THE HYDROGEN AGE

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Three chapters + lists of recommended reading and web sites
(Followed by a link to a Sept 6, 2008 Economist Magazine article expressing doubts)
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Chapter 7: The Matter Of Safety

"That damn zepplin's full of hydrogen, one bad shot and we'll all fry!" was heard shouted over the din of blazing bullets in the 1991 feature film *The Rocketeer.* Overhead in the movie loomed a gigantic Nazi airship filled with "explosive hydrogen" This fictional distortion inspired by history' greatest airship disaster, provided lots of popcorn action. It also painted a very scary, though grossly inaccurate, image of hydrogen among impressionable movie audiences.

The same can be said of the 1996 movie thriller *Chain Reaction.* In the film, Keanu *Reeves* plays a research assistant helping to develop a cheap way to produce hydrogen using some kind of technical amalgam of laser and harmonics that looks a bit like nuclear fusion. The film foolishly represents hydrogen as a peevishly unpredictable energy source that has the colossal explosive power of a nuclear bomb without the radiation. Dramatically engaging and action packed but frightening in the inaccuracy of its depiction, at one point *we see* the hero save himself from a monstrous, tsunami-like, explosive shock wave of fire and smoke by outracing it on a motorcycle. By implication this movie event that flattened eight fictional city blocks was caused by exploding hydrogen. In reality, hydrogen becomes explosive only when confined and mixed with air. Making it look a nuclear explosion for creative effect nay have served the plot, but the average viewer seeing this movie would come away with a distorted, seriously unsettling perceptions of hydrogen. Visually exciting, but just plain wrong.

And then there's *Terminator 3*, in which the Terminator (a.k.a. Arnold shwarzenegger) rips a defective fuel cell the size of a pack of cigarettes from his robotic body and tosses it out the window of the truck he's driving, only to have it explode a moment later like - yes, that's right - a small nuclear bomb. "Relax," Arnold the cyborg says with a snarl to his emotionally unglued human companion, "when ruptured, fuel cells become unstable." How's that for an introduction to hydrogen? Fortunately, Arnold Schwarzenegger later became the governor of California. In that role, he has become a powerful political force for environmental and energy policy. He has had nothing but good things to say about hydrogen and fuel cells.

It's not just in the movies that the public's impression of hydrogen gets muddled.

Dubious Myths

In the game of word association, when hydrogen is mentioned, what lights up in some minds is the word "bomb." This notion stems largely from the cold-war hysteria of the 50s when the hydrogen bomb was touted as the ultimate in nuclear deterrence. The reality is that the simple, garden-variety hydrogen that compromises about 90 percent of all atoms that exist has nothing to do with apocalyptic weapons. A hydrogen bomb cannot be made from ordinary hydrogen. It requires very special isotopes that are very, very hard to isolate in sufficient quantity to cause trouble. Indeed, it has never been done by anyone other than a handful of governments that fund multibillion-dollar weapons programs.

Another misguided notion about hydrogen relates to the loss of the NASA Space Shuttle *Challenger* 1986.

Because the shuttle's main booster tank was carrying several hundred thousand gallons of liquid hydrogen fuel, a few people still characterize that tragic incident as an example of the mythological ugly side of hydrogen. The link, in fact, is unfounded. During the official *Challenger* inquiry, the late Nobel laureate physicist Richard Feynman, a member of the investigating panel, employed a glass of ice water and a rubber band to show that the elasticity of the rubber “O” rings sealing the sections of the solid rocket boosters was degraded by cold pre-launch temperatures. Feynman's theory was later confirmed and was accepted conclusively in the panel's official report. The hydrogen aboard the shuttle did burn, but only after it was ignited by events set off by a fatal breach of an embrittled “O” ring between two sections of one of the solid rocket boosters. Incidentally, the propellant in that solid rocket booster was strikingly similar in chemical makeup to the stuff used to paint the skin of the ill-fated *Hindenburg* airship nearly fifty years earlier.

Few people know more about hydrogen than retired NASA engineer Addison Bain. As chief of propellants at Kennedy Space Center, Bain was one of the primary individuals responsible for the liquid hydrogen fuel that was used on some of the earliest manned space missions and continues to be used on the space shuttle. He designed many of the hydrogen storage, transport, and fueling systems that have been in use for decades at Kennedy Space Center. He also wrote many of the operating and safety protocols for those systems. "The systems we designed at NASA have worked very well," says Bain. He clearly takes pride in the space program's exceptional safety record. "Hydrogen is very predictable. We've had very few problems with it over the years."

Bain points out that pure oxygen can be at least as hazardous as hydrogen and is less predictable. Air is 20 percent oxygen and about *8o* percent nitrogen with some other gases present in minute quantity. It is the oxygen in air that sustains life. If the percentage of oxygen were to drop below 19.5 percent and continue to drop, breathing would become increasingly more difficult. At 0 percent, Bain says, we'd be "goners.') He also reports, "At 25 percent oxygen, any ignition source would trigger a fire that would engulf the Earth and destroy all living things" (1) A tragic example of oxygen's flammability or combustibility took place on January 27, 1967, during a launch pad training session for the first mission of the Apollo lunar program. Astronauts Gus Grissom, Edward White, and Roger Chaffee perished in a sudden flash fire facilitated by the oxygen-enriched atmosphere inside their capsule.

Getting Past the Fear Factor

"Never in history has society been confronted with power so full of potential danger and at the same time so full of promise for the future of man and for the peace of the world. . . ." So said the Report of the U.S. Congressional Horseless Carriage Committee in 1875. It went on, "Stores of gasoline in the hands of people interested primarily in profit would constitute a fire and explosive hazard of the first rank. Horseless carriages propelled by gasoline engines might attain speeds of fourteen or even twenty miles per hour. The menace to our people of vehicles of this type traveling through our streets and along our roads and poisoning our atmosphere would call for prompt legislative action. . . " (2)

The Horseless Carriage Committee was very right about the poisoning of our atmosphere, but despite the initial alarm, gasoline use increased and methods to handle it safely were developed. Although accidents do occur occasionally, the anxiety that preceded the age of the gasoline-fueled automobile was overstated. Despite the risk that goes with the use of gasoline, we put it to work, and *we* consume it in massive quantities every day all over the world.

Very quietly, operating in the background, a set of safety codes and standards guide our relationship with oil starting with the drilling and extraction from the ground, through its transport to refinery, to its distribution to gas stations. The entire infrastructure, from the underground storage tanks to the nozzles on the pumps *we* use to fill up our cars, is designed with reliability and safety in mind. Passenger vehicles are built to carry anywhere from fourteen to forty gallons of highly combustible gasoline on board with minimal risk.

We know fiery crashes are a real possibility. But it happens so rarely that, as far as the fuel is concerned, safety is not something *we* think much about when we drive our cars. It's just something we take for granted.

All fuels, including gasoline, natural gas, and hydrogen, are a concentrated form of potential energy, and as such are inherently hazardous. There's no getting around that. They burn and pose fire and explosion risks if their combustion is not controlled. Despite this, people pump gas into their cars at service stations routinely. Natural gas or sometimes propane flows into tens of millions of homes where it is used in water heaters, furnaces, and cooking ranges. The convenience and value of having easy access to so much energy in our personal lives is something we've come to expect, the risks notwithstanding. Given those facts, is there any more reason to be concerned about hydrogen?

