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Hydrogen Revolution: Growth, Jobs, Security & Sustainability

"The worldwide hydrogen energy web will be the next great technological, commercial, and social revolution in history."
— Jeremy Rifkin, *The Hydrogen Economy,* 2003

Will the hydrogen fuel cell replace the internal combustion engine, and is it useful beyond transportation? *Yes.*

- The replacement could start to happen within 10 years, if we begin the transition to the new energy economy today.
- All major car manufacturers already have advanced hydrogen fuel cell programs underway.
- The hydrogen fuel cell cleanly converts H_2 + O_2 into electricity + H_2O, for vehicles, businesses, and homes.
- Critics view the challenges as hydrogen fuel cell cost, and hydrogen production, distribution, safety, and storage.

The Hydrogen Racer

You may think that hydrogen power is some futuristic fantasy, fit only for science fiction writers like Jules Verne in his novel *Mysterious Island*. Or, at best you might consider it a viable technology that won't be ready for prime time for another 40 to 50 years. If so, think again. In a special edition on "Best Inventions 2006," *Time* magazine praises the decision by Shanghai-based Horizon Fuel Cell Technologies "to design and market the H-racer, a 6-inch-long toy car that does what Detroit still can't. It runs on hydrogen extracted from plain tap water, using the solar-power hydrogen station."[1]

Hydrogen vehicles are not mere toys. There are more than 500 now on the road. A BMW prototype with a hydrogen internal combustion engine attained a top speed of 186 mph. Mazda, Ford, Honda, and GM are developing a variety of hydrogen-powered engines: fuel cell, internal combustion, and Wankel. Perhaps most exciting, Honda is now powering vehicles with hydrogen derived from tap water in small stationary units that drivers can keep in their garages.

Honda's 80-hp experimental 2005 FCX fuel cell car is already being tested on public roads in Los Angeles, along with a second-generation hydrogen home energy station. In February 2007, Honda reported:

> With an EPA city/highway rating of 62/51 miles per kilogram (mpkg) (57mpkg combined) and an EPA-rated driving range of 190 miles, the hydrogen-powered FCX delivers nearly a 20% improvement in fuel efficiency and range versus the 2004 model . . . . In terms of energy efficiency, one mpkg of hydrogen is almost equivalent to one mile per gallon (mpg) of gasoline. The hydrogen-powered Honda FCX has been certified by CARB as a Zero Emission Vehicle and by the EPA [with] the lowest possible national emission rating.[2]

Since this announcement was made, Honda has stated its intention to sell production models of the car in 2008, with maximum ranges of 350 miles and speeds of 100 mph. Honda has also announced the development of advanced photovoltaic (PV) cells and an electrolysis unit that are mounted on the company's solar-cell powered hydrogen refueling station in Torrance, California. This technology is the primary engine for performing electrolysis, the process that separates the pure hydrogen from water. Let's remember that some 10-15 years ago, when the Japanese carmakers committed themselves to commercialize a hybrid car, Detroit was snickering that they must be joking! And now GM, Ford and others are playing catch-up hoping to someday compete with the likes of Honda and Toyota in hybrid technology that was in great part developed at Stanford University!

We believe the current rapid pace of invention, testing, and commercialization of fuel cell technologies is a sign of the early stages of the hydrogen revolution. By starting today, instead of waiting half a century as critics suggest, the large-scale commercialization of hydrogen fuel cell cars can begin very soon.

Hydrogen: The Next Energy Economy

We have come to a crossroads where a single, courageous decision by a few world leaders can fundamentally alter the course of history. That decision is to shift from our dependence on rapidly depleting, increasingly costly, and environmentally challenging fossil fuels to a plentiful, renewable, and clean-burning hydrogen economy.

Hydrogen is by far the most abundant energy molecule in the universe. Perhaps that fact can serve as a reminder to us of the energy source we should be tapping.

Hydrogen can be thought of as a gaseous form of electricity. Anything that electricity can do, a hydrogen fuel cell with a hydrogen supply can do as well. However, while electricity can be stored only in batteries and capacitors that have a very low energy density (energy per unit of weight), hydrogen can be stored in any container from an industrial tanker to an automobile gas tank. With advanced hydrogen storage technologies, plus water, an electrolyzer, and a renewable source of energy, in the near future cars, homes, and businesses will become independent power producers that can generate electricity and sell it to the grid. The grid will increasingly become a distribution system for many producers of electrical power. It will serve the homeowner who produces excess power just as effectively as it does a large utility plant dedicated to power production.

False Fears: Past American administrations, while recognizing that hydrogen may be important in the future, assumed that the orderly transition to hydrogen would require an implementation plan that spanned four or five decades. This forecast rests on two false assumptions. The first is that there will be sufficient supplies of cheap oil for the foreseeable future. The second is that even if oil prices increase significantly, new discoveries and fossil fuel technologies will fill the gap, creating at most, modest global dislocations.

Many critics and energy experts outside government believe these false assumptions about oil and think that "hydrogen won't fly" or that it will be viable only far in the future. This view is based on a series of common misconceptions about the cost, efficiency, technology, and history of hydrogen. Hydrogen is the energy source that flew the Apollo Project to the moon. It was chosen over other energy sources because of its numerous advantages, including its higher efficiency per unit of mass. When used as a power source, hydrogen produces only three things: power, pure water, and extremely small quantities of nitrogen oxides. The latter is so small that fuel cell vehicles are considered zero-emission vehicles. Thus, it is non-polluting and non-corrosive. While flammable, hydrogen burns at a low temperature and generates low radiant heat. It is more difficult to explode than most people realize because it dissipates into the atmosphere rapidly.

Enormous Potential. Basic scientific facts and economic realities create a compelling case for hydrogen's role as the centerpiece of the world's next energy economy for the following reasons:

- Except for hydrogen, there is no other clean, sustainable, and technologically-available energy *carrier*.
- Hydrogen does not contribute to global warming.

- While hydrogen is still expensive to create, when combined with fuel-cell technology, it generates more than twice as much energy as oil, and is therefore economically viable even at oil prices of $60/barrel.
- A hydrogen economy would allow America to achieve long-lasting energy freedom and independence from foreign oil.
- Hydrogen can be used to power any machinery in either stationary applications (homes and offices) or mobile applications (cars and trucks).
- In the long-term, the hydrogen fuel cell can replace the internal combustion engine and catalyze Detroit's economic renaissance and international economic growth.
- Hydrogen can be generated from natural gas and eventually from water via local, decentralized energy systems, removing the costs and risks of fuel distribution associated with fossil fuels and nuclear power.
- As an inexhaustible source of clean energy, hydrogen will enhance human health, protect the environment, and increase energy equality.

