A collection of news articles, and reports, setting to rest, once and for all, the facts about fuel cell products:

The Thing That a Couple of Technology Billionaires Will Do Anything To Sabotage

- Certain, known, technology billionaires spend billions of their dollars, per year, flooding blogs with anti-hydrogen lies because they don't have the products to beat it in the competitive market place. Their tactics are detailed in the feature film, ***The Merchants of Doubt,*** available now on **Netflix** and other Movie-on-Demand sites

- Some battery VC's, who are campaign financiers, have put moles in competitors, bribed senators and black-balled start-ups to keep you, the public, from getting clean energy-products

- Now the FBI, The U.S. Senate, and the entire Japanese and European auto industry have called these *"Solyndra-scammers"* out and the Hydrogen cars are now on sale! The world has said: ***"The lying Lithium battery billionaires are full of BS!"***

Here are the federally, and university, proven facts:

Lithium-ion batteries blow up spontaneously. They set homes, offices and planes on fire and have crashed multiple jets. They release cancer-causing, brain damaging, fetus mutating fumes when they burn. They kill the factory workers and nearby towns, where they are made, due to deadly toxins used in making them. They cause one to invade other countries in order to make them. They poison the Earth when they are manufactured and when they are disposed of. A "certain" group of Silicon Valley campaign financiers pushed for the invasion of Afghanistan, and Bolivian political fractures in order to take over the lithium mineral mines for their monopoly of these batteries. Those billionaires **"War Profiteered"! And paid** U.S. Senators with stock in their companies related to lithium ion batteries.

The greedy VC's didn't do their homework. They didn't see that the lithium ion was such a disaster. They only saw dollar signs. They now spend over a billion dollars per year to sabotage, troll, meat puppet and anti-blog any competing sustainable energy technology because..MONOPOLY!

So that idea "blew up", literally. A famous battery car billionaires is, point-blank, **LYING** about hydrogen and fuel cells in order to protect his lithium battery Afghanistan mining scam.

So What's next?

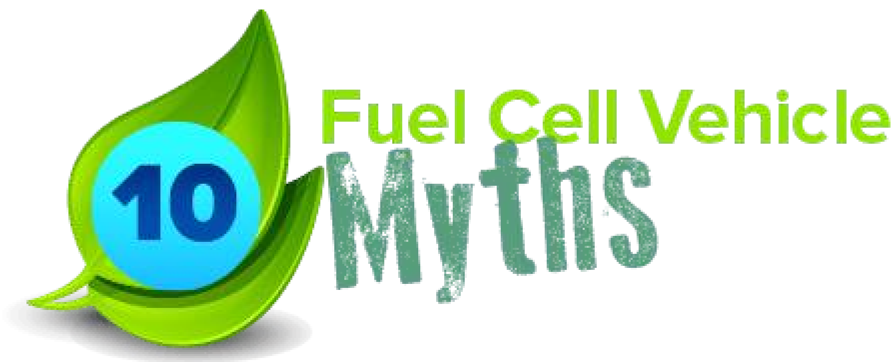
Wouldn't it be cool if you could provide the fuel stock, for the next generation of automobiles, from the water and waste materials that you generate at home?

Wouldn't it be cool if you could drive your next generation car across the nation with fuel you can carry on board, or pick-up from any grocery store?

Wouldn't it be cool if the only waste material that car gave off was simple water?

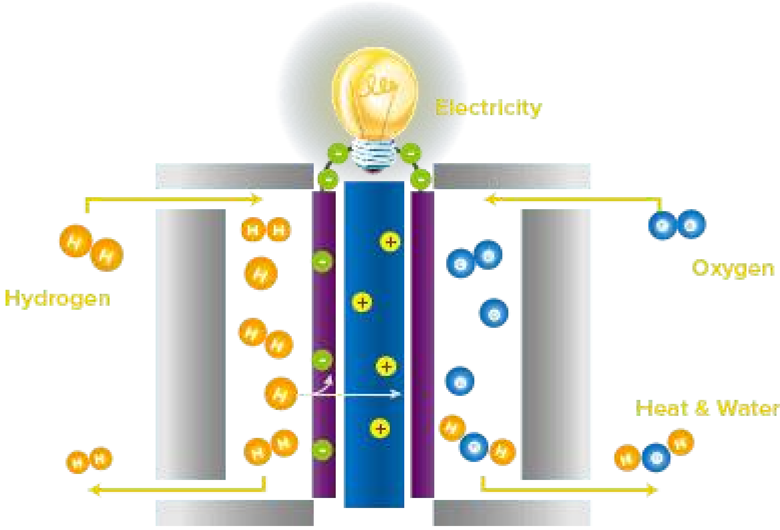
WELCOME TO COOL! WELCOME TO GETTING: BACK TO THE FUTURE! WATCH THIS VIDEO:

https://videos.files.wordpress.com/GlyLVuI9/toyota-fuel-cell_fmt1.ogv



With Toyota and others offering fuel cell powered vehicles in 2015, it's time to tackle some myths about fuel cells and the vehicles that will use them.

Myth #1: Fuel Cell Vehicles Burn Hydrogen

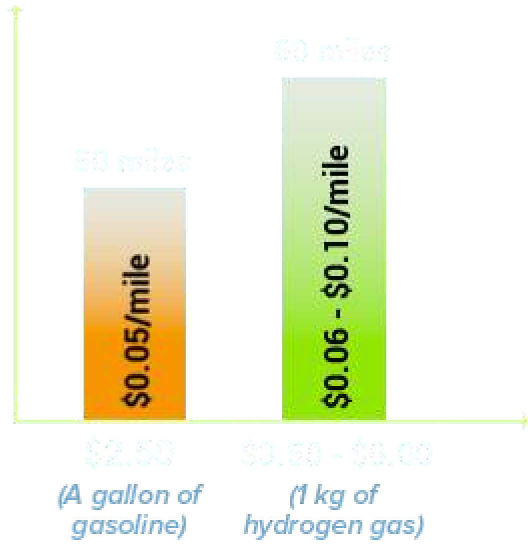


Fuel cells don't burn hydrogen - they use an electrochemical process to convert hydrogen and atmospheric oxygen into electricity and water. They have no moving parts and no open flames.

