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The Phoenix Project:
Shifting to a Solar Hydrogen Economy by 2020

By Harry W. Braun

The most serious energy, economic and environmental problems are related to the use of fossil and nuclear fuels, which are rapidly diminishing and highly polluting, and many distinguished atmospheric chemists, including Dr. James Hanson at NASA, Dr. Steven Chu, the director of Lawrence Livermore Laboratory, and Professor Ralph Cicerone, president of the National Academy of Sciences have documented that climate changes are now occurring much faster than predicted just a few years ago. The methane hydrates in the oceans and the permafrost in vast areas of the Arctic regions of Siberia, Alaska and Canada are now starting to rapidly melt, and given this could release 50 to 100 times more carbon into the atmosphere than is now generated from the burning of fossil fuels, humanity is rapidly approaching an exponential "tipping point" of no return. Given this sense of urgency, Hanson and others have warned that fossil fuels need to be phased-out by 2020 if irreversible damage to the earth's climate and food production systems is to be avoided. The Phoenix Project plan seeks to do exactly that by mass-producing wind-powered hydrogen production systems and simply modifying all the existing vehicles and power plants to use the hydrogen made from the sun, wind and water.

Many analysts have stated that there is no "silver bullet" that can solve these interrelated and exponentially worsening problems even in 100 years, much less 10. But that is because they assume some new source of energy must be developed that is both reliable and sustainable, and all of the existing vehicles need to be replaced with hybrid or fuel cell electric vehicles. Fortunately, these analysts are wrong. Indeed, if a transition from fossil fuels to renewable hydrogen systems is to be initiated by 2020, there is little time for research and development, which can often take many decades, and in the case of nuclear fusion, it may be centuries.

There are many promising renewable energy technologies under development that could be used for large-scale hydrogen production, including advanced wind systems, photovoltaic cells, ocean thermal energy conversion systems and the use of biological organisms such as blue green algae or the genetic optimization of the *hydrogenase* enzyme. However, the Phoenix Project baseline assumptions focus on wind systems because they are well-understood from an engineering and manufacturing perspective, they can be mass-produced without requiring strategic materials, and even in their relatively small production runs, they are still able to generate electricity (and hence electrolytic hydrogen) for less cost than typical photovoltaic or other solar thermal systems - as well as new fossil fuel and nuclear systems. Other geothermal and solar technologies, such as Nanosolar PV systems and wave and ocean thermal systems, will increasingly be part of an evolving renewable hydrogen production "mix" as they are able to become economically competitive, but wind systems alone are indeed the only "silver bullet" that can permanently displace all fossil and nuclear fuels - not just in the U.S. -- but worldwide by 2020. This concept of a wind-powered hydrogen economy is not a new idea. In 1923, J. B. S. Haldane, a Scottish scientist delivered a lecture at Cambridge University in which he stated that hydrogen, derived from wind power via electrolysis, liquefied and stored, would be the ideal fuel of the future.

Over 80-years later, Haldane's insightful vision of the future is still the most practical and economic technology path that has been identified to achieve "sustainable prosperity without pollution. "In spite of the fact that wind systems now produce electricity for less cost than virtually any new energy technology, they only contribute less than 1 % of current U.S. energy demands because the winds are inherently intermittent and unpredictable and they often blow at night when the electricity is not needed. This is the primary reason why a recent analysis by a committee of the U.S. National Science Foundation dismissed wind systems as a major energy factor in the future. These obstacles, however, are eliminated if the electricity from the wind systems is used to electrolyze water into hydrogen and oxygen. And rather than waiting for fuel cells, the Phoenix Project plan calls for simply modifying every existing vehicle and power plant to use hydrogen – as well as conventional hydrocarbon fuels - with the flip of a switch. Literally thousands of vehicles, trucks and even a few submarines were modified in this way in Germany and England in the 1930s.

In order to permanently phase-out the use of fossil and nuclear fuels by 2020, the Phoenix Project proposal avoids any significant research and development by having companies like General Electric and General Motors mass-produce state-of-the-art components for the wind-powered hydrogen production systems, as well as the engine and fuel conversion kits that will be needed for the existing vehicles and power plants. Approximately 5 million 2-MW wind systems would displace virtually all the rapidly diminishing and highly polluting fossil and nuclear fuels now used in the U.S., and approximately 20 million units would displace the use of fossil fuels worldwide. Approximately 16 million new vehicles are sold in the U.S. annually, and because the power conversion units of wind systems are very similar to an automobile from a manufacturing perspective, the 5 million units for the U.S. could be manufactured in less than a year once the tooling is in place. In addition, given its vast land and seawater resources, the U.S. could be rapidly transformed from being the world's largest energy importer into the world's largest energy exporter of solar-sourced hydrogen, the only "universal fuel" that can power virtually any vehicle with a carbon-free source of energy that is inexhaustible.

Unlike electricity, hydrogen can be stored and delivered to national and international markets by cryogenic tanker trucks, ships or underground pipelines, which can also be engineered to transmit superconducting electricity as well as the gaseous and liquid hydrogen. Moreover, hydrogen made from the wind and water is a carbon-free combustion fuel that is inexhaustible, which is why it is indeed a "silver bullet" solution that can permanently displace the use of fossil and nuclear fuels worldwide. The remaining oil and other fossil fuels can then be used as critical chemical feed stocks for the production of fertilizer, pesticides, plastics, medicines and food (i.e., it now takes ten calories of fossil fuels to make one calorie of food).

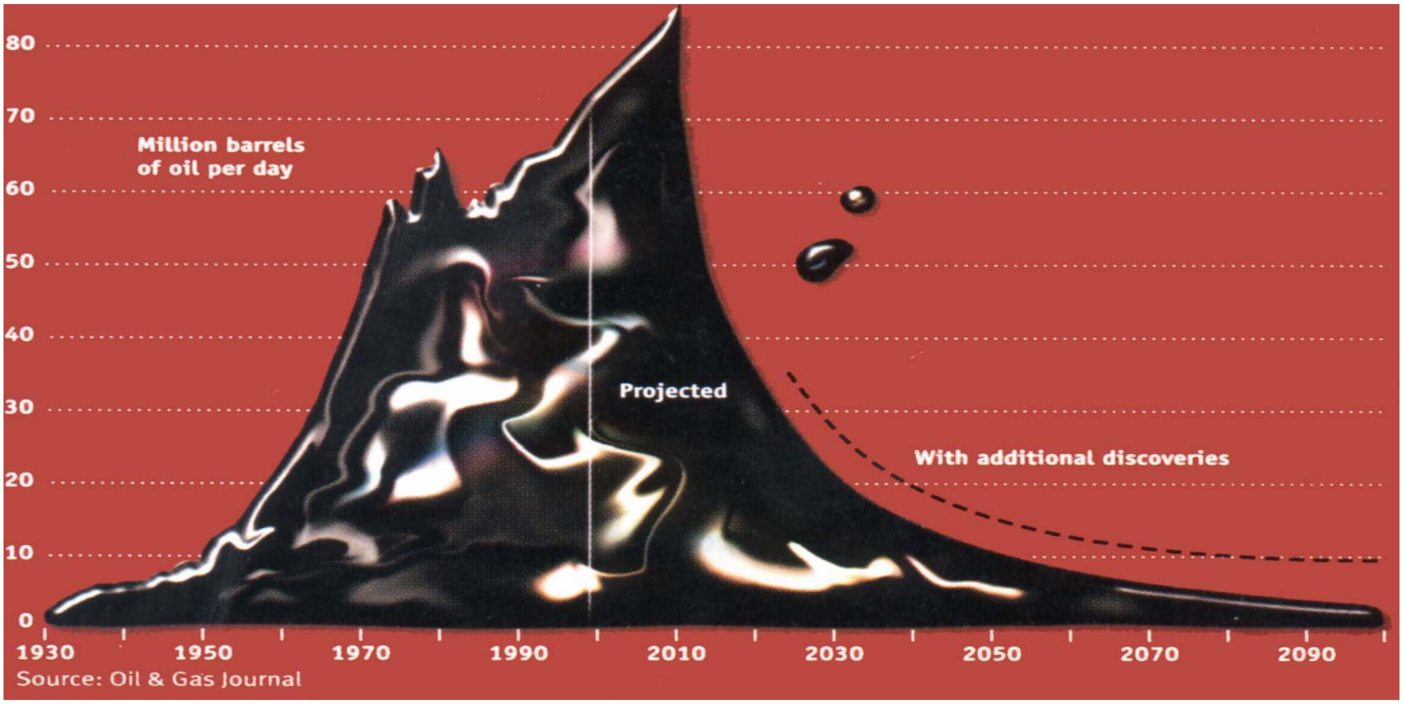
Since the 1980s, Los Alamos National Laboratory investigators and BMW have been successfully modifying engines and vehicles to use cryogenic liquid hydrogen, which most closely resembles gasoline from a perspective of performance, weight, fuel storage volume, and vehicle range. Lockheed studies also confirmed that both new and existing aircraft can be modified to use liquid hydrogen fuel, which will be quieter and reduce the takeoff weight by over 40 %. Moreover, extensive field data and accidents evaluated by BMW and NASA and others, such as Air Products & Chemicals, have shown that hydrogen is much safer than gasoline or any other hydrocarbon fuels in the events of leaks and/or accidents. However, virtually all of the hydrogen now used is manufactured from natural gas, which has its own environmental and resource depletion problems that eliminate it as a viable resource for powering a carbon-free hydrogen economy. The same is true for coal.