For most people, even though it is all around them, chemically bound in its natural state, hydrogen is an unknown quantity and is little understood. When asked about it, what often comes through is the notion that it is explosive and by nature is very risky to use. To the first part of that, there is no question, like other fuels, it is flammable and can be explosive under certain circumstances. Hydrogen's potential energy is what makes it a fuel. When that potential energy is turned into kinetic energy under controlled conditions, the result is a measure of useful work.

But is hydrogen very risky to use? The evidence suggests that it is no more risky than gasoline or natural gas or any of the other fuels we use on a daily basis. In the "safety" world, there is *absolute* safety and *relative* safety. When comparing one fuel to another, we are in the realm of *relative* safety; one fuel is *relatively* safer than the next. Engineers will tell you that hydrogen's physical and chemical properties make *it relatively* safer than gasoline in many respects. Hydrogen does not pool, it evaporates and dissipates quickly, it does not give off "radiant" heat like carbon-based fuels, etc. (Radiant heat is that heat you feel from your fireplace when standing away from the flames.)

Hydrogen does have a low energy of ignition, which can be used to our advantage, but it is also a safety concern. Hydrogen has a wide flammability range (combustion limit) of 4 to 85 percent concentration in air. That means that there has to be at least 4 percent of a volume of air occupied by hydrogen for the mixture to be flammable. And, if the volume of air contains more than 85 percent hydrogen it will not ignite.

Hydrogen has been a high-volume commodity used in industrial processes for nearly a century. A 400-kilometer-long, dedicated hydrogen pipeline in the Ruhr Valley near Cologne, Germany, has been in service continuously for almost seventy years. [3] Other hydrogen-dedicated pipelines have logged years of service without incident. Currently, about 5 percent of all natural gas consumed in the United States is processed to produce hydrogen for use in the refining of oil into gasoline and other petroleum-based products. There are many hydrogen production facilities located in industrial areas around the world. Systems at these facilities are designed to ensure safe operations, and over the years, the industry as a whole has established an exemplary safety record.

The executive summary of Ford Motor Company's 1997 Hydrogen Safety Report to the U.S. Department of Energy puts it in even more glowing terms: "If we consider the total fuel system, including hydrogen production, transportation, storage and dispensing, the total public exposure to fuel risks could be less than those of the existing gasoline fuel infrastructure . . . " [4]

There is one particular incident in history that has helped shape the public's attitude toward hydrogen. It deserves a closer look.

The *Hindenburg* ~ The Real Story

All seemed well as the gigantic rigid airship approached its destination, Lakehurst Naval Air Station in Manchester, New Jersey, on May 6, 1937. Nearly four times as long as a modern jumbo jet airliner, the

Hindenburg's massive, cigar-shaped hull was 804 feet in length and, with its sister ship *Graf Zeppelin II,* was one of the two largest man-made objects ever to achieve sustained flight. Designed to carry seventy-two passengers in grand comfort, she was the pride of Germany. More than seven million cubic feet of lighter-than-air hydrogen provided the buoyant lift to keep the *Hindenburg* aloft. The ship's design had called for nonflammable helium to be used for lift, but the only supply of helium was in the United States, which refused to make it available to Hitler and the Nazi regime in power.

At the time, traveling aboard a lighter-than- air zeppelin like the *Hindenburg* was a rare and exhilarating experience. Air travel of any kind was still novel. It wasn't until 1939 that fixed-wing passenger aircraft began transatlantic service.

On that fateful day in 1937, strong head-winds had set back the *Hindenburg* airship's arrival in Lakehurst until late that afternoon when reports of gusty winds and rain showers caused further delay. Then, shortly after 6 p.m., the commander on the ground radioed the airship's captain, Max Pruss, that all was clear to land. There were ninety-seven people aboard the *Hindenburg* including thirty-six passengers as she was maneuvered over Lakehurst airfield. On the ground, 92 Navy and 139 civilian crewmen waited to assist in mooring the giant lighter-than-air-ship.

Suddenly, at 7:25 p.m., spectators present reported a glowing aura coming from the tail section of Hindenburg just in front of its tall vertical fin. Almost instantly, fire engulfed the rear section of the airship. With flames rapidly spreading forward, the *Hindenburg's* tail section settled to the ground.

In less than a minute, the entire ship was consumed by fire. Remarkably, despite the overwhelming magnitude of the conflagration, only thirty-five of the ninety-seven people aboard the *Hindenburg* lost their lives and only a single person on the ground was killed.

In the aftermath, newspapers concluded, purely on assumption that the disaster was caused by the ignition of the flammable hydrogen gas that made the airship buoyant. Despite rampant wild speculation suggesting some sort of sabotage, an intense investigation into the cause proved inconclusive.

Six decades later, the circumstances surrounding the *Hindenburg's* demise were still unresolved. The tide started to turn when Addison Bain, the retired NASA engineer quoted earlier in this chapter, got on the case. An airship buff, Bain had a particular interest in the zeppelins that relied on hydrogen as their source of buoyancy. Because of his extensive experience working with hydrogen, Bain had serious doubts that the hydrogen onboard the *Hindenburg,* though vast in volume, had anything to do with starting the fire. During his tenure at NASA, Bain used much of his off-time to educate himself about the *Hindenburg disaster,* even making a trip to Friedrichshafen in southern Germany where the Zeppelin Company, builder of the *Hindenburg,* was located and where an archive commemorates the era of the zeppelin rigid airships.

When he retired from NASA in 1994, Bain took up investigation of the *Hindenburg* full time. His efforts were the heart of a National Geographic television report, titled *Hindenburg: Titanic of the Air.* Bain has also written a book, *The Freedom Element,* about his life's work with NASA and about his efforts to uncover the truth about the great airship disaster. When he examined weather conditions at the time of the airship's ill-fated landing attempt, Bain learned that thunderstorms had been in the area not long before. In fact, lightning was still visible in the distance at the time of the incident. This meant that atmospheric conditions were unstable and highly charged with static electricity. Bain recognized the importance of this when he looked at the way the *Hindenburg* was tethered for landing. Still two hundred feet in the air, the huge zeppelin dropped a mooring rope to the ground, which was then attached to a winch. Given the highly charged atmosphere, this ground-to-airship link created optimal conditions for severe coronal activity. Eyewitness accounts reported seeing a blue glow, indicative of coronal electrical activity, on the airship's skin near the tail just before the fire started.

For Bain, the big break came when he managed to acquire two small, undamaged swatches of the *Hindenburg's* fabric skin that had been picked up in the disaster's aftermath. Returning to NASA, Bain arranged for the Materials Science Lab at Kennedy Space Center to examine the fabric swatches intensely. They confirmed that the skin of the Hindenburg was painted with an extremely flammable dopant of [cellulose acetate butyrate with powdered aluminum and iron oxide. From a chemistry standpoint, this is virtually the same substance used to make solid rocket fuel.