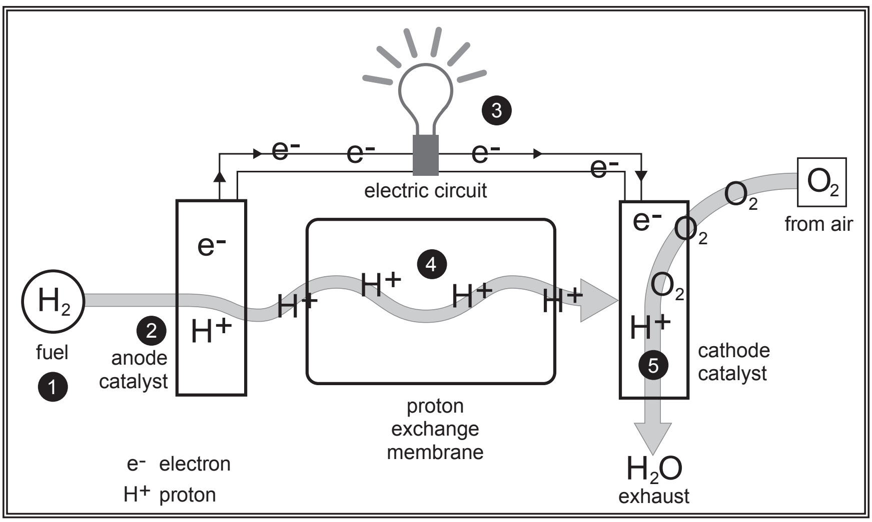
The Hydrogen Fuel Cell: How it Works

The hydrogen fuel cell is one of the simplest technologies for generating electricity. Electricity is essentially a stream of electrons. The hydrogen atom, comprised of one proton and one electron, is the lightest and most plentiful element in the universe. As Figure 1 shows, a hydrogen fuel cell uses an electro-chemical process, as opposed to the thermal-chemical process used in the internal combustion engine, to separate the electron from the proton; uses the electron to create electricity; and then combines the hydrogen with oxygen to make H_2O. Over 99% of its exhaust is ultra-pure, drinkable water. Since the hydrogen fuel cell has no moving parts, it is quiet, clean, and highly efficient.

Hydrogen can be transformed to generate electricity through five steps:

1. The hydrogen is ionized by placing a stream of hydrogen and oxygen at the anode and cathode catalytic electrodes, respectively, of the fuel cell.
2. On the anode catalyst, hydrogen is separated into protons and electrons.
3. The electrons are forced to travel an external path, thus supplying electricity.
4. The protons pass through the proton exchange membrane.
5. On the cathode catalyst, oxygen reacts with the electrons and protons to create water exhaust and some heat.

Figure 1. How A Hydrogen Fuel Cell Works
$2H_2 + O_2 =$ Electricity + $2H_2O$



Source: World Business Academy Energy Task Force

Currently, both the anode and the cathode are coated with an ultra-thin, finely-dispersed platinum surface, which is the most expensive component in the manufacture of hydrogen fuel cells. Other types of fuel cells can use diesel, methanol, and chemical hydrides to separate electrons and create electrical power. However, on a "well-to-wheels basis," these fuels cells will generate more carbon dioxide than the "classic" hydrogen-oxygen fuel cell.

To increase the output of electricity, a series of fuel cells are linked together, creating a fuel cell stack. Since a single fuel cell produces only about one volt of electricity, fuel cells are typically layered and combined in parallel circuits. The number of cells in a fuel cell stack is typically 45, but designs and capacity vary.

The efficiency of fuel cells vastly exceeds that of the internal combustion engine due to the fuel cells' relative independence from the thermodynamic, heat transfer limitations known as the Carnot cycle. In the process of generating power, a conventional thermal engine such as the internal combustion engine loses much more energy than a hydrogen fuel cell. Therefore, hydrogen fuel cells boast very high efficiencies in their ideal state of low power density (supplied by using fuel cell stacks), when using pure hydrogen and oxygen as reactants. If a fuel cell uses the common air we breathe as its source of oxygen, its efficiency drops slightly.

Diminishing Costs of Fuel Cell Technology. The high cost of manufacturing hydrogen fuel cells is falling at a rate that any other technology would envy. In 2002, the average fuel cell had a price tag for its catalyst content of $1000 per kilowatt of electric power. This was projected to drop by 2007 to $30[3] per kilowatt. Here, Ballard Power Systems (NASDAQ: BLDP) one of the world's foremost major manufacturers of Proton Exchange Membrane fuel cells, is experimenting with platinum supported on carbonized silk catalysts that would reduce platinum usage by 30%, with no reduction in performance.

Hydrogen's Critics Are Wrong

Seventy-five percent by weight of all matter in the universe is made up of hydrogen. On earth, it is ubiquitous, most typically bound up in water, natural gas, and coal. It can be stored as a gas or a liquid and can power anything from a car to a building to an ocean liner. Hydrogen has the potential to supply the world with relatively inexpensive, clean, renewable energy, and thereby stabilize the economy and the environment.

Several standard college text books on energy either ignore hydrogen completely or give it only cursory treatment before dismissing it as a significant potential source of renewable energy.[4] Currently, the perception of hydrogen's potential is clouded by numerous myths and misconceptions voiced by naysayers, whose critiques must be addressed.

Examples of Hydrogen Naysayers. Some well-informed energy experts contend that hydrogen will be viable only after 20 to 30 years of development. For example, Paul Roberts, author of the widely-acclaimed, *The End of Oil*, argues that, "Hydrogen fuel cells and a ready supply of hydrogen to fuel them are still decades away from mass deployment."[5]

Similarly, Dr. Lester Brown, a world-renowned environmental scientist and a Fellow of the World Business Academy, contends that, "Unlike the widely discussed fuel cell/hydrogen transportation model, the gas-electric hybrid/wind model does not require a costly new infrastructure, since the network of gasoline service stations and the electricity grid are already in place."[6]

The Worldwatch Institute, too, holds this view, noting that "Despite recent public attention about the potential for a hydrogen economy, it could take decades to develop the infrastructure and vehicles required for a hydrogen-powered system."[7]

Richard Heinberg, author of *The Party's Over* and *Power Down*, writes that, "At this point, much of the enthusiasm about hydrogen seems to be issuing from politics rather than science."[8]

Joseph Romm, a leading hydrogen critic and author of *The*

Hype About Hydrogen, states that, "Hydrogen vehicles are unlikely to achieve even a 5% market share by 2030."[9]

In our view, these predictions are needlessly pessimistic, and the last is off by at least a decade. In fact, more than 250,000 recently commercialized hybrid electric vehicles were sold in 2006, and sales are expected to grow by over 226% between 2005 and 2012.[10] If America makes hydrogen a national priority, we know the first commercially available hydrogen internal combustion engines will be BMWs delivered by late 2007, and we foresee the first affordable hydrogen fuel cell cars coming to market starting in 2010-2012, together achieving 5% new car market share by 2020 or earlier.

