Detecting Gas Saving Lives

**Batteries and Other New Power Opportunities**

# Application Brief

**March 2021**

# 1. Introduction

## Battery and fuel cells as storage of renewable energy

**The Paris Agreement on climate change holds nations accountable for reducing their greenhouse emissions and reliance on fossil fuels, thus driving them to invest and use renewable energies, such as solar and wind. However, the sun doesn't always shine and it's not always windy – or it might be very sunny or windy, leading to over-supply of the grid. To ensure that renewables are used for maximum benefit, any excess energy they produce (i.e., that isn't needed for the grid at that time) is stored in local storage facilities, which take the form of large batteries. These release energy later – when the grid requires more power, or when there is less sun or wind, such as overcast nights or calmer, duller days. However, these batteries can only release energy for a few (between 1 and 12) hours, so their use is limited to short-term, energy-on-demand requirements.**

Batteries are effective at reducing power outages since they can also store excess traditional grid energy. The energy stored within batteries can be released whenever a large volume of power is needed, such as during a power failure at a data centre to prevent data being lost, or as a back-up power supply to a hospital or military application to ensure the continuity of vital services. Large scale batteries can also be used to plug short-term gaps in demand from the grid. These battery compositions can also be used in smaller sizes to power electric cars and may be further scaled down to power commercial products, such as phones, tablets, laptops, speakers and – of course – personal gas detectors.

## Overview of battery technologies

**Battery technologies can be segregated into four main categories:**

**Chemical** – e.g. ammonia, hydrogen, methanol and synthetic fuel

**Electrochemical** – lead acid, lithium ion, Na-Cd, Na-ion

**Electrical** – supercapacitors, superconductive magnetic storage

**Mechanical** – compressed air, pumped hydro, gravity

Mechanical options, such as pumped hydro, currently account for 95% of the world's stored energy supply, but this requires large amounts of space in specific geographies, which calls for the flooding of large amounts of land and is very inefficient. The lead-acid battery is now regarded as the 'traditional' form, having been the battery chemistry of choice for decades; its many uses include car batteries and numerous appliances including gas detectors. Lithium-ion batteries are commonly used in electronic goods like laptops and cameras, and in electric cars.

Some of the electrical alternatives, such as supercapacitors, function like batteries since they store energy, but their use is less prevalent. For this application brief the technologies of interest are hydrogen, lead-acid batteries and lithium-ion batteries.

So, why are such batteries being increasingly used when there are lots of other options? Put simply, they have proven to be the most reliable and accessible way to quickly store and release energy to the grid.

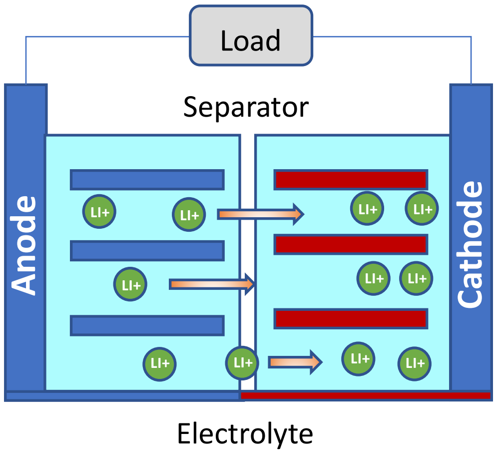
# 2. The Storage of Renewable Energy in Li-ion Battery and Hydrogen Fuel Cells

## Batteries

A battery is made up of an anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The anode and cathode store the lithium. ***Figure 1*** illustrates this.

The electrical current flows from the current collector through the device being powered to the negative current collector.

The movement of the lithium ions creates free electrons in the anode which creates a charge at the positive current collector.




The anode and cathode store the lithium.

The electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator.

***Figure 1: The components of a battery.***

## Hydrogen Fuel Cells

Fuel cell systems are a clean, efficient, reliable and quiet source of power. Fuel cells do not need to be periodically recharged like batteries; they continue to produce electricity as long as a fuel source is provided. A fuel cell is composed of an anode, cathode and an electrolyte membrane. A typical fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. At the anode site, a catalyst splits the hydrogen molecules into electrons and protons. The protons pass through the porous electrolyte membrane, while the electrons are forced through a circuit, generating an electric current and excess heat. At the cathode, the protons, electrons and oxygen combine to produce water molecules. As there are no moving parts, fuel cells operate silently and with extremely high reliability.