Bain', theory that the *Hindenburg* disaster was started by the coronal ignition of the airship's fabric skin was firmly corroborated by letters recently found buried in the Zeppelin Museum archive in Friedrichshafen. Otto Bayersdorff, an *elec*trical engineer employed by the Zeppelin Company, wrote about the *Hindenburg* disaster in June *1937*. In the long-lost letters, translated from German, Bayersdorff confirmed that the cause of the fire was the extreme easy flammability of the covering material brought about by discharges of an electrostatic nature. He also said the disaster would have happened even if helium had been used as the lifting agent instead of hydrogen. [5]

With a gleam in his eye, Addison Bain grins and says the moral of the story is, "Don't paint your airship with rocket fuel."' [6]

The *Hindenburg is* often the first thing that comes to mind when the word hydrogen comes up with people old enough to remember. Automatically, they tend to equate hydrogen with danger. This is under-standable, but we know now that hydrogen was not to blame for the airship disaster. Yes, it did burn, but it did not explode as was reported at the time. In fact, it now appears the presence of the hydrogen may actually have been a blessing for passengers, *crew,* and those close at hand on the ground for several reasons.

When the hydrogen aboard the *Hindenburg* caught fire, its buoyancy caused flames to be carried upward away from those in danger. Because it is highly flammable, the hydrogen burned very quickly. The remaining five million cubic feet of hydrogen gas aboard the airship was consumed in less than a minute. Further, because there is no soot given off by a hydrogen flame, one has to practically touch it to get burned. Hard to believe, but one couple who had been in their stateroom inside the *Hindenburg's* hull when the fire started, walked out of the charred remains moments later without so much as a scratch. It appears now that hydrogen had little to do with the casualties. Most of the deaths were the result of people jumping from the ship. Over two-thirds of the passengers survived the incident. Indeed, the buoyancy of the yet-to-burn hydrogen gas caused the airship to settle rather than plunge to the ground. These factors seen together surely contributed to so many lives being spared that fateful evening.

Filling Up with Hydrogen

Headquarters for Honda America Motor Company in Torrance, California, with its sprawl of attractive buildings, its sports fields, and its exercise facilities for employees, is more like a college campus than the apex of a multibillion-dollar auto manufacturing enterprise. This is the place where Honda's small fleet of hydrogen-powered, fuel-cell prototype cars is being tested and refined.

An attractively designed, state-of-the-art hydrogen fueling station has been built right on site. Solar photovoltaic panels convert the sun's energy to electricity that is used to produce hydrogen gas by splitting water molecules. Employing this technique, Honda has created a totally pollution-free hydrogen production, storage, and dispensing system.

"This is a showcase for the technology," says Steve Mathison, a young Honda test engineer who often shows off the facility to visiting guests. "We knew a lot of people would be coming in to see this fueling station. When they're *here,* they find out that filling up with hydrogen is not so different than what they do with their own cars"

When asked about safety, Mathison responds enthusiastically. "That was a priority. The facility was designed with safety in mind. This is a learning process for the public. They need to find out that hydrogen can be used with no more risk than they're accustomed to with gasoline."

Because this fueling station is a showcase, Honda has done everything possible to ensure safe operations.

Mathison points out that the fueling process follows a series of steps ensuring safety. "When the nozzle is attached to the fueling port on the vehicle, a locking mechanism ensures a secure, leak-free connection. Once connected, the rest of the refueling process is automated. We also have active sensors to detect leaks as well as a flame detector on site. The system will shut off the flow of hydrogen if a leak or a flame is detected."

The fact that a hydrogen flame is invisible is probably the least safe aspect of its character. But the visibility factor is hardly unique to hydrogen. Drag racers and open-wheel, oval-track race cars have long used alcohol fuel to boost engine performance. There has always been a significant danger associated with such fuels because there is no visible flame when they burn. Natural gas also burns with a very clean flame that is only marginally visible.

It is the presence of carbon that creates soot that causes a flame to be visible and to radiate heat. Alcohol and natural gas both contain very little carbon. Hydrogen represents the final step in the de-carbonization of energy. Because a hydrogen flame contains no carbon, it is invisible to the naked eye. It would be possible to walk into such a fire without knowing it. NASA and chemical manufacturers working with hydrogen used brooms at one time to confirm the presence of a hydrogen fire. This simple, if somewhat perilous, process involved a person holding a broom in front of them, moving toward a suspected hydrogen flame. If the broom caught fire, the presence of a hydrogen fire was confirmed. Nowadays, an infrared flame detector employs an electronic heat sensor to see a hydrogen fire, sound an alarm, and cut off the flow of the hydrogen at the same time.

The Leak Test

Early in 2001, a series of tests were initiated at the University of Miami, School of Engineering at the behest of the Ford Motor Company to determine the comparative safety of gasoline and hydrogen in automobiles. A late-model Ford Escort was used in the study that was designed to identify and compare the consequences of a catastrophic leak and fire under controlled conditions. Led by Professor Michael Swain, a group of students first converted the car to carry a hydrogen tank along with a venting system that might be expected in a commercially available hydrogen-fueled vehicle. In addition to converting the fuel system, Swain's team installed thermal sensors inside the passenger compartment of the car.

On a cool, cloudless January evening, with cameras rolling, the test was initiated. By remote control, a leak simulating a 3,000-cubic-feet-per-minute rupture of the fuel storage system was initiated, followed by the introduction of a spark. The ignited hydrogen vented according to system design through a relief valve port that was centered just behind the rear passenger compartment window and just in front of the trunk's hinge point. The burning hydrogen gas erupted under great pressure from the port, sending a roaring flame seventy feet skyward. The flame continued to vent under high pressure for about forty seconds before the pressure began to drop as the system purged itself of hydrogen. After about three minutes, the system was voided of hydrogen fuel.

Remarkably, in the aftermath, the car was examined and found to be virtually undamaged. Even the paint around the relief port did not peel. The temperature in the passenger compartment during the test had hardly risen at all. A thermal sensor set on the shelf beneath the rear window just on the other side of the glass from the high pressure hydrogen flame never rose more than 7 degrees above ambient temperature. Another sensor placed by the driver's seat registered a temperature rise of less than 3 degrees.

Because the car had not been damaged during the hydrogen leak test, it could serve as the test bed for the second part of the study. A few weeks passed as the car was converted back to its normal, factory-installed, gasoline fuel system.

When the evening came for the second part of the comparative leak study, the car was rolled out and placed in the same position as it had been for the earlier test. With cameras rolling, Dr. Swain initiated the simulated leak of gasoline and ignited it by remote control. The result could hardly have been more different. Within seconds, the car was on fire. After about thirty seconds, the entire vehicle including the passenger compartment was engulfed in flames, with thick black smoke venting skyward. The burning tires soon exploded. After less than two minutes the car was a total loss. Fire extinguishers were used to put the fire out.

Before going further, it should be remembered that this was a controlled test structured to induce a worst-case leak scenario. Dr. Swain is quick to point out that the automobiles designed by Ford and other manufacturers today are built with safety in mind and would not be subjected to the kind of extreme intrusion that was used to trigger the fuel leak in the test scenario. It is extremely unlikely that any similar circumstance could happen under normal driving conditions.

The result of the test with leaked gasoline speaks for itself. Gasoline is flammable and reacted predictably in the test scenario.

