Clean Power for future generation

At long last, a technology too long overlooked promises to transform society.

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Offering clean & abundant power, hydrogen-based fuel cells could soon end our reliance on oil and minimize emissions of pollution and global-warming gases.
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Arise!! Awake!! and stop not till the goal is reach ...  
-Swamy Vivekananththa.

Abstract

Fossil fuels (i.e., petroleum, natural gas and coal), which meet most of the world’s energy demand today, are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution, which are posing great danger for our environment, and eventually, for the total life on our planet. One of the solutions to all of these problems would be to replace the existing fossil fuel system with the Hydrogen Energy system. In this article I am going to indicate that the hydrogen energy system is the best energy system to ascertain a sustainable future. However, the knowledge about storage of hydrogen as an efficient way is still lacking and more expensive. From the safety and utility point of view hydrogen stored in a metal hydride is more plausible. In this article I analyze the possibility of different energy sources and evolution of scientific inventions in the hydrogen storage technology.

Introduction

Clean power mean the creation of electricity without the emission of greenhouse gases, and by definition, this precludes fossil fuels. Thus, the aim should be to use fossil-fuel-free energy.

One of the great achievements of the past century has been the rapid growth in energy use by a significant fraction of the world’s population. This has been the dominant driver for industrialization and economic growth, particularly in the so-called first-world countries. In such countries, a ready supply of varied and cheap food; access to comfort amenities such as hot water, lighting, heating, and increasingly air-conditioning; and access to a range of transport options has become the benchmark for civilized life. Such increases in living standard are also rightly being sought by the developing world, thus driving their industrialization and growth in food production. All of this is resulting in inexorable growth in the global demand for energy, raising fundamental problems of resource limitations and environmental pollution. A major challenge for the 21st century is to obtain sustainable
solutions to these problems in a way that does not discriminate against the least wealthy of the world’s population [1].

In general the energy is divided into two main categories

- Energy sources which are renewable and relatively common like wind, sunlight and so on but are not very convenient to use with the technology which we have today. Renewable sources also include energy from burning wood, straw, dung and other living material. This form of energy is the oldest which people have used.

- Then there are energy sources which are scarce and non-renewable but are convenient to use like coal, oil, gas, uranium and so on. Our technology is centred around these types of energy, and our economy is almost entirely dependent on them.

Currently, more than 90% of the world energy usage is based on non-renewable sources. A major component of this energy consumption is in the form of electricity, using technologies that depend largely on fossil fuels. A second major component is mechanized transport (e.g., land, sea, and air) that depends to an even greater extent on fossil fuels. This has resulted in a number of environmental problems, including local air pollution, discharge to soil and water, acid rain, and the risk of climate changes.

**Fossil fuel**

Approximately 80% of the world’s energy consumption is based on three sources of fossil: coal, oil, and natural gas. Over the course of the last 100 years, the world’s consumption of energy based on fossil fuels has increased by a factor of 20. Oil and gas resources are starting to run out, with current proven reserves standing at about 40 years for oil and 62 years for gas at current consumption rates [2].

There are three key factors that play a role in determining how best to utilize the qualities of the different fuels: 1) Physical properties 2) Energy content and 3) Environmental consequences.

The physical properties of the different energy sources have always been an important factor in mankind’s ability to make use the energy. Coal comes in the form of a solid, oil in liquid form, and, natural gas in the form of a gas. Coal has historically been the easiest of the three to utilize, followed by oil, and finally natural gas.
The energy content of the different energy sources has significance for their future growth potential on a global scale. It is the amount of the hydrogen that determines the energy content. The greater the concentration of hydrogen, the greater the energy content. The higher the content, the more CO₂ that is produced from combustion.

If we continue to burn fossil fuel at our present rate, we could experience a quadrupling of world CO₂ emissions over the course of the next 125 years as a consequence of population growth and increased energy demands [3].

**Fossil free energy**

On the current basis, there is the potential for 35-40% of global primary energy to be free of greenhouse gas emissions at the point of generation. There is already a trend toward increased electricity use for industrial and domestic applications, and as we shall see, there is the prospect for transport to be based on electricity generation using hydrogen and battery technology. Thus, the prize for moving to fossil-free-free generation is considerable, and it could be the basis for overcoming the threat of potentially devastating global climate change. There are two main options, namely, nuclear power and renewable-energy sources.

