Public Facing Safety and Education for Hydrogen Fueling Infrastructure

Grant, J. E. H.
Stations and Distribution, HTEC, 2920 Virtual Way, Vancouver, BC V5M 0C4, Canada, jhgrant@htec.ca

ABSTRACT

Building safe and convenient fuelling stations is key to deploying the arrival of commercial/public-use fuel cell electric vehicles (FCEVs). As the most public-facing hydrogen applications, second only to the FCEVs, hydrogen stations are an efficient tool to educate the public about hydrogen safety and normalize its use to fill up our vehicles. However, as an emerging technology, it is the industry's responsibility to ensure that fuelling infrastructures are designed and maintained in accordance with established safety standards and, thus, that the fuelling process is inherently safe for all users. On the other end, it is essential that consumers have all the necessary information at reach to help them feel safe while fuelling their zero-emission vehicles.

This paper will provide a snapshot of the safety systems used to help protect members of the public using hydrogen fueling stations, as well as the information used to educate people using this equipment. This will cover the different processes involved in hydrogen fueling stations, the dangers that are present to customers and members of the public at these sites, and the engineering design choices and equipment used to mitigate these dangers or prevent them from happening. Finally, this paper will discuss the crucial role of understanding the dangers of hydrogen at a public level and showing the importance of educating the public about hydrogen infrastructure so that people will feel comfortable using it in their everyday lives.

1.0 INTRODUCTION

In 2021, the Government of Canada announced a mandatory target for all new light-duty cars and passenger truck sales to be zero-emission by 2035, accelerating Canada's previous goal of 100 percent sales by 2040 [1]. Battery electric vehicles (BEVs) are the most common Zero-Emission Vehicle (ZEV), making up 5.3% of vehicle registrations in 2021 [2]. However, while they represent a cleaner alternative to fossil fuel vehicles, BEVs also suffer from several issues that hinder their adoption: charging time, range, and cold weather performance [3].

Without a doubt, hydrogen fuel cell vehicles (FCEVs) can fill these gaps left by electrification. With charging times between three to five minutes, ranges up to 646 km (402mi) [4], and better resistance to cold weather [3], FCEVs offer an additional clean fuel alternative and can provide even more benefits for applications such as fleet vehicles [5], buses, and heavy-duty vehicles.

Much like BEV charging stations have become increasingly common and normalized over the last decade, FCEV fueling infrastructure will need to experience the same level of growth and acceptance in order to help propel Canada towards its zero-emission targets by 2050.

Moreover, while this widespread adoption of new hydrogen technologies results in increasing interest from the general public, it also comes with its share of doubts and uncertainty. This is especially true considering the misconceptions around the sadly unfamous *Hindenburg disaster or the space shuttle Challenger. Both* incidents loom large for their spectacle and can colour the opinion of a public unfamiliar with hydrogen fuel that lacks a thorough understanding of the safety systems in place for hydrogen vehicles and hydrogen infrastructure. In fact, hydrogen vehicles are so safe that the Hyundai Nexo received the Insurance Institute for Highway Safety's *Top Safety Pick +* award for safety performance in crash testing [6]. In brief, bias around hydrogen safety will require the industry to follow strict rules in terms of safety and quality but also educate the public about hydrogen safety to increase acceptance and usage across the industry.

2.0 BACKGROUND

The hydrogen ecosystem is often referred to as the work done across the "hydrogen value chain" - an overarching view that looks at the hydrogen pathway from production through storage and distribution, dispensing, to consumption/application [7]. The hydrogen dispensing and consumption stage involves direct contact between a hydrogen infrastructure and the general public.

Hydrogen can be produced in several ways, including electrolysis using renewable energies, steam reforming of natural gas, and biomass and biogas reforming. Once produced and purified for the application, hydrogen can be stored in liquid or gaseous form for transportation to the application. The end application where hydrogen is consumed can vary widely, requiring other site infrastructures to deliver the hydrogen. Currently, light-duty vehicles and the hydrogen infrastructure used to fuel them are the primary application that the public will interact with.

