Battery electric vs. hydrogen fuel cell vs. HVO – which is the winning technology?

einride

There are various types of heavy-haul transportation that claim to be environmentally friendly, but just how resilient one type of technology or fuel might be depends on a range of factors – such as the GHG emissions associated with producing the required fuel, and whether there is a feasible chance that this type of fuel can meet the overall transportation demand.

Here, we compare the three most talked about alternatives to diesel – battery electric, HVO biofuel, and hydrogen fuel cell – assessing their use phases based on four essential factors for long-term viability.

Einride operates some of the largest fleets of battery electric heavy-haul vehicles in North America and Europe – but why focus on battery electric technology and not on hydrogen-powered fuel cells? Or why not HVO?

Determining which is the winning technology requires consideration of four key factors: if it's cost-effective (with low total cost of ownership); if it's scalable; if it's environmentally sustainable; and if it's future-proof.

When you boil it down, battery electric technology stands in a class of its own. And the consensus among researchers and academics supports the case for battery electric being the key to decarbonizing heavy-haul road freight on a global scale.

What is HVO?

HVO – hydrotreated vegetable oil – is a liquid fuel. More specifically, it is a biofuel, meaning it is derived from living matter, unlike fossil fuels. HVO is a diesel alternative that can be used to power HVO-ready vehicles, and it is made by hydrocracking (breaking larger molecules into smaller ones using hydrogen) or hydrogenation (the adding of hydrogen to molecules) of vegetable oil. HVO is a very different type of fuel from hydrogen, which is a gas.

Vehicles running on HVO still produce tailpipe emissions, although in lower volumes compared to vehicles running on diesel. Some formulations comprise of HVO mixed in with other fuels such as conventional diesel. However, fuels labeled "HVO100" refer to formulations that are not blended with other fuels; they are 100% HVO.

How sustainable is HVO?

How environmentally sustainable a liquid fuel is depends on a range of factors, including the type and origin of the feedstock used for its production (including the impact of land use on ecosystems and biodiversity), how the fuel is transported, the tailpipe emissions emitted once the fuel is used, and more.

One aspect worth highlighting is the "well to wheel" emissions; in other words, the CO2e emissions associated with extracting the primary energy source ("well") plus any emissions incurred from producing, processing or distributing the fuel, and any tailpipe emissions emitted when the fuel is combusted ("wheel").

Most HVO is derived from a mix of raw materials. Specifically where a given batch of HVO "comes from" has a big impact on its overall environmental sustainability. For example, when it comes to HVO derived from rapeseed oil, the well-to-wheel GHG emissions are around 40% lower than what is emitted with diesel. With waste oil, the reduction compared to diesel is almost 70%. (It's worth noting that most HVO comes from a mix of raw materials.)

One important consideration is that there is only a limited amount of sustainable HVO globally. That's because in order for HVO to be sustainable, it needs to come from runoffs, residues or waste products – in other words, biomass that wasn't produced for the purposes of making fuel. Biomass that was produced specifically to create fuel potentially sacrifices resources that could serve other uses, such as much-needed food, timber, or carbon storage.

5–6%

of the global transport demand in 2030 will be met with sustainable HVO.

Source: Einride

Even when combined with other liquid and gaseous biofuels, there isn't nearly enough biomass to create enough sustainable fuel to meet the world's demand for freight transportation. Estimates on biomass availability point to volumes that equate to only 5 or 6% of what Einride predicts (based on figures from the International Energy Agency) will be the global transportation demand in 2030.

If the world was to try to meet that demand, it would need to increase the production of biomass in order to increase the supply of biofuel. This simply wouldn't be sustainable anymore. Not only does this drive up the volume of "well to wheel" emissions, but it could also lead to the growing of crops that compete with food production, as well as other harms such as deforestation. The European Federation of Transport and Environment reports that biodiesel for cars and trucks has likely "wiped out forests the size of the Netherlands" (almost double the size of New Jersey) since 2010, causing up to three times more CO_2 emissions than the fossil diesel it replaced.

For HVO to be sustainable, it needs to come from runoffs, residues or waste products i.e. biomass that wasn't produced for the purposes of making fuel.

What are hydrogen fuel cells?

Hydrogen-powered fuel cell electric vehicles (FCEVs) – sometimes referred to as hydrogen vehicles – operate using a system of fuel cells. These generally generate electricity using oxygen from the atmosphere and compressed hydrogen. They produce no direct tailpipe emissions, emitting only water vapor and warm air as exhaust.