**Nuclear Power**

Currently there are 438 fission nuclear power stations, [4] mostly sited in the industrialized countries of the West and Asia, supplying some 17% of the world’s electricity, which is corresponds to 3,50,000 megawatts of electricity [5]. But if nuclear power were to eventually become a major primary energy source, thousand of reactors would be required[5,6]. In a nuclear reactor uranium is used as fuel, each and every reaction time 1/3 of the fuel is emitted as a waste, disposal of this waste is quit difficult because of the high radioactivity of them [7]. This waste must be isolated in a safe place for thousand of years so its radioactivity can die down and not be harmful to people and the environment. The average nuclear power plant contains 2,00,000 times more radioactive materials than what is in standard nuclear bombs [8]. Risk is a serious issue in many modern technologies and needs to be appropriately controlled but this is difficult because our initial guesses and perceptions about specific risks are often way out of line with reality. If the accidents happen it will affect not only the present generation but also the future generation. More over the circumference of affected area is several hundreds of kilometres. It can cause cancer, radiation damages, mutation or eventually death and seriously environmental damages [9,10].
Choice

Because of the above-mentioned factors, energy researchers are looking at the possible sources of energy to replace the fossil fuels and nuclear power. There are quite a number of primary energy sources available, such as solar energy, wind energy, hydropower, geothermal energy, ocean currents, tides and waves [11].

At the consumer-end, about one-quarter of the primary energy is used as electricity and three-quarters as fuel. The above mentioned primary energy sources must, therefore, be converted to these energy carriers needed by consumer. In contrast with fossil fuel, none of the new primary energy sources can be used as a fuel, e.g., for air transportation, land transportation. Consequently, they must be used to manufacture a fuel or fuels, as well as to generate electricity. Since we need to manufacture a fuel for the post fossil fuel era, we are in position to select the best fuel. There are many candidates, such as synthetic gasoline, synthetic natural gas (methane), methonal, ethonal and hydrogen. The fuel of choice must satisfy the following conditions [12].

- It must be convenient fuel for transportation.
- It must be converted with ease to other energy forms at the user end.
- It must have high utilization efficiency.
- It must be safe to use.

In addition, the resulting energy system must be environmentally compatible and economical.

Energy Utility

All production and use of energy have an impact on the natural environment. The energy consumption of today’s generations should not exceed that which is necessary to ensure a satisfactory quality of life for coming generations; hence the available energy must be used effectively. Over half of the current climate problems would cease to exist if energy were used in a more efficient and cost-effective manner [13]. Although many years of effort aimed at improving labour productivity have yielded positive results, there has been no corresponding development in energy efficiency. Energy efficiency entails not only consuming as little energy as technically possible, but also using the quality of energy in the most appropriate way. Environmentally efficient energy consumption = clean energy + correct quality + efficient use.
Best fuel

It is interesting to observe that the historical development of fuel sources, which was driven by the need for greater efficiency, has by chance, more than methodologically, also moved towards cleaner energy through the process of decarbonisation. Despite this shift to cleaner energy sources, from wood to coal, to oil and gas, however, the gains have been more than offset by large increases in energy consumption. Decarbonisation, the progressive reduction of carbon in relation to hydrogen content in fossil fuel energy sources required to produce a given amount of energy,[14] is illustrated by following: Burning wood to produce energy uses about 10 carbon atoms for each hydrogen atom, burning coal 1-2 carbon atom per hydrogen; in the combustion of oil the ratio is 1 carbon per 2 hydrogen and with gas the ratio is 1 carbon for each 4 hydrogen atoms. In the combustion process carbon ends up as soot, carbon monoxide and carbon dioxide, depending on the dioxygen/carbon molar ratio, while hydrogen ends up with water. Carbon is thus the dirty element which produces pollution while hydrogen is the clean one since it does not produce any pollutants. Decarbonisation is therefore, a desirable process, and, in order to reduce the environmental pollution, the ultimately clean fuel is di-hydrogen. Di-hydrogen is in this respect an ideal energy carrier. It is also widely available being the most abundant element in the universe on a molar basis.[15]

To avoid irreparable damage to the environment as a consequence of burning fossil fuels, energy production must become cleaner and the use of energy more effective. In an world where energy needs are constantly increasing, it will be difficult in the short term to replace all the forms that use of fossil fuels take. However, in a transition period, every energy need can be covered virtually pollution-free at a modest cost by converting fossil energy into electricity and hydrogen.

