# THE HOPE FOR HYDROGEN

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# The Hope for Hydrogen

*We should embrace hydrogen largely because of the absence of a more compelling long-term option.*

The history of alternative transportation fuels is largely a history of failures. Methanol never progressed beyond its use in test fleets, despite support from President George H. W. Bush. Compressed natural gas remains a niche fuel. And nearly every major automotive company in the world has abandoned battery-electric vehicles. Only ethanol made from corn is gaining market share in the United States, largely because of federal and state subsidies and a federal mandate. Some alternatives have succeeded elsewhere for limited times, but always because of substantial subsidies and/or government protection.

Is hydrogen different? Why do senior executives of Shell, BP, General Motors, Toyota, DaimlerChrysler, Ford, and Honda tout hydrogen, and why do Presidents George Bush and Romano Prodi of the European Union and California Governor Arnold Schwarzenegger all advocate major hydrogen initiatives? Might hydrogen succeed on a grand scale, where other alternative fuels have not?

Hydrogen clearly provides the potential for huge energy and environmental improvements. But skeptics abound, for many good reasons. Academics question near-term environmental benefits, and activists and environmental groups question the social, environmental, and political implications of what they call "black" hydrogen (because it would be produced from coal and nuclear power). Others say we are picking the wrong horse. Paul MacCready argues in the forthcoming book of essays *The Hydrogen Energy Transition* that improved battery technology will trump hydrogen and fuel cell vehicles. And many, including John DeCicco of Environmental Defense, also in *The Hydrogen Energy Transition*, argue that the hydrogen transition is premature at best. A February 2004 report on hydrogen by the National Academies' National Academy of Engineering and National Research Council agrees, asserting that there are many questions to answer and many barriers to overcome before hydrogen's potential can be realized.

What is remarkable in the early stages of the debate is the source of public opposition: It is not coming from car or oil companies but primarily from those most concerned about environmental and en-

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ergy threats. The core concern, as Joseph J. Romm argues so well in the preceding article, is that, "a major effort to introduce hydrogen cars before 2030 would actually undermine efforts to reduce emissions of heat-trapping greenhouse gases such as $CO_2$."

In fact, the hydrogen debate is being sucked into the larger debate over President Bush's environmental record. The environmental community fears that the promise of hydrogen is being used to camouflage eviscerated and stalled regulations and that it will crowd out R&D for deserving near-term energy efficiency and renewable energy opportunities. What the administration and others portray as a progressive long-term strategy, others see as bait and switch. Indeed, a backlash is building against what many see as hydrogen hype.

Perhaps this skepticism is correct. Perhaps it is true that without a hydrogen initiative, government leaders would pursue more aggressive fuel economy standards and larger investments in renewable energy. We remain skeptical. And even if true, what about the larger question of the size of the public R&D energy pie? If energy efficiency and climate change are important public issues, then quibbling over tens of millions of dollars in the U.S. Department of Energy budget is missing the point. It should not be seen as a zero sum game. If energy efficiency and climate change are compelling initiatives, then shouldn't the debate really be over the size of the budget?

In any case, we believe there is a different story to tell. First, hydrogen must be pursued as part of a long-term strategy. (Indeed, any coherent energy strategy should have a long-term component.) Second, hydrogen policy must complement and build on near-term policies aimed at energy efficiency, greenhouse gas reduction, and enhanced renewable energy investments. Hydrogen vehicles will not happen without those policies in place. In fact, hybrid vehicles are an essential step in the technological transition to fuel cells and hydrogen. And third, if not hydrogen, then what? No other long-term option approaches the breadth and magnitude of hydrogen's public benefits.

## The lessons of history

All previous alternative transportation fuels ultimately failed, largely for two reasons: They provided no private benefits, and claims of large public benefits regarding pollution and energy security proved to be overstated. The private benefits from compressed natural gas, ethanol, methanol, propane, and early battery-electric vehicles were nil. When compared to petroleum-fueled vehicles, all have shorter distances between refueling and different safety and performance attributes, often perceived as inferior. The only clear benefits are emissions and energy security, but few consumers purchase a vehicle for public-good reasons.

