

Calibrate or Die!

While the title of this white-paper may seem severe, the importance of calibration for handheld gas and vapor detectors cannot be under-emphasized because many gas sensors fail to an unsafe state. A Lower Explosive Limit (LEL) combustible gas sensor indicates a safe atmosphere when it reads zero but when it fails it also reads zero. A Chlorine (Cl_2) sensor indicates a safe atmosphere when it reads zero but when it fails it also reads zero. While some sensors, like oxygen usually fail to a safe or alarming state, they too can benefit from calibration to restore their accuracy. The only way to assure that many sensors are working correctly is to apply a gas to them to “calibrate” them.

OSHA’s Position on Calibration

In 29CFR1910.146 (the “Confined Space” standard) OSHA requires the use of a “calibrated” instrument. OSHA’s guidance letter CPL 2.100 OSHA says that the instrument must be maintained and calibrated according to manufacturer guidelines. Calibration identifies loss of sensitivity, failing or failed sensors.

Calibration Guards Against Loss of Sensitivity

Sensors can age, dry out and fail. They can be damaged by shocks, drops or exposure to liquids from immersion or when the detector’s pump sucks up liquids. Sensors can be poisoned by chemicals present in the atmosphere or lose sensitivity from innumerable other causes.

Calibration Improves User Confidence

Gas detectors are a “Flashlight” allowing people to “see” toxic gases and flammable vapors. You wouldn’t go into a dark basement without

checking the operation of your flashlight. Don’t go into a “dark” confined space or other potential dangerous

atmosphere without checking the operation of your detector. Manual calibration helps to



maintain “muscle memory” and user confidence in their detector. It’s almost like a mini-refresher training.

Calibration Types

“Bump”

A qualitative test where the detector is shown calibration gas and all the sensors show response and alarm. If one were to apply 25 ppm of Hydrogen Sulfide (H_2S) gas to an H_2S sensor with an alarm set to 10 ppm and it responds and goes into alarm, then it passes the “Bump” test. The number(s) on the display is not important for the bump test.

- Checks to show that the sensors AND alarms work
- Could be as simple as exhaling into an oxygen sensor or showing a Photoionization Detector (PID) a marker pen containing a solvent
- Pump check if applicable

“Calibration Check”

A quantitative test where the detector is shown calibration gas of a known and traceable value and the user verifies that the readings are within the manufacture’s plus/minus specification (typically $\pm 10\%$) values. So if one were to apply 50 ppm Carbon Monoxide (CO) to a CO detector and the display showed 49 ppm CO , the detector passes the “Calibration Check” because 49 ppm is within 10% of 50 ppm. If one got a reading of 42 ppm in the same test the detector would not pass because 42 is greater than 10% out of calibration. 10% of 50 is 5 ppm. So +5 is 55 ppm and -5 is 45 ppm. If the accuracy specification of the detector is $\pm 10\%$ any reading between 45-55 is considered to be in calibration if 50 ppm calibration gas is applied.

- Pump check if applicable

“Full Calibration”

The detector is shown calibration gas and readings are adjusted (automatically or manually) to the certified calibration gas value following the manufacturer’s procedure.

- Pump check if applicable

“Factory Calibration”

The detector is returned to a certified factory facility for testing and adjustment. Most

modern detectors do not have this requirement and any detector that has this requirement will be less available for use than one that does not have this requirement.

Calibration Check Catches a Bad CO Sensor

A fire department took a multi-gas detector that had been calibrated that day to a CO call. The wall-mounted CO detector in the apartment building went into alarm every time the furnace was turned on, but the fire department CO sensor only read 0. The apartment building's maintenance man's CO detector show 60 ppm when the fire department CO sensor still read 0. Upon returning to the station the fire department's CO sensor was "successfully" recalibrated. But the detector did not respond to CO when it was applied to the detector using a "bump" or "calibration check." It's possible that that fire department didn't fully understand how to calibrate their detector. But the "calibration check" did catch the problem. When in doubt, a "bump" or a "calibration check" is always helpful to establish that a detector is functioning properly even AFTER a calibration has been performed.

How Much Calibration is Enough?

Follow your manufacturer's written recommendations. Don't rely on unsupported verbal assurance from distributors or sales representatives concerning calibration requirements. If anyone says that you can calibrate LESS than once a month (every 6 months for example) then make sure this is documented IN WRITING. Calibration frequency should also be driven by the level of threat. The higher or more frequent the risk, the more frequent calibration should take place.