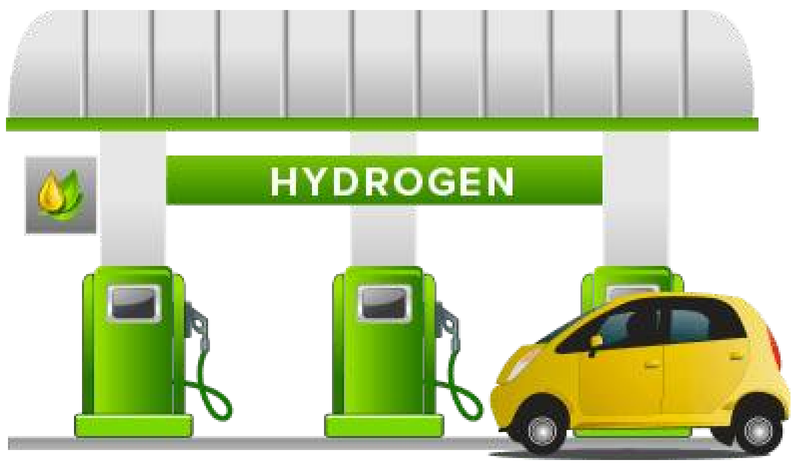
Myth #2   Fuel Cell Vehicles Are Expensive

This *used* to be true - a prototype 2007 Toyota FCV reportedly cost more than $1 million dollars to build.

However, recent advances in fuel cell manufacturing and catalyst performance have led to a dramatic cost decrease. According to the US Dept. of Energy, fuel cells will cost $30-$50 per kw of output by 2020, depending on production volume. To put this number in perspective, Tesla battery packs are estimated to cost over $250 per kw-hr of capacity today and may fall to $196/kWh by 2018. Some optimists belive battery pack costs could fall to $100/kWh by 2025, while others believe battery pack costs will fall no lower than $167/kWh by 2025. The point? A mid-sized car with a 60kWh battery pack will likely cost more than a similar sized car with a 125kW fuel cell, all things being equal. Fuel cell cars might not be "cheap," per se, but they likely won't be any more expensive than battery powered vehicles (and could be a great deal less).

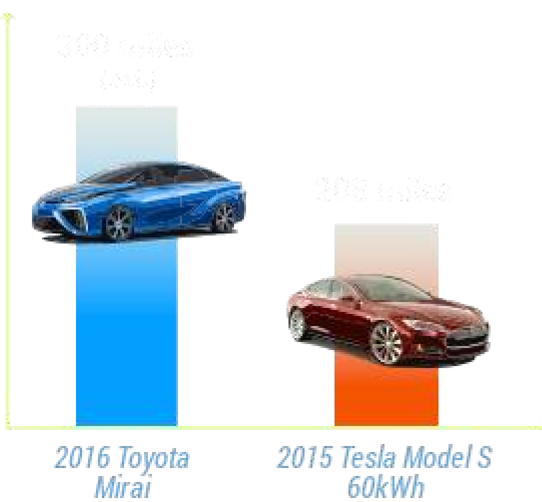


Hydrogen Costs less, is cleaner, and can be acquired from more sources than anything else:



You can fill up just like any car on Earth PLUS in many new ways

The entire supply and creation chain can be 100% clean



Hydrogen cars beat lithium battery cars on range, weight, safety, flexibility, fire issues, and hundreds of other metrics. In fact, lithium battery cars can't beat fuel cell cars on anything

myth #10 Fuel Cells Are “BS”

Elon Musk, with much of his personal wealth invested in lithium ion battery-electric car technology, says rival fuel cell vehicle technology is "BS."

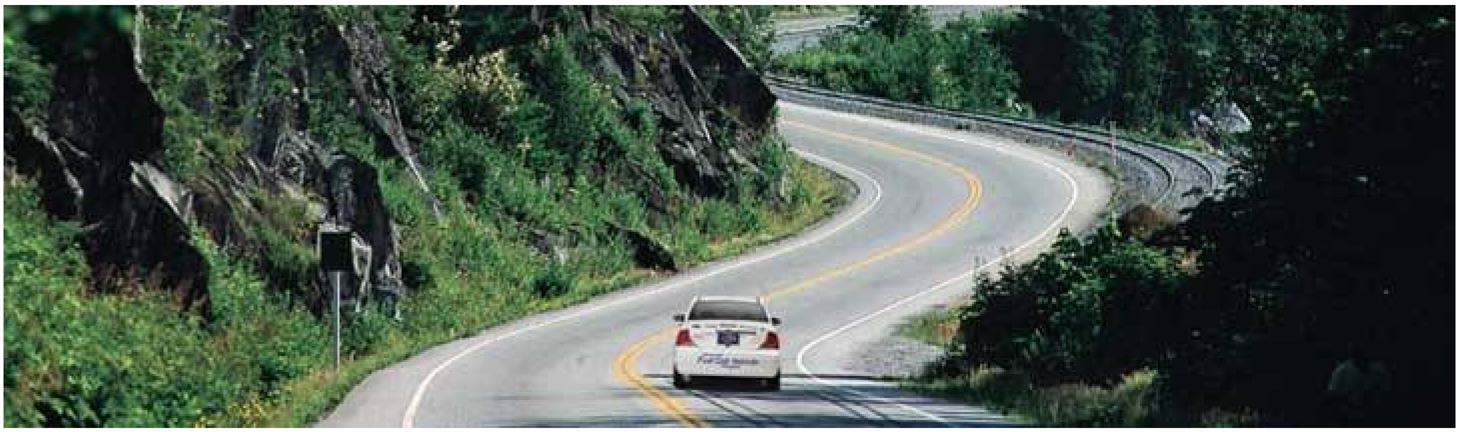
Tesla's Elon Musk once famously quipped that fuel cells are "so BS." Considering Musk's reputation as an innovator and his success with Tesla, many people have taken this comment at face value.

