Hydrogen: Fuel of the Future

by

Greg Blencoe
Chief Executive Officer

and

Dr. James G. Blencoe
Chief Scientist

HYDROGEN
DISCOVERIES

August 3, 2007

A Message from Greg Blencoe about Transitioning to a Hydrogen Economy

Reliance on foreign oil
Price shocks that can wreck the economy
Wars
Air pollution
Global warming

These are the problems we have with energy. And every time you and I fill up our cars with gasoline, we are contributing to them. Up until this point, we haven't had a choice, because there was no viable alternative. But within a couple of years we will have a choice, because of the technologies our company and other companies have developed. This paper describes a vision for a future with clean energy. This is the solution to the problems listed above.

A key point to mention upfront is that this isn't going to happen overnight and it will not be easy (though much less painful than if we maintain our current path). But if we begin the transition in the next few years, our goal of powering the world with clean energy by the end of 2020 is achievable.

A fair estimate is that it is going to cost about $1 trillion to pay for the infrastructure to power cars with hydrogen in the U.S. This is obviously a lot of money and critics use this as an excuse not to take action. However, it is not as much as you think when you realize that it would be spent over many years. For example, if it took ten years, the cost would still be $100 billion a year, but that is a small price to pay for all of the problems that would be solved.

In addition, when you pay for gasoline, the price that is paid at the pump is only the beginning. There are many more costs that are not included in this price. For example, how much has the Iraq war cost us? What does it cost to protect the global oil infrastructure each year? How much are the health-related costs of air pollution? What is the cost of global warming?

In the future, these hidden costs to what is paid at the pump will far exceed one trillion dollars if we don't do something soon about the serious energy problems that we have.

Some people might ask: Is this possible? The answer is absolutely yes. The timeline on the following page shows our plan for making it happen.

Greg Blencoe
Chief Executive Officer
Hydrogen Discoveries, Inc.
www.hydrogendiscoveries.com

Hydrogen Discoveries Mission and Timeline

Company mission

The mission of Hydrogen Discoveries is to utilize its fueling system, CO_2 sequestration, and polymer/metal pipeline technologies along with other complementary technologies, such as fuel cells and solar, wind, and nuclear power, to power the world with clean energy by 2020.

Timeline

2007-2008
Promote this vision to individuals, companies, organizations, and governments. Begin the development of prototypes for all three technologies.

2008-2010
Work with interested individuals, companies, organizations, and governments on planning the implementation of this vision. Complete the development of prototypes for all three technologies by the end of 2010.

2010-2012
Build the facilities necessary for the initial transition to this vision, including fuel cell car assembly plants, solar and wind power plants, retail hydrogen fueling stations, fuel recycling plants, CO_2 sequestration facilities, and hydrogen pipeline manufacturing facilities.

2012
Sell the first fuel cell cars with the Hydrogen Discoveries magnesium-hydride fueling system in a limited number of markets. For instance, the 20-25 largest cities could have up to 20-25 hydrogen fueling stations each, which would make consumers in those areas comfortable enough to purchase a hydrogen car. During the transition period, consumers in households with two cars could also own a gasoline-powered car to use when traveling to areas that do not have hydrogen fueling stations.

Construct the first CO_2 sequestration facility. Build the first pipeline that transports hydrogen produced from clean sources of electricity.

2013-2020
Continue the transition to clean energy until completion by the end of 2020.

Table of Contents

Synopsis

This paper presents a vision for a future U.S. hydrogen-based economy that solves the economic, national security, and environmental problems associated with the country's current use of fossil fuels.

We believe a solid form of hydrogen, magnesium hydride (MgH_2), will soon become the principal fuel in the U.S. transportation sector. Scientists at Hydrogen Discoveries have invented a fueling system that uses magnesium hydride to safely store large masses of hydrogen inside fuel cell-powered road vehicles. The magnesium hydride, stored in isolated compartments in a modular tank, reacts with heated water to produce small batches of hydrogen gas "on demand." By forming low-pressure gaseous hydrogen in this way, magnesium hydride will be a much safer fuel than gasoline or high-pressure hydrogen.

Cars, SUVs, and light trucks fueled by magnesium hydride will have a driving range of 500 to 750 miles. From the outside, these vehicles will look very much like ones that are powered by gasoline today. However, magnesium hydride-fueled vehicles will differ in that they will not emit air pollutants or carbon dioxide. In addition, a spent fuel, magnesium hydroxide, will be offloaded at fueling stations, and subsequently transported by truck and rail to recycling plants where it will be converted back to magnesium hydride. The resulting reformed fuel will then be transported by rail and truck back to the fueling stations to complete a closed-loop fueling/recycling process.