ISEA Calibration Statements

The International Safety Equipment Association (ISEA) is the leading organization of manufacturers of safety and health equipment including environmental monitoring instruments. ISEA has developed a statement to ensure definition consistency in all documentation, and to emphasize the need to validate the operational capability of portable gas detectors. The following recommendations are either taken from or comply with ISEA recommendations:

- The safest course of action is a daily check
- Fresh air calibration (make sure that the air is CLEAN)

- Expose the sensors to known concentration test gas before each day's use ("Bump" or "Calibration Check")
 - This test is very simple and takes only a few seconds to accomplish
- With pumped units ALWAYS check pump flow/alarm during daily check because connections, filters and tubing can fail and leaks can dilute & diminish readings
- Adjust span ("Full Calibration") should be done at regular intervals in accordance with instructions provided by the detectors manufacturer, company or regulatory agency policy
 - Best practice is AT LEAST once a month or when necessary

"Busting" the 30 day calibration "Myth"

It seems that "calibrate every 30 days" is the most common recommendation. But this is often not a safe enough course of action. According to ISEA: "Validation of an instrument's operability should be conducted if any of the following conditions or events occurs during use:"

- Chronic exposures to, and use in, extreme environmental conditions, such as high/low temperature and humidity, and high levels of airborne particulates.
- Exposure to high (over range) concentrations of the target gases and vapors
 - Could be found on any HazMat call or overhaul (post fire clean-up) detection assignment
- Chronic or acute exposure of catalytic hot-bead LEL sensors to poisons and inhibitors including volatile silicones, hydride gases, halogenated hydrocarbons, and sulfide gases
- Chronic or acute exposure of electrochemical toxic gas sensors to solvent vapors and highly corrosive gases.
- Harsh storage and operating conditions, such as when a portable gas detector is dropped onto a hard surface or submerged in liquid. Normal handling/jostling of the detectors can create enough vibration or shock over time to affect electronic components and circuitry. Detectors that live on a vehicle are particularly susceptible to wear, requiring more frequent calibration.

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- Change in custody of the detector, like shift changes when the detector is “handed off” from one user to another.
- Any change in work conditions that might have an adverse effect on sensors.
- Any other conditions that would potentially affect the performance of the detector.

Detectors are designed for the industrial TWA environment

Most gas detection equipment was designed for industrial detection where levels are expected to be at or near the relatively low TWA (Time Weighted Average) values. Calibration recommendations are largely based upon detector use in the industrial TWA environment. For applications where concentrations can exceed TWA values moving to IDLH and even higher (like first responders) more calibrations may be required. Non-industrial users of gas detectors should consider being more rigorous in calibration frequency:

- Calibrate after usage that over-ranged or otherwise “stressed” the detector, such as a big HazMat call
- Calibrate at shift changes so that a detector that was inadvertently stressed by the previous shift performs properly for the next shift

When Should I Check Calibration?

- If you don't trust detector readings
- If the detector has been subjected to unusually rough handling (drops)
- If the detector has been subjected to unusual environments (high humidity, high chemical concentrations)

Calibration gas is confidence in a can!

How to calibrate

First, ALWAYS follow your manufacturer's recommendation about calibration requirements. Diffusion products are easy, just flow to the detector with an appropriate manufacturer recommended constant flow regulator.

Pumped units have many more options.

Always check for pump flow on a daily basis by clogging the inlet and looking for a “pump” alarm

Generally the preferred method of calibrating a pumped detector is using some form of matched flow calibration. The exception to this is that for some highly reactive calibration

gases used for electrochemical sensors some manufacturers recommend a flow rate in excess of pump flow to “flood” the sensors with enough calibration gases so that the sensor is not “starved” for gas.

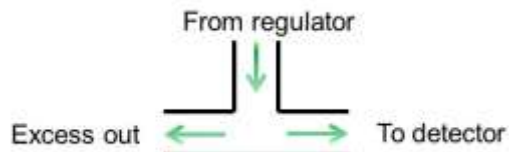
Flow matching regulator calibration

- + A flow matching regulator mechanically matches gas flow to the pump's flow rate
- + If pump isn't flowing well the regulator won't open and the calibration should fail
- + Conserves gas
- Can be expensive to purchase regulator
- Weak pumps may not open the regulator, sometimes this goes undetected

Tedlar bag calibration

- + A constant flow regulator is used to fill a Tedlar (non-reactive Teflon bag)
- + The pumped product draws from the Tedlar during calibration
- + Conserves gas
- + You can see if the pumps working by watching the bag deflate
- More time consuming and labor intensive

