Combustible Gas and its Detection

blacklinesafety

Version 1.0 | 20 Jul 2020

ABOUT BLACKLINE SAFETY

Blackline Safety is a global safety technology leader. We provide comprehensive live monitoring and wireless gas detection to help teams working in hazardous environments respond to emergencies in real-time and manage efficient evacuations. Our talented team of designers and engineers create and manufacture everything in-house, from wearable technology and personal gas detectors to cloud-hosted infrastructure and web-based interfaces for the global industry.

We have created the world's first turnkey, work-anywhere safety monitoring solution that offers 3G wireless, remote gas detection, a two-way speakerphone and live monitoring to meet the demanding safety challenges of organizations in over 100 countries. Our vision is to become the leading supplier of wireless gas detection products in the world, and to that end, we offer the broadest and most complete portfolio in the industry.

blacklinesafety

CONTENTS

INTRODUCTION

Numerous industrial processes introduce the risk of the release of combustible gases. This is one of the greatest risks an industrial facility can face. When combustible gases are released on an industrial site, the resulting events can include asphyxiation, fires, and explosions. In extreme cases, these events can even affect the public through direct exposure to a fire or explosion, or through indirect effects such as restricted supplies of essential products like gasoline.

In industries with a risk of exposure to combustible gases, workers are required to utilize devices that provide early warning of a potential gas exposure and allow them to evacuate to safety before levels become unsafe. This is a key component of a robust industrial safety program.

COMBUSTIBLE Gas Basics

Combustible gases are those which will burn when mixed with oxygen at sufficient concentrations. In this section, we will cover the basics of combustible gases, such as the elements required for a fire to burn, and the different ways that combustible gases can be measured.

THE FIRE TRIANGLE

For a fire to burn, there are three necessary elements: heat, fuel, and oxygen. Fire can only occur when all three elements are present at the right levels. Removing one element of the fire triangle eliminates the risk of a fire. Combustible gases are the fuel in the fire triangle, but without the introduction of heat and oxygen, there is no possibility of a fire.

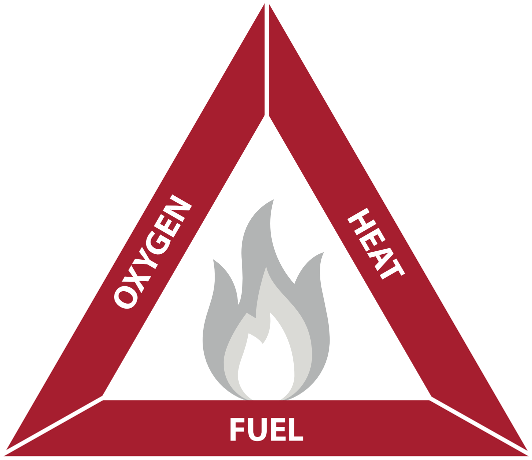


Figure 1: The fire triangle, which identifies the three necessary elements for a fire to burn.

COMBUSTIBLE GAS IDENTIFIERS

Common Name A unique name that unambiguously identifies that compound. Common names are not required to follow a specific structure and there are several compounds with similar common names.

CAS Number A unique identifier assigned to every known chemical compound by the Chemical Abstracts Service (CAS). Identifying a compound by its CAS number ensures that you are matching the gas to the properties you are looking for, especially when there are similar common names.

Chemical Formula Identifies the number of atoms of each element in a compound. This can be useful as a quick reference to help determine the other properties of the gas.

Table 1: Example of each type of combustible gas identifier.

Common name	Methane
CAS number	74-82-8
Chemical formula	CH_4

blacklinesafety

UNITS OF MEASURE

How combustible gas levels are measured depends on the application. Generally, there are three key measurements that can be applied:

- Percent Lower Explosive Limit (%LEL)
- Upper Explosive Limit (UEL)
- Volume per Volume (%v/v)

These measurements will vary depending on temperature, pressure and oxygen levels. Published limits apply at 25°C, in normal atmospheric conditions and pressure.

Lower Explosive Limit (%LEL) For the day-to-day safety of workers on a site, the lower explosive limit (LEL) of a gas is the primary concern. When the LEL is reached, there is enough fuel present for the gas to ignite. Therefore, it is important that the worker receive notification of the presence of the gas before the LEL is reached. LEL is measured as a percentage. 0%LEL is fresh air, without any combustible gas present. 100%LEL is when the lower explosive limit has been reached and a fire or explosion is possible.

Personal gas monitors should be configured to provide an alarm warning the user of the presence of the gas at 10%LEL. At 20%LEL, this should escalate to an alert that signals evacuation. This early warning allows for any inaccuracy in readings, as well as providing time for the worker to evacuate before the gas levels build up enough to cause a fire or explosion.

Percentage of the lower explosive limit is the universal language for measuring the combustibility of a gas. It is the primary measurement of gas levels that will be used throughout the remainder of this book.

Volume Per Volume (%v/v) The %v/v is a pure measurement of the percentage of a combustible gas in the atmosphere. Each gas is explosive at different %v/v levels, which also varies according the level of oxygen in the atmosphere.

Upper Explosive Limit (UEL) In some specific cases, it is necessary to monitor a gas' concentration above the upper explosive limit. In these cases, the primary concern is to ensure the level of the combustible gas does not drop below the UEL. For this reason, UEL measurements are primarily made within systems to ensure there is not sufficient oxygen being introduced to allow a fire or explosion to occur.

TYPES OF COMBUSTIBLE GASES

While there are thousands of combustible gases, most industries are only concerned with a handful. In this section we will introduce three categories of combustible gases likely to be encountered by industrial workers:

- Hydrocarbon gases
- Hydrogen gas
- Other combustible gases

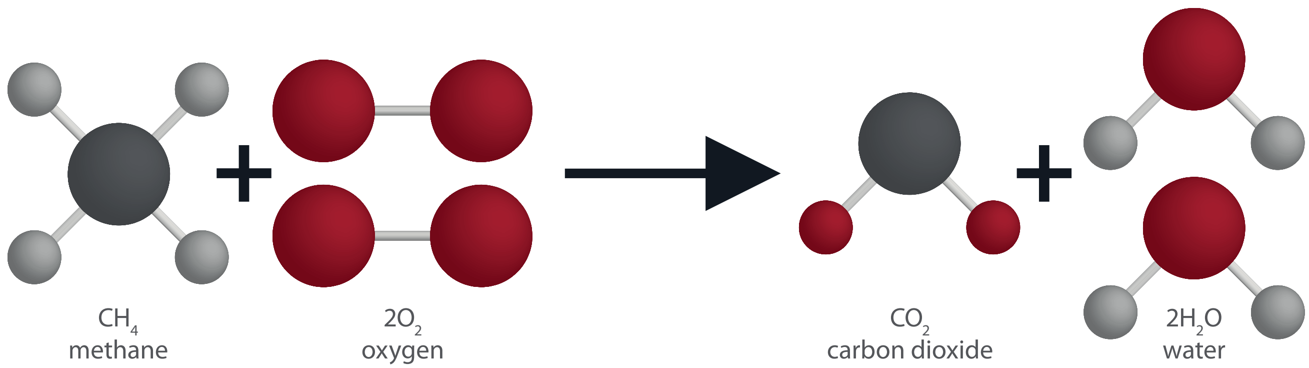


Figure 2: Molecular diagram of hydrocarbon combustion.

Hydrocarbon Gases There are many combustible gases that pose a risk to workplace safety. Most of these are hydrocarbon compounds. A hydrocarbon compound is an organic chemical compound made up of only carbon and hydrogen elements. Hydrocarbon combustion occurs when a hydrocarbon compound such as methane mixes with oxygen and is heated to sufficient temperature to cause a reaction. The heat source breaks the hydrocarbon bonds and creates carbon dioxide and water. The formation of carbon dioxide and water molecules releases energy in the form of heat.

blacklinesafety

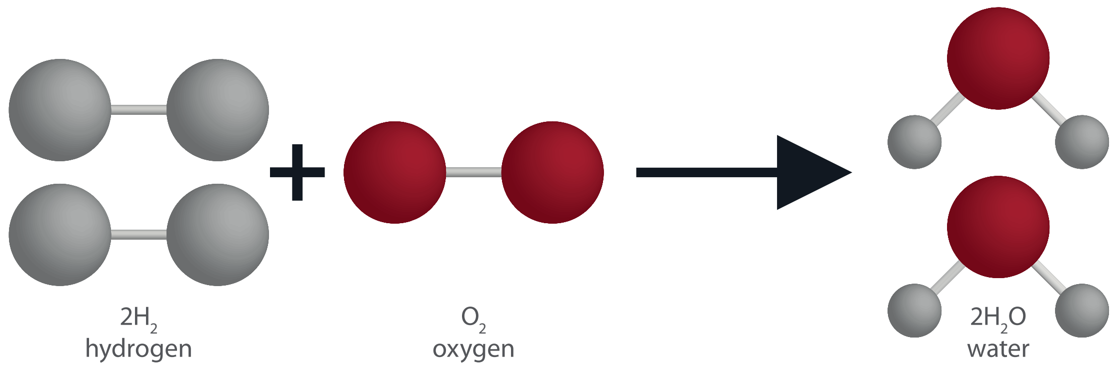


Figure 3: Molecular diagram of hydrogen combustion.

Hydrogen Gas Hydrogen combustion is similar to the reaction described on page 8 for hydrocarbon gases. The main chemical difference is that the hydrogen reaction produces only water as it has no carbon atoms available to create CO_2.

Table 2: IDLH and LEL toxicity levels of 4 key toxic gases.

	IDLH (ppm) Immediately Dangerous to Life and Health	**LEL (ppm)** Lower Explosive Limit
Ammonia (NH_3)	300	150,000
Carbon monoxide (CO)	1,200	109,000
Hydrogen cyanide (HCN)	50	54,000
Hydrogen sulphide (H_2S)	100	40,000

Other Combustible Gases Several other gases that are commonly present in industrial processes can also be flammable. Generally, the concern with these gases for worker safety is their toxicity rather than their flammability. For example, hydrogen sulfide (H_2S) is considered immediately dangerous to life and health (IDLH) at a level of 100 ppm (parts per million). It reaches combustible levels at 4%v/v concentration, or 40,000 ppm. Workers will be affected by the gas' toxicity long before there is the possibility of a fire or explosion. In some cases, a worker may be using supplied breathing air. If this is the case, monitoring for explosive levels of the gas is necessary.

PROPERTIES of Combustible Gases

While the basic principle of how combustible gases burn is nearly universal, the details of how each reacts can be significantly different. Understanding these properties assists in understanding how the detection of these gases is possible and analyzing the risks associated with each gas. In this section, we will describe six different properties of combustible gases.

FLAMMABLE RANGE

Every combustible gas has a flammable range. When the concentration of gas in the air is in this range, there is a flammable mixture and a risk of fire or explosion.

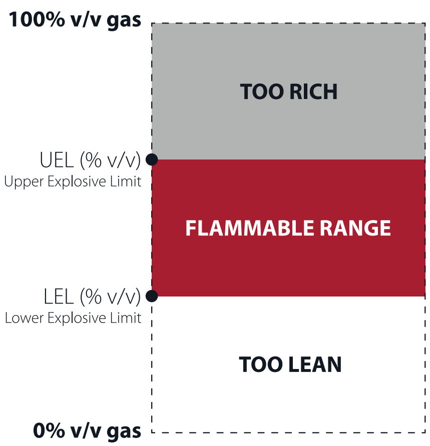
The upper level of this range is called the Upper Explosive Limit (UEL). Concentrations greater than the UEL for that gas cannot combust due to insufficient oxygen. The lower level of this range is called the Lower Explosive Limit (LEL). Concentrations less than the LEL for that gas cannot combust due to insufficient fuel. The concentration of gas is measured in volume per volume (%v/v). This is the percentage mixture of gas in the air.

It is important to understand that published limits can vary depending on the source. The United States Occupational Health and Safety Administration (OSHA) limits are described in this document. Other jurisdictions may have slightly different levels. Table 3 (right) contains examples of the flammable range for some common combustible gases.