Magnesium hydride will be produced domestically and sold at a price equivalent to gasoline sold at $2.79 per gallon. A retail fueling infrastructure adapted for widespread use of magnesium hydride will be similar to the network of fueling stations that exists today. Furthermore, since the electricity needed to make magnesium hydride will be created by solar, wind, and nuclear power, the production of the fuel will be environmentally friendly.

Finally, scientists at Hydrogen Discoveries have also invented a CO_2 sequestration technology and a hydrogen pipeline technology that will give two options for providing clean electricity to homes and businesses.

Introduction

The world is in the early stages of a long-term energy crisis. Currently, the price of crude oil is more than $75 per barrel. Fuel costs are poised to rise further in the future because of long-term supply and demand imbalances due to: the rapidly expanding economies of China and India; political instability in many major oil-producing nations; the threat of terrorist attacks on oil facilities in Middle Eastern and African nations; and the growing recognition that global peak production of conventional crude oil has either already passed or will occur in the next few years.

Although production of world conventional crude oil is at or near its peak, there is sufficient oil available from other fossil fuel sources to satisfy consumer demands for many years to come. For example, there are large reserves of non-conventional crude oil in the Canadian tar sands of Alberta, and in the oil shales of Colorado, Utah, and Wyoming. However, the environment would suffer greatly if fuels from these sources are used, because they would produce even higher levels of harmful emissions than crude oil from conventional sources.

Clearly, there must be a better way. Is it possible for the U.S. to have its energy needs in the transportation sector met by a fuel that is cost effective, domestically produced, clean, and renewable? Fortunately, the answer to this question is a resounding yes.

The Promising Future of Hydrogen

Hydrogen will play a key role in solving the world's energy problems. However, lingering technical challenges in hydrogen storage and delivery have precluded widespread use of hydrogen as an energy carrier for stationary and mobile applications. As a transportation fuel, hydrogen must be safe and cost-competitive with gasoline. It must also allow cars, SUVs, and light trucks to have a driving range of 300 miles or more on a single tank of fuel. The driving public is likely to reject transportation fuels that fail to meet these requirements.

Hydrogen can be stored in gaseous, liquid, or solid form. Its characteristics in each of these states have profound implications for its ultimate use as a transportation fuel.

Liquid and gaseous hydrogen

In liquid form, hydrogen has three major flaws. First, almost one-third of the energy originally contained in the fuel is lost in converting it to a liquid. Second, to store liquid hydrogen for significant periods of time, temperatures near -253°C must be maintained. Third, most storage units for liquid hydrogen cannot prevent its slow conversion to a cold gas. Consequently, a car fueled with liquid hydrogen, parked at an airport for an extended period of time, will vent a sizable amount of gaseous hydrogen.

In gaseous form, hydrogen's main problem is its low energy density. As far as road vehicles are concerned, this basically means that even with a full tank of fuel the driving range is limited. Current prototype gaseous-hydrogen vehicles have a driving range between about 180 and 350 miles, depending on the size of the fueling system and the amount of hydrogen that can be pumped into it. In order to achieve an acceptable driving range, the fueling system must be very large or the gaseous hydrogen must be stored at a very high pressure. The latter is a safety risk that may be unacceptable to customers.

Solid hydrogen

All indications are that, to be a practical transportation fuel, hydrogen must be stored in solid form. Since hydrogen is typically produced as a gas or a liquid, how can it be made into a solid? This is done by combining it with one or more other elements to form a special type of compound known as a "hydride." For example, Chrysler has developed a car that runs on sodium borohydride, which contains the elements sodium, boron, and hydrogen.

A major benefit of hydrides is that there is significantly more hydrogen gas stored per unit volume. This helps solve the driving range problem associated with gaseous hydrogen, because there is substantially more hydrogen available in the fueling system.

Since there are countless types of hydrides, a key consideration is how much hydrogen a particular hydride holds. In addition, cost and safety issues must be weighed. The cost is dependent upon how expensive it is to regenerate the hydride after the hydrogen is released. As far as safety is concerned, hydrogen and the other elements in the hydride must interact with each other, and react with other on-board materials, in ways that are not dangerous. For example, it is essential that toxic fumes are not released as a result of vehicle accidents.

We believe that magnesium hydride (MgH_2) is the solid hydrogen fuel with the greatest potential for on-board (vehicular) hydrogen storage. Our vision is that magnesium hydride will become the predominant transportation fuel. With gasoline prices high and heading higher, this transition will begin around 2012. With that expectation in mind, we will now describe how magnesium hydride can be a safe, cost effective, domestically produced fuel that releases no harmful emissions.

Magnesium Hydride Distribution and Fueling System

How magnesium hydride fuel will be used and recycled

Customers will pump water-slurried magnesium hydride into their vehicles at fueling stations in the same general way they pump gasoline today. However, there will be some differences with the distribution system because the fuel is recycled.