FCEVs can be refueled at hydrogen fueling stations, sometimes located within gas/petrol stations. Compressed hydrogen travels from the station's storage into the vehicle's fuel cell system via a special dispenser designed to safely handle the high-pressure gas. However, such stations aren't particularly commonplace. In 2023, there were 59 retail hydrogen fueling stations in the US, with a higher concentration in California.

What are the different types of hydrogen fuel?

There are many different types of hydrogen, and they are commonly differentiated using a system of colors. Gray hydrogen is the most common hydrogen on the market today. It is made by reforming natural gas – a fossil fuel – but without any efforts to capture and store the carbon dioxide byproducts. Creating gray hydrogen results in a high volume of emissions.

Blue hydrogen also refers to hydrogen that's produced from natural gas, however, it is supported by the capture and storage of carbon. While more sustainable than gray hydrogen, this still leads to greenhouse gas emissions due to the inevitable methane leaks (so-called "fugitive emissions") from carbon capture and storage technology.

Green hydrogen describes hydrogen produced using only renewable sources to power the electrolysis. While this may be environmentally sustainable regarding GHG emissions at the production phase, it is equally important to assess whether such hydrogen is scalable for transportation.

How gray, blue and green hydrogen are made

Gray Hydrogen	Blue Hydrogen	Green Hydrogen
Hydrogen is extracted from fossil gas releasing CO2 emissions into the air.	Hydrogen is extracted from fossil gas before CO2 emissions are trapped and stored permanently underground.	Hydrogen is extracted from water using renewable electricity and releasing oxygen into the air.

Source: Transport and Environment

7%

of the American transport demand in 2030 will be met with green hydrogen.

Source: Einride

Is green hydrogen scalable?

Can sustainably produced green hydrogen meet the transportation demands of countries and continents? Upon inspection, it's apparent that this fuel only has the potential to meet a fraction of the global demand for road freight.

In fact, if you took 100% of the green hydrogen available – based on projected figures on probable green hydrogen supply, which also accounts for a scale-up in technology – and deployed all of it to the transportation sector, the energy produced would meet just 7% of what Einride predicts (based on US EIA statistics) will be the total US transportation demand in 2030.

There is a role for hydrogen in a decarbonized future, but in the transportation sector, its role is limited due to the amount of energy it takes to produce, store, and transport hydrogen compared to what it provides when converted into "useful" energy. Thus, the scenario of prioritizing the world's green hydrogen for transportation is a stretch.

Green hydrogen is more likely to be prioritized for other industries in applications that are considered to be more impactful than powering fuel cell vehicles. For example, it can be used to decarbonize steel production by enabling the production of steel without the need for burning coal.

How sustainable are hydrogen-powered FCEVs?

Since they produce no tailpipe emissions, hydrogen-powered fuel cell vehicles do not emit greenhouse gases such as CO2 when driven. Nor do they produce air pollutants that can harm human health, such as carbon monoxide (CO) and nitrogen oxides (NOx). FCEVs can also be low in greenhouse gas emissions if they are powered by green hydrogen.

Hydrogen fuel cell vehicles bear higher lifetime costs than battery electric vehicles, and the refueling infrastructure for FCEVs is currently lacking. But even setting these factors aside, one critical factor that impacts both cost-effectiveness and scalability is the energy that is lost when you convert electricity to hydrogen and then move that energy into the fuel cell.

While hydrogen FCEVs may be suitable in certain niche scenarios, they fail to challenge battery electric technology in terms of cost-effectiveness and scalability. The research institute Fraunhofer says fuel cell vehicles are likely to remain uncompetitive against battery EVs.

With respect to the environmental sustainability of hydrogen fuel cell technology, it's therefore important to note that green hydrogen as a fuel requires more electricity to produce, while fuel cells – where the energy goes before powering the vehicle – lack efficiency when it comes to applying the energy.

What are battery electric vehicles?

Battery electric vehicles (BEVs) are powered entirely by the electricity stored in rechargeable battery packs onboard the vehicle. They only use electric motors to generate the mechanical energy – rotational motion – which propels the vehicle forward. This means there is no internal combustion engine (ICE) and they don't use any gasoline (petrol) or diesel.

It's worth noting that "motor" refers to a machine that converts energy into mechanical energy. "Engine" however is more commonly used to describe machines that do what a motor does but using heat or combustion. Based on these definitions, an engine is therefore a type of motor, but a motor isn't necessarily an engine. This is why you will most often hear people refer to "motors" with respect to battery electric vehicles, rather than "engines".

