

Greenhouse gas emissions and reduction studies using a portable TDL gas monitor

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ABSTRACT

Boreal Laser's GasFinder is a portable open path gas monitor based on laser technology. GasFinder is uniquely suitable for studies of greenhouse gas emissions. It is specific to the gas of interest, provides one second response and has a broad dynamic range. GasFinder is permanently calibrated and is very small and light (less than 5kg). Alignment is easy and stable. No on-site electronic tuning is required, so a series of paths of different lengths (between 1m and 1000m) can be measured in quick succession. Consequently, GasFinder has been used in several greenhouse gas studies, both to establish baseline emissions and to determine the effectiveness of process improvements to reduce emissions.

Examples presented in this paper include: CH₄ leak detection in the natural gas industry, CH₄ "hot-spot detection in landfills; NH₃ monitoring in agricultural operations; CO₂ emissions measurement; and emissions (esp. HF) monitoring in the aluminium industry. A multiple path version of GasFinder, GasFinder MC, that is ideally suited for permanent monitoring installations, is briefly described.

INTRODUCTION

Laser based gas detectors using room temperature tunable diode lasers (TDL) are gaining growing acceptance for critical ambient, safety, environmental and process monitoring applications. The laser method has several advantages over existing gas detection techniques (see Table 1 and References 1-3). For practical purposes, lasers generate light at a single wavelength. Room temperature TDLs emit light in the near infrared (NIR). Many gases of interest absorb light in the NIR. Each gas has a unique absorption signature, or spectrum, made up of a large number of individual “absorption lines”. A TDL can be tuned to select a single absorption line of a target gas, which does not overlap with absorption lines from any other gases. So, laser gas sensing is very selective, and does not suffer from interference from other gases.

Table I: Benefits of laser detectors compared with other gas measurement techniques.

Features	Benefits
Very high resolution	<ul style="list-style-type: none">• Minimum interference from other gases• Linear response over wide range
Intense light source	<ul style="list-style-type: none">• Rapid response – typically 1 second• Very sensitive – ppm to ppb levels
Lasers available throughout the NIR	<ul style="list-style-type: none">• Widely applicable
Solid state technology	<ul style="list-style-type: none">• Robust and reliable in all weather• No consumables and no maintenance
Fibre-optic coupling	<ul style="list-style-type: none">• Lower cost per measurement

TDLs generate only a few mW of power. However, all this power is concentrated at one wavelength, the wavelength where gas absorption occurs. So, high signal to noise ratios are achieved, and response times are short, typically about 1 or 2 seconds. This also means that long path lengths can be used, enabling accurate measurements of very low concentrations, even with weakly absorbing gases.

Diode lasers provide all the advantages of other semiconductor devices. They are small, solid-state devices. They operate at room temperature and have long-term reliability (over 5 years). Currently, they can be obtained for any wavelength throughout the NIR (700nm to 2000nm). Because many gases absorb in the NIR, the technique is widely applicable.

The laser light from TDLs can be easily coupled into inexpensive and highly transmitting optical fibres. The light from a single laser can then be switched into several fibres, enabling multiple point measurement with a single laser gas analyzer (Reference 4). This leads to lower cost per measurement.

GasFinder – a laser gas analyzer with additional benefits

Boreal Laser's GasFinder is a laser gas detector with some unique and patented features that give it significant advantages in cost, reliability and ease of use. The wavelength modulation technique used with all laser gas detectors (Reference 5) normally requires a phase matching procedure that takes time and expertise. This procedure must be repeated every time the path length is changed. GasFinder employs a patented "No Phase Adjustment" detection technique (Reference 6) that removes the need for this procedure. What this means is that different path lengths can be measured without requiring any adjustments to the GasFinder. This in turn means ratiometric measurements are possible. The signal from the measurement path is regularly compared with the signal from a calibration/reference cell inside the GasFinder in order to calculate the gas concentration in the path (see Figure 1). It also means that no special adjustments and no special expertise are needed to set GasFinder up for different path lengths.

