Nikola V.S. Tesla: Hydrogen Fuel Cells or Battery?

Ruoshui Li[†]

Nicholas School of the Environment,
Duke University

11^{th} July, 2020

Nikola Motor, a hydrogen and electric truck startup, has been a rising star in the market. After completing its reverse merger with public-traded company VectoIQ Acquisition Corp, Nikola Motor surged at most 130% in the first week of trading, even when no products are delivered in the market. As a fuel-cell pioneer in the vehicle industry, Nikola has gained a market value higher than any other automakers in America except General Motors and Tesla Motor. Discussion between hydrogen and battery-backed electric vehicles also revived with the new Nasdaq business. In terms of the specific market segment Nikola has targeted on –trucks, will full-cell trucks outweigh all-electric ones in price and technical design? Or to say, will Tesla have to share the road with the rising competitor in cleaning up the transportation industry? To meet ambitious market share in the truck niche, what challenges will Nikola have to address in the next few years before officially delivering the first commercial product to customer?

Comparison between two types of semi model

We first start with the main question – how do electric and fuel cell vehicles each work? While both essentially powered by electricity to run the motor and turn the wheels, general electric vehicles store electricity in a set of batteries, while fuel cell vehicles draw power from pressurized hydrogen tank. Batteries simply discharge electrons and hydrogen gas is fused chemically with oxygen to produce electricity. Both work in an entirely different and clean way compared to their internal-combustion engine peer.

Tesla is now occupying a substantial share of the electric vehicles market but focusing more on passenger cars. Its heavy truck division–the Semi model was unveiled in 2017 and though delayed, is scheduled to enter production in 2020. Walmart, FedEx, UPS, and many others have placed more than 2,000 total pre-orders of the Semi. In contrast, Nikola has more

[†]E-mail: ruoshui.li@duke.edu.

diversified products. Its truck motors include Nikola One (released in 2016), Two (2019, designed for U.S. market), and Tre (2019, designed for European market), which are slated to go into commercialization after 2022. Noticeable, the latter two products will be available as both a hydrogen-battery hybrid vehicle for long haul operations and an all-battery-backed truck for shorter-range trips. Arguments around the pros and cons of two types of vehicles from a technical perspective normally come down to 4 criteria, here, we mainly examine the fuel-cell version of U.S. model Nikola Two with Tesla's Semi model.

Performance

- **Truck Weight:** A big point of concern from the freight transportation industry was the truck weight. In the U.S., semi-trucks are limited to a weight of 80,000 pounds or less, including both the truck and cargos it carries. This makes the net weight of empty vehicles vital because the heavier the truck, the less cargo it's allowed to carry, and the fewer return investors can retrieve. Understanding the weight of an empty Tesla Semi is thus critical, given that each additional battery pack placed to support long-haul trips may incur a loss on cargo capability. Though not officially disclosed, some projected that the required battery capacity for a 500-miles Semi model will be 947.4 kWh, which can be translated to approx. 17,400 lbs for an empty truck. If closely estimated, that is a pretty average weight for Class 8 trucks (and even slightly lower than Nikola Two), which means the Tesla Semi is capable of hauling approximately the same amount of cargo as a standard semi-truck.
- **Fuel energy density and overall efficiency:** As a transportation fuel, hydrogen has a per kilogram energy content greater than any other commonly used liquid, gaseous or solid fuel. By mass, hydrogen fuel's energy density is 120 MJ/kg, nearly hundreds of times that of Tesla's current lithium-ion battery. This makes hydrogen a much viable energy storage medium. However, the energy losses of hydrogen-powered electric cars are also much greater. According to studies, all-electric cars can achieve an outstanding overall Well-to-Wheel efficiency of 70 90%, only incur losses during transmission and charging. In contrast, hydrogen fuel cells also experience losses during the production of hydrogen through electrolysis (about 45% loss) and conversion to electricity within the vehicle (another 55% loss in remaining original energy), giving an overall efficiency from 25% to 35%. This means that regardless of fuel mass, a hydrogen motor can require 2 3 times more energy to drive the same distance as an electric truck.