How could it have been so different, so much more benign with hydrogen? To understand this, let's recall what happened in the *Hindenburg* disaster. When the Hydrogen caught fire aboard the great airship and also in the car, its lighter- than -air character caused it to vent upward and safely away. Also, because its flame contains no carbon, hydrogen emits very little radiant heat. Thus there was no damage to the car's paint nor was there an appreciable temperature rise in the passenger compartment.

It is useful to know the results of another series of tests conducted by Swain and his students. In this case, they wanted to compare a leak scenario in a closed space like a family garage. After building a sophisticated mock-up of a single car garage, they simulated leaks for gasoline, and then natural gas, and then hydrogen. They found that gasoline would pool beneath the leak point with volatile vapors rapidly spreading across the closed garage space at floor level. Leaked natural gas also stayed at floor level and accumulated while spreading across the space. [However, with time, natural gas does disperse up and away from any leak.] In both instances, a spark would have caused an explosion and fire. When hydrogen was leaked, the result was different. Because hydrogen is lighter-than-air and diffuses at a speed of twenty meters a second, it quickly became diluted and dispersed harmlessly. It takes a four-times-greater minimum concentration of hydrogen than gasoline vapor for ignition to occur. (7) Swain and his team found that, with hydrogen, the source of ignition would have had to be within a few inches of the leak point in order for it to catch fire. This suggests that in a well-ventilated garage, a vehicle carrying hydrogen fuel onboard could be parked as least as safely as the gasoline-fueled vehicles we leave unattended everyday in our garages.

Dr. Swain cautions not to read too much into these test results, but he will say, "The evidence suggests that hydrogen is different but certainly no more dangerous than gasoline, natural gas, and other fossil fuels. And in certain conditions, it may actually be safer."

Ford Motor Company's Hydrogen Safety Report confirms Swain's assessment. "Overall, we judge the safety of a hydrogen FCV [fuel cell vehicle] system to be potentially better than the demonstrated safety record of gasoline or propane, and equal to or natural gas."' (8)

Codes and Standards

For anyone who travels outside the confines of their own country, one of the vexing problems one encounters is the different ways electricity is delivered. In the United States and Canada, power is universally available at 6o cycles per second at 110 volts. In Europe, it is mostly delivered at 50 cycles at 220 volts, and with a number of different plug configurations varying from country to country. This lack of standardization exists for a number of other technologies, particularly those that have been around for more than a few decades. Television has three separate broadcast standards, NTSC, PAL, and SECAM. These acronyms refer to technical specifications. In practice, they mean that an NTSC tape broadcast in the United States or Japan cannot be viewed in England, which long ago adopted the PAL format, or in France, which went with its own SECAM standard. The entire world is a crazy quilt of broadcast standards divided as often as not by the originating country's sphere of influence. It used to be that technologies were not easily standardized because innovators from different countries were more interested in preserving their own way than coming to a consensus based on the "best" way.

In 1946, the International Organization for Standards (ISO) was established in Geneva with the express purpose of establishing universal standards for products and services. Since that time, an increasing portion of the world's technical innovation has been subject to a rigorous and often exhausting process to establish a single universal standard for quality, safety, reliability, *efficiency*, and interchangeability. Participants in this multinational process, in addition to the primary innovators, can include technical and marketing experts, government policymakers, and insurers. Though ISO standards are voluntary, they are widely adopted because in the modern era of global markets, the only way to compete is to adhere to a universally accepted standard.

Whether in Brooklyn, Bangladesh, or Byelorussia, cell phones work pretty much the same way. Manufacturers in Korea, Mexico, or wherever all produce their phones based more or less on the same set of standards.

Safety is a very big part of the establishment of standards. It's in everybody's interest to have products in the marketplace that share common functionality and safety features.

As of 2007, scores of experts from many countries are meeting regularly to hammer out codes and standards for the storage, transfer, and dispensing of hydrogen. Called ISO TC 197, the technical committee working on hydrogen codes and standards is broken down into smaller working groups, each looking at some specific aspect of the entire picture with hydrogen. Some hydrogen standards have already been published. Others are in draft stage or remain in development. The completion of the entire ISO codes and standards process will mark an important milestone on the road to a hydrogen-powered economy. There is every reason to believe that the hydrogen technologies, products, and procedures that are standardized and adopted by the ISO in the next few years will provide end users with the same high degree of reliability and safety no matter where they are in the world.

Hydrogen is different, but certainly not more dangerous than other fuels. Extensive testing and analysis suggest that it may in fact be even safer under many conditions. We've become quite comfortable pumping gasoline into our own cars and living in homes where natural gas is used daily for heating and cooking. There is no reason to think *we* cannot become accustomed to doing the same with hydrogen.

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1 Addison Bain, The Freedom Element: Living with Hydrogen (Cocoa Beach, Florida: Blue Note Books, 2004), 278

2 Susan Leach, “Hydrogen: The Matter of Safety,” educational booklet, (2000) http://www.hydrogen2000.com

3 Science App;lications Internatinal Corporation, “Hydrogen Infrastructure, Reliability, R & D needs” (2004), prepared for U.S. DOE, http://www.netl.doe.gove/technologies/oil-gas/publication/td/final%20White%20paper%20072604.pdf

4 Ford Motor Company, “Direct Hydrogen Fueled PEM Fuel Cell System for Transportation Applications: Hydrogen Vehicle Safety Report” (May 1997), prepared for U.S. DOE, Office of Transportation Technologies, Report DOE/CD/50389-502

5 Bain

6 IBID

7 Amory Lovins, “Twenty Hydrogen Myths,” research paper, Rocky Mountain Institue (Sept. 2, 2003)

8 Ford Motor Company, “Hydrogen Vehicle Safety Report”

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Chapter 17: The INTERNET of Energy

Four percent of the vehicles in California represent more [electric power] generating capacity than the entire stationary capacity of California, and that means you've got twenty-five times the generating capacity of California running around on the streets," says Geoffrey Ballard, the Canadian-based entrepreneur who is considered by many as the father of the commercial fuel cell. "If you convert those cars from gasoline-powered engines into hydrogen-fuel-cell-powered engines, you suddenly have twenty-five times the electric generating capacity running around the street and no terrorist can tackle that infrastructure."' (1)

What Ballard is talking about is an exciting prospect that is enabled specifically by the unique character of hydrogen and the fuel cell. Because the power from a fuel cell is delivered in the form of electricity, a fuel-cell-powered car is essentially a mini-power plant on wheels.

Ballard is barely able to contain his enthusiasm: "The car is usually where we want to be. We go by car where we want to be and the car can plug back in and provide electricity into a building or into the grid. So there's a huge surplus of generating capacity for electricity the minute we move toward a hydrogen-powered fuel-cell automobile."

