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(71) Applicant(s)
Blacklight Power, Inc.

(72) Inventor(s)
Randell L. Mills; William R. Good; James M. Kendall

(74) Agent/Attorney
SPRUSON and FERGUSON,GPO Box 3898,SYDNEY NSW 2001

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~~(71) Applicant: BLACK LIGHT POWER, INC. [US/US]; Great Valley Corporate Center, 41 Great Valley Parkway, Malvern, PA 19355 (US).~~

(72) Inventors: MILLS, Randell, L.; 1780 Greenbriar Court, Yardley, PA 19067 (US). GOOD, William, R.; 21 LeForge Court, Wayne, PA 19087 (US). KENDALL, James, M.; 1607 Masters Way, Chadds Ford, PA 19317 (US).

(74) Agents: MONACO, Daniel, A. et al.; Seidel, Gonda, Lavorgna & Monaco, P.C., Suite 1800, Two Penn Center Plaza, Philadelphia, PA 19102 (US).

(71) Blacklight Power, Inc., 493 Edinburg Road,
Cranbury, New Jersey 08520, USA

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(57) Abstract

An energy conversion system is provided for generating heat based on hydrogen catalysis and for transferring the generated heat to a working fluid and utilizing the heat or converting it to mechanical or electrical energy. The energy conversion system comprises a hydrogen catalysis power cell, the power cell comprising a heat transfer assembly having at least one reaction chamber containing the means to dissociate molecular hydrogen gas to atomic hydrogen and a delivery assembly connected in fluid communication to the reaction chamber for delivering hydrogen gas and vaporous catalyst for hydrogen catalysis. The delivery assembly comprises a catalyst vessel for generating the vaporous catalyst, a source of hydrogen gas, and a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly. The power cell further comprises means for regulating the temperature of the catalyst vessel and means for regulating the temperature surrounding the semi-permeable membrane. An energy conversion system is also provided having a hydrogen catalysis power cell as described herein, a working fluid for receiving the heat released from hydrogen catalysis, means for converting the heat in the working fluid to mechanical or electrical energy, and preferably means to balance the heat removed by the working fluid with the energy produced by hydrogen catalysis.

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HYDROGEN CATALYSIS POWER CELL FOR ENERGY CONVERSION SYSTEMS

Field of the Invention

The present invention relates to power cells for gas turbine engines, boilers, heaters and other mechanisms for energy conversion and utilisation, and more specifically, to power cells enabling the catalysis of hydrogen atoms to lower energy states and the conversion of heat released therefrom to other forms of energy.

Background of the Invention

Hydrogen Catalysis

The continuing availability of reliable, economical sources of energy is essential for the survival and advancement of modern civilisation. Current global energy consumption is approximately 400 quadrillion Btu (4×10^{17} Btu) per year. Primary sources of energy are fossil fuels (oil, gas, coal, ~85%), nuclear fission (~6%), and renewable sources (wood, biomass, wind, solar, hydro, ~8%). The capability of existing energy sources to support the needs of civilisation into the future is limited, due to limited resources, environmental impact concerns, and cost considerations. Fundamental breakthroughs will be required to provide for long term energy needs. Nuclear fusion has long been identified as having this potential.

However, decades of high priority development efforts have failed to produce a viable design for nuclear fusion energy production.

A novel system for extracting energy from hydrogen based upon the catalysis of hydrogen atoms to lower energy states has been developed based on theoretical projections and experimental results reported by Mills & Good in Fractional Quantum Energy Levels of Hydrogen, *Fusion Technology*, Nov. 1995. The elements of the system are summarized below, with a more detailed documentation of the theory and experimental data provided in Mills, R., The Grand Unified Theory of Classical Quantum Mechanics, September 1996 Edition, BlackLight Power Inc., 41 Great Valley Parkway, Malvern, PA 19355, www.blacklightpower.com, ("Mills GUT"). PCT/US96/07949, PCT/US94/02219, PCT/US91/08496, and PCT/US90/01998 (hereinafter the "Prior Mills Publications") address certain aspects associated with the catalysis of hydrogen atoms. The entire disclosures of the Prior Mills Publications are incorporated herein by reference. Theoretical projections indicate, and experimental data confirm, an energy release orders of magnitude greater than the energy released from combustion of hydrogen. The products of the catalytic process are oxygen (released during production of hydrogen fuel from water by electrolysis or reforming), and *hydrino* (a low energy state of hydrogen defined in the following discussion).

Since the pioneering work of Neils Bohr in 1913, physical models of the hydrogen atom have prescribed that the total energy of the orbital electron is restricted to the energy states given by:

$$E_n = \frac{-e^2}{8\pi\varepsilon_0 n^2 a_H} = \frac{13.6}{n^2}\ (eV)$$

where n is an integer, $n = 1, 2, 3, \ldots$, and where a_H is the Bohr radius of the hydrogen atom, e is the charge of the electron, and ε_0 is the vacuum permittivity. The energy state corresponding to n=1 is said to be the "ground" state.

An innovative mathematical formulation has been developed using fundamental laws of physics, resulting in a closed form solution for the hydrogen atom along with a wide range of other physical phenomena (see, Mills GUT). The Mills formulation predicts allowed stable energy states ($n = 1, \frac{1}{2}, {}^{1}/_{3}, \ldots$), as well as the excited integer states (n = 2, 3, 4, ...) for hydrogen. In Mills' terminology, a hydrogen atom in a fractional quantum state is called a "hydrino" (the designation for a hydrino of radius a_H/p, where a_H is the radius of the hydrogen atom for $n=1$ and p is an integer, is $H[a_H/p]$). A molecule consisting of two hydrogen atoms in the same fractional state is called a "dihydrino molecule". Energy transitions from n=1 to a hydrino state, or from a hydrino state to a lower hydrino state, are not spontaneously radiative, and must be catalyzed.

Hydrinos are hydrogen atoms having a binding energy given by the equation

$$\text{Binding Energy} = 13.6 \text{ eV}/(1/p)^2$$

wherein p is an integer greater than 1. The binding energy of an atom, ion, or molecule, also known as the ionization energy, is the energy required to remove one electron from the atom, ion or molecule. Ordinary atomic hydrogen is characterized by a binding energy of 13.6 eV.

Hydrinos are formed by reacting hydrogen atoms with a catalyst having a net enthalpy of reaction of about m*27.2 eV, where m is an integer. This catalytic reaction releases energy with a commensurate decrease in size of the hydrogen atom to $r_n=na_H=a_H/p$. For example, the catalysis of $H[a_H]$ to $H[a_H/2]$ releases 40.8 eV, and the hydrogen radius decreases from a_H to $a_H/2$. One such catalytic system involves potassium. The second ionization energy of potassium is 31.63 eV, and K^+ releases 4.34 eV when it is reduced to K. The combination of reactions K^+ to K^{2+} and K^+ to K, then, has the net enthalpy of reaction of 27.28 eV, where $m=1$. The reaction is expressed by:

$$27.28\ eV + K^+ + K^+ + H[a_H/p] \rightarrow K + K^{2+} + H[a_H/(p+1)] +$$
$$[(p+1)^2 - p^2] * 13.6\ eV$$
$$K + K^{2+} \rightarrow K^+ + K^+ + 27.28\ eV$$

Where the overall reaction is

$$H[a_H/p] \rightarrow H[a_H/(p+1)] + [(p+1)^2 - p^2] * 13.6\ eV$$

The energy given off during catalysis is much greater than the energy lost to the catalyst. Also, the energy released is large compared to conventional chemical reactions. For example, when hydrogen and oxygen gases undergo combustion to form water,

$$H_2\,(g) + \tfrac{1}{2}\,O_2\,(g) \rightarrow H_2O\,(l)$$

the known enthalpy of formation of water is ΔH_f = -286 kJ/mole or 1.48 eV per hydrogen atom. By contrast, each (n = 1) hydrogen atom undergoing catalysis to n = ½ releases a net energy of 40.8 eV. Moreover, further catalytic transitions may occur: n = $^1/_2 \rightarrow {}^1/_3$, $^1/_3 \rightarrow {}^1/_4$, $^1/_4 \rightarrow {}^1/_5$, and so on. Once catalysis begins, hydrinos autocatalyze further in a process called disproportionation. This mechanism is similar to that of an inorganic ion catalysis. Hydrino catalysis, however, has a higher reaction rate than that of the inorganic ion catalyst because of the better match of the enthalpy to m•27.2 eV.

Thus, two mechanisms have been identified for catalysis of hydrogen. According to a first mechanism, hydrogen catalysis proceeds via a coupled reaction of a hydrogen atom with a nearby ion or combination of ions (a catalyst) having the capability to absorb the energy required to effect the transition (a multiple of 27.2 eV, which is equivalent to the potential energy for n=1). In this case, the net energy release is given by:

$$\text{Energy Release} = [(1/n_f)^2 - (1/n_i)^2] \text{ x } 13.6\ eV$$

According to a second mechanism, hydrogen catalysis proceeds via a coupled reaction of two fractional state hydrogen atoms (hydrinos), ionizing one of the atoms and collapsing the other to a lower state (disproportionation). In the case of disproportionation with $H[a_H/2]$ as the catalyst, the energy release is given by:

$$\text{Energy Release} = [(1/n_f)^2 - (1/n_i)^2] \times 13.6\ eV - 54.4\ eV$$

The total energy release in going from the "ground state" (n = 1) to a given fractional state (n_f) is given by $[(1/n_f)^2 - 1] \times 13.6\ eV$. For example, the energy released in catalysis of a hydrogen atom from n = 1 to n = $^1/_{10}$ is 1,346 eV, or 910 times the combustion energy of 1.48 eV.

The energy release and new forms of matter resulting from hydrogen catalysis have been observed for a broad range of processes and devices, from electrolysis cells to gas vapor cells, as documented in Mills GUT and PCT/US96/07949. The experimental data have demonstrated the production of energy consistent with predictions based on the theory. However, these earlier devices have been limited in their capability to produce and sustain the conditions required for hydrogen catalysis in the temperature range and scale needed for commercial applications. What is needed is an improved power cell which provides for the release of energy by hydrogen catalysis, and which may be adapted to commercial applications.

Energy Conversion Systems

Energy conversion systems generally require a power cell unit that generates heat that can be used to heat air or boil water, which in turn can be used to generate electricity. Gas turbine engines, for example, are based on the Brayton cycle, wherein a gas is compressed in a compressor, heated, and then expanded through a turbine to produce mechanical energy to operate the compressor and an attached load. Prior art in gas turbine cycles, as depicted in Figures 1A - 1D, includes primarily combustion based systems ranging from simple open cycle engines to more complex cycles such as recuperated open cycles, and recuperated and intercooled closed cycles (G. J. Van Wylen, Thermodynamics, John Wiley & Sons, 1963, pp. 322-332).

Gas turbine engines are in widespread use for power generation and motive power applications, with the majority of units in operation based on open cycle engines burning natural gas or liquid fuels. Advances in materials and manufacturing technology, and deployment of combined cycle units have led to continuing increases in thermal efficiency and related reductions in fuel consumption. However, gas turbines are typically limited to the use of expensive hydrocarbon-based fuels or liquid fuels.

Boilers are used to produce steam for industrial processes and space heating, and to power steam turbines for electricity generation and motive power applications. Primary categories of boilers include re-circulating boilers producing saturated steam, boilers augmented with super-heaters if superheated steam is required, and once-through boilers producing superheated steam. Boilers may be powered by oil, natural gas, coal, wood, bio-mass or nuclear fuel.

Heaters are used in industrial processes and for space heating in residential, commercial and industrial applications. Primary categories of heaters are radiant heaters, which provide heat through the radiation of thermal energy from a high temperature surface, and convection heaters, which provide heat by flowing a gas or liquid past heated surfaces. Heaters may be powered by oil, natural gas, coal, wood or biomass. Electric heater applications such as microwave and induction heating are powered indirectly through the generation of electricity.

