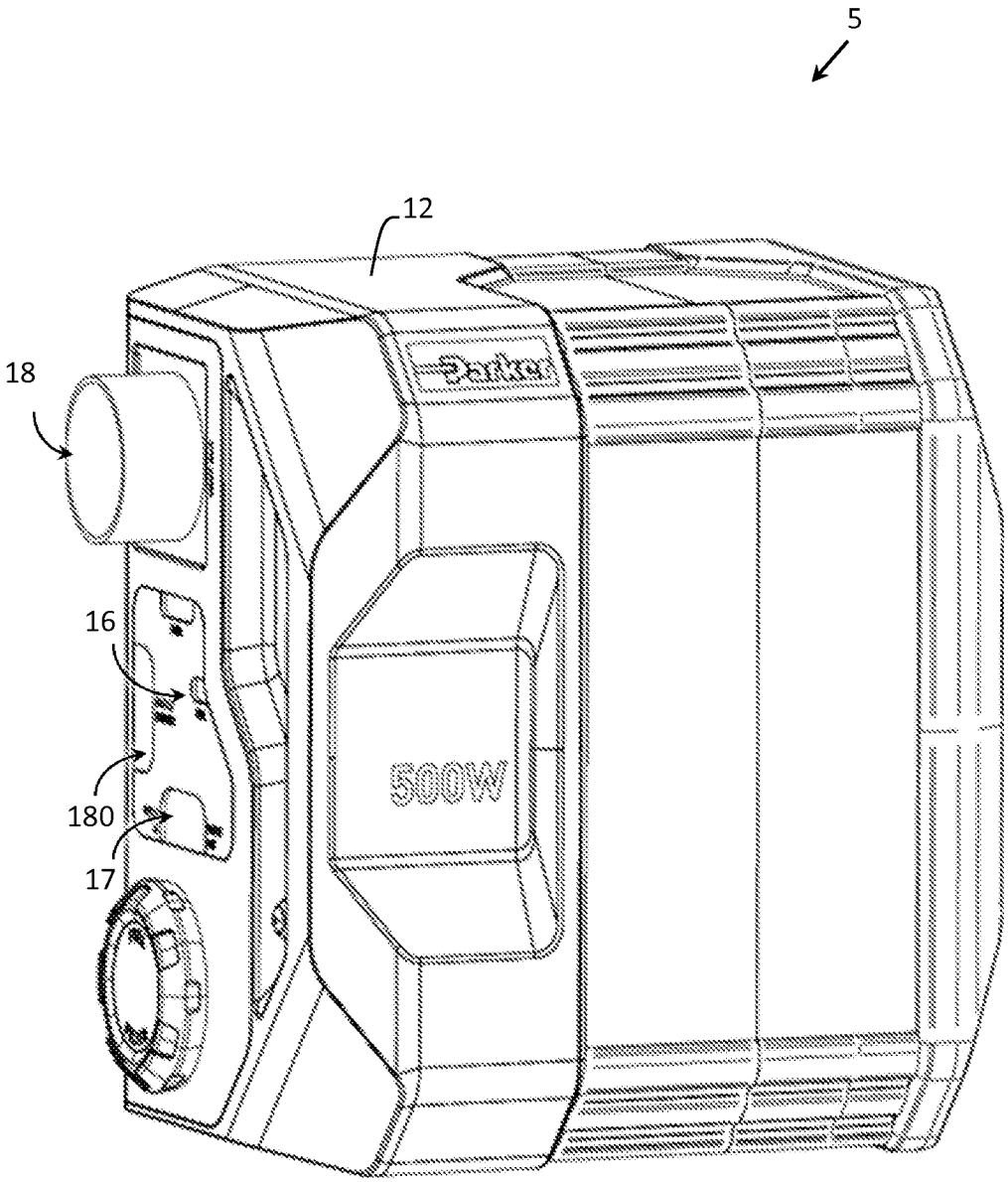


Fig. 5A

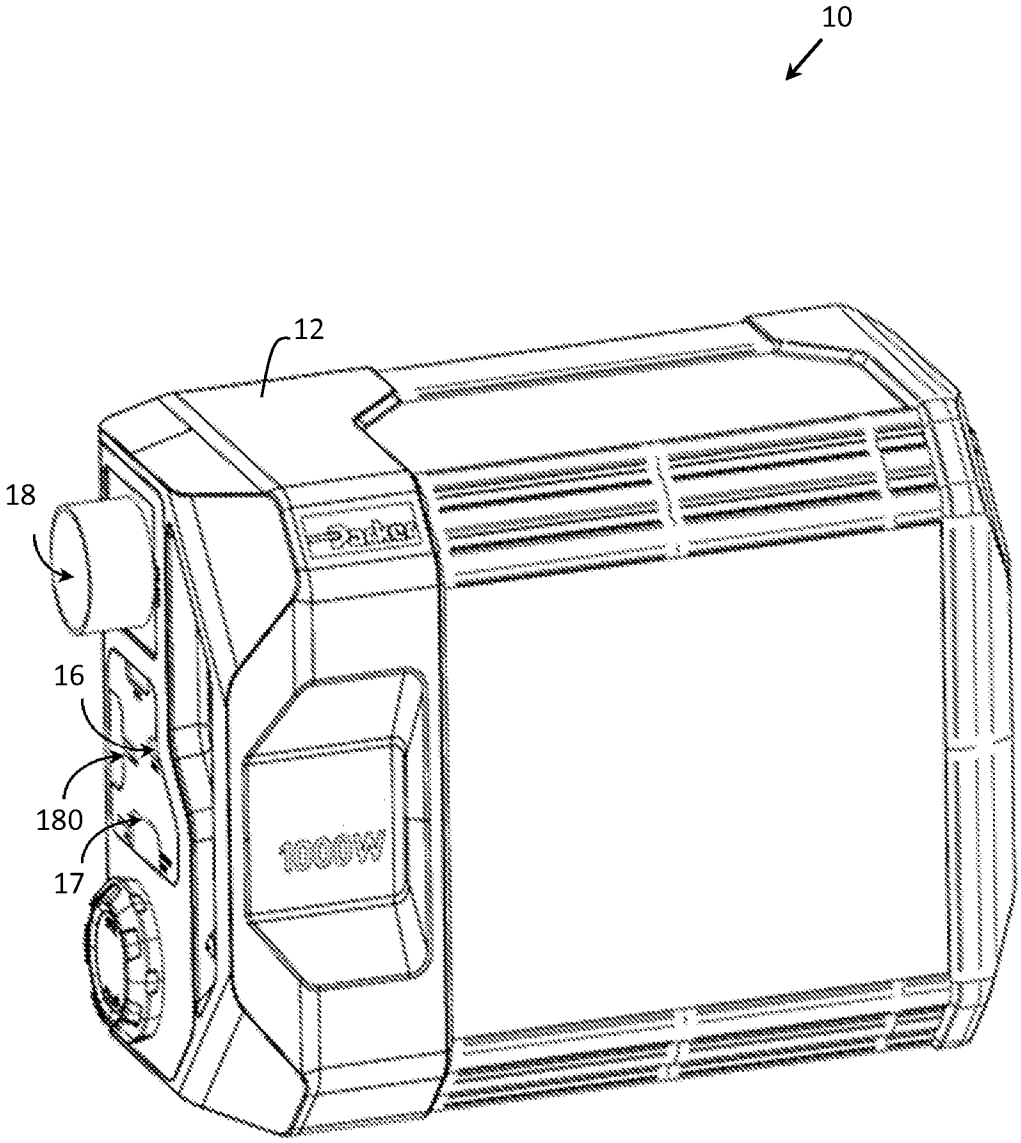


Fig. 5B

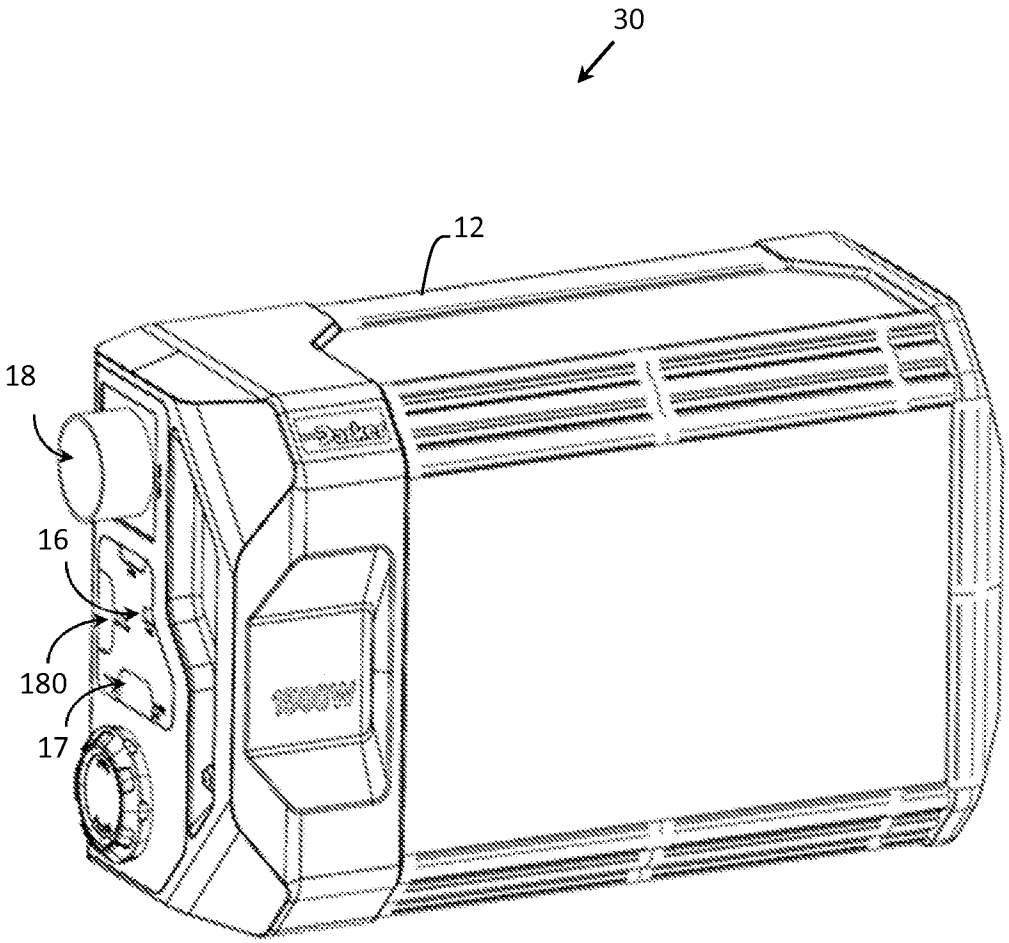


Fig. 5C

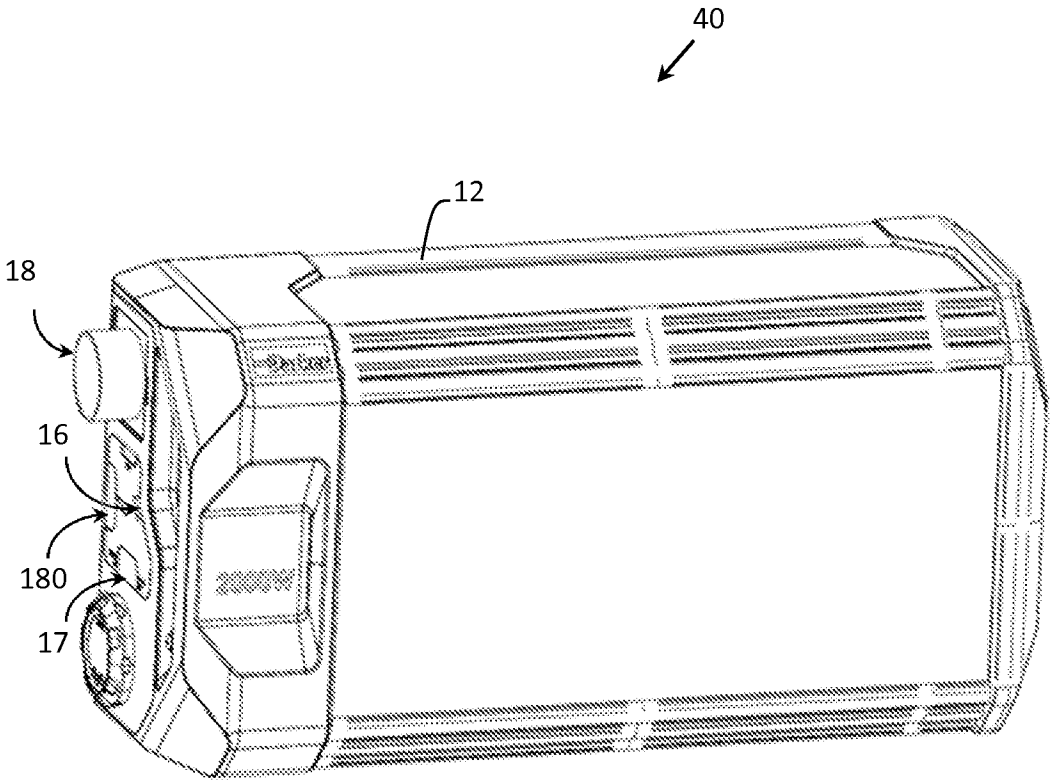


Fig. 5D

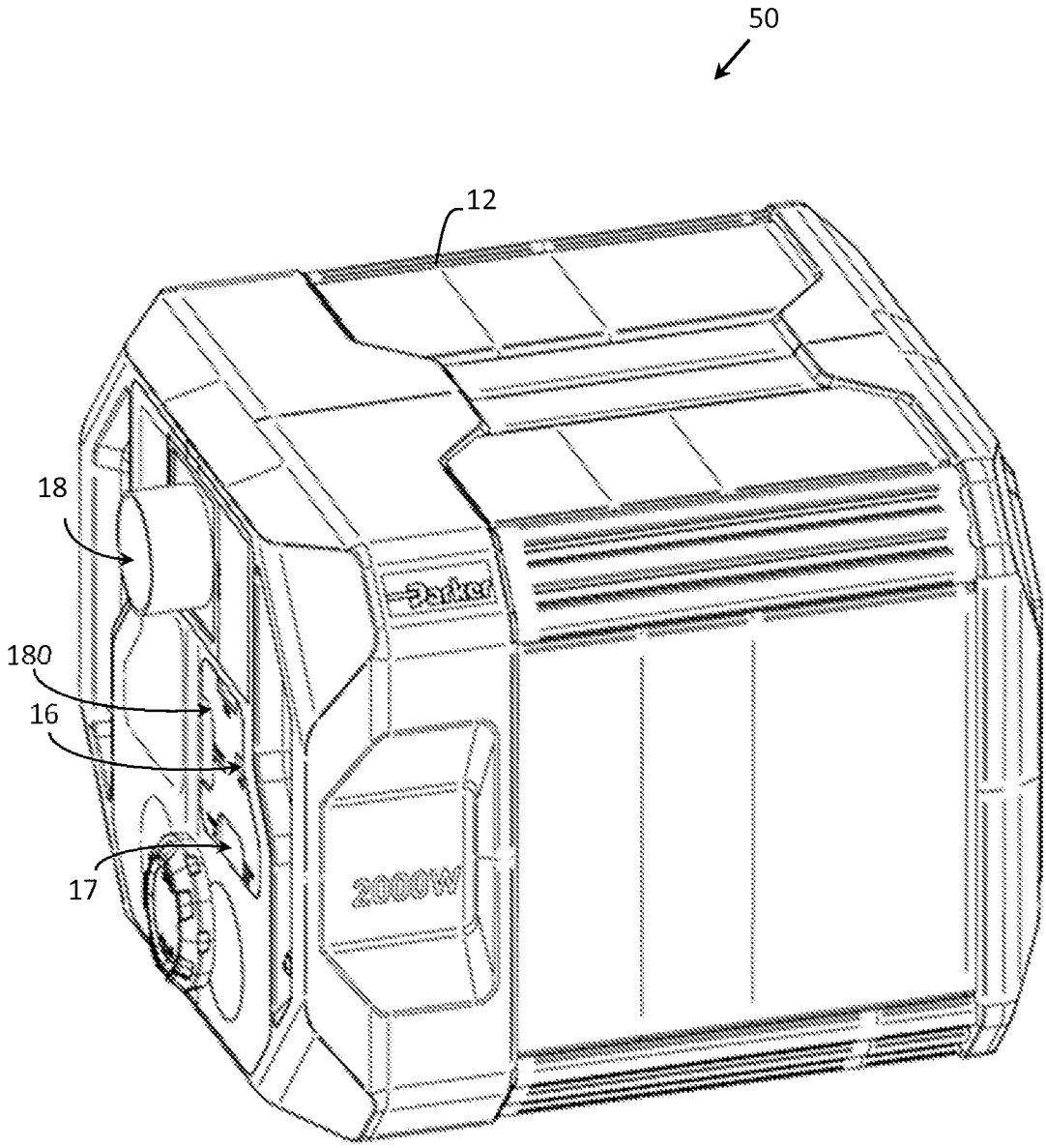


Fig. 5E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/032664

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01M8/24 H01M8/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/043274 A1 (SCARTOZZI JOHN P [US] ET AL) 4 March 2004 (2004-03-04)	1
