A method, apparatuses and chemical compositions are provided for producing high purity hydrogen from water. Metals or alloys capable of reacting with water and producing hydrogen in aqueous solutions at ambient conditions are reacted with one or more inorganic hydrides capable of releasing hydrogen in aqueous solutions at ambient conditions, one or more transition metal compounds are used to catalyze the reaction and, optionally, one or more alkali metal-based compounds. The metal or alloy is preferably aluminum. The inorganic hydride is from a family of complex inorganic hydrides; most preferably, NaBH₄. The transition metal catalyst is from the groups VIII and IB; preferably, Cu and Fe. The alkali metal-based compounds are preferably NaOH, KOH, and the like. Hydrogen generated has a purity of at least 99.99 vol.% (dry basis), and is used without further purification in all types of fuel cells, including the polymer electrolyte membrane (PEM) fuel cell.

13 Claims, 3 Drawing Sheets
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<table>
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<tr>
<th>Number</th>
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<th>Inventors</th>
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<td>6/2006</td>
<td>Graham</td>
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<tr>
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<td>11/1987</td>
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* cited by examiner
Figure 1
Figure 2
Figure 3
METHOD AND APPARATUS FOR HYDROGEN PRODUCTION FROM WATER

This is a divisional application of U.S. patent application Ser. No. 11/445,720, filed Jun. 2, 2006 now U.S. Pat. No. 7,803,349 and claims the benefit of priority from U.S. Provisional Application Ser. No. 60/688,886 filed Jun. 8, 2005 the contents of which are incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

The subject invention was made with government support under NASA, Grant No. NAG3-2751. The government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention provides a new method and chemical compositions for producing hydrogen from water and methods and apparatuses for using these compositions in energy-related applications, e.g., power generation using fuel cells, heating, etc.

BACKGROUND AND PRIOR ART

Hydrogen is universally considered a fuel of the future due to environmental advantages over conventional (i.e., fossil-based) fuels. Another important advantage of using hydrogen stems from the fact that it could be electrochemically (i.e., without Carnot-cycle limitation) converted into electricity with very high energy conversion efficiency using fuel cells (FC).

To be used in energy conversion devices, hydrogen has to be produced and stored; however, each of these aspects of hydrogen technology is associated with major technological challenges. Conventional (non-electrolytic) hydrogen production processes (for example, steam methane reforming) are complex, multi-stage devices that produce significant amounts of carbon dioxide (CO₂) emissions at the production site and, besides, are very difficult to down-scale (e.g., to sub-kilowatt range). Hydrogen storage is another major roadblock to a widespread use of hydrogen in power generation systems. Conventional hydrogen storage systems in the form of a compressed gas, or a liquid, or a metal hydride, suffer from either low gravimetric and volumetric densities, or high cost, or safety-related problems, and the like.

Various methods for generating or producing hydrogen based on the reactions of metal hydrides or metals or their alloys with water are known and are referenced below.


PCT publication WO 02/06153 A1 to E. Baldwin et al. discloses a method of contacting an aqueous liquid (alkali metal hydroxide) with a dissociation initiating material (Al or Na—Al alloys) in a reaction vessel and controlling the surface area of dissociation and pressure therein.

PCT publication WO 2002/14213 A2, to A. Chaklader, et al. discloses a method for producing hydrogen by reacting a metal selected from Al, Mg, Si, Zn with water in the presence of a catalyst at pH between 4 and 10.


A Japanese patent JP 62263946 to H. Kudo et al. describes the use of quenched aluminum-bismuth alloy for hydrogen production wherein Al—Bi alloy (solidified at >104°C) produced hydrogen by dipping in 70°C water.

A Soviet Union patent, SU 945061 (1982) to L. Kozin et al. disclosed an aluminum-based composition for preparing hydrogen; Al—Hg (3-5 wt. %) alloy was used to produce hydrogen from water.

K. Scherbera in “Solid-phase reaction products in hydrogen generation processes,” Problemy Mashinostroeniya (1983), v. 20, pp. 83-86 (in Russian) reports that hydrogen was produced by decomposition of water with Al—Li (16%), Al—Li (50%), Al—Na (50%) composites.