Figure 1 shows a map of the hydrogen value chain and the small overall section with which the public will interact. While this is a small portion of the full range of hydrogen processes, it is essential as it represents the FCEVs' driver experience and is an effective tool to educate the public about hydrogen use and safety.

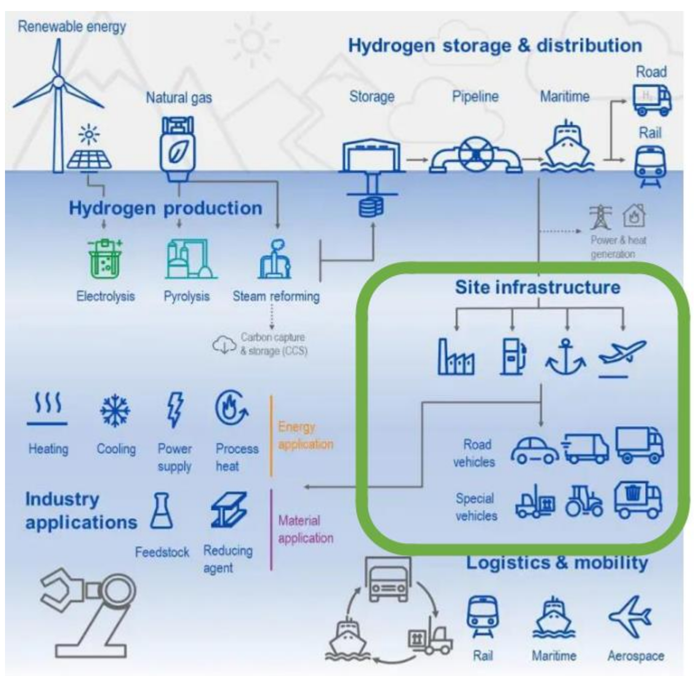

Figure 1. Hydrogen value chain, with public facing application, highlighted.

Existing commercial gas stations host the majority of hydrogen fueling stations in North America [8], and while fueling a regular gasoline vehicle is now perceived as one of the most basic actions of all, it is essential to note that several hazards are still omnipresent at all gasoline turning stations. Yet, the fact that these stations have been open to the public for over 100 years [9] has given people time to understand those hazards and become comfortable with them. The acceptance of mobile phone use at gas stations is a further example. In contrast, the first publicly available hydrogen fueling station was opened in 2000, with Canada's first public hydrogen station opening in 2018 [10] shown below in Figure 2.

Figure 2. Canada’s first retail hydrogen fueling station

Hydrogen fueling stations are complex equipment, but they can be described by three major processes: storage, compression, and dispensing. On the hydrogen station site are tanks to store the hydrogen in either gaseous or liquid form. Hydrogen is delivered to the station and stored for later use in these vessels. Delivery to these storage tanks can raise interesting issues. Indeed, available space on the gas station forecourt is much smaller than what would be available at an industrial gas site. The multitude of public vehicles and pedestrians moving through the site makes the logistics aspects of things more delicate. Additionally, the size of delivery vehicles can also vary, with some much larger tanks than the typical gasoline ones. Figure 3 shows the size of a hydrogen tube trailer while Figure 4 shows the size of a hydrogen delivery truck on the forecourt of a gas station. Although the public does not directly interact with hydrogen deliveries, this part of the process can impact other site users, and it is crucial to consider the public during the design and operation of this component.

Figure 3. Hydrogen tube trailer filling a hydrogen station

Figure 4. Hydrogen delivery truck delivering hydrogen to station

Compression is the process of increasing the pressure of stored hydrogen to the FCEV delivery pressure of 700 bar (10,150 psi). Delivered hydrogen can range in pressure from 9 bar (130 psi) (liquid) to 450 bar (6,500 psi) in some cases. A higher delivery pressure is beneficial as it means a larger amount of hydrogen can be delivered to the station in one trip, and the on-site compressor works faster and uses less power, but it comes with the added hazards related to higher pressures. The compression process is unseen from a public user point of view, as it occurs inside the station module. Figure 5 shows the major components of a station, with only the dispenser readily visible to the public.

