Fixed or Mobile Hydrogen Refueling:

An Analysis of Levelized Cost

Part of the LIFTE H2 White Paper series
"Methods of Making, Moving, and Using Hydrogen"

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Introduction

Clean hydrogen will play a significant role in the future of decarbonization.

It is an energy carrier that can be produced from renewable sources such as wind and solar power, as well as in a low-carbon emissions manner from natural gas with carbon capture and storage (CCS). Heavy-duty vehicles are a major contributor to greenhouse gas emissions and the use of hydrogen fuel cells or hydrogen-powered engines can drastically reduce these emissions.

There are various technological advances being made in heavy-duty transportation toward hydrogen-fueled vehicles (e.g. fuel cell technology, hydrogen engines and vehicle design). Notably, there is significant development underway surrounding the refueling infrastructure to support such a significant shift.

One of the first challenges that is being solved is how hydrogen can be transported hundreds, if not thousands, of kilometers from a production site to different geographical regions where it is needed. These significant distances inspire solutions akin to the existing energy paradigm (involving pipelines or shipping liquid fuels). However, once in that region the hydrogen will then need to be locally distributed (30 - 300 km) to refueling hubs to service fleets (trucks, buses, construction vehicles or boats).

Over these shorter distances, pipelines are often not a practical solution. Permitting barriers, slower deployment time, and land access obstacles often outweigh benefits. Over-the-road hydrogen transportation offers a robust and cost-effective solution, which is crucial to the financial feasibility of hydrogen mobility applications. It can also be rapidly deployed and scaled to provide the distributed refueling infrastructure that will be needed over the next decade to demonstrate the success of hydrogen technologies.

There are two leading options for distributing hydrogen for fleet refueling: hydrogen moved by tube trailer to a fixed Hydrogen Refueling Station (HRS) and hydrogen moved via a mobile refueler.

An HRS that dispenses directly to vehicles is most often supplied hydrogen via a tube trailer that carries in hydrogen from a production facility. Mobile refuelers carry the hydrogen from the production site as well, but are unique in that they directly refuel vehicles without the need for fixed infrastructure.

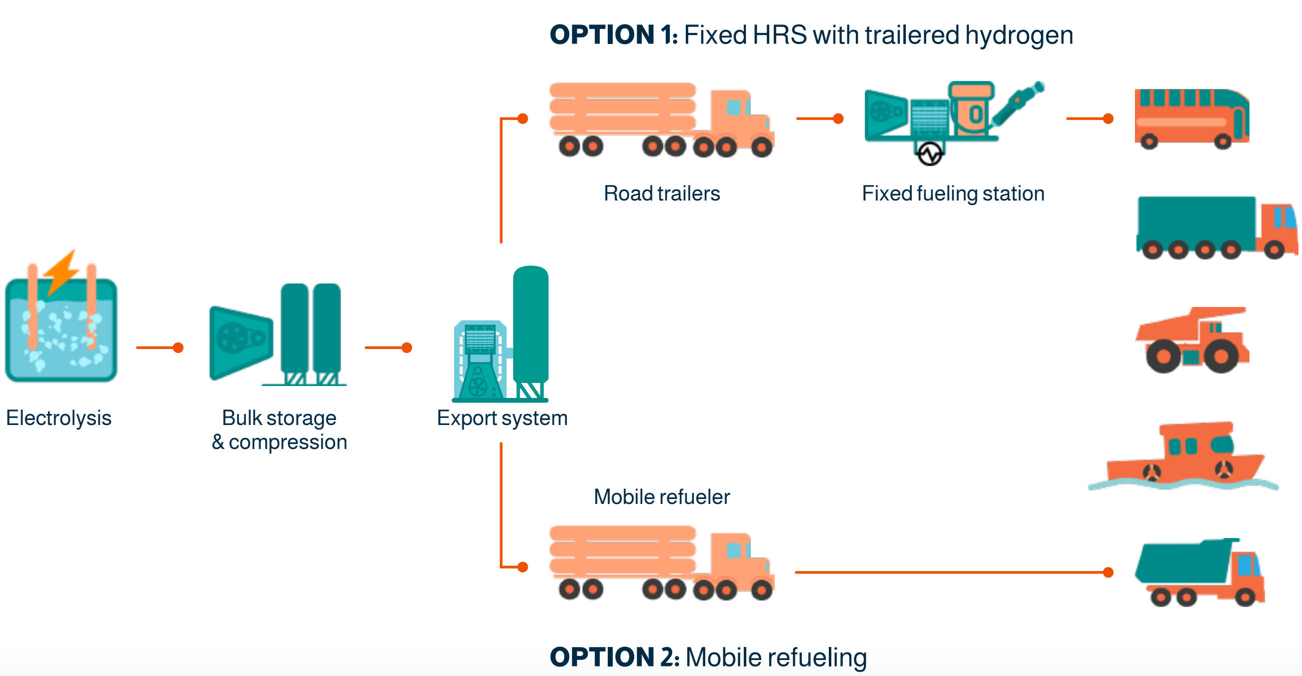
Mobile refuelers avoid almost all of the capital and operating costs that are associated with a fixed HRS, often encounter fewer planning restrictions, and can be significantly quicker to deploy. However, mobile refuelers generally do not supply as much hydrogen per delivery as tube trailers do. This means that if mobile refuelers are used instead of tube trailers for a given hydrogen demand, more trips will be required to meet the hydrogen supply, resulting in a potential increase in operating costs.