However, in light of FCV range and refueling ease, and Musk's personal investment in battery electric vehicle technology, it would be a mistake to accept his criticism of fuel cells without skepticism.

NOTE: A great deal of misinformation about hydrogen fuel cell vehicles stems from an article in The New Atlantis magazine. Please note that this article is several years old (it was written in 2007). Much of what was written is no longer accurate.

This page was created by Spork Marketing and references both cited data sources and official Toyota news releases. Visit http://www.toyota.com/fuelcell/ for more information about Toyota's new FCV.

More Myths and Misconceptions



Myth: Installing a hydrogen infrastructure will be prohibitively expensive

The hydrogen transition will not need enormous investments in addition to those that the energy industry is already making. Instead, it will displace many of those investments.

It is expected that the roll-out of a hydrogen infrastructure will occur regionally over time to coincide with vehicle deployment. Yet with the adoption of hydrogen fuel cell products in early markets such as forklifts, airport baggage tugs, back-up power for telecom sites; distributed power for remote communities; and in transit buses, we are seeing a near-term demand for hydrogen.

With automotive fuel cell electric vehicles in the near term horizon, we must begin to install a hydrogen infrastructure now.

Myth: Hydrogen and fuel cells are too expensive

What do computers, cell phones, televisions, wind turbines and solar panels all have in common? People initially thought that they were too expensive when they were first developed.

As with any new technology, cost can be an issue. But, as demand increases, scientists make new breakthroughs, and companies find ways to cut costs, the price will continue to go down. So, while cost remains an issue right now, hydrogen and fuel cells have the potential to be produced for even less than current technologies.

Hydrogen Costs

Many industries already use large quantities hydrogen as a raw material in the chemical synthesis of ammonia, methanol, hydrogen peroxide, polymers, and solvents. Even oil refineries use hydrogen to remove the sulphur from crude oil. But, because hydrogen products for consumers aren't widely available, there is little economic incentive to make and sell hydrogen fuel.

When analysis's evaluate hydrogen's cost to consumers, they often forget that hydrogen can be made nearly anywhere, from any power source, including renewable energy sources. This flexibility can eliminate most or even all transportation costs. Since a large portion of the price that consumers pay for fuel is for transportation, this is significant. For example, the present price of delivered liquid hydrogen is around four times the cost of producing hydrogen.

Finally, in any cost comparison of hydrogen to other fuels, we shouldn't compare apples to oranges. It isn't meaningful to compare the price of a gallon of hydrogen to a gallon of gasoline because both fuels produce a different amount of energy. What really counts is how many cents a kilometre your fuel costs. Even at the present price of delivered liquid hydrogen, if you used hydrogen to power a fuel cell vehicle, your cost per kilometre would be the same as getting gasoline for a dollar a gallon.

Fuel Cell Costs

The costs of fuel cells will inevitably decrease because the raw materials (such as graphite, commodity metals, plastics, and composite) are inexpensive. The only material that is expensive is current catalyst, typically platinum. To overcome this, scientists are researching alternative catalysts from base metals and reducing the amount of platinum needed. Furthermore, platinum may become less expensive due to new platinum recycling systems. Despite their higher setup and development cost, fuel cells have lower maintenance costs and longer operating life.

Myth: Hydrogen is dangerous

Most fuels have high energy content and must be handled properly to be safe. Hydrogen is no different. In general, hydrogen is neither more nor less inherently hazardous than gasoline, propane, or methane. As with any fuel, safe handling depends on knowledge of its particular physical, chemical, and thermal properties and consideration of safe ways to accommodate those properties. Hydrogen, handled with this knowledge, is a safe fuel. Hydrogen has been safely produced, stored, transported, and used in large amounts in industry by following standard practices that have been established in the past 50 years. These practices can also be emulated in non-industrial uses of hydrogen to attain the same level of routine safety.

Myth: Hydrogen caused the Hindenburg to blow up.

Actually, the cause of the fire that destroyed the German passenger airship Hindenburg in 1937 in New Jersey is still unknown. An investigation in 1990 by Addison Bain, a NASA engineer, showed that the paint coating used on the skin of the airship caused the fire. The coating contained reactive chemicals similar to solid rocket fuel. When the airship was docking in 1937, an electrical discharge ignited the skin, and the fire raced over the surface of the airship.

Myth: Commercial hydrogen can make a hydrogen bomb

It's not possible to make a hydrogen bomb with commercially available hydrogen fuel for a couple of reasons. The thermonuclear explosion from a hydrogen bomb results from a nuclear fusion reaction. Two isotopes of hydrogen – deuterium and tritium – collide at very high energy to fuse into helium nuclei, releasing tremendous amounts of energy. However, to get these rare isotopes of hydrogen to fuse requires extraordinary temperatures (hundreds of millions of degrees) supplied by a thermonuclear weapon by an atomic bomb to trigger the fusion reaction. The sheer amount of energy makes this impossible for anyone but professionals in a lab. Furthermore, commercial hydrogen gas doesn't even contain deuterium or tritium. Without these isotopes, it is impossible for ordinary hydrogen gas to produce a thermonuclear reaction under any circumstances.