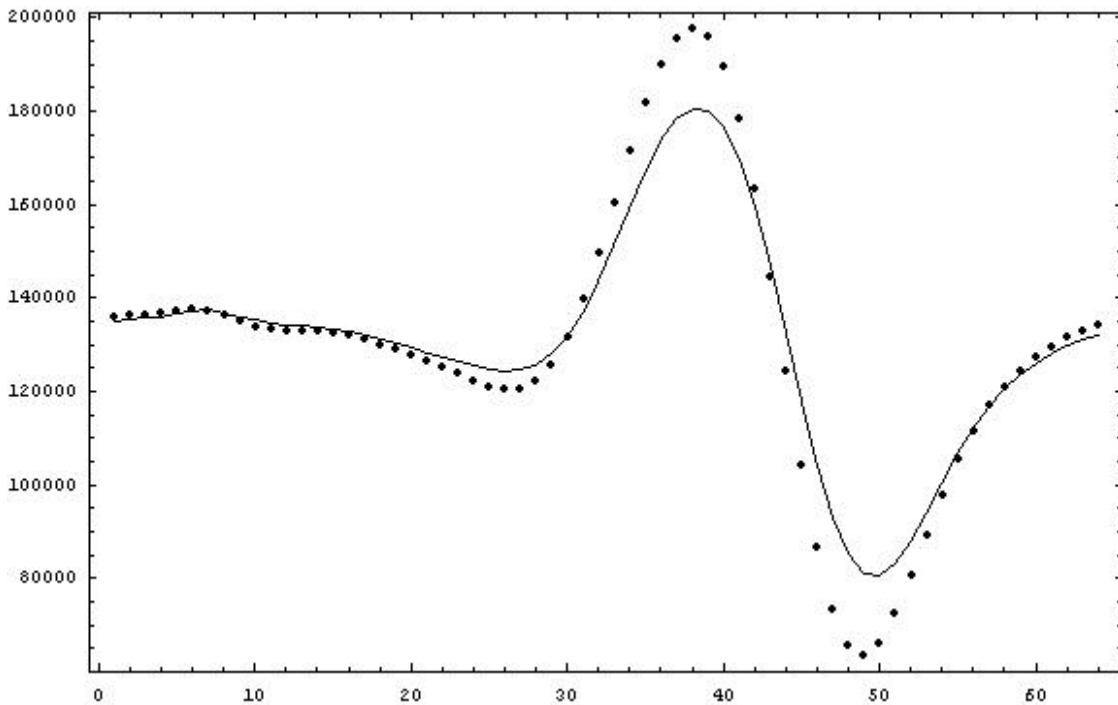


Figure 1 – Absorption line scan showing measured waveform (dotted) and reference waveform (solid). The absorption line is scanned 300 times per second.

A second unique aspect of GasFinder is the design and construction of a permanent **stable**, calibration cell for reactive gases (Reference 7). This means the ratiometric measurement will work repeatedly and reliably over years of operation. In addition, the laser in GasFinder is successively tuned to be off and then on the absorption line. When it is off the line, the reference cell measurement is equivalent to a zero check. When it is on the line, the reference cell reading is a span check. Because the calibration cell is stable, this means that:

- There is no zero or span drift.

- GasFinder can be calibrated in the factory, it does not need to be calibrated at installation, and it never needs to be calibrated again during operation.
- It is certain the target gas is being measured, and not some other gas with an adjacent absorption line – especially important when there is no target gas in the measure path.

Without a stable calibration cell, these claims cannot be made. As this is such an important feature of GasFinder, a built in diagnostic function continually checks the stability of the calibration cell.

GasFinder is currently available in two configurations. The portable GasFinder (see figure 2) consists of an integrated transmitter/receiver unit and a remote, passive retro-reflector array. The GasFinder is aligned with the retro-reflector using a two-axis instrument mount assisted by a telescopic sight and an on-board visible aiming laser. GasFinder can operate with path lengths from 1m to 1000m. GasFinder is battery operated and weighs less than 5kg. Because of “No Phase Adjustment” technology, it takes less than 10 minutes to set up GasFinder and commence measurements. So GasFinder is ideally suited for portable use, and temporary installations. GasFinder can be used for open path and across stack (or duct) measurements.