Hydrogen properties

It is important to note that the transportation fuel be as light as possible and also take as little space as possible. Among the liquid fuels, LH₂ has the best motivity factor, while methanol has lowest motivity factor. Among the gaseous fuels, GH₂ has the best motivity factor. The utilization efficiency advantage of hydrogen future improves hydrogen’s standing as the best transportation fuel. Of course, this is one of the reason why hydrogen is the fuel of choice for the space programs around the world, even though presently, it is more expensive than fossil fuels.
Availability

H is the most abundant element in the universe (75%). On earth we find it in small concentrations in air and of course in unlimited amounts, but chemically bound in H2O. In the area of energy technology we find H,

- in gaseous, liquid or solid hydrocarbons e.g. CH4
- in nuclear fusion and fission process and
- as future synthetic fuel produced by the dissociation of H2O or e.g. CH4 using an appropriate primary energy.

Hydrogen is generally combined with other elements, while molecular hydrogen, H2, is only found in trace amounts in the atmosphere. Technologies for H2 production, such as electrolysis, hydrocarbon cracking, photo conversion of water, biological production from waste, high temperature decomposition of water, etc., are well known. Further more, hydrogen has a high specific energy content of 33.3kWh/kg which is nearly three times that of gasoline or diesel. Despite these desirable properties, di-hydrogen has not yet become a major energy carrier except in special cases, e.g., in the launching of space vehicles where high specific energy content of the propulsion fuel is of utmost importance. Liquid di-hydrogen is in this case the fuel of choice to maximize the payload capacity.

Compatibility

At the user end, all fuels must be converted through a process (such as combustion) to other forms of energy, e.g., thermal energy, mechanical energy and electrical energy. If a fuel can be converted through more than one process to various forms of energy at the user end, it has become more versatile and more convenient to utilize. All the fuels, except hydrogen, can be converted through one process only; that of combustion. Hydrogen, however, can be converted to other forms of energy in five different ways; i.e., in addition to flame combustion, it can be converted directly to steam, converted to heat through catalytic combustion, act as a heat source and/or heat sink through chemical reaction, and converted directly to electricity through electrochemical process [16]. In the utilization point of view in almost every instance of utilization, hydrogen can be converted to the desired energy form more efficiently than other fuels.
Safety

The safety aspects of fuels involved their toxicity on one hand and the fire hazard properties on the other. In addition to the toxicity of their combustion products, the fuels themselves can be toxic. The toxicity increases as the carbon-to-hydrogen ratio increases. Hydrogen and its main combustion product, water or water vapor, are not toxic. However, NOx, which can be produced through the flame combustion of hydrogen (as well as through the combustion of fossil fuels) displays toxic effects.

Hydrogen evaporates very quickly much quicker than gasoline and burns almost without radiation heat. All fuel is combustible and can be explosive, which is why it is used as fuel. This means that there is no fuel which is 100% safe [17]. All fuels require careful handling in accordance with their physical properties. The hydrogen industry has over 100 years experience in safe use of hydrogen. NASA, which is the world’s largest consumer of hydrogen for transport purposes, such as fuel for space shuttles and the Titan missiles, classifies hydrogen as the safety fuel they use. It is also worth nothing that two of the accidents that people most often associate with hydrogen the Hindenburg and Challenger accidents were not caused by hydrogen. In the case of a collision causing a ruptured fuel tank, a hydrogen car with metal hydrides would be much safer than a car with a gasoline tank for several reasons. Gasoline, diesel, and the emissions they generate causes allergies and have been found to be a cause of cancer.

Lack of knowledge

One of the major negative factors contributing to the introduction of di-hydrogen as a major energy carrier is its cost. Di-hydrogen is not available as such and must be generated from other compounds with energy expenditure and as a result it is relatively expensive. This is not, however, the complete story. Fossil fuels cause pollution and damage to the environment and repairing the damage is not easily assessed, but should clearly be part of the comparative evaluation. Only when this is done can an accurate cost comparison be made and di-hydrogen given a fair evaluation.