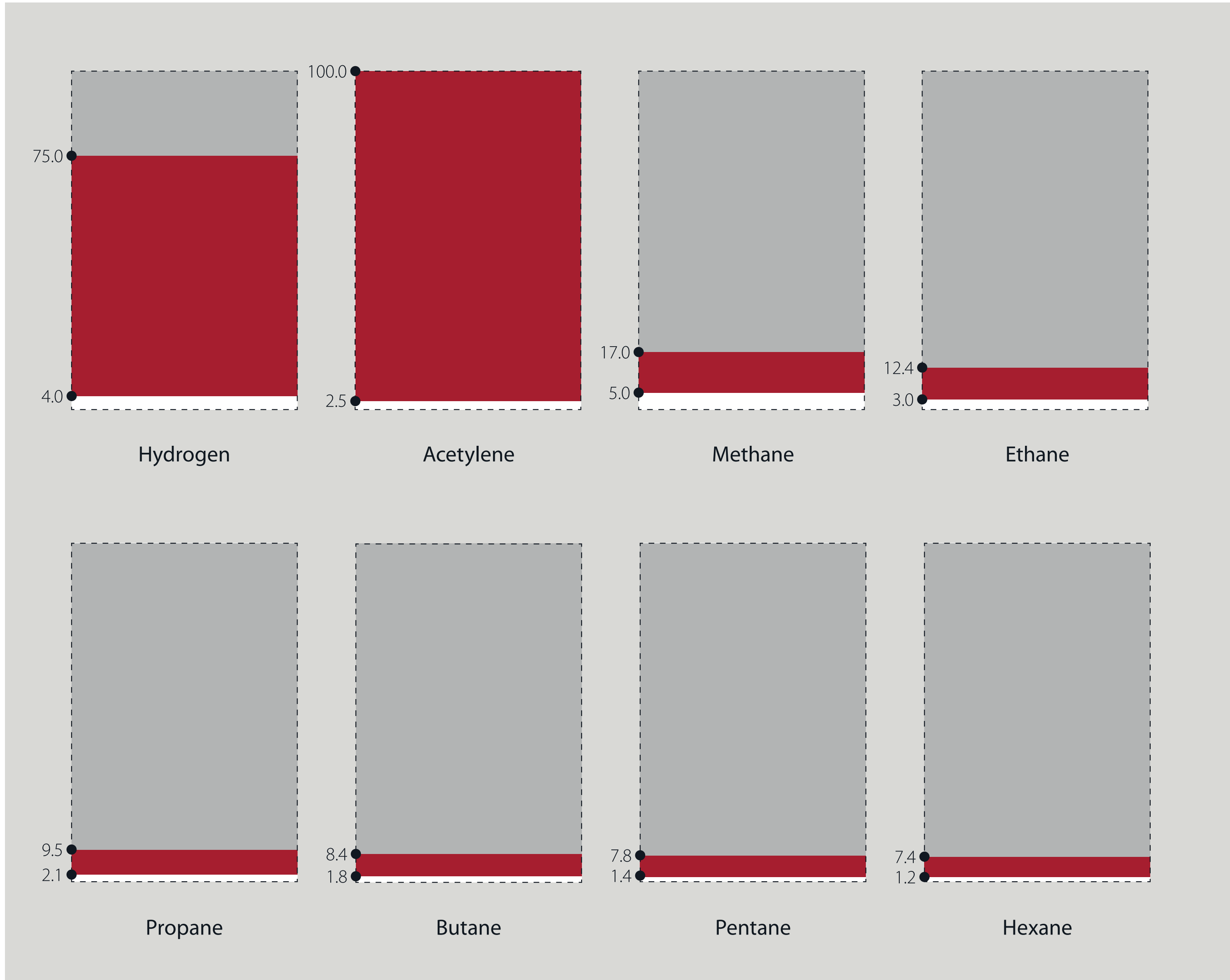
Table 3: LEL and UEL concentrations for eight key gases.

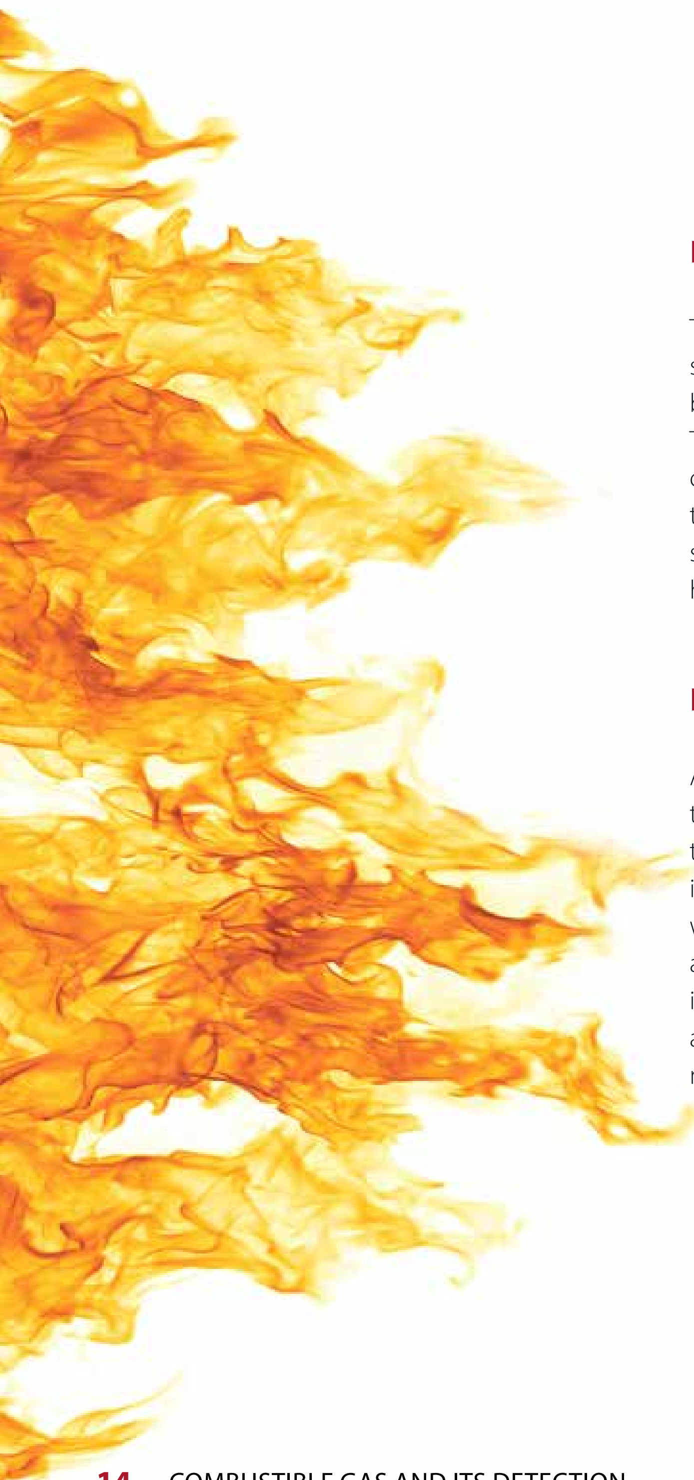
	LEL (%v/v)	UEL (%v/v)
Hydrogen	4.0	75.0
Acetylene	2.5	100.0
Methane	5.0	17.0
Ethane	3.0	12.4
Propane	2.1	9.5
Butane	1.8	8.4
Pentane	1.4	7.8
Hexane	1.2	7.4

Figure 4: Flammable ranges for eight key gases.



Legend





FLASH POINT

The lowest temperature at which a liquid's surface gives off enough vapor to be ignited by a spark or small flame is its flash point. The flash point of a combustible substance can be significantly different from its ignition temperature. Some substances remain in a gas state at all temperatures, and therefore do not have a flash point.

IGNITION TEMPERATURE

All combustible gases have a temperature at which the gas can ignite. This represents the "heat" in the fire triangle. This temperature is known as the ignition temperature. Equipment used in areas where there are flammable gases must not have a surface temperature that could exceed the ignition temperature of those gases. In addition, all equipment should be marked to indicate its maximum surface temperature or T-rating.

DENSITY

The density of any material is its mass divided by the volume containing it. In this document, density is described in kg/m^3. Density is one of the properties reported by the Molecular Property Spectrometer™ (MPS) sensor (see page 35 for more information about this sensor).

Table 4: Flash points and ignition temperatures for eight key gases.

	FLASH POINT (°C)	IGNITION TEMPERATURE (°C)
Hydrogen	Gas	560
Acetylene	-18	305
Methane	Gas	537
Ethane	Gas	472
Propane	-104	450
Butane	-83	287
Pentane	-49	260
Hexane	-22	225

MOLECULAR WEIGHT

Molecular weight is a universal measurement of the average mass of any chemical compound. It is calculated as the sum of the atomic weights of the atoms that make up the molecule. While there are several methods to express molecular weight, it will be described in g/mol in this resource. This is one of the properties reported by the Molecular Property Spectrometer™ (MPS) sensor, which we will discuss further on page 35.

RELATIVE VAPOR DENSITY

The density of a gas compared with the density of the air around it is known as its relative vapor density. Air is assigned a vapor density of 1.0. Gas that has a relative vapor density less than 1.0 will tend to rise. Gas with a relative vapor density greater than 1.0 will tend to fall. Understanding the relative vapor density of a target gas helps determine sensor placement for fixed or installed gas detection systems. The relative vapor density is also important in confined space entry. Gases with a relative vapor density below 1.0 are more likely to settle inside the confined space, increasing the likelihood of the gas concentrating enough to reach combustible levels.

However, it should be noted that the diffusion of gas in real life applications is complex. Gas leaks, for example, can be turbulent and this will affect how the gas diffuses.

Table 5: Relative vapor density for eight key gases.

	RELATIVE VAPOR DENSITY
Hydrogen	0.07
Acetylene	0.90
Methane	0.55
Ethane	1.04
Propane	1.56
Butane	2.05
Pentane	2.48
Hexane	2.97

PRINCIPLES of Combustible Gas Detection

Given the level of risk presented by combustible gases, the detection of these gases is one of the primary safety concerns of any facility which contains them. There are several goals of a gas detection monitoring program. First is to provide early warning to workers of a gas leak, activating site safety protocols to ensure workers are evacuated to a safe location when there is a leak.

The second goal is to prevent site safety events. Early detection of the presence of combustible gas and activation of safety protocols can prevent a gas leak from creating a fire or explosion on site. This section covers the basic principles of gas detection monitoring programs, such as types of gas detectors, compliance, and sensor failures.

TYPES OF GAS DETECTORS

A comprehensive gas detection program will include a mix of gas detection systems to ensure redundancy and reliability. There are three major categories of gas detectors:

- Personal gas monitors
- Area monitors
- Fixed detection monitors

Personal Gas Monitors The last line of defense against gas exposure events. Workers on a site with gas risks wear a personal gas monitor in their breathing zone to monitor the air they are being directly exposed to. When gas levels reach a predefined level, the personal monitor will alert the worker to the presence of gas. The worker must evacuate the area and seek fresh air. Connected personal monitors, like Blackline Safety's G7c and G7x wearable devices, can also have the option to provide an alert to monitoring personnel, ensuring an immediate response if the worker is overcome by gas.

Area Monitors In areas where fixed gas detection is not practical, or during temporary procedures or emergencies, area monitors are used to provide the benefits of fixed gas detection independent of the established site infrastructure. This is intended to provide early warning of a gas event to nearby workers and the public. Connectivity, battery life, durability, and ease of deployment are critical considerations when selecting an area monitor. Some common situations which require area monitoring include:

- Emergency response
- Confined space entry
- Shutdowns, turnarounds, and maintenance
- Perimeter and fence line monitoring
- Remote sites
- Construction
- Active well pads

Fixed Detection Monitors In areas with a known, ongoing risk of the presence of combustible gases, fixed detection is often the first line of defense. In these cases, a permanent sensor is placed at an appropriate location to provide early warning of a gas exposure. These sensors will operate continually and communicate with other systems on the facility to automate safety procedures such as equipment shutdown and worker evacuation.

COMPLIANCE

Every jurisdiction has its own legislation on the use, training, and maintenance of gas detection systems. Organizations in many of these jurisdictions are required to prove their compliance: that employees are using their gas detectors when required, are properly trained, and are maintaining their gas detection equipment according to legislation. This maintenance primarily takes the form of bump testing and calibration.

Bump Testing A functional check of a device's gas sensor(s). A successful bump test means that all lights, sounds and vibrations on the gas detector are working properly, and that the sensor has successfully detected the presence of gas. Even sensors that fail-to-safe can be affected by a physical blockage of the gas path, which is only detectable through a bump test. The minimum recommended frequency for bump testing is between one and thirty days.

Calibration Adjusts the measurement levels of the gas sensors by applying a known concentration of gas and adjusting the sensor outputs to match. Over time, sensor readings can drift. Calibration brings the device back to accurate readings for the gases being measured. Typically, vendors recommend calibrating combustible gas sensors with a gas containing a minimum of 18% O_2. Always follow the manufacturer recommendations for calibration gases.