Another Soviet Union patent, SU 11675199 (1991) to M. Khazin et al. describes the use of aluminum-iron-silicon alloy for producing hydrogen by decomposition of water. The alloy is 90% Al, 5% Fe, and 5% Si. Additional methods for producing hydrogen and heat energy are disclosed by A. Yelkin et al. in PCT publications WO 2003/104344 and WO 2002/14214 A1. The methods consist of preparing a composition based on activated textured aluminum or Al-containing material and reacting it with water. The activation of Al is carried out by means of applying molten fusible metals with low melting point (Ga, Sn, In) to the end surface of Al.

G. Antonini et al. in “Hydrogen generation from concentrated aluminum-water suspensions. Application for continuous heat production by catalytic combustion.” Recents Progres en Genre des Proceedes (1991) 5 (16) pp. 81-86. A process was developed for chemical storage of hydrogen as concentrated suspensions of Al powder in H₂O/NaOH. The suspension can be made to produce hydrogen on demand. Hot water for the reaction is taken from a boiler where catalytic combustion of hydrogen is carried out.

M. Matsuyama et al. in “Hydrogen production from water using waste aluminum,” Toiyama Daigaku Suiso Doitsu Kino Kenkyu Senta Hokoku (1992) 12, pp. 49-58 discusses factors affecting the rate of hydrogen production from water using Al and Al—Mg alloys were investigated.

In British patent GB 2344110 to G. Carlsson, the production of alloy granules for hydrogen generation is discussed. The granules are made from Al, Sn, Zn and trace amounts of Si and Sb. The granules react with hot water with the production of hydrogen gas.

Hydrogen generation is observed in the wet cutting of Al and its alloys due to the reaction between the fresh surface of Al with water as reported by K. Uchida et al. in “Hydrogen
A sixth objective of the present invention is to provide chemical compositions for producing hydrogen from water and hydrogen-containing compounds that are easily disposed of and/or regenerated into original reagents.

A seventh objective of the present invention is to provide a method, apparatus and chemical composition that produces high purity hydrogen gas (>99.9 volume %).

A preferred method for producing hydrogen from water includes selecting at least one metallic ingredient that can release hydrogen when reacting with water, selecting at least one inorganic hydride that can release hydrogen when reacting with water, selecting at least one transition metal compound that can catalyze the reaction of metallic ingredient and inorganic hydride with water, keeping the metallic ingredient and inorganic hydride separate until the reaction with water is desired for the production of hydrogen, placing the metallic ingredient in a first holding area and the inorganic hydride in a second holding area within a vessel without water, adding water to the vessel to cover the holding area with the metallic ingredient and the holding area with the inorganic hydride, and collecting hydrogen released from the decomposition of water in a synergistic reaction of metallic ingredient and inorganic hydride. The metallic ingredient in the preferred method is selected from elements of groups IIA-IVA and VIII and alloys thereof and preferably include aluminum (Al), magnesium (Mg), silicon (Si), iron, aluminum alloys, magnesium alloys, iron alloys and silicon alloys; most preferably, the metallic ingredient is aluminum.

The preferred inorganic hydride is selected from a family of inorganic complex metal hydrides and includes sodium borohydride, lithium borohydride, potassium borohydride, lithium aluminum hydride, sodium aluminum hydride; most preferably, the inorganic hydride is sodium borohydride.

It is also preferred to add an alkali metal-based compound to the inorganic hydride prior to adding water to the vessel and add a transition metal compound from groups VIII and IB to the metallic ingredient prior to adding water to the vessel to catalyze the azeotropic reaction resulting in hydrogen release.

The preferred alkali metal-based compound is added to the inorganic hydride at one of sodium hydroxide (NaOH), potassium hydroxide (KOH), lithium hydroxide (LiOH), sodium carbonate (Na₂CO₃), and potassium carbonate (K₂CO₃); most preferably the alkali metal-based compound is sodium hydroxide (NaOH).

The preferred transition metal and its compound is cobalt, cobalt chloride (CoCl₂), cobalt bromide (CoBr₂), cobalt iodide (CoI₂), cobalt nitrate (Co(NO₃)₂), iron, iron (II) chloride (FeCl₂), iron (III) chloride (FeCl₃), ruthenium, ruthenium (III) chloride (RuCl₃), copper, copper sulfate (CuSO₄), platinum, chloroplatinic acid (H₂PtCl₆), nickel, nickel nitrate (Ni(NO₃)₂), and nickel chloride (NiCl₂); most preferably the transition metal compounds are cobalt chloride (CoCl₂) and iron chloride (FeCl₂).