T-fitting calibration



- + A constant flow regulator is used that exceeds the maximum flow-rate of the pumped device. If a detector's pump draws at 250cc/min the regulator should flow at 500 cc/min.
- + A “T” tube connection is fitted to the tubing from the constant flow regulator
- + Calibration is done from one side of the “T” fitting and excess flow goes out the other side of the “T” fitting
- + Inexpensive
- Can use more gas

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Cup calibration



- + A constant flow regulator is used that exceeds the maximum flow-rate of the pumped device
 - + For example pump draws at 250cc/min so regulator should flow at 500 cc/min
- + A Cup is fitted to the tubing from the constant flow regulator
- + Calibration with the inlet of the pumped device drawing from the cup
- + Inexpensive
- Can use more gas

Flow matched vs. constant flow calibration

- + While a flow matched calibration is preferred, many manufacturers will accept a constant flow regulator for use with their pumped units
 - For example pump draws at 250cc/min so regulator should flow at 250 cc/min
 - Using a 250cc/min regulator with a 500cc/min pump could starve the sensors of calibration gas or draw in ambient air leading to an inaccurate calibration
- + The pumped device is connected directly to the tubing from the constant flow regulator
- + Relatively inexpensive
- + Easy to execute
- May have accuracy variations if flow rate of pump is radically different from that of the regulator

Automated calibration

- + Automated “docking” stations help to reduce operator error by automating the calibration process
- + Manufacturers have a variety of calibration procedures, some do a full calibration daily, some do a daily “bump” and periodic calibration but all are designed to make sure that the detector is ready for use when

you remove it from its charge/calibration cradle

- + Automates calibration, can document calibration
- Can be expensive to implement
- Tends to lock users into one vendor so customers don't select ‘best of breed’ products in each detection segment. For example one might feel that one manufacturers PID is the best while they prefer another multigas detector. Standardizing on one manufacturers calibration solution may reduce purchasing flexibility
- Discourages users from touching the detector and developing good “muscle memory” during manual calibration

Bad Calibration from a “Docking Station

After receiving new detectors and new docking stations a customer called their distributor to say that their new detectors were “acting funny.” When removed from their docking cradle the detectors had very unstable readings, this was unexpected because the customer had a lot of experience using the previous generation of this detector doing manual calibrations. Doing a “Calibration Check” with a bottle of calibration gas demonstrated that the calibration was not correct. After a manual calibration was performed the detector performed as expected. It was found that the docking station was improperly set up and the calibration gas was plumbed into the wrong input ports

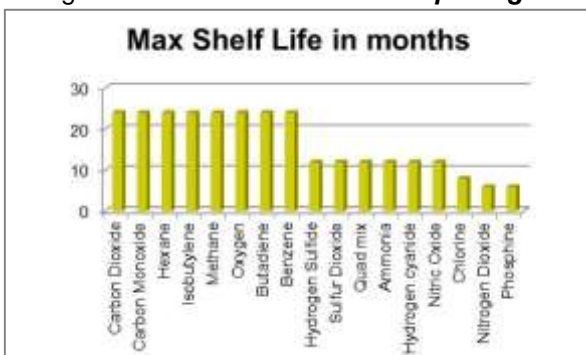
Lesson: it is a good idea to do a “Calibration Check” of detectors after a docking station is set up and after calibration cylinders have been replaced

Virtually any calibration is better than no calibration!

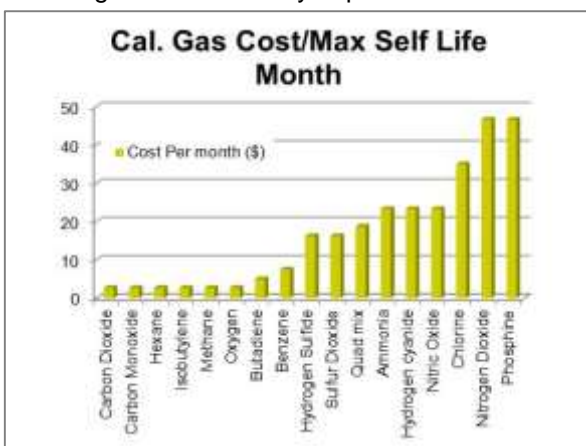
One can get caught up in calibration procedure on things like whether a flow-matching calibration is best. But don't lose sight of the fact that virtually ANY calibration is better than no calibration!

Calibration Gas Expiration

Calibration gas will typically last as long as 24 months and as little as 6 months depending on the gas. One should **Never use expired gas**



Some gases can be very expensive to own:



Combustible gas sensor calibration gas and multi-sensor, all-in-one or “quad gas” calibration gas all have some amount of oxygen (16-20.9% O₂) in them or else the combustible gas sensors won't work because it requires oxygen. Oxygen concentrations below 20.9% also allow “spanning” of the oxygen sensor. Reactive gases like NH₃ and Cl₂ are typically balanced with nitrogen because if there were any air in the bottle it would react with the gas resulting in very short shelf life. While electrochemical sensors do require oxygen to work there is typically enough oxygen in the sensor electrolyte to get through a calibration.