This White Paper presents a comparison of the levelized cost for these two different options of providing fleet refueling services. The distance between a hydrogen production site and a refueling site is a primary variable in the assessment, therefore this paper explores which option has the lowest overall cost (on a levelized basis) as the distance increases between the production and refueling locations. We identify the "crossover distance" as the point at which both options have equivalent costs, beyond which one option becomes more cost-effective than the other.

Options for fleet vehicle refueling

A typical hydrogen fueling scenario is shown in Figure 1. Low-carbon hydrogen is produced offsite where it is compressed and stored ready to be transported to a vehicle refueling location. Hydrogen can either be transported in trailers to a fixed HRS or it can be transported via mobile refuelers that are used to directly refuel vehicles.

Figure 1. Two options considered in this White Paper: Option 1 (fixed HRS and trailered hydrogen) and Option 2 (mobile refueling)



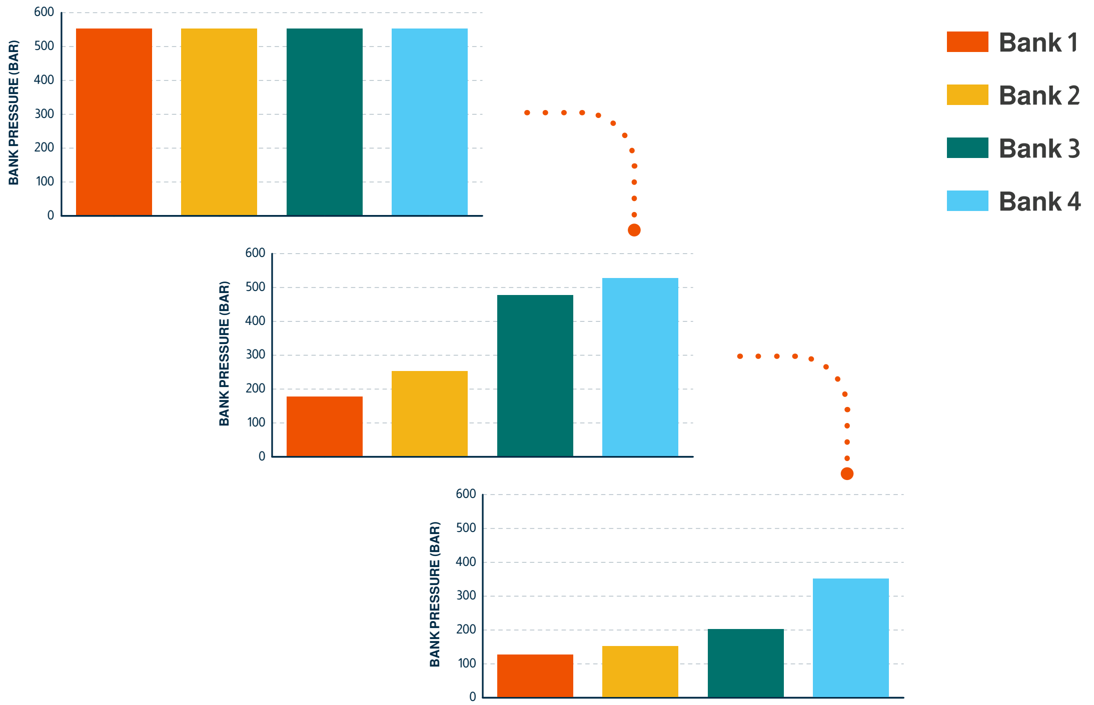
OPTION 1: Fixed HRS with Trailered Hydrogen

Tube trailers are loaded with hydrogen at the export system and the trailers then travel by road to the HRS. Grid-powered compressors at the HRS draw the hydrogen from the tube trailers, and, if necessary, recompress the hydrogen during dispensing. Tube trailers are able to maximize their hydrogen delivery by using the compressors installed in the HRS, which allow the trailers to be nearly emptied before returning to the production site for refilling.