Figure 5. The major components of a hydrogen fueling station

Dispensing is the process in the hydrogen fueling station that the public will directly interact with. Like any traditional gasoline fueling station, the customer will park their vehicle alongside a dispenser, go through a payment process, connect the nozzle to their car, and initiate the fill. During this process, 700b of hydrogen will be sequenced from the station module, chilled to low temperature, and flowed into the vehicle tank. The filling process takes between three to five minutes and has several safety features built in to end a fill in a non-safe situation safely.

When filling up at an integrated station, the customer will be able to fill from both sides of the dispenser as long as the fueling hose and nozzle can reach the vehicle fueling receptacle. Other hydrogen dispensers are built as stand-alone devices, seen below in Figure 6. In some cases, ancillary equipment such as a Point of Sale (POS), receipt printer, or intercom will be located in a separate container nearby, primarily to avoid contamination of hydrogen around electrical components that are not rated for use near flammable gasses.

Figure 6. *Left*, A hydrogen fueling station integrated to a gasoline station. *Right*, A stand-alone hydrogen station

From a customer's point of view, the hydrogen fueling process is similar to the familiar steps of filling up a gasoline vehicle at your local station. The customer parks the vehicle alongside the dispenser, turns it off, and opens the fuel door. At the dispenser interface, the customer can select their fill type, enter their payment information, and receive information about the hydrogen filling process. The next step is to attach the nozzle to the vehicle fueling receptacle. Unlike a gasoline nozzle that dispenses fuel in a liquid state, the hydrogen is delivered to the FCEV as a gas at high pressure. The dispenser nozzle makes a mechanical connection to the vehicle to make a gas-tight seal. The nozzle cannot be removed from the vehicle receptacle while under pressure, so there is no risk of accidentally removing the nozzle during a fill. Figure 7 shows two of the different styles of hydrogen nozzle available.

Figure 7. *Left*, A "pistol style" hydrogen nozzle connected to a Hyundai Nexo. *Right*, A "barrel style" hydrogen nozzle connected to a Toyota Mirai

The fill will commence, with a few pauses during the fill for safety checks and takes between three and five minutes to complete. The dispenser will fill the hydrogen tank in the FCEV until it reaches 100% of the target pressure, at which point the transaction will be complete, the customer's payment method will be charged, and a digital or printed receipt will be issued.

When the fill is completed, the dispenser hose will vent pressure, and the dispenser nozzle can be removed from the vehicle receptacle. The hydrogen is delivered at temperatures as low as -40°C [16], so there may be some ice or frost build-up on the nozzle and receptacle, preventing immediate removal. But this is only temporary, and the nozzle can be removed in the following minutes when the ice has melted. Once the dispenser nozzle is removed, customers can close the fuel door, start their vehicle, and drive away. FCEVs have the added feature of being unable to start their vehicle while the fuel door is open, preventing customers from driving away with the nozzle and hose still attached [11].

3.0 HYDROGEN DANGERS

As with any other energy source, such as gasoline and diesel, hydrogen is also a combustible fuel, and we handle it with the utmost respect. However, the unique properties of hydrogen and the form it is used in for FCEVs make the hazards different to public customers are different from other fuels [1].

Hydrogen at a fueling station is stored and delivered under high pressure, with the gas going into FCEVs at 700 bar (10,150 psi). For comparison, the typical tire pressures don't go over 2.4 bar (35 psi). High-pressure gas systems present several hazards, ranging from oxygen displacement, fire and explosions, loud release noise, and physical harm from the force of released gas [12].

Hydrogen is 14 times lighter than air [13], meaning that when it is released, it will rise at a rate of 20 m/s (65.5 ft/s) in the air [14] and disperse quickly into the atmosphere. Hydrogen facilities are designed with open roofs and high ventilation to allow hydrogen to disperse quickly and avoid a buildup of gas that could create an asphyxiation risk. Hydrogen dispensers are situated in outdoor areas to mitigate this hazard.

