Adapting Maintenance Facilities for Hydrogen

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Abstract

Transit planners and managers need to be armed with the best information on how to make the transition towards zero emission transit fleets. Although zero emission transit is becoming increasingly necessary, many transit operators are unsure of how to make the transition and how to replace their existing infrastructure, especially when it comes to on site bus maintenance facilities. Upgrading vehicle maintenance facilities to safely accommodate hydrogen can be a deciding factor in whether an operator chooses to adopt this fuel for its fleet. This paper reviews best practices in hydrogen bus maintenance facilities for transit agencies. It includes safety and infrastructure factors transit managers must consider when transitioning to servicing and maintaining fuel cell electric buses. Although local requirements and regulations vary, this paper will help the reader gain insights on what needs to be considered in transitioning a workshop. As with any fuel, hydrogen must be treated with respect and care. Today's hydrogen fuel cell technologies are mature in their safety features. Fuel cell electric buses are designed and built for safety, and the protocols for safe storage, maintenance and refuelling are well developed and understood.

1.0 About Ballard

Ballard Power Systems Europe A/S, Hobro, Denmark is the European head quarter of Canadian Ballard Power Systems Inc. Ballard's zero-emission PEM fuel cell solutions bring compelling value propositions to end users' markets such as backup power and enable electrification of mobility, including buses, commercial trucks, trains, marine vessels and forklift trucks. We are working to accelerate fuel cell technology adoption, committed to provide fuel cell power for a sustainable planet.

2.0.Executive Summary

Hydrogen fuel cell electric buses are starting to be adopted as part of the pathway to decarbonisation and improvements in air quality. One area that is vital to the operation of a bus but is often not considered is the maintenance of the vehicle. If a hydrogen leak were to occur, it is more likely to be during maintenance of the bus. Safety in the hydrogen workshop should not be confined to just the hydrogen, but also high voltage electrical safety and high pressure safety must also be considered. Regulation, codes and standard should be adhered to, but may not always be developed for the hydrogen fuel cell electric bus in the workshop.

It will be unlikely that bus depot staff have come across hydrogen before and may have preconceived ideas about hydrogen safety. With this in mind, hydrogen misunderstandings have to be removed and the correct safety information given. It is important that only the relevant properties of hydrogen are demonstrated, and this is often done visually by comparing it to well-known gases such as methane and petrol (gasoline) vapour. It is always important to keep it simple.

There are a few mitigations and depot conversions that are required to take place, understanding the basic behaviour of hydrogen will make sure that the appropriate measures are taken. It may require a hydrogen consultant to be introduced to assist with and depot conversion, documentation, and risk assessment. However, a hydrogen professional is unlikely to understand the way a bus depot operates so any assessment needs to be done in co-operation with the depot staff and the bus manufacturer.

It is important to ensure that any process or risk assessment is not too onerous as this will lead to shortcuts being taken negating the safety work that has been carried out. Again, it must also be remembered that not every hazard is directly related to hydrogen on a fuel cell electric bus.

3.0 Contents

4.0 Introduction

As the implementation of zero-emission vehicles, in the first instance buses, move from individual projects to wide scale adoption it is imperative that in parallel safe maintenance and a safe working environment is established. Also, there is a requirement for the workforce to be retrained to be able to safely carry out maintenance and repair on zero-emission vehicles.

This paper will concentrate on the conversion and adaptations required for a safe working environment for technicians working on hydrogen fuel cell heavy duty transport vehicles, focusing on hydrogen fuel cell electric buses. However, the information and principles which are highlighted in this paper can easily be converted to any hydrogen vehicle workshop.

5.0 Moving to Zero-Emission

With the awareness of climate change now at the fore across the world and the local issue of air quality, transport is at the vanguard of the change to low and zero-emission vehicles. Leading the way on this are battery electric buses (hereinafter referred to as BEBs). BEBs are starting to be adopted in full revenue service, but they cannot undertake all the current diesel bus operations, as BEBs face prominent challenges with operation efficiency, short daily operational milage capability and infrastructure set up. To fill the gap hydrogen fuel cell electric buses (hereinafter referred to as FCEBs) are being deployed in larger numbers to meet the needs of the transit operators. FCEBs fuelled with hydrogen are the only zero-emission technology to offer one-to-one replacement of diesel fleets with complete route flexibility, short refuelling time and similar depot space utilization.

