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Why We Still Can't Deliver on the Promise of Hydrogen Cars

John Voelcker

17-21 minutes

Predicting the future is always risky. But it's long been clear that vehicles are one of the main sources of air pollution that takes thousands of lives a year in the U.S. alone through lung disease, asthma, cancer and more. And that ultimately, the world would have to move toward vehicles that didn't treat our shared air like a giant trash bin, emitting toxic substances every time they were powered on.

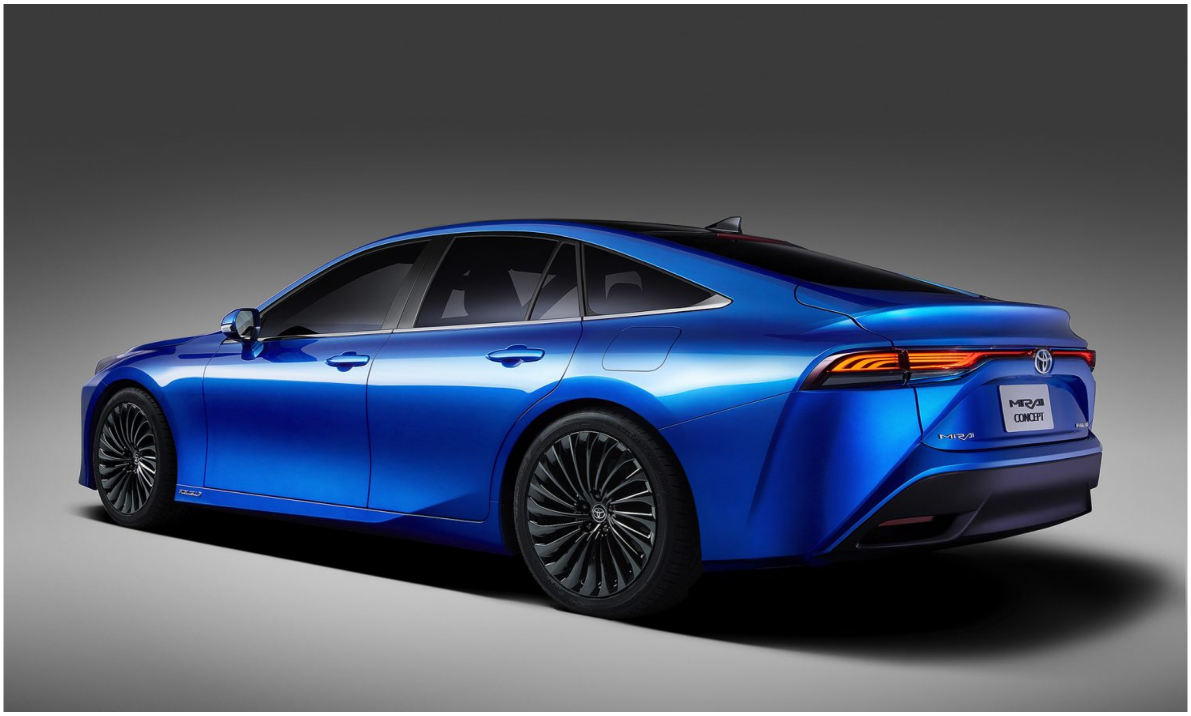
Two technologies could deliver vehicles with zero emissions: battery-electric powertrains and hydrogen fuel cells. For decades, hydrogen was presumed to be "the fuel of the future," with electric cars limited to the niche of small, short-range urban cars.

That's not how it's played out. And as 2020 seems poised to be a big year for electric car development—pandemic aside—it's worth examining how this happened.

EVs Have Swamped Hydrogen Cars

It all comes down to two things: battery cost and fueling infrastructure. Over the last 10 years, the consensus on both has changed quite radically.

Despite more than half a century of development, starting in 1966 with GM’s Electrovan, hydrogen fuel-cell cars remain low in volume, expensive to produce, and restricted to sales in the few countries or regions that have built hydrogen fueling stations.



Toyota

Progress on hydrogen vehicles has been slow but steady; the 2016 Toyota Mirai was the first such vehicle ever built in volumes of 1,000 a year or more. Toyota says its 2021 successor will be built in 10 times that volume. (It’s also much more visually striking, something that could never be said about its startling and ungainly predecessor. Rear-wheel drive now, too.)

Meanwhile, 10 years after the first modern EVs went on sale, electric cars sell in the low millions a year globally—two orders of magnitude higher than their hydrogen counterparts. They’re likely not yet consistently profitable for any maker, including Tesla, but General Motors and Volkswagen say that will change within the next few years, well before 2030.