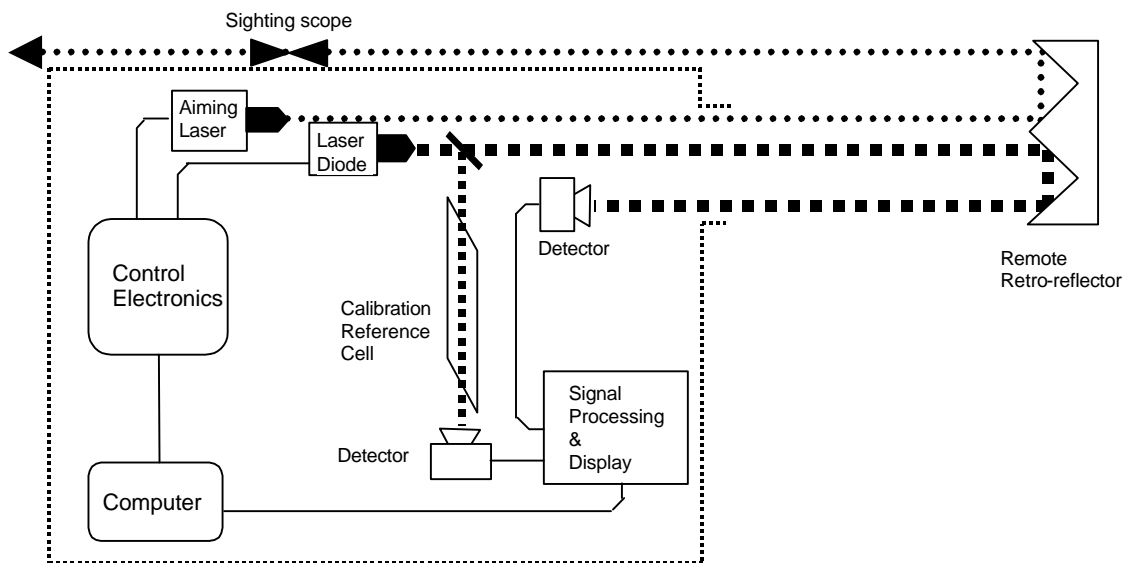


Figure 2 - Schematic diagram of GasFinder.

GasFinder MC is a multiple channel version that provides up to 8 independent measurement paths and 1 or 2 gases (see figure 3). The configuration for coupling multiple lasers into multiple optical fibers is unique and patented. The “No Phase Adjustment” technology is a requirement to make the multiple path configuration work, because the laser light is sequentially switched on to different paths of different optical length. The central control unit is a 19” rack mountable unit that contains the laser, multiplexing and data processing components. Fibre-optic cable carries the laser light to transmitter heads, which direct the beam along a path to a reflector. The return light is

collected on a non-biased photo-detector. The photo current is returned to the central box using coaxial cable. The transmitter heads are therefore intrinsically safe. GasFinder MC complies with Class 1, Div 1 and Cenelec Zone 1 hazardous area certifications. GasFinder MC is available in open path, stack/duct, and process monitoring configurations.

