ELECTRIC

WILL FUTURE TRUCKS BE POWERED BY BATTERY OR HYDROGEN TECHNOLOGY?

Battery- and fuel-cell-powered electric vehicles are new to the market. Can different technologies find a home, or will a single winner emerge?

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A volt is a volt, whether it comes from a hydrogen fuel cell or a lithium-ion battery. How that volt is produced makes no difference to the electric drive motors on commercial vehicles, but the stakes are enormous for everyone else, from fleet buyers to the people who design the assembly lines for such vehicles. We have two apparently viable ways of powering electric trucks, each currently somewhat better suited to certain applications than others. Will a clear winner emerge?

We have the battery-electric people in one camp and the fuel-cell-electric crowd in the other. The debates are loud and raucous and fun to watch, but not conducive to fact-finding.

A great deal of the conversation revolves around Tesla's attempts to build an electric Class 8 tractor. There are legions of Tesla fans who are quick to trash the "competition," including Daimler, one of the largest truck manufacturers in the world, for not knowing how to build an electric truck. Yet Tesla fans and many mainstream technology writers know little about the hard realities of trucking.

There's at least one mainstream writer who gets it: Steve Banker, a transportation logistics and supply chain management contributor to Forbes magazine. He had this to say about the Tesla Semi: "For Tesla stockholders, a move into this market is not something they should welcome. Carriers are hardheaded business people. They must be, to survive. There will be no trucking company buying premium-priced trucks to prove they are green or to make a fashion statement; the green their survival depends on is the shade of green you find on a dollar bill."

However, both Tesla and Nikola did something that traditional truck makers have yet to do: They designed and built trucks around their electric and hydrogen powertrains, while the truck OEMs are taking diesel truck chassis and adapting them for electric drive, says Rick Mihelic of Mihelic Vehicle Consulting, program manager for the North American Council for Freight Efficiency.

"Nikola and Tesla will be able to optimize their costs better than the OEMs, at least in the short term," he says. "There has to be a lot of extra cost that could be eliminated if they did a purpose-built design wrapped around the right powertrain."

That said, traditional OEMs are very good at building trucks that will last well beyond a million miles. The two upstarts have only engineering expertise to go on. So far they have few durability and reliability test miles under their belts. Only time will tell how well those designs will hold up over a million miles.

Hydrogen vs. lithium-ion

There are currently three hydrogen power systems in development: Nikola (Bosch fuel cells), Kenworth/Toyota (Mirai fuel cell), and a Canadian consortium collaborating on the AZETEC project (Alberta Zero-Emissions Truck Electrification Collaboration).

Contributors to the Canadian project include Ballard Power Systems (hydrogen fuel cells), Daimler Trucks (tractors), Dana Corp. (electric motors), and others. The goal is to put two fuel-cell-electric tractors pulling 140,000-pound combination vehicles over a 430-mile round trip between Calgary and Edmonton, Alberta, between

TRUCKS

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HYDROGEN: PROS & CONS

Hydrogen is the most abundant element in the universe, but it does not occur naturally. It's always found in combination with other organic compounds, such as water, or the hydrocarbons that make up diesel fuel, gasoline and natural gas. The process of separating pure hydrogen from its base compounds is energy-intensive, and from an energy-in versus energy-out point of view, it's not very efficient.

The two most common ways of producing pure hydrogen are steam methane reforming and electrolysis. SMR uses high-temperature steam that reacts with a high-carbon source such as methane or natural gas to free the hydrogen. About 90-95% of hydrogen produced today comes from SMR – but with that process you still have carbon dioxide (CO_2) emissions.

"When you're cracking a hydrocarbon like methane, the hydrogen is what you want, that's where the energy is; the carbon is the undesirable part, and a byproduct of SMR," explains Jesse Schneider, executive vice president of hydrogen and fuel cell technologies at Nikola. "While SMR and electrolysis are both about 60% efficient, our process is solar-powered. Our well-to-wheel emissions are very low."

On the vehicle, a polymer electrolyte membrane or proton-exchange membrane fuel cell produces electricity by combining hydrogen with naturally occurring oxygen – essentially reverse electrolysis. The flow of electrons through a membrane produces electricity. The only byproducts are water vapor and heat.

There are additional "costs" to hydrogen, such as 10-15% energy lost compressing the gas up to 10,000 psi and inefficiencies in the fuel cell itself. Most fuel cell makers claim 50-60% efficiency, but some developers claim efficiency could be as high as 80% in future generations of the technology.

