# The Role Of Hydrogen Energy In Sustainable Development

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**ABSTRACT**
In this paper, the role of hydrogen energy for the sustainable development is discussed considering its production, storage and utilization. In addition, the environmental impacts in using hydrogen energy base technology and possible adverse consequences that may arise in the production, transportation, storing and use of hydrogen are carefully studied from both environmental and economical perspective towards sustainable development.

**KEYWORDS:** Hydrogen Energy, Sustainable Development, Environmental impact.

## INTRODUCTION

Even though a majority of the hydrogen conversion technologies has already been developed and demonstrated, and most of them have a clear advantage over the existing technologies, hydrogen is not being used as a fuel on a large scale (except for the space programs). The reasons are various and complex, and include not only technical but economical and political aspects. As a result of the awareness on the environmental consequences of the present fossil fuel base technologies, a transition to a hydrogen-based economy has become a necessity.

Energy efficiency of hydrogen plant has the largest effect on the plant resources, emissions, waste, and energy use and thus the efficiency has the largest environmental impact. From both an environmental and economic standpoint, it is important to increase the energy efficiencies and ratios of any process. This in turn will lead to reduction in resources, emissions, wastes, and energy consumption.

Hydrogen has many commercial applications, including commercial fixation of nitrogen from the air to produce ammonia for fertilizer (about two-thirds of commercial hydrogen is used for this purpose), hydrogenation of fats and oils in which vegetable oils are changed from liquids to solids; methanol production, in hydrodealkylation, hydrocracking, and hydrodesulphurization, rocket fuel, hydrochloric acid production, metallic ore reduction, cryogenics and the study of superconductivity (liquid hydrogen).

Hydrogen, as fuel, can be used to produce electricity, power for vehicles, and heat for houses and other buildings. Since it is clean and renewable energy source, it can promote a healthy environment by reducing or eliminating harmful pollutants as otherwise would be emitted through other existing energy production technologies.
Although a majority of the hydrogen conversion technologies has already been developed and demonstrated, and most of them have a clear advantage over the existing technologies, hydrogen is not being used as a fuel on a large scale (except for the space programs). The reasons are various and complex, and include not only

technical but economical and political aspects. As a result of the awareness on the environmental consequences of the present fossil fuel base technologies, a transition to a hydrogen-based economy has become an attractive option. Therefore, it is expected that in the long term hydrogen will join electricity as a major energy carrier and that much of the hydrogen will be derived from renewable energy sources (Veziroglu and Barbir, 1992).

Hydrogen energy base technology is particularly attractive for the developing countries that do not have huge energy infrastructures in place. Introduction of modular and portable fuel cell power systems, for example, seems to be a viable alternative. Although initially these new technologies may be more expensive, in the long run they are definitely beneficial to both economy and the environment.

Hydrogen as a fuel must be considered in a frame of the entire energy system. Technologies for hydrogen utilization must be accompanied by the equally viable technologies for hydrogen production, storage, transportation and distribution.

## WHY HYDROGEN ENERGY?

### Depletion of fossil fuels

At the present time, a large portion (about 70%) of the world energy demand is met by the fluid fossil fuels (i.e., petroleum and natural gas) because of their availability and convenient use. However it is expected that the world fluid fossil fuel production will soon peak, and thereafter begin to decrease. The demand for energy continues to rise because of two main reasons: (a) the continuing increase in world population, and (b) the growing demand by the developing countries in order to improve their living standards.

It is expected that the world population growth (which is 5.88 billion at the moment and rising at a rate of 1.55 per year) will slow down and reach about ten to twelve billion by the end of the next century. Consequently, the world demand for fluid fuels will slow down and reach around 1.6 x 1012 GJ per year. There will be a growing gap, starting within the next ten years, between the demand and production of fluid fuels.

As the demand for fossil fuels continues to increase, fossil fuel prices increase over the next several decades. This will encourage the development technologies of non-fossil alternatives such as solar, wind, geothermal, biomass, and the transition to hydrogen.

### Environmental damage

Technologies for fossil fuel extraction, transportation, processing and particularly their end use (combustion), have harmful impact on the environment, which cause direct and indirect negative effects on the economy (Barbir et al., 1990).

