D-5149-2023

Hydrogen – making tomorrow's mobility safe on road and rail

Using renewable energy sources is a given for a cleaner future, with hydrogen seen as a game-changer. One of its uses is to decarbonise the transportation and heavy-duty vehicle sectors. For the large-scale deployment and use of hydrogen, its safety issues and how to manage them must be addressed.

Dräger

Technology for Life

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Hydrogen for transport and trucking

Hydrogen is emerging as a critical energy source in mobility, particularly for heavy-duty vehicles such as trucks, buses, commercial and utility vehicles, and trains. Unlike traditional fossil fuels, hydrogen offers a clean and sustainable alternative, producing only water vapour as a byproduct when used in fuel cells. This makes it an attractive option for reducing greenhouse gas emissions and combating climate change.

Heavy-duty vehicles, which are responsible for a significant portion of transportation-related emissions, present unique challenges for electrification. Their size, weight, and the long distances they often travel require power solutions that can provide high energy density and quick refuelling times. Hydrogen fuel cells meet these needs, offering longer ranges, less weight, and faster refuelling than battery-electric vehicles, making them particularly suitable for applications where downtime is costly, such as freight transport and public transit. Advances in fuel cell technology have enabled the use of hydrogen in the heavy-duty sector, making hydrogen-powered vehicles more efficient and reliable.

Infrastructure development remains a key challenge, with the need for widespread hydrogen refuelling stations and scalable hydrogen production facilities. However, governments and private companies increasingly invest in hydrogen infrastructure, recognising its potential to decarbonise transportation.

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As technology and infrastructure continue to evolve, hydrogen is poised to play a pivotal role in the future of mobility, particularly in sectors where electrification alone may not suffice, offering a path to cleaner, more sustainable heavy-duty transportation.

Specific challenges for the mobility sector

Making hydrogen applicable for road and rail mobility also means making it available at refuelling stations. Hydrogen's unique properties—such as its high flammability, wide explosive concentration range, and low ignition energy—demand rigorous safety measures during transport and when handling and maintaining hydrogen vehicles in indoor workshops.

One of the primary concerns is the risk of leaks. Hydrogen molecules are so small that they can permeate through materials typically impermeable to other gases, leading to undetected leaks. When hydrogen escapes from leaks in pipes or joints and comes into contact with oxygen, it creates a highly flammable gas-air mixture. Because of the low ingition energy required, even a static spark on clothing can be enough to cause an explosion. The risk of explosion is even more significant in workshop areas where vehicles that have been involved in accidents or require maintenance are brought and where sparks are produced during welding or angle grinding. A main safety challenge for workshops and refuelling stations is that hydrogen can form explosive gas clouds under roofs or in dispensers. Investing in upgrading maintenance bays is essential to ensure they comply with the latest safety standards.

High-pressure storage is another significant challenge. Hydrogen is often transported or stored in high-pressure containers. Depending on the degree of compression, the pressure can range from 350 to 700 bar. The integrity of these containers is critical, as any failure due to material fatigue or improper handling could result in a large-scale release of hydrogen, posing severe safety risks. The danger, however, is less from the tanks than the surrounding infrastructure. The weak spots are often at the transfer points, e.g., during loading and unloading, where manual handling is involved, or at the compressors, valves, flanges, and other necessary equipment.