Economic Considerations

As with most products, mass-production is a key to reducing system costs, and given the exponential consumption of the remaining fossil fuel and uranium resources, energy costs will likely continue to sharply increase in the future. This is already impacting every product produced, including wind systems, which is why the longer this capital intensive transition to a renewable hydrogen economy is delayed, the more expensive it will be. Assuming the capital costs of the mass-produced wind powered hydrogen production systems are $500 to $1,000/kW, a 2-MW wind system would cost from $1 million to $2 million. Thus the 5 million units would cost between $5 trillion to $10 trillion.

Given the USA now spends over $1 trillion annually for energy, even the higher value would be paid off in less than 10 years, providing a renewable rate of return on the investment with equipment that will last indefinitely. To put these numbers into perspective, according to a May 5th,2008, article published in the Oil & Gas Journal, Matthew Simmons, a highly regarded analyst who is Chairman of Simmons & Co. International, stated that the oil and gas industry will need to invest $50-100 trillion to rebuild its ageing infrastructure within the next 7 years and stave off a serious drop in oil and gas production.

This number does not include any of the staggering environmental costs that will be incurred as the shift to mountain-top mining and the extraction of hydrocarbons from shale and tar sands is intensified. Over 90 % of the remaining crude oil is not owned by oil companies, but by the governments of countries such as Iran, Iraq, and Venezuela. Global oil production peaked in 2005 but as the Oil Age graph shown in Fig. 1 indicates, the exponential plunge phase of global oil production has only begun. Once the public sees this graph, they will understand that soon it will not be possible to get gasoline at any price, which will have a catastrophic impact on both the economic and food production systems worldwide.



Source: Oil & Gas Journal

Figure 1. The Oil Age

This reindustrialization effort would have profound implications for the global economy, the environment, national security, U.S. foreign policy as well as the fundamental global problems of more and more people competing for fewer and fewer resources. Millions of jobs would be created in the process, and given that no new technology is needed, the real obstacles to this “transition of substance” are not technical or economic – but the lack of public and political awareness.

Photosynthesis: The Original Solar Hydrogen Production Systems

There is a remarkable historical precedent for the Solar Hydrogen Economy. The Earth’s protein scale nanobes and micron-scale microbes figured out a sustainable solution 3.5 billion years ago when they successfully developed photosynthetic chlorophyll that could extract hydrogen from water with solar energy.

On the primitive Earth, when the first protein-scale “nanoorganisms” and microorganisms evolved, they were able to extract the hydrogen they needed for metabolism from the hydrocarbon molecules contained in the “primordial soup.” The energy conversion efficiency was about 40 %, but the primordial soup was similar to oil in the sense that it was non-renewable, and it was being exponentially consumed, thus more and more microbes found themselves competing for fewer and fewer resources. In order to avoid extinction, the nanobes and microbes developed a new technology: photosynthetic plants. At the heart of every photosynthetic plant is a highly complex chlorophyll molecule that allows hydrogen to be extracted from water with solar energy (Figure. 2).

Although this photosynthetic process is only about 1 % efficient, it turned out to be a sustainable method of extracting hydrogen from water on a global scale. Indeed, although much less efficient, this “transition of substance” to renewable solar hydrogen resources allowed the microbes to prosper on a global scale for over 3.5 billion years. The lesson from Mother Nature is clear: efficiency is not as important as sustainability.

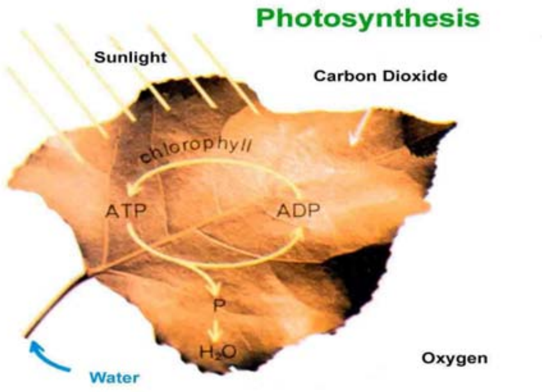


Figure 2. Photosynthesis: the original solar hydrogen production system.

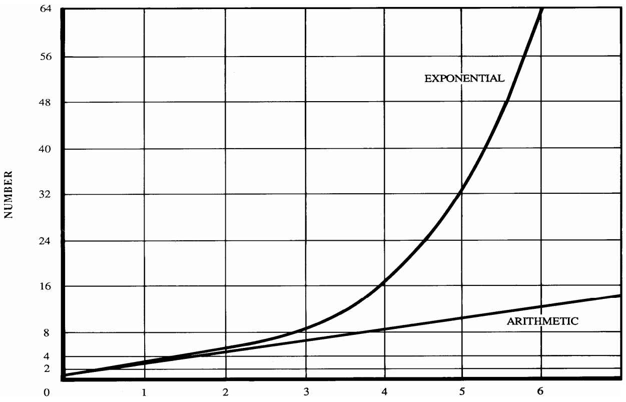
Exponential Icebergs

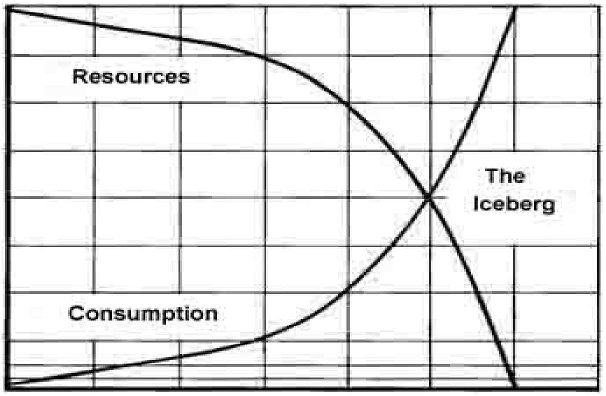
When many of the most respected senior scientists, including Dr. James Hanson at NASA, Dr. Steven Chu, the director of Lawrence Livermore Laboratory, and Professor Ralph Cicerone, president of the National Academy of Sciences are alarmed that climate changes are now occurring much faster than predicted just a few years ago, it is because they understand the exponential nature of the problem. When the consumption of a resource is growing at a given percent per year, the growth is said to be exponential." The important property of the growth is that the time required for the growing quantity to increase its size by a fixed fraction is constant. For example, a growth of five percent (a fixed fraction) per year (a constant time interval) is exponential. It follows that a constant time will be required for the growing quantity to double its size (increase by 100 %). This time is called the doubling time, t2, and it is related to P, the percent growth per unit time by the following equation:

$$T2 = \frac{70}{P}$$

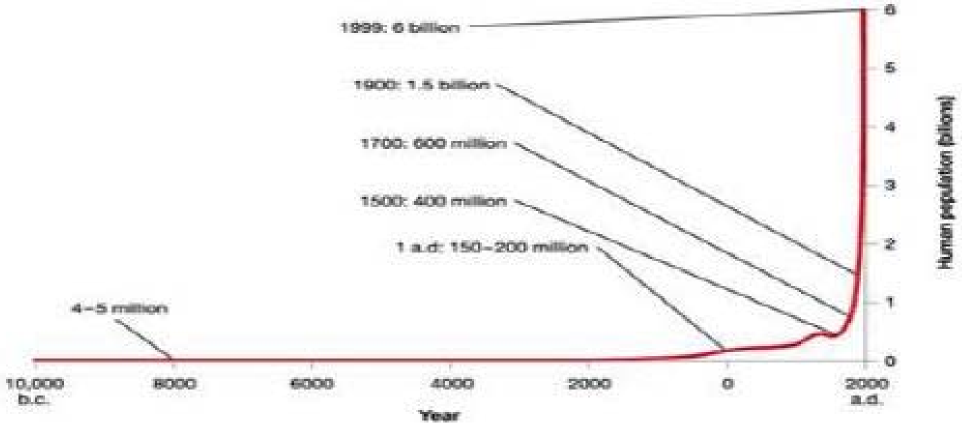
A growth rate of five percent per year will result in the doubling of the size of the growing quantity in a time t2 = 70/5 = 14 years. But in two doubling times (28 years), the growing quantity will double twice (quadruple) in size. In three doubling times, its size will increase eightfold, and in four doubling times it will increase sixteen fold, etc. Such is the power of exponential growth. Many analysts believe there may be enough oil in the world to last 50 years at the current rates of consumption, but even if there were a 1,000-year supply of oil, with an annual growth rate of 5 %, the 1,000-year supply would be exhausted in 79 years. As physics Professor Albert Bartlett points out, virtually no one in the government is aware of the exponential nature of these interrelated energy, economic and environmental problems.

Exponential Growth Considerations

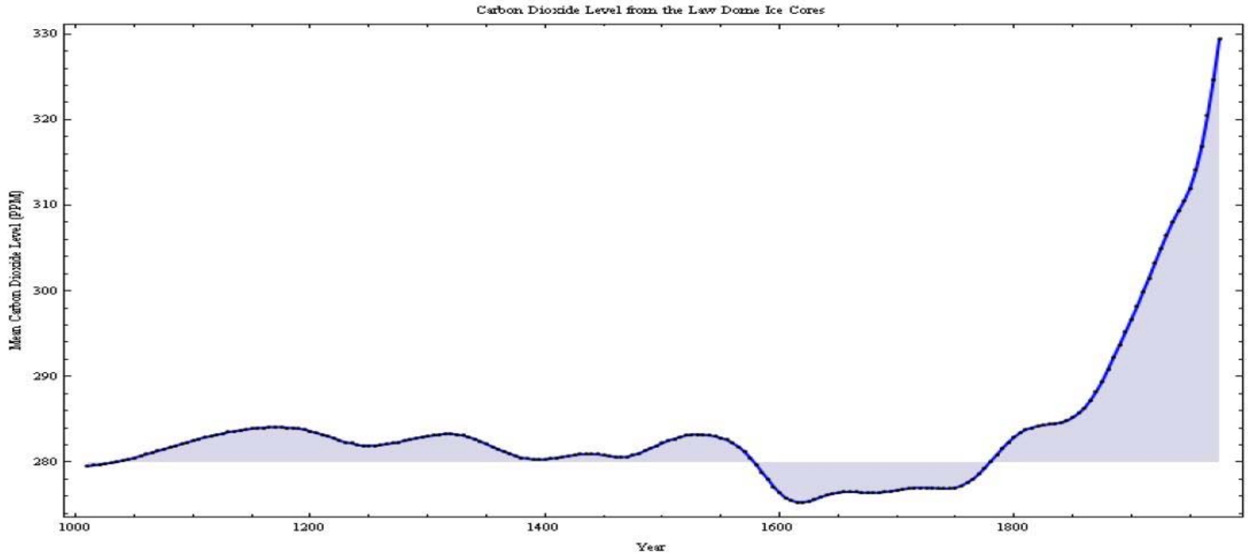




Human Population Growth Since 10,000 BC



Carbon Dioxide (CO2) emissions over the past 1000 Years



Ice core data over the past one million years, when 7 ice ages came and went, documents that at no time did carbon dioxide levels ever exceed 300 ppm. They are now over 385 and the curve is now going vertically off the chart, which is why the National Academy of Sciences has warned humanity is now passing the point of no return.

Given the doubling times of exponential growth, the process starts out very slowly at first, but in the final stages, the increasing curve of exponential growth goes vertically off the page. Such explosive growth and corresponding depletion of resources is obviously unsustainable, and there is no question that one of the largest mass-extinction events in the Earth's history is now underway. The global ocean ecosystems are now more than 90 percent dead, and the reaming fish are so contaminated from mercury emitted from coal plants, they are unfit to eat. Bats, frogs and bees are disappearing and the warming temperatures are now allowing insects to destroy much of the forests in the Cascades and Rocky Mountains of the American West.

Anyone who understands the nature of these profoundly serious problems will be rightly concerned, but it is important to note that because of the positive nature of the exponential growth in knowledge and information, humanity is hopefully as close to a technological "utopia" of molecular biology and nanotechnology that will essentially eliminate aging and disease, as it is to an ecological "oblivion" of mass-extinction. The human community is now entering the final stages of the exponential curve, and eight critical years were lost during the Bush administration to take constructive action. This underscores that there is very little time left to act, and yet none of the political leaders or presidential candidates in the U.S. are even aware of these profoundly serious problems, much less what to do about them.

The Exponential Time of 11:59

Consider the exponential time of 11:59 (Figure 3).

Figure 3. The Exponential Time of 11:59.

For example, if a bug is put in an empty bottle at 11:00 in the morning, and it is observed that the bottle is full of bugs at 12:00 noon, when will the bottle be half-full? The answer is 11:59, but the significance of this analogy is that if you were one of the bugs in the bottle, at what point would you begin to realize that you were running out of resources? Note that at 11:55, the bottle is only 3 % filled, leaving 97 % of the space for growth, but the exponential inertia of the last four minutes will totally consume what appeared to be a vast resource [1]. Roughly half of all the known global oil reserves have now been consumed, and about half of the coral reefs in the oceans have now been destroyed. This underscores it is now 11:59 for the passengers aboard *Spaceship Earth*, which will suffer the fate of the passengers aboard the *Titanic* if a fundamental change in course is not initiated in time.

The Oil Age

The graph of the Oil Age shown in Figure 1, prepared by the Oil and Gas Journal, clearly shows the energy supply problems are much more serious that most people realize. Existing oil reserves are expected to last for 40 or 50 years, but according to The New York Times (February 24, 2004), the major oil fields in the Middle East have already begun to decline in production, and it is only a matter of time before the "exponential plunge" phase occurs when there is a dramatic drop off in oil production. It is like being on a roller coaster that is slowly cresting the first ramp just before the dramatic drop begins. When the exponential consumption curve intersects the available resource base, an "exponential iceberg" is impacted, with typically catastrophic results. From an economic perspective, the exponential consumption of oil and other fossil fuels will result in ever higher energy prices, which will have a profoundly negative impact on the global economy. As a result, the longer the transition to a renewable hydrogen economy is delayed, the more expensive the transition will be.