A preferred composition capable of decomposing water and releasing hydrogen without the need for additional reagents or elevated temperatures contains a separate amount of a metallic ingredient that can release hydrogen when reacting with water in a reaction vessel, a separate amount of an inorganic hydride that can release hydrogen when reacting with water in a reaction vessel, and a separate amount of a transition metal compound that can catalyze the reaction of the metallic ingredient and inorganic hydride with water.

The preferred metallic ingredient in the composition of the present invention is selected from elements of groups IIA-IV and VII and alloys thereof, preferably aluminum (Al), magnesium (Mg), silicon (Si), iron (Fe), aluminum alloys,
magnesium alloys, iron alloys and silicon alloys; most preferably, the metallic ingredient is aluminum.

The preferred inorganic hydride of the composition of the present invention is selected from a family of complex inorganic hydrides which includes, but is not limited to, sodium borohydride, lithium borohydride, potassium borohydride, lithium aluminum hydride, sodium aluminum hydride; most preferably, the inorganic hydride is sodium borohydride.

The preferred composition of the present invention also includes an alkali metal-based compound added to the inorganic hydride prior to contact with water in a reaction vessel, and a transition metal compound from groups VIII and IB added to the metallic ingredient prior to contact with water in a reaction vessel to catalyze the aqueous reaction resulting in hydrogen release.

The preferred alkali metal-based compound is at least one of sodium hydroxide (NaOH), potassium hydroxide (KOH), lithium hydroxide (LiOH), sodium carbonate (Na2CO3), and potassium carbonate (K2CO3); most preferably, the alkali metal-based compound is sodium hydroxide (NaOH).

The preferred transition metal and its compound is cobalt, cobalt chloride (CoCl2), cobalt bromide (CoBr2), cobalt iodide (CoI2), cobalt nitrate (Co(NO3)2), iron, iron (II) chloride (FeCl2), iron (III) chloride (FeCl3), ruthenium, ruthenium (II) chloride (RuCl2), copper, copper sulfate (CuSO4), platinum, chloroplatinic acid (H2PtCl6), nickel, nickel nitrate (Ni(NO3)2) and nickel chloride (NiCl2); most preferably, the transition metal compound is cobalt chloride (CoCl2) and iron chloride (FeCl3).

A preferred apparatus for producing high purity hydrogen from the decomposition of water, is a reaction vessel having a lower part and an upper part, a bellows-shape wall portion forming the upper part of the vessel, a first holding area for a metallic component in the upper part of the vessel, a second holding area for an inorganic hydride in the lower part of the vessel, a rod to support the holding area for the metallic component extending through the upper bellows-shape wall portion to the lower part of the vessel, an inlet for water with a cap integrally attached and protruding upward from the bellows-shape portion of the vessel, an outlet for hydrogen with a valve to stop the flow of hydrogen and move the aqueous reaction water to the second chamber, said valve extending upward from the top portion of the vessel, and an outlet for a spent solution of reagents used in the reaction to release hydrogen extending downward from the bottom of the first chamber of the reaction vessel.

One of the plurality of reactant capsules preferably contains an alkali metal-based compound that is at least one of sodium hydroxide (NaOH), potassium hydroxide (KOH), lithium hydroxide (LiOH), sodium carbonate (Na2CO3), and potassium carbonate (K2CO3); most preferably, the alkali metal-based compound is sodium hydroxide (NaOH).

Another of the plurality of reactant capsules preferably contains a transition metal and its compound that is at least one of cobalt, cobalt chloride (CoCl2), cobalt bromide (CoBr2), cobalt iodide (CoI2), cobalt nitrate (Co(NO3)2), iron, iron (II) chloride (FeCl2), iron (III) chloride (FeCl3), ruthenium, ruthenium (II) chloride (RuCl2), copper, copper sulfate (CuSO4), platinum, chloroplatinic acid (H2PtCl6), nickel, nickel nitrate (Ni(NO3)2) and nickel chloride (NiCl2); most preferably, the transition metal compound is cobalt chloride (CoCl2) and iron chloride (FeCl3).

The water used for the reaction to release hydrogen includes, but is not limited to, tap water, reclaimed water, industrial grade water, and sea water.

Further objects and advantages of the present invention will be apparent from the following detailed description of a presently preferred embodiment which is illustrated schematically in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 provides a clear illustration of the synergistic action of the components of the composition during the release of hydrogen from water.