All that said, the relative inefficiency of hydrogen production isn't a serious issue with the business models currently being proposed and developed for a trucking application, at least by Nikola. With vast yet-to-be-built solar farms powering the electrolyzers, it's seen as untapped energy anyway as opposed to grid-produced energy that is only being used at 60% efficiency.

And for what it's worth, today's diesel engines are only about 45% efficient at turning the chemical energy in diesel fuel into kinetic energy to move trucks.

Hydrogen is not a fuel as we are used to thinking about fuel. It doesn't burn. In this context, it's an energy storage medium that has more in common with a battery than liquid fuel. However, it has a much higher energy density. The Office of Energy Efficiency and Renewable Energy says, by mass, the energy content of hydrogen is 33.3 kWh per kilogram versus 12.5 kWh/kg for diesel.

In California, where about 30 filling stations are currently dispensing hydrogen for cars, the price is about $14 per kg (equivalent on a price-per-energy basis to $5.60 per gallon of gasoline).

"I think in the short term, government incentives and subsidies will be the reality to help keep the fuel affordable," says Ash Corsen, alternative fuels vehicle manager with Toyota's Advanced Technologies Group. "In the medium term, I think you'll see parity with diesel fuel [on an energy-by-volume basis]. A Class 8 truck will consume much more hydrogen than a passenger car, and the kind of scale the energy majors like Shell want to see."

Under the business model proposed by Nikola Motors, the price of hydrogen would be baked into the lease price of the truck and therefore more or less invisible to the user. However, Jon André Løkke, CEO of Nel ASA, Nikola's hydrogen and technology partner, says, "We could sell the hydrogen we produce at less than $6 per kilogram, or about half the price that we see most other hydrogen customers paying."

Hydrogen's principle advantage over batteries is range. Aside from the weight of the storage tanks, about 4,000 pounds, a tractor with 80 kg of storage capacity at 6 to 10 miles per kilogram would provide 500-800 miles of range, making it a better candidate than batteries for longer hauls and inter-city movements. According to Nikola CEO Trevor Milton, the Nikola Two day-cab on display at Nikola World in April will weigh about the same as a typical highway sleeper-cab today – 18,000-20,000 pounds. It's said that it takes about 15-20 minutes for a full hydrogen refill.

Nikola's hydrogen-fuel-cell-powered Class 8 truck, the Nikola Two, is flashy and efficient. Is that enough to overcome our unfamiliarity with fuel cells?

refueling. Each truck will have three 70kW FCmove-HD Ballard fuel cells. The trial is set to get under way next year and run through 2022.

Hydrogen has two clear advantages over battery-electric today: longer range without sacrificing payload. Nikola has said its purpose-built truck will have a 500-800 mile range on 80 kg of hydrogen in a chassis that it says weighs no more than a typical diesel sleeper tractor. Kenworth and Toyota say their prototype trucks, unveiled at the CES electronics show in January, will have a range of 350 miles based on the hydrogen storage capacity. Since the tractors will be minus the diesel engine, transmission, fuel tanks and aftertreatment system, it will offset the weight of the six carbon fiber hydrogen tanks, the fuel cell stack and a 12-kW drive battery, making it close to weight-neutral compared to a diesel truck.

"A typical regional haul where you're going about 350 miles would use about 120 pounds of hydrogen," says Brian Lindgren, who heads up Kenworth research and development. "The heaviest part of this system is the storage tanks at about 4,000 pounds, but we're still way below the 16,000 pounds of batteries you'd need for the same distance. And then there's recharge time. Charging the batteries would take several hours, but you can fill 120 pounds of hydrogen in about 15 minutes. I think drivers would live with that."

Fuel cells are a bit like diesel engines in that they are most efficient operating at a steady state. The hydrogen flow can be controlled, but the battery provides the "throttle" modulation as more or less power is needed for

Kenworth and Toyota are partnering on a fuel-cell-powered Class 8 tractor for regional hauls of up to 350 miles.

hills, headwinds, etc. Regenerative braking can occur as well, but it's not as necessary as it is in a battery-powered truck to improve range.

Battery-powered trucks, on the other hand, benefit greatly from high transient, stop-and-go operation with more opportunities for regenerative braking. Any opportunity-charging helps extend range, in some cases up to 50%, NACFE's Mihelic says. "We've seen it in the field, but it cannot always be shown calculated range estimates."

