

Making our world more productive



Decarbonizing Transportation with Hydrogen

A guide for developing hydrogen fueling stations



What's in the guide?

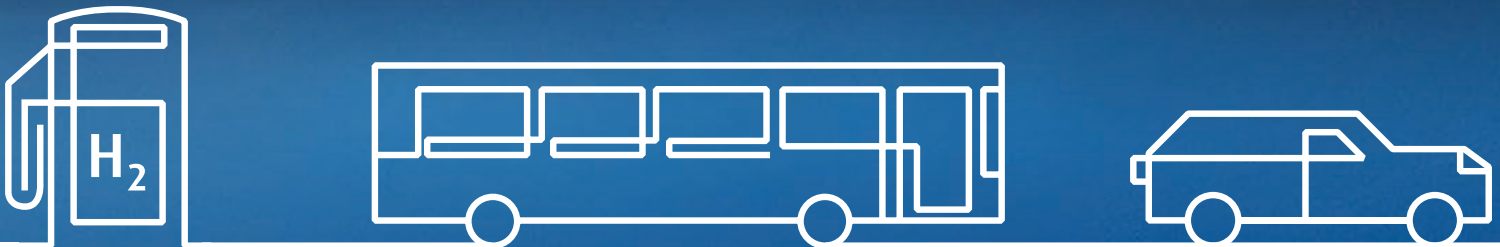
This is a practical guide designed to give a clear picture of what's involved in developing hydrogen refueling stations for bus and truck fleets.

Who is it for? Hydrogen is attracting interest around the world as a clean fuel for transport. This guide provides a primer for anyone looking for an effective way to decarbonize their truck or bus fleets as part of their commitment to reducing greenhouse gas emissions using hydrogen.

What's covered

- How hydrogen can help decarbonize bus and truck fleets
- Factors you need to consider before embarking on a project
- Steps involved in the process

How will it help? The guide will outline the benefits of hydrogen as a fuel source and addresses common questions to help you determine whether hydrogen is the correct choice to meet your decarbonization needs. This guide will also explain how to get started.



Hydrogen Can Help Decarbonize Truck and Bus Fleets

There is an increasing appreciation industry wide on the need to transition from fossil fuel based to zero emission type vehicles across all public and private transportation sectors. Hydrogen can help make that transition possible.

Zero-emission vehicles produce no greenhouse gas or air pollutant emissions at the tail pipe. Currently, only hydrogen fuel cell electric vehicles (FCEV) and battery electric vehicles (BEV) meet the zero-emission definition standard. Both BEV and FCEV use electric drive motors to power the vehicle. In the case of FCEVs energy to power the vehicle is stored on board the vehicle as hydrogen whereas in a BEV electrical energy is stored in a battery. Since both electricity and hydrogen can be produced using power from renewable energy sources, both technologies offer effective routes to fully decarbonize bus and truck fleets.

Long considered the 'fuel of the future', hydrogen is here. Hydrogen is now. It's gathering momentum each day and helping public authorities and businesses to decarbonize road, rail, waterway and air transport.

"Linde to Increase Green Hydrogen Production in the United States"

Woking, UK, September 8, 2022 - Linde (NYSE:LIN; FWB:LIN) announced today that it will build a 35-megawatt PEM (Proton Exchange Membrane) electrolyzer to produce green hydrogen in Niagara Falls, New York. The new plant will be the largest electrolyzer installed by Linde globally and will more than double Linde's green liquid hydrogen production capacity in the United States.

Is investing in hydrogen the right move for you?

Before deciding whether investing in hydrogen is the right decision for your fleet, you'll need to understand what's involved. Here are some of the questions you'll want to consider.



Does hydrogen suit your operations?

Hydrogen offers a significant advantage over BEVs when operating large, heavy vehicles. Larger vehicles require bigger batteries, which increases weight and re-charging times while reducing range.

The electrical infrastructure required to charge a truck battery is also substantial. Hydrogen can provide longer range than BEVs without sacrificing payload. It also offers a fast and familiar refueling process which can be applied to vehicles of all sizes. Faster refueling becomes increasingly important to optimize the time the vehicle spends on the road.