Regardless of how hydrogen is manufactured, its use will increase exponentially over the next few years. It is currently easiest to harvest hydrogen by using and separating fossil fuels, but the use of electrolysis for this purpose will catch up by 2050. Unlike fossil fuels, electrolysis splits water ($H_2O$) into hydrogen and oxygen, so it involves no waste and all parts are used, generating zero environmental impact. If the energy used for electrolysis is taken from renewables, this can be counted as 'green fuel' since there are no negative impacts on the environment at all.

## 3. Dangers associated with batteries and fuel cells

The two major dangers arising from fuel cells and hydrogen fuel cells are the risk of battery fires and the flammability of the hydrogen.

## Li-ion battery fires

A major concern arises when static electricity or a faulty charger has destroyed the battery's protection circuit. Such damage can permanently fuse the solid-state switches into the ON position, without the user knowing. A battery with a faulty protection circuit may function normally, but it does not provide protection from short circuit.

A short circuit inside the battery can occur if the battery is exposed to a static charge, has experienced a mechanical failure (such as an impact or piercing) or through ageing/long term degradation. This can cause the battery to heat up inside and once a certain level of pressure and/or temperature is met, the electrolyte gasses are released. Fortunately, modern batteries do this in a more controlled way than their predecessors, but it is possible that older or cheaper batteries won't behave in a controlled manner. At this point, a gas detection system can establish if there is a fault and may be used in a feedback loop to shut off power, seal the space and release an inert gas (such as nitrogen) into the area to prevent any fire or explosion. It is interesting to note that battery fires are not limited to industrial-scale batteries, they can also happen on smaller, more personal items such as laptops and mobile phones.

If there is no gas detection system or feedback loop installed, the battery will heat up exponentially – a phenomenon known as *thermal runaway* – and will spontaneously combust and explode. There are many studies to predict thermal runaway before it happens, and analysis of the gases released when batteries malfunction help researchers to understand how thermal runaway occurs.

## Leakage of toxic gases prior to thermal runaway

Thermal runaway of lithium-metal and lithium-ion cells has caused numerous fires. Studies have found the fires to be fuelled by the flammable gases that are vented from the batteries during thermal runaway. Gases that are commonly given off by faulty batteries are highlighted in Table 1, below.

*Table 1: The gases highlighted are commonly emitted by faulty batteries.*

| | | Workplace Exposure Limits (taken from EH40, Jan 2020) | | OSHA- PELs | Relative Density Air = 1 |
|---|---|---|---|---|---|
| **Substance** | **Chemical Formula** | **LTEL (8hr TWA) ppm** | **STEL (15- Min. TWA) ppm** | **LTEL (8hr TWA) ppm** | |
| **Ammonia** | $NH_3$ | 25 | 35 | 50 | 0.59 |
| **Carbon Dioxide** | $CO_2$ | 5000 (0.5%) | 15000 (1.5%) | 5000 | 1.53 |
| **Carbon Monoxide** | CO | 20 | 100 | 50 | 0.97 |
| **Chlorine** | $CL_2$ | 0.5 | 0.5 | 1 | 2.5 |
| **Chlorine Dioxide** | $CLO_2$ | 0.1 | 0.3 | 0.1 | 2.3 |
| **Diborane** | $B_2H_6$ | 0.1 | - | 0.1 | 0.96 |
| **Ethylene Oxide ETO** | $C_2H_4O$ | 5 | - | 1 | 1.52 |
| **Hydrogen Cyanide** | HCN | 0.9 | 4.5 | 10 | 0.94 |
| **Hydrogen Chloride** | HCL | 1 | 5 | 5 ceiling* | 1.3 |
| **Hydrogen Fluoride** | HF | 1.8 | 3 | 3 | 0.92 |
| **Hydrogen Sulphide** | $H_2S$ | 5 | 10 | 20 ceiling* | 1.2 |
| **Nitrogen Dioxide** | $NO_2$ | *0.5* | 1 | 5 ceiling* | 2.62 |
| **Ozone** | $O_3$ | - | 0.1 | 0.1 | 1.6 |
| **Phosgene** | $COCL_2$ | 0.02 | 0.06 | 0.1 | 3.48 |
| **Silane** | $SiH_4$ | 0.5 | 1 | - | 1.3 |
| **Sulphur Dioxide** | $SO_2$ | 1 | 1 | 5 | 2.25 |