Y	paragraph [0025] - paragraph [0028]; figures 4, 5 figure 2	3

X	US 2009/186245 A1 (FRANK DAVID GEORGE [CA] ET AL) 23 July 2009 (2009-07-23)	1,2,4,5
Y	paragraphs [0040] - [0052]; claims 1-8, 23; figures 1-5	3

X	US 2004/180253 A1 (FISHER JOHN M [US]) 16 September 2004 (2004-09-16)	1,2,4,5
Y	paragraphs [0030] - [0036]; figures 3-7	3

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 October 2013	26/02/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Goldbacher, Ute

3

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/032664

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-5

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/032664

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 741 605 A (GILLETT JAMES E [US] ET AL) 21 April 1998 (1998-04-21) column 9, line 38 - column 11, line 56; figure 1 column 14, lines 7-41; figure 3 column 2, lines 55-67 -----	3

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/032664

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004043274 A1	04-03-2004	AU 2001296856 B2	30-11-2006
		CA 2438144 A1	12-12-2002
		EP 1393397 A1	03-03-2004
		MX PA03010855 A	17-02-2004
		US 2003003337 A1	02-01-2003
		US 2004043274 A1	04-03-2004
		WO 02099915 A1	12-12-2002
US 2009186245 A1	23-07-2009	EP 2212957 A1	04-08-2010
		US 2009186245 A1	23-07-2009
		US 2013011755 A1	10-01-2013
		WO 2009052620 A1	30-04-2009
US 2004180253 A1	16-09-2004	NONE	
US 5741605 A	21-04-1998	AU 718146 B2	06-04-2000
		AU 2069297 A	22-09-1997
		CA 2256730 A1	12-09-1997
		CZ 9803802 A3	12-05-1999
		DE 69713337 D1	18-07-2002
		DE 69713337 T2	23-01-2003
		EP 0914687 A1	12-05-1999
		HU 9903954 A2	28-03-2000
		NO 990108 A	11-01-1999
		US 5741605 A	21-04-1998
		WO 9733333 A1	12-09-1997

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-5

   fuel cell module with module control electronics
   ---

2. claims: 6-12

   fuel cell module with functional blocks
   ---

3. claims: 13-20

   Combined heat and power system with fuel cell module and heater module
   ---