Another champion of this visionary distributed-energy concept is Amory Lovins from the Rocky Mountain Institute. "One of the advantages of integrating deployment of fuel cells in vehicles and buildings is that you can treat the vehicles as power plants on wheels and when they are parked, use them as power plants that sell electricity back . . . to the grid, thereby earning back most of the cost of owning the car" (2)

Let's say there are twenty fuel-cell cars sitting idle in an office building parking lot during the workday. And let's say each car has a fuel cell rated at 100 kilowatts. That's two megawatts of generating capacity sitting idle. What if the parking spaces in the building are equipped with a supply line that can feed hydrogen to the vehicles while they are parked, and what if there is a hookup for each car that allows electricity generated by the fuel cells in the idle cars to be fed into the utility grid? And what if there were Internet-like control protocols that managed the collection of power from the idle cars and automatically credited the owners of the vehicles for the use of the generating capacity of their parked cars? Those two megawatts of power generated by those parked cars are two megawatts that displace an equal need from a big utility power plant.

"So, it doesn't take many people liking the value proposition of a garage paying *you* to park there, to put the utility's nuclear plants out of business," says Lovins. "The hydrogen economy could profitably deal with up to two-thirds of the climate problem: not just the vehicle part, but also the power plant part, and a lot of associated furnaces and boilers and so on, that could all be displaced by climate-safe technology and at lower cost [which is the transportable fuel-cell power plant that is your car]."

Lovins acknowledges that fleet vehicles may be the quickest way of getting large quantities of fuel-cell vehicles on the road. But he also sees a pathway for the public to make the transition by leasing fuel-cell cars to people who work in buildings equipped to use their idle power generating capacity:

> Cars are parked about 96 percent of the time. You would be delivering the power at the time and place where it's most valuable to the utility, namely, at your workplace during the middle of the day. Now, it turns out that this is a really big deal,

> because about every fifteen months worldwide, the prime mover capacity of the light vehicles we produce equals the total installed capacity of the world's electricity system. Historically, that wasn't very important because power plants are designed to run for about thirty years, and cars only for a few thousand hours before their engine wears out. But with fuel cells, running on pure hydrogen, you have the option, at a modest extra cost, to make them durable enough to run for a very long time. So, if you use even a small part of the generating capacity in the [privately owned auto] fleet, you can displace all of the polluting and costly power plants that are now also increasingly vulnerable to disruption, including by terrorism ... A full fleet of U.S. cars and light trucks doing this would have about six to twelve times as much generating capacity as all the power companies now owned.

There is a system already running on the Internet that works just this way. And again, we are brought to SETI, the Search for Extra-Terrestrial Intelligence. As related in the sidebar in chapter 10, hydrogen provides the means for seeking radio signals from other intelligent life in the universe. Because the sky is so vast, huge quantities of data are received, all of which must be analyzed in hopes of finding an intelligent signal. The amount of computing power required to conduct this analysis in a thorough and timely fashion would have been prohibitive both in cost and in amount of dedicated computing power. Dr. Frank Drake and his SETI team came up with a unique and bold solution to their problem.

They used the internet and enlisted the use of desktop computers sitting in offices and homes around the world to process the raw data acquired in their search of the skies. Millions of recruited volunteers provide access via the Internet to their computers. A SETI-designed program is installed in each of these volunteer computers as a screensaver. When these lent computers are not serving their owners, they revert to their screensavers that automatically download and process raw SETI data. This borrowed computer processing power dramatically expands SETI's ability to process deep-space data input.

Applying the concept to the production of electricity, you get what's been coined the "Internet of Energy." Imagine for a moment what such a system would be like when fully implemented. At home, your fuel-cell-powered car is parked in the garage. It has an input receptacle mounted behind a small hatch near the front of the vehicle. In the garage, there's a standardized service unit about half the size of a refrigerator. This unit is linked to the house's electrical system and the electric grid that serves the house. It contains an electrolyzer for splitting water into hydrogen. This hydrogen is stored for use on demand. A hose from the service unit has a plug that fits the standardized receptacle on your car. The plug includes a port for delivery of a low-pressure flow of hydrogen to the vehicle, a connector to receive electricity generated by the vehicle's onboard fuel cell, and a data-link connecting the onboard computer with the service unit's computer. In these types of scenarios, you not only plug your car into your house, as you do with a battery electric vehicle, but you also plug your house into your car!

When plugged in, the service unit automatically assures a leak-proof seal of the dispensing line, and then initiates the flow of hydrogen to the car. The incoming hydrogen is converted by the vehicle's onboard fuel cell to electricity that flows out through the hose to the service unit. If needed, the electricity is used in the house; if not, it is sold directly to the public power grid. Of course, if you have a primary energy source such as solar panels on your roof, or wind turbines on your property, the electricity could be put onto the grid directly at the appropriate times when needed. This is currently done with some solar roof programs being implemented around the country.

In the interconnected scenario with a fuel cell, the fuel cell can provide "peak" power when electricity is most expensive by using hydrogen that was generated with "off-peak" or less expensive electricity.

When you leave your house, perhaps you'll go to the store, the doctor's office, or to work. In a fully developed system, most places you go with your car will be integrated into the energy net. In the parking lot of the doctor's office, you link your vehicle to the system via a service post at each parking slot. Once hooked up, hydrogen flows into your car, electricity flows out. Multiply this by tens of millions of vehicles all standardized to operate on the system; one begins to sense the transformative nature of this technology.

It is hydrogen and fuel-cell technology that makes the "Internet of Energy" possible. In essence, hydrogen and electricity become two sides of the same coin. Geoff Ballard calls this interchangeable energy currency ***hydricity***. "I think we'll move quickly to what we'll call the hydricity age and that's when you get the blending of hydrogen and electricity and [they can be used interchangeably and] you can't distinguish between the two."' (3)

"Power plants are now cheaper [to replace] than the grid, and more reliable than the grid," says Amory Lovins. "Ninety- eight or 99 percent of our power failures originate in the grid. Therefore if you want reliable, affordable power supplies, you have to produce power at or near the customers ... in a decentralized fashion. That happens to be ideally suited to [the linked use of idle automotive] fuel cells"

The Internet of Energy concept is truly awesome in scale. The prospect of replacing the mostly fossil-fuel-powered, utility-based electric power generating we rely on today is daunting to say the least. But the decentralized Energy Internet can be deployed over several decades as a patchwork that, with infill, will increasingly link together. It's worth recalling that the computer Internet hardly existed little more than twenty years ago. In that short time, it has mushroomed in size and sophistication, linking the world and human culture in ways that one can only begin to understand. The Energy Internet scenario described could play a role in the application of "distributed" power that is being implemented worldwide; that is, power is being generated closer to where it is used, closer to the customer, with more local control.

The Hydrogenics Corporation based in Toronto has staked a big part of its future on the Energy Internet. Pierre Rivard, the company's CEO, sees the time and money invested as well spent.

> This will make fuel-cell cars more affordable sooner as opposed to just displacing an incumbent [internal combustion engine auto] technology that is very difficult to compete with on a cost basis after a hundred years and multibillion dollars' worth of research going into it. So, the solution is to bundle features ... so that you're offering more than just replacement power in the car. You're offering . .. features that would not be achievable with any other technologies but the fuel cell in the hydrogen economy. And with that, you make things more efficient because then you get the [electric power] grid financed by [consumers buying fuel-cell cars], which means the long-term [government] bonds used to finance nuclear plants and large fossil plants are no longer required. It's also an opportunity for developing countries to leapfrog the old electrical generation technologies that *we* are stranded with in the developed countries. (4)

Amory Lovins could hardly agree more. "The general trend of decentralizing the electricity business, moving the power plant from the remote central station hundreds of miles away to your basement, backyard, rooftop, and office . . . is a perfect fit to fuel cells and the hydrogen economy."