FIG. 2 is an illustration of one preferred embodiment of the apparatus for hydrogen production according to the present invention.

FIG. 3 is an illustration of the second preferred embodiment of the apparatus for hydrogen production according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before explaining the disclosed embodiments of the present invention in detail it is to be understood that the invention is not limited in its application to the details of the particular arrangements shown since the invention is capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

The present invention provides a novel method, apparatuses and chemical compositions for producing hydrogen from water and hydrogen-containing compounds. The new chemical compositions include at least two components: A and B, and, preferably, a third component C, and, optionally, a fourth component D. The component A includes at least one metal or alloy. Although the reaction of the component A with water when producing hydrogen is thermodynamically favorable, it does not occur at ambient conditions of temperature and pressure or slightly elevated temperatures (up to 100° C.) due to a protective oxide layer on the metal or alloy surface. The component B includes one or more inorganic metal hydrides that can release hydrogen in aqueous solutions at ambient conditions in the presence of catalytic materials or
without catalytic materials. The composition also includes one or more transition metals or their compounds (the component C) that can catalyze the release of hydrogen and, optionally, one or more alkali metal-based compounds (the component D) to stabilize the component B and accelerate the reaction of the component A with water.

The component A of the composition is selected from the elements of groups II A-IVA and VIII (e.g., Al, Mg, Si, Fe, etc.), preferably, Al and its common alloys. The component B is selected from a family of inorganic metal hydrides including, but not limited to, NaBH4, LiBH4, KBH4, LiAlH4, NaAlH4, AlH3, preferably, NaBH4. The present invention composition also includes the component C, which is selected from the transition metals and their compounds from the groups VIII and IB including, but not limited to, Co, CoCl2, CoBr2, CoI2, Fe, FeCl2, FeCl3, Ni, Ni(OH)2, NiCl2, Ru, RuCl3, Pt, H2PtCl6, Cu, CuSO4, preferably, CoCl2, FeCl3. These compounds may be used in the form of fine powders, thin films deposited on the surface of the component A, or supported on a solid substrate such as Al2O3, SiO2, activated carbon, molecular sieves, etc., preferably, Al2O3.

The disclosed composition optionally includes the component D, which is selected from alkali metal-based compounds, such as NaOH, KOH, LiOH, Na2CO3, K2CO3, preferably, NaOH.

The hydrogen production method disclosed in the present invention involves adding water to a chemical composition consisting of the components A, B (stored separately before the reaction) and C, and optionally, D mixed at certain ratios at the moment when the release of hydrogen gas is desirable. It should be emphasized that neither component of the composition (except, the component B) is able to react with water to produce hydrogen at room temperature. In some cases, e.g., NaBH4, the component B very slowly reacts with water at ambient temperature. The component C can catalyze the reaction of both components A and B with water. The function of the component D is to stabilize the component B before the reaction (i.e., to prevent slow spontaneous decomposition of B) and also to facilitate the reaction of the component A with water.

The novelty of the invention resides in the synergistic action of the components A and B that lead to a facilitated reaction of both components with water and the release of hydrogen therefrom. Although thermodynamically favorable, the reaction of Al (component A) with water does not occur at room or elevated (up to 100°C) temperatures without the presence of a special reagent that eliminates the protective oxide layer from its surface. On the other hand, some complex metal hydrides such as sodium borohydride (component B) very slowly react with water at ambient conditions and usually require a catalyst to facilitate the reaction. When mixed together, the components A and B form a novel chemical composition that is able to decompose water and release hydrogen without the need for additional reagents. This becomes possible due to the catalytic action of the component A on the reaction of B with water; at the same time, the component B activates the component A (i.e., Al) by removing oxide layer from its surface and, thus, facilitates its reaction with water. In generalized form, the main reaction can be represented in the form of the following equation:

$$\text{A} + \text{H}_2\text{O} \rightarrow \text{H}_2 + (\text{AB})_O$$  \hspace{1cm} (1)

where, $(\text{AB})_O$ denotes the final product of the transformation of the components A and B in an aqueous solution.