Calibration Concentrations

Manufacturers have reasons for the calibration values and the flow values that they specify for their detectors. Low values may give an unstable calibration. Reactive gas sensors like Chlorine (Cl₂) are particularly sensitive to calibration gas concentrations. Generally the detector is not in an atmosphere with the reactive gas in it during the calibration process

(or this would lead to false zeroes). The detector might absorb some of the reactive gas into its sample components, like 1 ppm. The manufacturer specifies 10 ppm Cl₂ calibration gas knowing that they will lose just 10% of the calibration gas to the sample components of the detector. But if one substitutes 5 ppm calibration gas then 1 ppm of loss to absorption is now 20% of the span value which can lead to an unstable calibration. Conversely, if one were to substitute 100 ppm Ammonia (NH₃) calibration gas when the manufacturer specified 25 ppm calibration gas for a multigas detector not only could this stress the NH₃ causing it to fail early, but this high value of calibration gas could stress other sensors in the multigas detector leading to their premature failure.

Calibration Gas “Hygiene”

Users can cause calibration gas to go prematurely “bad.” Repeated introduction of small amounts of moisture, oxygen and other contaminants carried into cylinders by a closed regulator can affect the concentrations of the small amounts of highly reactive gases like Cl₂. When a closed regulator is screwed onto a cylinder the air and other contamination between its threads and the closed valve is forced into the cylinder. Oxygen, moisture and other contaminants can quickly degrade highly reactive calibration gases. It is best to open a regulator prior to attaching it to a cylinder of gas; this keeps any moisture and contamination on the regulator from entering the gas cylinder. Regulators and cylinders should be stored in a clean, dry place. Remove regulators from cylinders between uses because the valves on the regulators may not be fully closed or may even leak slightly leaving no calibration gas for the next use.



Not every gas uses the same regulator

Reactive gases often have special regulators AND non-reactive Teflon hoses. Isobutylene gas, used to calibrate PIDs, only needs Tygon calibration tubing but 6 inches of Tygon tubing will absorb much of 10 ppm Cl_2 so Tygon tubing is not appropriate for a reactive gas. Therefore it is best practice to use a specific gas cylinder.



Calibration hose can affect calibration

If a Cl_2 sensor “thinks” it’s going to see 10 ppm and the 6” of Tygon tubing on the calibration regulator absorbs 6 ppm then the sensor ends up thinking that 4 ppm is really 10 ppm. This is a primary cause of sensor “noise” and is easily fixed by following proper calibration procedure and using correct hose that will not absorb Cl_2 . Really what’s happening here is that the distance between zero and span is being accidentally compressed by Cl_2 absorption into the Tygon tubing. This compression results in a loss of sensitivity.

Disposal of Calibration Cylinders

The concentration of chemicals in calibration gas cylinders is typically below toxic and flammable levels. Even when gases like Cl_2 have 10 ppm in the cylinder and the TWA is just 1 ppm, if the cylinder were to leak the concentration of Cl_2 would quickly be diluted down to an insignificant level by the ambient air. The real “threat” of calibration gas cylinders is that they are pressurized cylinders not that they are toxic or flammable. Check with your vendor and local regulations for disposal directions, but typically a cylinder that is empty and depressurized is just a hunk of metal that can be thrown out or recycled appropriately. After all residual gas and pressure is bleed off using the regulator, often all that is required is a simple tire valve removal driver to remove all chance of pressurization prior to disposal. Some go an

extra step by drilling holes in the cylinder so it is obvious that it can’t hold pressure.

Don’t be afraid of Calibration

- Modern designs make calibration easy and automatic.
- Keep the Calibration Materials With the Instrument!
- All-In-One Calibration Mixtures Make Functional Testing Easy!
- Don’t buy a sensor unless you are willing to calibrate it!

Calibration: Record keeping

Documentation is critical! Without good records you cannot defend or explain your procedures (docking stations usually automate this). If you don’t have the records to prove it was being done right -- it wasn’t! Records can be as simple as the following chart:

Date	Time	Instrument	Serial Number	Cal Gas	Concentration	Lot Number	Expiration/ Mfg. Date	Calibrated By

Where do I calibrate?