Myth: Hydrogen isn't a clean fuel

Hydrogen as a fuel doesn't create any emissions when used in a fuel cell. However, it is only as clean as the energy source it's derived from. Producing hydrogen from fossil fuels does create emissions, but it is less than gasoline or diesel. It is also easier to control this pollution because the pollution is limited to the fuel production process. Hydrogen is best when produced from non-polluting renewable energy sources. Different countries will make different choices, depending on their current energy availability and future priorities.

For vehicles, according to well-to-wheels studies, hydrogen fuel cell vehicles are at least twice as efficient as gasoline vehicles, and 40% more efficient than a hybrid. Most hydrogen internal combustion engines are about 30% more efficient than their gasoline counterparts and fuel cells are 100-200% (2-3 times) more efficient.

If we continue to drive vehicles running on fossil fuels, we will continue emitting carbon dioxide into the atmosphere at an ever-growing rate. But if we drive vehicles running on hydrogen, and burn fossil fuels to make that hydrogen, we can choose to sequester the carbon emitted during production or emit it into the atmosphere. If we choose to produce hydrogen from non-polluting sources of energy, we will decrease the amount of global air pollution that we will create.

Myth: There isn't an abundant source of hydrogen fuel

Hydrogen can be made from almost any source of energy. Oil, coal, hydro power, solar power, nuclear power, geothermal power and other energy sources can all be transformed into electricity and then, by electrolysis, into hydrogen.

Contrast that with gasoline for cars. Even though people tend to talk about cars running on oil, they actually run on gasoline, which is manufactured, not found. Gasoline can only be made from oil, which we get out of the ground, as a feedstock. When we can no longer find oil at a reasonable cost, we can still make hydrogen.

Myth: In cars, hydrogen can't compete with regular gas

In many ways, hydrogen vehicles are more viable than gasoline. Vehicles that use hydrogen in an internal combustion engine are about 30% more efficient than comparable gasoline vehicles. Best of all, they produce ultra-low emissions, with no CO_2. Fuel cells are ideally suited for cars that use electrical systems instead of hydraulics for functions such as steering and braking. These cars are two to three times more energy efficient than gas cars. Also, in a fuel cell electric vehicle, automakers can put the power train anywhere, which gives them the ultimate in design freedom.

Myth: Using renewable power to produce hydrogen wastes energy

It would be ideal if you could just plug in to your solar panel or wind generator and use that power right away. However, it's not always windy or sunny, so renewable energy projects need a storage system that provides energy whenever you we need it. Hydrogen can store energy that would otherwise go to waste.

Myth: Hydrogen and fuel cell products are still in development and we can't buy them today

Hydrogen and fuel cell products are available today. Many hydrogen fuel cells are used today in forklifts in warehouses, buses in cities, and back-up power for communications companies. Companies and governments recognize the performance, financial, environmental and health benefits. These early uses are playing a pivotal role in refining the technology and establishing infrastructure.

Scientists and companies are currently testing micro fuel cells, often called portable power, to recharge and power cell phones and laptops. These should be available in the near future.

In the next couple of years, we'll start to see new vehicles available for customers too. For example, Honda, Toyota and Mercedes-Benz currently have concept cars on the go and are all planning on releasing fuel cell cars for consumers in 2015.

Twenty Hydrogen Myths That Battery Companies and Oil Companies Spend Billions of Dollar Per Year Trying to Make You Believe:

- **White paper published at www.rmi.org**
- **Download the detailed report at the links below:**

http://www.rmi.org/Knowledge-Center/Library/E03-05_TwentyHydrogenMyths

http://www.rmi.org/cms/Download.aspx?id=6667&file=E03-05_20HydrogenMyths.pdf&title=Twenty+Hydrogen+Myths

This peer-reviewed white paper offers both lay and technical readers a documented primer on basic hydrogen facts, weighs competing opinions, and corrects twenty widespread misconceptions. Some of these falsehoods include the following: "a hydrogen industry would need to be developed from scratch; hydrogen is too dangerous for common use; making hydrogen uses more energy than it yields; we lack a mechanism to store hydrogen in cars; and hydrogen is too expensive to compete with gasoline". This paper explains why the rapidly growing engagement of business, civil society, and government in devising and achieving a transition to a hydrogen economy is warranted and, if properly done, could yield important national and global benefits.

Abstract

Recent public interest in hydrogen has elicited a great deal of conflicting, confusing, and often ill-informed commentary. This peer-reviewed white paper offers both lay and technical readers, particularly in the United States, a documented primer on basic hydrogen facts, weighs competing opinions, and corrects twenty widespread misconceptions. **It explains why the rapidly growing engagement of business, civil society, and government in devising and achieving a transition to a hydrogen economy is warranted and, if properly done, could yield important national and global benefits.**

About the author

Physicist Amory Lovins is cofounder and CEO of Rocky Mountain Institute (www.rmi.org) and Chairman of Hypercar, Inc. (www.hypercar.com), RMI's fourth for-profit spinoff (in which, to declare an interest, he holds minor equity options). Published in 28 books and hundreds of papers, his work has been recognized by the "Alternative Nobel," Onassis, Nissan, Shingo, and Mitchell Prizes, a MacArthur Fellowship, the Happold Medal, eight honorary doctorates, and the Heinz, Lindbergh, World Technology, and "Hero for the Planet" Awards. He has advised industry and government worldwide on energy, resources, environment, development, and security for the past three decades.

