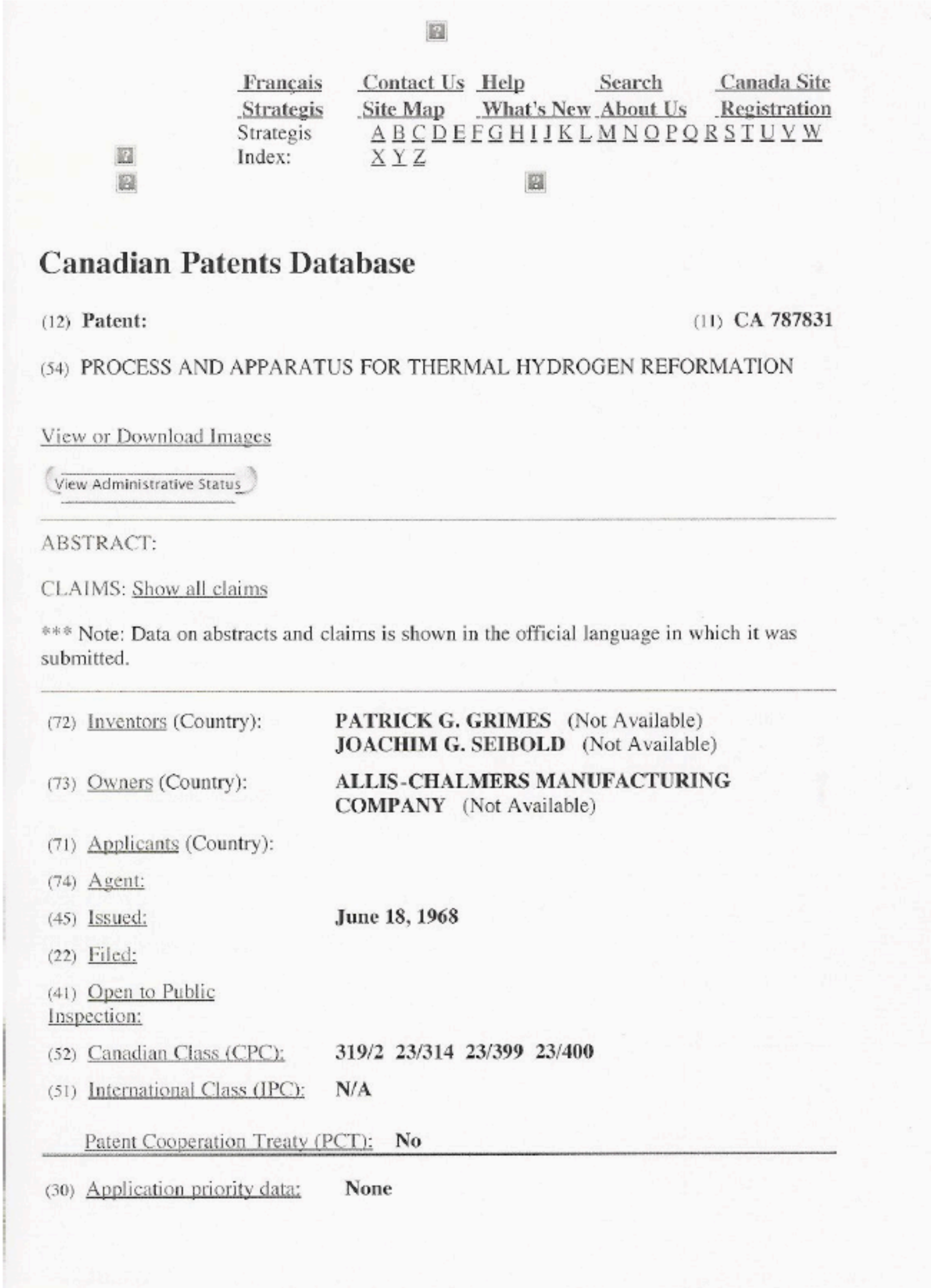

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(12) **Patent:** (11) **CA 787831**

(54) PROCESS AND APPARATUS FOR THERMAL HYDROGEN REFORMATION

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ABSTRACT:

CLAIMS: Show all claims

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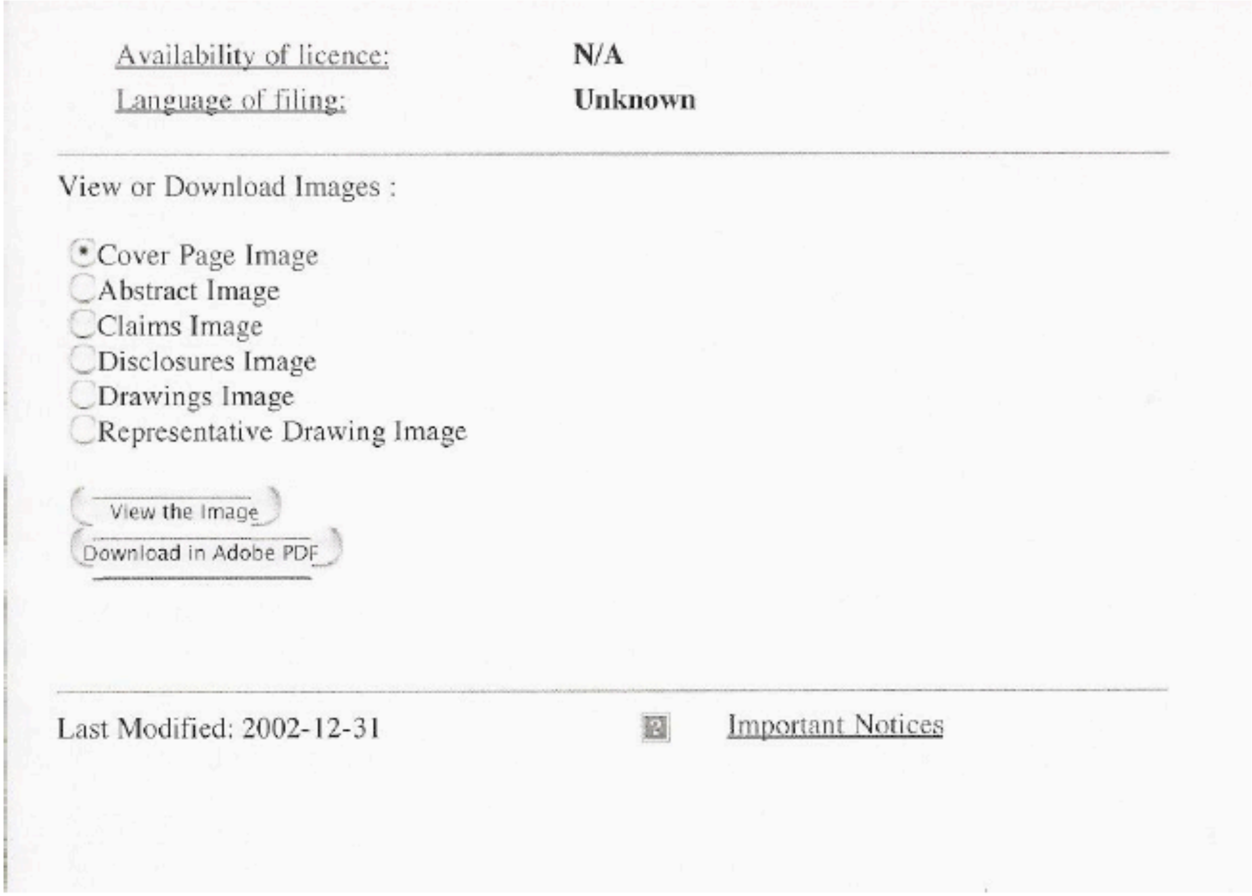

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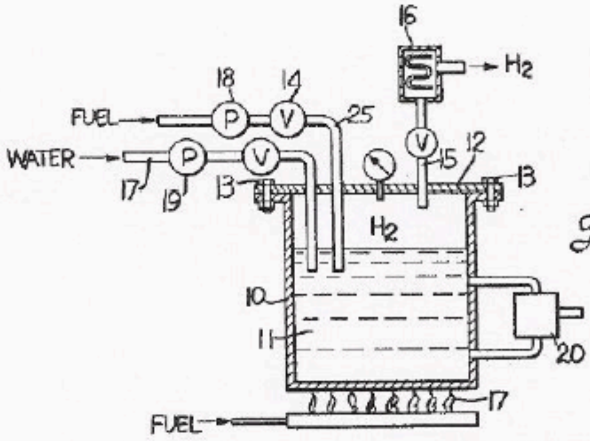

Fig-1

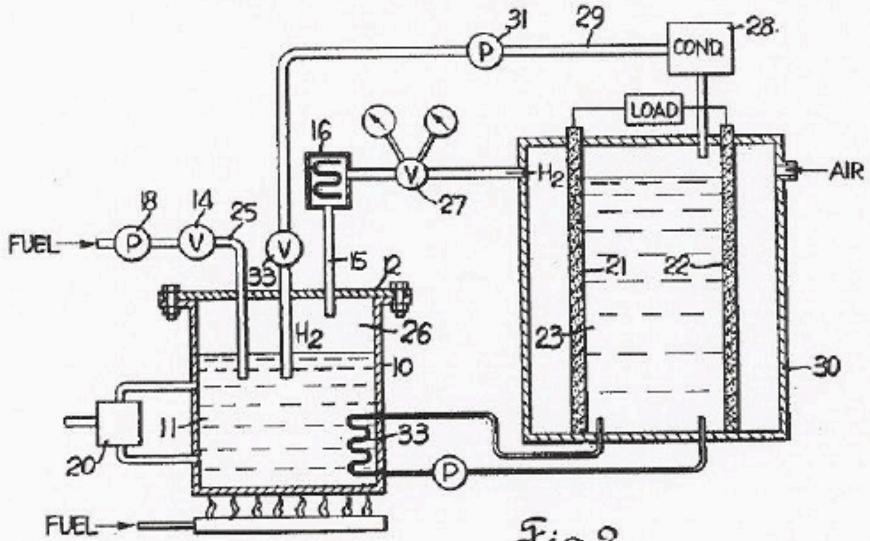

Fig. 2

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This invention relates generally to a new and improved method for producing hydrogen. More specifically, this invention relates to an economically improved method for producing hydrogen thermally and catalytically for almost any liquid or soluble organic oxidizable substance in a compact efficient reactor vessel. This invention may find particular utility in hydrogen production in compact or field applications and is especially ideal for use in combination with hydrogen-oxygen fuel cells.

The advent of the hydrogen-oxygen fuel cell has brought the demand for new methods to produce hydrogen as a fuel for the fuel cell. Although the hydrogen-oxygen fuel cell has already shown considerable promise as one of the best fuel cell systems, it has a major drawback in that the hydrogen fuel necessary is rather expensive and being in the gaseous state somewhat complicates handling procedures. This further complicates its functionality in that the gaseous fuel must be supplied in high pressure vessels from sources which are not greatly dispersed. The hazards involved are readily apparent. If hydrogen could be more readily available or producible on the spot from other more readily available fuels, such fuel cells would find particular utility as field or mobile power units of compact dimensions. By converting the chemical energy of the fuel directly into electrical energy, such fuel cells could go a long way in solving military logistical problems by replacing fuel engine-generator power plants, or solving power supply problems in mobile vehicles or space explorations. However, the presently known methods for producing the hydrogen gas from hydrocarbon fuels, or from any source for that matter, are either too complex and cumbersome or too expensive to be adopted to field or mobile applications in combination with such fuel cells.