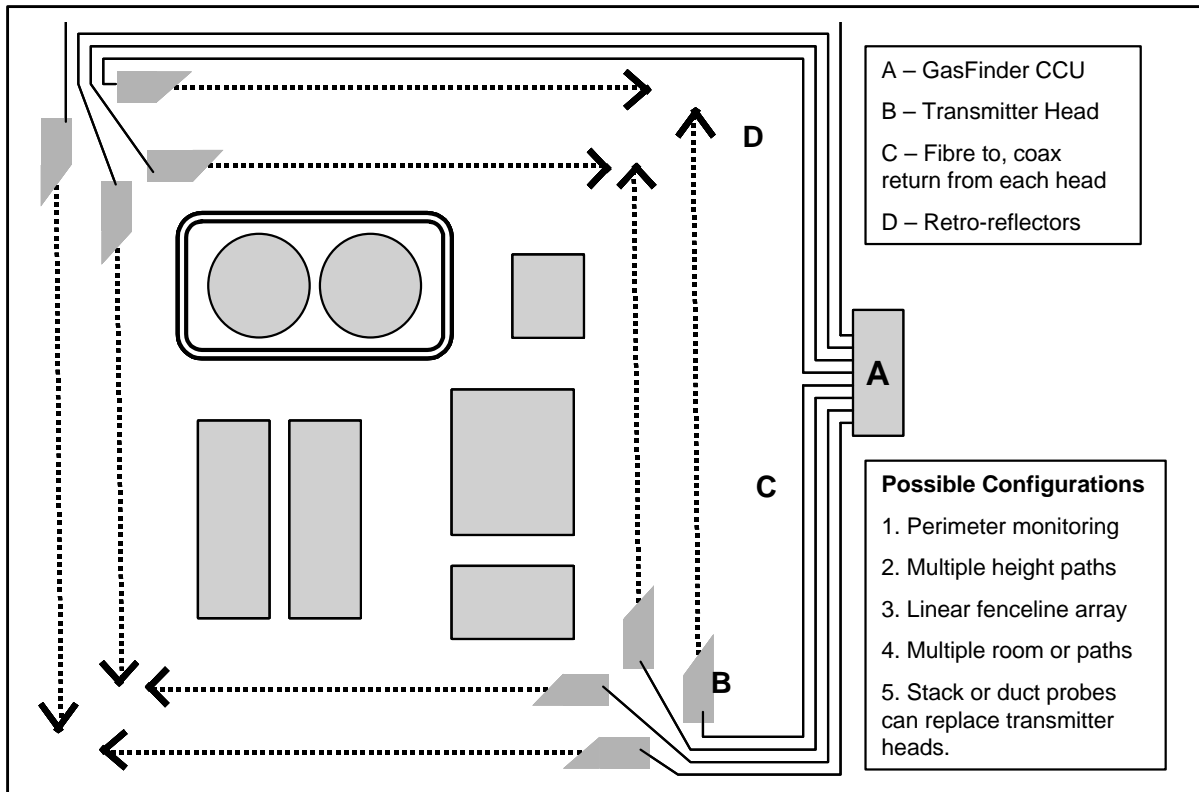


Figure 3 – GasFinder MC possible configuration

GREENHOUSE GAS MONITORING

Greenhouse gases (GHG) are typically released as controlled emissions from stacks and vents or as fugitive emissions from industrial facilities or operations. GasFinder (especially in the MC configuration) can readily monitor stack or vent emissions of GHG. However, it is as a tool for monitoring fugitive emissions of GHG that GasFinder possesses some unique advantages. Most sources of fugitive emissions are area (or multiple point) rather than point sources. So, open path area or perimeter monitoring provides more meaningful fugitive emissions data than an array of point sensors or a program of grab sampling. Point measurements may underestimate emissions because of missing locations with high gas concentrations, or conversely overestimate because they are located in areas of high concentrations. Grab sampling programs typically check only a small percentage of potential leak locations and extrapolate results to an entire facility. Wide margins of uncertainty are associated with such extrapolations. Open path monitoring provides continuously updated, real-time, integrated emissions

across a facility boundary. This provides a complete picture of the fugitive emissions across that boundary, enabling identification of specific operations and times that give rise to higher emissions, and so enabling these emissions to be properly managed and controlled.

Several optical techniques are available for open path monitoring. These include UV, IR and FTIR as well as lasers. However, the GasFinder laser technique has some specific benefits for open path monitoring:

- GasFinder is self-calibrating – so no field calibration is required.
- It is easy to set-up and align, can be used on paths from 10m to 1000m
- It is small, light and battery operated – and so, truly portable.
- No interference from other atmospheric gases such as H₂O and CO₂.

As a result of these persuasive benefits, GasFinder has been used to monitor all the common greenhouse gases – methane (CH₄), ammonia (NH₃) and carbon dioxide (CO₂). Table 2 summarizes the GasFinder MDLs for these and other gases. Several of these MDLs have been independently verified by the EPA’s Environmental Technology Verification (ETV) program (Reference 8). Specific applications are described below.