Considerable progress has been made in reducing emissions from turbines, boilers and heaters. However, all combustion-based energy sources are subject to siting restrictions and environmental concerns resulting from combustion product emissions. Long-term energy source issues include global climatic impact, availability, and stability of fuel supplies. There is therefore a need for a mechanism to efficiently harness the energy output from an energy source that minimizes global climatic impact, is widely available, and is comparatively cost effective.

What is needed are new energy conversion systems capable of harnessing the power of hydrogen catalysis into more usable forms.

Summary of the Invention

The design of the present invention improves upon energy conversion devices of the prior art to produce a power cell enabling the release of energy by hydrogen catalysis. The power cell of the invention may be adapted to commercial applications. Energy release by hydrogen catalysis is sufficient to enable the use of water as an energy source with essentially unlimited capacity, and with minimal environmental impact. Hydrogen catalysis power cells can be configured to address all major energy consumption sectors through gas turbine, steam boiler, heater and direct conversion applications.

According to the present invention, methods and apparati are provided for delivering thermal, mechanical or electrical power via the sustained, stable and controlled catalysis of hydrogen. Catalysis occurs within a hydrogen catalysis power cell in the gas phase via the controlled contact of catalyst with atomic hydrogen.

"Hydrogen catalysis", as meant herein, refers to (i) the reaction of a hydrogen atom with a catalyst having a net enthalpy of reaction of about $m \bullet 27.21$ eV, where m is an integer, which results in a hydrogen atom having a binding energy greater than about 13.6 eV and the release of energy, or (ii) the reaction of two or more hydrogen atoms having a binding energy greater than about 13.6 eV, which results in a net release of energy and at least one hydrogen atom having a binding energy higher than the initial binding energy of said hydrogen atom before the reaction.

A power cell is provided for generating heat based on hydrogen catalysis and for transferring said generated heat to a working fluid. The power cell comprises a heat transfer assembly and a delivery assembly. The heat transfer assembly comprises at least one enclosed, vacuum-tight reaction chamber containing a means for dissociating molecular hydrogen gas into atomic hydrogen. The delivery assembly is connected in fluid communication with the reaction chamber for delivering hydrogen gas and vaporous catalyst for hydrogen catalysis to the heat transfer assembly. The delivery assembly comprises a catalyst vessel for generating vaporous catalyst for hydrogen catalysis, a source of hydrogen gas, and a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly. The membrane assembly contains a semi-permeable membrane which permits the passage of hydrogen but substantially inhibits the passage of vaporous catalyst therethrough. The power cell further comprises a means for regulating the temperature of the catalyst vessel and means for regulating the temperature surrounding the semi-permeable membrane.

The power cell of the invention may further comprise a means for passage of working fluid in proximity with the reaction chamber to receive the heat generated by the hydrogen catalysis reaction in the reaction chamber. The power cell of the invention may further comprise means for controlling heat transfer from the reaction chamber to said means for passage of working fluid in proximity with the reaction chamber.

The semi-permeable membrane assembly preferably comprises a collection housing enclosing the semi-permeable membrane. The membrane is preferably shaped to form a closed internal space within the collection housing with the internal space being in communication with the hydrogen gas source. The collection housing preferably has an inlet end and outlet end, with the outlet end connected in fluid communication with the heat transfer assembly so that hydrogen gas passing through the membrane and collected in the collection housing is directed to the reaction chamber.

The means for regulating the temperature of the catalyst vessel in a power cell of the invention preferably comprises a conduit for carrying a heated working fluid from the heat transfer assembly to the delivery assembly. The means for regulating the temperature of the catalyst vessel may further comprise a conduit for returning a working fluid from the delivery assembly to the heat transfer assembly. The means for regulating the temperature surrounding the semi-permeable membrane in a power cell of the invention preferably comprises similar means.

The power cell of the invention preferably comprises means for evacuating the reaction chamber, means for terminating hydrogen catalysis within the reaction chamber, and/or means for initiating hydrogen catalysis within the reaction chamber.

A method is also provided for utilizing heat released from a hydrogen catalysis reaction. The method comprises introducing hydrogen gas and vaporous catalyst into a reaction chamber of a power cell. Hydrogen molecules of the gas are dissociated into hydrogen atoms. The method further comprises reacting hydrogen atoms and catalyst in a reaction such that (i) the reaction of a hydrogen atom with a catalyst has a net enthalpy of reaction of about $m \bullet 27.21$ eV, where m is an integer, which results in a hydrogen atom having a binding energy greater than about 13.6 eV and the release of energy, or (ii) the reaction of two or more hydrogen atoms having a binding energy greater than about 13.6 eV results in a net release of energy and at least one hydrogen atom having a binding energy higher than the initial binding energy of said hydrogen atom before the reaction. The method further comprises transferring released heat to a working fluid.

In a preferred method of the invention, the partial pressure of the hydrogen gas in the reaction chamber is from about 50 millitorr to about 100 torr, and the partial pressure of catalyst in the reaction chamber is from about 50 millitorr to about 100 torr.

The method of the invention preferably comprises a power cell comprising a heat transfer assembly and a delivery assembly. The heat transfer assembly comprises at least one enclosed, vacuum-tight reaction chamber containing a means for dissociating molecular hydrogen gas into atomic hydrogen. The delivery assembly is connected in fluid communication with the reaction chamber for delivering hydrogen gas and vaporous catalyst for hydrogen catalysis to the heat transfer assembly. The delivery assembly comprises a catalyst vessel for generating vaporous catalyst for hydrogen catalysis, a source of hydrogen gas, and a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly. The membrane assembly contains a semi-permeable membrane which permits the passage of hydrogen but substantially inhibits the passage of vaporous catalyst therethrough. The power cell further comprises a means for regulating the temperature of the catalyst vessel and means for regulating the temperature surrounding the semi-permeable membrane.

An energy conversion system is provided for converting thermal energy released by hydrogen catalysis. The energy conversion system comprises a hydrogen catalysis power cell as described above, a working fluid for receiving the heat released from hydrogen catalysis, and means for converting the heat in the working fluid to mechanical or electrical energy. The energy conversion system of the invention preferably may further comprise means for balancing the heat energy extracted by the working fluid with heat produced from hydrogen catalysis and consumed by said means for converting the heat in the working fluid to mechanical or electrical energy.

An energy conversion system is provided where the means for balancing the heat energy extracted by the working fluid with heat produced from hydrogen catalysis and consumed by said means for converting the heat in the working fluid to mechanical or electrical energy comprises an automated control system.

An energy conversion system is provided wherein the control system comprises means to control at least one of the rate of hydrogen catalysis, the temperature of the working fluid, the heat capacity of the working fluid, the amount of heat delivered to the heat transfer assembly, the amount of heat taken from the heat transfer assembly, and the power consumed by the means for converting heat in the working fluid to mechanical or electrical energy.

Brief Description of the Drawings

Fig. 1A is a schematic diagram illustrating an open cycle gas turbine configuration of the prior art.

Fig. 1B is a schematic diagram illustrating a modified open cycle gas turbine configuration of the prior art.

Fig. 1C is a schematic diagram illustrating another modified open cycle gas turbine configuration of the prior art.

Fig. 1D is a schematic diagram illustrating a closed cycle gas turbine configuration of the prior art.

Fig. 2 is a schematic diagram illustrating an embodiment of an energy conversion system of the invention having a simple open cycle gas turbine and heat exchanger based on a hydrogen catalysis power cell.

Fig. 3 is a schematic diagram of an embodiment of a hydrogen catalysis power cell of the invention.

Fig. 4 is a schematic diagram illustrating another embodiment of a hydrogen catalysis power cell of the invention.

Fig. 5 illustrates a heat transfer assembly for a hydrogen catalysis power cell of the invention, having a convection heat exchanger.

Fig. 6 is a cross-sectional view of an embodiment of a reaction chamber of a hydrogen catalysis power cell of the invention.

Fig. 7 illustrates a hydrogen permeable membrane for use in a delivery assembly of a hydrogen catalysis power cell of the invention.

Fig. 8 illustrates, in cross-section, a semi-permeable membrane positioned in a reaction chamber.

Fig. 9 illustrates, in partial cut-out, a catalyst vessel for use in a delivery assembly of a hydrogen catalysis power cell of the invention.

Fig. 10 illustrates an alternative embodiment of a hydrogen catalysis power cell of the invention having a radiant heat exchanger-based heat transfer assembly.

Fig. 11 illustrates an alternative embodiment of a hydrogen catalysis power cell of the invention having a radiant heat exchanger-based heat transfer assembly.

Fig. 12 is an enlarged view of a portion of the delivery assembly of Fig. 11.

Fig. 13 is a top plan view of the hydrogen catalysis power cell of Fig. 11.

Fig. 14 illustrates an alternative embodiment of a hydrogen catalysis power cell of the invention employed as a boiler.

Description of the Invention

The hydrogen catalysis power cell of the invention may be a component of an energy conversion system such as a gas turbine engine, steam boiler, heater, or other form of power utilization and conversion equipment. Some of the specific design characteristics of the hydrogen catalysis power cells of the invention are dependent upon the heat transfer requirements and other physical requirements of particular embodiments.

The hydrogen catalysis power cells of the subject invention, for generating heat based on hydrogen catalysis and for transferring the generated heat to a working fluid, generally include the following elements: (1) a heat transfer assembly comprising at least one enclosed, vacuum-tight reaction chamber; (2) means for dissociating molecular hydrogen gas into atomic hydrogen; (3) a source of hydrogen gas; (4) a catalyst vessel for generating vaporous catalyst for hydrogen catalysis; (5) a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly, having a semi-permeable membrane permitting passage of hydrogen but substantially inhibiting the passage of vaporous catalyst therethrough; (6) means for regulating the temperature of the catalyst vessel; and (7) means for regulating the temperature surrounding the semi-permeable membrane.

The hydrogen catalysis power cell of the invention also preferably contains (1) means for evacuating the reaction chamber and eliminating impurities from the reaction chamber and any connected subsystems; (2) means for initiating hydrogen catalysis within the reaction chamber; (3) means for terminating hydrogen catalysis within the reaction chamber; and (4) means to balance the heat removed by a working fluid with the energy produced by hydrogen catalysis.

Energy conversion systems of the present invention comprise an embodiment of a hydrogen catalysis power cell described above, as well as a means (such as a power converter) for utilizing or converting the heat received by a working fluid to mechanical or electrical power. An energy conversion system, as meant herein, refers to an operation or operations wherein energy is made useful, such as the conversion of heat to mechanical energy to electricity.

Embodiments of the present invention incorporating these common hydrogen catalysis power cell elements are set forth in the following discussion.

Gas turbine engines constitute a major category for application of the hydrogen catalysis power cell of the invention. The term "gas turbine system" is defined as any configuration of the class of systems for conversion of thermal energy to mechanical energy by compressing the gas (or working fluid), heating it, then expanding it using rotating compressors and turbines. A range of gas turbine configurations of the prior art are depicted in Figures 1A through 1D.

Fig. 1A shows a simple open cycle system gas turbine having a rotating compressor 10 with air inlet 12 and compressed air outlet 14 connecting compressor 10 to a combustor 16 for heating compressed air (the working fluid). A flow passage 18 delivers heated compressed air to a turbine 20, with the expanded air and combustion products then released to the atmosphere at the turbine exhaust 22. A shaft 24 powered by the turbine 20 provides mechanical energy to propel the compressor 10 and the attached load 26.

A modification of the simple open cycle to improve thermal efficiency by using the heated air and combustion products from the turbine exhaust to heat air from the compressor is shown in Fig. 1B. Air from the compressor 10 flows through an outlet duct 14 and is heated in a heat exchanger 28 (recuperator) by the air and combustion products from the turbine exhaust 22 before flowing to the combustor 16 via the recuperator compressed air outlet 30. The cooled turbine exhaust air and combustion products as delivered to the atmosphere via the recuperator exhaust 32.