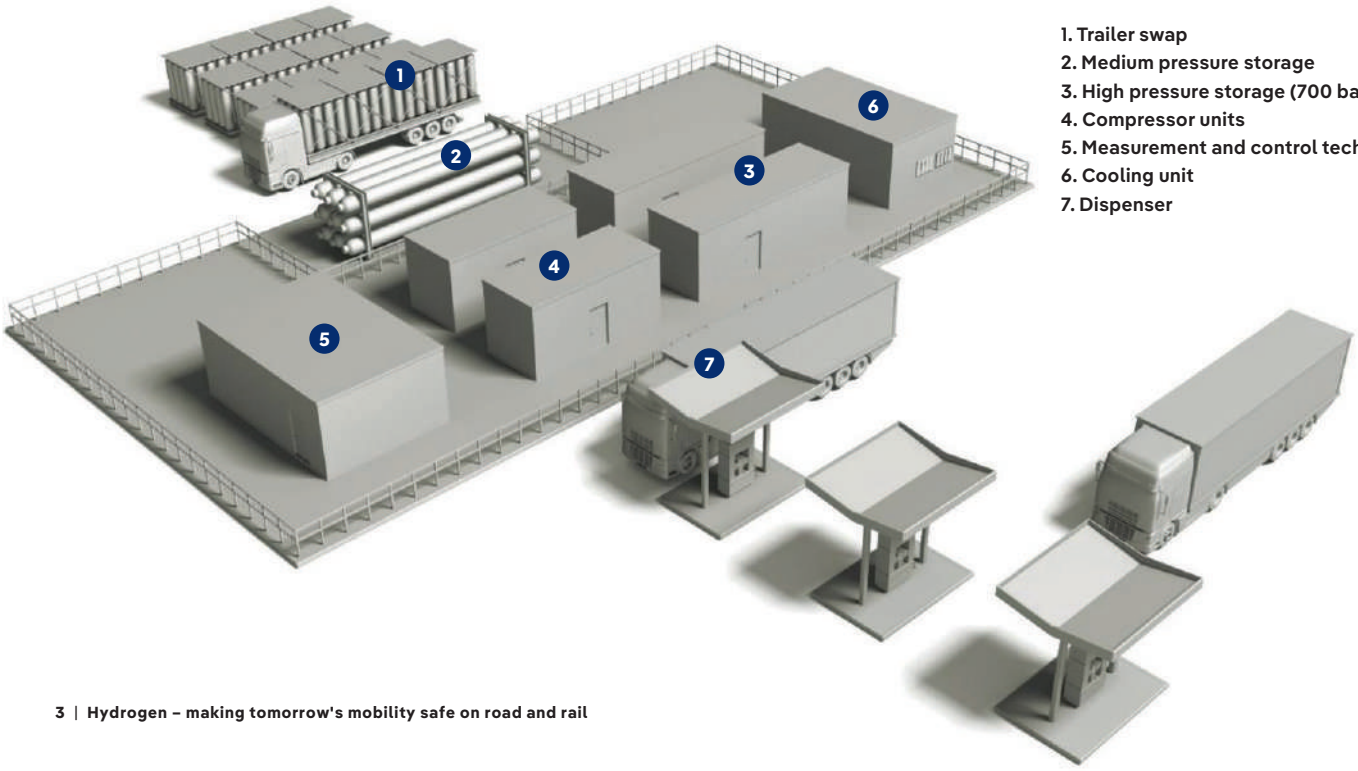
Refuelling stations themselves also require careful safety management. The process of transferring hydrogen from delivery vehicles to storage tanks must be meticulously controlled to prevent accidents such as leaks or over-pressurisation.

Additionally, refuelling and maintaining hydrogen vehicles involve specialized procedures to prevent accidents. Technicians must be well-trained in handling H_2-fueled vehicles, as hydrogen is odourless and its flames almost invisible, making leaks hard to detect without proper equipment.

Addressing these safety challenges by using appropriate safety equipment is crucial for the widespread adoption of hydrogen in transportation. Ongoing research, coupled with the development of stringent safety standards and robust infrastructure, is essential to mitigate the risks associated with the hydrogen mobility sector.

Design sample of a refuelling facility

(Compressed gaseous hydrogen)



1. Trailer swap
2. Medium pressure storage
3. High pressure storage (700 bar)
4. Compressor units
5. Measurement and control technology
6. Cooling unit
7. Dispenser

Hydrogen: Risks and safety challenges

To avoid risks, or at least to minimise them, it is necessary to know them. These characteristics make working with hydrogen challenging:

Explosive hazard

Pure hydrogen is not explosive. The danger lies in its exposure to air. Oxygen must be present for hydrogen to explode. Hydrogen requires very little energy to ignite (0.02 mJ) and can do so simply by friction between the gas and a leak surface, with a significant static impact (1 mJ). This means that if hydrogen were to be released, even a static spark from a piece of clothing would be sufficient to cause an explosion.