The addition of the component C to the composition accelerates the reactions of both components A and B with water, and, thus facilitates the overall process. It should be noted that the component C is also capable of accelerating the reactions of the components A and B with water separately (i.e., without the presence of a third component, such as B and A, respectively). In a generalized form:

$$\text{A} + \text{H}_2\text{O} + (\text{C}) \rightarrow \text{H}_2 + (\text{A} + \text{H}_2\text{O})(\text{C})$$  \hspace{1cm} (2)

$$\text{B} + \text{H}_2\text{O} + (\text{C}) \rightarrow \text{H}_2 + (\text{B} + \text{H}_2\text{O})(\text{C})$$  \hspace{1cm} (3)

where, C is the component C of the chemical composition, and AO and BO denote the final products of the transformation of the components A and B, respectively, in the presence of C in aqueous solutions.

The function of the component D is to stabilize the component B (i.e., to prevent its premature moisture-induced decomposition). Another important role of the component D is to accelerate the reaction of the component A with water by removing the protective oxide layer from its surface. In a general form:

$$\text{A} + \text{H}_2\text{O} + (\text{D}) \rightarrow \text{H}_2 + (\text{AD})_O$$  \hspace{1cm} (4)

where, D is the component D of the chemical composition, and $(\text{AD})_O$ denotes the final product of the transformation of the components A and D in an aqueous solution.

Table 1 below provides a generic composition of the present invention.

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<th>Component</th>
<th>Illustrative example</th>
<th>Concentration range, wt. %</th>
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<tr>
<td>A</td>
<td>Aluminum (Al)</td>
<td>10-80</td>
</tr>
<tr>
<td>B</td>
<td>Sodium borohydride (NaBH4)</td>
<td>15-75</td>
</tr>
<tr>
<td>C</td>
<td>Cobalt chloride (CoCl2)</td>
<td>0.1-20</td>
</tr>
<tr>
<td>D</td>
<td>Sodium hydroxide (NaOH)</td>
<td>0.5-50</td>
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**Example 1**

In a three-part experiment illustrated in FIG. 1, first, 0.27 g of Al foil (the component A) was brought into contact with 100 ml of water: no hydrogen production was observed at 50°C (curve 1 on FIG. 1). In the second part, 0.38 g of NaBH4 (the component B) was stabilized with 0.47 g of NaOH (the component D) and the mixture was added to 100 ml of water at 50°C, which resulted in some slow release of hydrogen gas (curve 2). (It should be noted that adding more NaOH to NaBH4 results in more stabilization of the latter and, hence, even slower release of hydrogen). In the third part of the experiment, 0.27 g of Al foil and (0.38 g) of NaBH4 were brought into contact with water and each other in a vessel (at 50°C). This resulted in a fast (but controlled) reaction between the components of the mixture and water and led to the energetic release of hydrogen gas from water and the hydride (curve 3). There was unreacted Al foil (0.149 g) remaining in the vessel after 1 hour. The volume of hydrogen produced after one hour was 1,205 ml, which is roughly equal to the sum of stoichiometric volumes of hydrogen that would be generated from Al and NaBH4 if they reacted with water (1,141 ml). The purity of hydrogen gas produced exceeded 99.99 vol. % (on dry basis). Hydrogen gas did not contain any harmful contaminants such as carbon monoxide, hydrogen sulfide, ammonia, etc., therefore it was directly fed to polymer electrolyte membrane (PEM) fuel cell to produce electricity.

**Example 2**

0.27 g of Al powder (component A) was mixed with 0.02 g of CoCl2 (component C) and ground in an agate mortar to
form a uniform fine powder. Separately, 0.39 g of NaBH₄ (component B) was mixed with 0.22 g of NaOH (component D). The second mixture was added to 100 ml of distilled water at room temperature, followed by adding the first mixture to the resulting solution. An immediate release of hydrogen gas was observed. The amount of hydrogen gas produced was 1.40 liters, which compares favorably within the experimental margin of error (5%) with the stoichiometric amount of hydrogen (1.34 liters).