OPTION 2: Mobile Refuelers

Mobile refuelers are loaded with hydrogen by the export system in a similar manner as tube trailers, but are outfitted with specialized equipment that enables them to directly refuel vehicles. Mobile refuelers often rely on the cascade principle, which employs the pressure within the tubes to fill the vehicle's tanks without the need of a compressor. These compressed hydrogen tubes are partitioned into banks, each opened sequentially to fill every vehicle (Figure 2). As the volume and pressure in each bank depletes, additional banks are accessed to complete the refueling.

Figure 2. Cascade refueling principle used by many mobile refuelers



While eliminating a fixed HRS has clear advantages, mobile refuelers implementing the cascade refueling method have an amount of unusable "pad gas" once bank pressure is insufficient to complete a vehicle fill. This may require additional trailer journeys to transfer the same amount of hydrogen.

Levelized Cost Comparison

A fixed HRS incurs an initial capital and construction cost along with ongoing operating and maintenance expenses, as well as staffing requirements and electrical power charges for compression, dispensing, and chilling of hydrogen. These costs vary depending on the hydrogen demand, but remain constant regardless of the distance between the production site and the refueling location. Additionally, transportation expenses for supplying hydrogen to an HRS includes the purchase, maintenance, and operation of tube trailers, as well as labor and fuel expenses, which are determined by both the hydrogen demand and distance.

Mobile refuelers may require the creation of a hard slab for their operation and incur transportation costs associated with buying and operating the mobile refuelers.

Comparing a fixed hydrogen refueling station (HRS) and mobile refueling for a specific hydrogen demand and distance, we find that the fixed HRS has elevated capital and operating costs, but reduced transportation expenses. In contrast, mobile refueling has negligible fixed infrastructure capital and operating costs but incurs higher transportation expenses. This is shown in Figure 3.

Figure 3. Cost comparison of fixed HRS and mobile refueling

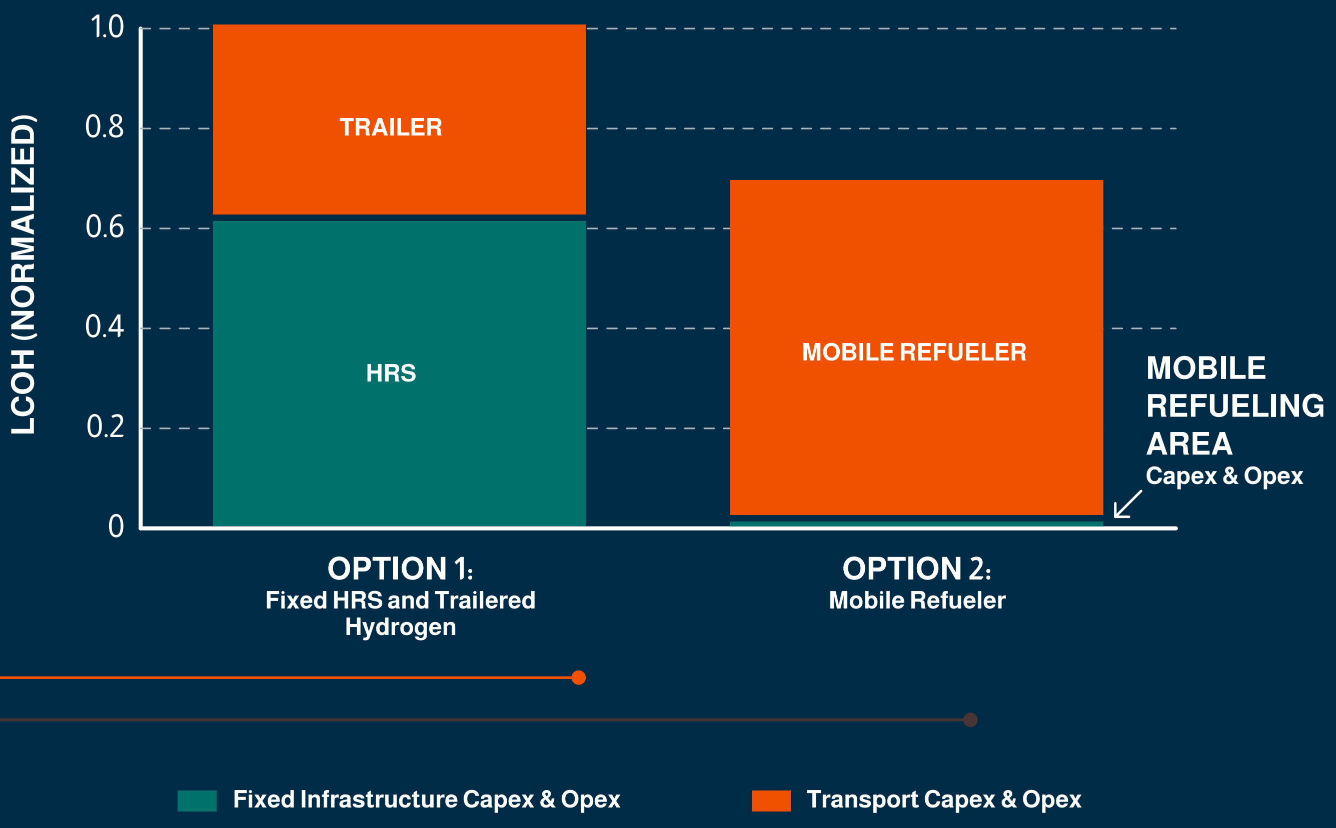
	OPTION 1: Fixed HRS with Trailered Hydrogen	**OPTION 2:** Mobile Refueling
Capital Costs: Purchase of equipment, permitting, construction, operations and maintenance	$$$$$	$
Transportation Costs: Purchase and operation and maintenance of trailers or mobile refuelers, fuel, driver labor	$$	$$$