Hydrogen is a hazardous material with an extensive flammability range: 4% to 74% in air and 4% to 94% in oxygen [15]. Additionally, the large flammability and explosive ranges of hydrogen mixed with oxygen mean that even a small amount of hydrogen (4%) mixed in the air can cause a flash fire, jet fire, deflagration, or detonation. Suppose the hydrogen is leaking from a pressurized storage source. In that case, this fire can be sustained until the leak is isolated, the hydrogen is completely consumed, or a larger storage release occurs.

Another challenge that arises from hydrogen flames is effectively detecting them. Hydrogen burns nearly invisible to the human eye, making it difficult to visually detect without means such as thermal imaging or an extended sacrificial indicator such as a corn broom. Figure 8 shows a comparison of an invisible hydrogen flame with a visible propane flame.

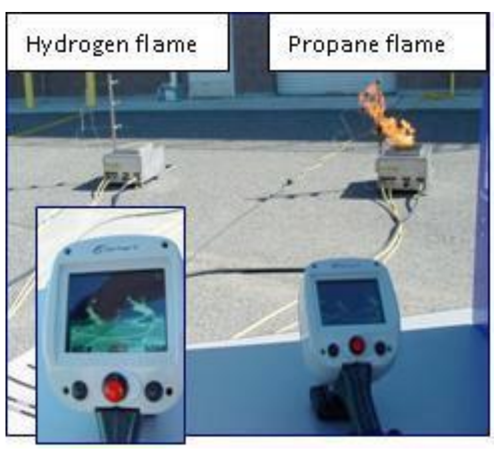

Figure 8. A hydrogen flame invisible to the naked eye but detected using thermal imaging

Hydrogen can also pose difficulties when used with certain materials due to hydrogen embrittlement. This occurs when metals exposed to hydrogen become brittle as hydrogen diffuses through the material and breaks apart the microstructure, weakening the material and making it susceptible to failure under stress [16]. If this failure occurs at the dispenser, then there is a possibility of a customer being exposed to a high-pressure hydrogen release.

A hydrogen leak at the dispenser is the cause of almost all hazards that could affect a member of the public at a hydrogen fueling station. The dispenser will see pressures of at least 700 bar (10,150 psi) so any leak will present the hazards of both high-pressure gas and a flammable substance, including loud noises, physical harm from the force of gas release, and flash fire or jet flame if there are sources of ignition nearby. With all these potential hazards in mind, strict safety measures are taken to significantly reduce the risk for customers using this equipment.

4.0 OVERVIEW OF SAFETY EQUIPMENT

Hydrogen facilities require rigorous planning and risk mitigation due to the complex processes and hazardous materials involved. One of the primary mitigations is ensuring that only personnel trained for this equipment can access it. This is not an assumption that can be made for hydrogen fueling dispensers, so it must be assumed that any public member will have access to the equipment. For this reason, more safeguards must be in place to minimize the risk of an incident caused by user error.

As previously mentioned, most dangers around the hydrogen dispenser are caused by a hydrogen leak, so most of the safeguards will work to either prevent a leak from happening or reduce the impact of a leak once it has occurred. Many of these safeguards are required by standards for hydrogen fueling or hydrogen infrastructure, including the Nation Fire Protection Code Hydrogen Technologies Code (NFPA 2) or SAE J 2601 Fueling Protocols For Light Duty Gaseous Hydrogen Surface Vehicles.

Actions aiming to minimize the likelihood of hydrogen leaks typically occur during the equipment's design phase. The components of the dispenser and refuelling station that are exposed to hydrogen should be rated for use with hydrogen. This includes using tubing and components made from types of stainless steel that are resistant to embrittlement; gaskets, o-rings, and seals that are made to seal more effectively against the small, leak-prone hydrogen molecule; and lubricants that are non-combustible and will not contaminate fuel cells.

Another safeguard is to design the equipment with an emergency shutdown system. Emergency shutdown procedures exist to prevent situations that could result in catastrophic events by implementing several safety features. These include isolation of bulk fuel storage, isolation of electrical equipment, depressurization of certain parts of the site, and increased ventilation [17].