High flammability

Hydrogen has an extensive flammability range compared to other fuels (4%-77% volume in air). Under optimum combustion conditions (29% hydrogen/air volume ratio), the energy requirement for the ignition of hydrogen is lower than for other standard fuels. Therefore, the equipment used must be suitable for use in hazardous areas.

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Invisible flame

Hydrogen flames are very pale and, in daylight, invisible to the human eye. However, they emit a certain type of electromagnetic radiation, primarily infrared. This is why dedicated flame detectors are needed to provide reliable warnings.

Odourless

Hydrogen is not detectable by smell. Although natural gas and propane are also odourless gases, a sulphurous odorant is added to enable humans to detect them. At present, no known odorants are light enough to travel with hydrogen at the same dispersion rate. Odours can also contaminate fuel cells. This makes gas and leak detectors indispensable.

Permeation

Hydrogen molecules are tiny and easily pass through matter. Appropriate selection, handling and upkeep of all materials that come into contact with the hydrogen is crucial.

Gas pockets

Hydrogen is less dense than air. As a very light gas (57 times lighter than petrol vapour and 14 times lighter than air), it can disperse quickly, possibly before gas detectors can detect the leak. When leaks occur, gas clouds can form on indoor ceilings. This is why gas detection technology must be installed at a high level.

CO-alarms

Monitoring carbon monoxide (CO) in specific applications is also necessary. These carbon monoxide (CO) sensors are cross-sensitive to hydrogen, so that false alarms can occur. Hydrogen-compensated CO sensors mitigate this issue.

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Gas detection technologies

By being aware of the risks and dangers, it is possible to prevent them. The progression from leak to gas dispersion to ignition to potential fire or blast can be significantly reduced with multiple layers of detection. Due to the properties mentioned above of H_2, a combination of different technologies is recommended.

Ultrasonic gas leak detection (UGLD): This advanced technology with ultrasonic acoustic sensors provides early warning in outdoor industrial process environments. Unlike conventional gas detectors, it responds faster by detecting the acoustic ultrasound of leaking gas, not the concentration of accumulated gas clouds. This unique feature allows it to instantly detect leaks over a large area, regardless of wind direction, making it ideal for outdoor hydrogen installations. It is not sensitive to gas dilution or wind direction, rain or other ambient conditions and can detect early leaks of compressed hydrogen and methane-hydrogen mixes in compressor stations.

Conventional catalytic point gas detectors: These detectors, equipped with catalytic bead sensors, are designed to monitor lower explosive limits (LEL). They can detect and measure combustible gases such as hydrogen within a few seconds, showing long endurance under the influence of poisonous substances. Approved for temperatures up to 302°F/150°C, they can detect very low gas concentrations from 0-10% LEL, making them a reliable choice for industrial safety.

Selective point gas detection with electrochemical sensors: These highly sensitive devices detect ppm concentrations and are selective to hydrogen or other gases – for example, oxygen, which may also be present in such processes.

Hydrogen flame detection: Because hydrogen flames have unique characteristics, the most suitable sensor technology can detect their radiation frequencies early and reliably. Flame detectors with triple IR sensors specially designed for hydrogen flames offer very high immunity to false alarms caused by sources of interference such as welding, hot CO_2 emissions or other fire sources. This is achieved by ensuring that only a unique relationship between the IR emissions picked up by the three sensors triggers an alarm, making it more effective and reliable than the typical UV/IR hydrogen flame detector and offering greater detection range and coverage. Ruggedness and resistance to weather conditions, such as ice fog or rain, are also critical.

Dräger offers a full range of fixed gas detection technologies designed for the specific and continuous monitoring and detection of highly flammable gases and vapours, such as hydrogen. Dräger solutions are specialized for the application and situation of individual facilities, resulting in significantly lowered risk and reliable safety solutions for your workers and your property.

Fire and Gas Detection Systems

Hydrogen gas leaks can occur in various parts of a hydrogen facility. With regard to fire and gas detection in the mobility and transportation sector, the focus is on hydrogen refuelling stations, garages, vehicle service centres, and repair shops.