Further improvement in thermal efficiency can be obtained by adding stages to the compressor and turbine with intermediate cooling and heating as shown in Fig. 1C. Air flows from the first stage compressor 10 through compressor outlet duct 14 and through a heat exchanger 28 (intercooler), losing heat to a cooling fluid entering from a cooling system supply line 34 (and exiting through a cooling system return line 36). Cooled air then flows through duct 34 to the second stage compressor 40. Air flowing in the exhaust duct 42 from the first stage turbine 20 is heated in a second combustor 44 before flowing in the inlet duct 46 to the second stage turbine 48.

In addition to the open cycle turbine designs represented by the examples above, gas turbines may be designed as a closed cycle, as exemplified in Fig. 1D, using gases such as nitrogen or helium as the working fluid. In Fig. 1D, the working fluid in exit duct 50 from the recuperator 52 is cooled in a heat exchanger

54 by a cooling fluid entering from a cooling system supply line 34 (and exiting through a cooling system return line 36), flowing back through air inlet 56 to the first stage compressor 10. Heat is added to the cycle in a heat exchanger 28 by a heating fluid supplied through duct 58 from an external heat source 60 and exiting at a reduced temperature through external heat source return duct 62, thus giving up heat to the working fluid entering the heat exchanger 28 through duct 64 from the recuperator 52 with the hot working fluid flowing through duct 66 to the turbine 20.

Gas turbines can be deployed in a wide array of variations as exemplified in Figures 1A through 1D. A required common element for all gas turbines is a means of adding heat to the compressed working fluid, either in a combustor or a heat exchanger. The present invention provides a means of adding heat to the working fluid, replacing the combustor(s) and/or heat exchanger(s) of the full range of prior art gas turbines.

In Fig, 2, a hydrogen catalysis power cell 90 according to the present invention serves as the mechanism for providing heat to a working fluid in a gas turbine system. In addition to hydrogen catalysis power cells of the invention, an electrolytic gas cell, gas discharge cell, and plasma torch cell described in Mills Prior Publications (e.g., U.S. Pat. Application Ser. No. 09/111,160, filed July 7, 1998 at pages 42-56.) can be adapted to an energy conversion system. The hydrogen catalysis power cell 90 receives compressed air from compressor 92 and heats the air by transferring heat evolved from hydrogen catalysis reactions occurring in the power cell 90. The heated air is then directed to a turbine 94 where thermal energy may be converted to mechanical energy.

Fig. 3 illustrates an embodiment of a hydrogen catalysis power cell of the invention that may be incorporated into an energy conversion system. The hydrogen catalysis power cell 100 generally comprises a delivery assembly 102 and a heat transfer assembly 104. The delivery assembly 102 supplies the raw materials (hydrogen gas and catalyst) under prescribed conditions of temperature and pressure to the heat transfer assembly 104. The hydrogen catalysis reactions take place in heat transfer assembly 104.

The delivery assembly 102 is comprised of a hydrogen gas source 106 connected in fluid communication with a semi-permeable membrane assembly 108, a catalyst vessel 110, and a vacuum system 112. The delivery assembly 102 is preferably enclosed within a housing 114.

The hydrogen gas supply source 106 may be a tank containing hydrogen gas under pressure or a vessel that provides hydrogen gas as a product of the electrolytic dissociation of water, for example. Hydrogen gas supply line 116 delivers hydrogen to semi-permeable membrane assembly 108. The semi-permeable membrane assembly 108, containing a semi-permeable membrane 109 for regulating passage of hydrogen gas, assures the delivery of pure hydrogen via conduit 118 to the heat transfer assembly 104. The semi-permeable membrane assembly 108 is discussed in more detail below. The regulation of hydrogen gas partial pressure delivered to the heat transfer assembly 104 is also discussed in more detail below.

The catalyst vessel 110 provides vaporous catalyst to the heat transfer assembly 104. According to one embodiment, the catalyst may comprise any eletrocatalytic ions or couple(s) given in the Tables of the Prior Mills Publications (e.g., Table 4 of PCT/US90/01998 and pages 25-46 and 80-108 of PCT/US94/02219, all incorporated herein by reference). A preferred catalyst is potassium ions. The catalyst vessel 110 operates to heat solid potassium iodide catalyst to a vaporous state. The regulation of catalyst vessel 110 temperature, and hence the partial pressure of the vaporous catalyst delivered to the heat transfer assembly 104, is discussed in more detail below.

The vacuum system 112 operates to evacuate the contents of the delivery assembly conduit(s) and the heat transfer assembly 104. The vacuum system 112 may be in fluid communication with a quenching system 120 which provides the means for terminating the hydrogen catalysis reactions.

The vacuum system 112 preferably comprises a pump connected in fluid communication with the reaction chambers 122. Alternatively, a cryogenic pump or getter can be employed. Appropriate getters are disclosed in co-pending, commonly assigned U.S. Pat. Application Ser. No. 09/111,160, filed July 7, 1998 and PCT/US98/14029, filed July 7, 1998, at pp. 72-75.

The quenching system 120 preferably comprises a source of inert gas, such as helium, neon or argon, in fluid communication with the heat transfer assembly. Inert gas operates to quench the hydrogen catalysis reactions, terminating the heat-generating hydrogen catalysis reactions.

Alternatively, the hydrogen catalysis reactions may be quenched by removing hydrogen or ion catalyst. Ion catalyst can be removed by lowering the temperature of the catalyst vessel, causing it to condense. The hydrogen can be removed by closing the hydrogen control valve or decreasing the temperature of the semi-permeable membrane. Hydrogen and catalyst may also be rapidly pumped away via vacuum or cryogenic pump. A getter may also be employed to remove ion catalyst and/or hydrogen.

Heat is generated in the heat transfer assembly 104 by virtue of hydrogen catalysis reactions taking place therein. The heat transfer assembly 104 is generally comprised of at least one, and preferably a plurality of, reaction chambers 122 wherein the hydrogen catalysis reactions occur. The reaction chambers 122 are in fluid communication with the delivery assembly 102. In Fig. 3, the delivery assembly 102 is connected in fluid communication with a header 146, the header 146 in turn is connected in fluid communication with the reaction chambers 122. A working fluid is passed through the heat transfer assembly 104 via inlet 124. The working fluid exits through outlet 126. Heat may be transferred from the reaction chambers 122 to the working fluid by radiation, conduction, and/or convection mechanisms. The heat transfer assembly 104 is contained within a shell 128.

In an embodiment of a hydrogen catalysis power cell employing a gaseous working fluid, such as air, a portion of the heated working fluid may be directed from the heat transfer assembly 104 to the delivery assembly 102 in order to maintain the temperature of the delivery assembly 102. Working fluid having circulated throughout the delivery assembly 102 may be returned to the heat transfer assembly 104. As shown in Fig. 3, heated working fluid is directed to the delivery assembly 102 via conduit 130 and returned to the heat transfer assembly 104 via conduit 132. A temperature sensing means (not shown), such as a thermocouple, may be positioned within the delivery assembly 102 for purposes of temperature control.

The delivery assembly housing 114 and the heat transfer assembly shell 128 are preferably made of stainless steel. The conduits (*i.e.*, 116,130) are preferably ducts and are preferably fabricated from stainless steel tubing. Insulation materials (not shown), such as refractory oxides, may be placed around any component of the hydrogen catalysis power cell to minimize heat transfer losses.

Another embodiment of the hydrogen catalysis power cell of Fig. 3 is shown in Fig. 4. In Fig. 4, the semi-permeable membrane assembly 108, the catalyst vessel 110, and the vacuum system 112, are independently connected in fluid communication with the heat transfer assembly 104 via (respectively) conduits 134, 136, and 138.

As shown in Figs. 3 and 4, valves 152, 153, 154, 155, and 156 may be positioned at any location along delivery conduits for flow control of the contents therein. For example, valve 154 controls the flow of catalyst vapor to the heat transfer assembly 104. Valves 151 and 154 may be closed either during the operation of the vacuum system 112 to clean the system and evacuate the reaction chambers 122 or during the introduction of quenching gas from the quenching system 120. The operation of any valve may be in concert with a control system, such as an automated system providing a control feedback loop.

As also shown in both Figs. 3 and 4, a starter system 140 may be connected to the heat transfer assembly 104. The starter system operates to deliver heat to the heat transfer assembly 104 by heating the working fluid entering the heat transfer assembly through inlet 140. The added heat promotes the reaction rates of the hydrogen catalysis reactions until enough heat is evolved in the reaction chambers 122 of the heat transfer assembly 104 to sustain the catalytic reactions.

The starter system 140 may rely upon the combustion of hydrogen or natural gas, for example, as a means for introducing heat to the interior 142 of the heat transfer assembly 104. In such case, conduit 141 supplies hydrogen or natural gas to the interior 142 of the heat transfer assembly 104 and conduit 143 introduces oxygen to the same space. A burner (not shown) located on the interior 142 of the heat transfer assembly 104 can ignite the combustion of the hydrogen or natural gas. Valves 144 and 145 regulate the delivery of hydrogen and oxygen. Heated combustion product exits through outlet 126.

As an alternative to providing heat by combustion, the starter system 140 may alternatively comprise resistive heater elements which lead into the interior 142 of heat transfer assembly 104 and surround and contact the reaction chambers 122.

Fig. 5 illustrates an embodiment of a heat transfer assembly 104 comprising a header 146 and a plurality of reaction chambers 122. The reaction chambers 122 are in fluid communication with the header 146, which in turn is in fluid communication with the delivery assembly 102 (not shown in Fig. 5). The heat transfer assembly 104 of Fig. 5 illustrates a convection heat exchanger embodiment of the heat transfer assembly. The shell 128 may be of any geometry, as would be understood by one skilled in the art, to enable a desired residence time for a working fluid receiving heat from the heat transfer assembly and a shell that is durable under the temperature and pressures achieved in the heat transfer assembly 104 as dictated by application demands.

Hydrogen gas and vaporous catalyst are delivered to the reaction chambers 122 via header 146. The hydrogen catalysis reactions are preferably maintained such that the partial pressure of the catalyst, *e.g.*, potassium iodide, is from about 50 millitorr to about 100 torr, and most preferably at about 200 millitorr and the partial pressure of hydrogen is from about 50 millitorr to about 100 torr, and most preferably at about 200 millitorr. Working fluid does not come into contact with the interior (not shown) of the header 146 or the interior of the reaction chambers 122 (not shown in Fig. 5).

A working fluid enters the heat transfer assembly 104 at inlet 124, flows around the reaction chambers 122 while absorbing heat evolved through the reaction chambers 122, and exits the heat transfer assembly 104 via outlet 126. Baffle plates positioned in the interior 142 of the heat transfer assembly (not shown) may be employed to increase the residence time of the working fluid in the heat transfer assembly 104. The heat transfer assembly 104 is anchored to the shell 128 by such means known to one skilled in the art, such that heat transfer losses are minimized and interior 142 space is maximized while providing adequate support for the heat transfer assembly under the conditions demanded of a particular application. An example of an anchoring means may be a metal bracket (not shown) extending from the header 146 to the shell 128.

In the embodiment of a heat transfer assembly shown in Fig. 5, the reaction chambers 122 are shown as having, preferably, a generally cylindrical shape with one end 148 closed and an opposite end 150 in fluid communication with the header 146.

Fig. 6 is a cross-sectional view of a reaction chamber 122 taken along line 6-6 of Fig. 5. The reaction chamber 122 is comprised of an inner chamber wall 170 defining a reaction chamber interior 172 and an outer structural wall 174 having an exterior surface 176 and an interior surface 178. The hydrogen catalysis reactions occur within the interior 172 of the reaction chamber 122. The structural wall 174 and the chamber wall 170 are preferably separated by an evacuated annulus 180. The annulus 180 serves to retard heat transfer from the reaction chamber interior 172 to the working fluid flowing around and against the exterior surface 176 of the structural wall 174. The annulus 180 retards heat transfer so reaction conditions in the reaction chamber interior can be maintained. The interior surface 178 of the structural wall 174 may be lined with a coating or film (not shown) to promote heat transfer across the structural wall 174 to the working fluid.