SENSOR FAILURE

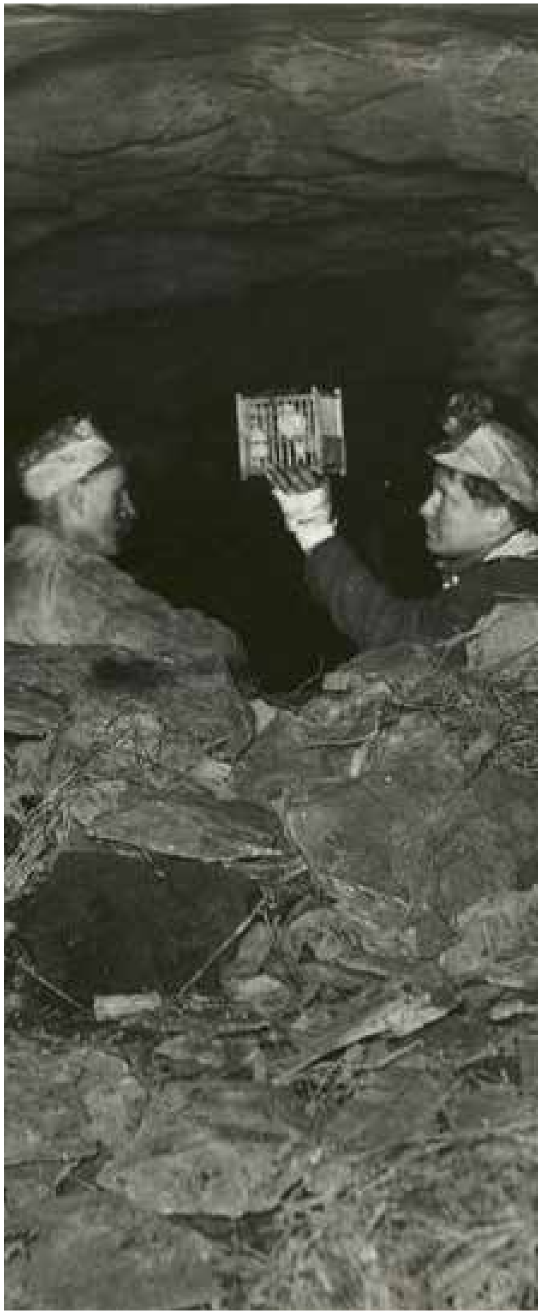
When a sensor becomes inaccurate or fails. There are several reasons a combustible gas sensor might fail or become inaccurate. Some sensors are more susceptible to certain causes of failure than others. One important factor in sensor failure is whether they fail-to-safe or fail-to-unsafe:

Fail-to-Safe The desired state for any sensor failure. Fail-to-safe means that the sensor has a built-in system to determine if it is not operating properly, allowing the device to notify the user of the fault.

Fail-to-Unsafe This means there is no method for the sensor to notify the user that it is not functioning properly. The risk in these cases is that the user continues to work, with the belief that they are still being protected.

HISTORY of Combustible Gas Detection

Over the past centuries of industrial activity, several combustible gas detection methods have been developed. Prior to the development of electronic instruments, analog methods of gas detection were used, with varying degrees of success. This section outlines key developments in the evolution of gas detection technologies.



1800s

THE DAVY LAMP

In 1815, Sir Humphry Davy developed the flame safety lamp, also known as the Davy lamp. The lamp's construction included an oil flame that was set inside a glass sleeve equipped with a mesh flame arrestor to prevent the flame from igniting any gas outside the lamp. The flame would be adjusted to a specific height in clean air. The height of the flame would increase in the presence of elevated levels of combustible gas and decrease in an oxygen-depleted environment.

The success of the Davy lamp as a safety tool is mixed. Mining explosions continued to occur, and some historians attribute specific explosions to workers' overconfidence to enter hazardous areas in the belief that they were protected by the lamp. Despite this, the period in which the lamp was used coincided with a significant decrease in the number of fatalities per ton of coal produced in the United Kingdom.

While not accurate to measure concentrations of gases, the Davy lamp represented a significant advancement in worker safety. Despite being outdated technology, flame safety lamps are still used in some parts of the world today.

Figure 5 (left): 19th or 20th century depiction of miners using a canary in a coal mine. From the NYPL Digital Collection.

1900s

THE CANARY IN THE COAL MINE

Most people have heard this expression as a general term for an early warning sign of trouble. Miners began using canaries to provide an early warning of the presence of toxic gases in 1911. Canaries are more sensitive to toxic gases and changes in oxygen levels than humans. Caged canaries were brought into the mines. If they stopped singing, this was a warning sign to the miners that they needed to evacuate.

Although canaries were primarily used to detect carbon monoxide, since the addition of combustible gases changes the oxygen level in the air, canaries were also sensitive to the presence of combustible gases. Canaries continued to be used in the United Kingdom's coal mining industry until 1986.

1920s

CATALYTIC BEAD SENSOR

In the 1920s, Dr. Oliver Johnson developed the catalytic combustion (LEL) sensor at the Standard Oil Company in California (now called Chevron).

Nowadays, this sensor, which uses catalytic beads (also known as pellistors or pellet-resistors), is one of the most common methods for detecting combustible gases.

1970s

INFRARED GAS DETECTION

A patent filing in the 1970s by Kozo Ishida contained the first known description of an infrared gas analyzer.

While the design of this type of sensor has evolved over the past few decades, the operating principle remains the same. Infrared light is shone through a sample at a specific wavelength. Any hydrocarbon gases present will absorb the infrared light resulting in a weaker returning sample.

2020

MOLECULAR PROPERTY SPECTROMETER

While catalytic bead and infrared sensors are still widely used in industry, new technology is overcoming many of their shortcomings.

The newest emerging technology in combustible gas detection is the Molecular Property Spectrometer™ (MPS). This advanced sensor analyzes the properties of the sample gas in order to categorize the gas, automatically calibrate the reading to be accurate to that gas and compensate for environmental conditions.

?

We will cover the catalytic bead, infrared and MPS sensors further in the next section.

blacklinesafety

MODERN Sensor Technologies

The detection of combustible gases has not significantly changed in the past forty years. Catalytic bead (pellistor) and infrared sensing technologies have been the dominant technology for personal and area monitoring for combustible gases. These technologies have seen minor improvements over the past several decades, but the basic technology has not changed. The new Molecular Property Spectrometer (MPS) sensor by NevadaNano has introduced a third option which addresses several of the shortcomings of pellistor and infrared sensors. This section describes these three transportable sensor technologies in detail.

- CBS — CATALYTIC BEAD SENSOR
- NDIR — NONDISPERSIVE INFRARED SENSOR
- MPS — MOLECULAR PROPERTY SPECTROMETER

CATALYTIC BEAD SENSOR

Catalytic bead sensors, also known as pellistor sensors, have been in use for several decades and are still in use today. A well-known technology, their main advantage is that they can detect any combustible gas.

Fundamental Operating Principle A pellistor sensor consists of a pair of heated metal beads contained inside a flameproof housing (see Figure 7 on the right). Each metal bead contains a platinum wire coil, capable of heating the bead to a surface temperature of 500°C. These beads are placed at opposite ends of a Wheatstone bridge circuit (see Figure 6 below), which measures changes in electrical resistance between the two beads. The catalytic bead is coated with a catalyst that causes combustible gas to burn at lower concentrations and temperatures than in normal air. The reference bead, or compensator, is not coated with a catalyst, meaning gas encountering it will not burn until it reaches the lower explosive limit (LEL).

When combustible gas contacts the catalyst bead it creates a reaction, releasing its energy as heat. This causes a change in resistance from the catalytic bead, while the reference bead maintains a steady resistance. This variation in resistance is measured by the Wheatstone bridge circuit, indicating the presence of combustible gas.

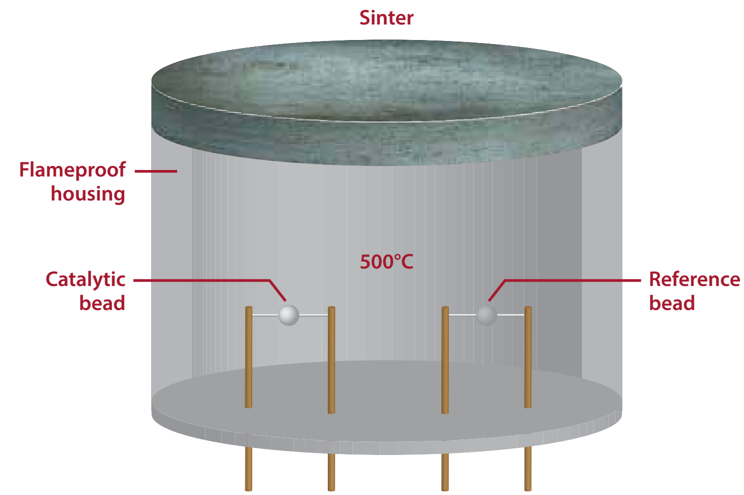


Figure 7: Pellistor sensor cutaway.

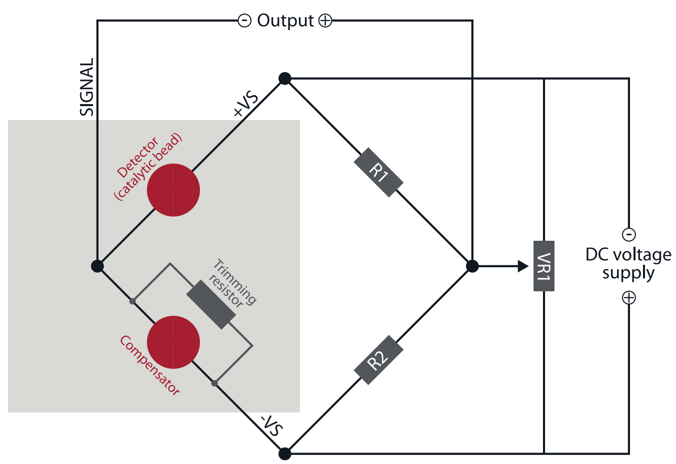


Figure 6: Wheatstone bridge circuitry diagram.

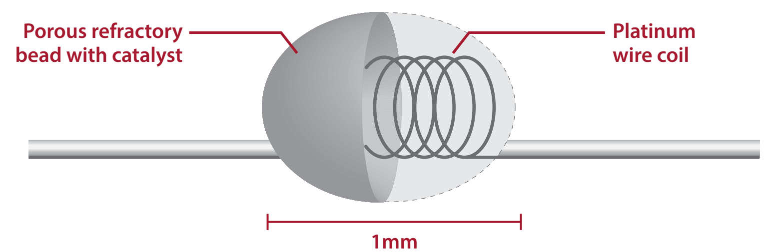


Figure 8: Pellistor sensor bead cutaway.

CATALYTIC BEAD SENSOR

Gases Detected Since the pellistor sensor is using a property common to all combustible gases (that they burn when heat is applied), it can detect a wide variety of combustible gases. However, since these gases all burn at different concentrations and temperatures, the reading is only fully accurate to the gas to which the sensor is calibrated.

In addition, the risk of poisoning (discussed below) presented to pellistor sensors means that many pellistor sensors are fitted with a filter to limit exposure to molecules that can affect the catalytic bead. In addition to filtering out these target molecules, the filters also restrict the flow of heavy hydrocarbons, artificially decreasing responsiveness to those gases.

Accuracy of Readings When a combustible gas encounters a pellistor sensor, it will react according to its specific properties. Some gases require higher concentrations than others to initiate the combustion reaction. The result is a sensor which can detect the gas to which it is calibrated with a high degree of accuracy, while all other gases will have inaccurate readings.

In most applications, the calibration gas selected for pellistor sensors is either pentane or methane. While the reason for selecting each is justifiable, both have significant weaknesses when it comes to the accuracy of gas readings.

Pentane is often selected as the calibration gas for pellistor sensors. The primary reason for this is the high concentration of pentane required to create a combustion reaction relative to other combustible gases such as methane, ethane, propane and butane. The practical result is that a pellistor sensor calibrated with pentane will provide accurate readings of pentane, but most other gases will cause an alarm at lower concentrations. This means that there will be more false alarms for those other gases, but also reduces the risk of falsely low readings of the other gases.

SCENARIO A worker encounters an LEL alarm while working near an acetylene tank. The gas level shown on the worker's gas detector is 28%LEL. The worker knows his gas detector is calibrated with methane. The worker wants to determine the correct LEL concentration for acetylene.