Electric motors are highly efficient. Torque measures the force that can cause an object to rotate, and electric motors can reach their maximum torque in little or no time. Vehicles powered by diesel, gasoline or even HVO biofuel will take longer to do this, meaning the acceleration isn't as smooth or responsive. As shown in a study from the Fraunhofer Institute for Material Flow and Logistics IML, electric vehicles are also significantly quieter than conventional vehicles with a reduction of about 50% in perceived loudness.

Battery electric vehicles have raced ahead of hydrogen fuel cell vehicles as the most popular alternative to vehicles that use an internal combustion engine. Factors driving the rapid uptake of battery EVs in recent years include: advances in battery technology, increased driving range, greater availability of charging infrastructure, and strong consumer interest in fossil-free transportation.

50%

reduction in perceived loudness when switching from conventional vehicles to electric vehicles.

Source: Fraunhofer Institute for Material Flow and Logistics IML

How sustainable are battery electric vehicles?

Battery electric vehicles do not depend on fossil fuels such as oil, and since they don't burn fossil fuels, they produce no tailpipe emissions. This means greenhouse gases such as CO2 are not emitted as a result of driving the vehicle. It also means that harmful air pollutant emissions are either drastically reduced or completely eliminated. These include carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM) and volatile organic compounds (VOC). Removing these from the atmosphere is essential as the health effects of air pollution are serious. According to the World Health Organization, one-third of deaths from stroke, lung cancer and heart disease are due to air pollution.

For battery electric vehicles to be sustainable, the sourcing of all materials and minerals needs to fit within a sustainable supply chain. Perhaps the most talked about component of BEVs is lithium. One criticism of battery electric technology points to the fact that lithium is a finite resource. However, it's worth noting that the world has enough lithium to power electric vehicles for decades into the future. A valid concern is that the rate of production needs to increase in order to keep up with demand.

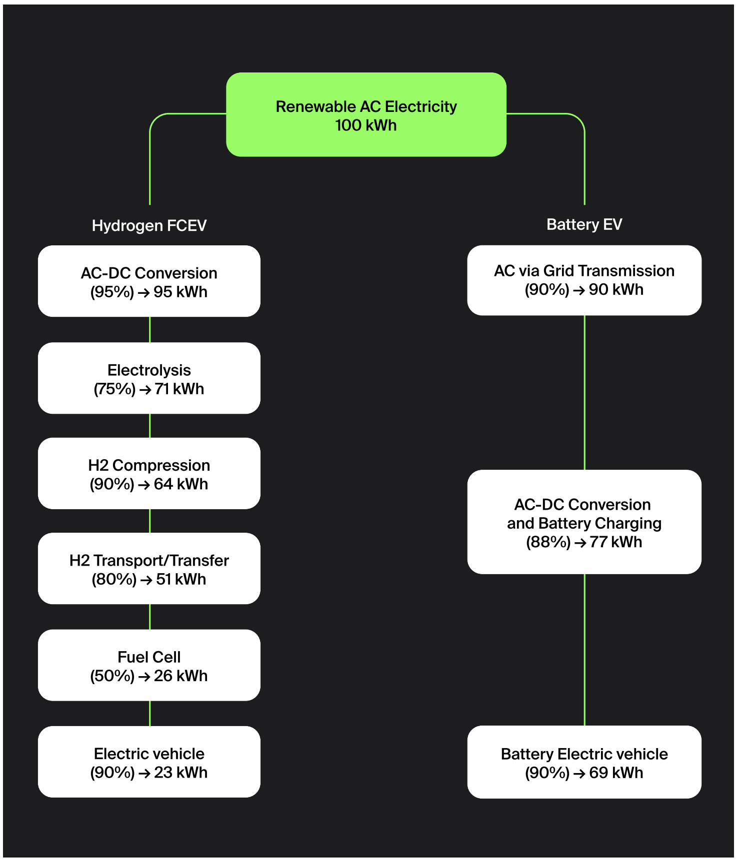
BEVs have raced ahead of hydrogen FCEV as the most popular alternative to vehicles with an internal combustion engine.