Overstated claims for new fuels were not intentionally deceptive. Rather they reflected a poor understanding of energy and environmental innovation and policy. Two errors stand out: understated forecasts of oil supply and gasoline quality and overstated environmental and economic benefits of alternative fuels. Oil turned out to be cheap and abundant, thanks to improved technologies for finding and extracting oil; gasoline and diesel fuel were reformulated to be cleaner; and internal combustion engines continued to improve and now emit nearly no harmful air pollutants.

What do these lessons imply for hydrogen? First, hydrogen is unlikely to succeed on the basis of environmental and energy advantages alone, at least in the near to medium term. Hydrogen will find it difficult to compete with the century-long investment in petroleum fuels and the internal combustion engine. Hybrid electric vehicles, cleaner combustion engines, and cleaner fuels will provide almost as much energy and environmental benefit on a per-vehicle basis for some time. During the next decade or so, advanced gasoline and diesel vehicles will be more widespread and deliver more benefits sooner than hydrogen and fuel cells ever could. Hydrogen is neither the easiest nor the cheapest way to gain large near- and medium-term air pollution, greenhouse gas, or oil reduction benefits.

What about the long term? Although incremental enhancements are far from exhausted, there is almost no hope that oil or carbon dioxide ($CO_2$) reduction improvements in vehicles could even offset increases in vehicle usage, never mind achieve the radical decarbonization and petroleum reductions likely needed later this century.

## The case for hydrogen

The case for hydrogen is threefold. First, hydrogen fuel cell vehicles appear to be a superior consumer product desired by the automotive industry. Second, as indicated by the National Academies' study, the potential exists for dramatic reductions in the cost of hydrogen production, distribution, and use. And third, hydrogen provides the potential for zero tailpipe pollution, near-zero well-to-wheels emissions of greenhouse gases, and the elimination of oil imports, simultaneously addressing the most vexing challenges facing the fuels sector, well beyond what could be achieved with hybrid vehicles and energy efficiency.

The future of hydrogen is linked to the automotive industry's embrace of fuel cells. The industry, or at least an important slice of it, sees fuel cells as its inevitable and desired future. This was not true for any previous alternative fuel. The National Academies' report highlights the attractions of fuel cell vehicles. It notes that not only are fuel cells superior environmentally, but they also provide extra value to customers. They have the potential to provide most of the benefits of battery-electric vehicles without the short range and long recharge time. They offer quiet operation, rapid acceleration from a standstill because of the torque characteristics of electric motors, and potentially low maintenance requirements. They can provide remote electrical power—for construction sites and recreational uses, for example—and even act as distributed electricity generators when parked at homes and offices. Importantly, they also have additional attractions for automakers. By eliminating most mechanical and hydraulic subsystems, they provide greater design flexibility and the potential for using fewer vehicle platforms, which allow more efficient manufacturing approaches. Fuel cells are a logical extension of the technological pathway automakers are already following and would allow a superior consumer product—if fuel cell costs become competitive and if hydrogen fuel can be made widely available at a reasonable cost.

Those two "ifs" remain unresolved and are central to the hydrogen debate. Fuel cell costs are on a steep downward slope and are now perhaps a factor of 10 to 20 too high. Huge amounts of engineering are still needed to improve manufacturability, ensure long life and reliability, and enable operation at extreme temperatures. Although some engineers believe that entirely new fuel cell architectures are needed to achieve the last 10-fold cost reduction, a handful of automotive companies seem convinced that they are on track to achieve those necessary cost reductions and performance enhancements. Indeed, massive R&D investments are taking place at most of the major automakers.

*Hydrogen's future appears to be tightly linked to automaker commitments to move fuel cells from the lab to the marketplace.*

The second "if" is hydrogen availability, which is perhaps the greatest challenge of all. The problem is not production cost or sufficient resources. Hydrogen is already produced from natural gas and petroleum at costs similar to those of gasoline (adjusting for fuel cells' higher efficiency). With continuing R&D investment, the cost of providing hydrogen from a variety of abundant fossil and renewable sources should prove to be not much greater than that of providing gasoline, according to the National Academies' study.