Acetylene has a correction factor of 1.7 for methane calibration.

28 * 1.7 = 47.6%LEL

The correct reading in this case is **47.6%LEL**.

blacklinesafety

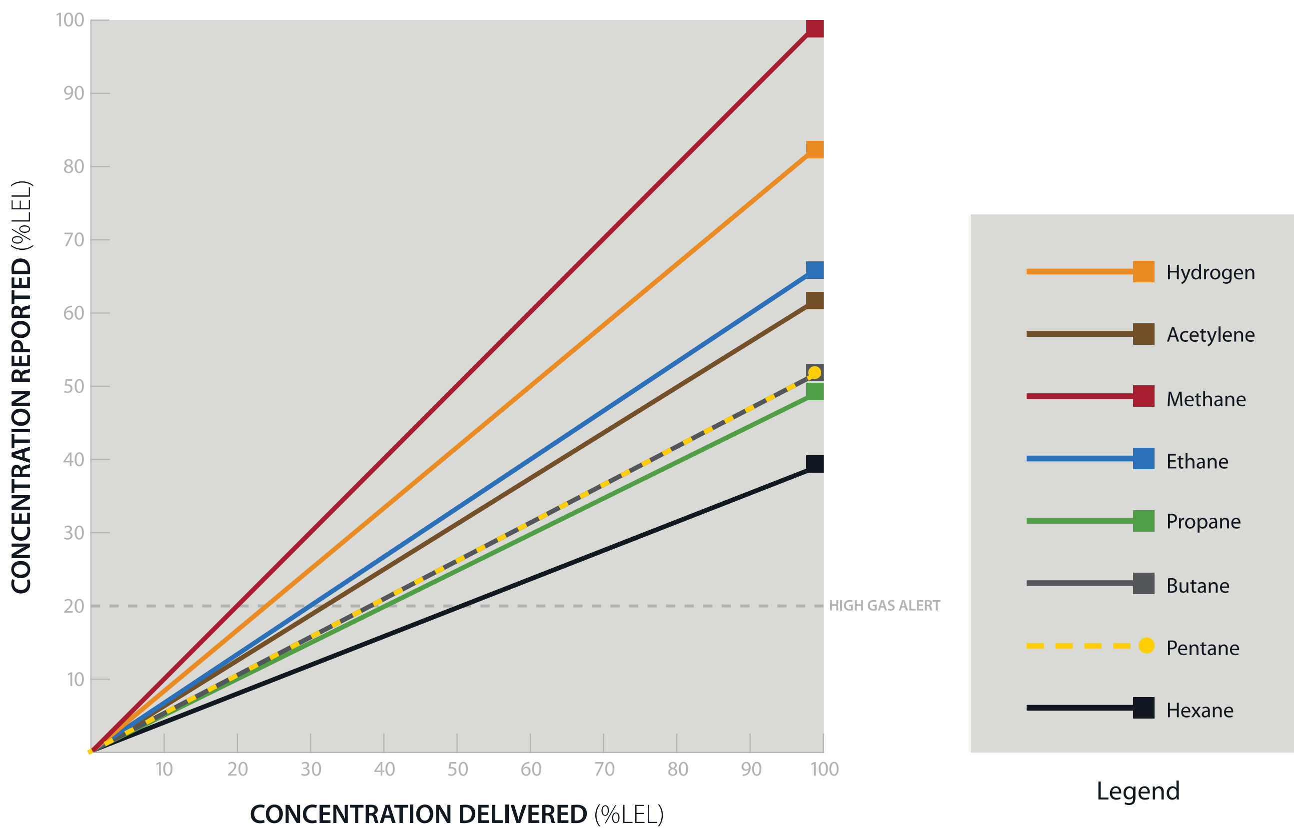
CATALYTIC BEAD SENSOR

Pentane calibration also introduces the risk of an undiagnosed failure to detect gases with a higher ignition temperature. As a pellistor sensor is exposed to contaminants (poisoning and inhibiting agents, described below) the surface temperature of the catalytic beads may decrease. For pentane gas, this will not affect its readings, since pentane has a relatively low ignition temperature of 260°C. This is not true for methane, the most common combustible gas encountered by workers worldwide. The ignition temperature of methane is 537°C. The higher ignition temperature of methane makes it possible for a poisoned pellistor sensor to pass calibration with pentane, but fail to detect the presence of methane.

On the other hand, calibration with methane will result in lower readings for other gases. If a pellistor sensor calibrated with methane is exposed to 50%LEL of acetylene for example, it will only read as 28% on the monitor. This is because when the sensor is calibrated to methane, it is less sensitive to acetylene, resulting in a lower reading.

In cases in which the user knows the gas they are encountering, users must manually enter the target gas into their gas monitor to automatically correct their readings, or manually calculate their readings based on a correction factor guide.

Figure 9: Concentration reported versus concentration delivered when pellistor sensor is calibrated for methane.



blacklinesafety

CATALYTIC BEAD SENSOR

Reliability The pellistor sensor carries significant risk, as many of its failure modes fail-to-unsafe.

- **Poisoning** The most serious concern for the reliability of pellistor sensors is poisoning. Several common compounds, especially lead, silicones, phosphate, and sulfur-based compounds can decompose on the surface of the catalyst, forming a solid coating on the surface. This coating permanently decreases the sensitivity of the sensor and can even lead to full failure. Several common products contain these substances, including: hair care products, lotions, cleaning supplies, and degreasers. Often this process happens slowly over time, but in extreme cases pellistor sensors can fail after a single event. This issue can only be identified by a bump test or calibration. Until one of these procedures are performed, it is possible that a worker could be going unprotected.

- **Temporary Inhibition** This is a serious concern with the pellistor sensor. Some compounds, such as certain VOCs and H_2S, can be absorbed by the catalyst on the catalytic bead. The absorption of these compounds creates a blockage in the reaction sites on the catalyst. This will inhibit normal reactions and result in a temporary loss of sensitivity. Sensor inhibition is generally resolved after a period of exposure to fresh air. However, while the sensor recovers, readings will be artificially low.

- **Lack of Oxygen** Since the pellistor sensor burns the combustible gas to identify a hazard, it is reliant on the fire triangle to make accurate readings of gas levels. When oxygen levels drop below 11%, complete combustion of the gas is no longer possible. If this occurs, the catalytic bead will be contaminated with soot, resulting in a permanent loss of sensitivity.

- **Mechanical Breakage** Pellistor sensors use fine platinum wires to heat the beads. While robust, these connections are subject to mechanical breakage. The heat of the beads and exposure to industrial chemicals can also weaken the platinum wires, leading to potential failure. In this case, the sensor is unable to detect the fault and fails-to-unsafe.

- **Sensor Overload** When a pellistor sensor is exposed to high concentrations (above 8%v/v of methane) of combustible gas, it may experience a baseline shift in readings.

SCENARIO Florinda is a driller on an oil rig. At 10:15 in the morning, her gas detector goes into alarm for H_2S. She evacuates the area, and follows protocol to return to work.

The next morning, Florinda performs the scheduled daily bump test on her gas detector before starting work. The pellistor LEL sensor fails the bump test because the sensor was poisoned by the H_2S exposure. **Florinda worked without a functioning LEL detector from 10:15 a.m. to the end of her shift**.

Environmental Factors The pellistor sensor is resistant to environmental factors. Only in extreme cases can these sensors be affected by environmental conditions.

- **Temperature** The average temperature range for a pellistor sensor is -40°C (-40°F) to 60°C (140°F). Only in extreme cases will a pellistor sensor be affected by temperature.
- **Humidity** Varying levels of humidity do not have a significant impact on the accuracy of pellistor sensors.
- **Pressure** Normal variations in atmospheric pressure do not have a significant impact on the accuracy of pellistor sensors.

Maintenance Requirements Given that many of the failure modes of the pellistor sensor fail-to-unsafe condition, testing and calibrating the sensors is critical to safe operation of a pellistor sensor. Failure to follow proper maintenance cycles presents significant risk of a worker unknowingly working unprotected.

- **Bump Testing** Since poisoning of pellistor sensors can happen very quickly, daily bump testing is required. This safety procedure ensures that the sensor is still reading the presence of gas at the beginning of every shift.
- **Calibration** Procedures are equally important for pellistor sensors. Poisoning of the catalyst bead is an inevitable process that in most cases slowly decreases the sensitivity of the sensors. By applying a known quantity of gas and adjusting the readings of the sensor to match, we can ensure the pellistor sensor remains as accurate as when it was shipped. Most manufacturers recommend calibration of pellistor sensors every three months.

CBS

CATALYTIC BEAD SENSOR

Advantages and Disadvantages The pellistor sensor has been used for several decades. Its advantages and disadvantages are widely known in the industry.

ADVANTAGES	DISADVANTAGES
Low cost	Susceptible to poisoning and inhibition
Simple to operate	Requires a minimum of 11% oxygen for safe operation
Predictable sensitivity and correction factors	Sensor failures default to fail-to-unsafe
Long-lasting	Significant variation in response to different gases
Detects all flammable gases	

blacklinesafety

NONDISPERSIVE INFRARED SENSOR

NDIR

Nondispersive infrared sensors (NDIR) have traditionally been the only alternative to pellistor technology. Rather than relying on combustion of the target gas, infrared sensors use absorption of infrared radiation to detect gas.

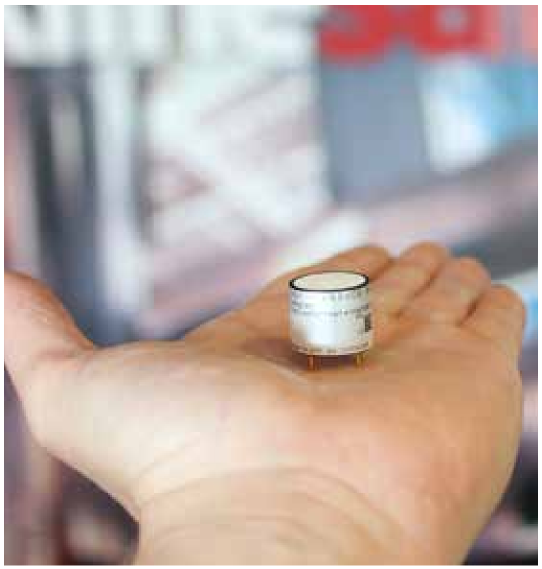


Figure 10: NDIR sensor.

Fundamental Operating Principle As discussed previously, most combustible gases encountered in the industry are hydrocarbon compounds. Infrared sensor technology leverages this shared characteristic to detect the presence of gas. Hydrocarbon compounds absorb infrared light at a certain wavelength. When the light encounters the molecule it causes vibration at the molecular level and some of its energy is absorbed.

The construction of infrared sensors leverages this characteristic. The main components of an infrared sensor are an infrared lamp, reflectors inside the sensor chamber, and a double detector (see Figure 12 on the next page). The infrared light transmits at two different wavelengths. The first is the absorption band of hydrocarbon gases and the second is a reference wavelength. When gas enters the sensor, it begins to absorb the infrared light on the absorption band. The reference wavelength is not absorbed. After the light has passed through the sensor chamber, the intensity of each wavelength is measured by the double detector. The presence of gas is indicated by a decrease in the intensity of the light at the absorption wavelength.

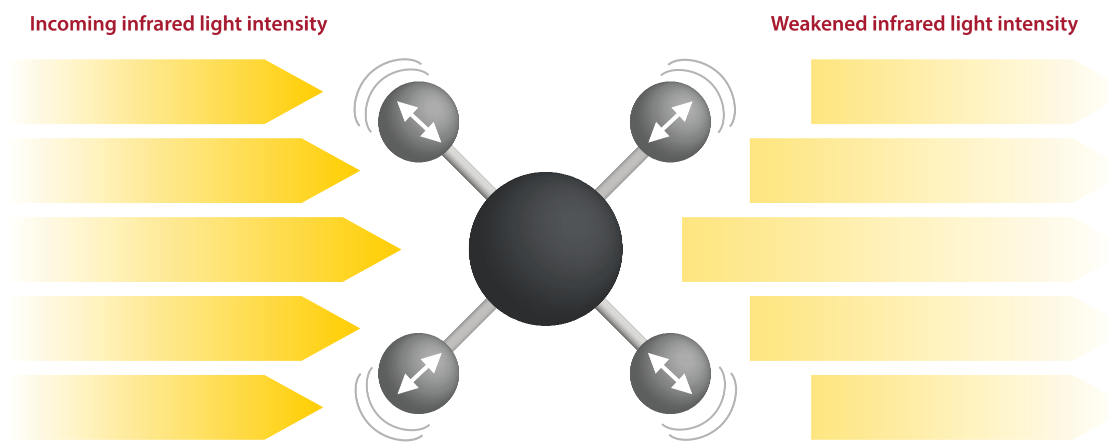


Figure 11: Methane molecule absorbs IR light.