A professional plant safety system relies on a thorough risk assessment, supported by selecting, deploying, and maintaining suitable gas detection technology. While standards apply, individual site assessments are crucial to determine local conditions, such as ceiling construction, ventilation, and potential valve leak points. Other conditions, such as weather and dispersion possibilities, also play a role. This systematic approach is crucial for determining the optimal number and position of gas and flame detectors. Each technology offers different properties and coverage, so an intelligent combination of gas detection devices is necessary. Countermeasures can only be initiated if sensors detect gas leaks or accumulations early. This comprehensive process can include consultation, design, management, and gas mapping services.

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Ultrasonic gas leak detectors have a large area of coverage, combined with high-speed detection of gas leaks. Therefore, they are generally installed centrally to cover the potential leakage area. The area they cover depends on the expected ultrasonic sound level, spatial conditions, and any obstructions, such as high columns. Other ambient noise does not affect the performance of the detectors. Small leaks at very high pressure, such as in tanks used in the refuelling process, will produce increased levels of ultrasonic noise. Depending on the plant layout, distances up to 20 meters can be covered.

Flame detectors identify and respond to flame by sensing radiation emissions. They can cover a roughly 90° cone-shaped area of up to 40 meters distance. They should clearly view all critical parts where hydrogen flames may occur. The number and positioning of the flame detectors depend on the specific layout of the facility. Ideally, the whole area should be monitored to make sure that blind spots are avoided. Integrated into a control and monitoring system, they trigger safety mechanisms to prevent fire-related hazards.

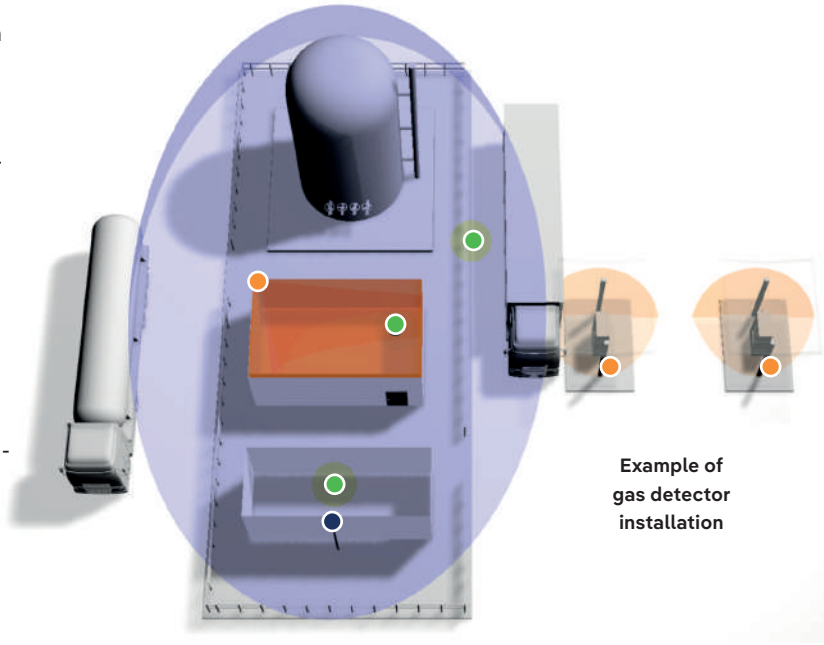
Point gas detectors measure the concentration of a gas at the LEL or ppm level. These devices tend to be sensitive to environmental conditions such as wind or rain and are, therefore, most commonly used indoors or in enclosed areas. As hydrogen is very light, dangerous concentrations can build up on ceilings. Point gas detectors should be used to monitor specific areas where, following a thorough risk analysis and gas mapping, the likelihood of hydrogen gas pockets is highest. In these areas, they should be installed high up. Correct sensor placement is one of the critical safety issues.

Monitoring gas concentrations in large or complex areas, such as high-ceilinged halls, can be challenging, especially if transmitters are installed in hard-to-reach locations or spread over long distances. Centralising data from multiple detectors in different locations offers a significant advantage. It allows real-time monitoring of critical points and ensures that potential hazards are quickly identified. Control systems help maintain safety by providing a clear overview and central access to all diagnostic information in the event of an alarm or fault.