Consider hydrogen if:

- Tare weight of the truck is important for maximizing payload
- Range is a factor. The current consensus seems to be moving towards a break point of 300 mi. between BEV and FCEV
- There's a need to maximize the hours in operation. It is estimated that the time to fuel a FCEV is similar to a traditional diesel bus or truck refueling
- A significant part of the operation is carried out during cold weather months
- If there are high torque requirements
- When seeking to minimize the upfront capital for fueling needs

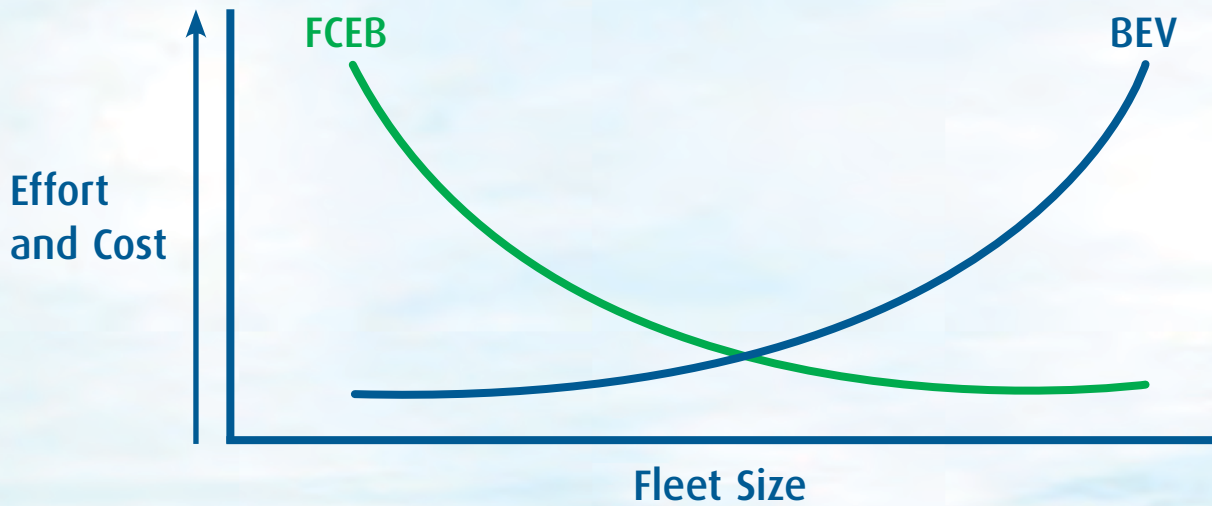
Linde supplies hydrogen across the U.S. today. If fueling vehicles on site is an attractive option for your business, Linde can provide a full engineering, procurement and construction (EPC) plan to help determine the required hydrogen infrastructure as well as providing the hydrogen fuel for the station. U.S. hydrogen supply from Linde is supported with coast to coast production facilities to ensure a reliable fuel supply.



Is your vehicle fleet large enough to make investing in a dedicated hydrogen refueling station worthwhile?

Hydrogen refueling can be done for any fleet size, however, economics improve dramatically as the fleet size increases. In other words, the total cost of ownership comes down rapidly as scale is achieved.

Infrastructure and Scalability



Shared hydrogen refueling facilities can drive up the number of users and demand for fuel. This is one way to improve the economics.





What size hydrogen refueling station will you need and how will you fund it?

At the outset, it can be difficult to forecast how much the initial requirement and then future growth demand will be.

Linde employs a modular approach to the design and build of hydrogen refueling stations. This provides an easy and economical way to expand capabilities. These back-to-base refueling scenarios fulfill the needs of any fleet size and may deliver CO₂ reductions, better air quality, and serve to introduce the technology into your operations.

Linde knows hydrogen and guides you every step of the way as you consider implementing hydrogen fuel cell technology. Linde brings merit across the full value chain and is both a technology leader and a fuel provider that has been in the business of manufacturing, distributing, and supplying hydrogen to our customer for over 60 years. Linde can provide hydrogen for your needs under what is known as a sale of gas model. Linde will install the storage system at your site and deliver the hydrogen as needed, based on your demand. You pay for the hydrogen and the monthly facility fee; Linde provides routine maintenance of our tank.