However, despite the similarity in the depot setup, both BEBs and FCEBs require a complementary and a different knowledge in the workshop and maintenance of the vehicles. Thus, this requires that the safety systems and process needs be looked at and given extra attention.

The transition to zero-emission means that depots, that are often set in their ways with well-established maintenance processes and safety precautions and only have experience working with diesel, are facing new tasks and new hazards that they have not come across before. Mitigation against the new hazards that zero-emission brings is very difficult to ascertain as within the depots there is a lack of experience, so expertise may have to be brought in from outside and they may not fully understand the bus business.

6.0 Hydrogen Safety in Relation to a Bus Depot

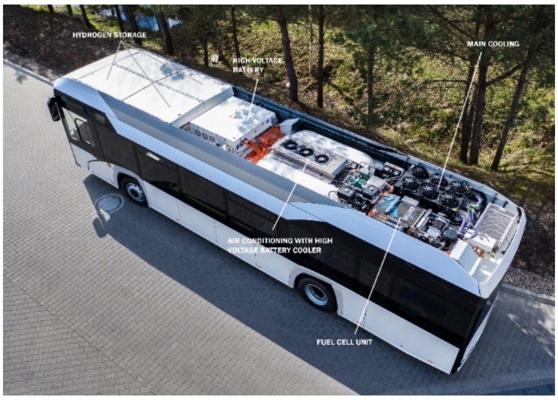

Figure 1

The properties of hydrogen are well known and can be ascertained by a quick search on the internet, although the interpretation, due to lack of knowledge, may lead to incorrect decisions being taken on safety. Difficulty in when deciding what safety measures are required in a bus depot depend on deciding what properties are appropriate to consider with the environment. There may also be a number of preconceived ideas born from the lack of hydrogen awareness and the application that is going to be used within the transport environment.

It must be remembered that in normal operation the hydrogen on a bus is in a sealed system, as shown in Figure 1. The fuelling is within a sealed system so the only way that hydrogen can create a hazard is if an abnormal event has occurred. There are two places where this is most likely to happen, either if there is a road traffic accident, not discussed in this paper, or during maintenance.

6.1 Preventative and Unplanned Maintenance

Planned or preventative maintenance will go through a set procedure to ensure that the bus including the driveline and fuel cell will work correctly to the next maintenance period. During this preventative maintenance there should be little chance of a hydrogen leak. If the procedures in the maintenance manuals are followed correctly, the technicians should not be exposed to hydrogen.

During the regular preventative regime there would also be a safety check on the bus. This is normal with diesel buses and it must be the same on and with a FECB. During this check there should be a basic hydrogen leak test and a visual inspection of the hydrogen storage system.

Unplanned maintenance is any incident that has occurred which would prevent the bus from going in to service. This can be a serious issue stopping the bus operating or a seemingly 'trivial' matter such as an end cap missing on a seat[1]. It is during this type of maintenance where it is more likely that a hydrogen leak could occur, or a leak could be the reason for the unplanned maintenance. As the technicians will have to diagnose a fault during this maintenance, possibly on the hydrogen system there is more chance that the system could be compromised causing a safety issue. It is with this unexpected circumstance that mitigation is required in the workshop.

6.2 Mixed Technology Workshops

As fleets are converted to low and zero-emission technologies there will be a transition period of many years. The life of a bus can be between 10 to 25 years, but normally around 15 years. This means that some diesel buses will still be operating in the 2030s as zero-emission buses are growing within the fleets.

Plans must be made and implemented for maintenance of different buses with different drivelines all in the same workshop. This can add extra complexity in making a safe working environment. There could be multiple safety regimes within the same workshop.

6.3 So, What Precautions?

With a FCEB not all the extra hazards are hydrogen, although this is normally the one that attracts the most attention by the depot staff and management, and often in the media when hydrogen is mentioned. However, there are two other hazards that cannot be overlooked, namely electrical safety and high pressure. Plus, there are other maintenance tasks that have to take place that could highlight more known workshop hazards such as working at height.