Table II – GasFinder minimum detectable limits (MDL) for various gases

Gas	MDL (ppm-m)	10m (ppm)	100m (ppm)	1000m (ppm)
CH ₄	1	0.1	0.01	0.001
NH ₃	5	0.5	0.05	0.005
CO ₂	1000	100	10	1
HF	0.1	0.01	0.001	0.0001
H ₂ S	10	1	0.1	0.01

CH₄ leak detection in the natural gas industry

Natural gas is a commodity that has multiplied in value in recent years. This has resulted in a significant increase in natural gas drilling, production and processing operations. A common use for GasFinder in sour gas operations is the quick and unambiguous detection of H₂S leaks. However, CH₄ and CO₂ leaks from natural gas operations are also common. Large producing fields and processing plants have many kilometres of pipeline and hundreds of valves. Detecting and quantifying a leak is a logistical nightmare.

A fixed GasFinder perimeter open path monitoring system give an early warning of a leak. A portable GasFinder can then be used to hunt down the source of the leak.

The only equipment required to do this is the GasFinder, tripod and battery at one end of the designated path and a retro-reflector at the other end. The length of path will determine the size of the reflector. Path length can be up to 1km, though the average is about 100m. A series of readings with the path in a grid pattern can often quickly locate the source of a leak (see Reference 9).

Gas turbine inefficiency and blow-by can be evaluated by monitoring exhaust stacks. Figure 7 shows the different values of emissions coming from a compressor station with six banks each having six turbine compressor units. Compressors #2 and #4 are very poor, #1 and #5 are good and #6 is not operating. Note the short time scale over which these measurements were taken. This is possible only because GasFinder is portable, and does not have to be adjusted for different path lengths.

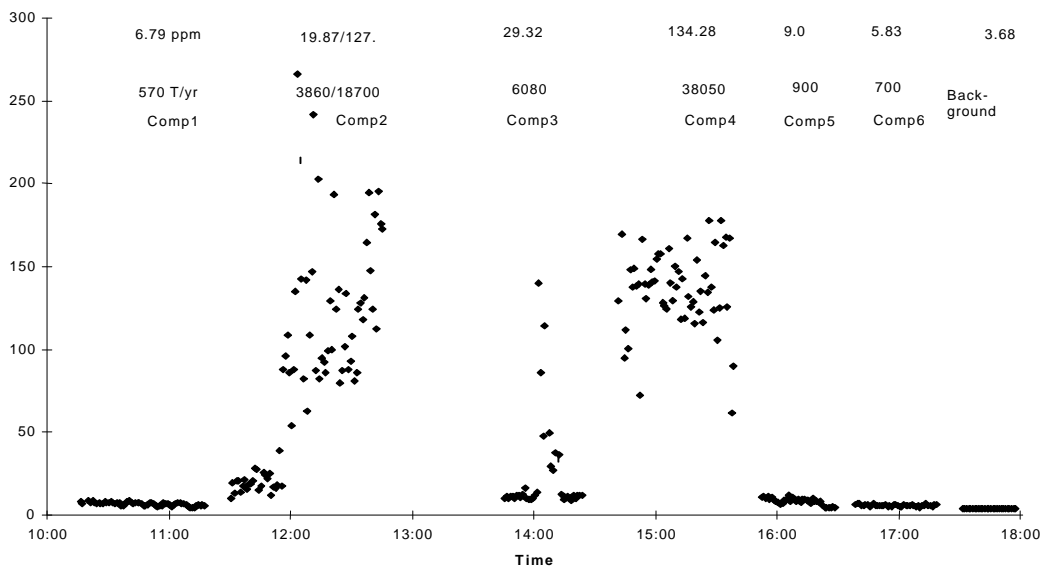


Figure 4 – Methane concentrations downwind of 5 turbine compressor units

An airborne version of GasFinder detects CH₄ leaks from natural gas pipelines. The airborne detector reports CH₄ content of the air above the pipeline five times per second (equivalent to every 10 m). Ambient methane levels are about 2 ppm. A warning is indicated at 5 ppm, and an alarm sounds at 10 ppm. Figure 8 shows an instance where a significant leak was found, the real time alarm was activated and the helicopter pilot went back and circled the source of the leak a few times to confirm the initial reading.