NDIR NONDISPERSIVE INFRARED SENSOR

Gases Detected While hydrocarbon compounds represent most combustible gases in the industrial space, there are exceptions to this rule. Most notable are hydrogen and acetylene. These gases absorb infrared light at different spectra than hydrocarbons, and therefore are not detectable by an infrared sensor targeting hydrocarbon gases.

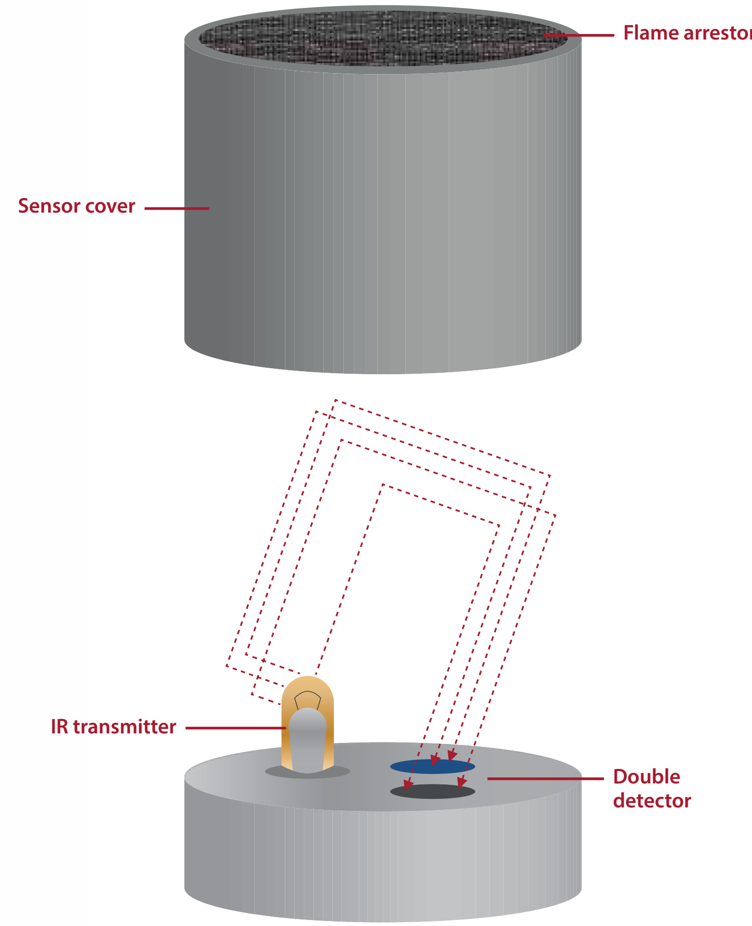
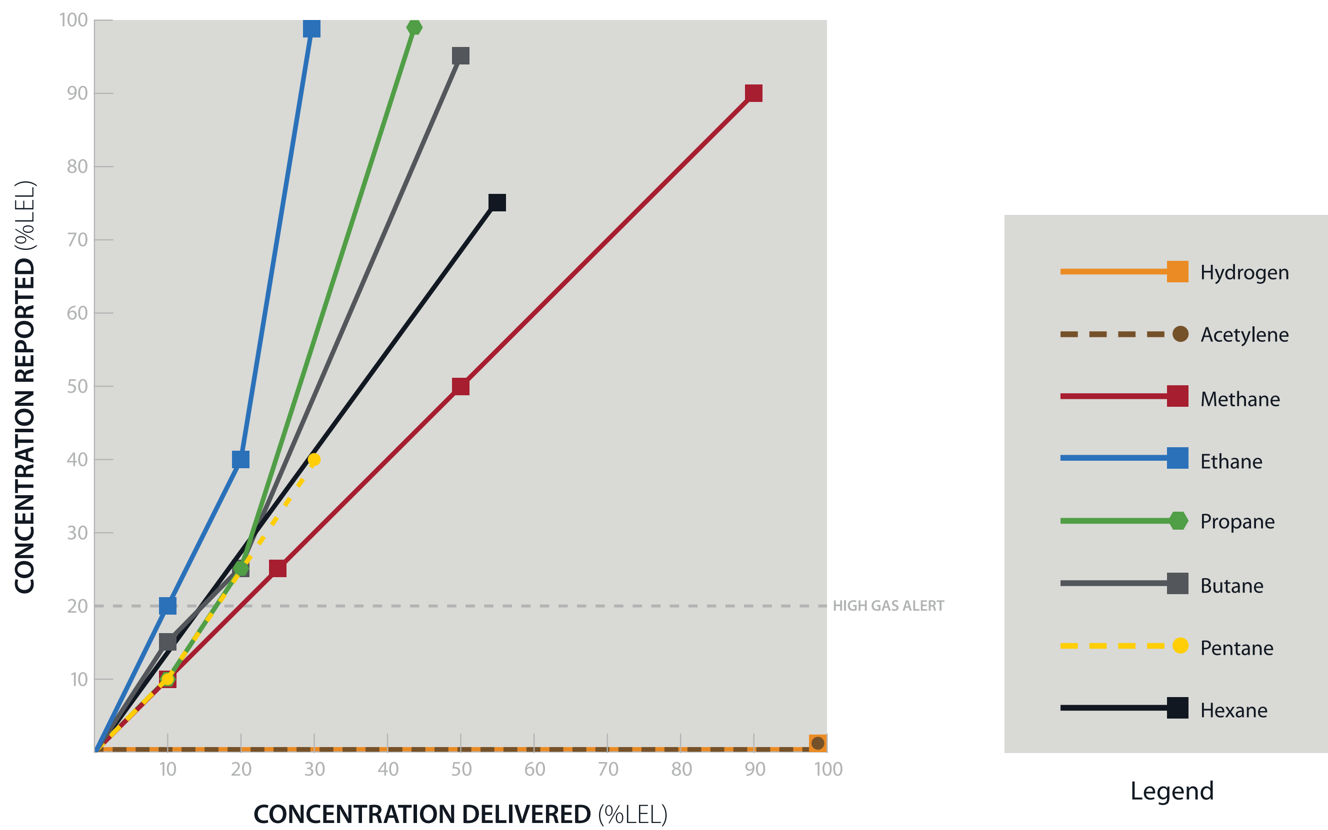


Figure 12: Expanded cutaway of an infrared sensor.

NDIR NONDISPERSIVE INFRARED SENSOR

Accuracy of Readings While all hydrocarbon compounds absorb infrared light at the same wavelength, each gas absorbs different amounts of the radiation. This creates an issue with accuracy. Most infrared sensors are calibrated for methane, which then provides accurate readings for methane. All other gases will read falsely high or low. In some cases, this difference can be dramatic. In the case of hexane, gas applied at 50% of the LEL will read as approximately 5%LEL on a gas monitor calibrated with methane. This presents a significant safety risk if there is the possibility of other hydrocarbons being present. For applications with a known target gas, the IR sensors should be calibrated with that gas for improved accuracy.

Figure 13: Concentration reported versus concentration delivered when NDIR



Reliability Infrared sensors do not suffer from the same reliability issues as pellistor technology. Infrared sensors default to a fail-to-safe state, ensuring workers know if they are not being protected.

- **False Alarms** Several common factors can obscure the infrared light inside the sensor chamber. When these conditions are present, false alarms can occur. Obscuring particles such as dust as well as condensation can cause these false alarms.
- **Mechanical Breakage** Infrared sensors are robust and resistant to mechanical breakage. In the rare case of a failure, the sensor will transmit a fault and alert the user of the error.
- **Poisoning and Inhibition** The issues with poisoning and inhibition described for pellistor sensors on page 26 do not apply to infrared technology.

Environmental Factors Infrared sensors are more sensitive than other technologies to environmental conditions.

- **Temperature** Workers in extreme climates may move from climate-controlled buildings into extremely hot or cold temperatures. This rapid change in temperature can cause condensation to build up on the internal components of the sensor, leading to false alarms.
- **Humidity** Like extreme temperature changes, humidity can cause condensation to build up inside the sensor chamber, leading to false alarms.
- **Pressure** Atmospheric pressure has a minimal impact on IR sensor readings. Calibrating at the expected altitude will help compensate for any minor variations.
- **Atmosphere** Since they do not rely on a combustion reaction, infrared sensors can operate in oxygen depleted and enriched environments.

NDIR

NONDISPERSIVE INFRARED SENSOR

Maintenance Requirements Infrared sensor readings can drift over time. This happens more slowly than pellistor sensors, but periodic bump tests and calibrations are necessary.

- **Bump Testing** As with any gas detection technology, checking the functionality of the sensor is highly recommended. Blackline recommends daily bump tests for infrared sensors.

- **Calibration** Sensor reading drift can occur over time with infrared sensors. Follow the manufacturer's minimum recommendation for calibration intervals. Blackline Safety recommends not exceeding 180 days between calibrations.

  For infrared sensors, the most common calibration gas is methane. If the gas likely to be encountered is known, using a different calibration gas can result in more accurate readings for that gas. In these cases, consult the manufacturer for their recommendation.

SCENARIO A facility is concerned with two combustible gases. Methane is present throughout the facility, but some processes on the site also produce ethane gas.

The health and safety team is determining appropriate protocols that will allow for safe detection of both gases with their infrared gas monitors. The concern is false alarms due to ethane gas exposure. **With a methane calibration at 10%LEL concentration of ethane the detector will report 20%LEL, initiating a high gas alarm.** If calibrated with ethane, a methane exposure will not cause a high alarm until approximately 50%LEL. Methane calibration will result in unnecessary false alarms due to ethane exposures. Ethane calibration will result in falsely low readings for methane exposures. Neither solution is ideal, but the safety team must chose between the two.

After considering their options, the safety team is forced to err on the side of caution and accept false alarms for ethane. They must plan for false alarms for ethane gas and enforce mandatory evacuation protocols in all areas of the facility.

NDIR

NONDISPERSIVE INFRARED SENSOR

Advantages and Disadvantages While infrared sensor technology overcomes the primary weakness of pellistor technology, significant weaknesses remain.

ADVANTAGES	DISADVANTAGES
Fail-to-safe failure modes	Higher cost
Immune to poisoning and inhibition	Unable to detect hydrogen and acetylene
Low power draw enables extended battery life	Readings are only accurate for the target gas. Other gases can be detected, but readings will be inaccurate.
Operates in oxygen-depleted and enriched environments	

MOLECULAR PROPERTY SPECTROMETER SENSOR

The Molecular Property Spectrometer™ (MPS) sensor is new to the personal gas detection market. An advanced sensor, the MPS categorizes the gases it is encountering and automatically compensates its readings based on the gas mix

Figure 14: MPS sensor by NevadaNano.

Fundamental Operating Principle When gas enters the MPS sensor, it encounters a Micro Electromechanical Systems (MEMS) sensor. In general terms, MEMS sensors combine mechanical and electrical components onto a single chip. In the case of the MPS sensor, the mechanical component of the sensor is a micromachined membrane with a Joule heater, which rapidly heats the gas. The electrical components are a smart sensor module, which measures the thermodynamic properties of the air/gas mixture and an environmental sensor measuring temperature, pressure, and humidity.

When a combustible gas enters the sensor chamber, its unique thermal properties are measured by the MPS transducer. Each gas has unique thermal properties, akin to a fingerprint. The MPS thermal measurements and environmental conditions are processed by an integrated microcontroller and patent-pending algorithms. The resulting gas concentration and classification are accurate for multiple gases, without user intervention.