EXAMPLE CASE:
Transporting Hydrogen 100km for Bus Refueling

A refueling depot requires 3,000 kg per day to refuel 100 buses (each bus requiring 30 kg). The depot is a distance of 100km from the hydrogen production facility. A fixed HRS could be constructed to refuel the buses that is supplied with hydrogen from tube trailers. Alternatively, with only minimal fixed infrastructure at the point of vehicle refueling (perhaps just a hard-standing), the buses could be refueled using mobile refuelers. Over a 10 year period, the levelized cost of the mobile refueler is approximately 35% less than trailering to a fixed HRS.

The fixed infrastructure solution has a higher capital cost but lower transportation costs, due to the lower number of journeys required.

Figure 4. Levelized cost of hydrogen delivery for OPTION 1 (fixed HRS with trailered hydrogen) and OPTION 2 (mobile refuelers) for a hydrogen demand of 3 tonnes per day (tpd) and a distance of 100km. LCOH has been normalized to OPTION 1: fixed infrastructure Capex and Opex.

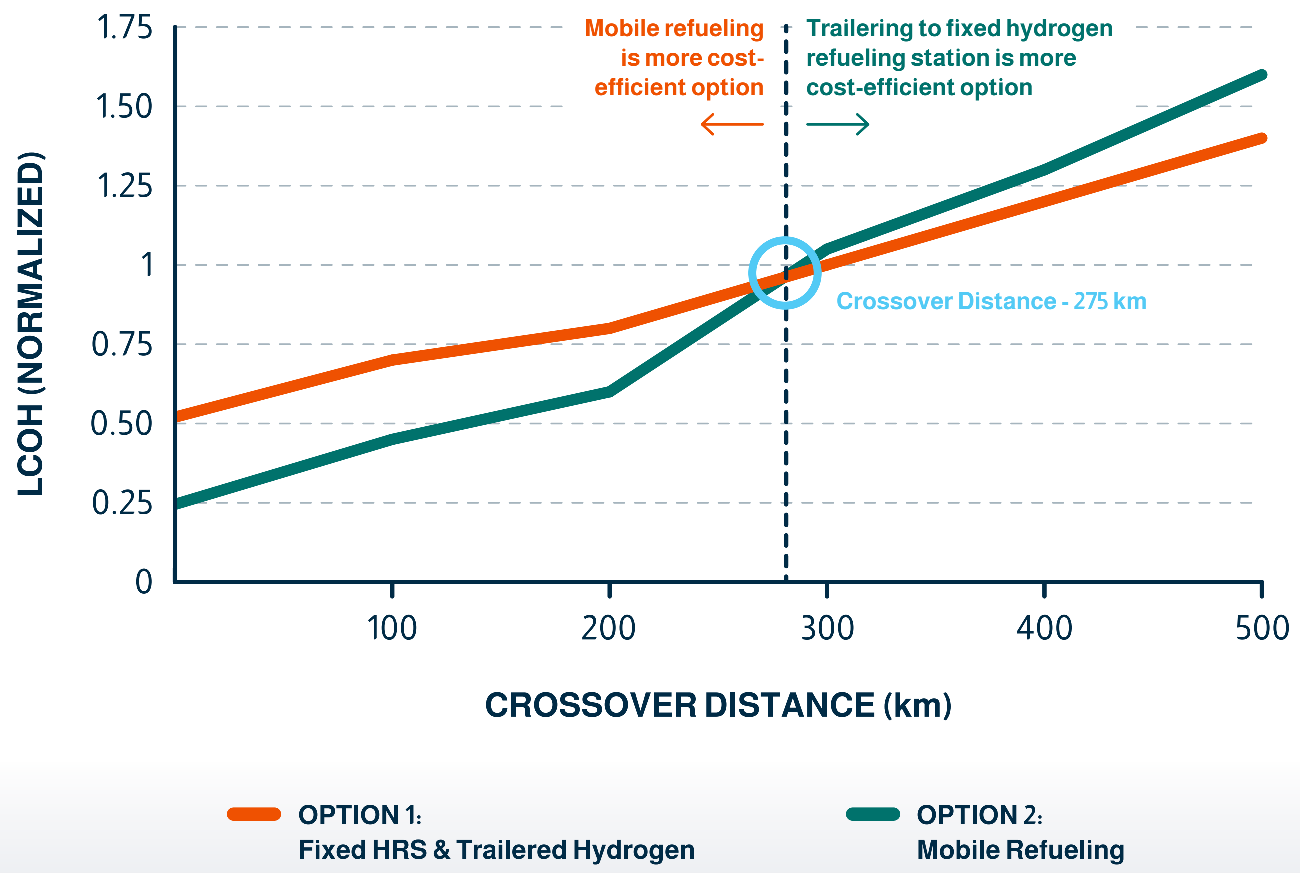


Increased distance between hydrogen production and refueling sites leads to higher transportation costs, which ultimately increases overall levelized costs for both options. Nevertheless, mobile refueling is more significantly impacted by distance as it requires more journeys to transport the same quantity of hydrogen compared to trailering to a fixed HRS.

Figure 5 shows how the levelized cost of both options changes with distance from hydrogen production to the refueling site. Based on the cost assumptions used here, mobile refueling is the most economically viable option for distances under 275 km. However, at a distance of 275 km, the cost curves crossover and beyond this point, trailering to fixed HRS becomes the more cost-effective choice.

Figure 5 is based on a hydrogen demand of 10 tpd. Transportation costs are mostly dependent on hydrogen demand, with some adjustments made for potential issues with partially filling trailers or mobile refuelers. On the other hand, fixed refueling stations' capital and construction expenditures benefit from economies of scale (i.e. the cost per kilogram of the plant drops in proportion to increasing demand). For the purposes of this analysis, it is assumed that capital costs will scale proportionally with hydrogen demand, thus making the crossover distance identical for various hydrogen demand levels.

Figure 5. Levelized Cost of Hydrogen (LCOH) transportation comparison between fixed HRS and trailered hydrogen with mobile refueling. LCOH has been normalized to the single value at the crossover distance.