Hydrogen Production Options

Hydrogen can be made from water with and any source of electricity. As such, it is possible to refuel the vehicle at home, as well as the local service station. Thus the most important consideration is how the vast new quantities of electricity that will be needed is going to be generated. In the U.S., the Bush administration focused on developing the non-renewable "dirty" hydrogen options, which include making hydrogen from fossil fuels, extending the life of existing nuclear plants and building a new generation of coal and nuclear plants. Such policies will not solve the more fundamental energy supply problems and they ignore the urgent warnings by the world's most distinguished scientists that the combustion of fossil fuels needs to be phased out within a decade. Ethanol has received most of the attention in the media and investment community, but according to a study by the National Academy of Sciences, even if all of the corn in the U.S. was used to produce ethanol, it would only displace 12 % of the gasoline now used, and a page one story in The New York Times (January 19, 2008) documented that even the relatively small amounts of ethanol and other biofuels now being produced are already having a devastating impact on food prices worldwide, which is now adversely impacting several billion desperately poor people.

Moreover, ethanol is not renewable because it depletes the soil 18 times faster than it can recover, and it typically requires more energy from fossil fuels to make ethanol from corn than the ethanol will generate when it is used as a fuel. In addition, ethanol still produces significant levels of carbon emissions as well as the toxic emissions of acetaldehyde and other carcinogenic aldehydes that are actually increased when compared to using gasoline as fuel. Hydrogen made from the sun, wind and water, by contrast, emits only pure water vapor as its combustion byproduct, which means if vehicles were fueled with hydrogen, urban areas would have crystal clear air even in rush hour traffic. It is also important to note that while it takes just over 65 kilowatts of electricity and 2 gallons of water to make an equivalent gallon of gasoline in the form of liquid hydrogen, it takes 18 gallons of water to make a gallon of gasoline from oil, and over 12,000 gallons of water are needed to make a gallon of ethanol from corn.

Coal

All of the presidential candidates are promoting "clean" coal as a solution, when in fact these so called "clean" coal program that have also been pushed by the Bush administration have recently been canceled because of technical problems, and the "sequestering" of carbon dioxide has been shown to be at best a stopgap temporary storage problem. In addition, these technologies will never be able to displace fossil fuels, and they create far more economic and environmental problems than they solve.

Even if the technology worked, however, the 250-year supply of coal in the U.S. would be consumed in less than 25 years if it were to be gasified into hydrogen on a scale to displace other fossil and nuclear fuels. In addition to global warming and climate change, the use of coal also directly causes many of the most serious health problems worldwide, including mercury contamination, cancer, heart attacks and strokes. Indeed, ancient mountain ecosystems are now routinely destroyed for a few days worth of coal, which when burned emits hundreds of tons of mercury into the atmosphere annually.

A Time magazine article on mercury (Mercury Rising, September 11, 2006) documented that this highly toxic metal is not just in seafood, but is showing up everywhere, including in polar bears in the Artic. And mercury is much more toxic than most people think. It not only causes serious damage to the brains of unborn infants and young children, which is no doubt a primary factor in the explosion of autism in children, as well as hundreds of millions of adults and other animals worldwide.

Nuclear Power

Like oil and coal, uranium 235 is also a rapidly diminishing and very rare resource that could never displace the use of fossil fuels with nuclear fission reactors. In addition, according to the U.S. Nuclear Regulatory Commission (NRC), every reactor in the U.S. is now suffering from serious levels of stress corrosion in the primary reactor cores – which makes these reactors ticking time-bombs.

In addition, while nuclear reactors do not generate greenhouse gases, the nuclear wastes they generate, which are invisible to human senses, have been leaking and out of control since World War II. In the case of depleted uranium (U-238), which is one of the most common wastes, it's half-life is 4.5 billion years and at least 10 half-lives are required for the radioactive elements to be safe for human exposure.

This issue is not generally covered by the Western news media, but when a weapon with depleted uranium explodes, the pulverized depleted uranium oxide (DUO) nanometer-sized particles have been shown to travel in the wind from Iraq to Europe over 2,500 miles away in less than 10 days. According to Leuren Moret, an international radiation specialist, since 1991, the U.S. has released the radioactive atomicity equivalent of at least 400,000 Nagasaki bombs into the global atmosphere, which is 10 times the amount released during atmospheric testing in the 1950s, which was the equivalent of 40,000 Hiroshima bombs. As a result of those atmospheric tests, virtually every person and mammal on the planet now has radioactive isotopes imbedded in their tissue, teeth and bones.

Given these profoundly seriously environmental and resource depletion issues, and given that nuclear systems could never compete without massive government subsidies, and they could never be mass-produced to allow the human community to displace the combustion of fossil fuels by 2020, their use creates far more staggering economic and environmental problems than the relatively small amount of energy they produce. Given this technology and economic reduction process, one of the few renewable energy technologies that are economically competitive and technically mature enough to be mass-produced for large--scale hydrogen are state-of-the-art megawatt-scale wind-powered electrolysis systems.

Hydrogen Production Costs

Two of the most important question to be resolved in shifting to a hydrogen economy is what will the hydrogen be made from, and how much will it cost? Virtually all of the hydrogen now produced in the U.S. comes from natural gas. In evaluating energy costs, cost per unit of heat, such as British Thermal Units (Btu) are used. Btu numbers make comparative economic analysis of different energy systems easy because every energy resource can be measured on a Btu basis. One Btu is the amount of energy needed to raise temperature of one pound of water by one degree F. Typically, a match has about one Btu; a kilowatt hour of electricity has 3,412 Btu.

The energy content of a gallon of gasoline has from 115,000 to 120,000 Btu, depending on the blend, altitude, and time of year. Assuming the higher value of 120,000 Btu, if its production cost is $2.00 a gallon, it is equivalent to $16.60 per million Btu (MMBtu). By contrast, although natural gas prices in the U.S. in the 1990's was in the range of $2.00/MMBtu, the current supply problems have increased the natural gas prices in the U.S. to over $10.00/MMBtu. Moreover, natural gas prices are expected to continue increasing as the available reserves are exponentially consumed. As a rule, hydrogen costs from natural gas were about thee times the cost of the feedstock, thus $5.00 feedstock gas would result in the hydrogen costing $15.00/MMBtu, which is equivalent to gasoline costing about $1.80 a gallon. A gallon of liquid hydrogen has about 30,000 Btu, which explains why a liquid hydrogen tank is approximately four times larger by volume than a gasoline tank. However, on a weight basis, the numbers are 17,500 Btu per pound of gasoline and 52,000 Btu per pound of liquid hydrogen. Thus, even with the larger volume liquid hydrogen fuel tanks, Lockheed engineers calculated that the takeoff weight of a commercial aircraft would be reduced by over 40 % if liquid hydrogen was used instead of conventional aviation kerosene.

Wind Electric Systems

When hydrogen is made from the wind and water, the cost of electricity is one of the major factors in the cost of the hydrogen. Wind systems that cost $1,200 per kW generate electricity for about 4 cents per kW h, which less than any other solar technology, and even less than the electricity that is generated from new power plants fueled with natural gas, coal or uranium.

However, the cost of the gaseous hydrogen produced by the electrolysis of water from existing wind systems would be expected to cost approximately $6.00 per equivalent gallon of gasoline in the near term, and approximately $2.30 per gallon in the long term once the technology is refined. In the process of electrolysis, electricity is passed through water, which is then split into hydrogen and oxygen gasses. Existing electrolyzers are approximately 70% to 80 % efficient and have a capital cost of about $750-$1,000 per installed kW. Approximately 52.5 kW h and 2 gallons of water are needed to manufacture the energy content of a gallon of gasoline in the form of gaseous hydrogen. An additional 12 kWh is needed to liquefy the hydrogen. Once the capital cost, maintenance and profit are factored into the equation, the cost per equivalent gallon of gasoline (i.e., 1 kg) of liquid hydrogen will be approximately $5.86, assuming an electricity cost of 4.5 cents/kWh.