The reaction chamber interior 172 contains a catalyst to facilitate the dissociation of molecular hydrogen gas to atomic hydrogen. The hydrogen dissociation catalyst preferably takes the form of a plurality of metal surfaces 182. The metal surfaces 182 must be maintained at an elevated temperature to facilitate the dissociation of molecular hydrogen gas into hydrogen atoms. Preferably, the metal surfaces are maintained at a temperature of at least about 700 °C, but a temperature in the range of about 600 °C to about 800 °C is generally sufficient. The surfaces 182 which catalyze molecular hydrogen dissociation into hydrogen atoms are comprised of a hydrogen dissociation catalyst. Such dissociating catalysts include, for example, noble metals such as palladium and platinum, refractory metals such as molybdenum and tungsten, transition metals such as nickel and titanium, inner transition metals such as niobium and zirconium, and other materials listed in the Prior Mills Publications. The hydrogen dissociating catalyst is preferably made from pure nickel or pure titanium. The metal surfaces 182 are also preferably arranged in a lattice structure as shown in Figure 6,to promote an increased surface area for the contact leading to dissociation. The chamber wall 170 is preferably made of the same metals as metal surface 182, that is, nickel or titanium.

Alternatively, the catalyst for dissociating molecular hydrogen gas to atomic hydrogen may be deposited or coated onto a substrate surface positioned in the reaction chamber interior 172.

The structural wall 174 is designed to withstand the comparatively high external pressures and flow that would otherwise pose a structural threat to the chamber wall 170 surrounding an evacuated or very low pressure reaction chamber interior 172. The structural wall 174 may be made from stainless steel, or any material offering the structural strength and favorable heat transfer properties necessary in the heat transfer assembly 104.

The hydrogen-permeable membrane of the semi-permeable membrane assembly 108 is shown in more detail in Fig. 7. A semi-permeable membrane 109 is connected in fluid communication with hydrogen supply conduit 116. Membrane 109 is permeable to hydrogen gas but not the vaporous catalyst which catalyzes the hydrogen catalysis reactions in the reaction chambers 122. The semi-permeable membrane is preferably cylindrical in shape and closed at one end 190. The opposite open end 191 of membrane 109 is preferably welded to the conduit 116. The membrane is preferably made from nickel or palladium-coated tantalum. The membrane 109 has an internal bore (not shown) running longitudinally along the membrane. Hydrogen gas from supply conduit 116 passes through the semi-permeable membrane 109.

The semi-permeable membrane 109 is essentially impermeable to hydrogen, except when heated. The permeability of the membrane 109 to hydrogen is controlled by regulating the temperature of the membrane 109.

The semi-permeable membrane assembly 108 further comprises a collection housing 194 shrouding the membrane. The collection housing 194 is secured in an air-tight fashion at an inlet end 196 to the hydrogen supply line 116. The interior space of the housing 194 is in fluid communication with outlet conduit 198 at an opposite end 199 of the housing 194. Hydrogen gas supplied through conduit 116 passes through the semi-permeable membrane 109 and is collected within the collection housing 194. Hydrogen flow into the collection housing 194 is controlled by a flow regulator (not shown), such as a valve. The hydrogen gas exits assembly 108 through outlet conduit 198. Conduit 198 supplies hydrogen gas to the heat transfer assembly 104. Semi-permeable membrane 109 acts to prevent vaporous catalyst from the reaction chambers 122, or other impurities, from migrating into the hydrogen supply conduit 116.

Alternatively, a plurality of semi-permeable membranes 109 may be contained within a collection housing 194.

An alternative embodiment of a semi-permeable membrane assembly in relation with a reaction chamber is shown in Fig. 8. In Fig. 8, a semi-permeable cylindrical membrane 111 connected to hydrogen supply line 117 is positioned directly within reaction chamber 123. Hydrogen gas migrates through the membrane and dissociates on metal surfaces 183 surrounding the reaction chamber interior. The semi-permeable membrane 109 precludes vaporous catalysts present in the reaction chamber from diffusing into the hydrogen supply line 117. Since the temperature of the membrane is equal to that of the reaction chamber, the hydrogen flow rate is controlled by a hydrogen flow regulator, such as valve 150 in Figs. 3 and 4.

A typical catalyst vessel for supplying vaporous catalyst for hydrogen catalysis is shown in Fig. 9. The catalyst vessel 110 comprises a bottom wall 205 and side wall 202 enclosing a catalyst chamber 204. The catalyst chamber 204 is closed by a cap 207. The cap is penetrated by a removable fill plug 206 and an outlet 208 for passage of vapor phase catalyst. A solid catalyst may be introduced to the interior 204 of the vessel through the removable fill plug 206. The solid catalyst is heated in the vessel to the vapor phase. The vaporous catalyst exits the vessel through an outlet 208. The vaporous catalyst is supplied to reaction chambers 122.

The side wall 202 of the catalyst vessel may contain a plurality of fins 212. The fins 212 promote heat transfer between the catalyst chamber interior 204 and the surrounding environment of the delivery assembly 102. Optional heater elements 214, such as resistive heater elements surrounding the vessel side wall 202, may also be employed to provide heat to chamber 204 and to regulate the temperature therein. A thermocouple (not shown) may be located in the chamber 209 to provide temperature control.

The temperature of the catalyst vessel 112 is preferably controlled such that the catalyst vessel is maintained at the lowest temperature within the delivery assembly 102, precluding condensation of catalyst vapor on any cooler surfaces within the delivery assembly 102.

An alternative embodiment of a hydrogen catalysis power cell of the invention is shown in Fig. 10. The hydrogen catalysis power cell 300 comprises a delivery assembly 302 and a heat transfer assembly 304. The heat transfer assembly 304 of Fig. 10 illustrates a radiant heat exchanger embodiment of a heat transfer assembly. The delivery assembly 302 and heat transfer assembly 304 are separated by a radiation shield 306. The delivery assembly 302 comprises a hydrogen gas supply source 308, a semi-permeable membrane assembly 310, catalyst vessel 312, and a vacuum system 314 which are arranged, and function, as previously discussed with respect to the delivery assembly 102. The corresponding elements of delivery assembly 102 comprise the hydrogen supply 106, the semi-permeable membrane assembly 108, catalyst vessel 110, and vacuum system 112 shown in Figs. 3, 4, 7, and 9. The delivery assembly 302 and the heat transfer assembly 304 of Fig. 10 are both housed within a shell 316.

The heat transfer assembly 304 comprises at least one reaction chamber 326. The heat transfer assembly also comprises at least one heat transfer conduit 328 for the purpose of directing passage of the working fluid through the heat transfer assembly. The heat transfer conduit 328 preferably directs the working fluid within close proximity of the reaction chmabers 326. The reaction chamber 326 is in fluid communication with the delivery assembly 302 through conduit 330. The reaction chamber 326 has the same basic construction as described for the reaction chamber of Figs 5 and 6, except that reaction chamber 326 has opposite closed ends 327 and 329. The reaction chamber 326 may not require an outer structural wall since working fluid is confined within heat transfer conduit 328. The delivery assembly 302 is connected in fluid communication to the reaction chamber 326 at a point along the length of the reaction chamber 326 via conduit 330.

As an alternative to the arrangement shown in Figure 10, the semi-permeable assembly 310, the catalyst vessel 312 and the vacuum system 314 may be individually connected to the reaction chamber 326. The reaction chamber 326 is preferably aligned spatially parallel to the heat transfer conduit 328 to promote heat transfer.

A working fluid, such as compressed air from a compressor, enters the heat transfer assembly via inlet 332, flows within heat transfer conduit 328, and exits via outlet 334. The working fluid does not contact the interior space 336 of the heat transfer assembly 304, which is evacuated by pump 370 connected in fluid communication with the heat transfer assembly 304. Heat evolved from hydrogen catalysis reactions occurring within reaction chamber 326 radiates to heat transfer conduit 328 and is conducted through the wall of the transfer conduit to the working fluid therein.

In the embodiment shown in Fig. 10, temperature control of the delivery assembly 302 is effectuated by the transfer via radiation of heat evolved from the hydrogen catalysis reactions occurring within reaction chamber 326. The transfer of heat from the transfer assembly 304 to the delivery assembly 302 is regulated by radiation shield 306. Radiation shield 306 is comprised of a stationary grating 338 and a movable grating 340, which is movable with respect to grating 338. An actuator 342 connected to movable grating 340 governs the movement of grating 340.

The stationary grating 338 and movable grating 340 are situated in a parallel fashion. Preferably, the movable grating is slidable on top of the stationary grating 338. The stationary grating 338 and the movable grating 340 each contain a plurality of openings 344. Actuator 342, located on the exterior of the shell 316 permits the movable grating 340 to slide along the stationary grating 338 in a back-and-forth motion. The radiation shield 306 is considered "open" when the apertures 344 of both the movable grating 340 and the stationary grating 338 are congruently aligned or partially aligned in congruent relation. The radiation shield is "closed" when the apertures 344 of the movable grating 340 and the stationary grating 338 are completely incongruous. The stationary grating 338 and the movable grating 340 are preferably made from high temperature stainless steel alloys or refractory metals.

Alternatively, the radiation shield may comprise at least one vane (not shown) extending continuously along a rotatable axis parallel to the heat transfer conduit 328. The vane may pivot between "open" and "closed" positions upon the movement of the axis which may be pivoted by an actuator located on the exterior of the shell 316.

Radiant heat transfer from the reaction chamber 326 to the heat transfer conduit 328 is similarly controlled by a radiation shield 350. Radiation shield 350 comprises an apertured stationary grating 352 and an apertured movable grating 354. An actuator 356 connected to movable grating 354 governs the movement of grating 354. The radiation shield 350 operates in the same fashion as radiation shield 306 described above. Radiation shield 350 may alternatively comprise at least one rotatable vane as described above.

An alternative embodiment of a hydrogen catalysis power cell of the invention employing a radiant heat exchanger-based heat transfer assembly is shown in Fig. 11. The hydrogen catalysis power cell 400 comprises a delivery assembly 402 connected in fluid communication with a heat transfer assembly 404. The delivery assembly 402 comprises a plurality of catalyst vessels 406 and semi-permeable membrane assemblies 408.

A portion of the delivery assembly 402 is shown in enlarged fashion, in Fig. 12. Each semi-permeable membrane assembly 408 and catalyst vessel 406 (both shown schematically) is respectively connected in fluid communication with a reaction chamber 410 of the heat transfer assembly 404. A hydrogen supply source

412 supplies hydrogen gas to a header 414 via a conduit 415. The header 414 in turn is connected in fluid communication with semi-permeable membrane assemblies 408 via conduits 416. A quenching system 470 is connected in fluid communication with reaction chamber 410 via conduit 472. The semi-permeable membrane assembly 408, catalyst vessel 406, and quenching system 470 are connected in fluid communication with reaction chamber 410 via a header 474 and conduit 476. The header 474 collects hydrogen gas and vaporous catalyst and delivers them to the reaction chamber 410. The catalyst vessels 406 and semi-permeable membrane assemblies 408 function as discussed above with respect to catalyst vessel 110 and semi-permeable membrane assembly 108.