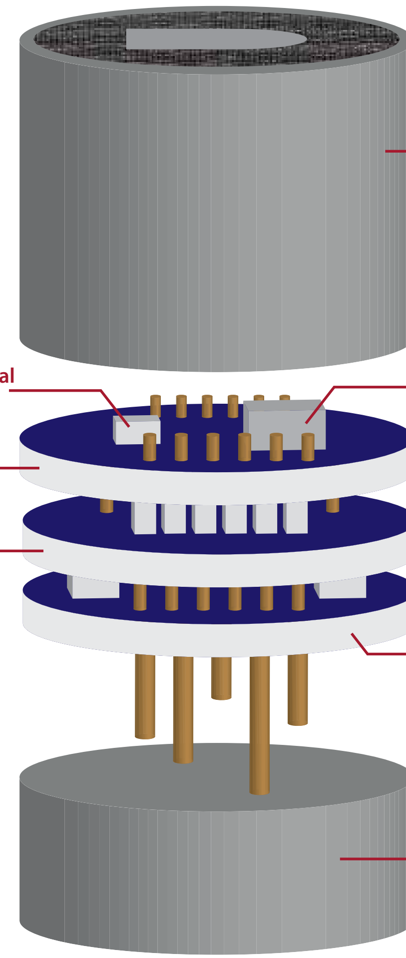
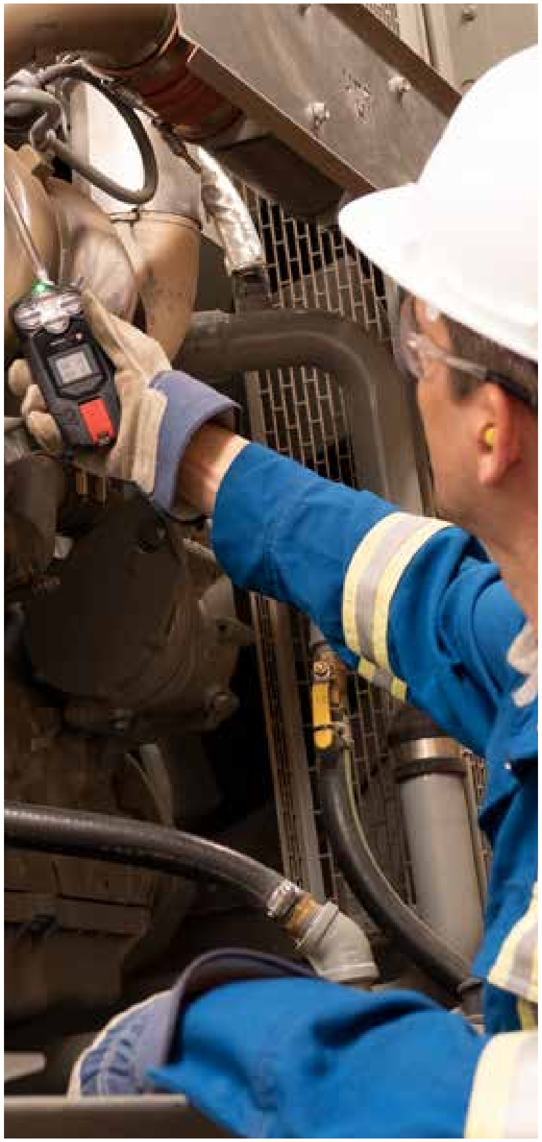


Figure 15: Expanded cutaway diagram of Molecular Property Spectrometer sensor.

MOLECULAR PROPERTY SPECTROMETER SENSOR



Gases Detected The MPS sensor can detect a wide range of combustible gases and gas mixtures. At the time of this writing, test data is available for many of the most common combustible gases. The gases listed below in Table 6 represent the vast majority of combustible gases present in industry. For gases not on this list, please contact Blackline Safety for testing data.

COMMON INDUSTRIAL GASES
Hydrogen
Methane
Ethane
Propane
Butane
Pentane
Hexane
Toluene
Xylene
Ethylene
Propylene
Isopropanol

Table 6: List of common combustible gases.

STEP-BY-STEP How does the MEMS sensor detect gas, and how does the environmental sensor help establish a baseline measurement?

1. Gas rapidly defuses through the sensor's mesh screen and into the sensor chamber, entering the MEMS sensor module.
2. The joule heater rapidly heats the gas sample.
3. Real-time environmental conditions (temperature, pressure, and humidity) are measured by the integrated environmental sensor.
4. The energy required to heat the sample is precisely measured using a resistance thermometer.
5. The gas level, corrected for gas category and environmental conditions, is calculated and output to the gas detector.

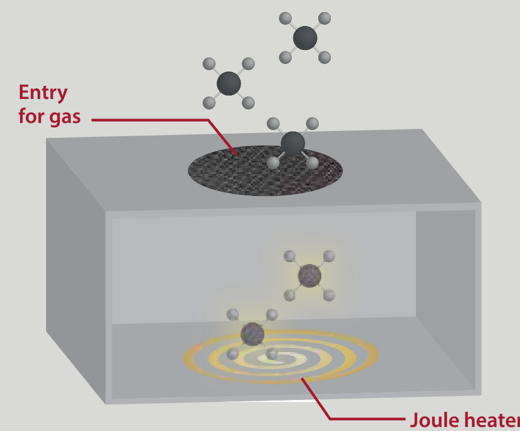
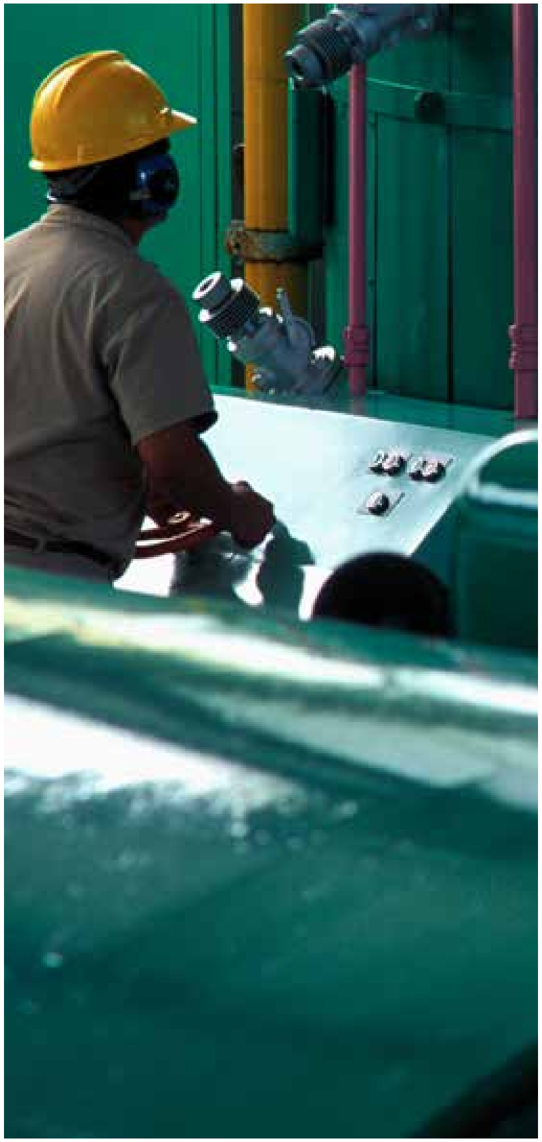


Figure 16: Close-up illustration of MEMS sensor.



Gas Classification Since the MPS sensor can analyze gas properties, it can classify gases based on their molecular weight and density. These 6 classifications (as identified below in Table 7), combined with Blackline's location-enabled connected devices, can provide important insights into the location, frequency and types of gases being encountered by a workforce. This data can be accessed by any Blackline Safety customer through our industry-leading online analytics portal, Blackline Analytics. The six classifications of gases are as follows:

- **Class 1** Hydrogen
- **Class 2** Hydrogen Mixture
- **Class 3** Methane / Natural Gas
- **Class 4** Light Gas / Light Gas Mixture
- **Class 5** Medium Gas / Medium Gas Mixture
- **Class 6** Heavy Gas / Heavy Gas Mixture

Table 7: Gas classifications and their four key properties as detectable by the MPS sensor.

	CLASS 1	CLASS 2*	CLASS 3	CLASS 4	CLASS 5	CLASS 6
Molecular weight (g/mol)	2.0	1.0 - 14.0	16.0 - 19.0	25.0 - 75.0	50.0 - 120.0	80.0+
Density (kg/m³)	0.09	0.1 - 0.6	0.6 - 0.9	1.2 - 2.5	1.5 - 4.0	3.5+
# of carbons	0	varies	1 -2	1-4	2 - 8	6+
Example gases	-	-	-	Ethane Propane Butane Isopropanol	Pentane Hexane	Octane Toluene Xylene

*This classification is unique as it guarantees the presence of hydrogen and another flammable gas.

blacklinesafety

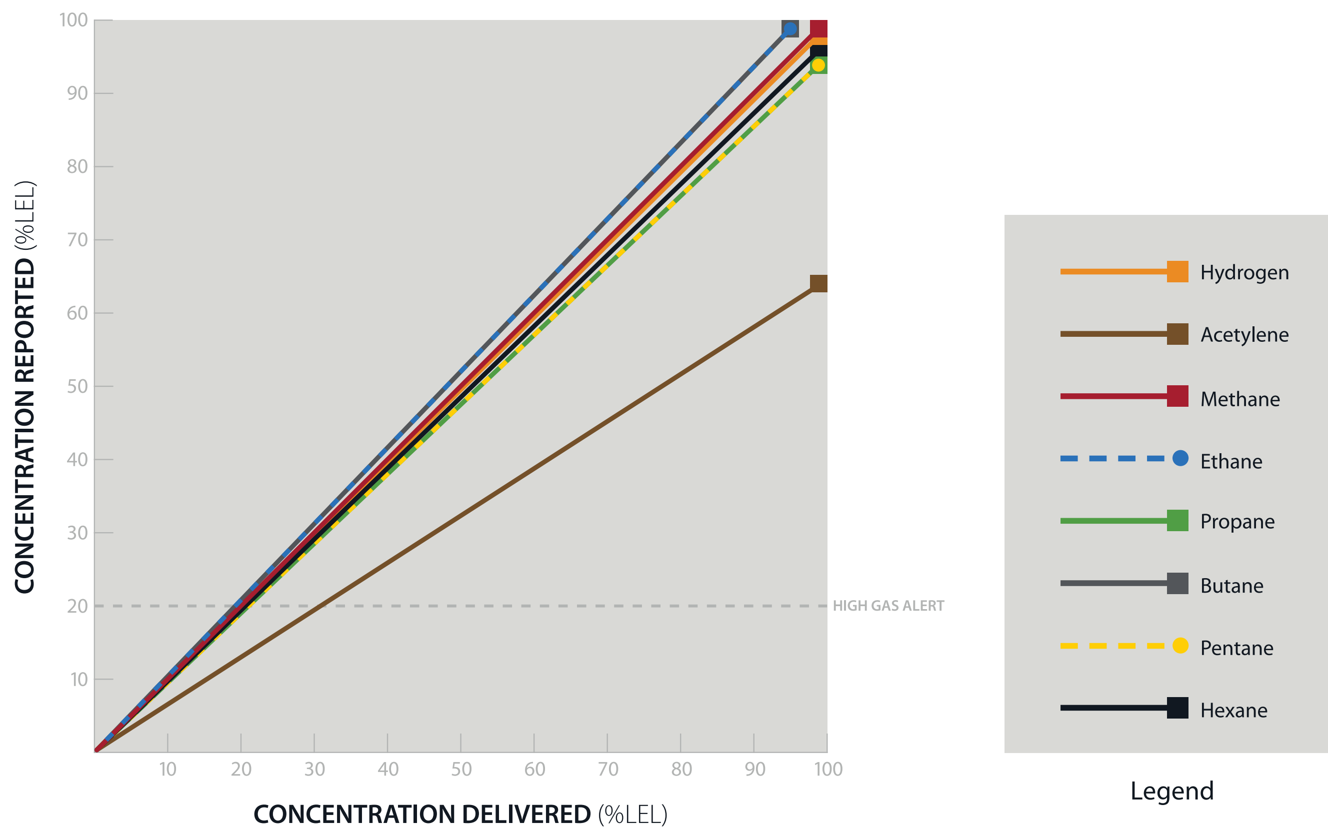
Accuracy of Readings After automatically applying real-time correction factors for the category of gas identified by the sensor and adjusting readings for temperature and humidity, the resulting readings are far more accurate than competing sensors.

Reliability With built-in self-diagnostic ability and no risk of poisoning, the MPS sensor is fail-safe. This means that if there is a failure with any component of the sensor, it will notify the user of the malfunction.

Environmental Factors The sensor will maintain its accuracy through extreme temperatures, humidity, and pressure changes, so environmental factors are not a concern.

- **Atmosphere** The thermodynamic properties that the MPS sensor measures can be affected by the concentration of oxygen in the atmosphere.

Figure 17: Concentration reported versus concentration



MOLECULAR PROPERTY SPECTROMETER SENSOR

Maintenance Requirements While the MPS sensor is highly reliable and its self-diagnostic ability will cause it to fail-to-safe, it is still important to continue to confirm proper operation of the sensor.

