

# COME CLEAN, PART 7 - HOW BIG OF A ROLE WILL HYDROGEN PLAY IN TRANSPORTATION?

***October 7, 2021***

When most people think about alternative fuels in the transportation sector, they think electric vehicles (EVs): Teslas, Mustang Mach-E's, F-150 Lightnings, and other zero-to-60 stunners. EVs have certainly jumped to the fore among low-carbon options, but other possibilities may prove to be even better. One is hydrogen-fueled vehicles, which while posing a number of economic and logistical challenges, could eliminate the range anxiety associated with EVs — assuming that a robust, nationwide network of hydrogen fueling stations can be developed. In today's RBN blog, we discuss hydrogen's potential as a transportation fuel, including its infrastructure-related challenges and how it qualifies for credits under California's Low Carbon Fuel Standard.

Over the past year, we've blogged extensively about low-carbon transportation fuel options as part of our "Come Clean" series. In Part 1, we took a big-picture look at how low-carbon fuel policies are changing the transportation sector. Then, in Part 2, we looked at California's LCFS and why it matters. In Part 3, we looked at ethanol's ability to cut gasoline's carbon intensity, or CI. Part 4 examined whether biodiesel is a viable low-carbon fuel. Part 5 put the focus on renewable diesel's sudden popularity. And in Part 6 we looked at sustainable aviation fuel's ascending status. Today, we turn our attention to hydrogen, which has emerged as perhaps the highest-profile alternative to conventional, hydrocarbon-based fuels.

When you come down to it, there are two categories of energy demand: stationary sources and mobile ones. Stationary energy sources provide electricity and heat for homes, businesses, and industries while mobile sources are vehicles, ships, and aircraft that carry their fuel onboard. In both cases, the ideal energy is safe, clean, affordable, and easily supplied and stored. Transportation fuels have additional requirements because, as we said, the fuel must be carried within the vehicle, requiring the expenditure of energy just to move around the onboard weight of the fuel.

Consequently, the ideal transportation fuel must also have a high energy density and an acceptable refueling time. Petroleum-based fuels, such as gasoline, diesel, marine fuels, and aviation fuels, have been the default choice for over a century because they have these basic qualities in spades. However, the growing importance of environmental and sustainability considerations, such as emissions and the large carbon footprint of petroleum-based fuels, is a driving force behind the interest in a transition to low-carbon fuels such as hydrogen.

**Hydrogen Vehicles**

Hydrogen has pros and cons as a transportation fuel. Figure 1 plots the energy density of different energy sources, both by their energy per unit volume in megajoules per liter, or MJ/l (y-axis), and energy per unit weight in MJ per kg (x-axis). (Yes, a lot of these analyses use metric measurements, but the relationships are the same.) The further a fuel is to the upper-right, the higher its energy density. (Only the DeLorean in "Back to the Future" is nuclear-powered, so uranium — or plutonium in Doc Brown's case — is not really an option.) As the chart shows, hydrogen (dashed pink oval) packs a lot of punch per unit of weight, but not so much by the unit of volume — in other words, it's light but takes up a lot of space. Traditional, petroleum-based fuels for internal combustion engine (ICE) vehicles (dashed blue oval), in contrast, take up less space but weigh a lot more. Hydrogen's low physical density makes it suitable as a transportation fuel only if compressed to high pressure (~10,000 psi) so that it occupies a lot less volume inside a vehicle. On the bottom left of the graph, lithium ion battery power (dashed purple oval) ranks low in energy density (more on that in a moment).