Referring now to FIG. 2, there is an illustration of the apparatus that is preferred for the present invention. However, a judicious selection of apparatus is required by someone skilled in the art and is not a limitation of the present invention. The apparatus 20 consists of two sections: bottom cylindrical part 21 and upper bell-shaped part 22. The component A or the mixture of A and C is placed in a holder 23 that is attached to the upper section of the vessel by a rod 26. The component B or the mixture of B and D is placed in a holder 25 that is attached to the bottom section of the vessel. When hydrogen is needed, water is introduced into the vessel 20 through an inlet 27. Water dissolves the component B (or B plus D) in holder 25, and the resulting solution reacts with the component A (or A plus C) in holder 23 with the release of hydrogen gas from water and the component B. Hydrogen gas exits the vessel through an outlet 28 having a valve 29. When hydrogen is no longer needed, the valve 29 is closed, causing pressure in the vessel to increase and expand the bell-shape section the vessel 22 upward. The holder 23 with the component A is drawn out of the reacting solution 24 and the hydrogen generation reaction stops. Hydrogen pressure in the exit line is regulated by the tension of a plurality of springs 30. The waste solution, after depletion of the components A and B, is withdrawn from the vessel through an outlet 31. Since the purity of hydrogen gas produced exceeds 99.99 vol.% (on dry basis), and it does not contain any potentially harmful contaminants such as carbon monoxide, hydrogen sulfide, ammonia, and the like; hydrogen can be directly fed to any type of fuel cell, including PEM fuel cell, to produce electricity.

FIG. 3 depicts another preferred embodiment of the inventive apparatus. The apparatus 40 consists of two chambers 41 and 42 divided by a partition 43. The components A (or A plus C) and B (or B plus D) are placed in two separate capsules 44 and 45, respectively. Reactant capsules 44 and 45 each have water-dissolving polymeric jackets. Both capsules are dropped on a grid 46 through a lid 47. When hydrogen is needed, water is introduced into the vessel 40 through an inlet 48 causing the reaction between the components of the composition to start and release hydrogen gas that exits through an outlet 49. By closing the valve 50, the operator stops the flow of hydrogen and simultaneously pushes the reacting solution 51 from the chamber 41 into the chamber 42, and the reaction ceases. The pressure of hydrogen in the exit line is controlled by the tension of a spring 52 in a piston 53 connected to the chamber 42 through a tubing 54. A waste solution can be dislodged from an outlet 55. FIG. 3 depicts the apparatus operating in a hydrogen production mode. Since the purity of hydrogen gas produced exceeds 99.99 vol.% (on dry basis), and it does not contain any potentially harmful contaminants such as carbon monoxide, hydrogen sulfide, ammonia, and the like; hydrogen can be directly fed to any type of fuel cell, including PEM fuel cell, to produce electricity.

The advantages of the present invention over known methods for generating or producing hydrogen from water, include, but are not limited to, the elimination of a need for a preliminary preparation of reacting solutions and the direct production of hydrogen from water; the variety of sources of water can include tap, reclaimed, industrial grade water and, even, seawater; inexpensive and readily available reagents and materials are used; hydrogen gas release occurs immediately upon adding water to the chemical composition and does not require pre-heating, mechanical activation or other ways of initiating the reaction.

The specific energy and power density characteristics of the system are superior to state-of-the-art systems due to the use of the combination of two high-energy content components (i.e., components A and B) of the disclosed chemical composition. The release of hydrogen gas starts immediately upon the addition of water without any induction or warming-up period that are required by state-of-the-art systems.

The preferred temperature range of the hydrogen releasing reaction (50-80° C.) is compatible with that of a power-generating system, e.g., a polymer electrolyte membrane (PEM) fuel cell. The reagents and the reaction products used in the method can be safely handled during the operation, and they are safe to humans, animals and environment.

The reaction products are easily disposable and could be recycled into original reagents in a specialized facility. For example, metal hydrogen could be easily regenerated from the reaction products by conventional electrolytic and carbothermic processes.

Five possible uses of the present invention include, but are not limited to, the following applications. The present invention can be used in the production of high purity hydrogen gas (>99.9 vol.%, not accounting for water vapor) with no potentially harmful impurities such as CO, H₂S, HCl, unsaturated and aromatic hydrocarbons, and the like.

The present invention can supply hydrogen for electric power generation via use of a fuel cell, preferably, a polymer electrolyte membrane (PEM) fuel cell, or other means of power production including turbines, internal combustion engines, diesel engines and the like.

The present invention provides a combined heat and power supply for residential and industrial applications can be provided when using the method of the present invention.

The present invention can be used in high-power density portable and miniature power systems for electronics and uninterrupted power supply (UPS) units.

The present invention can make hydrogen available for space and military applications, including soldier power supply, unmanned aerial vehicles, air-independent propulsion for submarines, and the like.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.