Air pollution causes damage to human health, animals, crops, structures, reduces visibility, etc. Once in the atmosphere, triggered by sunlight or by mixing with water and other atmospheric compounds, these primary pollutants may undergo chemical reactions, change their form and become secondary pollutants, like ozone, aerosols, peroxyacyl nitrates, various acids, etc. Precipitation of sulfur and nitrogen oxides, which have dissolved in clouds and in rain droplets to form sulfuric and nitric acids is called acid rain; but also acid dew, acid fog and acid snow have been recorded.

Carbon dioxide in equilibrium with water produces weak carbonic acid. Acid deposition (wet or dry) causes soil and water acidification, resulting in damages to the aquatic and terrestrial ecosystems, affecting humans, animals, vegetation and structures. The remaining products of combustion in the atmosphere, mainly carbon dioxide, together with other so-called greenhouse gases (methane, nitrogen oxides and chlorofluorocarbons), result in thermal changes by absorbing the infrared energy the earth radiates into the atmosphere and by re-radiating some back to earth, causing global temperatures to increase (Figure 1). The effects of the temperature increase are melting of the ice caps, sea level rise and climate changes, which includes heat waves, droughts, floods, stronger storms, more wildfires, etc.

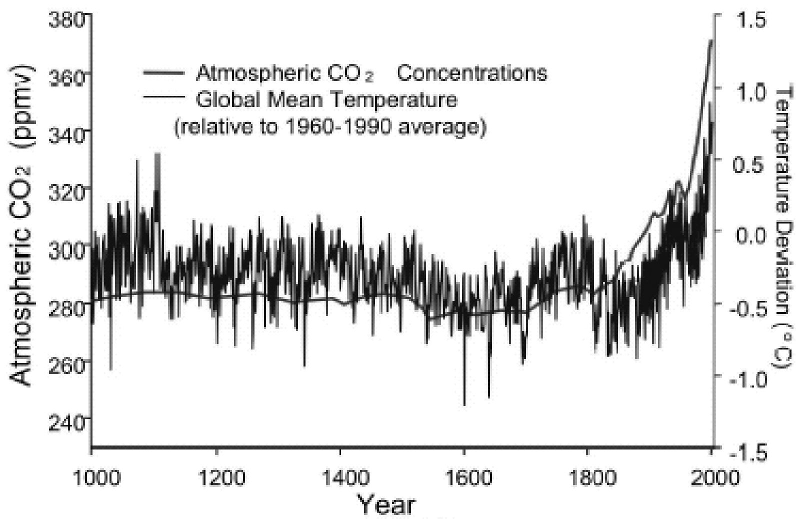


**Figure 1:** Rises of atmospheric $CO_2$ and associated global temperature as a result of increased $CO_2$ emissions during the last millennium. (Sources: $CO_2$ data from Ethridge et al. 2001, Keeling and Whorf 2002; temperature data from Jones et al. 1998, Peterson and Vose 1997)

## Properties of hydrogen

Hydrogen is an odorless and colorless gas. It is the lightest element with molecular weight of 2.016. Its density is about 14 times less than air (0.08376 kg/m$^3$ at standard temperature and pressure). The heat of combustion is two to three times higher than that of other fuels. It burns over a wide range of gas mixtures. The combustion process with oxygen emits no carbon monoxide or carbon dioxide by-products because water vapor is the by-product of hydrogen combustion. Hydrogen is part of a nonpolluting sustainable energy cycle when generated from renewable resources. It can be produced from water by separating it from the oxygen. Then it can be recombined with the oxygen in the air to produce electrical energy, water and heat. This is a clean and renewable cycle since no particulate, carbon dioxide or pollutants are produced during the processes involved.

There are several key issues that will likely affect hydrogen energy development. Concerns regarding national security due to dependence to foreign fuel supply, global climate change, and worldwide population and economic growth will increasingly promote systems that support hydrogen development. On the other hand, the lack of a national consensus on energy policy priorities, economical aspects of hydrogen energy production and use, and the public perception of hydrogen safety issues have the potential to inhibit hydrogen energy development.

Significant scientific and technical challenges must be overcome to achieve the implementation of hydrogen economy. These challenges relate to the three functional areas: production, storage, and use; each area has its own technical challenges.

In addition, two barriers must be overcome before the hydrogen economy can become a reality. First, the individual technical steps that make up the hydrogen economy must be connected by an infrastructure that provides a smooth transition from production to storage and use. In this regard, parts of the existing energy infrastructures can be utilized through hydrogen production from reforming natural gas and other fossil resources and its reaction with oxygen in fuel cells to produce electricity.