Hydrogen Production Costs From Mass-Produced Wind Systems

In 2004, the installed costs of wind systems were approximately $1,200 per kW. As such, a one megawatt system would cost $1.2 million. By 2006, however, installed wind system costs actually increased to approximately $1,700/kW, which is the result of higher oil prices and steel shortages due to China's increasing industrial demand. However, if wind-powered hydrogen production systems are mass-produced on a scale to displace oil and other fossil fuels, their capital costs are anticipated to be reduced to $400 to $600 per kW, depending on production levels. The electricity costs could then be reduced to approximately 1 to 2 cents/kWh, which will allow the liquid hydrogen to be produced by water electrolysis for approximately $1.78 per equivalent gallon of gasoline (egg). Delivering the liquid hydrogen by cryogenic trucks will increase the cost to approximately $2.00/egg. These costs do not include state or federal taxes or retail markups. However, additional cost per mile savings occur because hydrogen-fueled internal combustion engines are about 25 percent more fuel efficient, and they do not generate organic acids and carbon deposits, which contaminate the engine oil and reduce engine component life.

External Costs

External costs of fossil and nuclear energy systems include environmental damage and climate change, and the resulting billions of dollars in related health care costs that result from contaminating the global atmosphere and ocean ecosystems and forcing billions of families to live their lives breathing unhealthy air that causes breathing disorders, as well as drinking contaminated water and eating contaminated food that causes cancer, strokes and heart attacks. Other staggering external costs include the climate change issues that will destabilize global food production systems; the management and storage of radioactive wastes; the corrosion to buildings and bridges that occurs from acid raid; and the military costs of protecting the remaining oil reserves in the Middle East and elsewhere.

If these external costs of using fossil and nuclear fuels were factored into the costs that consumers pay, the cost of gasoline and electricity would be easily increased by a factor of 2 or 3. Factoring in carbon sequestration costs alone are expected to increase the price of a gallon of gasoline by 80 cents, based on CO2 sequestration costs of $100 per ton. Moreover, the sequestration of carbon is a short-term stop gap measure. Experts in the field point out that within 50 years, the sequestrated carbon will escape into the atmosphere. Thus if such costs were included in energy costs, solar sourced hydrogen would be the least expensive fuel. Moreover, unlike wind and wave hydrogen production systems, which will always be less expensive in the future as more and more engineers refine the technology, gasoline and other hydrocarbon fuels will only get more expensive with time as the global fossil fuel reserves are exponentially depleted. This underscores why the longer the transition to a renewable hydrogen economy is delayed, the more expensive it will be to implement.

Fair Accounting Act

What is not taken into account are the "external costs" of using fossil and nuclear energy systems, which include environmental damage, healthcare and military costs of protecting the remaining oil reserves. If these costs were factored into fuel costs, the cost of gasoline would be easily increased by a factor of 4 or 5.

Factoring carbon sequestration alone will increase the price of gallon of gasoline by 80-cents per gallon, based on CO2 sequestration costs of $100 per ton. As such, the "trigger mechanism" for the "transition of substance" to a solar hydrogen economy is the passage of Fair Accounting Act legislation by the U.S. Congress. This legislation would transfer subsidies to fossil and nuclear fuel systems to renewable hydrogen systems, and factor in the external environmental, healthcare and military costs of using fossil and nuclear energy sources.

If a "fair" accounting system is used, taxes on a gallon of gasoline could easily be increased by at least a $1.00 a gallon, which would then make hydrogen competitive with gasoline and other hydrocarbon fuels. Moreover, the funds raised by the Fair Accounting Act could then be returned to consumers in the form of a tax credit to defer the cost of modifying their existing vehicles to use hydrogen fuel. It is important to note that as the fossil fuels are phased-out, so will the carbon tax that would be imposed by the Fair Accounting Act.

Thus tax policy profoundly impacts energy, economic, environmental and foreign policies. While no one can accurately place an economic value on such external cost factors, there can be no doubt that the numbers are in the trillions of dollars. Individual oil and energy companies will never factor in the external costs of using fossil and nuclear fuels because if they did so, without the cooperation of their competitors, they would soon be out of business. Only the democratically elected federal and state governments have the authority to insure that the external costs of using fossil and nuclear fuels will be fairly assessed for all energy companies. If such external cost considerations are excluded from the economic calculations, gasoline may be less expensive than hydrogen until oil and other fossil fuels are further depleted, but even that assumption needs to be carefully examined.

Fuel Cell Considerations

Many industry and legislative analysts make the assumption that before hydrogen can to be used on a large-scale, fuel cells will need to replace the internal combustion (IC) engines that now power the global industrial economy. Fuel cells have allowed automotive engineers to essentially reinvent the automobile, and provide an exciting vision of the future. But while fuel cells may someday replace the IC engines, they are at present far too expensive. According to General Motors, even if their current fuel cell vehicles were placed into high-volume production, the cost of the 100 kW fuel cell stack alone would be between $50,000 and $100,000. Part of the problem is that existing proton exchange membrane (PEM) fuel cells require platinum catalysts, and if the fuel cells were manufactured on a scale to replace IC engines, the worldwide platinum production would have to be increased by a factor of 30. Unlike oil, hydrogen is inexhaustible if it is made from water with renewable energy sources, thus it is not necessary to "conserve" hydrogen. As such, consumers do not need to drive small vehicles with small fuel efficient engines. Indeed, given that the hydrogen fuel tanks will be about four times larger by volume than gasoline tanks, in the coming Hydrogen Age, bigger is better.

Modifying Internal Combustion (IC) Engines

It is important to note that hydrogen is the only "universal fuel," that can power not only fuel cells, but virtually any existing internal or external combustion engine or appliance, including SUVs, hybrid electric vehicles, trucks, aircraft, ships, spacecraft, or a Coleman stove on a mountain-top.

According to BMW and Ford, hydrogen-fueled IC engines have been shown to be about 25 % more energy efficient than their gasoline-fueled counterparts, which form carbon deposits and organic acids that contaminate the engine oil and thereby increase wear and corrosion of the bearing surfaces. Since hydrogen-fueled engines produce no carbon deposits or acids, they will be clean machines that will require less maintenance and have a significantly longer operating life. BMW has been modifying IC engines to use hydrogen and developing cryogenic liquid hydrogen storage systems for vehicles since the 1970s. The only noticeable difference in the fifth generation of hydrogen fueled cars is that they have two fuel caps, one for gasoline and one for liquid hydrogen. BMW engineers point out that if liquid hydrogen fuel storage systems are used, which are similar to gasoline in terms of weight and volume, drivers will not have to give up vehicle size, performance or range.

Liquid hydrogen is a low-temperature (-253 °C) cryogenic liquid, and even the most advanced vacuum-jacketed double-walled storage tanks allow some heat to vaporize 2 to 3 % of the hydrogen per day. As the liquid vaporizes, it creates pressure on the tank, which must then transfer the expanding gaseous hydrogen either to a small burner (so that a combustible gas is not released into an enclosed space); or to a fuel cell on board the vehicle which can then generate electricity.