About the publisher

Rocky Mountain Institute is an independent, entrepreneurial, nonprofit applied research center founded in 1982. Its ~50 staff foster the efficient and restorative use of resources to make the world secure, just, prosperous, and life-sustaining. The majority of its ~$7-million annual revenue is earned by consultancy, chiefly for the private sector; the rest comes from foundation grants and private gifts. Much of the context of its work is summarized in Natural Capitalism (www.natcap.org). Donations are welcome and tax-deductible (#74-2244146). RMI is at 1739 Snowmass Creek Road, Snowmass, CO 81654, phone + 1 970 927-3851

Twenty myths

Myth #1. A whole hydrogen industry would need to be developed from scratch.

Myth #2. Hydrogen is too dangerous, explosive, or "volatile" for common use as a fuel.

Myth #3. Making hydrogen uses more energy than it yields, so it's prohibitively inefficient

Myth #4. Delivering hydrogen to users would consume most of the energy it contains...

...Myth #17. A viable hydrogen transition would take 30–50 years or more to complete, and hardly anything worthwhile could be done sooner than 20 years

http://www.rmi.org/Knowledge-Center/Library/E03-05_TwentyHydrogenMyths

Full document (PDF)
http://www.rmi.org/cms/Download.aspx?id=6667&file=E03-05_20HydrogenMyths.pdf&title=Twenty+Hydrogen+Myths

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abc NEWS

THE INFLUENCE GAME: Toyota's Powerful DC Friends

THE INFLUENCE GAME: Toyota has friends in high places in Washington, but are they enough?

By SHARON THEIMER

The Associated Press

WASHINGTON

The lawmakers now investigating Toyota's recall include a senator who was so eager to lure the Japanese automaker to his state that he tramped along through fields as its executives scouted plant sites, and a congresswoman who owes much of her wealth to a Toyota supplier.

Twenty Hydrogen Myths

AMORY B. LOVINS, CEO, ROCKY MOUNTAIN INSTITUTE
20 June 2003

Hydrogen technologies are maturing. The world's existing hydrogen industry is starting to be recognized as big — producing one-fourth as much volume of gas each year as the global natural-gas industry. Industry, government, and civil society are becoming seriously engaged in designing a transition from refined petroleum products, natural gas, and electricity to hydrogen as the dominant way to carry, store, and deliver useful energy. New transitional paths are emerging, some with a vision across sectoral or disciplinary boundaries that makes them harder for specialists to grasp. Naturally, there's rising speculation about winners, losers, and hidden agendas. And as the novel hydrogen concept is overlain onto longstanding and rancorous debates about traditional energy policy, constituencies are realigning in unexpected ways.

In short, the customary wave of confusion is spreading across the country. What's this all about? Is hydrogen energy really a good idea? Is it just a way for incumbent industries to reinforce their dominance, or could it be a new, different, and hopeful melding of innovation with competition? Is it a panacea for humanity's energy predicament, or a misleading *deus ex machina* destined to inflict public disappointment and cynicism, or neither, or both?

The conversation about hydrogen is confused but hardly fanciful. The chairs of eight major oil and car companies have said the world is entering the oil endgame and the start of the Hydrogen Era. Royal Dutch/Shell's planning scenarios in 2001 envisaged a radical, China-led leapfrog to hydrogen (already underway): hydrogen would fuel a fourth of the vehicle fleet in the industrialized countries by 2025, when world oil use, stagnant meanwhile, would start to fall. President Bush's 2003 State of the Union message emphasized the commitment he'd announced a year earlier to develop hydrogen-fuel-cell cars (FreedomCAR).

Yet many diverse authors have lately criticized hydrogen energy, some severely.[1–12] Some call it a smokescreen to hide White House opposition to promptly raising car efficiency using conventional technology, or fear that working on hydrogen would divert effort from renewable energy sources. Some are skeptical of hydrogen because the President endorsed it, others because environmentalists did. Many wonder where the hydrogen will come from, and note that it's only as clean and abundant as the energy sources from which it's made. Most of the critiques reflect errors meriting a tutorial on basic hydrogen facts; hence this paper.

Introductory facts

To establish a common factual basis for exploring prevalent myths about hydrogen, let's start with six points that are universally accepted by hydrogen experts but not always articulated:

- Hydrogen makes up about 75% of the known universe, but is not an energy *source* like oil, coal, wind, or sun.[13] Rather, it is an energy *carrier* like electricity or gasoline — a way of transporting useful energy to users. Hydrogen is an especially versatile carrier because like oil and gas, but unlike electricity, it can be stored in large amounts (albeit often at higher storage cost than hydrocarbons), and can be made from almost any energy source and used to provide almost any energy service. Like electricity, hydrogen is an extremely high-quality form of energy, and can be so readily converted to electricity and back that fuel-cell pioneer Geoffrey Ballard suggests they be thought of together as a fungible commodity he calls "Hydricity™."

