Meeting Hydrogen Demands:

Refuelling Methods & Technology

by Paul Hodgson & Mohammad Saghafifar

OVERVIEW

The heavy-duty vehicle sector is progressively being revolutionised by innovative hydrogen (H2) technology. Alternative powertrains, such as hydrogen fuel cells and hydrogen engines, are becoming more widespread in the effort to decarbonise commercial applications. Vehicle developers and end-users are looking to rapidly introduce hydrogen heavy-duty vehicle fleets across the UK and Europe.

This paper takes a look at the methods most suitable for hydrogen vehicle refuelling and the various technologies available to facilitate the use of these low-carbon commercial fleets upon launch and through long-term establishment.

CONTENT

KEY TAKE AWAYS

- Cascade technology highly outperforms decant refuelling to deliver greater high-pressure refuel numbers.
- The Cascade Method removes the need for a compressor and large amounts of fixed infrastructure; allowing for deployment of mobile refuelling systems to be achieved far faster than building a fixed station.
- Mobile cascade systems enable centralised hydrogen production at scale to deliver a low-cost hydrogen value chain for the end user.
- The flexible and deployable nature of cascade technology, with no need for a mechanical compressor, makes it the perfect back-up solution should a production site suffer outages.

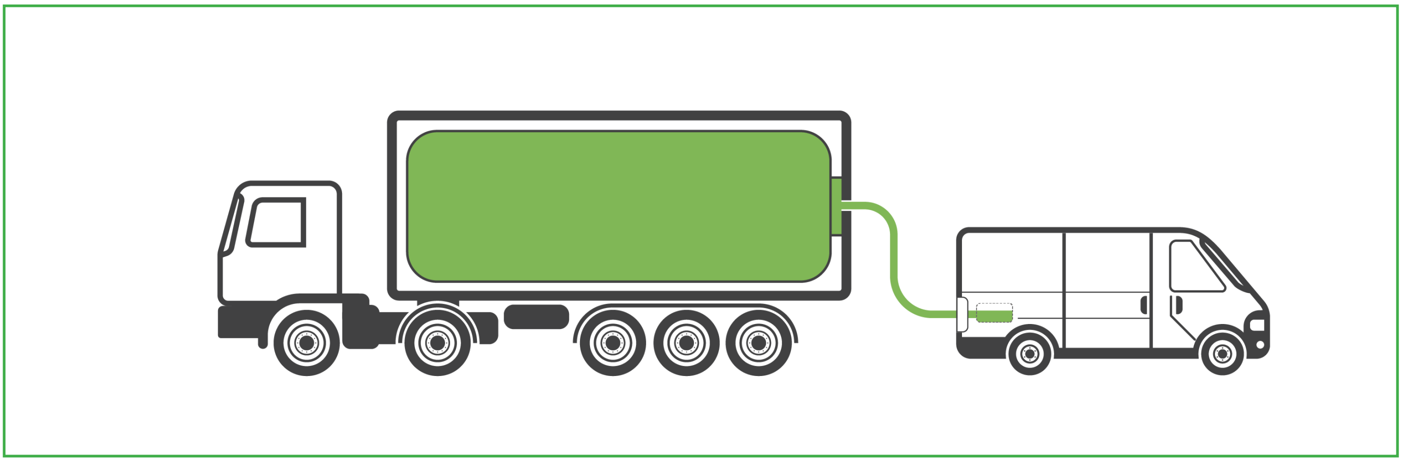
INTRODUCTION

The heavy-duty vehicle sector is progressively being revolutionised by innovative hydrogen (H2) technology. Alternative powertrains, such as hydrogen fuel cells and hydrogen engines, are becoming more widespread in the effort to decarbonise commercial applications. Vehicle developers and end-users are looking to rapidly introduce hydrogen heavy-duty vehicle fleets across the UK and Europe.

To facilitate the implementation of these low-carbon commercial fleets, vehicle operators must be able to depend on a reliable refuelling infrastructure for high pressure hydrogen, both upon launch of an introductory fleet and through long-term establishment. Over recent years we've seen various refuelling technologies develop, specifically designed for the purpose of refuelling hydrogen automotives. However, the performance, cost and reliability of these refuelling technologies must be analysed and compared to determine which options are most commercially viable, and how each is best suited to serve the hydrogen demands of a vehicle operator throughout their fleet's lifecycle.