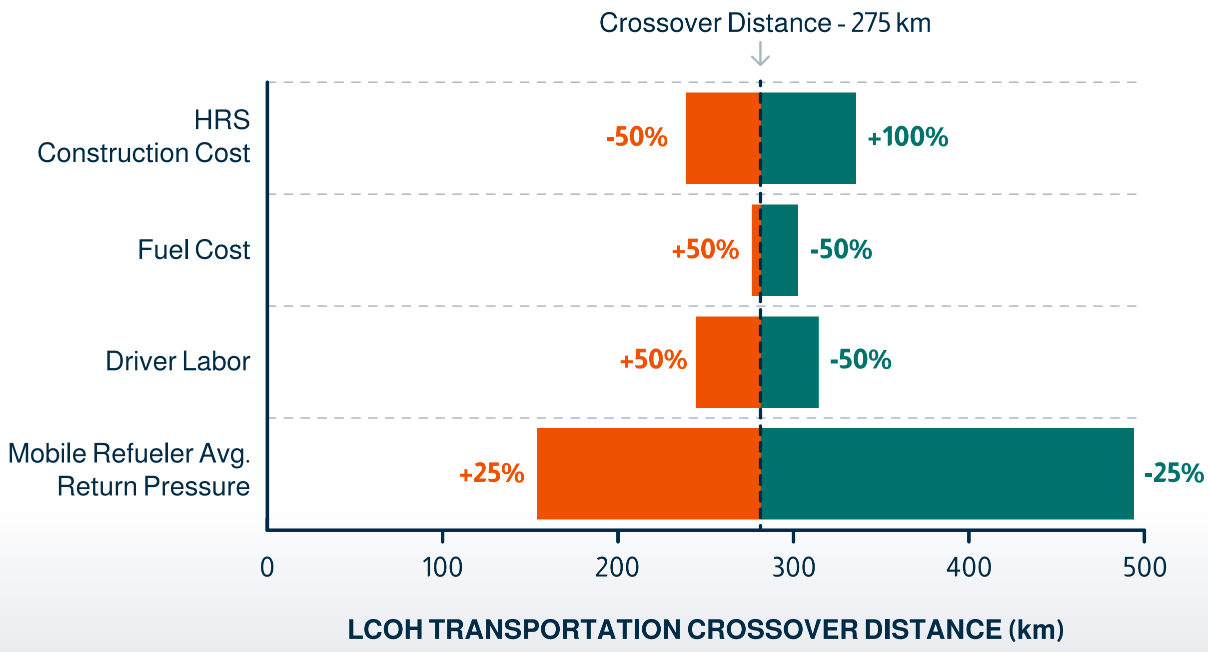


Discussion

In practice, the crossover distance where fixed refueling becomes more cost-effective than mobile refueling depends on a number of factors. Under a slightly different set of assumptions, for example with different technologies, geographic location or operational logistics, the crossover distance will change.

In **Figure 6**, the variation of the crossover distance with some of the significant parameters such as construction, fuel, and driver labor costs, and the average pressure at which the mobile refueler's storage tanks return for refilling (known as the "return pressure"), is depicted. Credible minimum and maximum realistic costs are employed in each instance to emphasize the relevance of each parameter to the crossover distance.

Figure 6. Impact of individual cost parameters on the crossover distance



If the construction cost of the HRS increases, this makes it a less competitive option and increases the distance range where mobile refueling is more cost-efficient. Conversely, reducing the construction cost narrows the range where mobile refueling is the more cost-effective choice. Construction costs tend to vary significantly by location and can result in crossover distances ranging from 220 km to 365 km.

Fuel and driver labor costs affect both options, but they have a more pronounced effect on mobile refuelers due to the higher number of trips required. An increase in fuel cost will reduce the crossover distance slightly to 270 km, while a decrease in fuel cost will increase the crossover distance to 300 km. A +/- 50% change in driver labor cost will have a larger impact and could decrease the crossover distance to 230 km or increase the distance to 315 km.

The mobile refueler return pressure has the most substantial effect on the crossover distance. Greater return pressure implies more hydrogen is returned to the production facility. Reducing the return pressure increases the trailer's utilized capacity and enhances the cost competitiveness of the mobile refueler, making it more comparable to trailers serving fixed refueling stations. A modification in the return pressure by approximately 25% can set the crossover distance as low as 155 km or as high as 495 km.

Further factors that influence the crossover distance include the time duration taken to load and discharge hydrogen, as well as the amount of personnel required for the hydrogen transportation operation. In reality, determining the most financially viable choice for a specific project necessitates taking into account the geographical and practical aspects of hydrogen distribution.

Conclusion

In conclusion, our analysis demonstrates that for shorter hydrogen distribution distances, mobile refueling is the more cost-effective option, while trailering to fixed HRS becomes the better choice for longer distances. Deciding on the most cost-effective solution for a particular project demands a thorough analysis of various factors including technology, geographical location, and operational logistics. It is also important to consider aspects that cannot be costed so easily such as permitting and construction overruns, disruption to customers and reliability issues that arise with additional infrastructure.

The hydrogen economy is evolving rapidly and flexibility for future proofing is extremely important. Among its many benefits, mobile refueling also enables immediate hydrogen demand to be met while simultaneously allowing for development of fixed infrastructure if necessary.

In order to move hydrogen forward as a significant catalyst of decarbonization, our team of experts have developed end-to-end hydrogen infrastructure solutions, including mobile refueling. Partner with us to bring your project to fruition.

LIFTE is prepared to guide every aspect of hydrogen infrastructure development, and to secure the industry's future.

Contact LIFTE H2 today to learn more.

Contact Us

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