One of the most widely utilized processes for the commercial production of hydrogen is the steam reformer process where steam and hydrocarbon fuels such as propane, butane and the like react catalytically to produce a carbon oxide and hydrogen gas. The following equations exemplify the reaction for propane:

$$C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$$

$$C_3H_8 + 6H_2O \rightarrow 3CO_2 + 10H_2$$

Although this process is satisfactory for commercial hydrogen production, it would not be practical for field or mobile operations because the reaction is effected in the gaseous state necessitating high temperatures, extremely large and complex reformer furnaces, and complex gas collecting systems. Furthermore, since the reactants and products are in the gaseous state and the reaction is not complete, the hydrogen gas produced by this process is not as pure as may be desired, thus additional refining operations are necessary. Thereafter, the hydrogen must be compressed by mechanical means and bottled.

Likewise all other commercial hydrogen reforming processes require such extremely large volume equipment as to preclude field or mobile applications. Therefore, the hydrogen fuel cells must presently be operated directly from a high pressure hydrogen tank or cyrogenic hydrogen obtained through commercial channels.

This invention is predicated upon our discovery of a new process for the production of hydrogen thermally from organic fuels or any oxidizable liquid or soluble organic compound which upon reaction with an oxidizing agent is capable of producing hydrogen. The fuels (oxidizable compound) found to be most efficient are the hydrocarbons, alcohols, acids, ketones and to some extent the aldehydes. Mixtures of these are also effective. The reaction of this invention proceeds catalytically from reactants in the liquid state and at markedly lower temperatures than utilized in prior art reformation processes and thus precluded the necessity of large and complex equipment. Furthermore, with the proper selection of operating conditions, the produced hydrogen gas is of sufficiently high purity as to make subsequent refining procedures unnecessary, and the gas as produced is under pressure so as to eliminate the need for mechanical compression.

Accordingly, it is a primary object of this invention to provide a thermal and catalytic process for the formation of hydrogen under pressure from a liquid or soluble organic oxidizable substance which is capable of producing hydrogen upon reaction with an oxidizing agent requiring only the liquid or dissolved organic fuel, an ionically conductive electrolyte solution, an electronically conductive catalyst, water and an energy input which may be purely thermal energy.

It is another primary object of this invention to provide a new method for the production of hydrogen which is readily adaptable to field or mobile applications being effected in a small compact reactor vessel thus precluding the necessity for large complex equipment for high temperature gaseous steam reforming.

It is still another primary object of this invention to provide a small compact and efficient hydrogen reforming unit readily adaptable for use in conjunction with hydrogen-oxygen fuel cells and adaptable for accepting any of a number of hydrocarbon and hydrocarbon derivatives or fossil fuels as a source of hydrogen.

These and other objects and advantages are fulfilled by this invention as will become apparent from a full understanding of the following detailed description, especially when considered in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic drawing of a high pressure reactor vessel for producing hydrogen showing examples of the necessary constituents; and

Fig. 2 is a schematic drawing of the hydrogen reformer of this invention used in combination with a hydrogen-oxygen fuel cell showing the mutual cooperation between the two primary parts.

As noted above, the basic requirements for producing hydrogen in accordance with this invention is an organic oxidizable liquid or soluble compound, which is capable of producing hydrogen upon reaction with an oxidizing agent, an ionically conductive electrolyte, an electronically conductive catalyst and water. It may be necessary to add heat or other forms of energy depending upon the fuel or oxidizable substance being utilized.

The drawing in Fig. 1 illustrates one of the favored embodiments of this invention for producing hydrogen gas. In this embodiment the reactor vessel 10 contains an ionically conductive electrolyte solution 11, for example, an aqueous solution of potassium hydroxide, KOH; and fine suspended granules of an electronically conductive catalyst, for example fine suspended granules of gold, silver, nickel, rhodium, platinum or the other group VIII A metals. The reactor vessel is provided with a lid 12, secured by bolts 13, so that the volume within the reactor is a gas tight pressure chamber. The oxidizable fuel is admitted into the solution by the valve 14 through pipe 25. For example, the fuel may be methanol, CH_3OH. In the case of methanol and most other fuels, heat may be applied to the system from any heat source 17, if a good practical rate of hydrogen production is desired. However, a heat input is necessary for most fuels only to control the rate of hydrogen production, as the reactions will proceed at ambient temperatures with a more limited production rate.

If a heat input is applied, the system at elevated temperatures is under pressure and the methanol commences to oxidize rapidly producing hydrogen gas. The reaction that proceeds may be expressed as:

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2$$

The hydrogen is bubbled out of the solution and collects at the top of the pressure vessel continually increasing the pressure of the system. For some fuels or oxidizable compounds, there is a certain maximum pressure limit attainable whereafter reverse or side reactions between the products will occur. If hydrogen is drawn off, however, then the forward reaction producing hydrogen predominates. As needed, the hydrogen is drawn off through the pipe 15. A condenser 16 may be provided which will collect and return any impurities such as water or fuel.