The key supply challenges are as follows. First is the need for flexibility. There are many possible paths for making and delivering hydrogen, and it is difficult at this time to know which will prevail. Second, because private investment will naturally gravitate toward conventional fossil energy sources, currently the lowest-cost way to make hydrogen, government needs to accelerate R&D of zero-emission hydrogen production methods. Renewable hydrogen production is a key area for focused R&D. $CO_2$ sequestration—a prerequisite if abundant coal in the United States, China, and elsewhere is to be used—is another possible path to very-low-emission hydrogen. Although the cost of capturing carbon from large fossil fuel plants and sequestering it is not prohibitive in a large range of locations and situations, $CO_2$ sequestration faces uncertain public acceptance. Will $CO_2$ be perceived in the same light as nuclear waste, leading to permitting delays and extra costs?

The third supply-related challenge is logistical in nature. How can hydrogen be provided at local refueling sites, offering both convenience and acceptable cost to consumers during a transition? Today's natural gas and petroleum distribution systems are not necessarily good models for future hydrogen distribution, especially in the early stages of hydrogen use when consumption is small and dispersed. If future hydrogen systems attempt to simply mimic today's energy systems from the beginning, distribution costs could be untenably large, and the hydrogen economy will be stillborn. Unlike liquid transportation fuels, hydrogen storage, delivery, and refueling are major cost contributors. Astoundingly, delivering hydrogen from large plants to dispersed small hydrogen users is now roughly five times more expensive than producing the hydrogen. Even for major fossil fuel-based hydrogen production facilities under study, distribution and delivery costs are estimated to be equal to production costs.

Clearly, a creative, evolutionary approach is needed, eventually leading to a system that serves both stationary and mobile users, relies on small as well as large hydrogen production facilities, accesses a wide variety of energy feedstocks, incorporates $CO_2$ capture and sequestration, and is geographically diverse. In the very early stages of a transition, hydrogen might be delivered by truck from a central plant serving chemical uses as well as vehicles or be produced at refueling sites from natural gas or electricity. Distributed generation will be a key part of the solution, with production near or at the end-use site. The National Academies' report argues that the hydrogen economy will initially and perhaps for a very long time be based on distributed generation of hydrogen. (Honda and General Motors propose placing small hydrogen refueling appliances at residences.) Other innovative solutions would be needed, especially during the early phases. In cities with dense populations, pipelines would probably become the lowest-cost delivery option, once a sizeable fraction of vehicles run on hydrogen. The transportation fuel and electricity and chemical industries might become more closely coupled, because the economics can sometimes be improved by coproduction of electricity, hydrogen, and chemical products. Transitions would proceed in different ways, depending on regional resources and geographic factors.

## No natural enemies

Although the challenges are daunting, perhaps the most important factor is the absence of natural political or economic enemies. For starters, hydrogen is highly inclusive, capable of being made from virtually any energy feedstock, including coal, nuclear, natural gas, biomass, wind, and solar.

The oil industry is key. It effectively opposed battery-electric vehicles, because companies saw no business case for themselves. Hydrogen is different. Oil companies are in actuality massive energy companies. They are prepared to supply any liquid or gaseous fuel consumers might desire, although of course they prefer a slow transition that allows them to protect their current investments. Most, for instance, prefer that initial fuel cell vehicles carry reformers to convert gasoline into hydrogen. They have been disappointed that all major car companies are now focused strictly on delivered hydrogen.

Oil companies will not allow the hydrogen economy to develop without them. Indeed, some have played key roles in promoting hydrogen, and many are active participants in hydrogen-refueling demonstration projects around the world. But oil companies would not realize a rapid payoff from being the first to market. Rather, they anticipate large financial losses that would be stanched only when hydrogen use became widespread. Without government support during the low-volume transition stage, oil companies are unlikely to be early investors in the construction of hydrogen fuel stations. They are best characterized as watchful, strategically positioning themselves to play a large role if and when hydrogen takes off.