The demonstration in the marketplace that hydrogen as an energy carrier is economically competitive is the second barrier to the realization of the hydrogen economy. For the time being hydrogen is far from being sufficiently attractive in cost, performance, and reliability to displace existing conventional technology, although it can be used for stationary generation of power, for automotive transportation, and as a battery replacement for personal electronics.

## HYDROGEN PRODUCTION TECHNOLOGIES

### Hydrogen from fossil fuels

The major portion of hydrogen used in industry is currently produced through steam reforming of natural gas. Most of the hydrogen made from fossil fuels is used in the fertilizer, petroleum, and chemical industries.

Hydrogen can also be generated via reforming processes of other fixed carbon reserves, such as coal or biomass. However, these resources generate approximately twice as much $CO_2$ for the same amount of hydrogen produced. They also contain variable amounts of water, sulfur, nitrogen, and nonvolatile minerals that complicate the reforming process.

Establishing a successful and sustainable hydrogen economy depends on developing safe, effective, and economical methods for the treatment or storing of $CO_2$ that is generated by natural gas and coal reforming processes. In this regard, among the potential technologies proposed are deep ocean injection, injection into depleted oil/gas wells and saline reservoirs (Kim and Edmonds 2000). Another technological challenge is that the hydrogen produced via reforming of natural gas or possibly other carbon reserves is not of sufficient purity for direct use in the low-temperature (<130°C) fuel cells under development for transportation applications.

### Hydrogen from solar energy

Solar energy represents a highly desirable, clean, and abundant source of hydrogen. The processes for generating hydrogen through solar energy include, electrolysis of water with solar cells, photocatalytic water splitting into hydrogen and oxygen, and water splitting by photobiological or by solar thermal processes. Hydrogen produces through these processes is pure and is suitable for use in low-temperature fuel cells and even in alkaline fuel cells. Although the potential capacity for solar hydrogen is quite large, current solar cells are either too expensive or too inefficient for widespread application. The present efficiencies of solar cells range between about 3% and 25%. Thus, it is necessary to reduce the cost and maintain a high level of efficiency for solar energy related hydrogen production to become an economically viable technology. Inexpensive, high-purity hydrogen would greatly accelerate the implementation of fuel cell technology and eliminate some of the costly purification systems currently used.

**Hydrogen from biological systems**

It is estimated that the biological processes in the world produce at least 250 Mtons/yr of hydrogen (Etiope and Klusman 2002). A major portion of this hydrogen comes from anaerobic fermentation of carbon previously fixed by photosynthesis. Six to 17 Mtons/yr of hydrogen is produced as a by-product of terrestrial biological nitrogen fixation. This biological hydrogen is completely used as an energy carrier that fuels the growth of organisms and the maintenance of essential life processes. However, efforts to understand the variety of organisms and the diversity of biochemical mechanisms that participate in this extensive biological hydrogen energy economy are still at an early stage (Reysenbach and Shock 2002). Considerable improvements in efficiency and reduction in the cost of solar hydrogen production may be possible if the components of these natural hydrogen-producing systems are better understood.

Although natural biological hydrogen production is substantial on a global scale, it is highly distributed and is low in density compared with humankind's more concentrated energy needs. That is the energy efficiency of hydrogen production in natural populations of microorganisms and ecosystems is low in comparison with production via PV electrolysis. The limits in the energy efficiency encountered in biological energy conversion systems are related to the energy needs of the living organisms.

**Hydrogen production by thermal energy**

Hydrogen can also be produced by using thermal energy from solar concentrators or from fossil or nuclear reactors to drive thermochemical water-splitting to hydrogen and oxygen without intervening electricity generation. These cycles need temperatures of 500°C or more, well within the range of solar concentrators. More than 100 different thermochemical cycles have been proposed for performing the overall water splitting reaction in high-temperature reactors (Brown et al. 2002). At present, the most promising high-temperature cycles appear to be the calcium bromide-iron oxide cycle, the sulfuric acid-hydrogen iodide (sulfur-iodine or S-I) cycle, and the Westinghouse cycle. A potential barrier for this technology is the problem of finding materials that resist corrosion and failure at high temperatures in such extremely aggressive chemical environments. Further research is needed to study the potential for exploiting the higher available temperatures from solar concentrators for more efficient thermo- chemical cycles.