A second major factor is due to the difficulty of storing di-hydrogen in an energy dense form. Di-hydrogen, being the molecular form of the lightest element hydrogen (atomic weight 1.0079), is a gas under ambient conditions. The density at STP is 0.08988 kg/m³ [18] which is by way of comparison only one seventh that of methane. Therefore, despite the high specific energy content, densification is required for most applications. Densification can be
achieved by compression and even more efficiently by liquefaction and solidification. These processes are energy intensive. Liquefaction, for example, consumes nearly 30% of the total energy contained in di-hydrogen and in addition requires expensive equipment and energy to retain di-hydrogen in the liquid state. Solidification requires even more energy, and compression of di-hydrogen up to say 35 MPa requires nearly 20% of its total energy content. Chemical conversion of di-hydrogen into a reversible metal hydride represents an alternative, and safe method of hydrogen storage. This form of storage has received a lot of attention in the past 30 years.

**Metal hydride**

Hydrogen can be considered an ideal fuel for many types of energy converters. However, a major obstacle to its use is difficulty in storing it economically. Neither storage as a compressed gas nor as liquid appears to be suitable for common application. Hydrogen storage as a metal hydride is the most promising alternative because of its unique feature. The rare earth hydrogen storage alloys are used for a wide range of applications owing to their high hydrogen density and ability to absorb hydrogen under moderate conditions. For example, LaNi$_5$ absorb hydrogen at room temperature under $20 \times 10^5$ Pa H$_2$ to form LaNi$_5$H$_{6.7}$, the hydrogen density of which is nearly twice that of liquid hydrogen ($6.2 \times 10^{22}$ H atoms/cm$^3$). Because of this peculiar property more research are going on to find the potential candidate for such type of application [19].

Hydrogen’s property to form metal hydrides may be used not only for hydrogen storage but also for various energy conversions. When a hydride is formed by the chemical combination of hydrogen with a metal, an element or an alloy, heat is generated, i.e., the process is exothermic. Conversely, in order to release hydrogen from a metal hydride heat must be supplied. These processes can be represented by the following chemical reactions:

\[
\text{Charging or absorption : } M+xH_2 \rightarrow MH_{2x} + \text{heat}
\]

\[
\text{Discharge or desorption : } MH_{2x} + \text{heat} \rightarrow M+xH_2
\]

Where, M represents the hydriding substance, a metal, an element or an alloy. The rate of these reactions increases with increase in the surface area. Therefore, in general, the hydriding substances are used in powdered form to speed up the reactions.
Elements or metals with unfilled shells or sub shells are suitable hydriding substances. Metal and hydrogen atoms form chemical compounds by sharing their electrons in the unfilled sub shells of the metal atoms and the K shell of the hydrogen atoms.

Ideally, for a given temperature, the charging or absorption process and the discharging or adsorption process takes place at the same constant pressure. However, actually, there is a hysteresis effect and the pressure is not absolutely constant- for a given temperature charging pressures are the higher than the discharging pressures. The heat generated during the charging process and the heat needed for discharging are functions of the hydriding substance, the hydrogen pressure and the temperature at which the heat is supplied or extracted. Using different metals and by forming different alloys, different hydriding characteristics can be obtained. In other words, it is possible to make or to find hydriding substance which are more suitable for a given application, such as waste heat storage, electricity generation, pumping, hydrogen purification and isotope separation. Many applications have recently been developed to take advantage of these properties, including rechargeable batteries and heating and cooling systems. As an example, a storage tank with a hydrogen storage alloy may contain 100 times more hydrogen than a conventional compressed gas cylinder. In general, these alloys are combinations of A (rare earth elements such as La, Ce, Th ) metals which can absorb H independently with B (Fe, Mn, Co) metals which cannot absorb H [20].

The final key to the hydrogen energy system is using the fuel economically in internal combustion engines, conventional combustion turbines, and fuel cells. The most common example of hydrogen storage alloys are Fe-Ti hydrides, La-Ni hydrides and Ti-Zr-V sereies of hydrides [21]. The kinetics of metal hydrides are normally so far that cyclic rates in practical storage system are controlled by the rate of the heat transfer to the material.