6.3.1 High Voltage Electrical Safety

FCEBs have high DC voltage to power the motors that ultimately propel the bus. This is no different from BEBs or diesel hybrid buses. Of all the hazards of a new technology bus this is the one that is potentially the most troublesome. A high voltage electric shock can often result in a fatal incident.

[1] This could lead to a sharp edge and potential incident with a passenger. In the UK this could result in a prohibition on bus.

All technicians that are working on high voltage should be trained to a national standard to make sure that they are competent and qualified for the task. This is no different for FCEBs. The training is needed to strengthen the competence of the technicians.

6.3.2 High Pressure

A FCEB will have the hydrogen storage at 35MPa.[2] Although in a bus workshop there will be some experience of high pressure systems, but not in the volumes that are stored on the FCEB. Mitigation against the release of a high pressure leak is inherently included in the design of the bus with excess flow valves and shut of valves when the bus is isolated. However, the understanding of working on a high pressure system must be trained to all technicians who are working on the bus.

6.3.3 Hydrogen

When mitigating against hydrogen leaks the most important element to remember is not letting hydrogen mix with air to stop any hydrogen atmosphere occurring in the first place. Remembering the fire triangle (see Figure 2.) is probably the simplest yet most effective principle to base mitigation in the workshop on.

Figure 2

When working on the bus, particularly the hydrogen system, two sides of the triangle must not be existent - the fuel and the heat.

6.3.4 Fire Triangle

The fire triangle is a simple yet effective way of getting a safety message across to the depot. When depicted such as figure 2, it is easy to be explained and can be used as a visual reminder in posters and safety literature.

The principle of the fire triangle can be the backbone of safety messaging when explaining hydrogen.

6.3.4.1 Fuel – Hydrogen

As mentioned prior to this, the fuel for a FCEB is hydrogen. It is vital that if the hydrogen system has to be maintained for any reason, the section of the system that will be compromised is purged of hydrogen and replaced with inert nitrogen. When the system is disturbed as part of maintenance, only nitrogen can be released and so no hydrogen will be released in the workshop. Any pressure or

[2] Passenger vehicles have hydrogen storage at 70MPa and it is possible that higher storage pressures may be introduced in heavy duty vehicles.

integrity test of the repair should be carried out using, in the first instance nitrogen. Although this will not guarantee that when hydrogen is introduced with the smaller molecule there could not be an escape, this is likely to small as the basic robustness of the repair has been determined using nitrogen. When hydrogen is reintroduced in to the area of the repair, it should be undertaken in stages, so at a low pressure gradually increasing, and constantly checked for leaks or signs of leaks.

6.3.4.2 Heat – Ignition Source

A heat or ignition source can come from a number of places and as hydrogen requires a very low ignition energy of around 0.019mJ. The obvious ignition source within a workshop is anything with a naked flame, or that produces sparks such as welding or grinding. These potential ignitions sources can be easily removed from the hydrogen bus working area, although care must be taken if the workshop is a mixed workshop with strict guidelines. All electrical wiring within zoned (see Section 7 – Regulations, Codes and Standards) areas that could potentially be a place where hydrogen can cloud and should be of the appropriate standard for this environment.

7.0 Regulations, Codes and Standards

Regulations, codes and standards (RCS) that are applicable may vary from country to country and there can even be variations within the European Union (EU). It must also be noted that the definition of RCS may vary from country to country. The handling and storage of hydrogen is well established as it has been used in industrial processes for many years. For example, in the chemical industry, where it is used as a building block for ammonia and methanol.