Driving range

Most people buying electric cars are grappled with range anxiety. Constraint by significantly lower battery energy density and limited vehicle weight, electric cars typically have half

Table 1: Parameters comparison between two vehicle models

	Tesla Semi	**Nikola Two**
Price	$150,000^{+}$/ or $180,000^{+}$	Approx. 90∼95 cents over a 7-year or 700,000 miles lease
Horsepower (HP)	*Not disclosed yet*	1,000
Torque (ft-lbs)	*Not disclosed yet*	2,000
Towing Capacity (lbs)	80,000	80,000
Est. Vehicle Weight (lbs)	17,400	18,000∼20,000
0-60 MPH (s) (with 80k lbs)	20	30
Range (miles)	300 or 500	Est. 500∼750
Fuel density	Approx. 0.6 MJ/kg	120 MJ/kg
Well-to-Wheel efficiency	70%∼90%	25%∼35%
Battery Capacity (kWh)	*Not disclosed (Est. 650 kWh ∼1MWh)*	250
Energy Consumption	<2 kWh/mi	Aver. 0.12 kg H_2/mi
Fuel cost		
Current	13 c/kWh	$6/kg
Essential price in Nikola's plan (included in total lease payment)	2 c/kWh	Essentially $2/kg at 2c/kWh
Refuel / Recharge cost ($/mile)		
Current	<26 c/mile	72 c/mile
Essential price in Nikola's plan (included in total lease payment)	<4 c/mile	Essentially 24 c/mile
Refuel / Charge time	Est. 30 mins to reach 80% capacity using a megacharger	10∼15 min

*Data from Tesla / Nikola official website, EIA estimation and editorial data

the range of most fuel cell cars. While this is tolerable for normal city driving or work commutes, it can be nervous for truck drivers who tend to put considerably higher miles on their rides. In that regard, the Nikola two model which can drive up to 750 miles after one refuel performs better than Tesla's electric Semi (300 or 500 miles designed by customers). Despite the range problem, some argue that the 500 miles Semi model is actually capable of meeting most of the truck driver's needs. According to an interesting observation, 80% of the truck routes in the U.S. involve less than 250 miles of travel. This means one can travel to the destination and still make his way back in a Tesla Semi, even without recharging in the middle of the trip.

Refueling / recharging time

Refueling a gas tank can never be more time-consuming than recharging a group of battery packs. According to Tesla CEO Elon Musk, the 500-miles Semi model can give 400 miles (80%) of range in 30 minutes of charging via one of Tesla's Megachargers, while Nikola only requires 10 15 minutes to fully refill the hydrogen tank. In comparison, thirty minutes might seem like a long time, however, Elon pointed out that 400 miles of range translates to about 6-7 hours of driving, after which a truck driver must take a mandatory rest stop. A 30-munites break is enough to restore a Semi's power. Besides, when waiting for loading or unloading in a depot, drivers can charge the semi at the same time for the way back as well.

Challenges and uncertainties for the startup

Based on the comparison above, we can see that in terms of vehicle design, hydrogen fuel cell trucks have a favorable driving range and refueling time, while Tesla motors benefit from lower fuel cost and higher energy efficiency. The battle between two ambitious truck players seems to be kind of a balancing act. However, when it comes to real competition in the market, a market that has reinvented by Tesla's faith and infrastructures since decades ago, Nikola still has a host of challenges lay beyond manufacturing and designing of vehicle itself to contend with.

1. Where do all hydrogen come from?

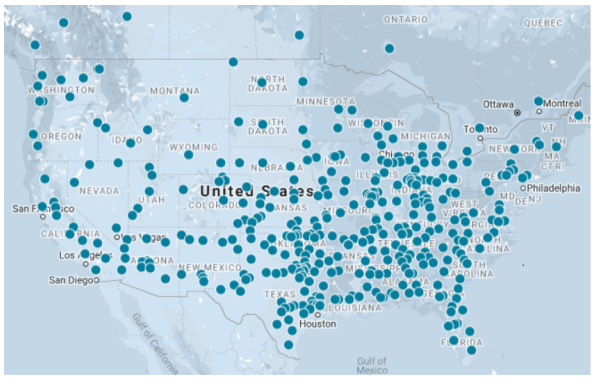
A continuous supply of hydrogen is the key to fuel cell motors. There are generally two ways to produce pure hydrogen: natural gas reforming and electrolysis. The formal way can cause carbon emissions during production, while the latter which simply applies electricity to water can produce green hydrogen. To use only clean energy for driving the motor, Nikola is planning to fuel hundreds or thousands of hydrogen trucks through electrolysis. Yet, current U.S. hydrogen production remains dominated by carbon-intensive natural gas reforming, and water electrolysis has been prohibitively expensive. Additionally, when hydrogen is compressed