Normally the hydrides are divided into high temperature hydrides and low temperature hydrides depending on the temperature of absorption/desorption. In the low temperature hydrides, the hydrogen normally is bound through covalent bonding and the metal hydride consists of low molecular weight material. The hydrogen storage capacities are higher for the higher temperature hydrides.

**Battery-driven electric cars**

In the course of the next few years, an advanced battery with high storage capacity will be on the market. From 1999, several electric cars will be manufactured with nickel
metal-hydride batteries [22,23]. These batteries are very durable and provide a range of about 150-200 km/charge. With a high output charger, the battery can be charged to 80% capacity in 20 minutes. In 1998, there were about 15,000 battery-driven electric cars in the world. Batteries are still expensive and provide a relatively short range compared to gasoline and diesel cars. On the other hand, they have a lower per kilometre fuel cost. The cost of certain new battery types can eventually be reduced significantly as compared to today’s prices.

Carbon is also a very promising material for hydrogen absorbents. Within the micropores (diameter less than 2 nm - carbon nanotubes) of a porous substance, gases can be adsorbed onto the solid surface. Due to the forces of attraction between the solid and the gas, an adsorbed hydrogen phases will be much denser than the bulk gas phase [24]. There is an exponential growth in the research of carbon nanotubes. Recent experimentalist achieved highly uniform carbon nanofibers, rightfully catching a lot of attention from the media and the car industry as hydrogen storage for fuel cell vehicles [25]. Graphite was found to store hydrogen significantly more compact than the nanostructure materials (280 g/l compared to 14-20 g/l for nanofibers).

**Status of Hydrogen Commercialisation:**

Only in the last few years has hydrogen begun to be taken seriously as a transportation fuel. Much recent activity in the field has focused on fuel cell applications in automobile. In 1993, Ballard Power Systems, based in Vancouver, Canada produced the world’s first fuel cell bus.

American Honda Motor Co. has opened the first solar-powered hydrogen production and fuelling station in the Los Angeles area, in last month [26]. It is the first station by any automaker that uses solar power as primary energy source to extract hydrogen from water via electrolysis [26]. The international fuel cell community has been set abuzz by reports that Toyota Motor Corp. plans to introduce a commercial fuel cell vehicle in two years (i.e., 2003).

Hydrogen storage has been the subject of intensive research for many years. Recent progresses with on-board production of hydrogen from liquid hydrocarbon fuels and adsorption on various solids including carbon have attracted a lot of attention by media and the automotive industry. Hydrogen is a promising alternative fuel since it can be used completely pollution-free and can readily be produced from renewable energy resources, thus
eliminating the net production of greenhouse gases. Recent studies have indicated that hydrogen fuel costs are reasonable and hydrogen is therefore an ideal candidate to replace fossil fuels as an energy carrier.

Conclusion

From the above discussion it is shown that, while increasing efficiency in energy generation and use is necessary to curb both environmental damage and resource depletion, it is not by itself sufficient. In the long term, we need to replace all types of fossil fuels with sources of energy that are both non-polluting and sustainable. At present, the only significant primary-energy sources with low carbon emissions that are not dependent of fossil fuels are nuclear (at ~8% of the total primary energy production) and hydropower (at~2%). Experimental renewable – energy sources such as solar power, wind, and sustainable biomass production have made little impact yet, but encouraging demonstrations have shown what could be done with better design and better materials.

Hydrogen contains more chemical energy per weight than any hydrocarbon fuel, but it is also the lightest existing substance and therefore problematic to store effectively in smaller quantities. Depending on the availability of efficient hydrogen storage vessels, hydrogen safety regulations, distribution system and market acceptance, hydrogen may become main fuel.

Around year 2004 when almost all major car manufacturers plan to release fuel cell vehicles, it is probable that hydrogen can be stored efficiently in the form of either recyclable hydrogen fuel containers, rechargeable hydrogen vessels and rechargeable batteries based on metal-hydride or carbon nanofibres. The cost of the storage materials in mass production in 2010 could be reduced enormously, and modern technology will provide new metal hydrides for end user needs.
References