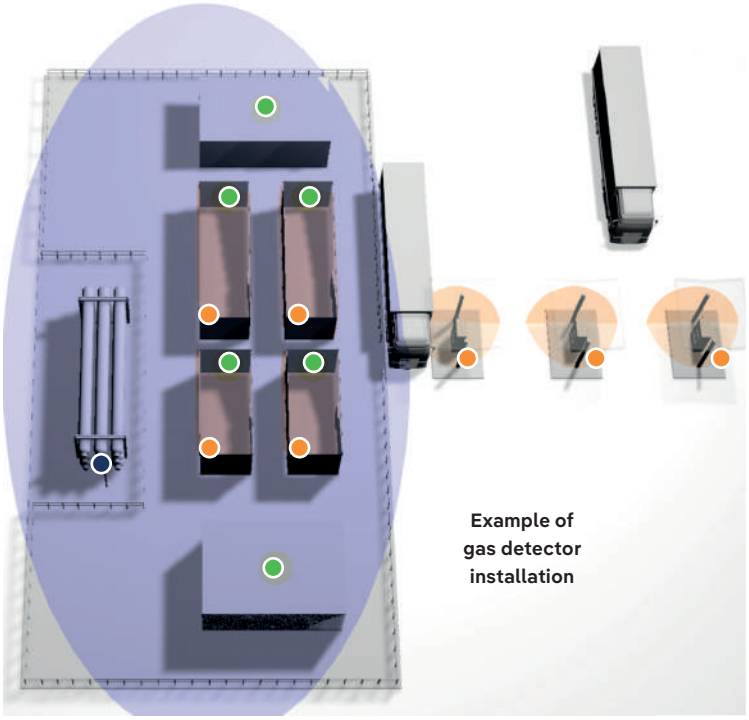
Safety solutions – monitoring of refuelling facilities

A standard hydrogen refuelling station includes hydrogen storage tanks, hydrogen gas compressors, a pre-cooling system and a hydrogen dispenser delivering H_2 at a pressure of 350 bar or 700 bar, whichever is required for the vehicle being refuelled. The various closed hydrogen-carrying components are often classified as ATEX Zone 2.

There are usually three different ways of obtaining the gas: Either hydrogen is produced on-site or delivered as gaseous or liquid hydrogen via pipeline or transported by trucks. For short distances, it is often supplied as gas, as the requirements for tanks transporting liquid hydrogen are high. Over longer distances, liquid hydrogen is used due to its higher energy density. The following safety measures must be observed at hydrogen refuelling stations.



Example of gas detector installation



Example of gas detector installation

Measures to mitigate risks for H_2 refuelling stations:

- Monitoring compressor units and enclosed spaces by using catalytic bead sensors
- Monitoring hydrogen-carrying containers or closed rooms that work with pressure and with the danger of H_2 leakages to be ignited, e.g. cryopump room by using flame detectors. (Monitoring of cold rooms or analysis rooms is not necessary.) A flame detector can be implemented into a fire alarm system that will initiate countermeasures.
- Monitoring of the tank columns (dispensers) by equipping the fuel dispenser with sensors for leak detection and interrupting the hydrogen flow if a leak is detected.
- Area monitoring with ultrasonic leak detectors for an early warning independent of wind and weather conditions.

In addition, as with vehicle electrification, firefighters and first responders must be trained to respond to incidents involving hydrogen fuel cell vehicles and refuelling stations.