- The reason hydrogen isn't an energy *source* is that it's almost never found by itself, the way oil and gas are. Instead, it must first be freed from chemical compounds in which it's bound up. There are broadly three ways to liberate hydrogen: using heat and catalysts to "reform" hydrocarbons or carbohydrates, or electricity to split ("electrolyze") water, or experimental processes, based typically on sunlight, plasma discharge, or microorganisms.[14] All devices that produce hydrogen on a small scale, at or near the customer, are collectively called "hydrogen appliances" to distinguish them from traditional large-scale industrial production.
- Fossil-fuel molecules are combinations of carbon, hydrogen, and various other atoms. Roughly two-thirds of the fossil-fuel atoms burned in the world today are hydrogen. (However, hydrogen yields a smaller share of fossil-fuel energy, because its chemical bonds are weaker than carbon's.) The debate is about whether combusting the last third of the fossil fuel — the carbon — is necessary; whether it might be cheaper and more attractive not to burn that carbon, but only to use the hydrogen; and to what degree that hydrogen should be replaced by hydrogen made with renewable energy sources.
- Using hydrogen as a fuel, rather than burning fossil fuels directly, yields only water[15] (and perhaps traces of nitrogen oxides if used in a high-temperature process). This can reduce pollution and climate change, depending on the source of the hydrogen. But when journalists write that hydrogen can "clean the air,"[16] that's shorthand for keeping pollutants out of the air, not removing those already there.
- Hydrogen is the lightest element and molecule. Molecular hydrogen (two hydrogen atoms, H_2) is eight times lighter than natural gas. Per unit of energy contained, it weighs 64% less than gasoline or 61% less than natural gas: 1 kilogram (2.2 lb) of hydrogen has about the same energy as 1 U.S. gallon of gasoline, which weighs not 2.2 but 6.2 pounds.[17] But the flip side of lightness is bulk. Per unit of *volume*, hydrogen gas contains only 30% as much energy as natural gas, both at atmospheric pressure. Even when hydrogen is compressed to 170 times atmospheric pressure (170 bar), it contains only 6% as much energy as the same volume of gasoline. Hydrogen is thus most advantageous where lightness is worth more than compactness, as is often true for mobility fuels.
- One of the biggest challenges of judging hydrogen's potential is how to compare it fairly and consistently with other energy carriers. Fossil fuels are traditionally measured in cost, volume, or mass per unit of *energy content*.[18] That's valid only if the fuels being compared are all used in similar devices and at similar efficiencies, so all yield about the same amount of energy service. But that's not valid for hydrogen. Fuel cells (explained further in Myth #6) are not subject to the same thermodynamic limits as fuel-driven engines, because they're electrochemical devices, not heat engines. A hydrogen fuel-cell car can therefore convert hydrogen energy into motion about 2–3 times as efficiently as a normal car converts gasoline energy into motion: depending on how it's designed and run, a good fuel-cell system is about 50–70% efficient, hydrogen-to-electricity,[19] while a typical car engine's efficiency from gasoline to output shaft averages only about 15–17%

efficient.[20] (Both systems then incur further minor losses to drive the wheels.) This means 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. Conversely, hydrogen costing several times as much as gasoline per unit of *energy contained* can thus cost the same *per mile* driven. Since you buy automotive fuel to get miles, not energy, ignoring such differences in end-use efficiency is a serious distortion, and accounts for much of the misinformation being published about hydrogen's high cost. Hydrogen's advantage in cars is especially large because cars run mainly at low loads, where fuel cells are most efficient and engines are least efficient.[21] (Hydrogen can also have other economic or functional advantages that go beyond its efficient use. For example, when hydrogen fuel cells power digital loads in buildings, hydrogen may yield even greater extra value because suitably designed arrays of fuel cells can be exceptionally reliable and can yield the high-quality power that computers need.[22])

To reinforce this sixth point, the U.S. Department of Energy (DOE) says bulk hydrogen made and consumed onsite costs about $0.71/kg.[23] That's equivalent in *energy* content to $0.72 per gallon of gasoline.[24] But *per mile driven* — which is the objective — it's equivalent to about one-third to one-half that price, *i.e.*, to about $0.24–0.36/gallon-equivalent, because of the 2–3-fold greater efficiency of a hydrogen fuel cell than a gasoline engine in running a car. Of course, the *price* of hydrogen *delivered* into the car's fuel tank will be much higher. For example, DOE says the delivered price of industrial liquid hydrogen is about $2.2–3.1/kg. If it could be delivered into the tank of a car for the same price, it would be roughly equivalent *per mile* to $1-a-gallon gasoline. Thus it can cost several times as much to deliver liquid hydrogen as to produce it. (Fortunately, as we'll see, gaseous hydrogen can be produced at a filling station and put into the car for well under $2/kg.) Price also depends on hydrogen purity. So to assess hydrogen's price or cost or value or benefit meaningfully, we need to know how it'll be used, whether it's pure enough for the task, whether it's delivered to the task, and how much of the desired work it actually does.

Different questions yield different answers

So much for the basics. What's different about Rocky Mountain Institute's perspective that underlies this paper?

- RMI believes that radical but practical and advantageous efficiency improvements at three levels — vehicles, energy distribution, and overall energy infrastructure — can make the hydrogen transition rapid and profitable.
- At least for the next decade or two, RMI envisions a distributed model for hydrogen production and delivery that integrates the gas, electricity, building, and mobility infrastructures. Instead of building a costly new distribution infrastructure for hydrogen, we'd use excess capacity inherent in the existing gas and electricity distribution infrastructures, then make the hydrogen locally so it requires little or no further distribution. Only after this decentralized approach had built up a large hydrogen market in buildings and vehicles could centralized hydrogen production merit much investment, except in special circumstances.

- RMI's insights into the full economic value of distributed power suggest that hydrogen fuel cells *today* can economically displace less efficient central resources for delivering electricity, paving the way for hydrogen use to spread rapidly, financed by its own revenues.
- RMI recognizes that especially in North America, natural gas is logically the main near-term fuel to launch the hydrogen transition, along with cost-effective renewables. If making hydrogen requires more natural gas (which it may not — see Myth #12), it should come first from natural gas saved by making existing applications more efficient. In the longer run, more mature and diverse renewables will play an important and ultimately a dominant role. Even during the initial, mainly fossil-fueled, stages of the hydrogen transition, carbon emissions will be much smaller than today's emissions from burning those fossil fuels directly. In time, those carbon emissions will approach zero. Insisting that they *start* at zero — that hydrogen be made solely from renewable energy sources, starting now — is making the perfect the enemy of the good. But done right, the hydrogen transition will actually make renewable energy more competitive and speed its adoption.

And what "headlines" will emerge from this perspective in the following discussion?