The first step in the process is for the magnesium hydride to be slurried with water at the fueling station and then pumped into your vehicle. While the vehicle is being driven, a portion of the fuel will be heated so that it reacts with water, producing hydrogen and the “spent fuel” magnesium hydroxide (the principal solid ingredient of milk of magnesia). The hydrogen formed is used to power the vehicle. The magnesium hydroxide is off-loaded during the refueling process and subsequently converted back to magnesium hydride at a fuel recycling plant.

Magnesium hydroxide stored in underground tanks at fueling stations will be hauled by truck to local collection centers. From that point, trains will transport it to a recycling facility. Once the spent fuel is recycled, the reformed magnesium hydride will be taken by rail back to the local collection centers. From there, tanker trucks will deliver it to underground storage tanks at the fueling stations. The result is a closed-loop fueling process.

Recycling the magnesium in magnesium hydroxide is much less expensive than mining and manufacturing new magnesium, which helps keep the cost of the fuel down. The recycling aspect of the system also minimizes the amount of new magnesium that needs to be produced, once an initial inventory is created. In principle, no magnesium is lost. In reality, very small losses are likely to occur and, consequently, small amounts of magnesium will have to be replaced regularly.

Magnesium-hydride fueling system

Hydrogen Discoveries has solved two of the most important problems associated with on-board storage of hydrogen: driving range and safety.

Most prototype road vehicles are powered by high-pressure hydrogen and have driving ranges between 180 and 350 miles. However, Hydrogen Discoveries has invented a magnesium-hydride fueling system, similar in size to those currently used to store high-pressure hydrogen, which will allow vehicles to drive approximately 500 to 750 miles on a tank of fuel.

In addition, this fueling system will be safer than gasoline or high-pressure hydrogen fueling systems, because it limits the amount of gaseous hydrogen present in the system at any given time. While the vehicle is being driven, most of the hydrogen on board is safely stored within the magnesium hydride. Gaseous hydrogen is only produced when it is needed. This greatly limits the potential harm that could be done during an accident.

How the use of magnesium hydride lessens the number of retail fueling stations

The extensive travel ranges of magnesium hydride-powered road vehicles will also provide another important benefit. One of the issues in transitioning to a hydrogen-based transportation system is that a new fueling infrastructure must be in place before people will buy hydrogen-powered vehicles. Current fueling stations will need to be retrofitted, or new fueling stations will have to be built.

The current gaseous-hydrogen prototype vehicles must be refueled frequently because they can only be driven about 180-350 miles on a tank full of fuel. Due to this short driving range, a large number of hydrogen fueling stations would have to be built before consumers would be willing to purchase hydrogen-powered vehicles. Moreover, energy companies will not build a large number of hydrogen fueling stations until hydrogen-powered vehicles are widely available.

Magnesium hydride-powered vehicles with travel ranges between 500 and 750 miles will make this “chicken-and-egg” problem much easier to deal with. Since drivers will only be filling up an average of once every two or three weeks, it won’t be necessary to have a large number of fueling stations in an area in order for consumers to be comfortable purchasing a hydrogen-powered car. This also means that energy companies will not have to invest as much money to get the initial hydrogen-fueling infrastructure in place.

Comparison of Hydrogen and Gasoline as a Transportation Fuel

Now that the magnesium-hydride fueling system has been explained, internal combustion engines and fuel cells will be discussed, because both can use hydrogen as a fuel. In each case, the main objective is to determine how many miles can be driven on a kilogram of hydrogen. Once that is done, a direct comparison can be made with gasoline.

Comparing the fuel efficiencies of hydrogen-powered and gasoline-powered internal combustion engines is easy. Assuming that the two types of engines are fully optimized, and otherwise equivalent, a kilogram of hydrogen will propel a vehicle approximately 1.25 times farther than a gallon of gasoline. Therefore, a price of $3.75 per kilogram of hydrogen is, in terms of driving distance, equivalent to a price of $3.00 for a gallon of gasoline.

Fuel cells are a little more complicated. Toyota, a leader in developing fuel cell-powered road vehicles, has produced an SUV that runs on gasoline or hydrogen. This permits comparisons to be made between the mileage obtained from a kilogram of hydrogen and, alternatively, from a gallon of gasoline. The gasoline-powered vehicle of interest for the present discussion is the Highlander Hybrid; the corresponding hydrogen-powered version is the Fuel Cell Hybrid Vehicle (FCHV), which was released near the end of 2002. From the outside, both vehicles look exactly the same.