Dräger detection systems and devices (selection):

D-9493-2022

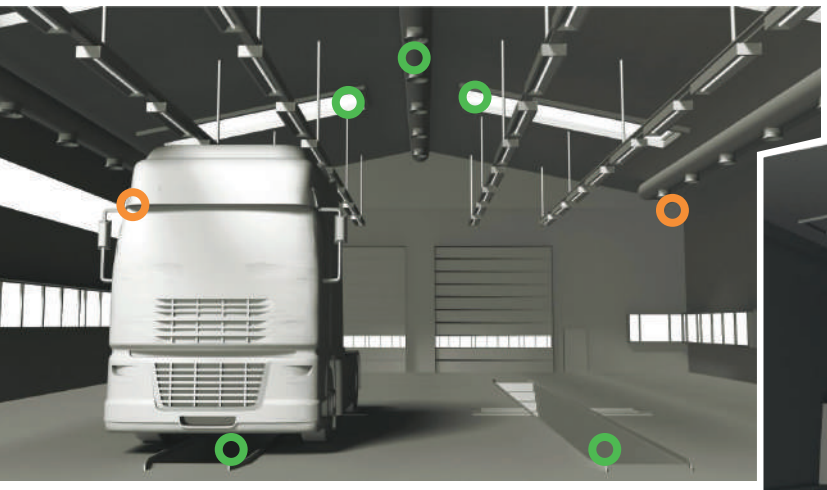
Dräger Flame 1750 H_2
With its triple IR sensor the Dräger Flame 1750 detects hydrogen-based fires.

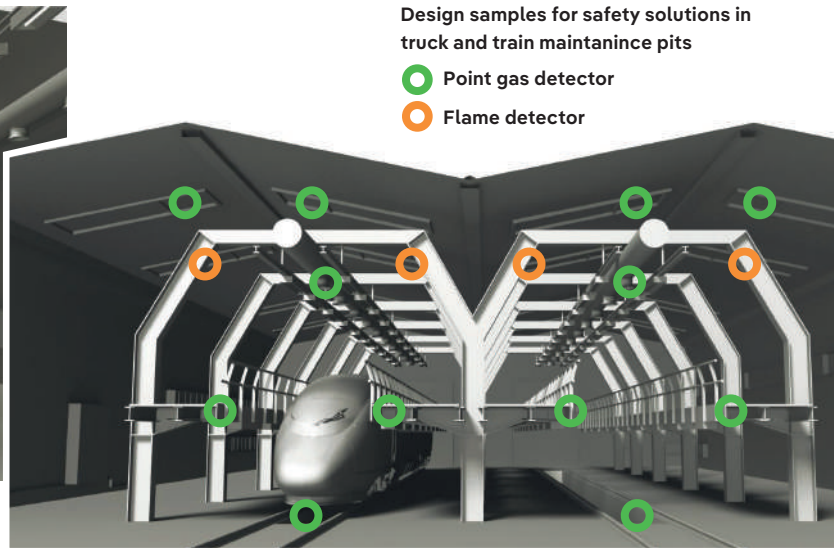
D-797-2016

The Dräger Polytron® 8200 CAT
is an advanced explosion-proof transmitter for the detection of flammable gases in the lower explosion limit (LEL).

D-5541-2018

The Dräger Polytron® 8900 UGLD
transmitter is an early warning area monitor for detecting high-pressure gas leaks in outdoor applications.





Design samples for safety solutions in truck and train maintanince pits

Point gas detector

Flame detector

Safety solutions – monitoring of truck and train maintenance pits

Although fuel cells in H_2-powered vehicles are normally constructed as intrinsically safe they could be damaged, e.g. due to an accident that was not reported or did not cause visible damage. Also, human failure, such as open valves or tanks that were not emptied properly, can lead to critical situations and emphasize the importance of a second safety layer. This additional layer of protection can also be beneficial for insurance.

H_2 Fuel Cell Electric Vehicles, especially for transport and heavy-duty, are often added to the existing fleet, including diesel or natural gas-powered vehicles. Besides fuels, other combustible substances such as brake fluid, bioethanol, or acetylene are used, handled at the workplace, and stored in separate storage rooms and hazardous goods cabinets. Therefore, the existing safety concept has to be reviewed and extended according to the new hydrogen safety challenges. Protective measures will be defined based on individual risk analysis. However, the following safety solutions are generally suitable for service centres dealing with H_2-vehicles.