Linde also offers traditional sale of equipment for those – typically transit authorities – that are looking to fund through the many government grant programs.





Is there a suitable site available at your facility for a hydrogen refueling station?

The look and feel of a hydrogen refueling station is very much like the typical gas station you see today on every street corner. These stations consist of either a liquid or gaseous fueling system and a fuel storage container with a supply line running to the dispensing pump(s) to refuel vehicles.

Site layouts can be flexible and are modular by design to allow customers the freedom to model stations that will fit their available footprint. Linde's unique ability to customize these fueling options means it can be fit to a wide variety of shapes and sizes.

Gaseous hydrogen consists of a high-pressure gas supply system onsite mated to the hydrogen fuel pump. Gaseous is best suited to lower volume requirements.

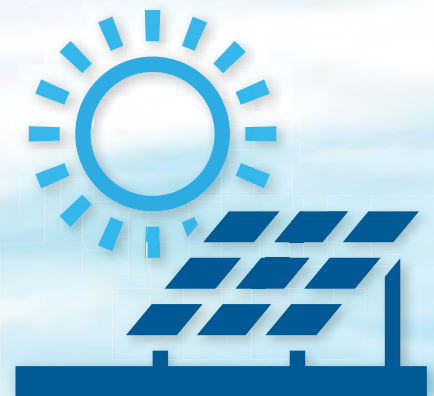
Liquid hydrogen supply consists of a liquid hydrogen storage system, which includes a tank, vaporizer, a hydrogen compressor (or pump) to bring the hydrogen up to the pressure necessary for refueling, optional high pressure receivers to speed up the refueling process, and a hydrogen refueling dispenser. Because more hydrogen can be stored as a liquid rather than as a gas, liquid hydrogen is better suited for applications with a higher volume demand.

Other than having suitable access for vehicles, there are few restrictions regarding site selection meaning a site can be located where you operate today. However, there may be local noise and zoning ordinances that affect where you can build a station. Be sure to confirm that your plans follow current local guidance and ordinances.



Do you require green hydrogen?

To be able to produce green hydrogen, renewable energy is required. This could be a local, co-located generation asset such as wind or solar, or could be procured from a renewable energy supplier.



Frequently asked questions



What carbon intensity meets your needs?

Hydrogen can be produced with a range of carbon intensity. Carbon intensity is the measure of CO₂ produced during the production process and is often grouped into categories – Grey, Blue, Green

Grey – Conventional steam methane reforming (SMR) where natural gas is separated into its components is a mature, efficient and reliable production resource. Carbon dioxide is emitted during the production process leading to a carbon footprint for the hydrogen produced. In the industry, hydrogen produced from natural gas or petroleum where the carbon dioxide emissions are not captured is referred to as grey hydrogen.

Blue – Converting natural gas into hydrogen and carbon dioxide through traditional SMR, but in combination with carbon capture or sequestration provides the potential for lowering the CO₂ emissions. When the carbon dioxide produced is captured and stored this results in hydrogen with lower carbon intensity and is identified as blue hydrogen.

Green – When the energy for liquefaction of hydrogen uses power derived from renewable energy sources like wind turbines, solar panel arrays or hydro-electric facilities in combination with electrolysis, there is no emitted carbon dioxide from the electricity production. Electrolysis splits water into its components producing hydrogen and oxygen. Combined with low-carbon power, electrolysis can be used to produce hydrogen without any carbon emissions. This hydrogen is categorized on the color scale as green.

Regardless of the carbon intensity of the hydrogen the emissions of an FCEV will be carbon free containing only water.

Linde can provide hydrogen with a range of carbon intensity allowing us to sell hydrogen meeting the lower carbon footprint requirements demanded by our customers. Whether you are seeking hydrogen to meet California's low-carbon fuel standards, meet sustainability targets, or have other needs. Linde is producing the fuel spectrum of hydrogen from green to grey today and has a reliable supply based on our existing network.



Does hydrogen refueling take longer than petrol/diesel?

Hydrogen refueling is a familiar process. No PPE (personnel protective equipment) is required to use the refueling station, and each fueling station can be tailored to the customer's fueling time requirements.