and transported from the electrolysis production center to Nikola's distributed refueling stations, considerable transportation cost will be incurred due to the low volumetric energy density of H_2 which makes it hard to store and transport. It seems that Nikola's value proposition to freight companies will not force them to switch if the price of hydrogen cannot compete with electric cars. The company's early partnership with Nel Hydrogen could be a positive sign. Nel is a Norwegian water electrolysis company that has been around for 90 years supplying water electrolysis machinery to C & I companies in Europe. The two companies inked an agreement in 2018 to have 448 electrolyzers deployed around the US. While Nel manufacture electrolyzer tanks and fueling equipment in Norway and Denmark, Nikola purchase other supporting components and sub-systems in the US, which reduce costs and minimize transportation needs. Such cooperation with proficient industry player and leverage of economies of scale enable Nikola to make use of scale effect and drop hydrogen price. Moreover, the blueprint presented during "Nikola World" also reveals the company's "truck stop" design, with parking facilities, stores, restaurants, and electrolysis equipment built together. In this model, hydrogen is produced at the same location it is pumped into drivers' trucks, the large-scale volumes of on-site production thus avoid transportation costs and enable producers to charge even less from end-users.

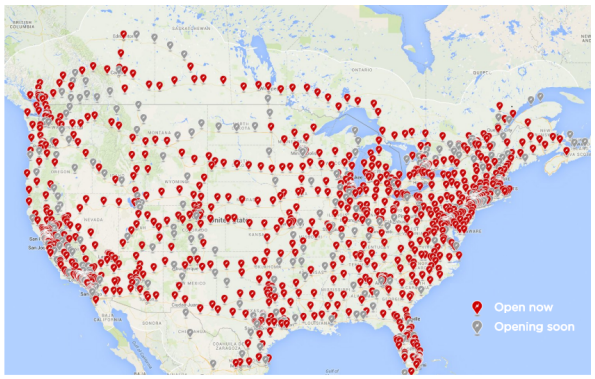
Another positive sign of Nikola's hydrogen production plan is related to the electricity used to decompose water. Company officials claim that every refueling station Nikola plans to build across the U.S. would be powered by "renewable energy supplemented by low carbon gird energy" using electrolysis equipment from Nel Hydrogen. However, rather than utilizing "conventional" renewable energy from solar, wind, or nuclear projects, Nikola is planning to make the best use of previously unexploited or under-utilized energy sources. The plan calls for building company-owned solar panels in specific areas or creating purchase agreements with other wind or hydro-electric generators to harness their unused capacity. For instance, the company would be targeting areas like Arizona and California, where there are tons of room for developing solar resources but not all energy is harvested. and areas like the Tennessee Valley, where hydroelectric power is dominant in day girds, but sluices are just opened up and let water go when demand is low at the night. These untapped energies, which otherwise are curtailed or abandoned, could all be used to decompose water and produce hydrogen, which will be kept in storage tanks and used to power fuel-cell motors the next day. This plan, if works, will not only make more clean and cheap energy available for the company but also enable the renewable energy industry to deal with capacity curtailment problems brought by an over-supplied market. Since the majority of electrolysis cost is tied to the price of electricity, if producers can have low-cost electricity out of untapped energy resources, drivers can enjoy low-cost hydrogen as well. Nevertheless, Nikola does not fully avoid setting up stations relying on carbon-heavy grids. In areas where electrolyzes need to use power sourced from fossil fuel or natural gas, Nikola will likely buy in carbon credits to offset the footprint of their hydrogen

products. From this perspective, hydrogen vehicles in fact outweigh electric cars which mostly run on natural gas and some renewable energy.