In trying to right-size its battery packs, Daimler's e-Mobility group went to its customer base to determine range expectations for applications that could be readily electrified, such as urban medium-duty and short-haul Class 8 applications. "We found that probably 80% of the group we spoke to were not running more than 150 miles per day," says Andreas Juretzka, head of Daimler's e-Mobility Group. "That led us to a battery spec of 230-mile range, which covers, among other things, the swings in ambient temperature that can affect battery performance and to alleviate the customers' range anxiety."

The first two Freightliner eCascadia Class 8 day-cab tractors emerged from the research and development center in Portland, Oregon, in mid-August sporting 550-kWh battery packs, enough for 250 miles of range. Daimler also has several eM2 medium-duty battery-electric trucks in customer trials with Penske Truck Leasing.

While Tesla continues to boast about 500-mile range and zero-to-60 times of less than 5 seconds, traditional truck builders are getting serious about putting battery-electric trucks into the market that will provide the

LITHIUM-ION BATTERIES: PROS & CONS

Lithium-ion batteries store energy, and they are pretty good at it. You pump so many kilowatts into a battery, and you get most of that back out again. However, they don't like discharging much less than 20% of their capacity, they lose some of their efficiency over time with fast-charging and repeated charge/discharge cycles, and they are subject to efficiency losses in low ambient temperatures. A 100-mile battery would need a 20% contingency to protect against excessive discharge and could lose up to 20% of its capacity as it nears the end of its useful life. If it's operated in winter weather, you may need to factor in as much as 30% reserve capacity. If it's a 100-mile battery you had in mind starting out, you'd soon realize that you need about 200 miles of capacity to cover all anticipated operating conditions over its expected life.

More battery capacity adds cost and weight. Costs are coming down fairly fast, but weight is slower to budge.

A September 2017 paper from the International Council on Clean Transportation, Transitioning to Zero Emission Heavy Duty Freight Vehicles, lists lithium-ion battery costs in 2007 at $1,000/kilowatt-hour (kWh). By 2015, costs had tumbled to $326/kWh. It's thought that prices could fall below $200/kWh in 2019.

The battery price point often cited as the transition point when commercial battery-electric vehicles reach cost parity with diesel is $150/kWh. Lifecycle cost is often overlooked in vehicle price estimates. Generally speaking, electricity costs much less than diesel fuel, and electric vehicles are presumed to require less maintenance; both are forecast to keep operating costs down, which will offset higher acquisition costs. Residual value and pricing in the secondary market are impossible to predict at this time.

"We're going to need to know that, because I suspect that very few people will be buying fuel-cell or battery-electric vehicles – most are going to want to lease them," says Brian Lindgren, Kenworth research and development director. "That means lessors like Paccar Financial are going to need some kind of a residual we can bake into our lease rates."

Further complicating matters, within the expected five-year life of such a truck, advances in battery chemistry and further cost reductions could render current price and weight modeling obsolete.

Battery weight is subject to less speculation than cost but is no less an issue for carriers. There's some consensus that the power requirements for Class 8 trucks are about 2 kWh/mile, and 1.5 kWh/mile or less for medium-duty trucks. Once you determine the range and build in contingencies (as above), you can calculate the anticipated weight of the battery pack.

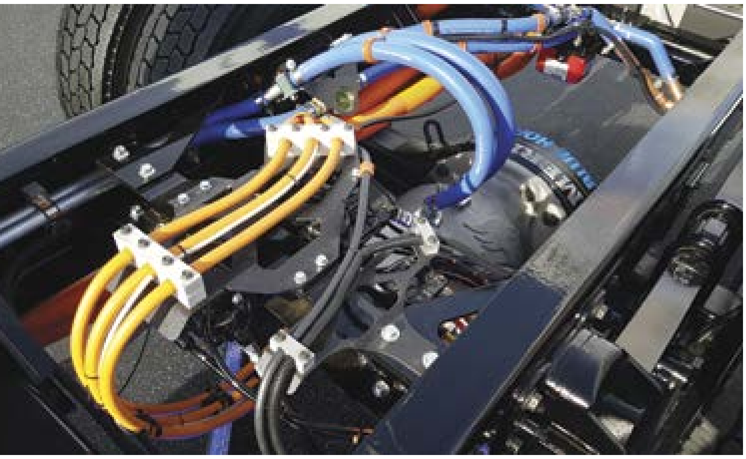
"Care must be taken not to oversize the batteries, as that could impact freight weight capacity — while being too conservative could adversely affect range," cautions Rick Mihelic of Mihelic Vehicle Consulting, program manager for the North American Council for Freight Efficiency. "When thinking about range, you also need to consider regenerative braking opportunities on your proposed routes. In some cases, they can be as high as 50% of the total battery capacity."