The relevant mileage estimates are 30 miles per gallon for the Highlander Hybrid and approximately 56 miles per kilogram of hydrogen for the FCHV.[1] Since Toyota has had four years to improve its fuel cell technology, the FCHV should now be able to get at least 60 miles per kilogram of hydrogen which is twice as far as the Highlander Hybrid can go on a gallon of gasoline. Therefore, this shows that hydrogen should be able to achieve the same cost per mile of travel when its price is double that of gasoline.

Although fuel cells are very promising, cost and durability issues must be overcome before they can compete commercially with internal combustion engines. Based on our analysis, fuel cells will reach this point in 2011 if they are mass-produced. Here is some evidence to support that claim:

- Ballard, a leading fuel cell company, has created a “Road Map” that tracks the company’s progress in trying to develop a commercially viable automotive fuel cell stack by 2010. At the end of 2005, Ballard achieved a cost of $73/kilowatt (based on a production volume of 500,000 units per year). The company had TIAX LLC conduct an external audit to confirm that the 2005 cost estimate was valid. Ballard appears to be on pace to meet their cost target of $30/kilowatt by 2010.[2]

- GM announced on September 15, 2006 that they could begin selling fuel cell vehicles as early as 2011. GM has reportedly spent $1 billion up to this point on fuel cells and will spend about the same amount on them between now and 2010.[3]

- GM announced on November 8, 2006 that fuel cell cars will cost the same as gasoline-powered cars once they reach a production volume of 1 million units. This is one out of every nine of the vehicles GM produces every year. The company is aiming to produce a fuel cell system that will cost $50/kilowatt by 2010.[4]

- Honda announced on September 26, 2006 that they would begin selling their FCX fuel cell car in 2008.[5]

Sources of Electricity in Magnesium Hydride Production

At the fuel recycling plants, electricity will be needed to convert magnesium hydroxide back to magnesium hydride. A key question is: How much electricity is required to manufacture a mass of magnesium hydride that will produce one kilogram of hydrogen in a vehicle? The best current estimate is 85 kilowatt hours.[6]

The cost of this electricity will constitute a large portion of the total cost of producing magnesium hydride. While the most inexpensive source of electricity is generally preferred, certain low-cost ways of creating electricity will not be considered here due to their negative impact on the environment. The most commonly cited sources of environmentally friendly ("green") electricity are solar, wind, hydroelectric, and, though some would disagree, nuclear power. Although hydroelectric power is an inexpensive and environmentally acceptable way to generate electricity, the total amount of hydroelectric power produced is unlikely to increase very much in the future. This is because the best locations for generating hydroelectric power have already been identified and utilized. Therefore, the discussion below focuses on electricity produced by nuclear, wind, and solar power.

Electricity from nuclear energy

Nuclear power can be used to produce large amounts of electricity without producing air pollution or carbon dioxide emissions. In the U.S., there have been no nuclear accidents since 1979; thus, it seems that the alleged negative safety and environmental consequences of using nuclear power are exaggerated. This conclusion is supported by the observation that not one person has died from a nuclear accident in the U.S. In contrast, losses of life in coal-mining accidents occur every year.

Although nuclear power has been out of favor in the U.S. since the accident at Three Mile Island in 1979, many people who previously opposed nuclear energy are now seeing its merits. For example, Patrick Moore, one of the founders of Greenpeace, wrote an article for the Washington Post on April 16, 2006 that touted the benefits of nuclear energy.[7]

Despite the negative publicity that nuclear power has received, research on it has continued and significant advancements have been made. Electricity produced by nuclear energy with today's technology is very cost-competitive.

A study conducted at The University of Chicago in 2004, *The Economic Future of Nuclear Power*,[8] included an analysis of the costs of various nuclear power technologies. The Westinghouse AP1000 nuclear power plant was one of the newest technologies discussed in the study. Depending on the particular assumptions that are made, it was estimated that the AP1000 could produce electricity at a cost somewhere between 3.6 and 5.1 cents per kilowatt hour. Westinghouse has stated that the AP1000 could produce electricity at a rate of about 3 to 3.5 cents per kilowatt hour.[9]

To keep the costs of electricity low, the magnesium hydride recycling plants discussed previously will need to be as large as possible to take advantage of economies of scale. If nuclear power is used, several plants could be built at a single, large site. In this circumstance, the AP1000 units would almost certainly be capable of producing electricity at a rate of less than 3.5 cents per kilowatt hour.

Despite the advantages of nuclear power, some people will try very hard to block nuclear plants from being built near their communities. Therefore, a more realistic scenario for future siting of large nuclear power plants is that most of them will be constructed in remote locations with low population densities. This strategy is a way of getting around the problem of local citizens delaying or blocking construction of new nuclear facilities.

Unfortunately, increased use of nuclear energy may also lead to further proliferation of nuclear weapons. In this regard, some key questions are: How can the U.S. legitimately take advantage of electricity produced from nuclear power without allowing others to do the same? How safe would the world be if all countries were allowed to develop nuclear technology? Clearly, issues associated with greater use of nuclear power are numerous and complex.