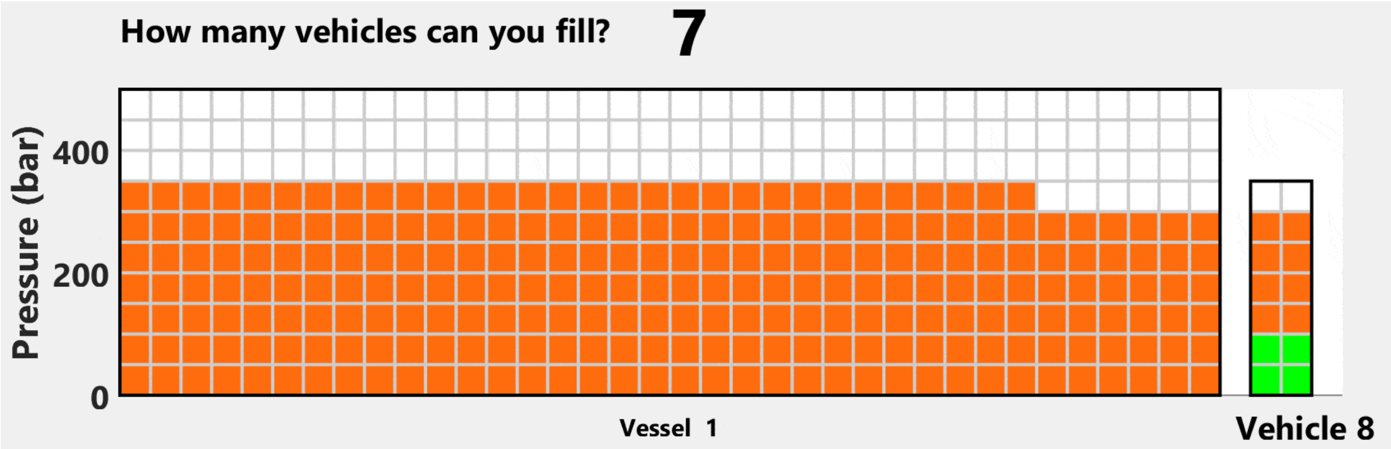
NanoSUN examines the most common hydrogen refuelling methods used today to present a detailed comparison of the various refuelling solutions available, and identify the optimum strategy most suitable and beneficial to the heavy-duty vehicle sector. This analysis looks at Decant vs. Cascade Method and Fixed Refuelling Station vs. Mobile Refuelling Station.

THE DECANT METHOD



The simplest hydrogen refuelling method is the decant method, where a large, high-pressure storage vessel (or several small vessels joined together) is connected directly to a user's vehicle to decant a portion of hydrogen. This works by allowing the pressure in the hydrogen storage vessel to balance with the vehicle's fuel tank. We see this refuelling system most commonly used in tube trailers, which are essentially trucks that haul trailers carrying up to 36 gaseous hydrogen tanks. These are generally employed to deliver large quantities of compressed hydrogen to local fixed hydrogen refuelling stations (HRS).

The decant method has the benefit that it is of minimal complexity, and has a low capital cost for a single fill. However, the downside is its inefficient operation. High pressure hydrogen is valuable in that you need to do work i.e., consume electricity in a compressor to compress hydrogen to a higher pressure. Therefore, 1 kg of hydrogen at 450 bar is more valuable than 1 kg of hydrogen at 200 bar. Both can be used to fill out a vehicle's fuel tank at 100 bar, but using 200 bar hydrogen is the more efficient choice since less compression work is employed to compress hydrogen to 200 bar than 450 bar. This is analogous to a game of tower-blocks shown in the animation below.



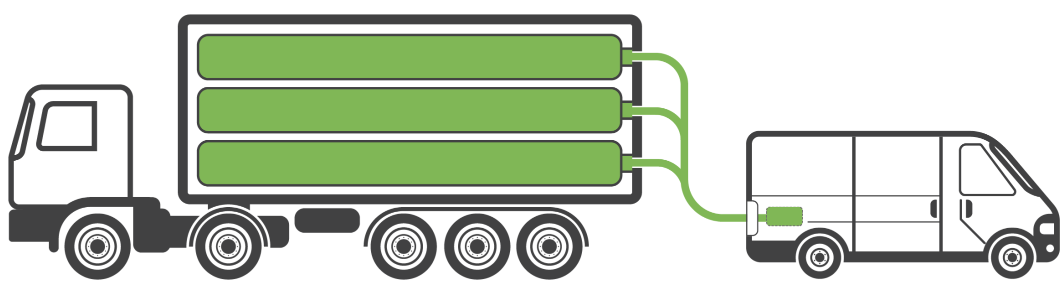
View animated game of tower-blocks **here**.

The goal is to fill out as many vehicles as possible with a simple rule: only blocks with a higher position (pressure) can be displaced from the vessel to the vehicle column – since gas will only flow naturally from a higher pressure to a lower pressure. For example, a block at 350 bar can be moved to any empty vehicle section at 0 bar to 300 bar. This makes the blocks with a higher pressure more valuable because they have the ability to fill out higher-pressure empty vehicle sections.