Crucially, battery-powered vehicles are the technology behind which China has thrown the weight of its government-industrial policy for the country's auto industry—not hydrogen fuel cells. It intends to dominate the global production of cars with plugs just as it already does photovoltaic solar cells—and will soon do in lithium-ion battery cells.

The Numbers Aren't Good

The first Toyota Mirai was delivered in the U.S. in November 2015. In due course, it was joined by the Honda Clarity Fuel Cell and the Hyundai Nexo. All run on hydrogen, and have no tailpipe emissions beyond condensed water vapor. They are the only three hydrogen-powered cars you can lease or buy.

Toyota

The original Toyota Mirai.

Since 2012, about 8,000 cars powered by hydrogen have been sold in the U.S. They can be operated only in California, because that's the only place with a (pricey and so far unreliable) hydrogen fueling network. They can travel through most of the state, but taking one from Los Angeles to Tucson and back? Can't be done.

In contrast, almost 10 years into the era of modern electric cars (which began in December 2010), fully 1.3 million battery-electric and plug-in hybrid vehicles have been sold in the U.S. Long-distance travel remains tough in anything that isn't a Tesla, but it's at least possible.

The hurdles to any automotive innovation are substantial, and a switch in fuels (or, technically, energy carriers) is among the most challenging. Ethanol hasn't changed the game as expected 15 years ago. As for passenger cars powered by diesel, we know how *that* story ended.

Meanwhile, cars with plugs are going from strength to strength. It's not due to what you might call "natural" market demand, but thanks to strong national and regional regulations designed to slash tailpipe emissions from road vehicles. Carmakers see electric cars as a much better response to those regulations than hydrogen fuel-cell vehicles.

Actually Nothing New

Electric cars have been with us since the dawn of the automotive age. In 1900, they represented one-third of all vehicle sales, with steam cars and gasoline splitting the rest. Their limitation was the range of their batteries, based on the lead-acid chemistry still found in your 12-volt starter battery today.

The invention of the electric self-starter in 1912 meant drivers no longer risked a broken arm just starting their gasoline car. And the fuel's greater energy density (meaning longer range) allowed it to win out over batteries. The downsides—from emissions to lead poisoning from gasoline additives—wouldn't start to come into focus until the 1950s.

Mazda

Mazda HR-X hydrogen show car from 1991.

Starting in the 1990s, consumer electronics provided the technology for better electric cars. Suddenly, the need for energy storage in small, light, sophisticated devices led to the creation and mass production of the lithium-ion battery cell, which hit the market in a Sony videocam 30 years ago. It had twice the energy density of nickel-metal-hydride cells (used in 20 years of Toyota hybrids), and four times the energy of the old reliable lead-acid batteries.

Since then, the cost-performance of small lithium-ion cells has improved at 7 percent a year on average. It's not Moore's Law, but it's better than the improvement in engine efficiency: Over 140 years, the thermal efficiency of the gasoline internal-combustion engine has gone from perhaps 20 percent to 50 percent (under perfect circumstances, when paired with hybrid power).

Those battery cells for EVs got cheaper far faster than was expected even 10 years ago. By 2025, the cost of a large battery pack (60 kilowatt-hours, say, for a range of 200+ miles) is expected to fall to the Holy Grail of $100 per kilowatt-hour or less. That's about when EV prices should start to reach parity with comparable gasoline vehicles.

Pioneering is Hard

The history of automotive technology suggests companies that invent or pioneer new technologies may not be those who end up profiting from it. Remember which company launched the first transverse-engine, front-wheel-drive small car back in 1959? (Hint: It no longer exists today.)

Pioneers make mistakes. For the U.S., one such mistake proved to be the assumption by major automakers that buyers would flock to battery-electric cars with rated ranges of, say, 75 miles. They didn't. In America, we like our long road trips. (Tesla figured that out.)

GM

A hydrogen Hummer concept from 2004.

Another mistake proved to be not explaining the reality that EVs are charged at home or at work—slowly, overnight or during an eight-hour workday—for 80 or 90 percent of the miles they cover, but people need confidence in on-road fast charging. (Tesla' Supercharger network was the result.) And there are many more.

Now, 10 years on, we know a few things:

- 200 miles is the minimum range required to get U.S. shoppers to consider an electric car; 300 miles is better.
- Those new to electric cars can't visualize, or don't "get," the home-charging experience.
- Public charging still isn't visible enough, pervasive enough, or fast enough.
- Most consumers don't want to take a chance on new technology, preferring to let others validate it first; and
- You have to have EVs of all types of vehicles, and multiple models, to make them serious contenders—and these days, that means

crossover utilities, SUVs, and pickup trucks.

So with all those hurdles facing electric cars, why haven't hydrogen fuel-cell cars taken off instead?