In North America alone there are thousands of kilometres of pipeline often in remote areas. Leak detection presents a challenge that can be overcome by using an airborne system. It is important to note that, aside from GHG emissions considerations, there is often a large economic benefit associated with early detection and resolution of pipeline CH₄ leaks.

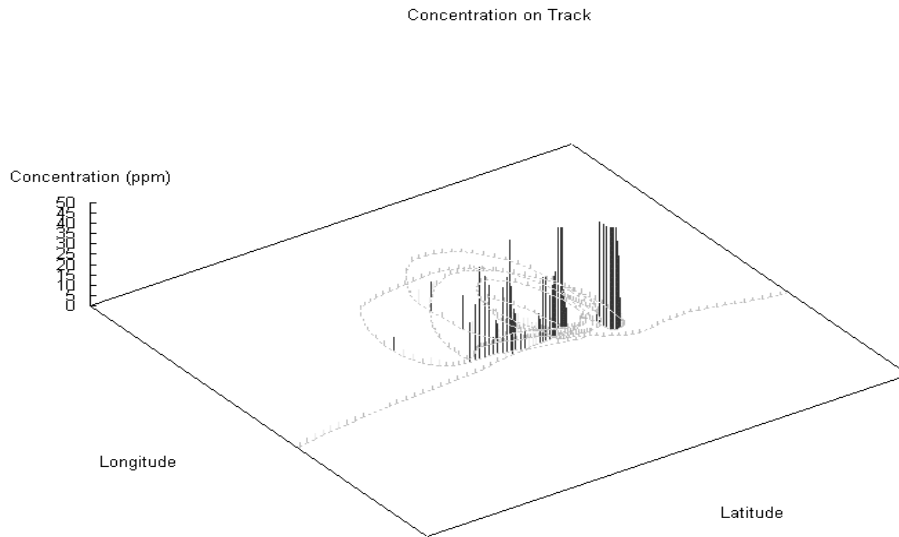


Figure 5 - Airborne monitoring of methane leaks from gas pipelines

CH₄ “hot-spot” detection in landfills

Landfill gas is created when waste in landfills decomposes. Landfill gas consists mostly of CH₄ (55%) and CO₂ (45%). H₂S and NH₃ are also present. CH₄ is explosive (lower limit of 4.5% in air) as well as being a GHG. So it is important to monitor methane emissions from landfills for both safety and environmental reasons. GasFinders have been used on many landfill studies worldwide.

In a typical study CH₄ concentrations are taken using multiple path measurements across the entire landfill. Measurements upwind of the landfill are made to locate any other influencing methane sources and to measure the local ambient methane levels. An overall ‘picture’ of surface emissions is mapped. Hotspots (areas with high concentration gradients) are located. If necessary, the flux (overall emissions) from the hotspots can then be measured. Reference 10 provides a detailed description of the use of dispersion models to calculate emission rates from concentration data measured with GasFinder.

NH₃ monitoring in agricultural operations

Various research organisations have used GasFinders to conduct measurements of NH₃ and CH₄ emissions from agricultural operations. For example, large hog populations produce large amounts of hog manure, which many operators store in open lagoons to be applied to land as fertilizer at some later date. The handling, storage and land applications of hog manure results in the release of ammonia and odourous compounds to the atmospheres. Public concern over the effect of these emissions has risen steadily in recent years. Reference 11 reports ammonia emission rates from hog farms in Alberta measured

with GasFinder. Emission rates from storage lagoons ranged from 4.8 to 38.2 g/m²/hr. During field spreading, emission rates of up to 8.2 kg/day/m² were measured.

NH₃ emissions from refining and chemical operations

Refining, petrochemical and chemical (e.g. fertilizer) operations consume or produce large amounts of ammonia, and so have the potential for significant fugitive emissions. A fence line monitoring system at a refinery in California, includes two NH₃ and two H₂S GasFinders for monitoring fluxes of these gases across the refinery boundary (Reference 12). These GasFinders have now been installed and have been working continuously, without any unscheduled interruptions, for over 4 years.