Another consideration when designing a hydrogen dispenser is the number of potential leak points. Because hydrogen can leak more easily than other pressurized gases, care must be taken to reduce the number of locations where hydrogen could exit the system. This can be achieved by using runs of seamless tubing between valves and instrumentation, utilizing fittings with a dedicated sealing surface, and balancing the utility of many instruments to monitor systems with the many leak points that these introduce.

While many steps can be taken to prevent a leak, it is nearly impossible to eliminate all leaks in a hydrogen system. With this in mind, any hydrogen site should have safeguards to handle hydrogen leaks. The first step consists in detecting whether a leak has taken place. This is most commonly done via leak checks and pressure monitoring.

The hydrogen fueling standard SAE J2601 requires several leak checks to be performed throughout a fill's duration, shown in Figure 9 below. The purpose of these leak checks is to ensure that there are no leaks at the dispenser during the vehicle filling process. While the vehicle is being filled, the flow of hydrogen will stop for approximately eight seconds, and the pressure in the nozzle will be monitored. If the measured pressure drops by a certain amount, then the fill will terminate, vent the hose, and disable the dispenser, preventing any more hydrogen from leaking.

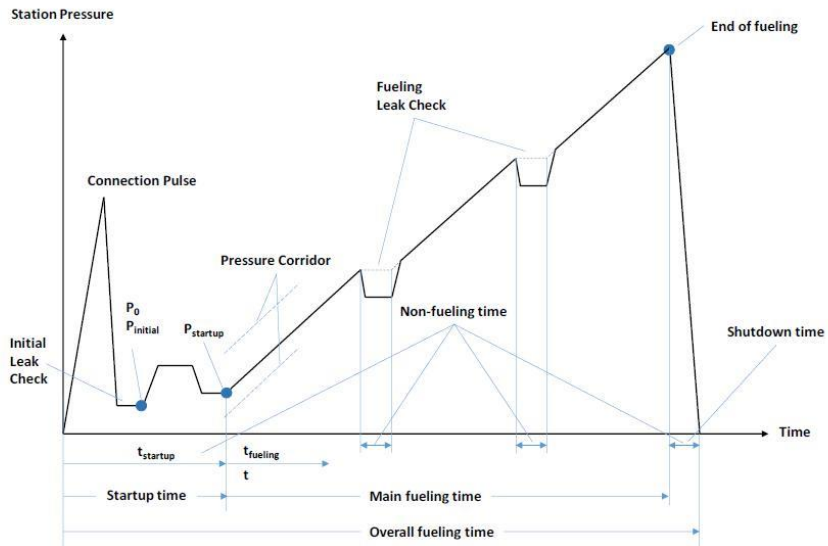

Figure 9. Leak checks performed during a hydrogen vehicle fill

Additional leak checks can be performed on the system over longer periods of time to detect more minor leaks that may not be noticeable over shorter pressure holds. These larger leak checks can be conducted over larger stretches of tubing and components, increasing the number of places where leaks can be detected. In addition to detecting leaks through pressure loss, hydrogen sensors are paced around the station to detect hydrogen gas that has left the sealed system and leaked into areas with critical equipment. These sensors will measure the concentration of hydrogen in the air as a percentage of the lower flammability limit (LFL), which is 4%. When specific percentages of the LFL are detected, the station will change into a safety state, shutting down the operation of certain equipment and isolating bulk storage. When a critical level of hydrogen is detected, the station will be sent into an ESD state and require a manual reset on site in order to ensure that equipment is inspected and corrected before the operation is reinstated.

Finally, there are safety measures to reduce a hydrogen leak's impact after it gets ignited. Some of these function by detecting flames, either through picking up an infrared/ultraviolet radiation emitted by a flame, or by detecting radiant heat above a certain temperature. Both of these detectors are able to pick up ignition conditions, taking actions in the system to reduce the overall impact of a jet flame or deflagration.
Tools and safeguards are also implemented to protect on-site operators during an ignition event. Sections of the hydrogen compound will be constructed using a two-hour fire-rated wall so that even in the event of a jet flame, the fire will be contained within the compound and won't be a direct danger to members of the public nearby.