Since nuclear energy will be needed in certain places around the world that are not near a large amount of economical solar and wind power, one option is to have international troops guard the facilities and manage the spent fuel. This strategy would allow these locations to have clean electricity without other countries worrying about nuclear weapons being built.

Electricity from wind energy

Wind power is a very promising source of inexpensive electricity in the U.S. If you ask about the cost of electricity generated by wind, the standard answer is that it is 4 to 6 cents per kilowatt hour for the largest projects that are currently in existence. The two factors with the greatest effects on the cost are: the quality of the wind at a given location, and the size of the wind farm.

The quality of the wind is simply how strong and how consistently it blows throughout the day at a given location. In the U.S., the strongest and most persistent winds are found in the Great Plains region from North Dakota to Texas. Due to its high potential for future large-scale generation of wind power, this area has been called the "Saudi Arabia of wind."

The size of a wind farm affects its cost due to economies of scale. At a given location, a wind farm with 200 turbines is able to deliver electricity at a per-kilowatt-hour cost that is significantly lower than a farm that has only 20 turbines. This is a key point to keep in mind when considering the future cost of wind power in the scenario that is proposed.

Electricity from solar energy

Like wind farms, geographic location and size affect the economics of solar facilities. The best locations in the U.S. for large-scale solar facilities are in the desert regions of Southern California, Arizona, and Nevada, where very few people live.

Although solar power has historically been expensive, new technologies are driving down costs. For example, Dr. David Mills, former president of the International Solar Energy Society, gave a presentation at the 2005 Solar World Congress in which he described ongoing work on a prototype for a large solar-thermal plant that will generate electricity at a cost of 4.1 cents per kilowatt hour. Many other companies (including several based in Silicon Valley) have recently announced that they have made breakthroughs that would allow them to produce electricity from solar power at a low cost.

The untapped potential of solar and wind energy

Solar and wind power are exceptional long-term options for producing electricity in a future U.S. hydrogen-based economy. Although it is still often claimed that solar and wind power are expensive, the truth is that they have already become inexpensive sources of electricity. In addition, future technological advancements are likely to result in further cost reductions.

Another factor that will lower costs is that the solar and wind facilities of the future will be many times the size of the largest ones currently in existence. Rough calculations indicate that the amount of electricity needed to produce the hydrogen fuel required for *all* road vehicles in the U.S. will be about the same as all of the electricity that is currently generated in the U.S. Therefore, the electricity-generating facilities that produce magnesium hydride will need to be very large.

Thus, it is important to recognize that future costs of solar and wind power will be significantly reduced from current levels due to economies of scale as a result of the increased size of the facilities. In addition, the costs of manufacturing solar and wind equipment will decrease as demand increases.

Having addressed the cost issues associated with solar and wind energy, it is time to ask a very important question: Is there enough solar and wind power available in the U.S. to meet the nation's electricity needs for producing magnesium hydride? The answer is yes. In fact, available solar power alone is sufficient. Though its potential is not as great as solar power around the world, wind power will also be a major factor in a future U.S. hydrogen-based economy.

Price of Magnesium Hydride

Having explained the sources and costs of electricity involved in producing magnesium hydride, we will now analyze all of the costs associated with selling the fuel. The goal is to accurately project a future retail price.

Cost of electricity

As previously mentioned, it will take approximately 85 kilowatt hours of electricity to create a mass of magnesium hydride that, when reacted with water, will form one kilogram of hydrogen. Due to factors discussed previously, a figure of 3.5 cents per kilowatt hour will be used for the cost of electricity. Therefore, the total cost of electricity to produce one kilogram of hydrogen is $2.98.

Cost of magnesium hydride recycling plants

The expenses incurred in building, operating, and maintaining the fuel recycling plants will now be discussed. The best estimate can be made by looking at the economics of oil refineries. The Energy Information Administration (EIA) has stated that 19% of the average 2005 retail price of gasoline of $2.27 per gallon went to oil refining costs and profits.[10] This equals $0.43 per gallon of gasoline.

Although the magnesium hydride recycling plants will be much simpler than oil refineries, the same figure will be used for them. Therefore, the cost to build and operate the magnesium hydride recycling plants is estimated to be $0.43 per kilogram of hydrogen.

Cost of transporting the fuel

The next costs to figure into the price are the expenses incurred to transport the magnesium hydride from the recycling plants to the retail fueling stations, and then to haul the magnesium hydroxide from the retail fueling stations back to the fuel recycling plants.