The main reason centers on a nerdy, specialized word that's underappreciated in the real world. It's the infrastructure, stupid.

Others include the realities of reducing CO2 emission, the mirage of "fast fueling" that sold regulators on hydrogen vehicles 25 years ago, and the simple issue of fill-up cost.

Fueling

Specifically, it has proven exceptionally challenging, complex, and expensive to build and support a network of consumer fueling stations that delivers a highly explosive gas, compressed to 10,000 psi, reliably, quickly, and safely.

A decade ago, California Assembly Bill 8 mandated a plan to spend $100 million establishing a network of 100 hydrogen fueling stations by 2020. Each of them costs about $2 million, at least in 2014. The state will not reach that goal, but it remains the sole state among 50 where hydrogen cars can be operated for daily use.

As of April 8, according to California Fuel Cell Partnership data, the state had 40 operating hydrogen stations. Another nine were under construction or being commissioned to open. Nine more were in various stages of planning, and three were listed as not operational. Almost five years after the first Toyota Mirai was delivered, that's not terribly impressive.

Mazda

The hydrogen Mazda RX-8.

Just keeping the stations up and running has been a challenge. As aggrieved fuel-cell drivers in Northern California discovered, a thin fueling network is no good if your supply is interrupted.

Last June, an Air Products hydrogen supply facility in Santa Clara suffered an explosion that cut off supply to 9 of the area’s 11 fueling stations. That led to diesel trucks carting tanks of compressed hydrogen hundreds of miles north from Southern California overnight—and to furious owners setting alarms for the wee hours of the morning, to reach fueling stations in time to take advantage of the reduced supply of hydrogen needed to make their cars run.

The shortage lasted well into the fall, and led Toyota to refund several months of lease payments to Mirai drivers across the state, even those in Southern California unaffected by the outage.

One imagines them looking wistfully at Tesla owners who could plug in at home, or at work, or use the company's network of hundreds of Supercharger sites.

More than that, a California network of 75 stations was expected to serve only 17,000 to 24,000 hydrogen vehicles in 2020. Today, the state already has half a million plug-in cars on its roads. Did we mention most of those get charged overnight at home, or during the day at work?

Globally, Japan and Germany have the most comprehensive national hydrogen fueling infrastructure. Several years ago, Germany announced plans to build 100 stations by 2018 and 400 by 2025. As early as 2018, it had pulled ahead of the U.S. (meaning California) on total stations.

The global debut for Japan's "hydrogen economy," with fuel-cell vehicles front and center, was expected to be the 2020 Tokyo Olympics. That event, obviously, has now been postponed. And zero-emission vehicles are likely not front of mind for the few customers still buying cars right now.

Carbon Footprint

California was the first state to tackle vehicle emissions, mandating positive crankcase ventilation (PCV) valves in 1960. National emissions rules starting in 1975 limited the volumes of carbon monoxide (CO), nitrogen oxides (NOx), and unburned hydrocarbons (HC) from tailpipes, to the point where emissions of those substances are less than 1 percent of their level in a 1974 car.

But California recognized the threat of climate change early, and began to limit tailpipe carbon dioxide (CO2)—the global-warming gas that is directly proportional to the amount of fuel burned. The state also mandated that rising numbers of vehicles with no emissions at all be sold starting in 2012. Along with analogous laws in Europe and later China, that's really what kicked modern electric cars and hydrogen fuel-cell vehicles into being.

But unless or until all electricity is fully renewable, hydrogen vehicles will always have higher CO2 emissions per mile than electric cars, when you start with the same kilowatt-hour. In an EV, you generate electricity, send it along a wire, charge a battery, then discharge the battery to turn the wheels. End of story.

In a hydrogen vehicle, you use that electricity to crack a feedstock (today, largely natural gas) to generate hydrogen. Then you have to compress that hydrogen, usually offsite, and transport it to a fueling station, where it is stored, then compressed into the vehicle's tank.

There, it feeds into a fuel-cell stack where it's turned back into electricity (at perhaps 60 percent efficiency) … that turns the exact same motor as in an EV to power the wheels.

The result is that EVs have CO2-per-mile footprints one-third to one-half those of fuel-cell vehicles. Mind you, the hydrogen car is still better than your average 25-mpg gasoline vehicle. But the EV is better still. Regulators have begun to notice.

Hydrogen proponents, incidentally, will sometimes release studies that show hydrogen at a CO2 advantage. These tend to cherry-pick the data—using, for example, the best possible hydrogen case against the average of all U.S. electricity generation. Here's one.

Fast Fueling

One of the premises that originally sold regulators on hydrogen vehicles was “fast fueling,” or the ability to get most of a car’s rated range restored in 5 minutes of fueling. Hydrogen stations promise this, and frequently deliver it, but electric-car charging certainly didn’t. Even the Tesla Supercharger stations that launched in late 2012 required 25 to 40 minutes to recharge the battery to 80 percent of capacity.