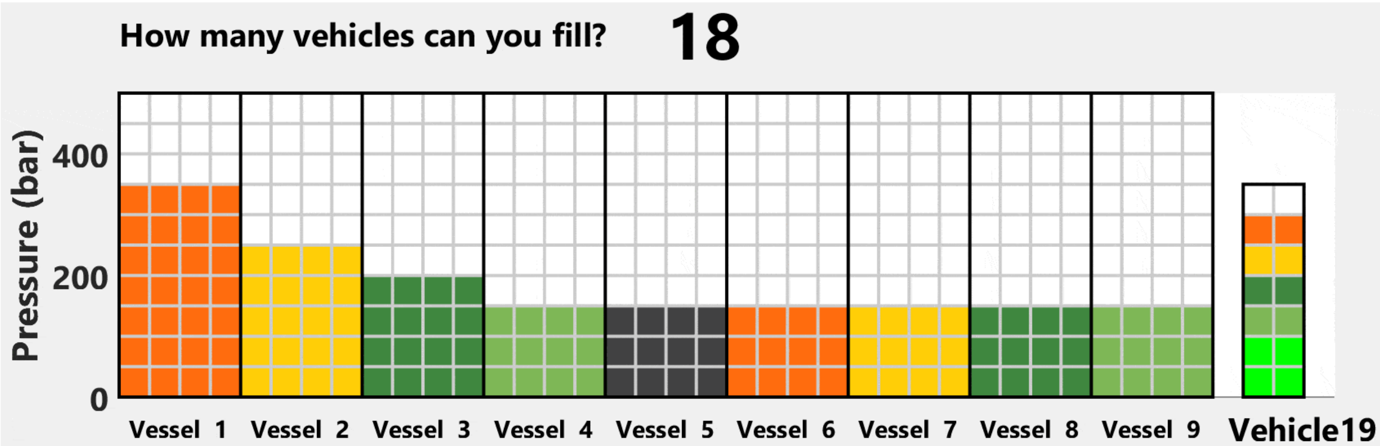
Using the Decant Method, blocks positioned at pressures of 400 bar are often used to fill empty vehicle sections at 100-200 bar – a big waste of their potential! Therefore, the vessel fails to fill out any more vehicles as soon as all the blocks positioned at 400 bar are moved from the vessel. We are only able to fill out 7 vehicles in this strategy while the vessel still contains a significant fraction of its initial blocks (254 out of 324). This presents significant performance drawbacks in that a tube trailer's decant system is only capable of delivering very few vehicle refuels at high pressure before being deemed too empty to give an adequate state of charge, and hence the need to be refilled itself.

For this reason, it's fair to say that the decant method is not the most appropriate solution for heavy-duty vehicle operators due to its inability to deliver sufficient high pressure refuelling for growing vehicle fleets. There are also significant operating costs associated with frequently transporting storage vessels to be refilled and returned to the refuelling site, and as such, low refuel numbers makes this an unfeasible option as a stand-alone refuelling solution. Consequently, the decant method and tube trailers tend to be used as a one-off solution, or a back-up solution, often in conjunction with a small booster compressor to support fixed hydrogen stations at times when the hydrogen source is down for maintenance.

THE CASCADE METHOD



A more effective standalone refuelling strategy is the cascade method. This refuelling technology is essentially a sequence of individual decants, in which multiple high-pressure vessels (not necessarily all at the same pressure) are individually, or in small groups, connected to the downstream tank of a vehicle. In using this approach, the cascade technology is able to first dispense fuel from its lowest pressure cylinder. Then, when the cylinder source has achieved balance, the next highest-pressure cylinder is connected. This process continues with each successive vessel source to ensure high pressure at every step of the refuelling cycle. Referring back to our analogy, the game of tower-blocks, it is possible to divide the vessel section into several smaller vessels as shown in the animation below. In the presented example, the number of blocks i.e., the total amount of hydrogen, remains the same but is now divided into a higher number of vessels i.e., 9 vessels instead of 1 vessel.



View animated game of tower-blocks **here**.

The strategy changes in that we first try to empty each vessel before moving to the next one. This results in filling 18 vehicles instead of 7, showcasing the importance of deploying the correct refuelling strategy. To reiterate, the reason for such a notable increase in the number of fills is that the blocks are better utilised with respect to their value i.e., height (or pressure). This results in fewer blocks being dropped from a great height and therefore being wasted i.e., using very high-pressure gas to fill up at low pressure. In addition, the number of blocks left at the end of the process is reduced from 254 to 144, and so more of the gas has been used.

The efficient use of hydrogen in the Cascade Method explains the primary advantage of cascade technology: optimising the utilisation of hydrogen to deliver a higher number of fills from the amount of gas available. This can be seen in the animation of the analogy, where vessel 1's blocks only begin to appear in later vehicle fills (vehicle 17 onwards).