Imagine, each and every one of us driving a fuel-cell car will become an energy entrepreneur, plugging our personal mobile power plant into the "net" wherever we park, serving society's electric power needs, and earning money in the process. One day, the entire world could be linked this way. With the ever-worsening crunch on oil supplies and the looming threat of global climate change, one can't help but ask why a concept like the Internet of Energy isn't on the minds of energy policymakers the world over.

The Super Grid

On August 14, 2003, a power plant in Ohio suddenly shut down, overloading high voltage lines on the electric grid spanning the northeastern United States and Ontario in Canada. The entire system short-circuited with 265 power plants being knocked off-line, leaving New York City and much of the surrounding area, about 24,000 square miles, without power for several days. (5)

Over the past hundred years, the North American power grid has come together as a patchwork of interlinked high voltage lines. Millions of kilometers of high-capacity wire, each carrying as much as 765,000 volts, crisscross the continent tying much of the power-generating capacity of North America together. The system depends on the cooperation of dozens of utilities. At any given time, the grid must deliver exactly the amount of power demanded by customers, and not one bit more. With demand for electricity expanding at about 2 percent annually, the aging North American power grid is stuck perilously close to its breaking point, barely able to keep up.' [(6)]

The Electric Power Research Institute [EPRI] is a nonprofit energy and environmental research organization based in Palo Alto, California, funded largely by the U.S. public electric utility industry. EPRI founder Chauncey Starr and his colleagues have coined the term "Super Grid" to describe their bold vision for the twenty-first century. The EPRI Super Grid vision recognizes that The Super Grid will use superconducting transmission cables, each capable of carrying up to five gigawatts. Just four of those cables could carry the entire generating capacity of China's gigantic Three Gorges Dam. The current power grid averages about 10 percent loss just from resistance in the wire. By contrast, superconducting cables offer no resistance and thus experience no loss during transmission.

To achieve superconductivity, transmission lines must be maintained at extreme cold temperatures. How does the Super Grid manage this feat? By encasing the lines in a pipe filled with liquid hydrogen [LH_2 at minus 412 degrees E Chilled to that temperature, there is no resistance when electricity is transmitted.

EPRI's vision for the Super Grid calls for an underground energy corridor that would carry high-voltage, superconducted electricity and also serve as a means of transmitting LH_2 to wherever it is needed. Assuming the system has a forty- centimeter diameter pipe filled with LH_2 it would be capable of storing a lot of hydrogen. In fact, the hydrogen stored in a 7o-kilometer long section of the system would be convertible to about 32 gigawatt-hours of electricity." [(7)]

Chauncey Starr believes his Super Grid vision is the right answer for North America's energy future. "If terrorism remains a risk, all major parts of the system could be underground. [If hydrogen fuel cells eventually] replace the internal combustion engine, the reduction of U.S. dependence on oil imports might radically change our foreign policies and commitments. The long term consequences might make the Continental Super Grid a twenty-first century equivalent of the Panama Canal or the first transcontinental railroad."' [(8)]

Without a doubt, the Super Grid is a public works project of enormous scale. The cost of a continental-scale system is estimated at one trillion dollars. Of course, the investment would be spread out over the hundred years it might take to be fully realized. And, put in perspective, one trillion dollars is a reasonable estimate of the value of the overstressed power grid currently serving North America. It is also less than the amount of money consumed by America's most recent oil-driven military venture in Iraq.

EPRI's conception of a Continental Super Grid is a splendid complement to the vision for an Internet of Energy. Together, they allow a broadly diverse mix of primary energy sources like wind and solar to be integrated seamlessly with the generating capacity of parking lots filled with idle fuel-cell cars. The result is a twenty-first century energy system capable of delivering both hydrogen and electricity as interchangeable energy currencies, whenever and wherever needed.

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9 Geoffrey Ballard interview by Geoffrey B. Holland on June 20, 2003
10 Amory Lovins interview by Geoffrey B. Holland on Sept. 7, 2003
11 Ballard Interview
12 Pierre Rivard interview with Geoffrey B. Holland on Jan. 4, 2003
13 Paul M. Grant, et al, “A Power Grid for the Hydrogen Economy (June 30, 20006)
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Chapter 18: Misconceptions

Whenever a change takes place from the old to the new there are bound to be concerns tend to be magnified by those who are heavily invested in the status quo, for whatever reason. Generally, the bigger the transition, the more formidable are the forces lined up against it. The move away from the fossil energy era toward the age of hydrogen is a big deal. It will likely be the greatest of all energy transitions, and it may end up being viewed historically as one of the most important, if not the most important, cultural turning points of all time. Much of the antagonistic chatter about hydrogen comes from those people whose vested interests are mired in the past.

Just the same, there are a few issues about hydrogen that have gained traction and need to be addressed. The first and most obvious relates to the safety of hydrogen. This is important enough that it was reviewed thoroughly in chapter 7. That complete extended coverage, *we* hope, will have already assuaged any anxiety the reader may have about comfortably coexisting with hydrogen. Hydrogen safety is a concern, but it is certainly no more of a problem than gasoline and other forms of liquid or gaseous fossil energy.

We now briefly examine several other issues where a bit of reassurance may be in order.

Myth: Hydrogen Is a Pollutant

In 2003, an article published in *Science* magazine made a startling claim. Researchers from the California Institute of Technology suggested that widespread use of hydrogen - assuming a 10 to 20 percent leakage rate from pipelines, production facilities, and end users - could result in a tripling of hydrogen escaping into the upper atmosphere where it could combine with free oxygen, dramatically increasing atmospheric water vapor. [1] This increase in water vapor could then interfere with atmospheric ozone chemistry, resulting in longer-lasting ozone holes over the planet's polar regions. After this study was published, some in the media seized on it and attempted to exploit it as proof of the hidden cost of the hydrogen economy.

There are a couple of problems with the media reporting on this study. First, the scientists who did the study *were* careful to point out that little was known about what happens when hydrogen does escape into the atmosphere. It is possible that the natural cycling of free hydrogen atoms may cause them to end up sequestered in the soil, instead of making chemical mischief high in the sky.

The fatal flaw in this study is the assumption on which it is based. The assertion that 10 to 20 percent of hydrogen could escape from a globally functioning hydrogen infrastructure is overstated ... hugely overstated.

"The systems we work with to produce, store, and distribute hydrogen are extremely well designed," says Jeff Richards, manager of hydrogen production for the Praxair Plant in Ontario, California. "It would be a big surprise if we experienced even a one percent loss from the production process right through to delivery to our customers. *We* know how to manage hydrogen. The standards we follow have very little tolerance for product loss. There is no reason to think that scaling up the use of hydrogen will result in greater losses in the future." (2)

The wind appears to have gone out of the sails of this controversy since it was first reported in 2003. A rash of critical commentary followed its publication. Nothing of consequence has come out on the subject since.