Thresholds of safety measures have been established such as in the EU the Seveso-III regulations that aims at the prevention of major accidents involving dangerous substances. [1]

The buses themselves now have regulations and standards that dictate the safe design over and above a conventional diesel bus, again an EU example would be regulation (EC) No 79/2009. [2]

Individual components within the hydrogen system, such as the hydrogen storage cylinders will also be approved and tested according to well recognised standards. The types of test that could be undertaken, but not limited to, are bonfire test, gunfire penetration, chemical exposure and drop test. [3]

Establishment of explosive areas, and the equipment that can be used within them is well defined in EU's ATEX directive. Hazardous places are classified in terms of zones based on the frequency and duration of the occurrence of an explosive area where:

> **Zone 0**
> A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.
> **Zone 1**
> A place in which an explosive atmosphere consisting of a mixture with air or flammable substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.
> **Zone 2**
> A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

The vast majority of health and safety specialists will understand the ATEX directive and have a working knowledge of the obligations required with this directive. They may not however understand the specific duties of bus maintenance in the undertaking of these requirements. [4]

8.0 Keep it Simple!

When deciding on safety measures and a safety regime for a bus depot, care must be taken not to confuse either the technicians that are undertaking the day to day maintenance of the buses, or the supervisors who have to implement a regime. Basic hydrogen safety should be taught to any personal who come in to contact with the bus. Drivers as part of their type training on the hydrogen bus, technicians on their maintenance training (this will also be part of most manufacturer's training) and depot supervisors and management. Other staff in the depot can be updated during their team meetings, depot induction or toolbox talks.

Visual representation is often better than long explanations to get a safety message across. Figure 3 is an excellent, yet simple way to demonstrate the properties of hydrogen and gets the message across in a way that can be easily explained and understood. The comparison to well-known gases is understood in a bus depot environment, so when for example ignition energy is described mJ has not meaning but a comparison to petrol (gasoline) vapour is known by all as very flammable so an understanding is made. Slide in figure 3 is taken from ICHS_2005_HySafe_150002.ppt. [5]