The electrolyte in a lithium-ion battery is flammable and generally contains lithium hexafluorophosphate (LiPF6) or other Li-salts containing fluorine. In the event of overheating, the electrolyte will evaporate and eventually be vented out from the battery cells. Researchers have found that commercial lithium-ion batteries can emit considerable amounts of hydrogen fluoride (HF) during a fire, and that emission rates vary for different types of battery and state-of-charge (SOC) levels. Hydrogen fluoride can penetrate skin to affect deep skin tissue and even bone and blood. Even with minimal exposure, pain and symptoms may not present for several hours, by which time damage is extreme.

Consequently, it is very important to have HF detectors wherever Li-ion batteries are stored, so that any release is detected and the relevant authorities can deal with it. If inhaled, especially as part of a fire, HF may cause severe throat and lung irritation leading to pulmonary oedema (water on the lungs) and ultimately death within hours. It can also cause severe eye damage, which may lead to blindness – and again, exposure and symptoms may go unnoticed until it is too late. It can also react with blood calcium to produce calcium fluoride, which weakens bones as the body removes the calcium from them, in a bid to equilibrate. This cycle continues and ultimately muscles shut down, including the heart, since they need calcium to function. The result is cardiac arrest and death.

The same study has found that carbon monoxide (CO) and carbon dioxide ( $CO_2$) are also released during thermal runaway. The dangers of CO to humans are well documented in health and safety guides worldwide. Carbon monoxide is often called 'the silent killer', as it displaces oxygen in the blood and deprives the heart, brain and other vital organs of oxygen. Large amounts of CO can knock a person unconscious in minutes, without warning, and lead to death by suffocation; CO is also very good indicator of combustion, so the release of CO may allow the early detection of thermal runaway. Some applications may require gas detector alarm levels to be set below the short-term exposure limit (STEL) and long-term exposure limit (LTEL), to ensure that action is taken before thermal runaway occurs.

Carbon dioxide can be produced within Li-ion batteries under certain conditions. It is widely known that toxic levels of $CO_2$ prevent sufficient oxygen being breathed into the lungs, which can lead to suffocation and, in extreme cases, death. Both CO and $CO_2$ can be used (alongside voltage drop) as early indication of thermal runaway. The detection of CO or $CO_2$ can be via detectors linked to a controller that triggers nitrogen gas venting.

The relative density of gases versus air helps to determine where the detectors should be placed for maximum detection opportunity. Carbon monoxide and HF are of a similar density to air, so sensors for these should be placed at head height, but $CO_2$ detectors should be placed lower down.

Crowcon's XgardIQ with remote sensor option gives the end user flexibility in terms of installing sensors according to recommended placement level, while the XgardIQ display can be kept at eye-level for ease of operation. The XgardIQ's output can be connected to a controller or feedback loop to trigger nitrogen gas venting or alert plant operators.

## Hydrogen and explosion risk

With hydrogen fuel cells gaining popularity as alternatives to fossil fuel, it is important to be aware of the dangers of hydrogen. Like all fuels, hydrogen is highly flammable and if it leaks there is real risk of fire. However, there are major differences between hydrogen fires and those of other fuels. When heavier fuels like petrol or diesel fuels leak, these hydrocarbons will pool close to the ground. Hydrogen is one of the lightest elements on earth, so when a leak occurs the hydrogen quickly disperses upwards, making ignition less likely. Another difference is that hydrogen ignites and burns more easily than petrol or diesel – even a spark of static electricity from a person's finger is enough to set off an explosion. Hydrogen flame is also invisible, so it is hard to pinpoint where is the 'fire' is, but it generates a low radiant heat due to the absence of carbon and will burn out quickly. You can read more about the dangers of hydrogen in our blog.

Traditional lead acid batteries produce hydrogen when they are being charged. These batteries are normally charged together, sometimes in the same room or area, which can generate an explosion risk, especially if the room is not properly ventilated.