5.0 EDUCATION

There are many safeguards put in place to make hydrogen fueling stations safe for members of the public to use. However, these precautions are only sometimes known, and it can be easy for people to jump to conclusions about how safe using hydrogen really is. These concerns rarely come to mind when it comes to fueling traditional gasoline and diesel vehicles. Certain actions like not smoking or not using a phone near a gas station are second nature and can be taken for granted by many people. In order to bring hydrogen fueling stations to the point where the safety of filling is taken for granted, the public needs to be familiar with and trust that this new technology is safe.

As of 2022, over 800 hydrogen fueling stations are deployed worldwide [18], a fraction of the number of conventional gas stations in operation. With these few hydrogen stations open, many people have likely never heard of a hydrogen refuelling station, let alone seen one. This is a crucial point to remember when considering the safety of hydrogen infrastructure, as many members of the hydrogen industry will possess a deep and vast knowledge of hydrogen, and this familiarity can be taken for granted. The information that has been learned over the years and decades must be condensed into accessible formats that the public can learn from. Organizations such as Hydrogen Europe, Mission Hydrogen, and the Hydrogen Fuel Cell Partnership regularly produce this information and share it widely to raise awareness, while many companies in the hydrogen industry will also provide easily accessible information about the benefits and safety of hydrogen.

In addition to being open about the benefits of hydrogen, the industry must also maintain a level of transparency when facing issues to uphold public trust. Recent hydrogen incidents, such as the tube trailer hydrogen release in Diamond Bar, California, in 2018 [19] and the hydrogen station explosion at Kjørbo, Norway, in 2019 [20] are examples of major incidents that received significant publicity highlighting the dangers of hydrogen. The incident reports, and investigations into these failures are available and can be used as valuable lessons learned for other industry members. The openness and availability of these reports set an example for how the industry can demonstrate to the public that the dangers involved in using hydrogen are continually being examined and addressed.

On a more local level, information can be shared at the hydrogen dispenser itself. Information describing the filling process of an FCEV is critical to making the customer experience as straightforward as a gasoline vehicle fill. Providing instructions at the hydrogen dispenser itself and during the filling process is one way to ensure that the customer has the information they need to fill their FCEV safely and successfully. Offering information at the dispenser can be a balancing act however, as too much information or instructions presented in a poor format can cause people to ignore them, attempting to use the dispenser through intuition alone.

Further engagement with the public has therefore been a successful way to help educate people on the dispensing process and hydrogen in general. Linking online resources can supply people with the answers to their questions, but directly interfacing with customers can provide an immediate response to a question that may not be followed up on if people need to do their own research. Installing an intercom in the dispenser or having a direct phone line to someone who can answer these questions can alleviate frustration with the unknown and provide insight into the difficulties that customers face at the dispenser.

6.0 CONCLUSION

The future of hydrogen as a clean fuel is tied not only to the safe regulation of the industry but also to the way hydrogen safety is perceived by the public. While many sections of the hydrogen value chain will be implemented at an industrial level, hydrogen fueling stations are in a unique position to show the public a direct hydrogen application that can be used directly by consumers. Because of the high level of visibility that hydrogen stations have, station operators need to be conscious of the need for safeguards for public safety and the public’s perception of hydrogen as a fuel. Taking a transparent and informative stance to educate the public about the dangers of hydrogen and the engineering measures to mitigate these dangers is an important step to normalizing hydrogen as a part of moving towards a zero-emission future.