Since water is being utilized by the reaction, it will be necessary to have additional water supplied to the system, such as through pipe 17, if continual operation is desired. If the fuel and water are not from pressurized sources, driving means such as pumps 18 and 19 will be necessary to force the fuel and water into the vessel 10 since the vessel is usually under pressure. It may also be desirable to provide a separator 20 to collect and remove the oxidation products from the electrolyte if continuous operation is desired.

Many fuels, including methanol in a potassium hydroxide solution, continue to produce hydrogen at exceedingly high hydrogen pressures, and this equilibrium is not attained within the ordinary pressure limits of the vessel. Accordingly, as long as these fuels are added to the system, the reaction will proceed producing more hydrogen to increase the pressure of the system. For example, in a small reactor vessel as described using methanol as a fuel, we have produced hydrogen gas at pressures up to 5000 psi.

In order to better understand the mechanism of the above described thermal reformation process, it can perhaps be somewhat analogized to an electrolytic cell system or electrical reformation process as described in United States patent 3,092,516. By understanding the electrolytic cell system, a close following of the progressive developments will make the reaction in thermal reformation more readily understandable.

First an electrolytic cell is provided which contains an electrolyte. To be more closely analogous to the embodiment of Fig. 1, described above, the preferred electrolyte solution should be a caustic electrolyte, preferably an aqueous solution of potassium hydroxide. However, acid electrolyte will work. The cell is provided with two electronically conductive electrodes, in this case made of nickel and plated with a catalyst. Now then, if methanol is added to the electrolyte in this cell and if a sufficient electrical potential is applied between the electrodes, an electrolysis reaction will proceed wherein the methanol is oxidized at the anode to a carbonate, and at the cathode, water is reduced to hydrogen gas and hydroxyl ions. The two half cell reactions are:

$$CH_3OH + 6OH^- \rightarrow CO_2 + H_2O + 6e^-$$

$$6H_2O + 6e^- \rightarrow 3H_2 + 6OH^-$$

Therefore, the net reaction is:

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2.$$

The CO_2 will react with the alkali according to the following reaction:

$$CO_2 + 2OH^- \rightarrow CO_3^{=} + H_2O.$$

If the electrolyte is decreased in pH, CO_2 will eventually stop reacting as noted above and be expelled from the electrolyte. Accordingly, the reaction products can be controlled between CO_2 and $CO_3^{=}$ by controlling the pH of the electrolyte.

It should be noted, however, that if the electrical potential between the electrodes is eliminated or reduced below a certain minimum value, the reaction will stop, or at least be reduced to such a slow rate as to be virtually at equilibrium. Thus, a certain minimum value for the electrical potential at the electrodes must be maintained in order for the reaction to proceed. That is, a certain minimum electrical energy input is necessary to overcome diffusion and polarization effects. If a value above this minimum voltage is maintained, the reaction will proceed with the rate of reaction dependent primarily upon the current density. In combination with a fuel cell then, the electrical reformation process poses the disadvantage in that electrical energy is needed to ultimately produce electrical energy.

We have noted, however, that the value of the minimum necessary voltage for a spontaneous reaction is inversely proportional to the temperature of the system. Accordingly, the higher the temperature of the system the lower the voltage needed to cause the reaction to proceed. To express this in a completely theoretical manner, an increase in temperature causes a slight increase in the total energy requirements of the reaction, but the free energy requirements decrease. For example, at room temperature (25°C) the reaction of propane in an acidic electrolyte will require an input of 152.4 Kcal of energy per mole of propane. Of this energy 62.9 Kcal must be electrical energy, that is, the free energy (ΔF) of the reaction. The additional energy, 89.5 Kcal (152.4 - 62.9 Kcal) may be supplied as thermal energy. Although increasing the temperature may cause an increase in the total energy requirements, it will also cause a decrease in the free energy or that proportion which must be electrical energy. In actual practice however, the electrical energy requirements are greater than theoretical because of inefficiencies due to diffusion and polarization effects. Lower current densities in effect lower the critical voltages for any given temperature or lower the necessary temperature at any given voltage. The reaction rate is also a function of the current density, being directly proportional thereto for a constant voltage and temperature. Therefore sufficiently moderate current densities would be necessary to maintain a useful reaction rate.

Since the relationship between the critical voltage and temperature at a constant current density has a negative slope, it might be concluded that at some given temperature for each fuel the critical voltage will approach zero. This in a sense is true at lower current densities where the rate of reaction is too slow to effectively produce hydrogen. But at the higher current densities necessary for good production of hydrogen, the temperature at which the critical voltage would approach zero is far above the normal boiling points of almost all of the desirable fuels. Operating at such high temperature above the fuel's normal boiling point would cause the fuel and the water and perhaps even the electrolyte to boil thus contaminating any hydrogen that may be produced and tremendously lowering the efficiency of the system. However, if the reaction is allowed to proceed in a pressure vessel where the fuel and water can be prevented from boiling out, the reaction will proceed at a given rate at temperatures above the normal boiling point of the fuel. It is not necessary to apply any external pressure to the system, since all that is necessary is to allow the partial pressures of the liquids in the vessel to increase responsively as heat is applied. Thus, there is enough thermal energy supplied to the system to cause the reaction to proceed spontaneously, completely overcoming diffusion and polarization effects, which normally must be supplied by electrical energy. Theoretically then, the electrons would flow from the anode to the cathode not by the force of the external EMF, but by chemical energy of the cell as in a battery or fuel cell and the only external energy supplied to the system is thermal energy. The current density, or of more concern the reaction rate, will be determined by the temperature of the system.