Based on the cost to transport coal by rail, the estimated cost to transport both the magnesium hydride to a local distribution center and the magnesium hydroxide back to the recycling plant by rail is $0.25 per kilogram of on-board produced hydrogen.[11] This cost figure assumes an average distance of 500 miles between the recycling plant and the local distribution center.

The cost estimates for transporting gasoline by tanker truck to retail fueling stations is about $0.03 per gallon.[12] The total cost of transporting magnesium hydride and magnesium hydroxide will be at least double that amount, because delivery tanker trucks must also transport the spent fuel back to the local distribution center. In addition, the weight of the magnesium hydride and magnesium hydroxide involved in the production of one kilogram of on-board produced hydrogen is much heavier than a gallon of gasoline.[13] This will increase trucking costs to $0.22 per kilogram of on-board produced hydrogen.[14]

Therefore, when the rail cost is added to the trucking cost, the total transportation cost is $0.47.

Cost of retail fueling stations

Gasoline stations typically charge about $0.15 on each gallon of gasoline they sell to cover their costs and make a small profit.[15] Due to the increased complexity of dispensing the fuel, the amount to compensate retail fueling stations is estimated to be $0.37 per kilogram of hydrogen.

Cost of the initial inventory of magnesium

In the closed-loop process that includes both dispensing the magnesium hydride and recovering the magnesium hydroxide, the magnesium will be recycled over and over again. This will allow the cost of the initial inventory of the metal to be spread over many uses.

It takes 13.2 pounds of magnesium to create enough magnesium hydride to produce one kilogram of hydrogen in a vehicle. The cost for that amount of magnesium is $11.48.[16] This expense would be paid upfront by the energy companies, and would be recouped by including it in the price of the magnesium hydride.

For magnesium hydride-fueled vehicles that have a driving range of 500-750 miles, it can be assumed that each vehicle on average will use approximately 20 full tanks of fuel each year.[17] A reasonable expectation is for the initial investment to be recovered in five years with 8% interest. For this to happen, the amount to charge is $0.14 per kilogram of hydrogen.[18]

Cost of taxes

The last expense that needs to be discussed is the cost of taxes. Currently, combined local, state, and federal gasoline taxes average about $0.455 per gallon.[19] Assuming that a kilogram of hydrogen will be able to propel road vehicles twice as far as a gallon of gasoline, this figure should be doubled for magnesium hydride fuel. Therefore, the cost of taxes for each kilogram of hydrogen produced by the fuel is estimated to be $0.91.

Price of a kilogram of hydrogen in the form of magnesium hydride

When all of the above costs are combined, the estimated price for a kilogram of hydrogen in the form of magnesium hydride is $5.30. However, since approximately 5% of the hydrogen in the fuel will not be released, the final amount must be adjusted to

$5.58 to account for this. With the assumption that using fuel cell technology a kilogram of hydrogen will result in twice the driving distance of a gallon of gasoline, this cost figure equates to gasoline sold at $2.79 per gallon.

The price will be lower in the future

One key point to recognize is that the price of magnesium hydride will decrease over the coming years. Technology breakthroughs will continue to lower the costs of solar and wind power. In addition, fuel cells will become even more efficient. On the other hand, with supplies of conventional crude oil becoming much more difficult to find and demand steadily increasing, gasoline prices are almost certain to go up.

Summary

If the vision outlined here is implemented, road vehicles in the U.S. will be powered by a hydrogen fuel that:

- is totally domestically produced;
- will cost less than gasoline;
- allows cars, SUVs, and light trucks to have a 500-750 mile driving range;
- will be recycled over and over again;
- is safer than gasoline or high-pressure hydrogen;
- creates no air pollution; and
- produces no carbon dioxide emissions that contribute to global warming.

Appendix A:
Two Options for Providing Clean Electricity

Although the main subject of this paper is the use of "solid hydrogen" (magnesium hydride) as a transportation fuel, the need to produce clean electricity for homes and businesses must be addressed. The main reason is that there is a growing realization that global warming is causing serious environmental problems. If carbon dioxide emissions are not significantly reduced in the next decade or two, future generations will pay a steep price for the resulting harmful effects on global climates.

Sequestering the carbon dioxide produced from coal and natural gas

In the U.S., coal and natural gas are used to create about two-thirds of the nation's electricity. These fossil fuels produce carbon dioxide emissions that contribute to global warming—coal being, by far, the largest source of that greenhouse gas. Consequently, even if all road vehicles in the U.S. and elsewhere were run on magnesium hydride produced from a combination of solar, wind, and nuclear power, the Earth's atmosphere would still continue to be polluted by extraordinary amounts of carbon dioxide emissions created by burning coal and natural gas.

At some point in the future, governments around the world are likely to insist on taking much more drastic measures to eliminate carbon dioxide emissions. One course of action often mentioned is capturing the carbon dioxide emissions and permanently storing ("sequestering") them in some manner. Although most forms of CO_2 sequestration are not good for the environment and/or potentially dangerous, the technology invented by Hydrogen Discoveries has solved both of these problems.