BMW

BMW's Hydrogen 7 from the 2000s.

But now that’s changed. The Porsche Taycan can charge at up to 270 kilowatts, meaning a 20-minute recharge to 80 percent. With larger battery packs, rates of 350 kw are possible, bringing that down to 15 minutes. Sure, it’s not five minutes—but when you factor in bathroom breaks, coffee or soda purchases, and checking your phone, it's probably close enough not to matter on long road trips.

Cost Per Mile

The "rack rate" to refill a Toyota Mirai or Honda Clarity Fuel Cell with compressed hydrogen runs north of $50. With a larger infrastructure and more cars on the road, say hydrogen-fuel companies, the cost will come down to approach the cost-per-mile of gasoline.

Those numbers may have been believable in a future with $4 gasoline. With prices of $1 to $2 a gallon in the U.S. today, they seem less likely. It's worth noting that home-charging an electric car, on average, costs what a gasoline car would if gas sold at $1 a gallon.

None of that matters if EVs have higher sticker prices than "regular" cars, as they do today. But within this decade, they'll reach parity. Then EVs' much lower operating costs may come into play—at least for the smarter half of the car-buying couple. Who might, incidentally, love the idea of never having to visit a gas station again.

Ranking the Automakers

Virtually every automaker in the world is planning for more models and higher volumes of electric cars through the 2020s. The Chinese makers have to; the Europeans want to, because their regulators believe in science; and even the Detroit 2.5 have plans for big electric trucks they hope will appeal to U.S. buyers.

But on hydrogen, the landscape is considerably more varied. Volkswagen Group is all-in on electrics, and recently went so far as to issue a press release explaining why hydrogen was not its preferred path. The Nissan-Renault-Mitsubishi Alliance pioneered the Leaf EV 10 years ago, and has no plans for volume hydrogen vehicles as it prepares to launch an expanded new generation of battery-electric cars this year or next. It also has much bigger problems at the moment, stemming from the arrest of its former CEO. Nor do Ford or Fiat Chrysler have anything of substance in hydrogen fuel-cell cars.

GM Heritage Center

Electrovan!

GM has long experience with hydrogen vehicles, dating back to that Electrovan. In the late 2000s, it operated the largest single fleet of hydrogen vehicles in the world under the auspices of Project Driveway, a test program of 100 Chevy Equinox crossovers converted to run on hydrogen. Its bankruptcy and restructuring put those efforts on ice, and its hydrogen work is currently limited to military and heavy-duty truck applications.

In Germany, post-Dieselgate, the auto giant VW Group is now fully committed to battery-electric vehicles. In late April, Daimler took a hard look at its future development plans—and canceled all its hydrogen fuel-cell development plans for passenger vehicles.

South Korea's Hyundai-Kia is doing everything any automaker is doing, and it has one of the three dedicated hydrogen vehicles, the Hyundai Nexo SUV. It's a very nice vehicle, produced in very low volumes.

Honda

Honda Clarity FCEV

The Japanese are the foremost promoters of hydrogen transport, with the world's most profitable volume carmaker at the forefront. Toyota has long envisioned the transition to cleaner cars being led by its hybrid-electric powertrains, until hydrogen fuel-cell cars are ready for a mass rollout from 2025 through 2040. And 10 years after the arrival of modern electric cars, it remains totally and viscerally opposed to them—building them in China only because that country's government requires it to do so.

Honda is almost as dedicated, and actually offered the first "production" hydrogen car back in 2008, in the form of 200 or so Clarity FCX sedans. That car's successor, the flagship Clarity Fuel Cell, is also used as the basis for a low-volume, low-range electric car and a much higher-production plug-in hybrid vehicle. Honda just announced GM will build two separate electric cars for it, but it still appears committed to fuel-cell vehicles.

Electric cars, then, are easy to understand. Tesla and its rabid fans have boosted the technology from nerdy to stylish, selling 1 million EVs along the way. And the electric "fueling" infrastructure already exists, more or less. So what's so great about hydrogen cars again?

In the end, the fate of the hydrogen car may be—globally—the punchline that cynics have always used on hearing the prediction: "Hydrogen vehicles are the technology of the future."

"And they always will be."

John Voelcker edited Green Car Reports *for nine years, publishing more than 12,000 articles on hybrids, electric cars, and other low- and zero-emission vehicles and the energy ecosystem around them. His work has appeared in print, online, and radio outlets that include* Wired, Popular Science, Tech Review, IEEE Spectrum*, and* NPR's *"All Things Considered."*