CO₂ emissions measurement

Fugitive emissions of CO₂ occur in almost every industrial process and commercial activity. Efforts to quantify reductions in CO₂ emissions are only meaningful if baseline emission levels are established. GasFinder is an ideal tool for enabling actual baseline levels to be measured. Figure 6 shows baseline CO₂ emission measurements performed on aircraft. The background was fairly steady at 330ppm. Aircraft 1 contributed 40ppm and aircraft 2 20ppm. In another example, GasFinder measured CO₂ levels of 700 ppm downwind of a steam generating plant.

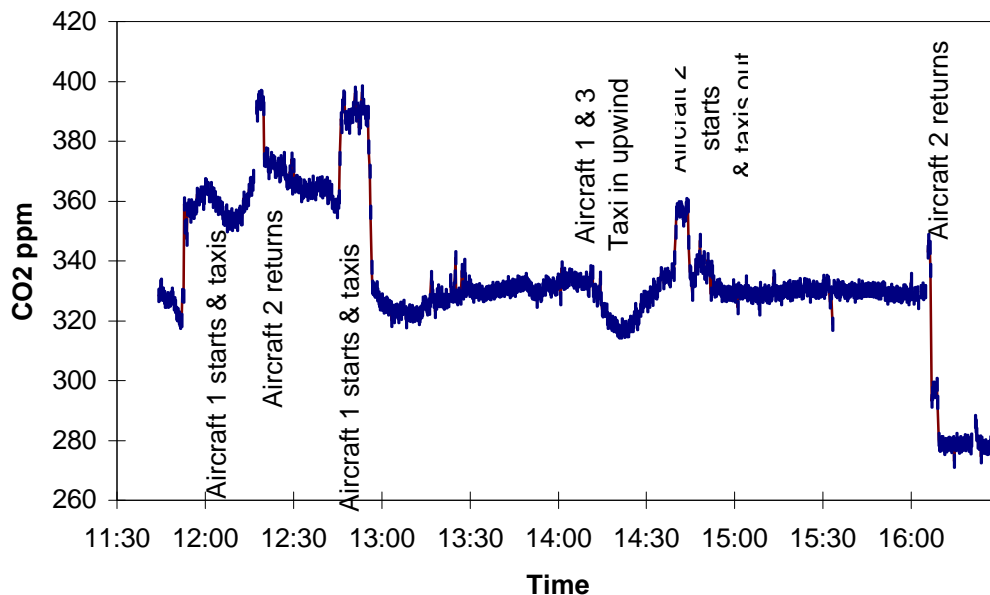


Figure 6 – Increased levels of ambient CO₂ resulting from aircraft emissions

HF monitoring in the aluminium industry

PFC is a GHG emitted in significant quantities during primary aluminium smelting operations. Aluminium smelting also generates large amounts of hydrogen fluoride gas (HF). Because HF is highly toxic, most of this gas is collected and treated.

However, different stages of the smelting process create more or less HF in the ambient air of the smelter building (also called pot rooms), and this HF can escape through roof vents. So, worker safety and ambient air quality concerns require that HF be monitored at several locations in aluminium smelters. These include roofline monitoring, stack monitoring, scrubber efficiency and general process monitoring. GasFinders have been used extensively in smelters worldwide to monitor and reduce HF levels. Many of the process improvements implemented to reduce HF also reduce PFC emissions.

In four independent studies with major aluminium companies (e.g. Reference 13) HF data generated with GasFinder differed from standard sampling data by less than 10% always, and usually less than 5%. Figure 7 shows typical data from a smelter.