Pipelines that transport hydrogen produced from green electricity

A breakthrough in hydrogen-pipeline technology made by Hydrogen Discoveries will provide another option for producing clean electricity. This technology would eliminate the embrittlement and leakage problems associated with high-pressure hydrogen pipelines manufactured from carbon steel.

Once hydrogen is mass-produced at solar, wind, and nuclear facilities by electrolysis or thermochemical cycling, the new pipeline technology would allow the gas to be transmitted and distributed across the country. Fuel cells could then be used locally to convert the hydrogen back into electricity for use in homes and businesses.

Although a thorough cost analysis of both approaches is needed, it is clear that they will increase the cost of electricity significantly. Consumers will either have to purchase energy-efficient products in order to offset the higher cost of electricity or face the consequences of global warming.

Appendix B:
Plug-in Batteries in Magnesium Hydride-Fueled Vehicles?

Plug-in hybrid electric vehicles use an on-board battery as a power source to minimize fuel consumption. The battery in a plug-in hybrid electric vehicle can be charged at any electrical outlet. Since a typical plug-in hybrid battery takes about six to eight hours to fully charge, owners usually choose to do this overnight at home.

Currently, a plug-in battery will power a road vehicle for approximately 25 to 30 miles, which is a greater distance than many people drive on a normal workday. A general rule of thumb is that plug-in hybrid vehicles run on the battery about half the time (until the stored energy in the battery runs out).

The cost of the electricity required to fully charge a plug-in battery is usually quoted as being the equivalent of \$0.75 to \$1.00 per gallon of gasoline with no taxes added. One key point to keep in mind, however, is that the cost of the plug-in battery system needs to be considered. If they are mass-produced, a plug-in battery system will probably add an average of \$3000 to the total cost of the vehicle. An economic analysis shows that road vehicles with plug-in battery systems only have a very small economic advantage when all of the costs are taken into account over the lifetime of the vehicle.[20]

Another point to consider is that plug-in hybrid electric vehicles have environmental issues. For example, approximately half of the electricity in the U.S. is generated by coal, which is a major source of air pollution and carbon dioxide emissions that contribute to global warming.

Notes

1. If you look at the presentation on the following link by Dave Hermance of Toyota on November 5, 2003, you will see on page 14 that the uncorrected efficiency for the FCHV is 64 miles per kilogram of hydrogen (http://www.4cleanair.org/hermance.pdf).

This number is calculated with the vehicle in a laboratory. In order to more accurately reflect the actual performance outside of the laboratory, this figure must be adjusted downward. The assumption is that city driving will account for 55% of the total and highway driving will account for the other 45%. To get the city fuel economy number, the uncorrected efficiency is multiplied by 0.9. To get the highway fuel economy figure, the uncorrected efficiency is multiplied by 0.78.

The corrected fuel efficiency is the total of the city and highway numbers. With the FCHV, the total would be:

City: 64 miles per kilogram of hydrogen * 0.55 * 0.9 = 31.68
Highway: 64 miles per kilogram of hydrogen * 0.45 * 0.78 = 22.464
Total = 54.144 miles per kilogram of hydrogen

However, this figure must be revised upward because the hybrid system in the FCHV is four years older than the Highlander Hybrid. Therefore, the number has been slightly revised upward to 56 miles per kilogram of hydrogen to reflect this.

2. Available online at:
http://www.ballard.com/be_informed/fuel_cell_technology/roadmap

3. Available online at:
http://www.msnbc.msn.com/id/14848423/

4. Available online at:
http://www.koreaherald.co.kr/SITE/data/html_dir/2006/11/08/200611080024.asp

5. Available online at:
http://world.honda.com/news/2006/4060925FCXConcept/

6. This amount is broken down into two parts. The electricity to convert the magnesium hydroxide to magnesium will constitute a major portion of the total energy needed. Using the SOM (solid oxide membrane) process developed by Uday Pal at Boston University, the amount of electricity needed to convert the magnesium hydroxide to magnesium is 60 kilowatt hours.

The other 25 kilowatt hours of electricity is needed to produce one-half a kilogram of hydrogen by electrolysis. The large-scale electrolyzers require about 50 kilowatt hours to make a kilogram of hydrogen. It should be noted that the other one-half a kilogram of hydrogen comes from the water that is slurried with the magnesium hydride prior to fueling.