## SAFETY HAZARDS IN HYDROGEN USE

Safety and the environmental concerns are key issues affecting the viability of the hydrogen economy. Long term exposure of the public to hydrogen in everyday life requires a thorough assessment of the safety hazards for each element of the hydrogen economy. Safety and the environment are social as well as technical issues that require careful attention for the successful hydrogen economy.

Safety is probably the most important issue in utilization of fuels. The safety hazards associated to the use of hydrogen can be characterized as **physiological** (frostbite, respiratory ailment, and asphyxiation), **physical** (phase changes, component failures, and embrittlement), and **chemical** (ignition and burning) (NASA Report, 1997).

**Physiological hazards**

Leakages, fires, explosions or toxic emissions of hydrogen systems can cause several types of injury of the people around. Leakage of gaseous hydrogen into the air in closed spaces may dilute the oxygen below 19.5 percent by volume and cause asphyxiation. Blast waves from explosions may cause injury of people as a result of overpressure.

People may be affected by the radiant heat originating from a hydrogen flame. This likely injury is directly proportional to a number of factors including exposure time, burning rate, heat of combustion, size of the burning surface, and atmospheric conditions (especially water vapor). Contact with cold fluids or cold liquid hydrogen vessel surfaces may cause cryogenic burns. Exposure to large amount of liquid hydrogen spills could result in hypothermia if proper precautions are not taken.

**Physical hazards**

The ability of hydrogen to leak through holes or joints of low pressure fuel lines is 1.26 to 2.8 times faster than a natural gas leak through the same hole (Larminie and Dicks 2003). Continued use of a hydrogen system may cause hydrogen embrittlement that will degrade the mechanical properties of metallic and nonmetallic materials and storage containers.

Flammability range of hydrogen/air mixture is considerably wide, between 4% and 75% of hydrogen in air volume as shown in Figure 2. Other fuels have much narrower flammability ranges, for example, natural gas 5.3-15%, propane 2.1-10%, and gasoline 1-7.8%. Lower flammability limit of hydrogen is 4 times higher than that of gasoline, 1.9 times higher than that of propane and slightly lower than that of natural gas (Larminie and Dicks 2003; Ogden 2002).