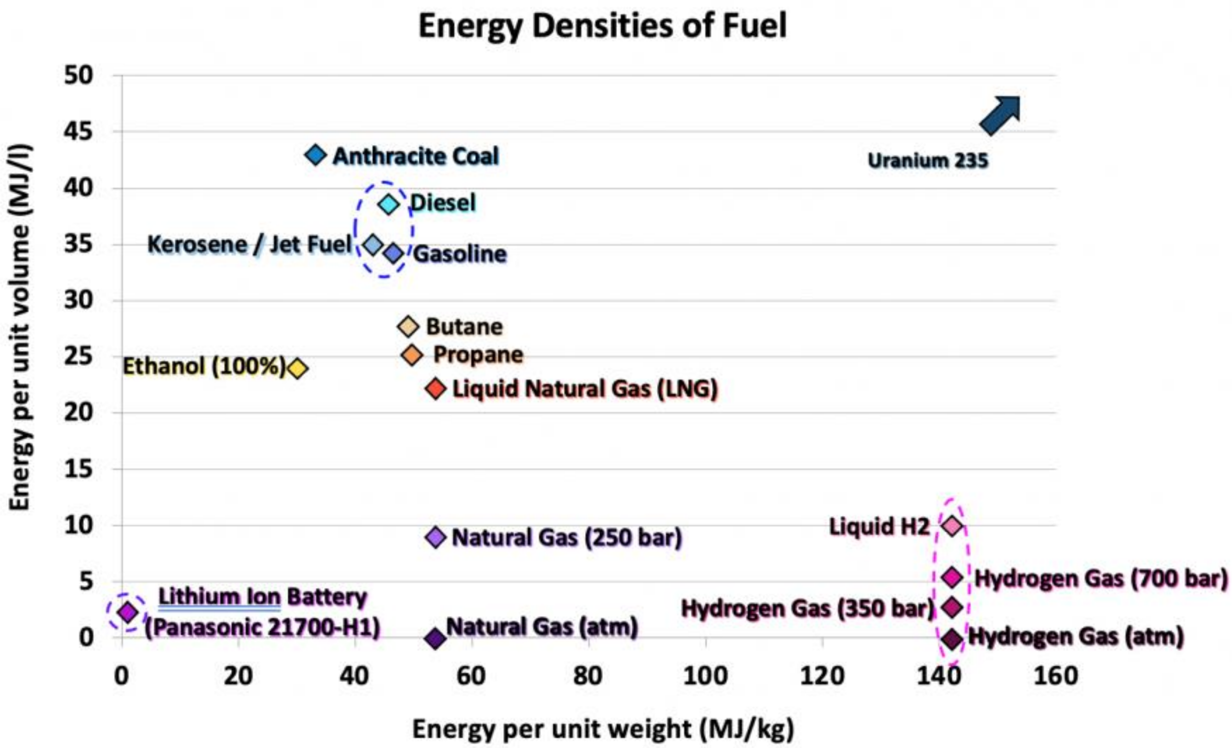


*Figure 1. Energy Density of Fuel. Source: Baker & O'Brien analysis*

Hydrogen as a vehicle fuel is not a new technology. It was approved as an alternative fuel under the Energy Policy Act of 1992 and it has long been used as rocket fuel. The mechanics of a hydrogen vehicle are similar to an EV in that one or more motors are used to drive the vehicle's wheels. In a hydrogen-fueled car, SUV, or truck there are no main batteries, like in an EV; instead, one or more fuel cells as well as high-pressure gas storage. [A brief explainer on fuel cells: A fuel cell is just a negative electrode (or anode) and a positive electrode (or cathode) sandwiched around an electrolyte. In this case, hydrogen is fed to the anode, and air is fed to the cathode and a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.] Hydrogen vehicles do contain small batteries, which are used for short-term electrical demands and which are continuously charged by the fuel cells.

There are currently about 7,000 registered hydrogen vehicles in California — that state leads the way on hydrogen because it's the only one with a significant number of retail fueling stations. Hydrogen fuel cell cars are currently offered by Toyota, Hyundai and Honda (see photo below), with prices starting around $60,000 in the U.S. before government subsidies, which is a bit pricy compared with similar ICE cars. This price premium could likely be reduced if hydrogen cars were built in mass numbers with economies-of-scale savings. According to their manufacturers' specifications, hydrogen-fueled cars are comparable with ICE cars in performance. There are currently no hydrogen performance cars, such as Tesla's Model S Plaid (standing still to highway speeds in less than two seconds!), but concept hydrogen cars do exist.

*Honda's Clarity Hydrogen Fuel Cell Vehicle. Source: Honda*

While the range of EVs has improved, range anxiety is still a concern — the worry that you won't make it to your in-laws or a beach vacation without a mid-trip recharge is not an issue with hydrogen cars. Fuel tanks in current models provide a similar range as ICE vehicles. More important, perhaps, hydrogen vehicles can be refueled in minutes, similar to the time it takes to refill an ICE vehicle. Depending upon the charging system being used, EV recharging can take hours for a full charge. However, whereas you can potentially recharge an EV in your driveway, as we will come to later, there are only a limited number of places where you can fill up your hydrogen-fueled vehicle.