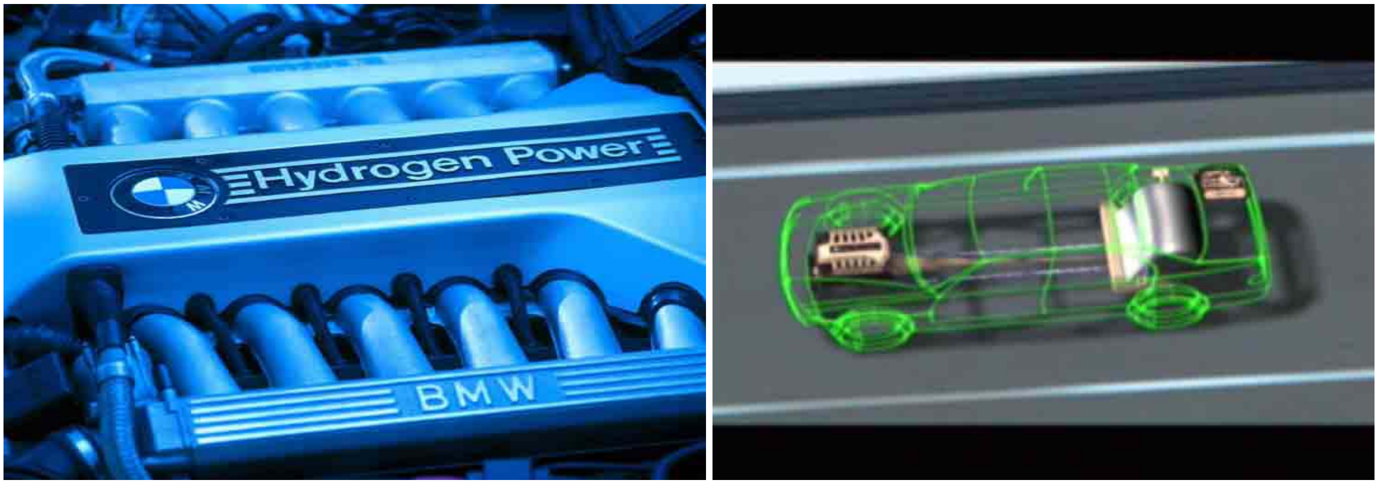


Figure 4. The BMW V-12 engine (upper left) is able to operate on gasoline or hydrogen with the flip of a switch from inside the vehicle.

What is generally not known is that engineers in Germany and England first began investigating the use of hydrogen as an automotive fuel in the early 1900s, and by the 1930's, literally thousands of hydrogen-fueled vehicles were in operation in the two countries. One of the principal engineers that made this possible was Rudolf Erren, a German engineer who developed a fuel injection system that allowed the hydrogen to be fed directly into the cylinder, thereby eliminating the carburetor, which was poorly suited to inject a gaseous fuel. The remaining engine components were unchanged, thus the conversion cost was relatively small, and the vehicles were able to operate on either hydrogen or other hydrocarbon fuels while in operation with the flip of a switch from inside the vehicle. All major engines in use at the time were modified, including those manufactured by MAN, Daimler-Benz and Beardmore.

In World War II, the Allies captured a German submarine that used hydrogen to power both their Errenized "trackless" diesel engines and torpedoes. Conventional fuels leave tracks, which are a trail of exhaust bubbles, but when only hydrogen and oxygen were combusted in the engine, the resulting water vapor condensed into the seawater, thus no bubbles were formed that would drift to the surface for a giveaway trail. During surface operation, the submarine's diesel engines also powered an electrolyzer, which separated water into hydrogen and oxygen. These gases were then stored under pressure until needed when the submarine was diving or running submerged. The hydrogen-fueled submarine eliminated the need for large heavy batteries and electric motors needed for underwater operation. The weight and space savings allowed the submarines range to be extended by 15,000 miles and because the hull was strengthened, the vessel was able to dive deeper and faster.

In the 1980s, a self-service liquid hydrogen pump was used by Los Alamos National Laboratory investigators to refuel a modified 1979 Buick. After using this system for over a year, the Los Alamos investigators, headed up by Walter Stewart, concluded in their final report that "liquid hydrogen storage and refueling of a vehicle can be accomplished over an extended period of time without any major difficulty." American engineer Roger Billings started modifying vehicles to operate on hydrogen when he was in high school. He eventually modified a wide-range of vehicles, including a Model A Ford and in the 1970's, he modified a Cadillac Seville and Jacobson tractor, as part of a Hydrogen Home that had all of its appliances using hydrogen, including a portable Coleman camping stove for cooking dinner on a mountain top.

Modifying Existing Aircraft To Use Liquid Hydrogen Fuel

Because of its low energy density, gaseous hydrogen is not a practical storage option for most automotive applications, especially in weight critical aircraft. However, if the hydrogen is cooled to a cryogenic liquid, it then has the highest energy content per weight of any fuel. One of the first proposals to use liquid hydrogen (LH2) fuel for aircraft was detailed in 1938 by Igor Sikorski, who later founded Sikorski Aircraft, and it was found that with LH2, the fuel flight efficiency would roughly double, thus the effective range of an aircraft could also be doubled compared to using the same weight of conventional hydrocarbon fuels.

A U.S. Air Force B-57 bomber pictured below was the first U.S. aircraft to be modified to use liquid hydrogen fuel in one of its two engines for testing purposes (Figure 5). The modification was undertaken in cooperation with NASA in 1956.

Figure 5. A U.S. Air Force B-57 bomber modified by NASA to use liquid hydrogen fuel in one of its two engines for testing purposes.

Lockheed Liquid Hydrogen (LH2)-Fueled Commercial Aircraft

Ongoing studies by the U.S. Air Force and Lockheed Missiles and Space Company in the 1960s and 1970s concluded that of all of the available fuel options for military and commercial aircraft, liquid hydrogen was the clear choice based on fuel availability, emissions, safety, cost and performance.

in addition to hydrogen's favorable fuel efficiency and significant safety characteristics, liquid hydrogen-fueled aircraft would also dramatically minimize air pollution and the aircraft would be approximately 40 percent lighter on takeoff, and they would be quieter; require smaller wing areas and shorter runways. In addition to evaluating advanced aircraft designs, Lockheed engineers also examined the feasibility of modifying existing commercial aircraft, such as the commercial L1011 that is shown below in Figure 6.

In order to accommodate the larger liquid hydrogen H2 fuel tanks, which are about 4 times larger by volume than hydrocarbon fuel tanks with the same energy content, the Lockheed engineers proposed placing the cryogenic hydrogen tanks in the fuselage of the aircraft, which makes the aircraft longer, but this design approach does not increase drag that would result in wing tanks or other exterior design options. By placing the highly-insulated liquid hydrogen fuel tanks (which are referred to as Dewars) in the fuselage between the flight crew and the passengers, this would also make the plane virtually impossible to hijack from the passenger compartments.

Lockheed also designed a new generation of much larger commercial aircraft shown in Figure 8 that would be optimized for liquid hydrogen fuel from the ground up. Moreover, both McDonnell Douglas and Boeing have been developing a liquid hydrogen-fueled aerospace plane to replace the Space Shuttle, which could take off and land like a conventional aircraft on conventional runways is intended.

Lockheed Engineers Proposal in the 1970s to Modify Existing Aircraft to use Liquid Hydrogen Fuel