Most of these criticisms can be reduced to a question of the timing of the economic viability of hydrogen fuel cell cars, rather than the viability, availability, or cost of the technology. They are encapsulated in Paul Roberts's assertion that "a self-sustaining fuel cell car industry is, at best, at least two decades away, and probably more—too long to wait to begin reducing our automotive emissions or energy use."[11]

Unlike the critics, we believe that, if we simultaneously implement the Prometheus Plan and the strategy for launching the U.S. hydrogen economy outlined below, then the widespread commercialization of hydrogen as a fuel source in cars, homes and businesses will be well underway by 2010. We reiterate that the oil savings that will accrue from the Prometheus Plan are *in no way dependent* on hydrogen technology. We see the freedom from Middle East oil as only a beginning. Therefore, this plan includes the outlines for a Beyond Prometheus Strategy, in which hydrogen is the core initiative.

Eight Hydrogen Myths

Let's examine the facts about actual hydrogen usage and then analyze the critics' misconceptions about viability, availability, or cost of the technology. The most elegant and comprehensive rebuttal to these criticisms appears in World Business Academy Fellow and energy guru Amory Lovins' 2003 paper, "Twenty Hydrogen Myths."

We have consolidated his main insights below in order to address the most significant misconceptions about hydrogen.[12]

- About 75% of the known universe is comprised of hydrogen, which unlike oil, coal, wind, or sun, is not an energy source. Rather, it is an energy carrier, like electricity or gasoline.
- As an energy carrier, it needs to be freed from the chemical compounds, such as water or natural gas, into which it is bound.
- Fossil-fuel molecules are combinations of carbon, hydrogen, and other atoms. The debate centers on whether it is cheaper and more beneficial to burn the remaining carbon or simply to free and use the hydrogen.
- Using hydrogen as a fuel yields only water and traces of nitrogen oxides. This shift can significantly reduce pollution and climate change.
- Hydrogen is the lightest element in the universe. Per unit of volume, hydrogen contains only 30% as much energy as natural gas when both are at atmospheric pressure. Thus, hydrogen is most advantageous where lightness is worth more than volume, which is true for most transportation fuels.

One of the biggest challenges in addressing criticism of hydrogen is to compare hydrogen fairly and consistently with other energy carriers. For example, fuel cells, as electrochemical devices, are not subject to the same thermodynamic limits as gasoline-driven engines, which do their work by generating heat. As a result, "You can drive several times as far on a gallon-equivalent (in energy content) of hydrogen in a fuel-cell car as on a gallon of gasoline in an engine-driven car."[13]

Myth #1: An entire hydrogen industry needs to be developed from scratch.

The production of hydrogen is already a large, mature industry, and new technology will allow the average consumer to power his or her home and car from the garage. Currently, the global hydrogen industry annually produces 50 million metric tons of hydrogen, worth about $150 billion. That's the same as 170 million tons-equivalent of oil. U.S. hydrogen production alone accounts for at least one-fifth and probably nearer one-third of the world total. To put it in perspective, the current global output of pure hydrogen has the energy-equivalence of 1.2 billion barrels of oil, or about a quarter of U.S. petroleum imports.[14]

Hydrogen production is now centralized, primarily because hydrogen usage is centralized. In the future, usage will become decentralized, leading to a demand for a distributed hydrogen production system. The growth of a distributed network of small "reformers" which extract hydrogen from natural gas or electrolyzers (which extract hydrogen from water) will easily support this demand. Initially the reformers or electrolyzers can operate on the excess power capacity of existing gas and electricity grids at off-peak hours.

Our current production is already far greater than even the above numbers indicate. If we were to funnel all current hydrogen production into advanced ultra-light vehicles as efficient as the quintupled-efficiency Revolution concept car from Hypercar, it would displace two-thirds of today's entire worldwide gasoline consumption. In contrast, one-third of all hydrogen is used in the production of gasoline. Furthermore, the world's current hydrogen production could potentially be created via direct electrolysis of water, using only cost-efficient wind power from North and South Dakota.

The hydrogen industry is growing at 6% a year and doubling every 12 years. All this is happening absent the incentive that would be provided by a growing fleet of hydrogen fuel cell vehicles in need of fuel. If the hydrogen industry can expand so quickly while "below the radar," it will have no problem expanding quickly enough to fuel any number of hydrogen fuel cell cars.

The new models of the Honda FCX are powered entirely by hydrogen, and come with a home-based hydrogen energy station that produces enough hydrogen to fuel the car and also power the owner's house by reforming hydrogen from a natural gas line. The station will soon be configured to function with 20 square yards of solar material that will make it independent from the grid. Large commercial structures can place this nano-solar material on any non-transparent surface to power both buildings and vehicles.

Myth #2: Hydrogen is too dangerous or explosive for common use as fuel.

This myth begins with the hydrogen-filled passenger dirigible, the Hindenburg. The Hindenburg air disaster occurred at Lakehurst, New Jersey, in 1937. Recently, the event was revisited through a detailed analysis by NASA scientist Dr. Addison Bain. He found that the incident would have occurred almost identically even if the dirigible had been filled with nonflammable helium gas. It was not the hydrogen that originally combusted, it was the dirigible's outer coating, which was a highly flammable material similar to that used in rocket propellants. There was no explosion, and it was unlikely that anyone was killed by the hydrogen fire. The surviving passengers lived by riding the dirigible to the ground, since the burning hydrogen rose quickly into the air without spreading its heat to the gondola. In comparison, the explosive power of gasoline is 22 times greater by volume.

Anyone who has seen the endless replays of the September 11 disasters knows precisely how flammable our aviation fuel of choice truly is. Hydrogen is much safer. Period.

In reality, the hydrogen industry has an excellent safety record over the past half-century. Last year alone, in 40,000 shipments to 1,000 locations, it carried 100 million gallons of liquid hydrogen. Over 30 years, liquefied hydrogen shipments have logged 33 billion miles. In all this time, there have been no product losses and no fires.[15] Gasoline, our automotive fuel of choice, has a dismal safety record in comparison.

Hydrogen, though flammable, is generally more easily managed than hydrocarbon fuels, including gasoline. It is extremely light—14.4 times lighter than air and approximately seven times lighter than natural gas.

Hydrogen-air mixtures are difficult to combust, requiring a constrained volume of elongated shape. Hydrogen explosions require at least twice as rich a mixture of hydrogen as does an explosion of natural gas (i.e., they need double the density of gas to container volume). In other words, leaking hydrogen will ignite and burn, but not explode. If hydrogen is ignited, it burns with a clear flame with only one-tenth the radiant heat of a hydrocarbon fire. The heat that is produced tends to dissipate much more rapidly than does heat from gasoline or oil fires. Victims in a hydrogen fire generally are not burned unless directly in the flame, nor do they choke on smoke.