Frequently asked questions



How safe are hydrogen refueling stations?

Linde optimizes its hydrogen offerings with safety as the highest priority. It ensures that all health and safety regulations are adhered to and demonstrated including the installation of safety controls such as pressure relief devices and valves and alarms.

The storage vessels used to contain the hydrogen are built specifically to hold hydrogen at the required pressure and incorporate technology to maintain pressures at optimal, safe levels.



How long does it take to build a hydrogen refueling station?

Typical total build time from point of order is 15-18 months. This timeframe incorporates activities such as design, permitting, civil engineering works, construction, and commissioning. A temporary mobile hydrogen refueling station skid can be available in less than nine months.

Conversion Tables

Unit Conversion Data for Hydrogen

	Weight		Gas		Liquid	
	pounds (lb)	kilograms (kg)	cubic feet (scf)	cu meters (Nm ³)	gallons (gal)	liters (l)
1 pound	1.0	0.4536	192.0	5,047	1.6928	6.408
1 kilogram	2.205	1.0	423.3	11.126	3.377	14.128
1 scf gas	0.00521	0.00236	1.0	0.02628	0.00882	0.03339
1 Nm ³ gas	0.19815	0.08988	38.04	1.0	0.3355	1.2699
1 gallon liquid	0.5906	0.2679	113.4	2.981	1.0	3.785
1 liter liquid	0.15604	0.07078	29.99	0.7881	0.2642	1.0

Scf (standard cubic foot) gas measured at 1 atmosphere and 70°F.

Nm³ (normal cubic meter) gas measured at 1 atmosphere and 0°C.

Liquid measured at 1 atmosphere and boiling temperature.

Conversion Tables

Energy Equivalency of Fuels

The table below shows the amount of each fuel necessary to provide the same energy as 1 kg of hydrogen, 1 million cubic feet natural gas, 1 barrel of crude oil, or 1 gallon of other fuels, based on lower heating values.

	Hydrogen (kg)	Natural Gas (million cubic feet)	Crude Oil (barrel)	Conventional Gasoline (gallon)	Reformulated Gasoline (RFG) (gallon)	California RFG (gallon)	U.S. Conventional Diesel (gallon)	Low-Sulfur Diesel (gallon)
Hydrogen, 1 kg =	1	0.000117	0.0211	0.992	1.014	1.011	0.896	0.889
Natural Gas, 1 million cubic feet =	8538	1	180.5	8468	8653	8628	7653	7591
Crude Oil, 1 barrel =	47.30	0.00554	1	46.91	47.94	47.80	42.40	42.06
Conventional Gasoline, 1 gallon =	1.008	0.000118	0.0213	1	1.022	1.019	0.904	0.897
Reformulated Gasoline (RFG), 1 gallon =	0.987	0.000116	0.0209	0.979	1	0.997	0.884	0.877
California RFG, 1 gallon =	0.989	0.000116	0.0209	0.981	1.003	1	0.887	0.880
U.S. Conventional Diesel, 1 gallon =	1.116	0.000131	0.0236	1.106	1.131	1.127	1	0.992
Low-Sulfur Diesel, 1 gallon =	1.125	0.000132	0.0238	1.115	1.140	1.137	1.008	1

Note:

The following unit conversion factors are used in the calculations:

1 kg = 2.2046 lb

1 barrel = 42 gallons

Source:

The above table is based on values in the GREET Transportation Fuel Cycle

Analysis Model: <https://greet.es.anl.gov/>

Think Hydrogen. Think Linde.

Linde is a global leader in the production, storage and distribution of hydrogen, with an unrivalled track record in delivering hydrogen projects, including:

- Over 200 hydrogen refueling stations installed worldwide
- More than 1.5 million successful refuels of hydrogen vehicles
- The UK's first hydrogen refueling station
- The UK's largest and highest performing hydrogen bus refueling station
- Supplier of the world's first hydrogen station for passenger trains

As your hydrogen partner, Linde can manage the entire project. The project scope includes assessing your needs, designing, installing, and maintaining the fueling station as well as supplying the liquid or gaseous hydrogen.

For additional information visit
www.lindeus.com/mobility



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