- **Bump Testing** As with any gas detection technology, checking the functionality of the sensor is highly recommended. Blackline recommends daily bump tests for MPS sensors.
- **Calibration** Since the MPS sensor automatically adjusts its readings in real-time, the calibration process is simply a confirmation that the sensor is still accurately reading gas levels. Adjustment of the readings is not required but can be performed if desired. Blackline Safety recommends not exceeding 180 days between calibrations.

SCENARIO A large facility is looking to find a new gas sensor for their workers. Throughout the facility, there is potential for a variety of hydrocarbon combustible gases to be present. The facility's safety team currently uses a pellistor sensor calibrated with pentane gas, which means that workers are receiving false alarms for methane. These false alarms are impacting productivity on site and the workers' faith in their gas detectors. The first goal of the safety team is to find a new solution that reports fewer false alarms and reduces the risks of poisoning presented by pellistor sensors.

A secondary goal of the safety team is to proactively locate sources of gas exposure for workers. **They are encouraged by the potential of the MPS sensor to classify gas exposures, combined with the ability of Blackline Analytics to map the locations of the exposures.** The data produced by their personal gas detectors will help the safety team identify clusters of unusual gas readings. This will give them targeted locations to test for leaks and make repairs to prevent safety incidents.

The MPS sensor is the natural choice for this facility. This sensor provides more accurate gas readings, reduces the risk of fail-to-unsafe sensor failures, and provides location-enabled analytics for gas exposures.

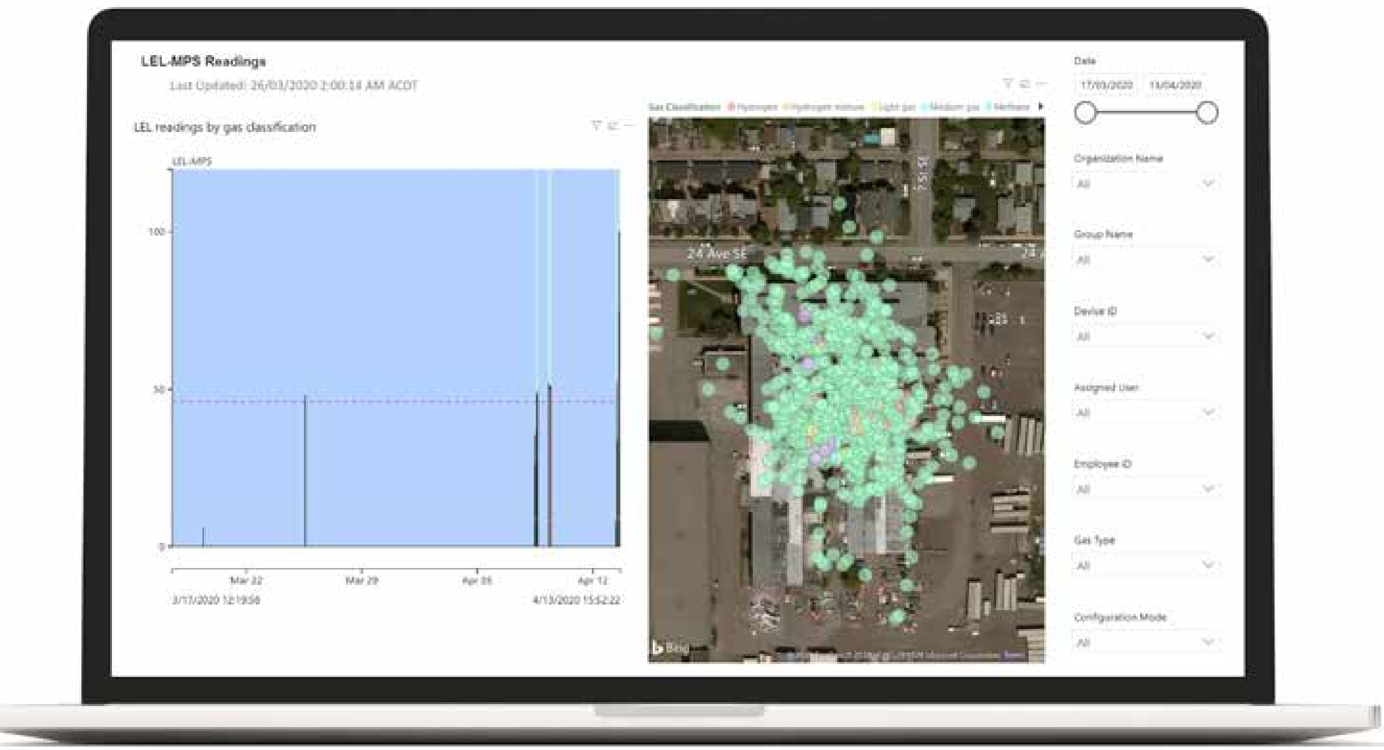


Figure 18: Screenshot of theLEL-MPS Readings report in Blackline Live.

MOLECULAR PROPERTY SPECTROMETER SENSOR

MPS

Advantages and Disadvantages The MPS sensor overcomes many of the weaknesses of traditional sensor technology, leaving few disadvantages.

ADVANTAGES	DISADVANTAGES
Five-year expected lifetime	Requires a minimum of 10% oxygen for accurate readings
Responds to a full range of flammable gases	While the most common combustible gases have been fully tested, data for less common gases is incomplete. Testing is ongoing to add test data for less common gases.
Real-time auto-calibration to a full range of gases	
Classifies gases into one of six categories	
Environmental compensation for temperature, pressure and humidity	
Immune to poisoning	
Low power consumption	
Excellent response time	
Fail-safe self-diagnostic capability	

SELECTING THE RIGHT SENSOR

With a working understanding of pellistor, infrared and MPS sensor technologies there are several factors to consider to select an appropriate sensor for your application. As the MPS sensor overcomes the biggest weaknesses of both the pellistor and infrared technologies without presenting new ones of its own, it is the default recommendation for most applications.

Environment Unless the application requires combustible gas detection in oxygen-depleted environments, the MPS sensor is the best sensor for all environmental conditions. For oxygen-depleted environments, an infrared sensor is more appropriate.

Reliability Both infrared and MPS technologies are highly reliable, with fail-to-safe default failure modes. For reliability of accuracy in gas readings, the MPS sensor is the better choice.

Target Gases Both pellistor and MPS sensors can detect a full range of combustible gases. Pellistor sensors are known to detect most combustible gases, but with inaccurate readings for many of the most common gases. The MPS sensor is highly accurate, but test data is still in development. For information on gases outside of the 12 most common combustible industrial gases, contact Blackline Safety.

Table 8: Measurement capability and accuracy for common flammable gases at a delivered concentration of 50% LEL, based on a calibration using methane.

	GAS MEASUREMENT ERROR (%LEL)		
	MPS	**Pellistor**	**NDIR**
Hydrogen	±5		Not detected
Acetylene	-35		Not detected
Methane	±3		
Ethane	±5		
Propane	±5		
Butane	±5		
Pentane	±5		
Hexane	±8		

<10%LEL error   +10%LEL error

blacklinesafety

ADDITIONAL RESOURCES

Blackline Safety website:
blacklinesafety.com

Blackline Safety support website:
support.blacklinesafety.com

LEL-MPS Combustible Gas Sensor Info Sheet:
www.blacklinesafety.com/lel-mps-one-sheeter-download-0

G7c Personal Safety Wearable information with cellular connectivity:
www.blacklinesafety.com/g7c-wireless-gas-detector

G7x Personal Safety Wearable information with satellite connectivity:
www.blacklinesafety.com/g7x-wireless-gas-monitor

G7 EXO Area Gas Monitor information:
www.blacklinesafety.com/g7-exo

Blackline's cloud connected sensor information:
www.blacklinesafety.com/cloud-connected-sensors

Blackline Safety video:
www.youtube.com/watch?v=JyH7FkKapNc

blacklinesafety

GLOSSARY

Area monitoring In areas where fixed gas detection is not practical, or during temporary procedures or emergencies, area monitors are used to provide the benefits of a fixed gas detection system that is independent of the established site infrastructure.

Balance gas The gas used to fill the remainder of the calibration gas cylinder after the correct concentrations of the calibration gases have been included. This is typically either air or nitrogen.

Bump testing Checks functionality of a gas detector by applying gas to the sensors to confirm that it continues to detect the presence of gas.

Calibration Applies a known quantity of gas to a sensor and adjusts the resulting measurements to match the gas applied.

Calibration gas Used to calibrate gas sensors. Contains known quantities of all gases required to perform the calibration procedure.

Chemical Abstract Service number A unique numerical identifier assigned to every known chemical compound.

Catalytic bead (pellistor) sensor A combustible gas sensor design consisting of a catalyst bead and a reference bead. The catalytic bead burns the target gas and the reference bead does not.

Chemical formula Identifies the number of atoms of each element in a compound.

Combustible gas A gas which will burn when mixed with oxygen at sufficient concentrations.

Common name A unique name that unambiguously identifies a chemical compound.

Compliance Legislated requirements of businesses to report on proper use and maintenance of gas detection equipment.

Density Mass divided by volume. This is an important property for gas classification with the Molecular Property Spectrometer (MPS) sensor.

Fail-to-unsafe A failure mode in which the operator is not made aware of the fault. This presents a risk that the operator will continue to work unprotected.

Fail-to-safe A failure mode which ensures that in the case of a device failure, the user is notified of the fault.

Fire triangle The fire triangle represents the three conditions necessary for a fire to occur: heat, oxygen, and fuel.

Fixed detection Permanent sensors are placed at appropriate locations to provide early warning of a gas exposure.

Flammable range The range concentrations of a combustible gas mixed with air which when heated to sufficient temperature will cause a fire.

Flash point The lowest temperature at which a liquid's surface gives off enough vapor to be ignited by a spark or small flame.

Hydrocarbon compound An organic chemical compound made up of only carbon and hydrogen elements.

Hydrocarbon combustion Occurs when a hydrocarbon compound mixes with oxygen and is heated to sufficient temperature to cause a combustion reaction.

Hydrogen combustion Occurs when hydrogen gas mixes with oxygen and is heated to sufficient temperature to cause a combustion reaction.

Ignition temperature The lowest temperature at which a heat source can cause a combustible gas to ignite.

Inhibition Occurs when certain compounds are absorbed into the catalyst on a pellistor sensor. This temporarily occupies the catalyst sites, creating temporarily low readings.

Lower explosive limit (LEL) The lowest concentration at which a combustible gas and air mix can ignite.

Micro Electromechanical Systems (MEMS) sensor Combines mechanical and electrical components onto a single chip.

Molecular Property Spectrometer (MPS) A combustible gas sensor which analyses the properties of the target gas and automatically classifies the gas and adjusts reading for greater accuracy.

Molecular weight A universal measurement of the average mass of any chemical compound.

Nondispersive infrared (NDIR) sensors A combustible gas sensor that utilizes a compound's absorption of infrared radiation to detect the presence of gas.

Percent lower explosive limit The percentage of a gas' concentration relative to its lower explosive limit.

Personal monitoring The last line of defense against gas exposure events. Workers on a site with gas risks wear a personal gas monitor in their breathing zone to monitor the air they are being directly exposed to.

Poisoning Occurs on a pellistor sensor when contaminants decompose on the surface of the catalyst bead, decreasing the sensitivity of the sensor or in some cases causing a full failure. This condition is permanent.

Relative vapor density The density of a gas relative to the air around it.

Sensor overload A shift in baseline readings of a pellistor sensor caused by exposure to high concentrations of combustible gas. This shift can take several days to revert to normal.

Upper explosive limit (UEL) The upper limit of the flammable range of a combustible gas.

Volume per volume (%v/v) The percentage mixture of a gas in the air.

Wheatstone bridge An electrical circuit used to compare electrical resistance between two sources.