As shown in Fig. 11, the heat transfer assembly 404 comprises a plurality of heat transfer conduits 420 positioned within interior 422 of the heat transfer assembly 404, in parallel fashion with the reaction chambers 410. A working fluid enters a heat transfer conduit 420 via inlets 424 and exits via outlets 426. Alternatively, working fluid entering the hydrogen catalysis power cell 400 may be delivered to a header, which in turn opens to individual inlets 424. The heat transfer conduits 420 and reaction chambers 410 are preferably positioned in alternating fashion as shown in Fig. 12. The heat transfer conduits 420 and reaction chambers 410 operate as discussed above with respect to heat transfer conduit 328 and reaction chamber 326.

Heat released in the reaction chambers 410 is conducted through an outer wall 430 of the reaction chamber and radiated to the heat transfer conduit 420, then absorbed by the working fluid therein.

In a preferred embodiment of the hydrogen catalysis power cell 400, a plurality of radiation shields 440 are rotatable about an axis running parallel to the heat transfer conduits 420 and reaction chambers 410. The radiation shields 440 limit heat losses from the reaction chambers 410 to the interior 422 of the power cell 400 and the heat transfer conduits 420 during start-up of the system when the temperature within the reaction chambers 410 must reach between about 600 °C to about 800 °C. Each radiation shield is connected to a central shaft 442 via connecting rods 444. The central shaft 442 may be manipulated from the exterior of the hydrogen catalysis power cell 400 to open or close the radiation shields 440.

A top plan view of the hydrogen catalysis power cell of Fig. 11 is shown in Fig. 13. As can be seen in Fig. 13, "open" radiation shields 440 are aligned perpendicular to the rows of reaction chambers 410 and heat transfer conduits 420. In Fig. 13, the reaction chambers 410 and heat transfer conduits 420 are situated in orderly rows, but any positional arrangement is appropriate, limited only by the ability to effectively transfer heat to the working fluid.

The hydrogen catalysis power cell 400 is preferably enclosed within a shell 450, and particularly bearing insulation (not shown) to minimize heat losses to the exterior of the shell 450. As noted above with respect to the discussion of Figs. 3 and 4, the delivery assembly 402 may be separate and apart from the heat transfer assembly 404, so long as both are in fluid communication.

Regulation of temperature in the delivery assembly 402 to control the permeability of the membrane in the semi-permeable membrane assembly 408 and the production of vaporous catalyst in the catalyst vessel 406 follows those means previously discussed with respect to Figs. 3, 4, and 10. Means for initiating the hydrogen catalysis reactions in the reaction chambers 410 (not shown) and means for terminating the hydrogen catalysis reactions in the reaction chambers (not shown) may be provided as set forth in the discussions above.

An embodiment of a hydrogen catalysis power cell of the invention employing a recirculating boiler-based heat transfer assembly is shown in Fig. 14. A hydrogen catalysis power cell 500 comprises a delivery assembly 502 connected in fluid communication with a heat transfer assembly 504. The delivery assembly 502 comprises a hydrogen supply source 505, catalyst vessel 506 and a semi-permeable membrane assembly 508. The catalyst vessel 506 and semi-permeable membrane assembly 508 function as set forth in the discussion above with respect to catalyst vessel 110 and semi-permeable membrane assembly 108.

The heat transfer assembly 504 comprises a plurality of reaction chambers 510, which may be connected in fluid communication to the delivery assembly 502 via a conduit 512 and a header 514. A hydrogen gas source 509 provides hydrogen to the semi-permeable membrane assembly 508. The header 514 receives hydrogen gas from the semi-permeable membrane assembly 508 and vaporous catalyst from the catalyst vessel 506 and supplies both to the reaction chambers 510. The reaction chambers 510 are constructed, and function, as set forth above in the discussion of reaction chamber 122.

The heat transfer assembly 504 further comprises an interior space 520 defined by sidewalls 522 and 523, reaction chamber sheet 524, and a top section 526. The reaction chambers 510 penetrate into the interior 520 through reaction chamber sheet 524, which secures the reaction chambers 510. Hence, sheet 524 functions as a tube sheet to support reaction chambers 510.

The interior 520 of the hydrogen catalysis power cell 500 contains the means to transport working fluid (e.g., water) through the heat transfer assembly 504 and means to separate liquid and vapor phases of the working fluid to ensure that only steam leaves the hydrogen catalysis power cell 500.

The means to transport water include feed conduit 530 and, preferably, a perforated ring header 531 (shown in partial cross-section) connected in fluid communication with feed conduit 530 which supplies water to the interior 520. A downcomer 532 directs the water along a baffle 534. The baffle 534 preferably runs continuously along a substantial length of the reaction chambers 510. Water is then directed into contact with the reaction chambers 510.

Heat released by hydrogen catalysis reactions within the reaction chambers 510 is conducted through the wall of the reaction chambers 510 and absorbed by the water, causing the water to boil, thus producing steam. Rising steam is preferably contacted against a means for separating steam from water vapor, such as swirl vanes 540. Steam is preferably further separated in a dryer 542, then exits the hydrogen catalysis power cell 500 via outlet 544. Steam, containing the heat energy converted from energy released from hydrogen catalysis, may thereafter be converted to kinetic energy of a rotor, for example, in an energy conversion system.

Regulation of temperature in the delivery assembly 502 to control the permeability of the membrane in the semi-permeable membrane assembly 408 and the production of vaporous catalyst in the catalyst vessel 406 follows those means previously discussed with respect to Figs. 3, 4, and 10. Means for initiating the hydrogen catalysis reactions in the reaction chambers 510 (not shown) and means for terminating the hydrogen catalysis reactions in the reaction chambers 510 (not shown) may be provided as set forth in the discussions above.

In energy conversion systems of the present invention, the power that can be extracted or converted from a heated working fluid is dependent upon regulation of the flow rate of the working fluid, the temperature of the working fluid, and the quantity of heat absorbed by the working fluid. The quantity of heat made available to the working fluid may be controlled by regulating the rate of hydrogen catalysis. The rate of hydrogen catalysis may be controlled by regulating the vapor pressure of the catalyst (e.g., controlling the temperature of the catalyst vessel), by regulating the vapor pressure of hydrogen (e.g., by controlling the flow rate of hydrogen gas and/or controlling the temperature of the semi-permeable membrane), and controlling the dissociation of molecular hydrogen in the reaction chamber (e.g., by controlling the temperature within the reaction chamber or introducing controlled amounts of inert gas in the reaction chamber).

An energy conversion system of the invention comprises a hydrogen catalysis power cell as described above, a working fluid for receiving the heat released from hydrogen catalysis, and means for converting the heat in the working fluid to mechanical or electrical energy. It is understood that heat in the working fluid may be converted to a variety of energy forms before ultimately being converted to mechanical or electrical energy.

The energy conversion system of the present invention further comprises a control system such as an automated computer-controlled monitoring and actuating system with feedback to balance the flow of energy (or power). "Balance" the flow of energy refers to maximizing a desired energy output in view of efficiency concerns, energy demands, and cost considerations. The flow of energy consists of power generation, power transfer, and power consumption. Power generation comprises hydrogen catalysis. Power transfer comprises power removed by the working fluid (heat transfer medium) and delivered to the load. Power consumption comprises utilization or converter loads (such as space and process heating loads) and mechanical loads (such as turbine engines and turbine generators).

The control system is capable of monitoring the power flow by measuring parameters in each stage of the energy conversion flow and altering the flows to achieve a desired power balance. Means to control the rate of hydrogen catalysis are described above. The power flow of the heat transfer assembly may be controlled by controlling the temperature of the heat transfer medium, the pressure of a gaseous heat transfer medium, the flow rate of the heat transfer medium, the residence time of the heat transfer medium in the heat transfer assembly, the heat capacity of the heat transfer medium, the amount of heat recuperated from the load and added to the heat transfer medium, or heat diverted to or from the heat transfer assembly. In the latter case, for example, gas turbine baffles may divert compressed air from a compressor to increase or decrease the percentage of the compressor's output to the heat transfer assembly versus that directed to the turbine directly.

Power consumption by the load may be controlled by increasing or decreasing the load, as exemplified by increasing or decreasing the thermal, mechanical, or power line load by controlling parameters such as heat transfer rates, turbine speeds, and turbine temperatures and pressures. Sensors for parameters such as temperature, pressure, flow rate, turbine shaft speed and torque, and methods and apparatus to control the flow of the heat transfer medium around or through the heat transfer assembly, and to control the power consumed in the load, comprise those methods and apparati generally known in the art of power engineering.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description; and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Claims:

1. A power cell for generating heat based on hydrogen catalysis and for transferring said generated heat to a working fluid, the power cell comprising:

(a) a heat transfer assembly comprising at least one enclosed, vacuum-tight reaction chamber containing a means for dissociating molecular hydrogen gas into atomic hydrogen;

(b) a delivery assembly connected in fluid communication with the reaction chamber for delivering hydrogen gas and vaporous catalyst for hydrogen catalysis to the heat transfer assembly, the delivery assembly comprising

(1) a catalyst vessel for generating vaporous catalyst for hydrogen catalysis,

(2) a source of hydrogen gas, and

(3) a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly, which membrane assembly contains a semi-permeable membrane which permits the passage of hydrogen but substantially inhibits the passage of vaporous catalyst therethrough;

(c) means for regulating the temperature of the catalyst vessel; and

(d) means for regulating the temperature surrounding the semi-permeable membrane.

2. The power cell of claim 1, wherein the heat transfer assembly further comprises a header for distributing hydrogen gas and vaporous catalyst to said at least one reaction chamber.

3. The power cell of claim 1, wherein the heat transfer assembly further comprises a means for passage of working fluid in proximity with the reaction chamber to receive the heat generated by the hydrogen catalysis reaction in the reaction chamber.

4. The power cell of claim 3, wherein the heat transfer assembly is enclosed in an evacuated housing.

5. The power cell of claim 3, further comprising means for controlling heat transfer from the reaction chamber to said means for passage of working fluid in proximity with the reaction chamber.

6. The power cell of claim 5, wherein the means for controlling heat transfer from the reaction chamber to said means for passage of working fluid comprises a radiation shield.

7. The power cell of claim 3, wherein the means for regulating the temperature of the catalyst vessel and the means for regulating the temperature surrounding the semi-permeable membrane comprise a radiation shield for regulating heat evolved in the reaction chamber radiating to the delivery assembly.

8. The power cell of any one of claims 1 to 7, wherein the radiation shield comprises an apertured grating slidably movable over an apertured stationary grating.

9. The power cell of any one of claims 1 to 7, wherein the means for dissociating hydrogen gas is a catalyst for the dissociation of hydrogen gas.

10. The power cell of claim 9, wherein the catalyst is coated on a substrate surface in said at least one reaction chamber.

11. The power cell of claim 9, wherein the catalyst forms a lattice structure in the reaction chamber and the reaction chamber further comprises:

a) an inner wall surrounding the lattice structure;

b) an outer wall surrounding the inner wall, the outer wall having an interior surface and an exterior surface; and

c) an evacuated annular space between the inner wall and the outer wall.

12. The power cell as in claim 11, wherein the reaction chamber further comprises a surface coating lining the interior surface of the outer wall, which surface coating promotes the transfer of heat from within the reaction chamber to the working fluid.

13. The power cell of any one of claims 1 to 12, wherein the semi-permeable membrane assembly comprises a collection housing enclosing the semi-permeable membrane, which membrane is shaped to form a closed internal space within the collecting housing, said internal space being in communication with the hydrogen gas source, said collection housing having an inlet end and an outlet end, said outlet end connected in fluid communication with the heat transfer assembly, so that hydrogen gas passing through the membrane and collected in the collection housing is directed to the reaction chamber.

14. The power cell of any one of claims 1 to 12, wherein at least one of the semi-permeable membrane assembly and the catalyst vessel are independently connected in fluid communication with said at least one reaction chamber.

15. The power cell of any one of claims 1 to 12, wherein the semi-permeable membrane comprises palladium-coated tantalum.

16. The power cell of any one of claims 1 to 15, further comprising a heater for supplying heat to the catalyst to generate vaporous catalyst.