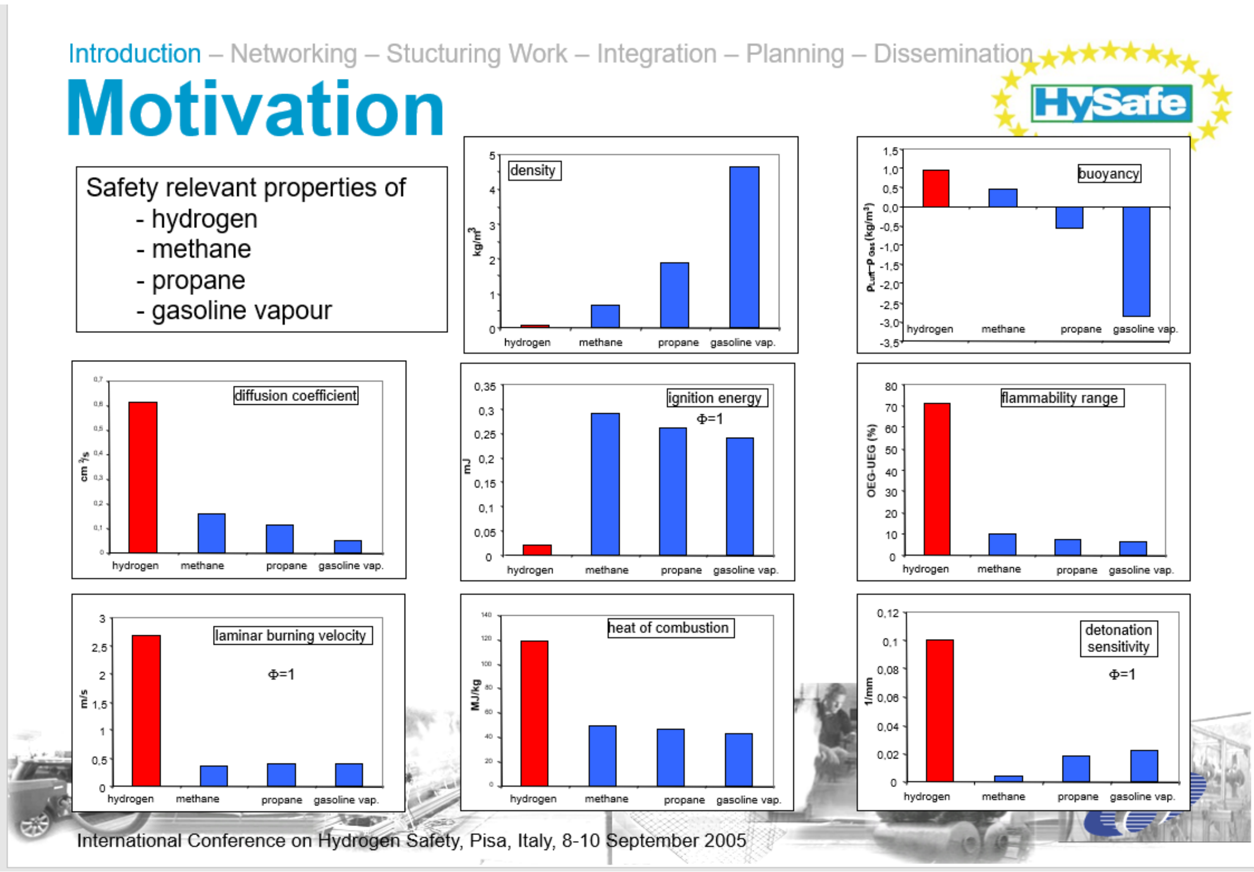

Figure 3

Popular misconceptions about hydrogen also need to be dispelled. People in the bus depot will not have come in to contact with hydrogen before so may well have deep held beliefs about its safety possibly and understandably from incidents such as the Hindenburg disaster. These perceptions should not just be dismissed out of hand but explained and the reality of today's situation re-enforced.

9.0 Mitigations and Depot Conversions

When a transit operator takes the decision to run FCEBs, they are unlikely to have any experience or knowledge on the safety requirements that may be necessary. To determine the scope of the changes required for a workshop that will start to maintain hydrogen FCEBs it would be recommended that transit agencies consult and advice with a reputable safety consultant, professional building contractor and the local regulators.

It must be remembered that any equipment that is used in the workshop must be subject to regular inspection and calibration. The following mitigations are what the transit operator must think about when taking on FCEBs for the first time.

9.1 Facility Roofline

One of the main properties of hydrogen that has to be addressed in a hydrogen vehicle maintenance workshop is that hydrogen will rise and could get trapped and pool in the ceiling area of the workshop. By having sloping ceilings, it can be easier to predict where a hydrogen cloud could develop, and venting can be installed in this area to exhaust any hydrogen to the outside.

9.2 Working at Height

Often the hydrogen components on a single deck hydrogen FCEB are located on the roof, as seen in Figure 1. Regular access to the roof of the bus will be required for inspection and maintenance, so a mechanism for safe working at height must be installed in the depot.

It must also be considered that there is a requirement to remove and/or replace heavy components that are located on the roof of the bus. Therefore, a hoist must be installed to enable this to happen.

9.3 Venting or Air Changes

Venting will allow any hydrogen present in a workshop to escape to outside the building. Permanent vents can be installed to allow a constant escape route for hydrogen; however, this may not be practical if heating of the workshop is compromised. Fans could be used that activate at a certain concentration of hydrogen. Also, a regime of air changes can minimise the potential build-up of any released hydrogen gas.

9.4 Electrical Equipment

All electrical equipment must be classified to the local standard for hazardous locations. Care must also be taken into the type of heating equipment that is employed and generally overhead heating is not suitable.

A grounding system for the hydrogen FCEB should be in place before work is undertaken on the bus, a simple and quick procedure to stop a static spark.

9.5 Hot Works

As a general rule, hot works, such as welding and grinding, should not be carried out on a hydrogen FCEB , or in the workshop in the hydrogen zone. If there is an instance where hot work needs to be undertaken on the bus a full risk assessment must be carried out and hydrogen must be purged from the system.

9 .6 Defuelling System

There may be a requirement in certain maintenance procedures for the bus to be removed of hydrogen. All buses will have a method of defuelling, but the depot must have a process to undertake this safely in order not to release hydrogen into the workshop. The hydrogen can either be defuelled into a suitable storage vessel to use at a later date or vented to atmosphere. If the hydrogen is vented to atmosphere there must be a suitable ‘vent pipe’ to exhaust the hydrogen safely outside of the building.