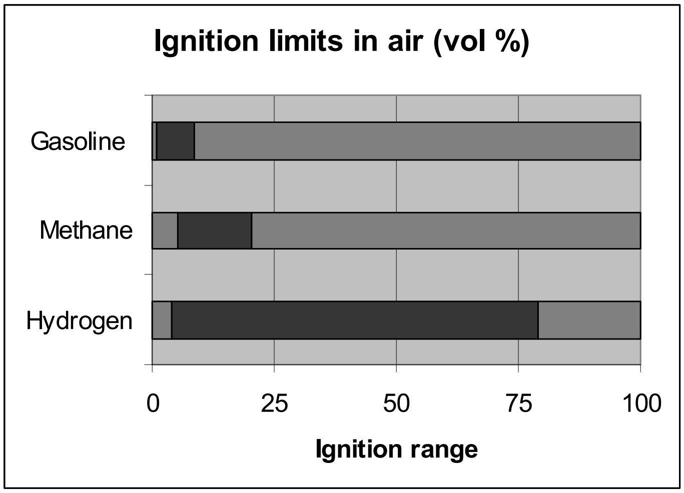


**Figure 2:** Comparison of ignition limits of three gaseous fuels in air.

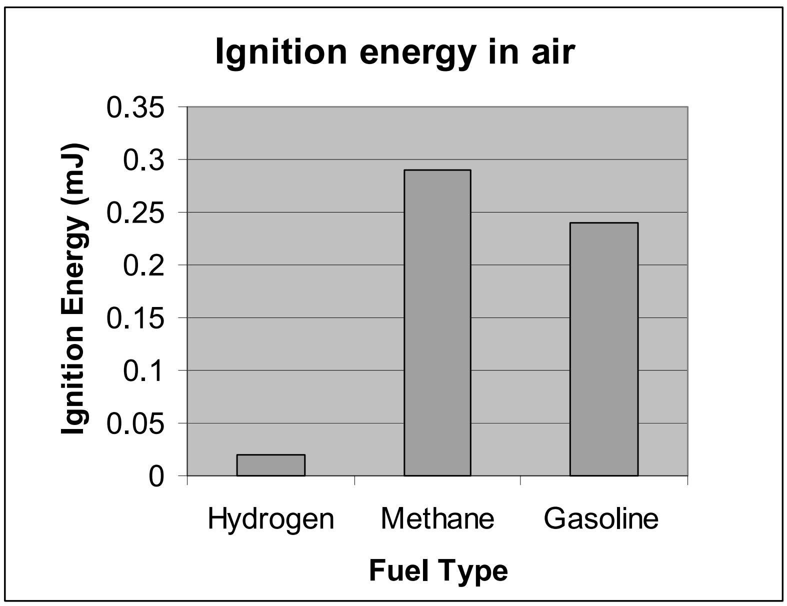


**Figure 3:** Comparison of ignition energies of three gaseous fuels in air.

Ignition energy of hydrogen in air is very low (0.02 mJ) that is about ten times lower than other fossil fuels as shown in Figure 3.

Flame velocity of hydrogen is 7 times faster than that of natural gas or gasoline. Therefore hydrogen flame is more likely to progress to a deflagration or even a detonation than other fuels. The lower hydrogen/air ratio for detonation is 13%-18%, which is two times higher than that of natural gas and 12 times higher than that of gasoline.

In case of an explosion, gaseous hydrogen would have 22 times less explosive energy when compared with gasoline vapor per unit volume of fuel. Violent explosion of a boiling liquid expanding vapor in case of a pressure relief valve failure, however, is a potential danger.

Hydrogen flame is almost invisible. This may be dangerous, because people in the vicinity of a hydrogen flame may not even know there is a fire.

**Chemical hazards**

The combustion of hydrogen originating from regeneration processes (e.g., from natural gas) causes permanent removal of oxygen from the atmosphere. This is a serious environmental problem called oxygen depletion (Santilli, 2000). Production of hydrogen from the electrolytic separation of water using electricity originating from fossil fueled power plants has essentially the same environmental consequences (excessive carcinogenic emission, production of carbon dioxide, and oxygen depletion).

Since hydrogen in gas form does not possess sufficient energy density to permit its use in a compressed form in transportation vehicles, it needs to be liquefied. This process increases the cost and complexity for transportation, storage, delivery, and end use.

Gaseous hydrogen would be required to remain confined in storage devices and delivery lines as it moved from production to use. However, it is important to fully understand the behavior and danger of hydrogen if significant quantities were to leak into the open environment or into enclosed spaces. Because of its tendency to embrittle metals and other containment materials, its rapid leaking behavior, its fast diffusion through the atmosphere, its high buoyancy, and its combustion behavior, hydrogen is significantly different from today's common fuels. Thus, further research is needed in order to understand and control the safety hazards in hydrogen economy. Towards establishing a hydrogen economy both public education about the safe use of hydrogen and suitable training of personnel working with hydrogen are needed.

## CONCLUSIONS

The superiority of hydrogen energy economy over the conventional fossil fuel dependent one is demonstrated. Although the hydrogen economy represents a superior sustainable future and development, significant scientific and technical challenges must be overcome to achieve its implementation. Recent advances in materials science, chemistry, physics, biology, computation, and nano-science provide considerable promise for breaking through many of these challenges.

Safety aspects associated with the use of hydrogen were discussed in the present paper. The superiority of hydrogen as a fuel is demonstrated considering its properties, environmental impact and depletion of fossil fuels. The physiological, physical and chemical safety hazards that may occur during hydrogen production, transportation, storage and usage have been discussed. The impacts of these safety hazards to the personnel, equipment and the environment have been presented.

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# دور طاقة الهيدروجين في التنمية المستدامة

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**ملخص**
في هذا البحث تم مناقشة دور طاقة الهيدروجين في التنمية المستدامة، مع الأخذ في الاعتبار طرق إنتاجها، و تخزينها، والاستفادة منها. إضافة إلى ذلك تم دراسة التأثير البيئي من استخدام تكنولوجيا هذه الطاقة، وتوابع تأثيراتها السلبية الممكن بروزها عند إنتاجها، وتقلها، وتخزينها، واستخدامها؛ وقد تم دراسة ذلك بعناية من منظور بيئي- اقتصادي حيال التنمية المستدامة.