Following a test drive HDT did in March of a Peterbilt Model 220 EV with a Dana electric drivetrain (93-kWh battery pack with an anticipated 100-mile route), Harry Trost, Dana's senior product planning manager, said the truck weighs nearly the same as a diesel. "The battery-electric version is about 262 pounds heavier than the diesel vehicle," he said. "The main focus of that build was functionality, not specifically the weight differential, and there are ample ways to reduce the vehicle weight by that [amount] with other weight-savings features."

Battery weight is more critical for Class 8 tractors. Greater gross weights require more energy, so do you give up payload or range?

Daimler's e-Mobility Group is developing electric powertrains for vehicles in several different markets.

PHOTOS: JIM PARK



The hydrogen fuel cell stack is something new to Class 8 trucks. Nikola started with a clean-sheet design. Will traditional OEMs find ways to package this technology on existing chassis or start fresh with purpose-built designs?

As chassis integration evolves, electric trucks will become lighter and less expensive. Wheel-end motors could replace traditional drive shafts and differential axles.

best return for their customers. Peterbilt, for example, has identified three markets with the best prospects for success in these early days.

"Peterbilt believes three applications — refuse, regional, and urban pickup and delivery — represent the best opportunity for immediate and near-term payback for our customers," says Peterbilt General Manager Jason Skoog. "We will be placing electric versions of the Model 579, 520 and 220 into customers' hands this year for performance evaluations."

At the moment, charging battery-electric vehicles remains a bit of a stumbling block. It can take up to eight hours to fully charge a large battery pack. They can be charged faster, but that has long-term implications and shortens the life of the batteries. Applications such as refuse and urban P&D lend themselves well to overnight charging, but Class 8 regional could be hampered by lower utilization rates due to charging times.

The charging infrastructure is also in its very early days and not yet even close to being optimized. Truck makers and fleets are working with utility companies to move this forward, but on-site does require a substantial commitment from both the carrier and the utility company. This is still a work in progress.

How do we pay for electric trucks?

We have all heard the toenail-curling numbers tossed around regarding EV pricing. They won't be cheap, but when the early dust has settled, they may not be as pricey as some fear. As battery production increases, prices are bound to fall lower still before eventually stabilizing to some extent.

"Battery prices are trending down now, but we don't know where that price is going," Mihelic says. "Increased supply will bring the cost down, until demand catches up. If we get to building 20,000 electric trucks a year, that will certainly create new demand for raw material that wasn't there before. Where does pricing go in a high-demand, low-supply world? The price always goes up."

Dakota Semler, co-founder and chief executive of start-up Xos Trucks (formerly Thor Trucks) said last year during a conference call with industry analyst Stifel that he expects to bring a truck to market with a 100- to 300-mile range for between $150,000 and $250,000 without subsidies.

Medium-duty truck maker Workhorse and UPS have said they could build a Class 6 truck for the same price as the diesel vehicle it was replacing without any incentives.

But subsidies and grants will be part of the game for the foreseeable future as various governments try to encourage adoption of zero-emissions vehicles.

"California wants drivers to migrate us to zero-emissions vehicles by 2045, so they are setting up the infrastructure for grants and tax breaks for the long term," Mihelic says. "I expect grants and incentives will be around for a long while. If these vehicles are too expensive, people won't buy them."

Meanwhile, Nikola's pricing model is a lease deal that will see the customer pay a per-mile rate for the truck, with warranty, maintenance and hydrogen fuel included. As of April 2019, the plan called for a 1 million mile or 84-month trade-in cycle with a lease rate of 90 cents per mile.

The battery-electric business and operating model is becoming clearer, and we now have a firmer idea of what it will look like in a few years' time, but the hydrogen model is less clear. Fuel cells have yet to prove themselves in this application, though they have been proven in transit bus applications around the world. Hydrogen production suffers from the fact that the conversion of some form of energy into hydrogen gas and back to electricity is pretty inefficient in most cases.

However, Nikola's idea of a dedicated solar grid harvesting currently untapped solar energy for hydrogen production, rather than relying on traditional sources of energy, is intriguing. It would be hugely capital intensive to get off the ground, but the solar energy becomes essentially free.

Batteries, on the other hand, will continue to evolve, and energy densities are expected to improve over time. But the raw materials will always be subject to market forces, extraction costs, speculation, and even geopolitical concerns.

The next decade or so, as electric vehicle designs stabilize and customer acceptance rises, will be interesting indeed. Will you be along for the ride?