2. How convenient will drivers refuel their trucks?



Source: https://nikolamotor.com/hydrogen#hydrogen-map



Source: https://www.tesla.com/supercharger

Figure 1: Left: The planned Nikola hydrogen fueling network; Right: Tesla Supercharger network by 2020

Pumping hydrogen into the tank indeed requires less amount of time than electric cars, however, if no refueling infrastructure is available nearby, the truck driver will have to go to a certain hydrogen station – not necessarily along the route, which can cost extra time and range. As of 2020, there are only 44 publicly available hydrogen stations for fueling fuel cell vehicles, mostly in California. In this case, there is basically little repower time or driving range advantage in the hydrogen truck's practical use. Realizing that before effectively establishing a fueling network, all truck motors are just parking lot ornaments, Nikola is planning to build a network of more than 700 truck stop-size hydrogen fuel stations across the U.S. starting 2022. The plan will start deployment in the West before migrating eastward with the market. Once built, a standard fueling station can provide 8 tons of hydrogen per day – enough to support 150 heavy trucks for one refueling. Locations next to truck depots with 300 to 600 vehicles can also update to a 32-ton facility. However, though Nikola has ambition distributing hydrogen production facilities around the country, Tesla's electric Semi may still outweigh Nikola Two in effectively finding a charging station. Currently, Tesla is operating 16,103 Superchargers in 1,826 stations worldwide, within which 908 stations are in the US. The company is also planning to set up another network of "Megachargers" for supporting the rapid charging needs of Semi trucks. If not newly-built, it is possible to use a box that bridges cables from an existing Supercharger stall to the truck as well. Though detailed status is unknown for now, by 2028 when Nikola finishes building all 700 refueling stations, Tesla should as well be finished developing the Megacharger network, further increasing electric charging station availability to truck drivers. And this has not counted the fast-growing non-Tesla specific (but still compatible

with Tesla vehicles) charging infrastructures. Undeniably, the supply chain, infrastructure, and technology of hydrogen motors are still years behind electric vehicles.

Understanding all the technical details and challenges, the last question becomes: can Nikola replicate the success of Tesla and build a sizeable hydrogen network in the truck market? Nikola is smart for being far away from the battery-dominated passenger car market and targeting only on the truck segment, where they can make the best use of hydrogen fuel's advantages. Nevertheless, even with all plans perfectly set up to roll out fueling stations and vehicles simultaneously, several external factors that can become either exciters or resistances still need to be discussed.

- **Policy support:** Nikola CEO Trevor Milton once commented on how government regulations might get in the way of the hydrogen network's development during a press conference, he mentioned that regulators should "just let us go build stations and pull these diesels off the road", because some standards are so stringent that it can take "three to four years to permit a hydrogen station". This number might be a little exaggerated, but truly reflecting the roles of federal and state-level supports in advancing hydrogen technology. The strong momentum of global EV markets has relied heavily on government support and been buoyed by years of overall vehicle market growth. U.S. government and states offered a variety of fiscal and non-fiscal incentives to support EVs manufacturing and infrastructure building to promote EV adoption in the country. These subsidies, credits, or other tax benefits all enable a healthy growth of the U.S. EV market. In contrast, fuel cell systems and hydrogen energy have been less lucky. U.S. Department of Energy (DOE)'s Fuel Cell Technologies Office and the Department of Transportation indeed appropriated funds to initiate research, development, and demonstration (RD & D) activities for hydrogen energy and evaluate hydrogen fuel cell buses on local transit routes across the country. Nonetheless, only one state, California, is racing to become a leading market while the U.S. as a whole barely merits a mention. It's not clear whether there will be increased federal government initiatives for the development of fuel cell infrastructure in the next decades, but for reaching substantial market share like electric vehicles, Nikola's hydrogen network development will be better off with appropriate policy supports, and perhaps less bureaucracy. Another interesting point here is related to the uncertainty of the U.S. Election in November 2020. While current president Mr. Trump personally mocks at low-emission electric vehicles and pledges to end EV buyer's tax credit, democratic candidates Joe Biden is planning to expand government supports on electrifying the transportation industry, restore the full tax credits and deploy more public charging outlets. Therefore, industry's interests on hydrogen fuel cell vehicles may be directly associated with whether the new president will stay in the way of and pressure on electric vehicle expansion.