Alternatively, venting can happen outside, but it must be sure that there are no ignition sources nearby. Furthermore, weather conditions may cause a delay in the process taking place.

9.7 Gas Detection System

A hydrogen gas detection system must be installed in the workshop to give an early warning if there is a leak of hydrogen. Sensors must be positioned in places where it is likely for hydrogen to gather. Normally a two-stage alarm will be employed to give a lower warning that may trigger some urgent action followed by a second stage alarm where full evacuation and venting must take place. It must be ensured that the hydrogen gas detection system is tested and calibrated at regular intervals.

9.8 Training

It must be certain that technicians working on hydrogen FCEB have the relevant training to ensure that they work in a safe manner. A generic understanding of hydrogen must be undertaken, but also manufacturer's training on specific elements of the FCEB.

However, on a bus there are many systems that are not related to hydrogen, for example the doors. The technician that undertakes the maintenance on this element may only require an induction to the hydrogen and fuel cell technology in order to understand that there are extra safety requirements in the workshop that needs to be taken into consideration when working with a FCEB and also what the limits of the maintenance are.

9.9 Personal Protective Equipment

Personal protective equipment (PPE) should be issued to all staff working on the FCEBs. What PPE is required will depend heavily on the risk assessment on working in the FCEB vicinity and potentially the task that is being carried out. Personal hydrogen detectors can be a useful addition to PPE when working on a FCEB. They are small and re-assuring that no hydrogen is near the technician. A person detector could give an early warning to a bigger issue developing in the workshop as a whole.

9.10 Bus Wash

The bus wash is used daily and can have aggressive brushes. It must be considered that the FCEB may have sensitive components on the roof of the bus so a full risk assessment must be made on the use of the wash. It may require manufacturer's input on whether the wash is suitable.

9.11 Extinguishing Equipment

On the bus, the hydrogen is contained within the fuel storage systems, so any escape of hydrogen is accidental. If there is a slow undetected leak the hydrogen could get trapped and form a cloud, if there would be a rapid leak due to the high pressure. So, there are three types of incident involving hydrogen and fire that could occur in a FCEB workshop, detonation, deflagration occurring from the ignition of a hydrogen cloud or a jet flame occurring from a high pressure release.

9.11.1 Detonation or Deflagration

If the hydrogen detection system has sensors in the most likely area where hydrogen can pool and create a cloud, there should be an early warning to staff before a detonation of deflagration can occur. Once happened, a detonation or deflagration could lead to secondary fires.

As a detonation or deflagration is a sudden event, the only effective extinguishing mitigation would be an inert gas. However, in a workshop environment this would be difficult due to the volume of inerting gas required and the potential of asphyxiation if technicians were in the workshop and the system activated.

9.11.2 Jet Flame

A jet flame will form if a hydrogen release of high pressure is ignited. The length of the flame will vary dependent on the aperture size and pressure that is being released. From a 35MPa system on a bus, although unlikely, the potential jet flame length could be up to 10metres. To extinguish a jet flame is almost impossible and the jet flame will self-extinguish when the fuel, hydrogen, is depleted. Attempting to manually extinguish using traditional firefighting equipment would be futile and dangerous.

9.12 Evacuation

A robust evacuation process must be put in place in the event of a hydrogen detection, or suspicion of an issue with the hydrogen integrity on the FCEB. The best way to keep personnel safe is to remove them from the workshop to a safe, pre-defined, distance.

Any evacuation process should be practiced at regular intervals to ensure that the process is robust. The practice should be logged, and any required adjustments made to the process.

10.0 Processes and Documentation

Production of any processes and documentation for working on hydrogen FCEBs must be undertaken with a safety first approach. Thus, it should take the hydrogen safety into account, but not disregarding the other potential hazards associated with FCEBs. All processes and maintenance tasks must be undertaken with the manufacturer's requirements implemented.