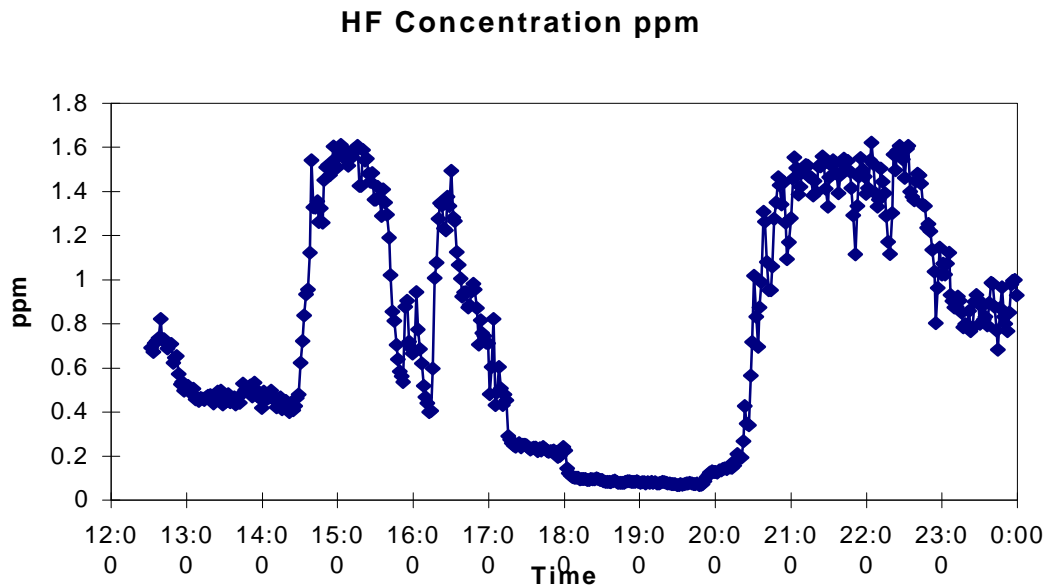


Figure 7 – Ambient HF levels within an aluminium smelter pot room.

CONCLUSIONS

GasFinder laser-based gas detectors have many advantages over established gas detection techniques in process, quality, safety and environmental monitoring. Laser technology does not suffer from interferences, provides fast response and can measure a wide range of concentration values. GasFinder is portable, self-calibrating and easy-to-use. It is ideally suited for making long, open-path measurements of fugitive emissions of specific gases. As a result, GasFinder is being used for a growing number of Greenhouse Gas emissions monitoring projects. In this paper we presented successful experience with several CH₄, CO₂ and NH₃ projects in a variety of industries. GasFinder enables meaningful, reliable baseline emissions to be MEASURED rather than estimated, so that the results of efforts to reduce GHG emissions can be reliably monitored and reported.

REFERENCES

1. A.M. Ballangrud, Diode laser spectroscopy for gas monitoring of environmental pollution and for industrial process and emission control, Dr. Scient. Thesis, University of Oslo, June 1993.
2. J. A. Silver, "Frequency-modulation spectroscopy for trace species detection: theory and comparison among experimental methods", *Applied Optics*, Vol 31, 1992, 707-717.
3. D. Bomse, "Diode Lasers: Finding Trace Gases in the Lab and the Plant", *Photonics Spectra*, No. 6, 1995, 88.
4. J. Tulip, "Gas Detector for Plural Target Zones", U.S. Patent, No. 5,748,325, May 1998.
5. D. Bomse, A.C. Stanton and J.A. Silver, "Frequency Modulation and Wavelength Modulation Spectroscopies: Comparison of Experimental Methods Using a Lead Salt Diode Laser", *Applied Optics*, Vol 31, 1992. 718.
6. John Tulip, "Gas Detector", U.S. Patent, No. 5,637,872, June 1997.
7. John Tulip, "Gas Detector with Reference Cell", U.S. Patent, No. 6,121,627, January 2001.
8. GasFinder Verification Statement, The Environmental Technology Verification, EPA and The Battelle Institute. See http://www.epa.gov/etv/07/boreal_vs.pdf.
9. J. Bauer et al., "Results of the Application of a New Laser Based Open-Path Spectrometer for the Measurement of Fugitive Emissions From Gas Processing Plants", Proceedings of an AWMA International Specialty Conference, Dallas Texas, 1996
10. E. Thornton and N. Bowmar, "The Application of a Laser-based Open-Path Spectrometer for the Measurement of Fugitive Emissions and Process Control", AWMA Annual Symposium, June 1999.
11. P. Dzikowski et al., "Measuring Ammonia Emissions from Liquid Hog Manure Storage Lagoons and Land Application", AARI Project Number 980817, December 1999.
12. "Fenceline-monitoring system solves big problem", Oil & Gas Journal, May 24, 1999.
13. K. Whitely, "Continuous Long Path Gaseous HF Monitoring in a Potroom Vent", Proceedings 6th Smelting Workshop, Australia, 1998.