Myth: Hydrogen Is Not Economically Feasible

At one time, when the price of gasoline was under two dollars a gallon, the argument was commonly made that hydrogen couldn't compete. It was too expensive. That may have been literally true, but hardly a fair comparison. Where gasoline is concerned, the price at the pump has reflected its true cost. Consider the cost to the economy when exporting nations cut the supply of oil to the rest of the world. In his March 2006 testimony before Congress, Milton Copulos, president of the National Defense Council Foundation, stated, the [oil] supply disruptions of the 1970s cost the U.S. economy between $23 trillion and $2.5 trillion. Today, such an event could carry a price tag as high as $8 trillion—a figure equal to 62.5 percent of our annual GDP or nearly $27,000 for every man, woman and child living in America." (3)

The public is not aware of the actual cost of our oil dependence, according to Copulos, because these costs are not reflected in the price we pay at the pump. "The principal reason why we are not fully aware of the true economic cost of our import dependence is that it largely takes the form of what economists call 'externalities' that is, costs or benefits caused by production or consumption of a specific item, but not reflected in its pricing. It is important to understand that even though external costs or benefits may not be reflected in the price of an item, they nonetheless are real."

The National Defense Council Foundation has done exhaustive studies of the hidden costs of our oil dependence. These costs include direct and indirect economic costs, oil supply disruption impacts, and military expenditures.

Copulos summed up our oil dependence this way:

> Because the price of crude oil is expected to remain in the sixty-dollar range this year, expenditures for imports are expected to be at least $320 billion this year. That amounts to an increase of $70 billion in spending for foreign oil in just one year. That increase would raise the total import premium or 'hidden cost' to $825.1 billion ... This would bring the 'real' price of a gallon of gasoline refined from Persian Gulf oil to $10.86 [per gallon]. At these prices the 'real' cost of filling up a family sedan is $217.20, and filling up a large SUV $325.80.4 (4)

It's important to note that the avoided costs tallied by the National Defense Council Foundation do not include the substantial, externalized health costs of air pollution or the environmental costs directly linked to the burning of fossil fuels.

Even when all the externalized costs are disregarded, the price of oil is still increasing. The days of two-dollar gasoline are gone. As of this writing, the cost of regular unleaded in the United States is hovering around $3.50 a gallon. With the supply of oil expected to chronically lag behind demand, the price at the pump will surely go higher - maybe a lot higher.

By comparison, hydrogen as a fuel does not suffer from any of the hidden costs that plague oil. Hydrogen is nontoxic and it does not pollute. It has no health or environmental costs, except for those associated with the manufacturing of the hardware for the hydrogen infrastructure. And the amount needed for hydrogen is a lot less than has been required for oil.

A hydrogen economy also means that virtually all military costs and concerns about politically motivated energy supply disruptions would be eliminated. The United States is far less likely to risk American lives and taxpayer dollars on military adventurism in the Middle East when it is not dependent on that region for energy.

As was pointed out in an earlier chapter, the evidence suggests that when economies of scale kick in with hydrogen, its price will drop to a level well below what people are currently paying for gasoline. Even when the massive hidden costs of oil are disregarded, the economics of hydrogen are going to be very favorable to the consumer.

Hydrogen energy systems are inherently simpler than other fuel systems. It is a carbonless fuel; therefore, downstream pollution prevention systems are eliminated. Renewable hydrogen used in a fuel-cell drivetrain is truly pollution free. No other energy system can make this claim. Also, it is important to point out that it is the lifecycle cost of a system that is important, not the upfront capital cost of the equipment, or the cost per gallon of gasoline equivalent energy content (gge). What is important to the customer is how much does it cost to travel each mile? With fuel-cell cars being two to three times as *efficient* as gasoline cars, hydrogen can sell for two to three times the price per gge.

Renewable hydrogen is the only fuel where the cost can be guaranteed. The cost of hydrogen generated through electrolysis, using electricity from renewable energy sources, is directly related to the cost of the electrons. If you know the cost of your electrons, then you know the cost of your fuel. As the capital cost of renewables comes down, so will the cost of hydrogen. No other fuel holds *that* promise. Hydrogen can *only* get less expensive with time.

Myth: The Natural Gas Supply Is Inadequate for a Transition to Hydrogen

Job one is to cut greenhouse pollution in a very big way, and it needs to happen now, not decades from now. Natural gas is the path of least resistance for hydrogen, for good reason. A robust gas infrastructure has been in place for more than half a *century*. There are few places across the United States where gas is not readily available. Natural gas is the feedstock for producing the 4o million tons of hydrogen currently used annually by industry worldwide.

David Hart, an energy technology analyst at the Centre for Energy Policy and Technology, Imperial College, London, in a study commissioned by Linde Industrial Gases, determined that a distributed network of just under 3,000 gas-reforming, hydrogen-fuel dispensing stations could be put in place over all of Europe for a cost of about 3.5 billion Euros. If the mandate and funds were available, Hart believes the entire network could be in place in just a couple of years. The same circumstance applies to the United States, and probably also to Japan, and maybe even China. Layering the initial generation of hydrogen-fueling stations on top of the nation wide natural gas delivery system allows a rapid ramp-up of the hydrogen-dispensing infrastructure at relatively modest cost.

While the evidence suggests we have passed the peak in natural gas production in North America, there is a lot of gas available in other parts of the world. But getting it to customers in North America could be very costly. It will carry the same kind of burdensome political baggage we have now with oil, and it will rely on an LNG delivery system that could be seriously undermined by even a single accident or terrorist attack.

Just the same, the overriding focus must be on global warming. The world must begin to replace vehicles powered by gasoline, diesel, and other carbon-based fuel supplies with vehicles that operate pollution-free as soon as possible.

In fact, the first big piece of this puzzle in the United States is already coming together in California where the California Hydrogen Highway Network launched by Governor Arnold Schwarzenegger is setting up hydrogen- dispensing centers in all of the state's major cities and along its interstate highway corridors.

What of the natural gas supply crunch coming down the line? Does it mean the investment in natural-gas-fueled hydrogen-fueling stations will inevitably become a gigantic stranded asset? No. Cellulosic biomass can be fermented to produce biogas instead of liquid ethanol. Syngas from coal will also work, though it would be foolishly counterproductive unless the carbon generated in the process were sequestered permanently. Biogas and syngas, deliverable through the natural gas distribution system, are both quality feedstocks for steam gas reforming to hydrogen.

Here is the bottom line: at this time, reforming natural gas is the most convenient and most accessible way to launch the hydrogen age. Over the longer term, first-generation, natural-gas-based reforming systems for producing hydrogen will gradually be replaced by systems that produce hydrogen via water electrolysis using renewable clean, sources of energy.

Myth: The Water Supply Is Inadequate for a Transition to Hydrogen

Absolutely not so. A little over two gallons of water breaks down via electrolysis to about a gallon of gasoline equivalent of hydrogen. It takes a lot more water than that to refine a gallon of gasoline.