The belief that hydrogen is unusually dangerous is easy to dispel with videotapes showing modern tests of an ignited leak in a car's hydrogen fuel cell.[16] The most important comparison is between a hydrogen fire and a gasoline fire. First, a hydrogen fire was created in a test car by by-passing the triple-redundant safety interlocks. (Current industry standards for hydrogen leak detection and safety interlocks are thorough and very effective.) The leak was engineered at the highest-pressure location and discharged a full 1.54 kilograms of hydrogen in approximately 100 seconds. The resulting vertical flame plume raised the car's interior temperature by a maximum of 1-2° F (0.6-1.1° C), and its outside temperature rose by the same amount as a car sitting in direct sunlight. The passenger compartment was unharmed. In other words, a passenger wouldn't notice the heat, let alone be hurt by it.

In the second test, a 2.5-fold slower leak of *gasoline* from a 1/16 inch (1.6 mm) hole in a fuel line incinerated the car's interior and would have killed anyone trapped inside.

Bottom line: the hydrogen safety critics should turn their fire against gasoline, and agitate for the rapid adoption of hydrogen on safety grounds alone!

Myth #3: Making hydrogen is inefficient because the energy used is greater than the energy yield.

According to physics, any conversion of energy from one form to another will use more energy than it creates. If you created more energy than you used, you would have a perpetual motion machine, which violates the laws of physics. Since it is impossible to avoid a loss of energy, the relevant question is actually, "Is the loss of energy associated with converting matter from one form to another worth the cost?"

If the answer were categorically "no," as the myth implies, then we would not make gasoline from crude oil (~73-91% efficient from wellhead-to-pump) or electricity from fossil fuel (~29-35% efficient from coal at the power plant-to-retail meter). Hydrogen converts at 72-85% efficiency in natural-gas reformers or at 70-75% efficiency in electrolyzers.

So why is it worthwhile to accept these conversion losses? It is worthwhile because hydrogen's greater and more versatile end-use efficiency can more than offset the conversion losses. This makes sense in the same manner that an air conditioner can offset fuel-to-electricity conversion losses by using one unit of electricity to deliver several units of cool air. In other words, conversion losses are acceptable if the energy produced is more versatile and can be more efficiently used than in the original form, resulting in greater economic value. Hydrogen easily meets these criteria.

It is an unfortunate fact that for today, natural gas presents the most feasible source of hydrogen. As a petrochemical feedstock that both contributes to global warming and is in questionable supply, natural gas presents many difficulties. The long run solution is obvious: use renewables to fuel the processes that will generate hydrogen from water in a decentralized system.

Another misconception commonly associated with this myth is that crude oil can be more efficiently converted into *delivered* gasoline than natural gas can be converted into *delivered* hydrogen. Any difference in the efficiency with which gasoline and hydrogen can be converted from one form of energy into another is overshadowed by hydrogen's greater efficiency over gasoline in powering a vehicle. Using hydrogen to run a fuel-cell car is two to three times more efficient than using gasoline to run an internal combustion engine. Again, this is because combustion is always limited by the thermodynamic constraints of the so-called Carnot Cycle. This is not so for electrical devices such as a fuel cell.

Using numbers from Toyota, 88% of the energy in the oil at the wellhead becomes energy in the gasoline in your tank, and 16% of gasoline's energy reaches your wheels. This well-to-wheels efficiency is therefore only 14%. On the other hand, locally reformed natural gas (with the advantage of a potentially decentralized hydrogen generation network) delivers 70% of the wellhead energy into the car's tank. The super-efficient fuel-cell drive system brings a whopping 60% of that energy to the wheels. This results in a well-to-wheels efficiency of 42%, or three times the efficiency of gasoline (i.e., 42% / 14% = 3), and even 1.5 times the efficiency of the gasoline hybrid electric car.

It is precisely because of these efficiencies that it makes sound economic and environmental sense to take the leftover natural gas which will be saved by the aggressive implementation of renewables in the electric sector, and convert it to hydrogen which will be used to power hydrogen fuel cell vehicles, thereby displacing most of the remaining oil use in the transportation sector.

Furthermore, hydrogen's efficiency is so great that it may even make good sense to use hydrogen as an electric storage medium, especially for expansion and peaking power, in the electricity market. Using hydrogen for on-site energy during peaks is a particularly interesting idea for large metropolitan areas with transmission constraints, as well as for remote off-grid locations. This would facilitate more flexible energy usage and save power plant fuel by encouraging greater use of intermittent sources like wind. And for developing countries and other remote areas where no infrastructure exists, the answer is obvious—fuel cell power is the preferred motive force, just as solar power is today.

Myth #4: Delivery to end users consumes most of hydrogen's energy.

In 2003, two Swiss scientists analyzed the energy needed to deliver hydrogen, using a number of different methods.[17] It is only fair to note that their net-energy figures were basically correct, though not their conclusion that hydrogen's "physical properties are incompatible with the requirements of the energy market. Production, packaging, storage, transfer, and delivery of the gas . . . are so energy consuming that alternatives should be considered." There are five relevant pieces of information which invalidate this conclusion.

First, the Swiss scientists' report was published by the Methanol Institute, which promotes methanol over hydrogen, which renders their findings generally suspect.

Second, the paper presented certain hydrogen processes that have already been rejected, except in special markets, because they are too costly.

Third, the researchers focused entirely on electrolysis—the costliest method—and since the writing of their paper, the price of electrolysis has dropped from $8/kg to $3/kg, and continues to fall. Even with the high cost of electrolysis, they completely ignored any transitional hydrogen production processes such as steam reforming of natural gas.

Fourth, they admit that reforming fossil fuels such as natural gas is cheaper than electrolysis, but reject reforming because, according to their calculations, it releases more CO_2 than simply burning the hydrocarbon. This completely ignores hydrogen's fuel-cell efficiency advantage of 200 to 300% relative to conventional gasoline internal combustion engine cars. Using the most conservative assumptions, a car powered by hydrogen fuel cells emits 40 to 67% less carbon dioxide per mile than a gasoline-powered car of otherwise identical design. Eliminating the burning of hydrocarbons achieves a net reduction in CO_2 emissions.

Fifth, all of their energy transportation numbers are relevant only under a centralized hydrogen system, and not a distributed system. If the hydrogen economy were a centralized system, we would miss one of the great benefits of hydrogen—its ability to be generated in a basement or garage with a supply of water or natural gas plus an electrolysis machine or small reformer. It is the *de-centralized* system that will grow. The initial investment for a reformer is relatively small (as noted earlier, the Honda FCX already comes with a home hydrogen power system), eliminating the need for anything more than a natural gas line, a water line, and some electricity (off-peak grid or renewable-fueled). The reformer produces hydrogen with no transportation cost.