17. The power cell of claim 16, wherein the heater comprises heating elements surrounding the exterior of the catalyst vessel.

18. The power cell of any one of claims 1 to 12, wherein the semi-permeable membrane assembly is positioned within the reaction chamber.

19. The power cell of any one of claims 1 to 18, wherein the means for regulating the temperature of the catalyst vessel comprises a conduit for carrying a heated working fluid from the heat transfer assembly to the delivery assembly.

20. The power cell of claim 19, wherein the means for regulating the temperature of the catalyst vessel further comprises a conduit for returning a working fluid from the delivery assembly to the heat transfer assembly.

21. The power cell of any one of claims 1 to 18, wherein the means for regulating the temperature surrounding the semi-permeable membrane comprises a conduit for carrying a heated working fluid from the heat transfer assembly to the delivery assembly.

22. The power cell of claim 21, wherein the means for regulating the temperature surrounding the semi-permeable membrane further comprises a conduit for returning a working fluid from the delivery assembly to the heat transfer assembly.

23. The power cell of any one of claims 1 to 22, wherein the power cell further comprises means for evacuating the reaction chamber.

24. The power cell of any one of claims 1 to 22, wherein the power cell further comprises means for terminating hydrogen catalysis within the reaction chamber.

25. The power cell of any one of claims 1 to 24, wherein the power cell further comprises means for initiating hydrogen catalysis within the reaction chamber.

26. The power cell of any one of claims 1 to 25, wherein the working fluid is water and the power cell further comprises means to separate steam from water vapor.

27. A power cell for generating heat based on hydrogen catalysis and for transferring said generated heat to a working fluid, the power cell being substantially as hereinbefore described with reference to any one of Figures 2 to 14.

28. A method for utilizing heat released from a hydrogen catalysis reaction, the method comprising:

a) introducing hydrogen gas and vaporous catalyst into a reaction chamber of a power cell;

b) dissociating hydrogen molecules of the gas into hydrogen atoms;

c) reacting hydrogen atoms and catalyst in a reaction such that (i) the reaction of a hydrogen atom with a catalyst has a net enthalpy of reaction of about $m \bullet 27.21$ eV, where m is an integer, which results in a hydrogen atom having a binding energy greater than about 13.6 eV and the release of energy, or (ii) the reaction of two or more hydrogen atoms having a binding energy greater than about 13.6 eV results in a net release of energy and at least one hydrogen atom having a binding energy higher than the initial binding energy of said hydrogen atom before the reaction.

d) transferring the released heat to a working fluid.

29. The method of claim 28, wherein the catalyst is potassium iodide.

30. The method of claim 28 or claim 29, wherein the partial pressure of the hydrogen gas in said reaction chamber is from about 50 millitorr to about 100 torr, and the partial pressure of catalyst in said reaction chamber is from about 50 millitorr to about 100 torr.

31. The method of any one of claims 28 to 30, wherein the power cell comprises

a) a heat transfer assembly comprising at least one enclosed, vacuum-tight reaction chamber containing a means for dissociating molecular hydrogen gas into atomic hydrogen;

b) a delivery assembly connected in fluid communication with the reaction chamber for delivering hydrogen gas and vaporous catalyst for hydrogen catalysis to the heat transfer assembly, the delivery assembly comprising

(1) a catalyst vessel for generating vaporous catalyst for hydrogen catalysis,

(2) a source of hydrogen gas, and

(3) a semi-permeable membrane assembly connected in fluid communication with the hydrogen gas source and the heat transfer assembly, which membrane assembly contains a semi-permeable membrane which permits the passage of hydrogen but substantially inhibits the passage of vaporous catalyst therethrough;

c) means for regulating the temperature of the catalyst vessel; and

d) means for regulating the temperature surrounding the semi-permeable membrane.

32. The method of any one of claims 28 to 30, wherein the power cell is as set forth in any one of claims 1 to 27.

33. An energy conversion system for converting thermal energy released by hydrogen catalysis, the energy conversion system comprising:

a) a hydrogen catalysis power cell as set forth in any one of claims 1 to 27;

b) a working fluid for receiving the heat released from hydrogen catalysis;

c) means for converting the heat in the working fluid to mechanical or electrical energy.

34. The energy conversion system of claim 33, further comprising means for balancing the heat energy extracted by the working fluid with heat produced from hydrogen catalysis and consumed by said means for converting the heat in the working fluid to mechanical or electrical energy.

35. The energy conversion system of claim 34, wherein the means for balancing the heat energy extracted by the working fluid with heat produced from hydrogen catalysis and consumed by said means for converting the heat in the working fluid to mechanical or electrical energy comprises an automated control system.

36. The energy conversion system of claim 35, wherein the control system comprises means to control at least one of the rate of hydrogen catalysis, the temperature of the working fluid, the heat capacity of the working fluid, the amount of heat delivered to the heat transfer assembly, the amount of heat taken from the heat transfer assembly, and the power consumed by the means for converting the heat in the working fluid to mechanical or electrical energy.

Dated 4 April, 2001
Black Light Power, Inc.