Automakers see a different business reality. They see benefits from being first to market. They see hydrogen fuel cells as the desirable next step in the technological evolution of vehicles. Hydrogen's future appears to be tightly linked to automaker commitments to move fuel cells from the lab to the marketplace. The key question is whether and when they will ratchet up current investments of perhaps $150 million per year (in the case of the more aggressive automakers) to the much larger sums needed to tool factories and launch commercial products. Without automaker leadership, the transition will be slow, building on small entrepreneurial investments in niche opportunities, such as fuel cells in off-road industrial equipment, hydrogen blends in natural gas buses, innovative low-cost delivery of hydrogen to small users, and small energy stations simultaneously powering remote buildings and vehicle fleets.

## If not hydrogen, then what?

What are the alternatives to hydrogen? The only other serious long-term alternatives for fueling the transport sector are grid-supplied electricity and biomass. Electricity is quite appealing on environmental and energy grounds. It allows for many of the same benefits as hydrogen: accessing renewable and other feedstocks and zero vehicular emissions. But every major automaker has abandoned its battery-electric vehicle program, except for DaimlerChrysler's small factory in North Dakota producing the GEM neighborhood vehicle. For battery-electric vehicles to be viable, several-fold improvements in batteries or other electricity storage devices would be required, or massive investments would be needed in "third rail" electricity infrastructure that would require substantial added cost for vehicles. These massive improvements are unlikely. Continued battery improvements are likely, but after a century of intense research, there still remains no compelling proposal that might reduce material costs sufficiently to render batteries competitive with internal combustion engines. The same is not true of fuel cells.

The other long-term proposal is biomass. Cellulosic materials, including trees and grasses, would be grown on the vast land areas of the United States and converted into ethanol or methanol fuel for use in combustion engines. Although this energy option is renewable, the environmental effects of intensive farming are not trivial, and the land areas involved are massive. Moreover, there are few other regions in the world available for extensive energy farming.

Other options include fossil-based synthetic fuels, in which shale oil, oil sands, coal, and other abundant materials are converted into petroleum-like fuels and then burned in combustion engines or converted into hydrogen at fuel stations or on board vehicles for use in fuel cells. But with all these options, carbon capture at the site is more difficult than with coal-to-hydrogen options, $CO_2$ volumes would be massive, and the overall energy efficiency would be far inferior.

We conclude that hydrogen merits strong support, if only because of the absence of a more compelling long-term option.

## Hydrogen's precarious future

The transition to a hydrogen economy will be neither easy nor straightforward. Like all previous alternatives, it faces daunting challenges. But hydrogen is different. It accesses a broad array of energy resources, potentially provides broader and deeper societal benefits than any other option, potentially provides large private benefits, has no natural political or economic enemies, and has a strong industrial proponent in the automotive industry.

In the end, though, the hydrogen situation is precarious. Beyond a few car companies and a scattering of entrepreneurs, academics, and environmental advocates, support for hydrogen is thin. Although many rail against the hydrogen hype, the greater concern perhaps should be the fragile support for hydrogen. Politics aside, we applaud the United States, California, and others for starting down a path toward a sustainable future. Although we do not know when or even if the hydrogen economy will eventually dominate, we do believe that starting down this path is good strategy.

The key is enhanced science and technology investments, both public and private, and a policy environment that encourages those investments. Fuel cells and hydrogen provide a good marker to use in formulating policy and gaining public support. Of course, policy should remain focused on near-term opportunities. But good near-term policy, such as improving fuel economy, is also good long-term policy. It sends signals to businesses and customers that guide them toward investments and market decisions that are beneficial to society. It appears to us that hydrogen is a highly promising option that we should nurture as part of a broader science, technology, and policy initiative. The question is how, not if.

*Recommended readings*


National Research Council and National Academy of Engineering, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. (Washington, D.C.: The National Academies Press, 2004) (available online at www.nap.edu).

Daniel Sperling and James S. Cannon, *The Hydrogen Energy Transition: Moving Toward the Post-Petroleum Age in Transportation*. (St. Louis: Elsevier, 2004).