7. Available online at:
http://www.washingtonpost.com/wp-dyn/content/article/2006/04/14/AR2006041401209.html

8. Available online at:
http://www.ne.doe.gov/reports/NuclIndustryStudy.pdf

9. Available online at:
http://www.nuclearinfo.net/twiki/pub/Nuclearpower/WebHomeCostOfNuclearPower/AP1000Reactor.pdf

10. Available online at:
http://www.eia.doe.gov/bookshelf/brochures/gasolinepricesprimer/eia1_2005primerM.html

11. The most recent EIA coal transportation rates are from 2001 (http://www.eia.doe.gov/cneaf/coal/page/trans/coaltrans.xls#figures2.01_2.03!A1), Table 2.07). The 2001 rate per ton-mile was $0.0122 (in 2001 dollars). However, in the book *Big Coal: The Dirty Secret Behind America's Energy Future*, author Jeff Goodell states on page 77 that:

"In 2004, a ton of Wyoming coal delivered to a power plant in Georgia sold for about forty dollars. Of that, as much as 80 percent went to the railroads."

If you assume that 80 percent of the forty dollars went to the railroads and the distance between where the coal is mined in the Powder River Basin in Wyoming and the power plant in Georgia is about 1500 miles, then the rate per ton-mile is $0.02133. Although this figure is significantly higher than the 2001 EIA number, it will be used to determine the rail costs to transport magnesium hydride and magnesium hydroxide.

The weight of the amount of magnesium hydride and magnesium hydroxide involved in producing one kilogram of on-board hydrogen will determine the transport cost. The magnesium hydride will weigh 14.36 pounds and the magnesium hydroxide will weigh 31.82 pounds. The reason for the difference is that the magnesium hydride is slurried with water at the fueling station. Therefore, the water will not be with the magnesium hydride in the rail car. But the magnesium hydroxide that is shipped back in a rail car includes the weight of the magnesium hydroxide along with a significant amount of water.

At $0.02133 per ton-mile, the rail cost will be $10.67 per ton for 500 miles. With the magnesium hydroxide and water weighing 31.82 pounds, the cost of each ton will cover 62.85 kilograms of hydrogen. This equals $0.1698 or $0.17 per kilogram of hydrogen. Since the magnesium hydride weighs 14.36 pounds, the cost of each ton will cover 139.28 kilograms of hydrogen. This equals $0.0766 or $0.08 per kilogram of hydrogen. Therefore, the final rail cost figure will be $0.25 per kilogram of hydrogen.

12. Available online at: http://www.nacsonline.com/NACS/Resource/PRToolkit/Campaigns/prtk_gp2007_Retailer+Margins.htm

13. The magnesium hydride will weigh 14.36 pounds and the magnesium hydroxide will weigh 31.82 pounds. A gallon of gasoline weighs about 6.2 pounds.

14. With the magnesium hydroxide and water weighing 31.82 pounds and a gallon of gasoline weighing 6.2 pounds, the cost of trucking will be 5.13 times as much. This will equal $0.1540 or $0.15 per kilogram of hydrogen. Since the magnesium hydride weighs 14.36 pounds, the cost will be 2.32 times as much. This will equal $0.0695 or $0.07 per kilogram of hydrogen. Therefore, the total trucking cost will be $0.22 per kilogram of on-board produced hydrogen.

15. Available online at: http://www.nacsonline.com/NACS/Resource/PRToolkit/Campaigns/prtk_gp2007_Retailer+Margins.htm

16. The end of the third quarter of 2006 China free market price was $1915 per metric ton (http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mgmis3q06.pdf). This equals $0.87 per pound. Therefore, the total price for 13.2 pounds would be $11.48.

17. The middle of this range is 625 miles. With 20 full tanks of fuel used each year, the annual mileage would be 12,500. This is close to what the average person drives.

18. With an interest rate of 8% on a loan amount of $11.48, the monthly payment would be $0.232773. This equals $2.793276 per year. This amount divided by 20 times per year equals $0.1396638 or $0.14.

19. Available online at: http://www.api.org/policy/tax/stateexcise/upload/october_2006_gasoline_and_diesel_summary_pages.pdf

20. The following assumptions were made for the analysis:

- The plug-in battery system will cost $3000 and last for 150,000 miles.
- The plug-in hybrid vehicles will run on the battery half of the time.
- The plug-in hybrid vehicles will go 30 miles on a full charge of the battery.
- The plug-in hybrid vehicles will go 30 miles for $0.75 in electricity plus $0.45 in taxes for a total of $1.20.
- The vehicles that only run on magnesium hydride will go 30 miles for $2.79.
- The total fuel costs will be calculated at the end of each year.
- Both vehicles will last ten years and be driven 15,000 miles per year.

- The discount rate to determine the present value of the cash flows will be 5%.

The present value of the total fuel and system cost of the plug-in hybrid vehicle is $10,702.43. The present value of the total fuel cost of the vehicle that only runs on magnesium hydride is $10,771.82.