References

1. 2030 Emissions Reduction Plan – Sector-by-sector overview. Government of Canada, July 2022, https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html#sector6 Accessed March 8, 2023.
2. Market Snapshot: Global EV sales need to significantly increase to meet 2030 Paris Agreement goals. Government of Canada, March 2021, https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2021/market-snapshot-global-ev-sales-need-to-significantly-increase-to-meet-2030-paris-agreement-goals.html Accessed March 8, 2023.
3. Henning, Mark; Thomas, Andrew R.; and Smyth, Alison, "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses" (2019). Urban Publications. 0 1 2 3 1630., https://engagedscholarship.csuohio.edu/urban_facpub/1630
4. Toyota. 2023 Mirai. https://www.toyota.com/mirai/ Accessed March 9, 2023.
5. Victoria-based Geazone Eco-courier expands hydrogen fleet after phase-one success. Electric Autonomy. November 2021, https://electricautonomy.ca/2021/11/17/geazone-hydrogen-vehicle-toyota/
6. Insurance Institute for Highway Safety. Hyundai Nexo, 2019, https://www.iihs.org/ratings/vehicle/hyundai/nexo-4-door-suv/2019
7. TÜV SÜD. EXPLORE THE HYDROGEN VALUE CHAIN. https://www.tuvsud.com/en-us/themes/hydrogen/explore-the-hydrogen-value-chain#:~:text=The%20hydrogen%20value%20chain%20is,%2C%20and%20standards%20(RCS)
8. Hydrogen Fuel Cell Partnership. Station Map. https://h2fcp.org/stationmap Accessed March 31, 2023.
9. America's Oldest Gasoline Station Since 1909 Still Offering Full Service. Pennsylvania Mountains of Attractions. http://www.pennsylvania-mountains-of-attractions.com/oldest-gasoline-station.html
10. Canada’s First Retail Hydrogen Refuelling Station in Vancouver. Canadian Auto World, June, 2018, http://www.canadianautoworld.ca/industry- news/canadas-first-retail-hydrogen-refuelling-station-in-vancouver Accessed March 30, 2023
11. Toyota. Opening the fuel door. Toyota Owner's Manuals. https://www.toyota.com/owners/resources/warranty-owners-manuals.mirai.2022.digital.om62084u.ch05se040401 Accessed March 29, 2023.
12. How to Work Safely with - Hazardous Products using "Gas Cylinder" Pictogram. Canadian Centre for Occupational Health and Safety. December 2017, https://www.ccohs.ca/oshanswers/chemicals/howto/gas_cylinder.html Accessed March 26, 2023.
13. Hydrogen Compared with Other Fuels. Hydrogen Tools. https://h2tools.org/bestpractices/hydrogen-compared-other-fuels#:~:text=Hydrogen%20is%20about%2057%20times,typically%20rise%20and%20disperse%20rapidly Accessed March 25, 2023.
14. Safety, Codes, and Standards Fact Sheet. U.S. Department of Energy. February 2011, https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fct_h2_safety.pdf Accessed March 18, 2023
15. Rhodes, R. Explosive lessons in Hydrogen Safety. Ask Magazine, 46-50. https://www.nasa.gov/pdf/513855main_ASK_41s_explosive.pdf
16. Hydrogen Embrittlement of Steel. Industrial Metallurgists, LLC. September 2016, https://www.imetllc.com/hydrogen-embrittlement-steel/ Accessed March 28, 2023.f

17. Custom Control Sensors, LLC. What is an emergency shutdown system and where are they used? Custom Control Sensors. March 2020, https://www.ccsdualsnap.com/what-is-an-emergency-shutdown-system/#:~:text=An%20emergency%20shutdown%20system%20or,economically%2C%20environmentally%2C%20or%20operationally Accessed March 29, 2023.
18. Ludwig-Bölkow-Systemtechnik GmbH. Statistics: Hydrogen Infrastructure. H2 Stations. March 2023, https://www.h2stations.org/statistics/
19. Air Products and Chemicals, Inc. Tube Trailer Module Hydrogen Release and Subsequent Fire Diamond Bar, California February 11, 2018. National Transportation Safety Board. October 2019, https://www.ntsb.gov/investigations/AccidentReports/Reports/HZM1902.pdf March 30, 2023.
20. Nel investigation into explosion at Kjørbo hydrogen station, Fuel Cells Bulletin, Volume 2019, Issue 7, 2019, Page 7, ISSN 1464-2859, https://doi.org/10.1016/S1464-2859(19)30280-9. (https://www.sciencedirect.com/science/article/pii/S1464285919302809)