Source: Automotive World

Mining capacity will increase over time and new reserves will be discovered, however, it is important that raw materials are sourced in accordance with international standards to ensure long-term ecological damage is minimized. The process of extracting lithium and other battery raw materials consumes significant amounts of water and energy. Using renewable energy significantly lowers the environmental impact of these processes. Lithium can also be recycled – the batteries are ground up so the minerals can be extracted, ideally using renewable energy.

Once a truck battery is phased out from operations, it is possible to have it repurposed as a second-life battery energy storage system (BESS). Technologies for battery storage are key to speeding up the transition to electric transportation, as they can help relieve the electrical grid as it works toward integrating additional intermittent energy resources. Among the benefits of second-life BESS are more efficient operations – including more cost-effective supply of renewable energy – as well as the circularity advantages of extending the length of time that a battery can be good for use.

Electric efficiency comparison: Battery EV vs. hydrogen FCEV



To offer a clearer picture of the difference between hydrogen fuel cell and battery electric, Professor David Cebon – from the University of Cambridge Centre for Sustainable Road Freight Transport – gives an example in which you take 100 kWh of renewable electricity (AC) and calculate the resulting "useful transport energy" once you factor in the efficiency losses along the chain.

With the battery electric vehicle, you might expect about a 10% loss when transferring the energy via the electricity grid, meaning the vehicle receives about 90 kWh when charging at the depot. The next stage, converting to AC-DC to charge the battery, is about 85% efficient – so you have around 77 kWh at this point. That goes into the drivetrain of the battery EV, which is about 90% efficient – meaning 69 kWh reaches the wheels. "You end up losing about 30% of the energy on the way, and about 70% goes into the propulsion of the vehicle," says Prof. Cebon.

On the other hand, if you look at the chain of efficiencies when it comes to hydrogen fuel cell vehicles, you can expect a few smaller losses, such as AC-DC conversion near the point of generation (around 95% efficient), electrolysis (around 75% efficient), hydrogen compression (around 90% efficient), and hydrogen transport/transfer (around 80% efficient). But what happens to the hydrogen next is where the biggest loss is incurred: decompressing the hydrogen and putting it into a fuel cell is a process that is only around 50% efficient.

Prof. Cebon says there is no way around this loss of efficiency: "That is governed by the second law of thermodynamics which puts a limit on the efficiency of converting hydrogen to electricity – just like there's a limit on a diesel engine of about 40%. So converting hydrogen back into energy comes at a huge penalty."

Once the fuel cell is used to power the vehicle (around 90% efficient), the amount of energy that goes to the wheel is just 23 kWh. "You've thrown away 77 kWh of electricity in the process of going from electricity to hydrogen to electricity again," says Prof. Cebon. Figures around this may vary slightly depending on a range of factors and conditions, but they all paint a similar picture: that battery electric vehicles require much less electricity to supply power to the wheel.

There is also an economic argument for why the energy-intensiveness of hydrogen production is unsustainable for long-term widespread application. "Energy efficiency and economic efficiency go hand in hand. If you use energy efficiently, you pay less in subsidies and the economy benefits," says Prof. Cebon. "Any economy that goes hydrogen, when they don't need to, will be wasting a lot of money in subsidies that they otherwise wouldn't have to spend – which would be bad for the economy."

Battery electric vehicles: The most resilient way forward

Diesel is unviable for transportation in the long term due to its high greenhouse gas emissions, not to mention the increasing rollout of diesel bans and restrictions. So when it comes to alternatives, which technologies are future-proof?

With HVO, costs may be comparatively low, but the environmental sustainability is modest at best compared to what is achievable with battery electric. At worst, usage of HVO could be actively unsustainable. It depends on what the raw ingredient is, how much biomass is available, and the tailpipe emissions released when the fuel is combusted. But there's also the fact that tracing emissions and production sources of HVO is challenging – if not controversial – and the fact that there isn't enough HVO available to decarbonize freight transportation at scale, unless volumes of biomass were to be produced in an unsustainable manner. Additionally, zero-emission zones will most likely prohibit vehicles that run on HVO.

With hydrogen-powered fuel cell electric vehicles, it is possible to achieve a degree of environmental sustainability – using green hydrogen – but it's costly to produce. And the fact that it requires much more renewable electricity to create, due to its low efficiency in application, means that this type of fuel simply isn't likely to be prioritized for transportation.

Meanwhile, battery electric technology is already showing clear signs that it is – and will continue to be – future proof. In fact, batteries are on a learning curve with the entire automotive industry, meaning the gap will widen between the feasibility of BEVs versus that of hydrogen-powered FCEVs.