- **Persistence on capital investment before market maturity:** Vehicle is capital and technology-intensive industry. It will need to adapt to any new technologies as investments continue to be made to improve the supply chain, infrastructure, and concept in the market. Tesla was constantly burning through its cash before finally made two consecutive profit quarters in the second half-year of 2018. Thanks to the increased production of Model 3 which finally starts to pay off, Tesla turned a loss into profit for the first time in its 15-year history. One vital reason for the company to not only survive as a bran-new player but consistently lead the way of other vehicle competitors is its substantial and constant capital investment in new charging stations, sophisticated battery tech, and branch marketing. The company CEO Elon Musk and investors all firmly believe that battery is the future of the transportation industry and the passenger vehicle segment will ultimately pay off after the perfect EV-charging station network brings permanent customer flow. Hence, capital input persists even seldom sees close to the path of profitability. So, will Nikola be able to keep up their momentum in the coming years until their hydrogen semi finally pay off? Nikola is smart for rolling out trucks and fuel stations almost at the same time, but many motor carriers still want to see the hydrogen infrastructure up and running well before committing orders. Besides, the leasing model requires more follow-up capital investment to provide better customer services. Therefore, hydrogen cars are not likely to threaten electric vehicles or even overtake them until decades of investments, and Nicola should be prepared for that.
- **Social inertia:** Electric cars have dominated U.S alternative fuel vehicle market, but not only on the roads or in the retail stores. It is also integrated into the development of a whole society. Customers are increasingly accustomed to the driving and charging style of electric vehicles, policymakers are familiar with ways to incentivize EV manufacturer, university researchers put efforts on studying and improving battery performance. Even police, firefighters, and emergency medical personnel are more trained in responding properly to accidents involving an electric vehicle. It is not completely impossible for Nikola to break such an electrified society. However, the public may need strong incentives before making the shift. Besides, since hydrogen and electric vehicles are both emission-free and environmental-friendly, it is less likely that Nikola can replicate what Tesla once did to dirty fossil fuel cars when clean electric vehicles first enter the market. A last factor that may protect EV's market share comes from rideshare company Lyft. Committing to having 100% electric vehicles on its platform by 2030, Lyft is hailing a ride to an all-electric future. Though is not directly involved with the truck segment, deeper electrification in the society may attract and encourage more businesses to choose an electric model for long haul trips.
- **Safety:** Battery condition and charging technology of electric vehicles are continuously

improving, which means electric cars may have more stable performance and perhaps fewer safety problems. However, there are still concerns among the public around the production of hydrogen and storage facilities. Hydrogen gas has a low ignition point, thus is extremely flammable. Each point along the network, including truck tanks, hydrogen generation plants and fuel stations would need to be highly secure. Specific safety plan that deals with hydrogen explosions should also be in place before commercial products enter production. Hence, Nikola should really take the responsibility to ensure hydrogen could become reliable and safe energy for powering vehicles.

Conclusion

Hydrogen energy and fuel cells were considered the "next big thing" in powering the society since the launch of the Apollo space rocket in the 1960s. Six decades later, there are hardly any fuel cell vehicles on the U.S. streets, but a substantial proportion is electric cars. Until recently, hydrogen vehicle startup Nikola motor finally gave it a strong entry to the heavy truck segment and committed to building a world's largest hydrogen network, starting from the U.S. and Canada. Advocates for Nikola claim that the infinite energy potential, longer driving range and lower refueling time make hydrogen motors a best fit for the truck industry, and by utilizing previously untapped renewable electricity to produce H_2, the company could contribute more to net-zero in the transportation industry. While opponents argue that electric semis are already better in battery performance, energy efficiency and fuel cost, not to mention the well-developed charging station network among the nation. The uncertainties from policymakers, company investors, and the whole society's inertia may also hold the company's ambition up. A new hydrogen network can become an alternative for more businesses and drivers to go emission-free, it may also turn out to be just an expensive distraction from the world's main goal of switching from fossil fuels to renewable energy. However, people need to know that, in either way, the fuel cell is just another way to use electricity rather than fossil fuel for powering the car, it should be counted as a rival for Tesla, if not an enemy. And we can clearly see that fuel cells still have some way to go before truly promote a low-carbon society.