In actual practice however, the electrons will not readily flow from the anode to the cathode without the applied EMF. This is because at this point both electrodes are at the same potential and accordingly either of the half cell reactions could occur at either of the electrodes. Therefore, in this system under pressure and at elevated temperatures, the water being in contact with the anode as well as the cathode can just as readily be reduced at the anode and also the fuel can just as readily be oxidized at the cathode. Therefore, it is more likely that a majority of the electrons will not flow through the external circuit, but will merely flow from one point on an electrode where a fuel molecule is oxidized to another point on the same electrode where a water molecule is reduced.

Further considerations indicate that since there is no external EMF, and the electrodes do not have to be of dissimilar materials, there is no need for two electrodes and just one electrode will suffice. The electrons will then be conducted from one portion of the electrode to another and each small area of the electrode will in a sense constitute a cell. Further, since there is no circuit, there is no need for an electrode as such at all, and the conducting electrode may be replaced by suspended particles of any electronically conducting material. The reactor vessel as modified then is the specific reactor vessel as described in the embodiment above and Fig. 1.

We have found that without the presence of the catalyst (the electronically conductive material) the reaction will not proceed or will proceed so slowly that it could not be of any possible commercial interest even at elevated temperatures. Therefore, this conducting catalyst is an absolutely necessary element for the production of hydrogen. Apparently, the catalyst particles suspended in the electrolyte enhance the speed of the reaction by accepting the electrons from the fuel molecule at one point on the surface to oxidize the fuel molecule. The catalyst being electronically conductive, allows these electrons to be conducted to another surface point where they are given up to a water molecule to produce hydrogen gas and a hydroxyl ion. Thus, each suspended conductor particle acts as a tiny cell, the catalyst being the medium through which the electrons are transferred. It is apparent that the conductive catalyst need not be of any particular size and shape, since all that is necessary is a conductive surface area to enhance the electron transfer. However, fine particles are preferred because of the increased surface area available and their ability to remain in suspension.

It has already been noted that some fuels will react at room or ambient temperatures to produce hydrogen in accordance with this invention. However, since the rate of the reaction is dependent upon temperature, and most fuels react at rates which are quite slow at room or ambient temperatures, it will usually be necessary to heat the reacting system for practical or commercial applications. To be more specific, the reactions with a methanol fuel and most short chain alcohols will proceed quite noticeably at room temperatures, while the hydrocarbons and most long chain fuels will usually require some degree of heat input before the reaction can even be detected. As a rule of thumb it can be said that for any given rate of production, the alcohols will require the lowest temperature followed in order by the aldehydes, acids, ketones, and hydrocarbons. As a further rule of thumb it can also be said that as chain length increases for any class of fuel, the temperature necessary for any given rate of production will also increase. Thus the shorter chained alcohols, aldehydes, acids and possibly ketones will proceed at room temperature with an optimum operating temperature of about 300 - 700°F. On the other hand the hydrocarbons and longer chained compounds will commence to proceed at temperatures of from 100 - 200°F with an optimum operating temperature anywhere from 400 - 700°F. Although further increases in temperature to say about 1500°F will cause increased reaction rates, a practical upper limitation of about 800 - 900°F should be kept in mind because of the structural limitations of the equipment, the dangers of contamination of the gas by boiling reactants and other products, and because the extreme high energy input requirements at higher temperatures would not be economical.

In the embodiment described above, the electrolyte used was an aqueous solution of potassium hydroxide. Although any electrolyte will work with varying degrees to success, basic electrolytes are favored for most fuels if high yields and high purity of hydrogen is desired. This is because with a basic electrolyte, most fuels will oxidize to form a carbonate or carbon dioxide which is a product that cannot contaminate the hydrogen gas. Furthermore, one of the products being dissolved in the electrolyte solution in the form of carbonate or dioxide is analogous to a situation where such a product is being removed from the system, so that the reaction does not readily reach a state of equilibrium to reverse or cause side reactions. Alkaline systems are further preferred because they will operate at lower temperatures. Acid electrolyte systems will require high temperatures and usually do not produce hydrogen gas in as high a purity as do alkaline electrolyte systems. It should also be noted that strong acid solutions may dissolve some of the conductive catalyst to greatly reduce or even halt the reaction altogether. The fuels most efficient in the production of hydrogen in such a thermal reformer are the organic fossil fuels as the hydrocarbons and derivatives such as alcohols which have relatively high heat contents. As stated above, however, any readily oxidizable compound will work as a fuel. For example, such a reformer was utilized to successfully produce hydrogen from such other unusual fuels as cyclohexane, cellulose, orange juice, sugar, octane, and the like. Although the aldehyde compounds will also work, they are not desirable in a basic electrolyte because of side reactions as condensation and polymerization.

Since the reaction is effected in the liquid state, the apparatus involved may be considerably smaller in volume than the huge steam reforming plants necessary for gaseous state thermal reactions. Such a compact liquid state hydrogen reformer may easily be adapted to mobile or field uses. Thus, the compact hydrogen reformer can readily bring about wide scale acceptance of the hydrogen-oxygen fuel cell as a compact efficient power source since the combination reformer-fuel cell may be operated with any readily available liquid or soluble fuel. This will eliminate the attendant problems and hazards of supplying and storing quantities of compressed hydrogen gas or liquid hydrogen.

In combination, the compact hydrogen reformer and the hydrogen-oxygen fuel cell greatly complement each other to produce efficiencies never before thought possible. Not only does the fuel cell utilize the hydrogen produced by the reformer, but the reformer can be adapted to utilize the waste products of the fuel cell, namely, water and heat. The result is a compact unit with an extremely high efficiency.