Hydrogen is 15 times less dense than air, so will rise and collect at the highest part of the space, which is where the hydrogen detector should be located for maximum benefit. Unfortunately, this also means the detector is out of reach and difficult to maintain.

The Xgard Bright with MPS™ sensor provides a far better solution for hydrogen detection, and the challenges faced with traditional sensor technology are completely removed. It is a long-life hydrogen sensor that does not require calibration throughout its life cycle, carries no risk of poisoning or false alarms and can significantly reduce the total cost of ownership and interaction with the unit. All of this gives peace of mind and reduced risk for operators, thanks to its MPS™ technology. You can find out more about MPS™ technology here.

Most hydrogen applications cannot use odorants for safety, as hydrogen disperses faster than odorants do. There are applicable safety standards for hydrogen fuelling stations, whereby appropriate protective gear is required for all workers. This includes personal detectors, capable of detecting ppm level hydrogen as well as %LEL level. The default alarm levels are set at 20% and 40% LEL which is 4% volume, but some applications may wish to have a custom PPM range and alarm levels to pick up hydrogen accumulations quickly. The Crowcon Gas-Pro detector can be used to detect both ppm and %LEL hydrogen levels, and takes into account the cross sensitivity of gases, as hydrogen will positively affect CO readings. A special $H_2$-compensated CO sensor can be used to accurately determine CO levels.

**References:**

1. Lithium Battery Thermal Runaway Vent Gas Analysis (Federal Aviation Administration, Nov 2016)
2. Lessons Learned from a Hydrogen Explosion (Powermag.com, 1 May 2009)
3. What are the dangers of hydrogen-powered vehicles? (Howstuffworks.com)
4. Hydrogen Compared with Other Fuels (H2tools.org)
5. Hydrogen Fuel Safety: Essential Facts for Transit Operators (Ballard.com, 12 Oct 2017)

# Crowcon detectors for use with batteries and renewables

## Portable Monitors

### T4

- Easy to use one-button functionality
- TWA resume function
- MED certification
- Easy servicing and quick turnaround
- Bump test station available

### Gas-Pro

- Integrated pump (up to 30 m sampling)
- One-button operation
- IR sensor for wide range of hydrocarbons
- MED certified
- Confined space entry (CSE) kit available
- Bump test station available

### Clip SGD

- One-button operation
- Suited for $CO_2$ and $NH_3$

### Gas-Pro TK

- Easy to use one-button functionality
- TWA resume function
- MED certification
- Easy servicing and quick turnaround
- Bump test station available

### LaserMethane mini (LMm)

- Long range methane detector
- Detects up to 100m with reflector
- Highly visible green laser light
- No moving parts and requires little maintenance
- Self-check and autocalibration upon start-up

## Fixed Monitors and Controllers

### Xgard

- Rugged reliable detector
- Available in various gases and material
- mA or mV output

### Xgard Bright

- Modbus or Hart output
- Local display
- Non-intrusive calibration
- Modbus or Hart Output
- Now available with MPS (molecular property spectrometer) for calibration free flammable gas detection

### XgardIQ

- Universal transmitter for all sensor types
- Hot swap sensor module – no special tools required
- Non-intrusive calibration
- Modbus or Hart Output
- $SIL_2$ rated
- Remote sensor option available

### Vortex


- Up to 12 configurable channels
- MODBUS compatibility
- SIL 1 (IEC 61508) validated

### GM Controllers


- Up to 128 channel inputs
- Modular configuration
- Touch screen display

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## ABOUT CROWCON

**For over 50 years, Crowcon has been developing and manufacturing high-quality gas detection products, securing a reputation for reliability and technical innovation that continuously improves efficiency and safety. Globally respected, and part of FTSE 100 Halma, today, over 500,000 Crowcon devices are in use around the world.**

Our vision is to grow a safer, cleaner, healthier future for everyone, every day, by providing best in class gas sensing solutions. The Crowcon range offers both fixed and portable gas detection equipment enhanced with Crowcon Connect, our digital solution, which protects people and places in industries including petrochemical, oil and gas, water, industrial manufacturing and food production. In every case, we combine our expertise with emerging technologies to develop process insights and protection for our customers, improving their operational efficiency and creating safer, cleaner and healthier workplaces.

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