- **The oft-described technical obstacles to a hydrogen economy — storage, safety, and the cost of the hydrogen and its distribution infrastructure — have already been sufficiently resolved to support rapid deployment starting now. No technological breakthroughs are needed, although many will probably continue to occur. Until volume manufacturing of fuel cells starts in the next few years, even costly hand-made or pilot-produced versions can already compete in substantial entry markets. Automotive use of fuel cells can flourish many years sooner if automakers adopt recent advances in crashworthy, cost-competitive ultralight autobodies. If fuel cells prove difficult to commercialize or hydrogen's benefits are desired sooner, there might even be a transitional role for hydrogen-fueled engine-hybrid vehicles.**
- **The hydrogen transition should not need enormous investments in addition to those that the energy industries are already making. Instead, it will displace many of those investments. Hydrogen deployment may well need *less* net capital than business-as-usual, and should be largely self-financing from its revenues.**
- **A well-designed hydrogen transition will also use little more, no more, or quite possibly *less* natural gas than business-as-usual.**
- **A rapid hydrogen transition will probably be *more* profitable than business-as-usual for oil and car companies, and can quickly differentiate the business performance of early adopters.**
- **Most of the hydrogen needed to displace the world's gasoline is already being produced for other purposes, including making gasoline. A hydrogen industry big enough to displace all gasoline, while sustaining the other industrial processes that now use hydrogen, would be only severalfold bigger than the mature hydrogen industry that exists today, although initially it will probably rely mainly on smaller units of production, nearer to their customers, to avoid big distribution costs.**
- **A poorly designed hydrogen transition could cause environmental problems, but a well-designed one can resolve most of the environmental problems of the current fossil-fuel system without making new ones, and can greatly enhance security.**

Now for the currently prevalent hydrogen myths, and what their correction implies about desirable courses of action. Writing for a mainly U.S. audience, we'll use a mixture of U.S. and international units of measurement.

Twenty myths

Myth #1. A whole hydrogen industry would need to be developed from scratch.

Producing hydrogen is already a large and mature global industry, using at least 5% of U.S. natural gas output. Globally, about 50 million metric tons of hydrogen is made for industrial use each year. That's over half a trillion cubic meters measured at atmospheric pressure.[25] The U.S. Department of Energy (DOE) reports[26] that about 48% of global hydrogen production is reformed from natural gas, 30% from oil, and 18% from coal (chiefly in China and South Africa for producing nitrogen fertilizer; half the world's hydrogen goes into ammonia-based fertilizer). Only 4% of the world's hydrogen comes from electrolysis, because that process can compete with reforming fossil fuels only under three main conditions: with very cheap electricity, generally well under 2¢/kWh (see Myth #9 below); if the hydrogen is a byproduct (about 2%, for example, is unintentionally made during "chloralkali" electrolytic chlorine production); or perhaps if the producer is charged for carbon emissions and has a carbon-free source of electricity but no way to sequester (keep out of the atmosphere) carbon released from reforming fossil fuels.

U.S. hydrogen production is at least one-fifth and probably nearer one-third of the world total,[27] is equivalent to ~1.8% of total U.S. energy consumption, and comes ~95% from natural gas at ~99% purity from steam reforming and associated cleanup processing.[28] Roughly 47% of U.S. or 37–45% of world hydrogen production is reportedly used in refineries;[29] it is made onsite, mostly by steam reforming of gas or oil, and is used mainly to make gasoline and diesel fuel. Most hydrogen production by refineries is deliberate, used to make hydrogen-rich refined products or to remove sulfur from them; some is a byproduct of making aromatic compounds. The rest of the world's hydrogen output goes to ammonia fertilizer, methanol, petrochemicals, edible fats and oils, metal production, microchips, and other products, and a little to special industrial furnaces. World hydrogen production is reportedly doubling about every decade, driven by refineries' need to make lower-sulfur fuels and by other growth industries. Usage for fertilizer has been relatively flat for the past decade, and usage for methanol is growing more slowly (roughly with GDP) as prospects fade for wide use of methanol-derived MTBE gasoline additive, so the biggest growth market for industrial hydrogen appears to be refineries.

The industrial infrastructure for centralized hydrogen production already exists. Throughout industry, most hydrogen is currently made at large plants and is used at the industrial site or nearby. There are ~1,500 km (~930 miles) of special hydrogen pipelines (720 km or 446 miles in North America) operating at up to 100 bar.[30] Moving hydrogen gas through pipelines takes about half as much of its energy as is currently lost when transporting electricity, and the pipeline is far smaller — a 1.7-meter-diameter hydrogen pipeline at 70 bar delivers 16 GW, whereas a 60-meter-tall pylon with three pairs of ±500-kVDC power lines delivers only 9 GW.[31] Hydrogen is less dense and takes more compressor energy than natural gas, but also flows better, so transporting hydrogen through existing natural-gas pipelines would deliver only ~20–25% less energy, net of compressor consumption[32] — thus enabling hydrogen's more efficient end-use to deliver more service than from the original natural gas flow. Pipelines may also be cheaper, easier to site, and more secure than aboveground high-voltage electric transmission lines.

Hydrogen pipelines normally carry compressed hydrogen gas, not super-cold liquid hydrogen. Only about 1–3 thousandths of all hydrogen produced is liquefied and cryogenically piped, mainly to NASA launch pads for rocket fuel — an ideal use for a fuel whose density is about as low as the denser grades of Styrofoam.[33]

Centralized hydrogen production has coevolved with centralized consumption by major industrial plants. Yet most future uses of hydrogen are not centralized; they'll serve millions of dispersed customers. This dispersed pattern of usage calls for a different pattern of production, not so much in centralized plants as in small ones near the customers. This can often deliver cheaper hydrogen, because reformers and electrolyzers, which both work well at a small scale, can make hydrogen delivery simpler or unnecessary: instead, they'll leverage the existing gas and electricity distribution grids, especially during off-peak periods when (by definition) they have excess capacity. Driven by the economics of supply and demand, the hydrogen industry will evolve organically at many scales and for many uses — if it's not unduly retarded by myths.