As noted above, EV batteries (dashed yellow circle) are in the extreme lower-left in Figure 1. EV batteries are heavy and take up a lot of space compared with on-board fuels because of their low energy density, which is the primary factor in EV range limitations. This drawback would be fatal to EV technology if it was not largely compensated by the fact that the combination of batteries and electric motors is very efficient. About 90% of the energy in an EV battery is converted to forward motion, with very little being converted into waste heat. Even accounting for electrical grid losses, EVs still get about 70% useful work from the utility-supplied electrical power. In comparison, the hydrogen supply chain to produce, compress, transport, and use in a fuel cell car only gets about a quarter of the electrical power expended. ICE vehicles are not particularly efficient either, with about two-thirds of the fuel's energy creating waste heat rather than moving the vehicle forward.

However, hydrogen vehicles have particular advantages over EVs in large truck and bus applications. Larger vehicles have plentiful space for fuel storage and hydrogen's light weight gives EV trucks and buses good range without a lot of added pounds (or kilograms if you're still thinking metric). Electric batteries, in contrast, both take up a lot of space and add weight compared to diesel, the traditional fuel for trucks and buses. Additionally, it is expected that extra-large EV truck batteries may have even longer charging times than smaller EVs, and time is money in the trucking business in particular.


*A Hydrogen Fuel Cell Bus at Orange County, CA's Hydrogen Fueling Station. Source: Orange County Transportation Authority*

Mercedes-Benz, Toyota, and Hyundai are all developing fuel-cell hydrogen trucks. Hydrogen buses already are in use in many locations around the world and domestically, including southern California's Orange County, which began operating a 10-bus pilot program in 2020 that it says includes the world's largest transit-focused hydrogen fueling station (see photo above).

**Hydrogen Fueling Infrastructure**

Fuel stations and fuel infrastructure are where hydrogen's problems loom. Hydrogen fuel systems must safely handle very high-pressure and flammable materials, which quickly add to the cost of the infrastructure. While a commercial-level EV charging station costs about $50,000 to install, and a gasoline station's tank and handling equipment cost about $400,000, a comparable hydrogen fueling station costs in the vicinity of $2 million. [These costs are illustrative rough order magnitude estimates and do not include any cost for buildings, parking, land, etc.] This poses severe hurdles for the financial viability of private investments into hydrogen fueling stations. California has invested heavily in hydrogen fueling stations to encourage development but has only built 52 throughout the state. Only one other hydrogen fueling station exists in the rest of the U.S., and that's in Hawaii. Germany and Japan have growing fleets of hydrogen retail stations, but their numbers are still limited.

There are also other logistical and transportation costs for the compressors and pipelines necessary to supply hydrogen to the stations. Since the U.S. has a developed hydrocarbon pipeline system, it has been proposed that some costs could be defrayed by converting some pipelines to hydrogen service. However, as discussed in RBN's recent It's A Gas: Hydrogen webinar, some profound technical issues may limit that option's viability. The bottom line is that transitioning to a hydrogen economy would entail very high infrastructure costs that would be borne by taxpayers and/or consumers (both of which are really one and the same anyway).

**Hydrogen Production**

Pure hydrogen gas is the most common element in the universe but is not readily available in commercial quantities on Earth and so has to be manufactured, which is a fairly expensive process compared to many other energy sources. Today, most hydrogen is produced via the steam methane reforming (SMR) of natural gas, which results in what is commonly known as gray hydrogen. This process has a by-product of carbon dioxide ($CO_2$), the leading greenhouse gas, although the environmental impact of SMR can be alleviated through carbon capture — the result being blue hydrogen. Hydrogen also can be produced from water through electrolysis powered by renewable energy, but the cost of producing this green hydrogen is two to three times the cost of making blue hydrogen. (RBN's Been Around a Long Time discusses these various methods in more detail, and all current U.S. green, blue, and turquoise hydrogen projects as well as their power requirements are tracked in the weekly Hydrogen Billboard.) The cost of producing hydrogen would have to be significantly reduced for the fuel to be commercially viable on a large scale without government support.

**Hydrogen Within California's LCFS Program**

California sets carbon intensity (CI) scores each year for gasoline, diesel, and the fuels that replace them under its Low Carbon Fuel Standard (LCFS) program. CI is the measure of greenhouse gas emissions associated with producing, distributing, and consuming fuel. Figure 2 shows the CI of various fuels in California for light duty vehicles (LDVs), from California reformulated gasoline (black bar) on the high end to landfill compressed natural gas (CNG; brown bar) on the low end. The CI for hydrogen (purple bar) produced by natural gas is 61.8 versus about 96 for reformulated gasoline, allowing hydrogen to generate LCFS credits when sold as a fuel in California. (Review Come Clean, Part 2 for a refresher on CI scores and LCFS.) This CI value will improve as hydrogen production transitions from gray to blue to green (and all the colors in between). Further, the CI values for both production and EVs ought to improve as California's electrical power mix becomes less carbon-intensive.