According to research scientist John Turner from the National Renewable Energy Laboratory in Golden, Colorado, if the entire light-duty vehicle fleet in the United States about 230 million vehicles - were powered by fuel cells, the water required to supply the hydrogen fuel would be on the order of 1oo billion gallons annually. Compare that to the 300 billion gallons that currently go into the yearly production of gasoline. Just to put those numbers in perspective, 70 trillion gallons annually are consumed in the United States by the thermoelectric generation of power, and the domestic personal use of water amounts to 4,800 billion gallons. [53]

Myth: Storage On Board Vehicles Is Inadequate

There are certain performance standards that motorists look at when they visit auto showrooms. One of them is range. People have grown accustomed to getting around 300 miles between fill-ups. One of the standard arguments used by hydrogen critics is that there is no way to store enough hydrogen onboard an automobile to give it 300 miles of range. There was a time when that was true. Not anymore.

Since 2002, Quantum Technologies has marketed commercially available, compressed-hydrogen storage systems for auto applications that provide 300 miles of range. The carbon-fiber-wrapped tanks that hold the hydrogen are designed to function at 23,000 psi but are operationally limited to 10,000 psi. [6] These tanks have been tested rigorously to assure their safety even in the most extreme crash simulations. Moreover, because the valve that controls the pressure is mounted inside the tank, the hydrogen pressure in the feed lines connected to the tank is reduced to the low operational pressure inside the car's fuel cell. These tanks, whose design was inspired by the space program, meet ISO and other applicable safety specifications and are already approved for use worldwide. The latest General Motors fuel-cell prototype, the "Sequel," has a range rated at 300 miles thanks in part to the Quantum Technology hydrogen- compressed hydrogen storage tank nestled within its chassis.

Other storage technologies like metal hydrides are also advancing rapidly and, if the promise of nanotechnology for storage is fully realized, drivers could find themselves in need of a fill-up only a few times a year.

Hydrogen Is An Energy Carrier

A statement appears occasionally in online discussions, popular documentaries, and general consumer magazines saying things like, "Hydrogen is only an energy *carrier*, it's not an energy *source. So*, where is the energy coming from?" This is leveled as a criticism of hydrogen when in reality it is one of the best attributes of hydrogen. It is a good thing that hydrogen is an energy carrier. An energy carrier is what one needs if one is looking for a transportation fuel. Gasoline is an energy carrier. But gasoline can only be made efficiently from fossilized, hydrocarbon feedstock like oil. Hydrogen, on the other hand, can be produced from electricity generated from any source, including inexhaustible resources like sunlight and wind. Hydrogencan also be made from organic material. Hydrogen has may feedstocks. Can other fuels make the same claim? Not to the extent that hydrogen is able to do so. Since life began, hydrogen has served as a uniquely efficient energy carrier for biological systems. It is poised to play the same highly effective, envornmentally friendly role for humanity.

Myth: Hydrogen Is Inefficient

When the storage issue is raised, there are those who will point out that it takes energy to compress hydrogen for storage, and that it takes even more energy **to** superchill hydrogen into liquid form. To that, we can only say, "You're right" Amory Lovins points out in his excellent overview of hydrogen, titled *Twenty Myths About Hydrogen,* that "any conversion from one form of energy to another consumes more useful energy than it yields"

Lovins compares the efficiency of oil to hydrogen, noting that an analysis by Toyota indicates that 88 percent of oil at the wellhead ends up as gasoline in one's car. By the time the energy in that oil is converted to work at the wheels of a typical modern car, the well-to-wheels efficiency is down to around $_{14}$ percent. On the other hand, says Lovins, "locally reforming natural gas can deliver $_{70}$ percent of a gas wellheads energy into the car's compressed hydrogen tank." When hydrogen is converted to electric power in a fuel-cell car’s 60-percent efficient drive train, the well-to-wheels efficiency ends up being about 42 percent. [(7)]

In general, arguments about efficiency are mostly irrelevant, especially when perpetual energy sources like the sun and wind are utilized. What matters ultimately is whether or not the cost of said inefficiency is acceptable to the end user. "If [inefficiencies] were intolerable as a matter of princi ple," writes Lovins, "we'd have to stop making gasoline from crude oil" [(8)]

How many people stop and think about where the gasoline they are putting in their car comes from? What would they think about the efficiency of having to drop a drill through nine thousand feet of water, and then grinding through another 20,000 feet of rock to get to the latest crude oil find in the Gulf of Mexico? Then, after pumping it out, the oil has to be moved to shore, processed into gasoline at a refinery, and then delivered by truck to filling stations around the country. How much does it cost to do A that? Is that efficient?

In fact, the issue of efficiency with gasoline rarely comes up because drivers, even though they will surely gripe about high prices, have always been willing to step up and pay the price they find at the pump.

In direct, unbiased comparison with other forms of energy, all factors considered including efficiency, hydrogen comes out on top every time. Again, efficiency is not applicable to the customer. What is important to the customer is what it costs to travel each mile. The customer does not care if fuel delivered to the station carried only 1 percent of the original energy content of its feedstock, as long as it competes with other fuels on cost per mile and environmental benefits.

Is Hydrogen Perfect?

The short answer is, no. In nature as in life, perfection is a goal that is entirely noble, yet never truly attainable. However, where energy carriers are concerned, hydrogen does appear very much to be as good as it gets. Were that not so, how could it be that hydrogen plays such an essential role in both the physics of the cosmos and the biology of life on Earth? Because there is hydrogen, there is a universe, there are stars, and there is life. Hydrogen truly is the grand enabler. It is the ultimate common currency, the elegantly simple answer that brings all the ways of producing energy into a whole that reflects the efficiency and grace of nature's design.

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A CONTRARY VIEW

For a look at the other side of the hydrogen fuel debate check out this article from the Sept. 6, 2008 Economist Magazine.

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BIONEERS, http://www.bioneers.org/

CALIFORNIA FUEL CELL PARTNERSHIP, http://www.cafcp.org

CALIFORNIA HYDROGEN BUSINESS COUNCIL, http://www.californiahydrogen.org/

CANADIAN HYDROGEN ASSOCIATION, http://www.h2.ca

CHINA ASSOCIATION FOR HYDROGEN ENERGY, http://www.chinahydrogen.org/

CLEAN AIR NOW, http://www.cleanairnow.us

COMMON CAUSE, http://www.commoncause.org

CONSUMER REPORTS GREENER CHOICES: PRODUCTS FOR A BETTER PLANET, http://www.greenerchoices.org

EUROPEAN HYDROGEN ASSOCIATION, http://www.h2euro.org/

FUEL CELL WORKS, http://www.fuelcellsworks.com

FUEL CELLS 2000, http://www.fuelcells.org/

HYDROGEN & FUEL CELL LETTER, http://wwW.hfcletter.com/

INTERNATIONAL CLEARINGHOUSE FOR HYDROGEN COMMERCE, http://Www.hydrogencommerce.com

INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION, http://www.theicct.org

INTERNATIONAL PARTNERSHIP FOR THE HYDROGEN ENERGY, http://www.iphe.net/links.htm

NATIONAL HYDROGEN ASSOCIATION (UNITED STATES), HTTP://WWW.hydrogenassociation.org/

NATIONAL RENEWABLE ENERGY LABORATORY, http://www.nrel.gov /

NEW AMERICA FOUNDATION, http://www.newamerica.net

THE CIRCLE OF SIMPLICITY, http://www.simpleliving.net

THE ENERGY BLOC, http://thefraserdomain.typepad.com/energy

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