Some have expressed concern about the range of battery electric vehicles when it comes to tackling long-haul journeys. Importantly, however, battery EVs can already cater to the vast majority of use cases today. Figures from the US Department of Energy show that in 2021, 87% of US truck freight tonnage was shipped less than 250 miles. Furthermore, the range potential of battery EVs will increase over time. This, combined with the continued rollout and ramp-up of charging infrastructure, will enable greater flexibility for battery electric fleets.

Regarding cost-effectiveness, scalability, environmental sustainability, and future-proof operations, the facts and figures point to battery electric vehicles (BEVs) as the clear winner – and the most resilient way forward. They produce no tailpipe emissions, are highly efficient, and are the only non-fossil based technology that can meet the 2030 transportation demand. Additionally, the environmental benefits of battery electric vehicles increase as renewable sources of energy become more accessible.

	Cost-effective today Low total cost of ownership	Scalable today Can meet global freight transportation demand	Environmentally sustainable Low CO2e emissions with renewable energy	Future-proof Supports business resilience
Diesel ICE	Yes	Yes	No	No
HVO100 biofuel	Yes	No	Depends on source	No
Hydrogen fuel cell	No	No	Yes	Depends on technology advancements
Battery electric	Yes	Yes	Yes	Yes

Why Einride deploys battery electric vehicles

Einride is at the forefront of electric freight because BEV technology presents the strongest long-term business case, compared to all other non-diesel technologies. It is also the technology favored by regulators in the US with regulations such as the Inflation Reduction Act, California Advanced Clean Fleets (ACF), and the National Zero-Emission Freight Corridor Strategy speeding up the electric transition in the US. Additionally, in March 2024, the Environmental Protection Agency – under the Clean Air Act – released its new rules for greenhouse gas emissions from passenger cars and trucks; the standards require automakers to ensure that a certain percentage of vehicles coming off their production lines are those which are free from direct (tailpipe) emissions.

At Einride, we are constantly evaluating new technologies to assess their potential against the four essential criteria. We have tested hydrogen-powered fuel cell technology and HVO100. And while they may perform well in one domain or another, it is only battery electric technology that shows remarkable promise when it comes to all four criteria: cost-effectiveness, scalability, environmental sustainability, and future-proof operations.

Electric freight is complex – digitalization makes it easy

One thing to bear in mind is that you can't just replace diesel vehicles with electric vehicles on a 1-1 basis. This simply wouldn't work due to the increased level of complexity that comes with switching away from diesel-based operations, such as the infrastructure demands of going electric. Maximizing asset utilization is essential if shippers are to unlock cost-effective electric freight operations, and that is why you can't go electric without going digital.

For businesses that ship with Einride, the digital requirements are all handled by the intelligent freight platform Einride Saga, which unlocks cost-effective and reliable operations while maximizing CO2e reduction for transportation. It does this by leveraging data from four essential domains: transportation demand, vehicle telematics, charging telematics, and driver updates. Saga combines such unique data with proprietary algorithms, enabling it to act as a centralized control tower for operating and expanding electric fleets.

How to scale up electric freight operations

As many of the world's leading shippers are proving, it is possible to start this transition now. However, a successful transition to sustainable road freight is far from a one-size-fits-all solution. Electrifying in the best way will vary dramatically from business to business. It depends on factors such as the size and scale of the transport network, the operational prerequisites, and geographical factors.

To make the switch to electric a cost-efficient one, it's essential to have a tailored long-term roadmap that gives businesses a broad perspective on how to navigate the transition – in other words, how they can ramp up the electrification of their shipping network over the next 5 to 10 years. This roadmap should also tell them where in their network – down to which specific lanes – they should electrify first in order to yield the highest cost efficiency and curb the most CO2e emissions.

Einride is the shipper’s transformation partner

Now is the time to make the switch. Businesses around the world – including Fortune 500 companies – are shipping sustainably with Einride as their transformation partner. Einride guides shippers at every step of the journey, with world-leading expertise from operating some of the largest fleets of electric heavy-duty vehicles in North America and Europe. In addition, Einride is building a global charging network of Einride Smartcharger Stations. In fact, in March 2024, Einride opened North America’s largest charging station for electric heavy-duty vehicles in Lynwood, south of Los Angeles.