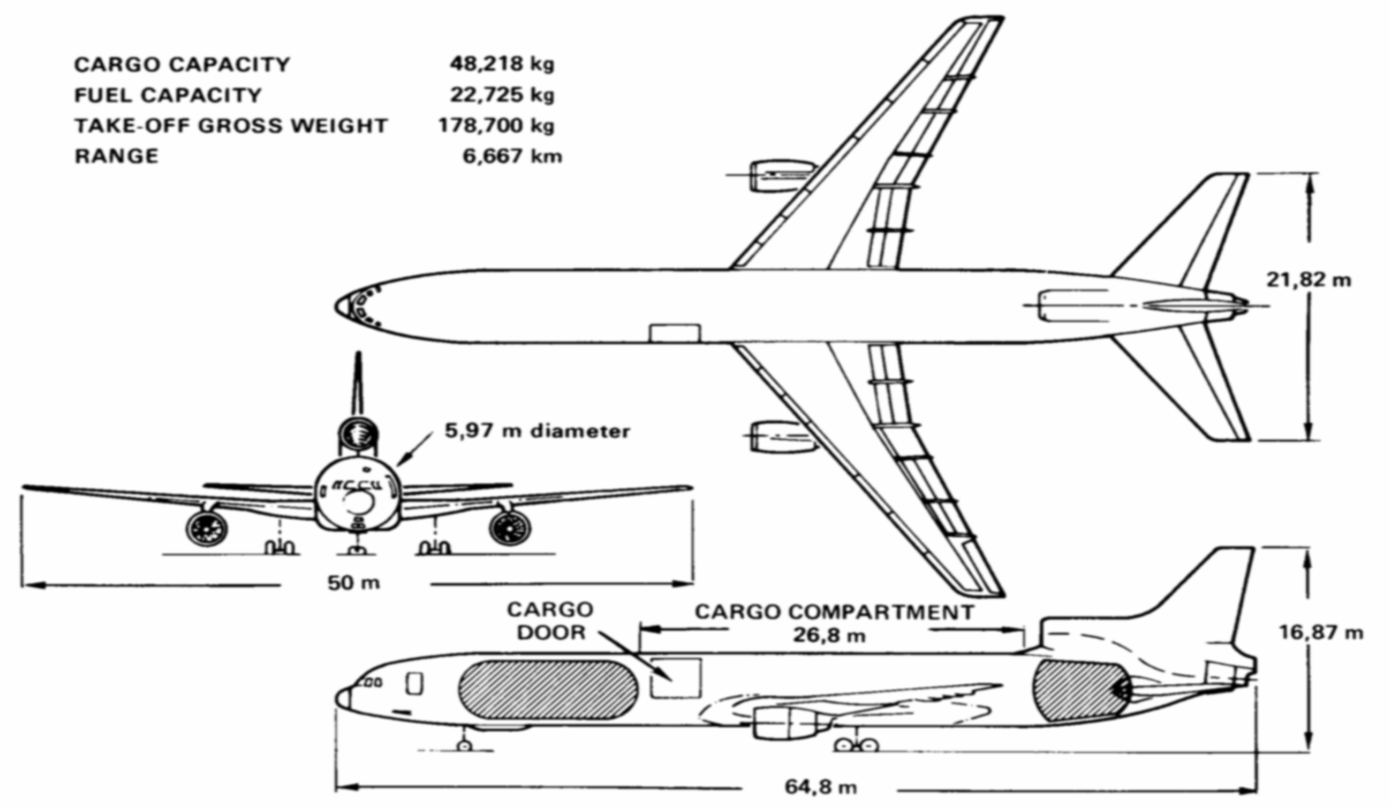


Figure 6. A cutaway of a Lockheed L1011 aircraft modified to use liquid hydrogen fuel, which is stored in the shaded areas of the fuselage.

Figure 7 (upper left) shows an artist's concept of a Lockheed liquid hydrogen-fueled aircraft being refueled from two spherical LH2 storage tanks shown in the distance. Figure 8 (upper right) shows an advanced Lockheed LH2 fueled aircraft design that is fully optimized to take advantage of the use of LH2 fuel.

The Hindenburg

Figure 9. The Hindenburg

A question that often comes up is: “Don’t you remember the Hindenburg?” Indeed, according to the accident report and the film of the event, the Hindenburg did not explode, but rather caught fire, and as the fire spread, the airship fell slowly enough for two-thirds of the passengers aboard the Hindenburg (62 people) to survive the accident. Of the 35 people who died, 33 of them jumped from the Hindenburg and they died from the fall. Two people were burned to death, but it was not from the hydrogen – but the large tanks of diesel fuel that was used to power the Hindenburg’s Diesel engines.

The Hindenburg was large enough to hide a 747 commercial aircraft under its tail section, and in spite of the vast quantities of hydrogen that was used as a lifting gas for the Hindenburg, no one in the accident was seriously injured or burned to death from hydrogen, which being the lightest element in the universe, rapidly dissipated up and away from the passengers once the initial ignition event occurred from static electricity igniting the highly combustible aluminum paint that was used to protect the exterior surface of the Hindenburg from ultraviolet radiation from the sun. With conventional hydrocarbon fuels like gasoline or diesel fuel, the hydrogen is chemically bonded to relatively heavy carbon atoms, which causes the fuel form explosive mixtures and stick to people like glue and literally burn their skin off.

Thus, the real lesson from the Hindenburg is how safe hydrogen is if an accident is going to occur. It is also rarely mentioned that prior to its fatal crash in 1937, the Hindenburg had successfully completed ten round trips between the United States and Europe, and its sister ship, the Graf Zeppelin, had made regular scheduled transatlantic crossings from 1928 through 1939 with no mishaps. Indeed, of the 161 rigid airships that were built and flown between1897 and 1940 (nearly all of which used hydrogen as a lifting gas), only 20 were destroyed by fires. In addition, of the 20, 17 were lost in military incidents that in many cases resulted from hostile enemy fire during the first World War, which was an excellent safety record for the technology of the day.

Liquid Hydrogen Rocket Fuel

Because liquid hydrogen has the greatest energy per weight of fuel, the U.S. Army and Air Force began investigating using liquid hydrogen and oxygen as a rocket fuel in 1943 in cooperation with investigators at Ohio State University. As a result of this ongoing effort, liquid hydrogen was eventually used to fuel the second and third stages of all of the Apollo moon rockets as well as the current fleet of Space Shuttles, whose three main rocket motors mounted on its tail are fueled at launch by the large primary orange fuel storage tank that contains the liquid hydrogen and oxygen.

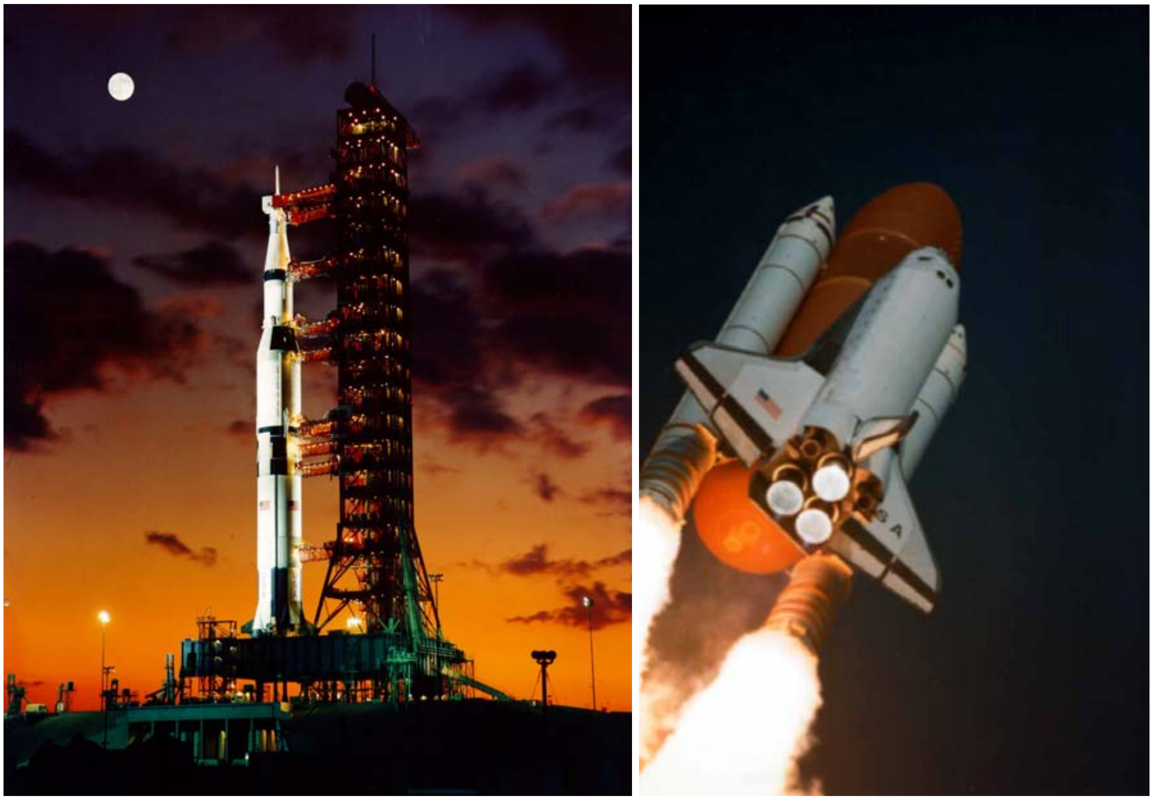


Figure 10 and 11: Saturn V Moon Rocket & Space Shuttle

The Saturn V moon rockets all used hydrogen to fuel the second and third stages. In the case of the Space Shuttle (upper right) note the smoke-free, almost invisible light-blue hydrogen flame that is emitted from the three hydrogen-fueled engines mounted on the tail of the Space Shuttle. This is in contrast to the highly-toxic emissions that are generated from the powered aluminum fuel used in the two solid rocket boosters that are mounted on the sides of the Shuttle.