Measures to mitigate risks for hydrogen truck and train workshops

Before driving into the hall, it should be ensured that no hydrogen escapes, for example in the case of poor vehicle condition, unknown origin, or mechanical damage of unknown extent. Cavities of a vehicle that can be reached without dismantling, e.g., the engine compartment, interior, wheel arches, luggage compartment, tank feed, should be tested for hydrogen leaks with an H_2-sensor.

Inside a hall, the safety concept considers fixed gas detectors for explosion protection.

- Depending on the relevant monitoring association, an Ex-area of up to 2 m around H_2-carrying parts is designated for vehicle repairs.
- Catalytic bead sensors are installed in the roof area at its highest point and in the skylights/dome lights, where gas pockets are likely. These must be laid out in Ex-design.
- Catalytic bead sensors are also positioned around the train at the roof workstations. Electrical consumers such as lights, driving signals, or other things are mounted on the roof work stands. These can extend into the hazardous area, thus the equipment has to be Ex-certified according to the declared zones.
- According to the safety concept, the gas detectors can be connected to a control unit that triggers countermeasures as soon as an alarm threshold is reached. Typical countermeasures are switching on ventilation systems, opening windows in the roof at indoor ceilings, and switching off electrical consumption. Acoustic alarms are triggered inside, whereas optical alarms are triggered also outside. Alarm devices are also typically triggered at this point, raising awareness among operators in the area.
- The entire room (at least four corners) should be monitored using flame detectors for fire detection. Flame detectors can be implemented into a fire alarm system that will initiate countermeasures.

Mobile gas detection

Portable Gas Detectors are used for personal air monitoring to detect explosive atmospheres in the immediate surroundings when working in areas where hydrogen leakages are likely to occur. A second important application for portable gas detectors is leak detection and localization. Some gas detectors can also be used to locate hydrogen leaks with the help of pumps and probe rods. Hydrogen's lower explosion limit (LEL) is just 4 Vol.-%, so gas detection equipment must meet the highest standards (explosion group IIC).

Catalytic bead sensors, which trigger an A1-alarm typically at 10% of the LEL, are recommended for warning of hydrogen concentrations. These sensors must be tested and calibrated with H_2, as no alternative test gases are available.

Electrochemical sensors, which can take measurements in the parts per million (ppm) range, are used to determine the exact concentration of hydrogen in order to detect any leaks.

Smart data management with digital records
Today, with more compliance requirements in place, industrial facilities must maintain detailed records of gas values and alarms to prove that they adhere to applicable safety standards. With smart safety solutions, records can be made available more quickly during audits and offer valuable insights, which lead to higher efficiency and improved safety.

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Ask an expert – be prepared!

As a specialist with decades of experience in safety and gas detection, Dräger offers integrated solutions ranging from consulting, designing, realising, and implementing fire and gas detection systems to system maintenance ensuring compliance with regulations and appropriate safety measures. When it comes to workplace safety, Dräger offers the full range of personal air monitoring devices and personal protection equipment needed to keep every employee safe. Dräger's technical trainers provide comprehensive instruction and training, either on-site or at our training facilities.

The key to working intelligently and safely with hydrogen is choosing the most suitable detection solutions, safety measures, and best practice approaches.

For more information on Dräger consulting services and safety services, visit www.draeger.com/hydrogensafety

Corporate Headquarters
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany

www.draeger.com

Region Europe
Dräger Safety AG & Co. KGaA
Revalstraße 1
23560 Lübeck, Germany
+49 451 882 0
+49 451 882 2080
info@draeger.com

Region Middle East, Africa
Dräger Safety AG & Co. KGaA
Branch Office
P.O. Box 505108
Dubai, United Arab Emirates
+971 4 4294 600
+971 4 4294 699
contactuae@draeger.com

Region Asia Pacific
Draeger Singapore Pte. Ltd.
61 Science Park Road
The Galen #04-01
Singapore 117525
+65 6872 9288
+65 6259 0398

Region Central and South America
Dräger Indústria e Comércio Ltda.
Al. Pucurui - 51 - Tamboré
06460-100 - Barueri - São Paulo
+55 (11) 4689-4900
relacionamento@draeger.com

Locate your Regional Sales Representative at:
www.draeger.com/contact

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