The drawing in Fig. 2 is a schematic illustration of the reformer-fuel cell combination indicating the mutual cooperation between the two components. The hydrogen-oxygen fuel cell is but a basic design of any typical fuel cell. The fuel cell 30 consists of two porous electrodes 21 and 22 separated by an electrolyte such as a potassium hydroxide solution 23. Hydrogen enters the electrode 21 at one side of the cell, and oxygen or air enters the electrode 22 at the other side of the cell. The two gases diffuse through the respective porous electrodes reacting to form water and liberating electrons which flow through the circuit. At the hydrogen electrode 21, the hydrogen gas, assisted by a catalyst, reacts with hydroxyl ions to produce water and give up electrons to the electrode. At the oxygen electrode 22, the oxygen, also aided by a catalyst, absorbs electrons from the electrode and reacts with the water to produce hydroxyl ions. A high percentage of the reaction energy is released as electricity which flows through the external circuit and is utilized for any purpose desired. This, of course, is the objective of the entire system. However, there is a portion of the reaction energy which is given off as heat which results from the resistance of the electrolyte and entropy effects. This heat loss is directly proportional to the current flow or reaction rate of the closed circuit.

The fuel cell also manufactures water since water production at the hydrogen electrode is greater than the water consumed at the oxygen electrode in producing hydroxyl ions.

Adjacent to the fuel cell the hydrogen reformer receiving an oxidizable fuel through pipe 25 and at the proper pressure and temperature will proceed spontaneously to produce hydrogen gas under continuously increasing pressure collected in the chamber 26 above the electrolyte 11. After a predetermined pressure has been reached, the hydrogen valve to the fuel cell 27 is opened and hydrogen gas is admitted to the hydrogen electrode 21 under pressure after being purified in the condenser 16. Oxygen or air is admitted to the oxygen electrode 22. The fuel cell then begins to function producing an electrical current, water and heat. The water produced in the fuel cell may be collected in condenser 28 and fed into the hydrogen reformer through a pipe 29. A pump 31 and valve 32 may be needed to prevent hydrogen from feeding back through the water pipe 29. Thus, no external water supply may be needed to replenish the water consumed in the reformer.

The heat produced by the fuel cell may in turn be utilized to heat the hydrogen reformer. This can be accomplished by encircling the cell and reformer with a suitable heat exchange media, or by circulating the heated fuel cell electrolyte around the reformer or within the reformer electrolyte as shown by pipes 33 or by burning a fuel as shown by plane 17. If the heat produced by the fuel cell is greater in quantity than the heat input necessary to operate the reformer and is at a higher temperature than the reformer, then the external heat supply may be shut off. The result is a power system having an input of only the oxidizable fuel and an output of only the electrical current. The system thus utilizes some of its own waste products.

The above described system is merely but one embodiment of the hydrogen reformer in combination with a fuel cell. Besides the many possible embodiments of the reformer itself resulting from the many fuels, electrolytes, catalysts and structural designs that may be employed plus utilization of the reformer in other combinations, there are other desirable embodiments of reformer-fuel cell combinations worth mentioning.

Another such embodiment would utilize both thermal and electrical reformation. For example, the reformer may have a construction similar to that discussed above except that it would also contain two catalyst plated electrodes. Under the appropriate temperature and pressure, the reformer will operate strictly on thermal energy as described herein. If then a fraction of a volt is fed back to the reformer from the fuel cell, the hydrogen production rate can be greatly increased. On the other hand, a certain bias could be inserted in an electrode and a fraction of a volt reversed which would greatly reduce or stop the reaction altogether. Thus, with a selective feedback at a fraction of a volt, the reformer could be completely controlled electrically.

This system would have a further advantage in that the reaction products from most fuels can be somewhat controlled by the electrical potential between the electrodes. Thus, a small fraction of the total energy input may be electrical for the sole purpose of maintaining a certain potential at the fuel cell.

It is seen from the foregoing that other modifications and embodiments of this invention can be employed without departing from the spirit of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A process for producing hydrogen gas which comprises; admixing water, an ionically conductive electrolyte and an organic compound which upon reaction with an oxidizing agent is capable of producing hydrogen with an electronically conductive catalyst, causing the organic compound to oxidize producing hydrogen gas.

2. A process for producing hydrogen gas which comprises; admixing water, an ionically conductive electrolyte and an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones and hydrocarbons with an electronically conductive catalyst, causing the organic compound to oxidize producing hydrogen gas.

3. A process for producing hydrogen gas which comprises; admixing water, an ionically conductive electrolyte and an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones and hydrocarbons with a plurality of electronically conductive particles, causing the organic compound to oxidize producing hydrogen gas.

4. A process for producing hydrogen gas which comprises; admixing water, an ionically conductive electrolyte, an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones and hydrocarbons and a plurality of electronically conductive particles in a pressure vessel sealing said mixture into said pressure vessel, heating said mixture to a temperature of from 100 to 900°F causing said organic compound to oxidize producing hydrogen gas.

5. A process for producing hydrogen gas which comprises; forming an aqueous solution of an ionically conductive electrolyte and an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons, sealing said mixture in a pressure vessel with an electronically conductive metal particle immersed in said mixture, heating the said mixture to a temperature of from 100 to 900°F, causing the organic compound to oxidize producing hydrogen gas.

6. A process for producing hydrogen gas which comprises the steps of:

(a) forming an aqueous mixture of an ionically conductive electrolyte containing at least one particle of an electronically conductive metal and at least one organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons;

(b) sealing said mixture in a pressure vessel;

(c) heating said mixture to a temperature of from 100 to 900°F to effect a sufficient temperature and pressure combination as will cause the organic compound to oxidize producing hydrogen gas;

(d) allowing the hydrogen gas to collect within the pressure vessel above the liquid mixture; and

(e) drawing off the hydrogen gas.