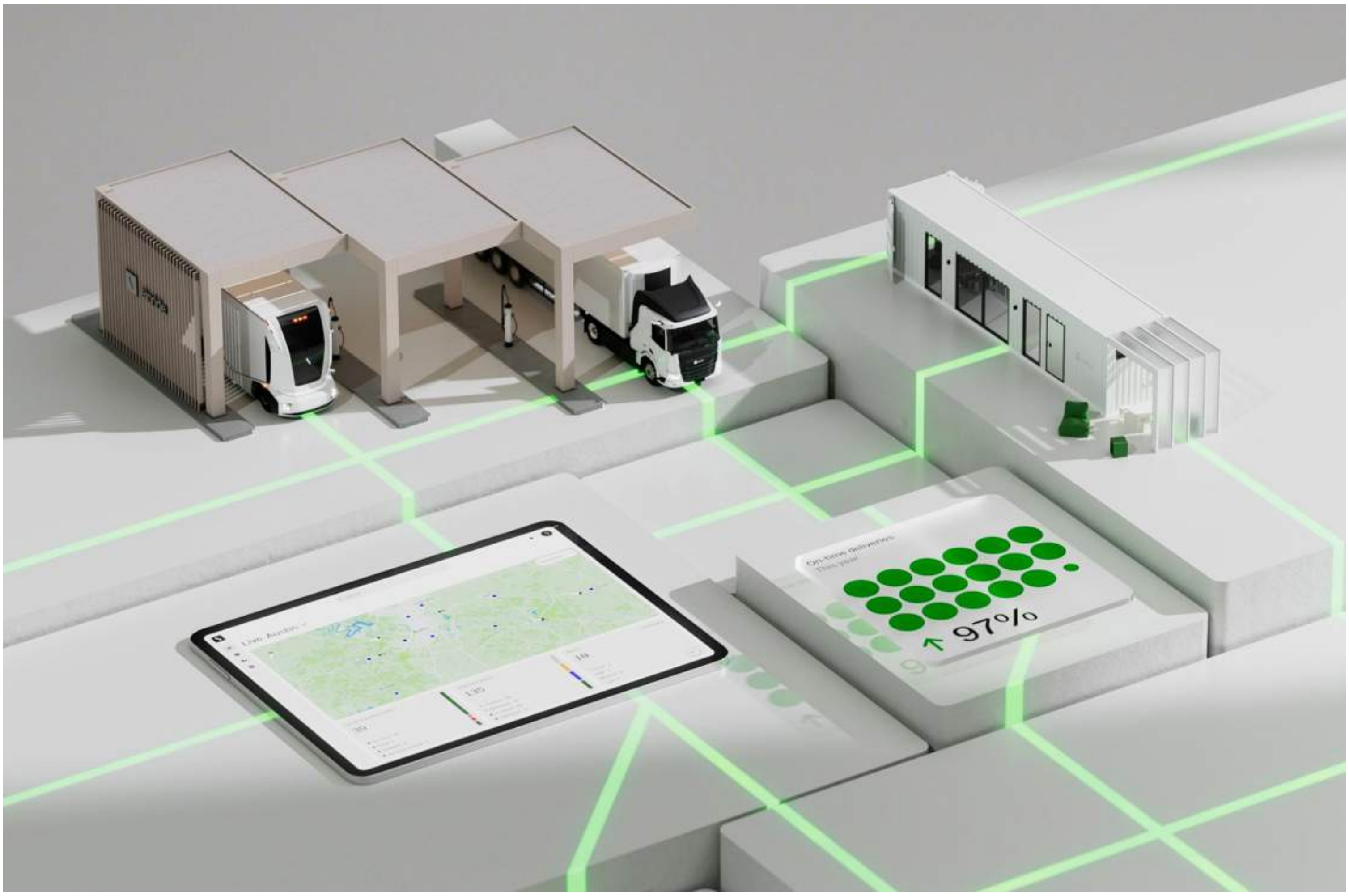
Shippers can access the complete ecosystem via freight capacity as a service, which allows them to go electric without complexity or costly CAPEX investments. Einride provides everything businesses need: physical infrastructure – including electric vehicles, charging, and operational resources such as drivers and maintenance – as well as the vitally important digital infrastructure.

Going electric with Einride is much more than running tests or pilots. It’s about decarbonizing transportation – swiftly and at scale – for good.

Want to learn more?

The Einride Webinar – “Sustainable road freight: Why now is the time to make the switch” – featured a deep-dive on this topic. Register to watch on demand.

Ready to go electric?
To learn more or to get in touch,
visit: www.einride.tech/shippers



einride