However, the electrolysis technology that is rapidly being developed and tested in Iceland and Hawaii to produce hydrogen with electrolyzers and water will prove to be far preferable to producing hydrogen by reforming natural gas because electrolysis does not contribute to global warming. Electrolysis will be a superior methodology for extracting hydrogen in both small and large-scale facilities. While for all the foregoing reasons, producing hydrogen from natural gas is superior to the gasoline-powered internal combustion engine, we hope the industry will rapidly switch to the far more intelligent solution of producing hydrogen with electrolyzers and water.

Furthermore, if society ever decided that the best choice is centralized hydrogen production by steam reforming of natural gas to hydrogen with carbon dioxide as a by-product, a conclusion with which we strongly disagree, this centralized production would be done near cities, not thousands of miles away. It would be easy to turn an existing oil refinery into a merchant hydrogen plant. And, if it made sense to pipe the carbon dioxide a long distance (which we doubt because it would be easier to capture the carbon dioxide and feed it to algae at the plant site), the piping of carbon dioxide is an inexpensive process and can be managed in almost any of the current types of transmission pipelines.

Myth #5: Hydrogen cannot be distributed through existing pipelines.

The transportation of hydrogen, one of the most frequently mentioned concerns of critics, is easily accomplished through pipelines, using one of hydrogen's most beautiful advantages—simple distributed production. There is no need to create a new pipeline network to move hydrogen; we can use the one already in existence. Some existing pipelines are already hydrogen-ready. The others can easily be modified with existing technologies by adding polymer-composite liners, similar to the process used to renovate old sewer pipes. To complete the process, we could simply add a hydrogen-blocking metallic coating or liner, and convert the compressors.

Using existing pipelines creates no additional safety concerns. A 200-mile, crude-oil pipeline has already been converted to hydrogen. Because many older natural gas pipeline systems were originally created for the use of "town gas," which was 50 to 60% hydrogen by volume, they are either entirely or largely hydrogen-compatible. Any pipelines that do need to be built have the advantage of small size, making them easy to site. Furthermore, installing small reformers in buildings—which can not only power the buildings but fuel the car as well—eradicates worries about delivery of the fuel supply.

Already, hydrogen refueling stations are appearing. Governor Arnold Schwarzenegger has pledged his commitment to a California Hydrogen Highway Network initiative "to support and catalyze a rapid transition to a clean, hydrogen transportation economy."[18] Florida and British Columbia have already created similar initiatives. Other states are sure to follow.

Myth #6: There is no practical way to run cars on hydrogen.

Turning wheels with an electric motor has well-known and long-established advantages of torque, ruggedness, reliability, simplicity, controllability, quietness, and economy. Virtually every light rail and subway system has been doing precisely this for more than a century. So, where does 21st century technology get the electricity? A hybrid electric vehicle generates energy from braking or from an onboard engine. It provides all the advantages of an electric motor without the disadvantages of size, weight, and price associated with traditional batteries. With the addition of fuel cells, this becomes the most efficient, clean, and reliable way to make electricity from fuel, using current technology.

Hydrogen fuel cells have been used for space flights since 1965 and they were used in a passenger vehicle as early 1966 (GM's Electrovan). Fuel cells have been used for decades in aerospace and military applications. They are emerging as power sources for portable electronics and appliances. They are already competitive for buildings, as well as industrial niches, when installed in the right place and used properly.

As of today, fuel cell vehicles are undergoing rigorous testing and are far advanced. As of mid-2003, manufacturers had tens of fuel cell buses and upwards of 100 fuel cell cars on the road. There were 156 different fuel cell concept cars and 68 demonstration hydrogen filling stations (see Figure 2 below). Fuel cells are currently being tested for military vehicles on land and sea, and submarines have used them for years. Heavy trucks, which spend up to half their engine run-time idling because they have no auxiliary power source, are also beginning to utilize fuel cells. FedEx and UPS plan to introduce fuel-cell trucks by 2008.

With such a massive wave of research and trial, fuel cells will quickly advance, as each successful application benefits from its predecessors' experience. As a whole, mass production will drive down the price of fuel cells. With the 2006 sale in the U.S. of over 250,000 hybrid electric cars operating on electric motors, there is no longer any reason to perpetuate the myth that cars can not run on electricity.

Myth #7: We lack a safe, affordable way to store hydrogen in cars.

The real issue here is mobile storage of hydrogen. The concern is that it would be necessary to equip every hydrogen fuel cell car with a steel storage tank, as opposed to the cheap plastic tanks of modern automobiles.

This concern was addressed several years ago with the creation of filament-wound, carbon-fiber tanks lined with an aluminized polyester bladder. Compared to the now-obsolete solid metal liner tanks, advanced carbon-fiber tanks reduced the weight of the fuel tank by half and cut the materials cost by a third. They have approximately 9 to 13 times the strength of their metal counterparts. They are immune to corrosion, and extremely tough, escaping undamaged in crashes that shred gasoline tanks. The pipes of a hydrogen fuel cell car are also maintained at the same low pressure as the fuel cell, thus removing the corresponding concern over the weakness of high-pressure hydrogen pipes.

The carbon-fiber tanks can be mass produced for just a few hundred dollars apiece. A 350-bar (5,000 pounds per square inch) hydrogen tank is almost 10 times the size of a comparable gasoline tank in terms of energy content. If you include the hydrogen fuel cell's greater two- or three-fold efficiency advantage over an internal combustion engine, this size differential decreases to only about four times. Furthermore, with a hydrogen fuel cell car, you can remove other car parts, such as the catalytic converter, thus compensating for the additional volume required by the hydrogen tanks.

With modern design methods and materials, cars will enjoy advanced efficiencies thanks to less aerodynamic drag, rolling resistance, and weight. Thus, they will use two-thirds less power, thereby decreasing the amount of hydrogen needed to drive over a comparable distance. The magic number that all automotive makers are targeting is a range of 300 miles on a single fueling with hydrogen. GM's Sequel, a fuel cell concept car, has achieved this range by boosting the hydrogen to 10,000 p.s.i.

Myth #8: Hydrogen is too expensive to compete with gasoline.[19]

Despite decades of U.S. policies favoring the use of petroleum, hydrogen technologies are already close to economic viability. When we consider system-wide life cycle costs, hydrogen *already* is a desirable alternative to fossil fuel.

The relative costs of hydrogen and gasoline-powered vehicles cannot be calculated without considering their relative wellhead-to-wheels efficiencies (i.e., the percentage of the total energy extracted that ends up powering the vehicle). As discussed above, only 14% of the total energy extracted from oil in the ground ends up powering a car. If we use natural gas as the interim source of hydrogen, the wellhead-to-wheels efficiency of hydrogen is 42%—three times greater than the efficiency of internal combustion engines which have been optimized over the past 100 years. Gasoline can't compete. These comparative efficiencies of hydrogen over gasoline also apply to cars with hydrogen internal combustion engines. This technology can play a role in a short-term hydrogen transition strategy.