7. A process for producing hydrogen gas which comprises the steps of:

(a) forming an aqueous solution of an ionically conductive electrolyte containing particles of an electronically conductive metal;

(b) sealing said mixture in a pressure vessel;

(c) causing an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons to be mixed into the solution in the pressure vessel;

(d) heating the mixture in said pressure vessel to a temperature of from 100 to 900°F to effect a sufficient temperature and pressure as will cause the organic compound to oxidize producing hydrogen gas without boiling the aqueous solution;

(e) allowing the hydrogen gas to collect within the pressure vessel above the aqueous solution; and

(f) drawing off the hydrogen gas.

8. A process for producing hydrogen gas which comprises the steps of:

(a) forming an aqueous solution of an ionically conductive electrolyte containing fine suspended particles of an electronically conductive metal;

(b) sealing said mixture in a pressure vessel;

(c) causing at least one organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones and hydrocarbons to be mixed into the solution in the pressure vessel;

(d) heating the mixture in said pressure vessel to a temperature of from 100 to 900°F to effect a sufficient temperature and pressure as will cause the organic compound to oxidize producing hydrogen gas without boiling the aqueous solution or organic compound;

(e) allowing the hydrogen gas to collect within the pressure vessel above the liquid mixture;

(f) drawing off the hydrogen and other gaseous products at such a rate as will not reduce the pressure in the vessel below the minimum pressure necessary to prevent boiling of the aqueous solution and organic compound; and

(g) separating the hydrogen gas from the other gaseous products.

9. A process for producing hydrogen gas which comprises the steps of:

(a) forming an aqueous solution of an alkaline ionically conductive electrolyte having fine suspended particles of an electronically conductive metal;

(b) sealing said mixture in a pressure vessel;

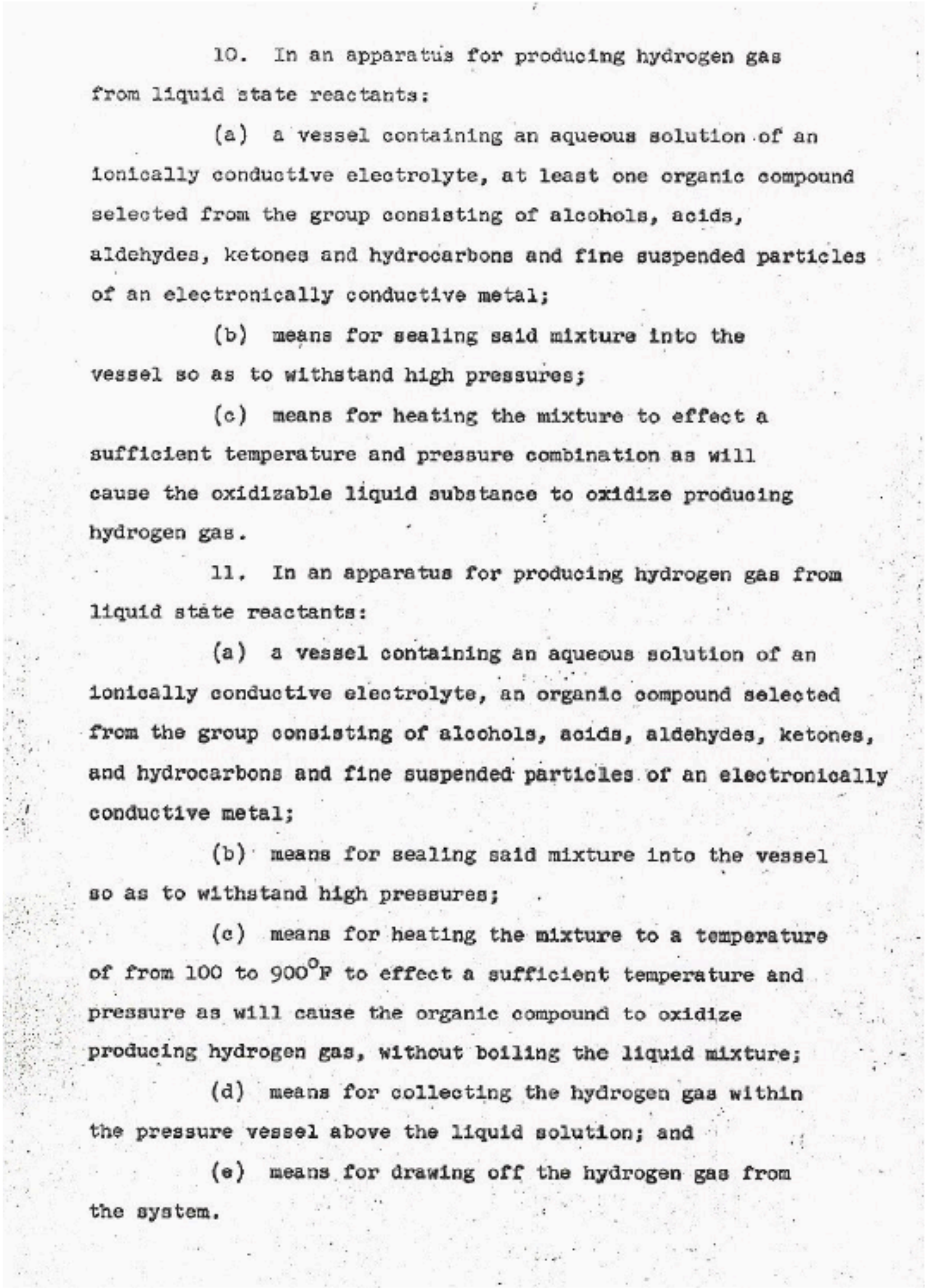
(c) causing at least one organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons to be mixed into the solution in the pressure vessel;