Patent Attorneys for the Applicant/Nominated Person
SPRUSON & FERGUSON

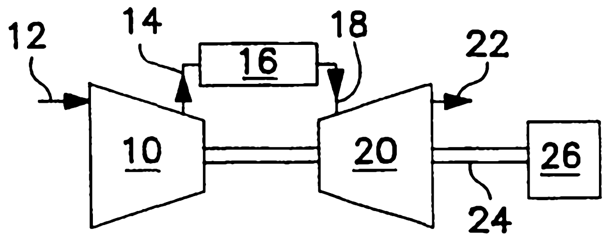

FIG. 1A
PRIOR ART

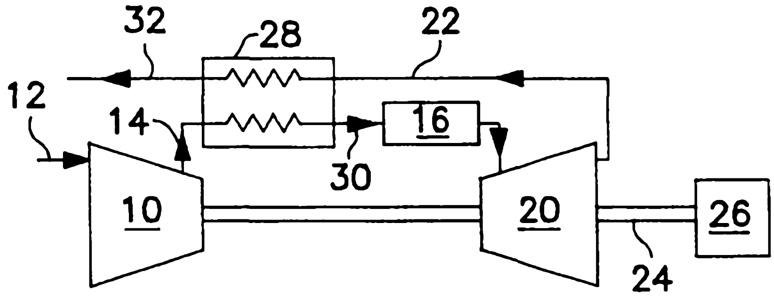

FIG. 1B
PRIOR ART

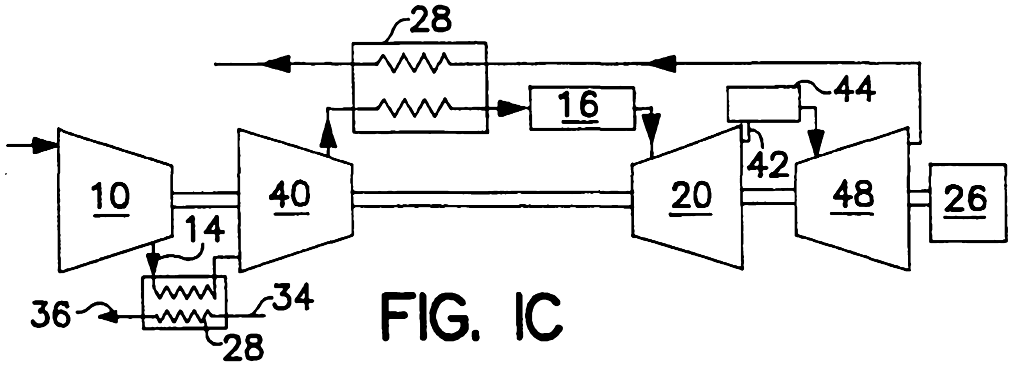

FIG. 1C
PRIOR ART

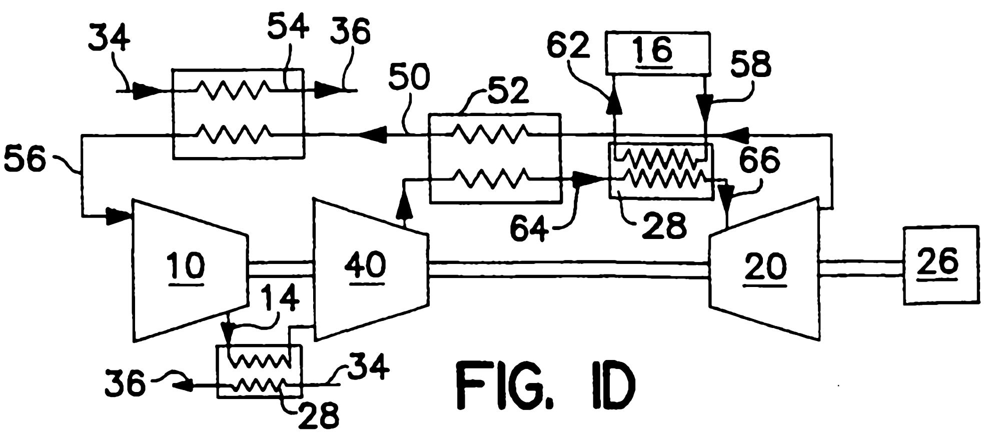

FIG. 1D
PRIOR ART

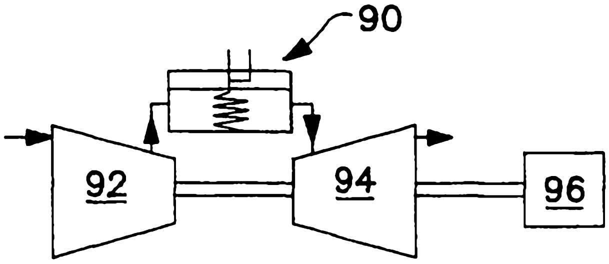

FIG. 2

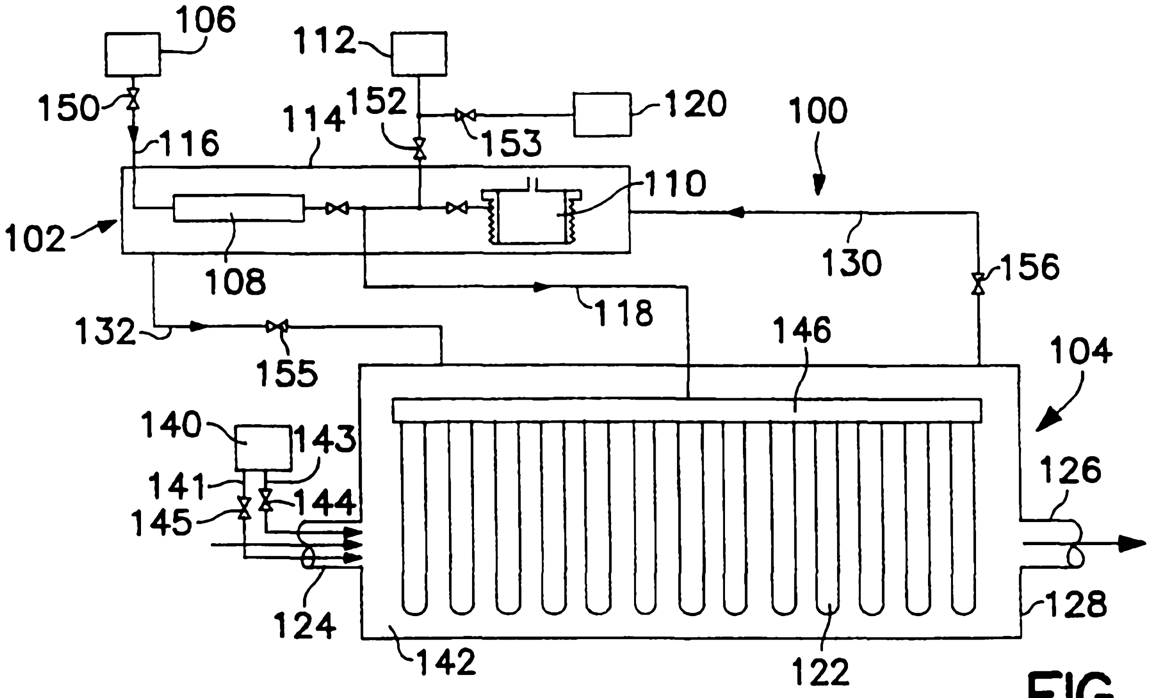

FIG. 3

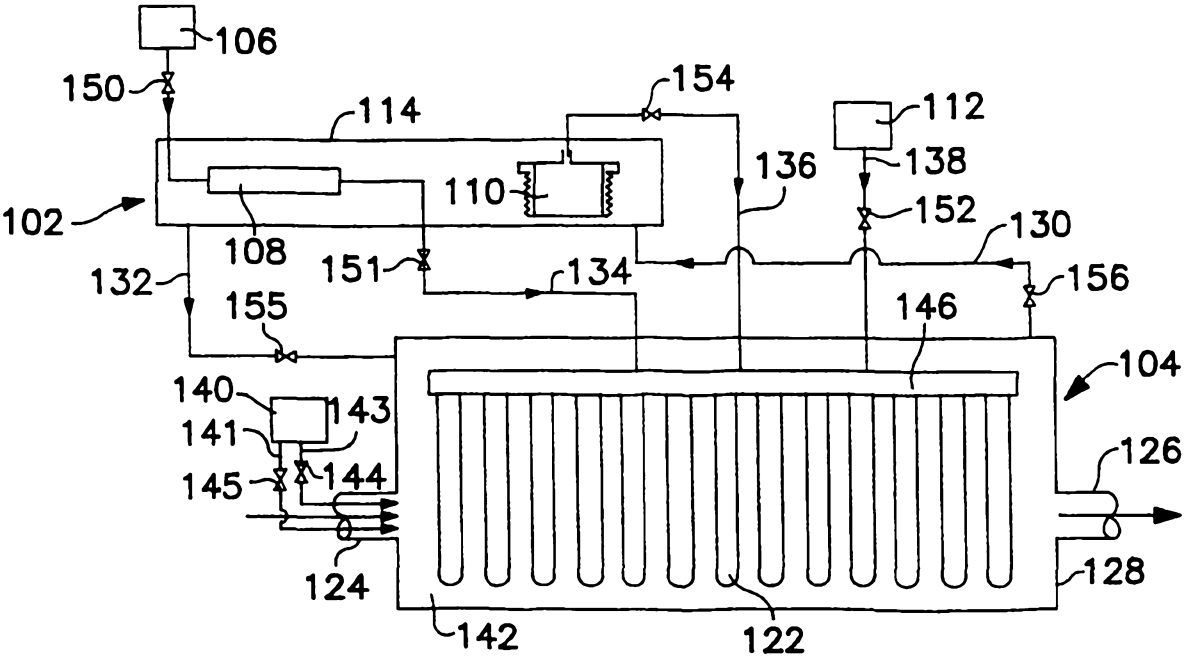

FIG. 4

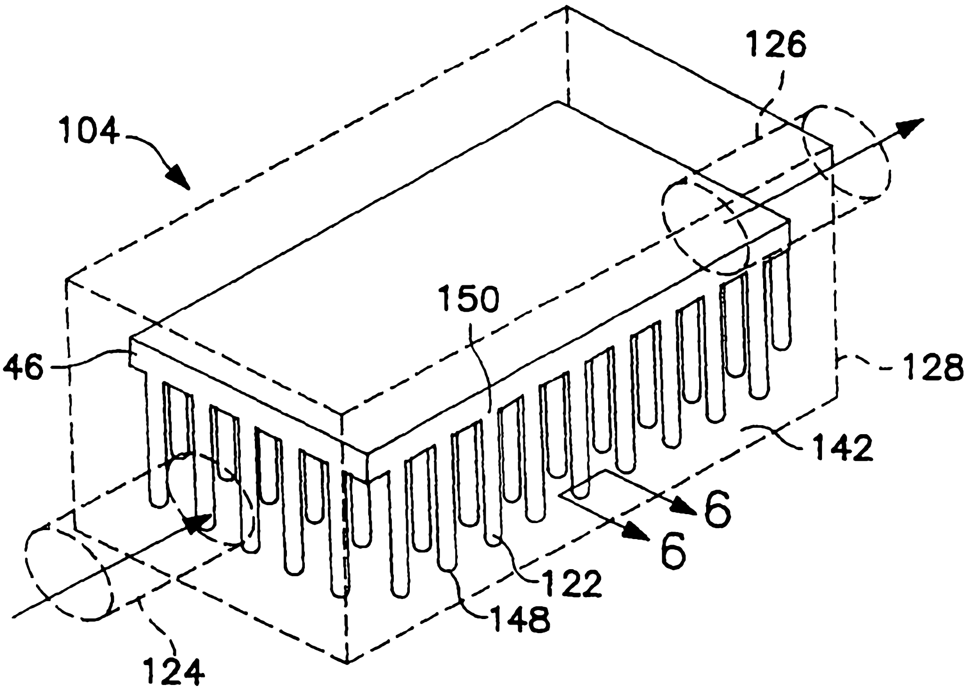
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FIG. 5

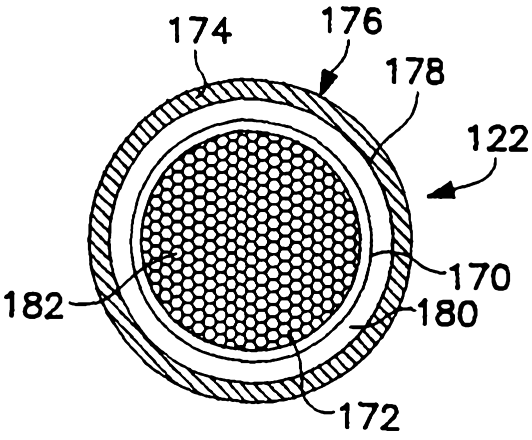
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FIG. 6