The greenhouse gas emissions story is overwhelmingly favorable to hydrogen. Even when hydrogen fuel is produced from natural gas, on a per-mile-driven basis, fuel cell cars generate as little as 30% of the carbon dioxide produced by gasoline-powered cars.

Cost is the bottom line factor for many consumers contemplating the adoption of new technologies. One kilogram of hydrogen is energy-equivalent to one gallon of gasoline. Small hydrogen generators manufactured by the hundreds, installed at service stations supporting a few hundred fuel cell-powered cars that use natural gas as a raw material at a cost of $6 per million British Thermal Units, would deliver hydrogen to cars at $2.50 per kg. This is equivalent to $2.50 per gallon gasoline. As current trends continue, we believe that the days of $2.50 per gallon gasoline will be very fond memories.

In more comparable terms, namely the cost per mile driven, using modestly efficient hydrogen fuel cell cars that are two to three times more efficient than internal combustion engine cars, fully taxed gasoline at $2.25 per gallon would be equivalent to hydrogen selling at $5 per kg. In other words, hydrogen could be priced even at $5 per kg and compete with gasoline at $2.25 per gallon.

With more technological improvements certain to rapidly reduce the price of 99.99% pure hydrogen, we can rest assured that an affordable, clean energy future is not so far away. General Motors has even stated that hydrogen becomes competitive with gasoline at $2.25 per gallon.[20]

> *"Hydrogen made in 20- or 180-nominal-car-per-day natural-gas reformers would have remained competitive with retail and wholesale gasoline, respectively, at the actual average prices of U.S. natural gas and gasoline for the past 22 years."*
>
> **— Amory Lovins, *Twenty Hydrogen Myths*, 2003**

Gentlemen, Start Your Fuel Cells

Automakers have been researching hydrogen-powered cars for over a decade, but it is only within the past five years that R&D concepts have been translated into prototypes and in some cases production-line products. As Figure 2 shows, BMW, Daimler-Chrysler, Ford Motor, General Motors, Honda, Hyundai, Mazda, Nissan, Toyota, and Volkswagon have been leading the pack and spending billions of dollars on the next frontier of automotive technology: the hydrogen fuel cell car.[21] While Honda is leading the charge with the Honda FCX and its home-based hydrogen energy station, other companies are quickly catching up with hydrogen fuel cell concept cars that push the envelope in terms of design, efficiency, and creativity.

For example, the Revolution from Hypercar, Inc. may be the most advanced hydrogen fuel cell concept car yet. Hypercar vehicles are ultralight, ultra-low-drag, hybrid electric vehicles with a highly integrated and simplified design emphasizing software-controlled functionality. While currently expensive and handmade, a new patent-pending manufacturing process is expected to make these carbon-fiber cars affordable at automotive volumes of 10,000 to 100,000 vehicles per year. This concept car will have the size, safety, comfort, and performance of a Lexus RX300, yet with a model average efficiency of 99 mpg-equivalent. Estimates are that the Revolution will have a driving range of 330 miles, with 3.4 kg of hydrogen at 350-bar (5,000 pounds per square inch) pressure. The driving range can be extended to over 500 miles with the new fuel tanks, which are being incorporated by many manufacturers.[22]

Figure 2. Hydrogen Car Programs by Major Automobile Manufacturers

Company	Concept Car Name	Program Description
BMW	750hL, H2R	Hydrogen internal combustion engine
DaimlerChrysler	F-Cell	Based on Mercedes A-Class
Ford Motors	Ford FCV	Fuel Cell modification of Ford Focus
GM	Sequel, HydroGen3	Multiple other models, listed are most important
Honda	Honda FCX	Current Leader, Home Hydrogen Energy Station
Hyundai	Tucson FCEV	Based on UTC Power fuel cell technology*
Mazda	RX-8	Duel-fuel (hydrogen or gasoline) rotary engine
Nissan	X-TRAIL FCV	Based on UTC Power fuel cell technology*
Morgan Motor	LIFEcar	Performance-oriented, with other British groups
Toyota	Highlander FCHV	Under development and in active testing
Volkswagon	Bora Hy.Power	Projected to be in showrooms by 2010

* UTC Power is a United Technology Company (NYSE: UTX)

Research is proceeding quickly on other storage methods, including liquid hydrogen, metal hydrides, and carbon nanotubes. Each method has advantages and disadvantages; but so far none compare with the currently available high-pressure tanks in terms of weight or cost. In addition, there are no size or safety reasons that preclude using current generation tanks. While further research on storage technology is desirable, it is not essential for hydrogen car development. In the end, and analogous to natural gas as the initial source of hydrogen for automotive fuel cells, pressure tank storage can easily serve as the means to introduce fuel cell cars, while further development unfolds a host of other technologies that increase hydrogen storage density and extend driving range.

Honda is one of the few companies that are already road testing a hydrogen fuel cell car, the Honda FCX. In 2005, Honda leased its home energy station and a 2005 Honda FCX to a family in Los Angeles. It is reported to offer "every comfort and quality of a regular Honda, drove seamlessly, smoothly, and handled like the best vehicles the company makes."[23] This hydrogen fuel cell car is expected to go into production sometime between 2008 and 2009.

As GM, Ford, and Chrysler jockey for positions, foreign competitors are already announcing production dates. However, "When any of these companies roll out their production models in 2009 or 2010, those cars will not be available at showrooms, but to select commercial and government customers, such as municipalities, the military, and major corporate and government fleet owners. It will be another year or two for the production volume to bring down costs to consumer levels."[24]

> *"Ironically, the American companies will not be leading the parade onto the hydrogen highway. That will be Honda, which will have to look over its shoulder continuously as it is chased by BMW, Audi, Toyota and other foreign car makers."*
>
> **— Edwin Black, *Internal Combustion,* 2006**

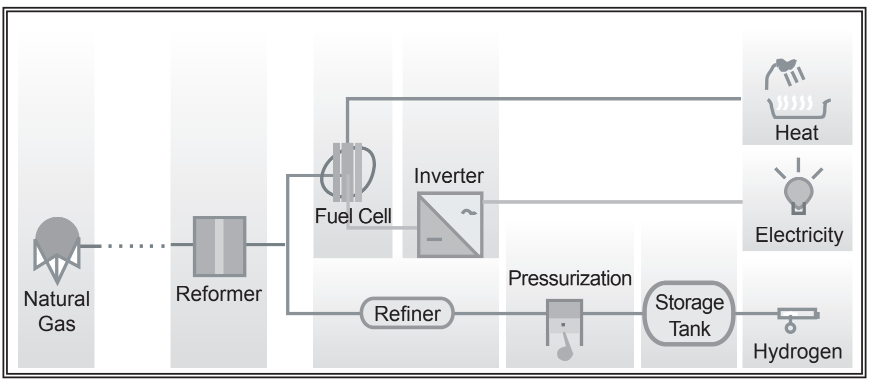
It is noteworthy that both BMW and DaimlerChrysler made significant progress with the hydrogen internal combustion engine. In fact, BMW has already announced a 2008 date for initial production of its BMW Hydrogen 7 "Eco-Luxury" cars. However, we do not believe that the hydrogen internal combustion engine will become the standard for hydrogen-powered cars. Although environmentally friendly, it uses current internal combustion technology and thus loses the fundamental advantages of the extremely efficient hydrogen fuel cell.