(d) heating the mixture in said pressure vessel to a temperature of about 400 to 700°F to effect a sufficient temperature and pressure as will cause said organic compound to oxidize spontaneously producing hydrogen gas without boiling the aqueous solution and organic compound;

(e) allowing the hydrogen gas to collect within the pressure vessel above the liquid solution;

(f) drawing off the hydrogen gas and other gaseous products at such a rate as will not reduce the pressure in the vessel below the minimum pressure necessary to prevent boiling of the aqueous solution and organic compound; and

(g) condensing the other gaseous products to separate the hydrogen gas therefrom.



10. In an apparatus for producing hydrogen gas from liquid state reactants:

(a) a vessel containing an aqueous solution of an ionically conductive electrolyte, at least one organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones and hydrocarbons and fine suspended particles of an electronically conductive metal;

(b) means for sealing said mixture into the vessel so as to withstand high pressures;

(c) means for heating the mixture to effect a sufficient temperature and pressure combination as will cause the oxidizable liquid substance to oxidize producing hydrogen gas.

11. In an apparatus for producing hydrogen gas from liquid state reactants:

(a) a vessel containing an aqueous solution of an ionically conductive electrolyte, an organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons and fine suspended particles of an electronically conductive metal;

(b) means for sealing said mixture into the vessel so as to withstand high pressures;

(c) means for heating the mixture to a temperature of from 100 to 900°F to effect a sufficient temperature and pressure as will cause the organic compound to oxidize producing hydrogen gas, without boiling the liquid mixture;

(d) means for collecting the hydrogen gas within the pressure vessel above the liquid solution; and

(e) means for drawing off the hydrogen gas from the system.

12. In an apparatus for producing hydrogen gas from liquid state reactants:

(a) a pressure vessel containing an aqueous solution of an ionically conductive electrolyte having fine particles of an electronically conductive metal suspended therethrough;

(b) means for introducing at least one organic compound selected from the group consisting of alcohols, acids, aldehydes, ketones, and hydrocarbons, into said aqueous solution;

(c) means for heating the mixture to a temperature of from 100 to 900°F to effect a sufficient temperature and pressure as will cause the oxidizable liquid to oxidize producing hydrogen gas without boiling the mixture;

(d) means for collecting the hydrogen gas within the pressure vessel above the said mixture;

(e) means for drawing off the hydrogen gas and other gaseous products at such a rate as will not reduce the pressure in the vessel below the minimum pressure necessary to prevent boiling of the liquid mixture; and

(f) means for separating the hydrogen gas from said other gaseous products.

13. Apparatus for producing hydrogen gas from liquid state reactants comprising in combination; a pressure vessel containing an aqueous solution of an ionically conductive electrolyte and particles of an electronically conductive metal, means for introducing an oxidizable soluble organic compound into the said aqueous solution, means for heating said aqueous solution in the pressure vessel, and means for extracting hydrogen gas from the upper portion of the pressure vessel.

14. Apparatus for producing hydrogen gas from liquid state reactants comprising in combination; a pressure vessel containing an aqueous solution of an ionically conductive electrolyte and suspended particles of an electronically conductive metal, means for introducing oxidizable liquid organic compounds and water into said aqueous solution while said pressure vessel is under pressure, means for heating said aqueous solution in said pressure vessel, and means for extracting hydrogen gas from the upper portion of said pressure vessel at a controlled rate.

15. In combination with a hydrogen-oxygen fuel cell power plant wherein the water forming catalytic reaction between oxygen and hydrogen is utilized to produce an electric current; a high pressure reactor vessel containing an aqueous solution of an ionically conductive electrolyte containing particles of an electronically conductive metal, means on said vessel for introducing a liquid fuel substance into the electrolyte while said vessel is sealed and under pressure, means for heating the vessel, means for conveying the excess water produced in the fuel cell into the vessel, and means for extracting hydrogen gas from the upper portion of said pressure vessel at a controlled rate.

16. In combination with a hydrogen-oxygen fuel cell power plant wherein the water forming catalytic reaction between oxygen and hydrogen is utilized to produce an electric circuit; a high pressure reactor vessel containing an aqueous solution of an ionically conductive electrolyte solution and particles of an electronically conductive metal, means on said pressure vessel for introducing a controlled amount of an oxidizable

organic fuel into said electrolyte while said vessel is sealed and under pressure, means for removing gaseous hydrogen from the pressure vessel and transporting said hydrogen to the fuel cell, means for transferring excess water from the fuel cell to the pressure vessel while said pressure vessel is sealed, and means for heating the electrolyte solution.

17. In combination with a hydrogen-oxygen fuel cell power plant wherein the water forming catalytic reaction between oxygen and hydrogen is utilized to produce an electric circuit; a high pressure reactor vessel containing an aqueous solution of an ionically conductive electrolyte solution and particles of an electronically conductive metal, means on said pressure vessel for introducing a controlled amount of an oxidizable organic fuel into said electrolyte while said vessel is sealed and under pressure, means for removing gaseous hydrogen from the pressure vessel and transporting said hydrogen to the fuel cell, means for transferring excess water from the fuel cell to the pressure vessel while said pressure vessel is sealed, means for heating the electrolyte solution, and means for transferring a portion of the excess heat from the fuel cell to the electrolyte within the pressure vessel.