Myth #2. Hydrogen is too dangerous, explosive, or "volatile" for common use as a fuel.

The hydrogen industry has an enviable safety record spanning more than a half-century. Any fuel is hazardous and needs due care, but hydrogen's hazards are different and generally more tractable than those of hydrocarbon fuels.[34] It's extremely buoyant — 14.4 times lighter than air (natural gas is only 1.7 times lighter than air). Hydrogen is four times more diffusive than natural gas or 12 times more than gasoline fumes, so leaking hydrogen rapidly disperses up and away from its source.[35] If ignited, hydrogen burns rapidly with a nonluminous flame that can't readily scorch you at a distance, emitting only one-tenth the radiant heat of a hydrocarbon fire and burning 7% cooler than gasoline. Although firefighters dislike hydrogen's clear flame because they need a viewing device to see it in daylight, victims generally aren't burned unless they're actually in the flame, nor are they choked by smoke.

Hydrogen mixtures in air are hard to explode, requiring a constrained volume of elongated shape. In high-school chemistry experiments, hydrogen detonates with a "pop" when lit in a test tube, but if it were in free air rather than a long cylindrical enclosure, it wouldn't detonate at all. Explosion requires at least twice as rich a mixture of hydrogen as of natural gas, though hydrogen's explosive potential continues to a fourfold higher upper limit. Hydrogen does ignite easily, needing 14 times less energy than natural gas, but that's of dubious relevance because even natural gas can be ignited by a static-electricity spark.[36] Unlike natural gas, however, leaking hydrogen encountering an ignition source is far likelier to burn than to explode, even inside a building, because it burns at concentrations far below its lower explosive limit. Ignition also requires a fourfold higher minimum concentration of hydrogen than of gasoline vapor. In short, in the vast majority of cases, leaking hydrogen, if lit, will burn but not explode. And in the rare cases where it might explode, its theoretical explosive power per unit volume of gas is 22 times weaker than that of gasoline vapor. It is not, as has been claimed, "essentially a liquid or gaseous form of dynamite."[37]

Contrary to a popular misunderstanding, these safety attributes actually helped save 62 lives in the 1937 *Hindenburg* disaster. An investigation by NASA scientist Dr. Addison Bain found[38] that the disaster would have been essentially unchanged even if the dirigible were lifted not by hydrogen but by nonflammable helium, and that probably nobody aboard was killed by a hydrogen fire. (There was no explosion.) The 35% who died were killed by jumping out, or by the burning diesel oil, canopy, and debris (the cloth canopy was coated with what nowadays would be called rocket fuel). The other 65% survived, riding the flaming dirigible to earth as the clear hydrogen flames swirled harmlessly above them. This would hardly be the case if an aircraft with only liquid hydrocarbons caught fire while aloft. It emphasizes that hydrogen is generally at least as safe as natural gas or LPG, and is arguably inherently safer than gasoline,[39] although the character of their risks is not identical. For example, leaking hydrogen gas will accumulate near the ceiling of an airtight garage, while gasoline fumes or propane will accumulate near the floor — a greater risk to people because they're typically near the floor, not the roof. Standing in a carpet of fire is far more dangerous than standing below a nearly non-luminous clear flame that goes upwards.

Lingering perceptions that hydrogen is unusually dangerous are likely to be dispelled by the kinds of compelling videotaped demonstrations now becoming available, such as a comparison of a hydrogen fire with a gasoline fire. First, a hydrogen leak was created, assuming a very unlikely triple failure of redundant protective devices (industry norms for hydrogen leak detection and safety interlocks are convincingly effective). The tested leak, deliberately caused at the highest-pressure location, discharged the entire 1.54-kg hydrogen inventory of the fuel-cell car in ~100 s, but the resulting vertical flame plume raised the car's interior temperature by at most 1–2 F° (0.6–1.1 C°), and its outside temperature nearest the flame by no more than a car experiences sitting in the sun. The passenger compartment was unharmed. But then in the second test, a 2.5-fold-lower-energy leak from a 1.6-mm (1/16") hole in a gasoline fuel line gutted the car's interior and would have killed anyone trapped inside.[40] Because the hydrogen-leak test didn't damage the car, both tests were conducted successively *using the same car*.[41]

Finally, of course, there is no connection whatever between ordinary hydrogen gas, whose chemical reactions make it useful as a fuel, and the special isotopes whose thermonuclear reactions power hydrogen bombs. A hydrogen bomb can't be made with ordinary hydrogen, nor can the conditions that trigger nuclear fusion in a hydrogen bomb occur in a hydrogen accident; they're achieved, with difficulty, only by using an atomic bomb.

Myth #3. Making hydrogen uses more energy than it yields, so it's prohibitively inefficient.

Any conversion from one form of energy to another consumes more useful energy than it yields. If it could do the opposite, creating energy out of nothing, you could create a perpetual-motion machine violating the laws of physics. Conversion losses are unavoidable; the issue is whether they're worth incurring. If they were intolerable as a matter of principle, as Myth #3 implies, then we'd have to stop making gasoline from crude oil (~73–91% efficient from wellhead to retail pump[42]) and electricity from fossil fuel (~29–35% efficient from coal at the power plant to retail meter). Such conversion losses are thus not specific to producing hydrogen. Hydrogen production is typically about 72[43] to 85[44] percent efficient in natural-gas reformers or ~70–75% efficient in electrolyzers;[45] the rest is heat that may also be reusable. (These efficiency figures are all