10.1 Risk Assessment

Risk assessment is a powerful tool to mitigate against hazards in the workshop. Bus workshops should be familiar with risk assessment, but they may not possess the expertise required to fully assess the new hazards that are in the fuel cell workshop. A consultant maybe required to undertake the risk assessment; however, it is highly important that the consultant has an extensive knowledge about hydrogen and the understanding of how hydrogen behaves in a vehicle workshop environment. Thus, this could be very different to how hydrogen behaves and should be handled in another industrial environment. Currently it would be rare that a consultant on hydrogen safety would also have knowledge on bus maintenance so a member of the depot team should also undertake the risk assessment. It may also be required to draw on the experience of the FCEB manufacturer who will be able to assist greatly in the risk assessment process.

The related hazards of a hydrogen FCEB , high pressure and high voltage, must also be assessed. If a bus depot already has BEBs or diesel hybrid buses, they should already be familiar of the risks associated with high voltage. If not, a specialist consultant may again have to be brought in, as mentioned above.

Figure 4

The hazards associated with the high pressure of the hydrogen storage system maybe unknown in a bus depot, however there may be some experience of compressed natural gas (CNG) storage on buses where the mitigation would be similar.

CNG buses have a similar high pressure storage systems on the bus and a leak of this systems could also lead to a detonation, deflagration or jet flame similar to a hydrogen storage system.

CNG buses have been used in many countries for a number of years so there have been a number of well publicised incidents with these buses, including with the storage system. Lessons learn from CNG bus incidents in the past can be analysed and appropriate mitigation inserted in to risk assessments undertaken for the hydrogen bus workshop.

It must be noted that a CNG bus is an internal combustion engine (ICE), so hazards associated with high voltage are not applicable and so there are no learnings.

A hydrogen consultant will often also understand the high pressure component. As a risk assessment is a live document that should be continually reviewed, there should be some expertise developed within the depot so that action can be taken immediately to reassess the risk assessment if required.

The five basic steps of the risk assessment, shown in Figure 4, must be reinforced to the depot management and staff to ensure that the process is ongoing through the life of the buses.

10.2 Depot Processes

Having good maintenance processes is one of the most powerful tools that you have to keep the work environment safe. Depot processes must be developed alongside the risk assessment to make sure that the two are not contradictory. If the work processes are onerous and cumbersome then shortcuts are likely to be taken that can lead to an incident with the hydrogen. When producing work processes, it must be ensured that they comply with any safety requirements, are in line with the manufacturer's processes and are simple to follow. It is good practice to develop the processes with the technicians that are going to carry them out. This will ensure that the process has the 'buy in' of the personnel that will be using them, and it will mean that an efficient process is written. Processes as with all documentation must be constantly reviewed and updated when necessary.

10.3 Personnel

Safety is heavily dependent on the personnel that are involved. It is vital that the personnel are trustworthy and thorough, as they will be carrying out operations on the FCEB. Although familiar with the basic hydrogen safety, it is likely that the supervisory staff may know less about a FCEB than the operatives working in it.

10.4 Keep Practical

As stated in 10.2 above, when establishing risk assessments and appertaining documentation it is very important that it is simple, easy to understand and comprehend and also practical to carry out within the confines of maintaining a bus. If processes or risk assessments are over onerous, it is likely that short cuts will be taken rending all the safety assessments irrelevant. It is therefore vital that when putting together depot processes and undertaking risk assessments, professionals who understand both the maintenance of a bus and the assessment of a hazardous area is involved in the process and establishment.

11.0 Conclusion

Hydrogen FCEB are starting to become mainstream as one of the options for zero-emission heavy duty transport. While the vehicle itself and the fuelling infrastructure is focused on in the early stages of adoption, an element that is often not mentioned is the maintenance of the FCEB.

Safety is at the core of any bus depot operation, but there is no reason to assume that there would be any experience in the safety around hydrogen and the maintenance of FCEBs. Following simple guidelines, a safety system can be set up to make the maintenance of FCEBs safe and practical within the existing bus depot environment.

Particular attention must be paid to risk assessment, and it must be ensured that professionals with the correct experience are involved in writing processes.

To get a successful safe maintenance regime when setting up a workshop in a depot for hydrogen fuel cell electric buses, there are three things to keep in mind:

1. Keep it simple.
2. Remember the audience.
3. Focus on the relevant hydrogen properties.

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