This technique achieves a significantly higher rate of vehicle refuels to the target pressure due to the focus on preserving high-pressure cylinders and only using high pressure gas, when necessary, versus a standard decant. However, separating the gas storage into multiple vessels, and increasing the number of stages can introduce additional complexity and expenses to the system. As such, there is an optimum number of stages that offsets complexity/cost vs. hydrogen utilisation.

FIXED REFUELLING STATION

Most of the hydrogen refuelling stations currently operating around the world today are fixed refuelling stations. A conventional fixed station uses a compressor to compress and dispense hydrogen directly to the vehicle tank. High pressure gas compressors, however, are expensive, typically absorbing up to 50% of the capital cost of a fixed HRS. They are also susceptible to mechanical wear on seals and require regular maintenance to prevent unplanned downtime. To mitigate the mentioned risks of solely relying on a compressor, fixed stations currently deploy buffer vessels storing compressed hydrogen ready for dispensing. These buffer vessels can be operated using both Decant and Cascade Methods. Typical fixed stations commonly have a hydrogen source connected to a compressor, with low, medium and high-pressure buffer storage vessels connected in parallel downstream. This acts as a small cascade in an attempt to gain the benefits of the Cascade Method integrated with compression techniques. Referring back to our analogy, the game of tower-blocks, adding buffer vessels capable of dispensing hydrogen with the Cascade Method enables the system to better utilise the stored hydrogen with respect to its pressure. This reduces the station's operating cost, as less compressor work is needed by compressing a portion of hydrogen to small and medium pressure instead of high pressure.

This technique however introduces risk. As the hydrogen dispensing is done via the buffer storage, the refuelling system is only able to carry out a small number of refuelling cycles before it needs to be topped up by the compressor. This means that to meet high demand, the station will often experience downtime while the buffer storage is recharged, resulting in lost service time and profit.

MOBILE REFUELLING STATION

The latest, new and innovative refuelling technology available today is the mobile refuelling method.

A mobile refuelling station can use both decant and cascade methods. However, owing to its better utilisation of hydrogen, the cascade method provides significant advantage for use with a mobile refuelling station. In particular, hydrogen utilisation becomes crucial in assessing the feasibility of a mobile station since it is directly proportional to the number of fills it can perform per station fill trip, as well as the amount of dead hydrogen it will carry on each trip. A cascade mobile refuelling station consists of a number of vessels fitted with their own valves and is integrated with a control system enabling the station to divide these vessels into several banks of cascade. This provides flexibility to the cascade operation and allows vessels to dispense fuel in the most efficient and effective order, optimising hydrogen utilisation. Furthermore, unlike the fixed form, the mobile alternative delivers an additional advantage in that it is transportable to any location.

In a cascade mobile refuelling station, needs for a compressor, as a significant source of mechanical failure and unreliability, is eliminated while providing all the same flow control functionality. In principle, this allows for centralised hydrogen production to be carried out at large hydrogen plants where compression is required, removing the need for costly machinery at the refuelling point. This drastically reduces the cost associated with hydrogen refuelling stations to deliver a low-cost, hydrogen infrastructure heavy-duty vehicle developers can implement quickly.

CONCLUSION

This analysis comprehensively outlines the advantages of a cascade mobile refuelling station. It's clear that cascade technology highly outperforms decant refuelling to deliver greater high-pressure refuel numbers. This technology also allows for transportable deployment to any suitable site, removing the need for large amounts of fixed infrastructure. As a result, a cascade mobile refuelling station allows for deployment to be achieved far faster than building a fixed station, as the design of the system does not need to change to adapt to the physical layout of a site. This delivering a reliable, in-field refuelling solution that is most appropriate in facilitating the quick introduction of heavy-duty vehicle fleets.

Another key benefit highlighted, is that mobile cascade systems enable centralised hydrogen production at scale to deliver a low-cost hydrogen value chain for the end user. In utilising a transportable cascade method, centralised compression of hydrogen can be carried out at a production site where hydrogen can be centrally produced in much greater volume, reducing the overall cost of fuel. Eliminating the need for a compressor at the refuelling site also significantly reduces the capital cost of a HRS.

Further to this, the mobile cascade method continues to present additional value, in that its flexibility and deployable nature, with no need for a mechanical compressor, makes it the perfect back-up solution should a production site suffer outages, whilst its robust and reliable design can also be employed to mitigate hydrogen supply chain issues.

All in all, a cascade mobile refuelling method delivers the optimum solution for heavy-duty vehicle developers looking to implement low-carbon commercial fleets. While static cascade technology delivers the same high-pressure refuelling performance, it is just not practical for those in need of a reliable, cost effective and quick to deploy refuelling system that will enable the fast introduction of heavy-duty vehicles.

For more information on mobile cascade refuelling stations, take a look at NanoSUN's Pioneer HRS.

PIONEER HRS

Or contact us at:

01524 63517

info@nanosun.co.uk

nanosun.co.uk