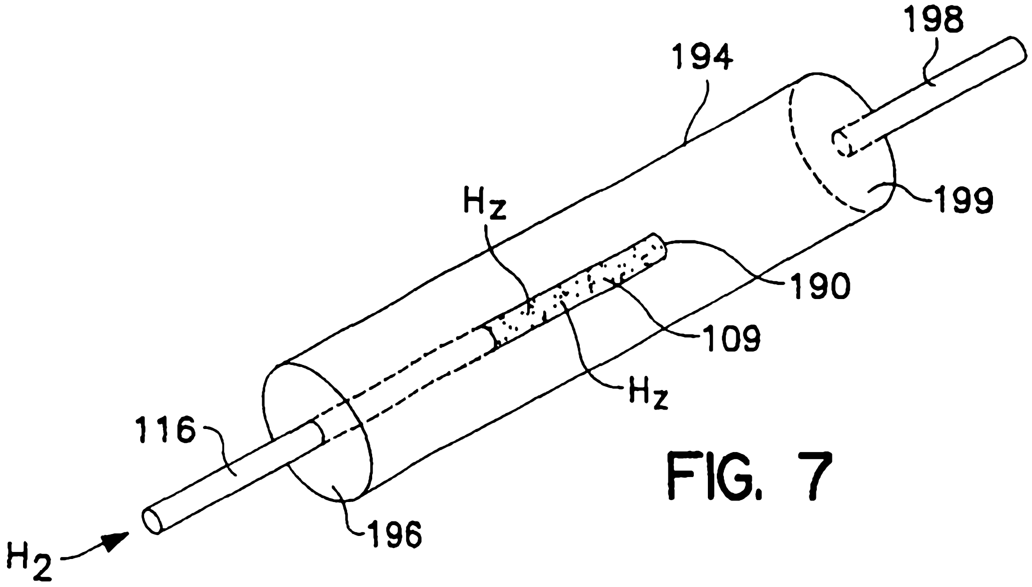

FIG. 7

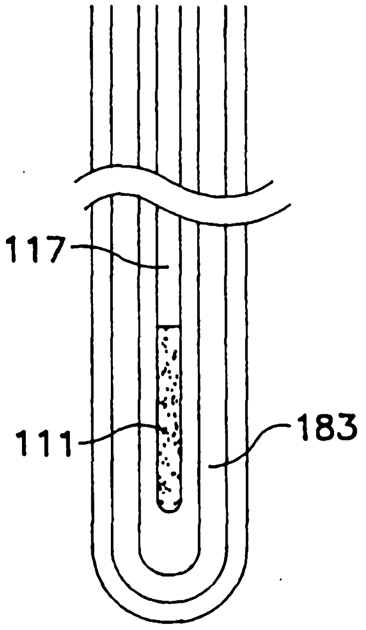

FIG. 8

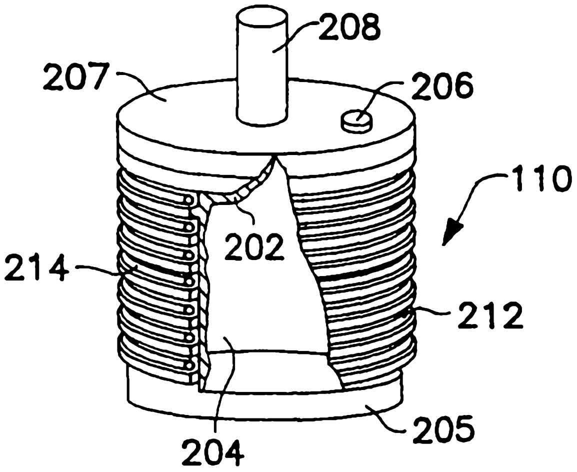

FIG. 9

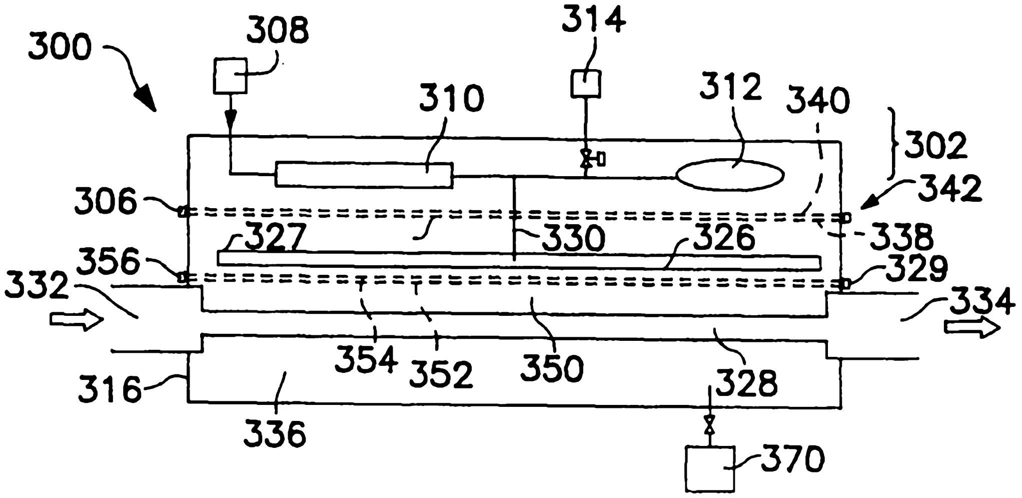
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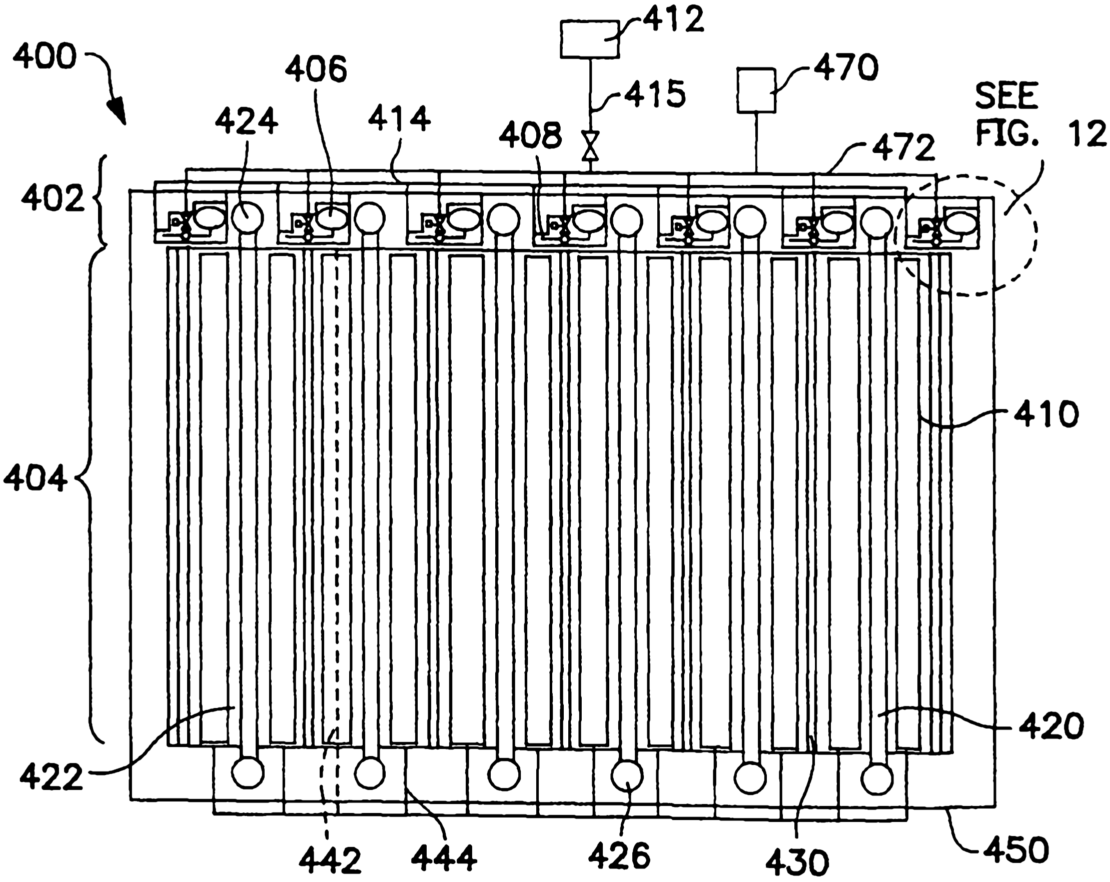
FIG. 10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SEE FIG. 12
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FIG. 11

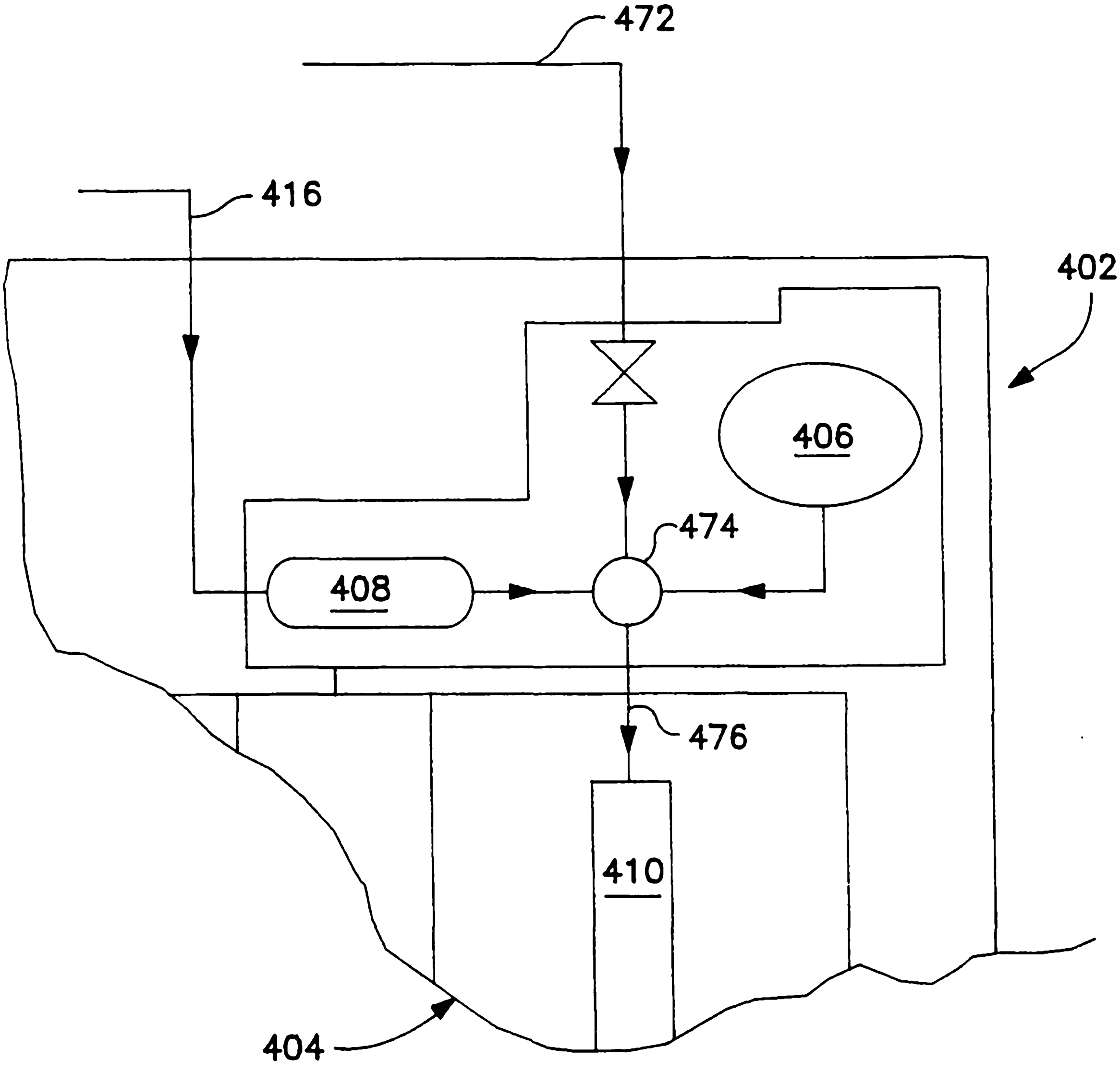

FIG. 12

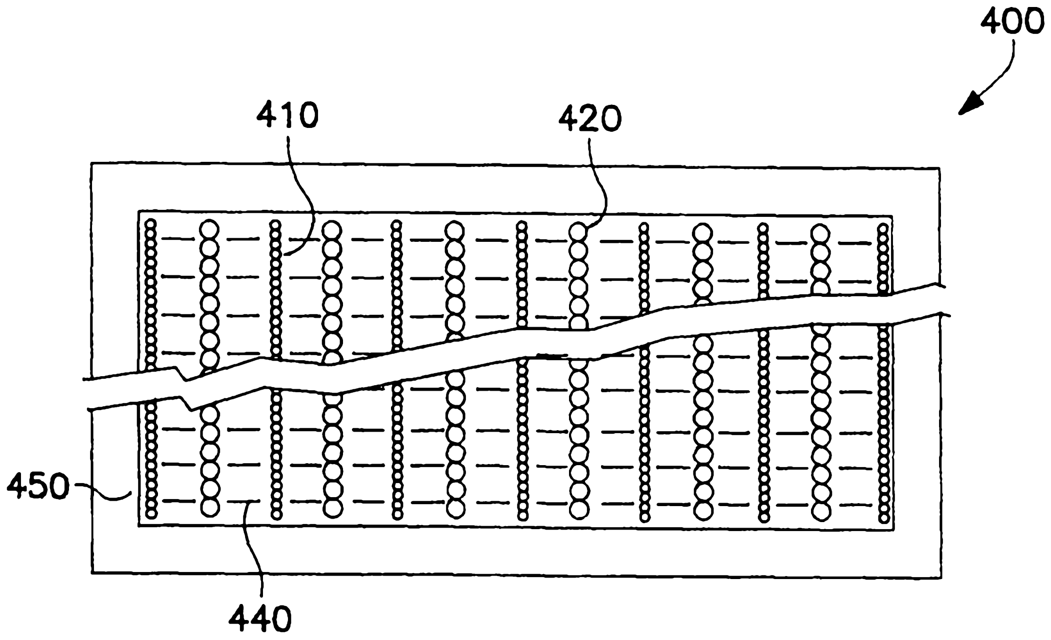

FIG. 13

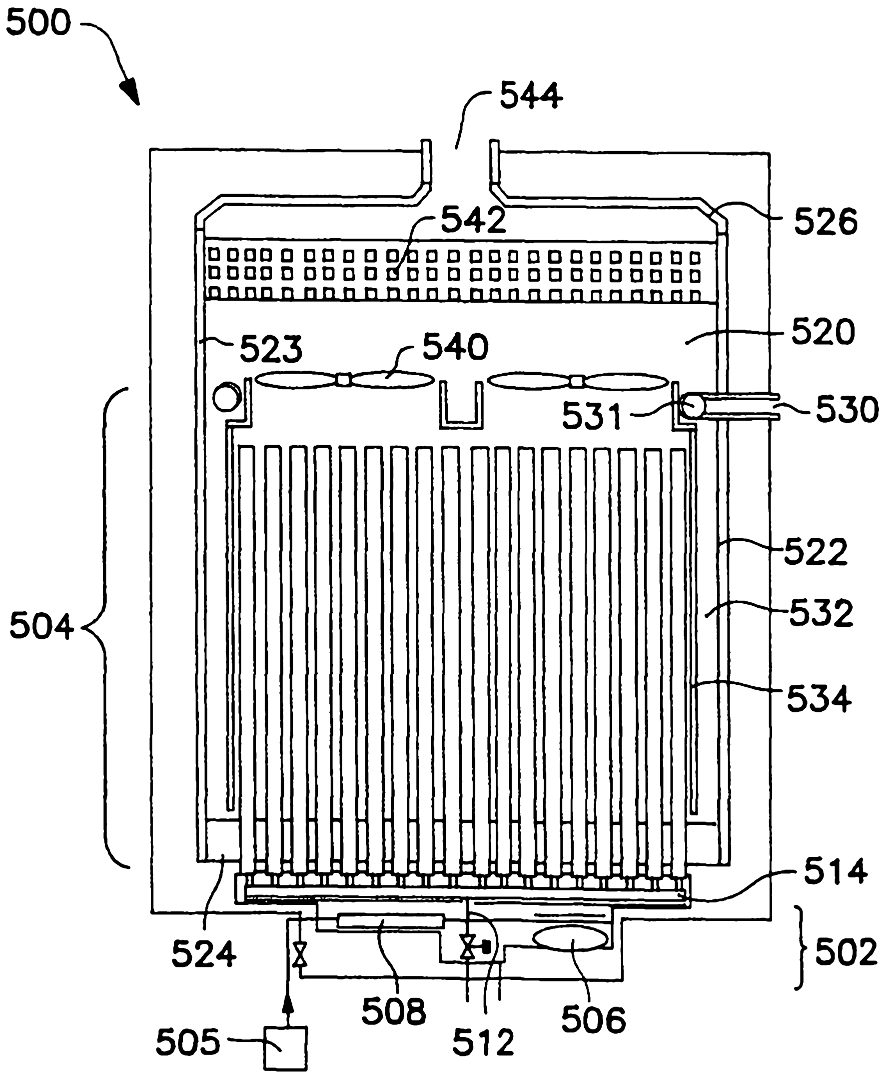
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FIG. 14