Generating Hydrogen At Home

Honda R&D Co., Ltd. jointly developed its hydrogen home energy station with Plug Power Inc., Honda's strategic fuel cell partner for research and development in hydrogen energy sources. During field tests of the station's ability to generate hydrogen from natural gas for use in fuel cell vehicles while supplying electricity and hot water for the home, Honda concluded that the station can currently produce enough hydrogen to refill the tank of the Honda FCX fuel cell vehicle in a few minutes once a day. The station is made up of the following processes and components:

1. A reformer to extract hydrogen from natural gas;
2. A fuel cell unit to provide power for the overall system that uses some of the extracted hydrogen;
3. A refiner to purify the hydrogen;
4. A compressor for pressurizing the extracted hydrogen; and
5. A high pressure tank to store the pressurized hydrogen.

Figure 3. Structural Outline for Honda Home Energy Station[25]



Looking ahead, Honda has also announced the development of next-generation solar cell panels made by Honda Engineering, as well as a high-efficiency electrolysis unit. Both the advanced lightabsorbing solar panels and the electrolysis unit are mounted on Honda's solar cell-powered hydrogen refueling station in Torrance, California, to improve total system efficiency. As a proponent of the hydrogen future, Honda believes that "hydrogen fuel cell power has the potential to be the next-generation power plant needed to overcome problems related to the development of alternative fuels, reducing exhaust gas emissions, and reducing the effects of global warming."[26]

Hydrogen Technology and Global Economic Growth

In a paper on "Hydrogen and the New Energy Economy," Julian Gresser and James A. Cusumano (one of this book's co-authors) contend that many environmental and national security arguments on behalf of hydrogen miss what is perhaps its most beneficial impact: "Hydrogen could become a strategic business sector and an engine of global economic growth within the decade and for the remainder of the 21st century."[27]

It is well known that at critical times in a nation's development, certain industries have made key technological breakthroughs and have provided dynamic engines of broader economic growth. This growth occurs when competitive advantages won through productivity gains in a strategic business sector are transferred to other industries.

Famous examples of the convergence of key technologies and rapid economic growth include: the canals and railroads of 18th and 19th century Europe and the United States; the New England machine tool factories of the early 19th century; the German chemical dye industry of the late 19th century; and most recently, the U.S. convergence of computer hardware, software, and Internet technology of the late 20th century. Japan's post-World War II industries (steel, auto, electronics, semiconductors, computers and telecommunications) show how economic innovation can trigger rapid economic growth.

Due to the tremendous public benefits realized through the success of strategic technologies and industries, governments have usually played a critical catalytic role in accelerating their development. Notable historical examples are President Franklin D. Roosevelt's Rural Electrification Administration, President Eisenhower's interstate highway system, and President Kennedy's Apollo Project.

California has taken the national lead in implementing a "Hydrogen Highway Network Action Plan" that will build 150 to 200 hydrogen refueling stations, approximately one every 20 miles on California's major highways. Similarly, Florida has launched an innovative program to promote hydrogen as a strategic growth sector. Crafting a broad alliance among private companies, state and local government, universities, and environmental groups, the Florida Hydrogen Strategy initially focuses on fuels cells, hydrogen storage, and power-grid optimization. The strategy offers tax refunds, investment tax credits, performance incentives, and enterprise bond financing.

Japan, Germany, Canada and Iceland have major hydrogen programs underway. All of these nations understand that, in addition to laying the foundation for independence from oil and creating a key industrial sector, the rapid development of hydrogen will accelerate innovation in related sectors, such as nano-materials, biotechnology, solar photovoltaics, ultra-light materials, and even the Internet, through distributed power generation and grid interface.

Launching the U.S. Hydrogen Economy

Given the urgency of the energy and climate crisis, in addition to adopting the Prometheus Plan, we urge the development of a broad political consensus around a plausible strategy for the transition to a hydrogen economy. This strategy will apply regulatory, financial and other market-driven incentives, while drawing on the best available technology and talent. Under the rubric of a non-partisan National Hydrogen Task Force, the President and the Congress should convene the nation's leading hydrogen scientists, engineers and inventors, along with top environmental lawyers, finance experts, and specialists in public/private enterprises.

Their mission should be the development of a draft Strategic Hydrogen Alliance Reform and Enterprise Act (SHARE) that will create the statutory framework for accelerating the development of the hydrogen economy as quickly as possible, on a par with the urgency that accompanies a state of war or a natural disaster.

The main stages of this transition plan are outlined below and include the following milestones:

Phase I (2007-2010)—Deploy existing technologies and capabilities to expedite fuel cell research and development and to vigorously market smaller fuel cells to homes and businesses as local, distributed power, while the hydrogen car runs on a modified internal combustion engine that is cost-effective today. Where needed, build a national hydrogen infrastructure, including production facilities, pipelines and fueling stations in core metropolitan areas.

Phase II (2010-2015)—Introduce multiple varieties of fuel cell cars that run on hydrogen, generated from natural gas reformation or electrolyzed from water.

Phase III (2015-2020)—Achieve widespread commercialization of fuel cell vehicles that operate on hydrogen generated by renewable energy sources such as solar- and wind-powered electrolysis.

The ultimate goal is the broad transition to clean and "Green" hydrogen generated from wind, solar, geothermal and possibly biological systems, and minimum sales of 1,000,000 hydrogen fuel cell vehicles, equal to a 6% new car market penetration. The specific goals of each phase, which complement the automobile efficiency and biofuels strategies of the Prometheus Plan, are as follows. In parallel to these hydrogen milestones, the plan would require automobile engines to be developed so that they could function on a mix of plug-in technologies, renewable fuels such as ethanol or biodiesel, and hydrogen fuel cells powered by electricity from the utility grid.

Phase I: Deploy Existing Technologies and Capabilities (~2007-2010)[28]

Hydrogen Fuel Cell Status: Plug-in hybrid electric vehicles and internal combustion engines that run on hydrogen come into the market; hydrogen fuel cell prototypes tested

1) Immediately implement the Prometheus Plan, which focuses primarily on oil savings through automobile efficiency and biofuels in the transportation sector.

2) Establish financial incentives through the SHARE Act to put hydrogen on an economic par with petroleum.

3) Market existing fuel cells to businesses and homes and also to the growing high- reliability niche for information technologies and commercial computer operations.

4) Conduct extensive applications research and expedite commercial development and construction of the first large-scale fuel cell plants, to bring production costs down to at least $400 per kw, competitive with most electric power.