APPENDIX

GAS PROPERTIES TABLE

COMMON NAME	CAS NUMBER	FORMULA	FLAMMABLE RANGE (OSHA)		FLASH POINT (°C)	IGNITION TEMPERATURE (°C)	DENSITY (g/cm³)	RELATIVE VAPOR DENSITY (OSHA)	MOLECULAR WEIGHT (g/mol)
			LOWER EXPLOSIVE LIMIT (%/vol)	UPPER EXPLOSIVE LIMIT (%/vol)					
Acetaldehyde	75-07-0	C_2H_4O	4.00	60.00	-38	185	0.79	1.52	44.05
Acetic acid	64-19-7	$C_2H_4O_2$	4.00	19.90	39	485	1.05	2.1	60.05
Acetic anhydride	108-24-7	$C_4H_6O_3$	2.70	10.30	49	316	1.08	3.5	102.09
Acetone	67-64-1	C_3H_6O	2.50	12.80	-18	465	0.791	2	58.08
Acetonitrile	75-05-8	C_2H_3N	3.00	16.00	6	524	0.787	1.42	41.05
Acetylene	74-86-2	C_2H_2	2.50	100.00	-18	305	0.377	0.907	26.04
Allyl alcohol	107-18-6	C_3H_6O	2.50	18.00	21	378	0.854	2	58.08
Ammonia	7664-41-7	NH_3	15.00	28.00	gas	630	1.023	0.6	17.031
Aniline	62-53-3	C_6H_7N	1.30	11.00	76	630	1.03	3.2	93.13
Benzene	71-43-2	C_6H_6	1.20	8.00	-11	498	0.8756	2.77	78.11
Butadiene	106-99-0	C_4H_6	2.00	12.00	-76	414	0.6149	1.9	54.09
i-Butane	75-28-5	C_4H_{10}	1.60	8.40	-82.99	460	0.55092	2	58.12
n-Butane	106-97-8	C_4H_{10}	1.60	8.40	gas	365	0.573	2.11	58.12
i-Butanol	78-83-1	$C_4H_{10}O$	1.20	10.90	28	415	0.8018	2.55	74.12
n-Butanol	71-36-3	$C_4H_{10}O$	1.40	11.20	29	345	0.8098	2.6	74.12
t-Butanol	75-65-0	$C_4H_{10}O$	2.40	8.00	11	470	0.7886	2.55	74.12
Butene-1	106-98-9	C_4H_8	1.60	9.30	gas	385	0.588	1.93	56.11

GAS PROPERTIES TABLE (cont.)

COMMON NAME	CAS NUMBER	FORMULA	FLAMMABLE RANGE (OSHA)		FLASH POINT (°C)	IGNITION TEMPERATURE (°C)	DENSITY (g/cm³)	RELATIVE VAPOR DENSITY (OSHA)	MOLECULAR WEIGHT (g/mol)
			LOWER EXPLOSIVE LIMIT (%/vol)	UPPER EXPLOSIVE LIMIT (%/vol)					
Butene-2, trans	624-64-6	C_4H_8	1.60	10.00	gas	324	0.6042	1.9	56.11
Butyric acid	107-92-6	$C_4H_8O_2$	2.00	10.00	72	452	0.959	3	88.11
Carbon monoxide	630-08-0	CO	12.5	74.00	gas	605	0.791	0.97	28.01
Carbonyl sulfide	463-58-1	COS	12.0	29.00	gas	not available	0.002456	2.07	60.08
Chlorobenzene	108-90-7	C_6H_5Cl	1.30	9.60	27	590	1.1058	3.88	112.55
Chloropropane	540-54-5	C_3H_7Cl	2.60	11.00	-18	520	0.8899	2.7	78.54
Cyanogen	460-19-5	C_2N_2	6.60	43.00	gas	not available	9.54E-07	1.82	52.03
Cyclohexane	110-82-7	C_6H_{12}	1.30	8.40	-18	260	0.7781	2.9	84.16
Cyclopropane	75-19-4	C_3H_6	2.40	10.30	gas	497	0.001879	1.88	42.08
n-Decane	124-18-5	$C_{10}H_{22}$	0.80	2.60	46	210	0.7255	4.9	142.28
Dichloroethane	75-34-3	$C_2H_4Cl_2$	5.40	11.40	-6	458	1.175	3.44	98.96
Dichloromethane	75-09-2	CH_2Cl_2	13.0	23.00	not available	605	1.3255	2.93	84.93
Diisobutyl ketone	108-83-8	$C_9H_{18}O$	0.80	7.10	49	396	0.8062	4.9	142.24
Dimethyl sulfide	75-18-3	C_2H_6S	2.20	19.70	-49	205	0.8483	2.1	62.14
Dimethylbutane	75-83-2	C_6H_{14}	1.20	7.00	-48	405	0.6444	3	86.18
Dimethylpentane, 2,3	108-08-7	C_7H_{16}	1.10	6.70	–7	337	0.7076	3.45	100.20
Dioxane	123-91-1	$C_4H_8O_2$	2.00	22.00	12	180	1.0337	3.03	88.11
Ethane	74-84-0	C_2H_6	2.90	13.00	gas	472	1.0493	1.05	30.07
Ethanol	64-17-5	C_2H_6O	3.30	19.00	14.0	400	0.7893	1.59	46.07
Ethene	74-85-1	C_2H_4	2.75	28.60	-100	330-410	0.91-0.96	0.98	28.05
Ethyl acetate	141-78-6	$C_4H_8O_2$	2.00	11.50	-4	427	0.9003	3.04	88.11
Ethyl benzene	100-41-4	C_8H_{10}	0.80	6.70	18	432	0.8626	3.66	106.16

GAS PROPERTIES TABLE (cont.)

COMMON NAME	CAS NUMBER	FORMULA	FLAMMABLE RANGE (OSHA)		FLASH POINT (°C)	IGNITION TEMPERATURE (°C)	DENSITY (g/cm³)	RELATIVE VAPOR DENSITY (OSHA)	MOLECULAR WEIGHT (g/mol)
			LOWER EXPLOSIVE LIMIT (%/vol)	UPPER EXPLOSIVE LIMIT (%/vol)					
Ethyl chloride	75-00-3	C_2H_5Cl	3.80	15.40	-50	519	0.9214	2.23	64.51
Ethylamine	75-04-7	C_2H_7N	3.50	14.00	-17	385	0.689	1.61	45.08
Ethyl formate	109-94-4	$C_3H_6O_2$	2.80	16.00	-20	440	0.9168	2.6	74.08
Ethyl mercaptan	75-08-1	C_2H_6S	2.80	18.00	-48.3	299	0.8315	2.14	62.14
Ethyl methyl ether	540-67-0	C_3H_8O	2.00	10.10	-37.2	190	0.7251	2.1	60.10
Ethyl pentane-3	617-78-7	C_7H_{16}	0.80	5.00	-14	not available	0.7	0.70	100.2
Ethylene oxide	75-21-8	C_2H_4O	3.00	100.00	-29	429	0.882	1.5	44.05
n-Heptane	142-82-5	C_7H_{16}	1.05	6.70	-7	220	0.6795	3.5	100.2
Hexadiene, 1.5	592-42-7	C_6H_{10}	2.00	6.00	-27	240	0.692	2.9	82.14
n-Hexane	110-54-3	C_6H_{14}	1.10	7.50	-22	225	0.6606	2.97	86.18
Hydrazine	302-01-2	N_2H_4	4.70	100.00	40	270	1.0036	1.1	32.046
Hydrogen	1333-74-0	H_2	4.00	75.00	gas	560	8.20E-05	0.07	2.016
Hydrogen cyanide	74-90-8	HCN	5.60	40.00	-18	538	0.6875	0.94	27.025
Isobutene (Isobutylene)	115-11-7	C_4H_8	1.80	9.60	-76.1	465	0.589	1.94	56.11
Isopropanol	67-63-0	C_3H_8O	2.00	12.70	11.7	456	0.78509	2.07	60.1
Methane	74-82-8	CH_4	5.00	15.00	gas	537	0.716	0.55	16.043
Methanol	67-56-1	CH_4O	6.00	36.00	9	440	0.792	1.11	32.042
Methyl acetate	79-20-9	$C_3H_6O_2$	3.00	16.00	-13	505	0.9342	2.6	74.08
Methylamine	74-89-5	CH_5N	4.90	20.70	-10	430	0.6624	1.08	31.057
Methyl bromide	74-83-9	CH_3Br	10.00	16.00	gas	537	1.6755	3.36	94.94
Methyl chloride	74-87-3	CH_3Cl	8.10	17.40	gas	632	0.911	1.78	50.49
Methyl ether	115-10-6	C_2H_6O	2.00	50.00	gas	350	0.61	1.6	46.07

blacklinesafety

GAS PROPERTIES TABLE (cont.)

COMMON NAME	CAS NUMBER	FORMULA	FLAMMABLE RANGE (OSHA)		FLASH POINT (°C)	IGNITION TEMPERATURE (°C)	DENSITY (g/cm³)	RELATIVE VAPOR DENSITY (OSHA)	MOLECULAR WEIGHT (g/mol)
			LOWER EXPLOSIVE LIMIT (%/vol)	UPPER EXPLOSIVE LIMIT (%/vol)					
Methyl ethyl ketone	78-93-3	C_4H_8O	1.40	11.40	-9	505	0.805	2.42	72.11
Methyl formate	107-31-3	$C_2H_4O_2$	4.50	23.00	-19	449	0.987	2.1	60.05
Methyl hexane, 2-	591-76-4	C_7H_{16}	1.00	6.00	-18	220	0.68	3.4	100.2
Methyl mercaptan	74-93-1	CH_4S	3.90	21.80	-18	360	0.87	1.66	48.11
Methyl n-propyl ketone	107-87-9	$C_5H_{10}O$	1.50	8.20	7	505	0.809	3	86.13
Methyl propionate	554-12-1	$C_4H_8O_2$	2.50	13.00	-2	469	0.915	3	88.11
Methylcyclohexane	108-87-2	C_7H_{14}	1.20	6.70	-4	258	0.7694	3.4	98.19
Methylpentane, 2-	107-83-5	C_6H_{14}	1.20	7.70	-32	264	0.6550	3	86.18
Napthalene	91-20-3	$C_{10}H_8$	0.90	5.90	80	540	1.16	4.42	128.17
Nitromethane	75-52-5	CH_3NO_2	7.30	63.00	35	417	1.1371	2.1	61.04
n-Nonane	111-84-2	C_9H_{20}	0.80	2.90	31	205	0.7176	4.41	128.25
n-Octane	111-65-9	C_8H_{18}	1.00	6.50	13	220	0.6986	3.94	114.23
n-Pentane	109-66-0	C_5H_{12}	1.50	7.80	-49	260	0.6262	2.48	72.15
i-Pentane	78-78-4	C_5H_{12}	1.40	7.60	-51	420	0.6201	2.48	72.15
Neopentane	463-82-1	C_5H_{12}	1.40	7.50	-7.15	450	0.613	2.5	72.15
Phosphine	7803-51-2	PH_3	1.79	98.00	gas	38	0.00139	1.18	33.998
Propane	74-98-6	C_3H_8	2.10	9.50	-104	450	0.493	1.6	44.1
n-Propanol	71-23-8	C_3H_8O	2.20	13.70	15	371	0.8053	2.1	60.1
Propene	115-07-1	C_3H_6	2.00	11.10	gas	460	0.5139	4.46	42.08
isopropyl ether	108-20-3	$C_6H_{14}O$	1.40	7.90	-28	443	0.7258	3.5	102.17
n-Propylamine	107-10-8	C_3H_9N	2.00	10.40	-37	320	0.719	2	59.11
Propylene oxide	75-56-9	C_3H_6O	2.80	37.00	-37	430	0.8304	2	58.08

blacklinesafety

GAS PROPERTIES TABLE (cont.)

COMMON NAME	CAS NUMBER	FORMULA	FLAMMABLE RANGE (OSHA)		FLASH POINT (°C)	IGNITION TEMPERATURE (°C)	DENSITY (g/cm³)	RELATIVE VAPOR DENSITY (OSHA)	MOLECULAR WEIGHT (g/mol)
			LOWER EXPLOSIVE LIMIT (%/vol)	UPPER EXPLOSIVE LIMIT (%/vol)					
Propyne	74-99-7	C_3H_4	1.70	11.70	gas	not available	0.607	1.4	40.06
Toluene	108-88-3	C_7H_8	1.10	7.10	4	480	0.87	3.1	92.14
Triethylamine	121-44-8	$C_6H_{15}N$	1.20	8.00	-17	230	0.7275	3.5	101.19
Trimethylamine	75-50-3	C_3H_9N	2.00	11.60	gas	190	0.633	2	59.11
Vinyl chloride	75-01-4	C_2H_3Cl	3.60	33.00	-78	472	1.41	2.2	62.5
m-Xylene	108-38-3	C_8H_{10}	1.10	7.00	27	527	0.8698	3.7	106.16
o-Xylene	95-47-6	C_8H_{10}	0.90	6.70	32	463	0.8801	3.7	106.16
p-Xylene	106-42-3	C_8H_{10}	1.10	70	27	528	0.86104	3.7	106.16

blacklinesafety

For more information, please email us at **info@blacklinesafety.com**