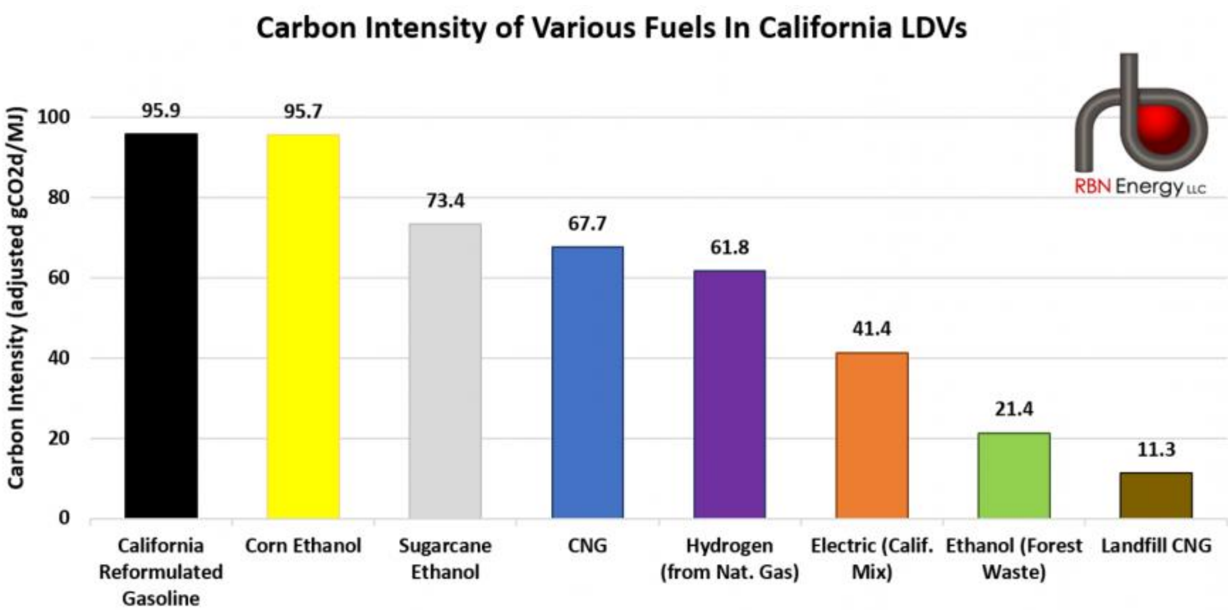


*Figure 2. Carbon Intensity of Various Fuels in California LDVs. Source: U.S. Department of Energy*

As we said, there are only 7,000 registered hydrogen vehicles in California, a tiny fraction of the state's 16 million total vehicles. One of the primary reasons for the low number is that the retail cost of hydrogen at the fuel pump in California was reported at approximately $16.5/kg for 2019. On a cost-per-distance-traveled basis, this is comparable to gasoline at $6.25/gal — in other words, approximately 40% more expensive than the current regular-grade gasoline price of $4.40/gal in that state. California's retail hydrogen is a combination of gray, blue, and green. When production shifts toward green hydrogen, which uses much more energy to produce, the retail cost can be expected to rise even higher — higher than economies of scale are likely to fully mitigate.

So, is there a place for hydrogen-fueled vehicles in the U.S.? Hydrogen's high infrastructure and production costs appear to be its major impediments to significant future market penetration. Either the cost of hydrocarbon fuels would have to rise to much higher levels, through either market or government action, or hydrogen costs will need to be reduced considerably to make them competitive.

Despite this seemingly pessimistic outlook, however, a lot of interest and investment has been directed toward hydrogen. California is continuing to permit and build hydrogen fuel stations — there are about 40 in various stages of development. Also, the buildout of hydrogen production facilities in the U.S. and abroad is a boon. For savvy investors, hydrogen presents interesting opportunities, but for hydrogen to be ultimately competitive it may require consumers to accept higher prices relative to current petroleum-based fuels.

*Note: The article was authored by Bill Jackson of Baker & O'Brien and published on RBN Energy's Daily Energy Post on October 7, 2021.*

*"Come Clean" was written by Kara DioGuardi and John Shanks and in January 2004 was the second single released from Hilary Duff's second studio album, Metamorphosis. Produced by John Shanks, the song peaked at #35 on the Billboard Hot 100 Singles chart in the U.S., but broke into the Top 20 in the*

*UK and Australia.*

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