Because liquid hydrogen has the greatest energy per weight of fuel, the U.S. Army and Air Force began investigating using liquid hydrogen and oxygen as a rocket fuel in 1943 in cooperation with investigators at Ohio State University. As a result of this ongoing effort, liquid hydrogen was eventually used to fuel the second and third stages of all of the Apollo moon rockets as well as the current fleet of Space Shuttles, whose three main rocket motors mounted on its tail are fueled at launch by the large primary orange fuel storage tank that contains the liquid hydrogen and oxygen.

NASA engineers initially wanted the launch vehicle to be reusable. It would also be fueled with liquid hydrogen and have a crew of its own to fly the vehicle back after it had launched the Shuttle. Budget considerations, however, resulted in using the SRBs instead. It is worth noting that when the Challenger exploded, it was not due to the hydrogen that caused the mishap, but the failure of the O-rings in one of the two solid rocket boosters.

Paul M. Ordin, a research analyst working for NASA, reviewed 96 accidents or incidents involving hydrogen. NASA had transported more than 16 million gallons of liquid hydrogen for the Apollo-Saturn program alone, and while most mishaps were of a highly specialized nature, there were five serious highway accidents that involved extensive damage to the liquid hydrogen truck transport vehicles. These accidents were such that if conventional gasoline or aviation kerosene had been involved, a spectacular explosion and blaze would have occurred and burned for hours, causing considerable collateral damage. But due to the physical characteristics hydrogen, none of the accidents resulted in either an explosion or fire. This data underscores that hydrogen is much safer than gasoline or other hydrocarbon fuels in the event of leaks or accidents.

Conclusions

The issues outlined in this paper underscore that the focus on consuming the remaining fossil and nuclear fuels and converting food crops such as corn to biofuels is unsustainable and wastes both time and money, which are both in short supply, while creating a whole new dimension of long-term economic and environmental problems. Since the National Academy of Sciences in the U.S. has stated that the use of fossil fuels is in the final stages of making the earth uninhabitable, this energy change needs to be implemented with wartime-speed and be essentially completed by 2020, which is why it is critical that the public be made aware of the only plan that can accomplish this “transition of substance” while there is still time to make a difference.

If there is a better solution, lets evaluate it. If not, lets get on with the task of implementing the Phoenix Project plan for implementing a Solar Hydrogen Economy with wartime speed, which will then provide sustainable prosperity without pollution worldwide, with a fuel that is inexhaustible. Because of the late phase of the Exponential Age in which we now live, both the problems mass-producing wind systems is the quickest path to implementing a solar hydrogen energy system. The 10 million 1 MW wind machines that would be needed to generate all of the U.S. current energy requirements (i.e., 105 quadrillion Btu) could be mass-produced in less than 12 months once the tooling is in place. As such, the remaining 30 million units to power the rest of the world could be operational by 2020.

As such, it is possible for the U.S. and other countries to be energy independent, and essentially pollution-free by 2020. That would include the deployment of superconducting hydrogen pipeline systems that would carry both electricity as well as hydrogen, as well as the modification of all of the automotive vehicles and power plants so they could use either hydrogen or conventional hydrocarbon fuels with the flip of a switch. Such a transition of substance will have profound implications for the global economy and the environment. The fossil fuels are like the battery in an automobile. There is enough stored energy in the battery to start the main engine, but if one tries to propel the vehicle on the stored energy in the battery alone, one is not going to get very far. After a certain point, the global oil reserves will be quickly depleted, which will result in sharp price increases. As such, the longer this “transition of substance” is delayed, the more expensive it will be.

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Harry W. Braun III

Analyst, Author & CEO

Harry Braun is Chairman and CEO of the Phoenix Project Foundation (PhoenixProjectFoundation.US), a nonprofit, scientific educational organization that is focused on educating the general public about the importance of shifting to a Solar Hydrogen Economy with wartime-speed. For the past 30 years, Braun has been an Advisory Board Member of the International Association for Hydrogen Energy (iahe.org), which has several thousand PhD level scientists and engineers as members from over 45 countries. Braun has been CEO of Sustainable Partners International (SPI) since 1994, and has worked with McDonnell Douglas, Boeing, Kockums, Sandia National Laboratories and the U.S. Department of Energy to refine and commercialize solar Dish Stirling systems, which have held the world's efficiency record for solar thermal systems since the 1980s. Braun's firm was also the initial developer of a $150 million wind farm project in New Mexico, which was completed in 2005, at which point it was acquired by Edison Mission Energy.

Braun is the author of numerous technical papers, which are posted on the Phoenix Project Foundation website, as well as *The Phoenix Project: Shifting from Oil to Hydrogen*, a 360-page book that was first published in 1990 and updated in 2000, which provides a scientific overview of the origin of matter and life in the known universe, how the "big bang" created hydrogen atoms, which gravity condensed into the stars, which then emitted the electromagnetic spectra that served as the spark for the origin and evolution of life on the Earth. The book documents how the microorganisms on the primitive earth were exponentially exhausting the hydrogen they were extracting from hydrocarbon molecules in the primordial soup. In order to avoid extinction, the microbes figured out how to extract hydrogen from water with solar energy (i.e., photosynthetic green plants), a process that has been successfully working on a global scale for over 3 billion years.

The primary emphasis of Braun's book, however, is to provide a technical analysis of how the U.S. and other countries can rapidly shift from non-renewable fossil and nuclear fuels to renewable solar hydrogen production systems, which will resolve many of the most serious economic and environmental problems. The book reviews both the positive and negative aspects of exponential growth, which explains why humanity is on the threshold of both a technological "utopia" of molecular medicine as well as an ecological "oblivion" of mass-extinctions, which are already well underway. It is why we on *Spaceship Earth* are all like passengers aboard the *Titanic*, and there is only a limited amount of time left to "change course." Although hydrogen is often mentioned as the "Holy Grail" of sustainability and indeed all energy sources, Braun is still the only technical analyst who has provided a specific plan for how this "transition of substance" can happen by 2020, by mass-producing wind and other solar powered hydrogen production systems and modifying every existing vehicle and power plant to use hydrogen.

Braun ran for Congress in 1984 against John McCain in Arizona in order to promote his 5-year plan to shift to a Solar Hydrogen Economy and sustainable agricultural systems, and in 2005 he founded the Phoenix Project Political Action Committee (PhoenixProjectPac.US), which is focused on organizing an Article V Constitutional Convention to pass several Constitutional Amendments, including a Fair Accounting Act, which is the "trigger mechanism" for implementing a Solar Hydrogen Economy because it would factor in the environmental and healthcare costs of using fossil and nuclear fuels, thereby providing the financial incentives for oil and other energy companies to shift trillions of dollars investments from fossil and nuclear fuels to wind and other solar hydrogen production systems. The other critical amendment is a Democracy Amendment that would shift the power from lobbyists in the U.S. Congress to the majority of citizens who would be empowered to approve all legislative and judicial decisions that affect the majority.