I claim:

1. An apparatus for producing high purity hydrogen from water comprising:

   a reaction vessel having a first chamber for receiving a plurality of reactant capsules prior to addition of reaction water to the vessel and a second chamber to accommodate the reaction water from the first chamber when a reaction between the reactant capsules and the reaction water is stopped, the first chamber and second chamber being divided by a partition, with a lower end of the partition suspended above and distanced from a bottom of the reaction vessel, thereby permitting fluid communication between the first and second chambers underneath the partition;

2. The apparatus of claim 1, wherein the reagent capsules are divided into at least two corrosively inert capsules;

3. The apparatus of claim 1, wherein the reagent capsules are divided into at least two components;

4. The apparatus of claim 1, wherein the reagent capsules are divided into at least two different compositions;

5. The apparatus of claim 1, wherein the reagent capsules are divided into at least two different compositions; and the reaction products are disposed in a specialized facility.

6. The apparatus of claim 1, wherein the reagent capsules are divided into at least two different compositions; and the reaction products are disposed in a specialized facility.

7. The apparatus of claim 1, wherein the reagent capsules are divided into at least two corrosively inert capsules; and the reaction products are disposed in a specialized facility.

8. The apparatus of claim 1, wherein the reagent capsules are divided into at least two corrosively inert capsules; and the reaction products are disposed in a specialized facility.

9. The apparatus of claim 1, wherein the reagent capsules are divided into at least two corrosively inert capsules; and the reaction products are disposed in a specialized facility.

10. The apparatus of claim 1, wherein the reagent capsules are divided into at least two corrosively inert capsules; and the reaction products are disposed in a specialized facility.
a piston and tension spring assembly coupled to a top portion of the second chamber to accommodate pressure that builds up from the reaction between the reactant capsules and the reaction water;
a supporting grid contained in the first chamber to support the plurality of reactant capsules, the supporting grid located above and distanced from a bottom of the first chamber, and the supporting grid permitting the reaction water therethrough;
an inlet for adding the reaction water said inlet disposed at a top portion of the first chamber of the vessel with a cap attached;
an outlet for releasing hydrogen, disposed at the top portion of the first chamber, said outlet including a valve to stop a flow of hydrogen and move the reaction water to the second chamber; and
an outlet for dislodging a waste solution of the reaction, disposed at the bottom of the first chamber of the reaction vessel.

2. The apparatus of claim 1, wherein one of the plurality of reactant capsules contains an alkali metal-based compound that is at least one of sodium hydroxide (NaOH), potassium hydroxide (KOH), lithium hydroxide (LiOH), sodium carbonate (Na_2CO_3), and potassium carbonate (K_2CO_3).

3. The apparatus of claim 2, wherein the alkali metal-based compound is sodium hydroxide (NaOH).

4. The apparatus of claim 1, wherein one of the plurality of reactant capsules contains a transition metal and its compound that is at least one of cobalt, cobalt chloride (CoCl_2), cobalt bromide (CoBr_2), cobalt iodide (CoI_2), cobalt nitrate (Co(NO_3)_2), iron, iron (II) chloride (FeCl_2), iron (III) chloride (FeCl_3), ruthenium, ruthenium (III) chloride (RuCl_3), copper, copper sulfate (CuSO_4), platinum, chloroplatinic acid (H_2PtCl_6), nickel, nickel nitrate (Ni(NO_3)_2) and nickel chloride (NiCl_2).

5. The apparatus of claim 4, wherein the transition metal compound is cobalt chloride (CoCl_2) and iron chloride (FeCl_3).

6. The apparatus of claim 1, wherein the water used for the reaction to release hydrogen is at least one of tap water, reclaimed water, industrial grade water, and sea water.

7. The apparatus of claim 1, wherein the reactant capsules each have water dissolving polymeric jackets.

8. The apparatus of claim 1, wherein one of the plurality of reactant capsules contains a metallic ingredient selected from elements of groups IIA-IVA and VIII and alloys thereof.

9. The apparatus of claim 8, wherein the metallic ingredient is selected from the group consisting of aluminum (Al), magnesium (Mg), silicon (Si), iron (Fe), aluminum alloys, magnesium alloys, iron alloys and silicon alloys.

10. The apparatus of claim 8, wherein the metallic ingredient is aluminum.

11. The apparatus of claim 1, wherein one of the plurality of reactant capsules contains an inorganic metal hydride.

12. The apparatus of claim 11, wherein the inorganic metal hydride is selected from a group consisting of sodium borohydride, lithium borohydride, potassium borohydride, lithium aluminum hydride, sodium aluminum hydride.

13. The apparatus of claim 12, wherein the inorganic hydride is sodium borohydride.

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