5) Build on Ford and BMW strategies to offer current model internal combustion engines that run on hydrogen—25% more efficient and 70% less carbon dioxide emitting than conventional engines—including leased transit and business fleets with access to a central hydrogen generator unit.

6) Expand the number of hydrogen filling stations in metropolitan areas and lease prototype hydrogen fuel cell vehicles in these areas.

7) Accelerate current research into nano-materials for hydrogen storage and initiate research for hydrogen generation from solar photocatalysis and genetically modified organisms (bio-hydrogen).[29]

Phase II: Expand Infrastructure Beyond Core Metropolitan Areas (~2010-2015)

Hydrogen Fuel Cell Status: Initial commercialization of affordable hydrogen fuel cell and plug-in hybrid electric vehicles / hydrogen fuel cell cars

1) Commercialize nationwide prototype fuel cell vehicles, newly affordable due to financial incentives provided to automakers, oil companies, and consumers. This should include early adoption of fuel-cell plug-in hybrid vehicles. Visionary oil companies and utilities complete the transformation into energy service companies.
2) Install new advanced wind- and solar cell-powered facilities for efficient, economic generation of "Green" hydrogen via electrolysis.
3) Expand hydrogen energy stations across the country, based on hydrogen generated from water by electrolysis, to fuel stationary fuel cells in homes and businesses.
4) Convert most large sea vessels to run on biofuels or fuel cell power.
5) Build new high-capacity hydrogen storage tanks based on breakthroughs in nanomaterials research.
6) Adapt existing pipelines to carry hydrogen, or where that is not feasible, construct new hydrogen pipelines as needed in metropolitan areas.

Phase III: A Hydrogen Nation (~2015-2020)

Hydrogen Fuel Cell Status: Widespread commercialization of hydrogen fuel cell cars, at least 5% of market

1) As homes and businesses supply increasingly large amounts of hydrogen fuel cell-generated power to the grid, electric utilities increasingly become power distributors and much less power generators.

2) Consumers plug in parked fuel cell vehicles at home and work to supply electric power to the grid at peak-cost periods.
3) Businesses provide hydrogen to employees as a benefit.
4) Most services stations are converted to produce hydrogen via solar photovoltaic, wind-powered electrolysis, or by access to the national hydrogen pipeline system.
5) Dramatically reduce costs through new technologies for generating hydrogen via solar photo catalysis and bio-hydrogen and for storing hydrogen via advanced materials. This includes the early adoption of specially developed algae for farms to produce bacteria to generate hydrogen.[30]

An International Hydrogen Prometheus Plan

The path toward the hydrogen future is already being paved by private initiatives and government support in the United States, the European Union, and Japan. Beginning with flexible-fuel hybrids and natural gas reformers, the hydrogen revolution could take place along the lines of the scenario that follows, based on *evolutionary* rather than breakthrough improvements in technology.

A viable hydrogen platform requires the development of a decentralized energy economy, beginning with the installation of natural-gas reformers or water electrolyzer units in office buildings and for use by commercial transportation fleets. Next, hydrogen fuel cell cars will be deployed in commercial fleets that return to central depots for a nightly refueling. Once there is excess hydrogen-generating capacity at fleet depots and in commercial buildings, this will be quickly followed by the leasing of mass market hydrogen fuel cell cars to people who work in or near buildings equipped with natural-gas reformers. The spare capacity of the buildings' hydrogen appliances will be sold to the leased hydrogen fuel cell cars.

As stationary hydrogen production units become cheaper, they will be deployed outside buildings. Using natural gas or electricity, these local hydrogen fuel stations will take the place of today's filling stations. Without the cost burden of transportation and distribution, hydrogen will become relatively cheap and economically viable, while reducing vehicle emissions by 50 to 82%. It is noteworthy that in addition to the fuel cell itself, many of the components have been well developed over the last decade. For example, several companies such as United Technologies Corporation in the U.S. and Haldor Topsoe in Denmark developed commercial, compact steam reformers that can generate pure hydrogen from natural gas on call. When directly interfaced with a fuel cell, they can electric-load follow, *i.e.,* they produce just the right amount of hydrogen depending on the instantaneous requirement of the fuel cell.

The hydrogen revolution will conform to the same key principles as the Prometheus Plan, including no major technological breakthroughs, just inevitable improvements on current known technologies. There will be no need for new taxes, or huge government subsides for infrastructure even though strategic federal incentives, as outlined above, will be needed to accelerate the transition.

The building of the decentralized hydrogen production economy assumes a 10% or greater per year real return. Those who participate will be able to make substantial profits even during the initial phase, and enjoy the benefits of being strategically well-positioned once the transition is complete. Major improvements in stationery hydrogen production units will be driven by a desire to either minimize the costs of improvements or maximize their durability, which criteria will respectively favor cars and buildings. It matters little which one happens to arrive first; either way the increase in production in one market will accelerate the other. Technologies will bootstrap each other as we learn from disparate applications.

As Gresser and Cusumano point out, "As hydrogen becomes a strategic economic driver for the United States and the major industrialized nations, it can serve this same function for many other countries, rich and poor."[31] Here, the size and risks of some hydrogen projects are well-suited for international collaborations that can be pursued on the same grand scale as the Apollo Project in the United States, the Marshall Plan in Europe, the worldwide International

Thermonuclear Experimental Reactor, and the Intergovernmental Panel on Climate Change projects.

As new countries enter the hydrogen consortium, each one can develop special expertise and leverage based on its unique resources and skills. Public/private hydrogen alliances can provide powerful catalysts for innovation. For example, accelerating cost breakthroughs in hydrogen generation and storage, and in fuel cell manufacturing, can produce huge commercial and governmental returns.

The financial foundation of the hydrogen Prometheus Plan could be an International Hydrogen Innovation Fund, initially capitalized with $5 billion provided by national and international entities. The fund would be managed by an international team of successful technology, business, and social entrepreneurs, with the goal of achieving superior rates of return for shareholders within five years for funding early, middle and late stage projects.

> *"We don't receive wisdom. We must discover it for ourselves after a journey that no one can take for us or spare us."*
> **— Marcel Proust, author, 1871-1922**

The hydrogen economy is the only reliable long-term solution to the energy and climate crises confronting civilization. There is now no other technology option that can safely produce clean energy to power transportation systems and our stationary infrastructure to sustain current levels of global prosperity, let alone increase these levels to sustain our fellow planetary citizens. If properly managed, this great transition will be profitable and beneficial for all stakeholders. The hydrogen revolution is one of the greatest legacies our generation could pass on to our children and children's children.

Horace Mann, a pioneering advocate of free, public education in the America, said, "Be ashamed to die until you've won some great victory for humanity."[32] All who join in this grand enterprise to bring about the birth of the hydrogen age will participate in one of humanity's greatest victories: the creation of a safe, clean and sustainable energy future.

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