Always follow your manufacturer’s recommendations. It is ideal to calibrate under a fume hood. If lacking a fume hood, use a well-ventilated area so that the calibration gases don’t affect you or others. Always calibrate in a clean environment so that contaminants don’t affect the calibration. Some detectors do a “fresh air” or zero when turned on so they must be turned on in a clean environment!



Calibrate wherever you need to regain confidence in your detector

Docking stations are increasingly used by many to calibrate their detectors, but these fixed systems may not be immediately accessible when one loses confidence in their detector (ex: fire dept. HazMat team). Typically the docking station is in a firehouse or an office that is away from where the detector is detecting. Mobile users may want to consider carrying calibration gas on their vehicle to restore confidence in their detector when in the field away from their docking station. A small calibration cylinder and regulator in a case (pictured below) can quickly help restore confidence in a detector. Always calibrate in a well-ventilated area



Calibration “Headaches”

A gas detection salesman complained that customer in-service detector trainings were so stressful that they gave him real headaches. But over time the salesman noticed that he only got headaches on classes where there was an actual hands-on calibration. He later found that his headaches were due to H₂S exposures. Even at very low levels H₂S would give him a head-splitting headache. Calibrating under a fume hood or outside in well-ventilated areas solved the problem.

Calibrating cross-sensitive sensors

It is possible to combine two cross-sensitive sensors, like ammonia and chlorine, in the same detector when absolutely necessary. When calibrating a multi-gas sensor that has two sensors whose gas have significant cross-sensitivity, be sure to allow adequate time between calibrations to allow the sensors to clear. When calibrating sensors with cross-sensitivities, calibrate the most cross-sensitive sensor first, followed by the least cross-

sensitive sensor. Wait for both sensors to recover to zero, and then expose both to gas again with most cross sensitive first and least cross sensitive second. While some manufactures say that you cannot put a Cl₂ and NH₃ sensor in the same detector it is possible if calibration is done properly.

For example, 65 ppm of NH₃ produces 0 ppm response on a Cl₂ sensor and 1 ppm of Cl₂ produces about -0.5 ppm of response on a NH₃ sensor. Calibrate the NH₃ sensor first with 50 ppm of NH₃. This should have no effect on the Cl₂ sensor. Calibrate the Cl₂ sensor on 10 ppm Cl₂. This will send the NH₃ sensor negative for some period of time. After calibrating the Cl₂ sensor, return the detector to clean air and wait until the most cross-sensitive sensor (NH₃) fully recovers and/or stabilizes (if it stabilizes to a number other than zero then re-zero the detector). After both sensors return to zero apply calibration gas in the same order (NH₃ first then Cl₂) and note the sensor response. If both sensors are within 10% of the value on the gas cylinder then the calibration of the cross-sensitive sensors was successful. In most cases it's just easier to separate these two sensors in separate detectors

Calibration to help improve your confidence in your detector

Unsafe zero calibration

A HazMat officer was making an entry into a sewage pump station for preplanning. All the right confined space entry operations and permitting were completed. Upon entry to the confined space the officer immediately exited feeling difficulty in breathing and light headedness. He thought it was from drinking too much coffee and a long night at the station. They then went to the next confined space to preplan, but this time he could tell from experience that the atmosphere was most likely bad. So he asked him to check it. The attendant lowered the tubing into the space and then turned the confined space detector on. The officer was alarmed but waited until the attendant gave the “everything is normal” sign. The officer asked the attendant to take the tubing out of the space and re-zero the unit in a clean atmosphere. With a fresh air calibration complete, he lowered the tubing back in the space. The unit immediately went into alarm

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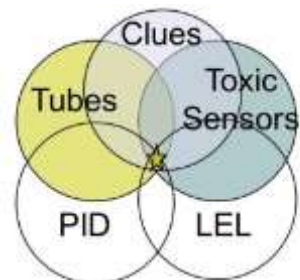
for high H₂S, and low O₂. If they had entered the space this time, the odds are they would have collapsed

- **Some detectors zero themselves when turned on. If they are turned on while sampling a contaminated atmosphere they will zero out that atmosphere**

Printed Circuit Board Plant

The CO sensor in a 5-gas detector indicated 35-45 ppm in a printed circuit board plant with styrene, xylene, acetone and other aromatics and ketones expected to be in the air. The user of the detector jumped to false conclusion that CO sensor was bad or it was responding to hydrocarbons, but the PID showed no significant reading. When the detector was fresh-aired outside of the plant it still showed high CO inside. After the detector was calibrated with CO gas and still showed the same high CO levels in the plant. When the air was checked with a CO colorimetric tube it registered a 50 ppm CO reading which agreed within 10% to what the detector was reading. So the user finally started to look for CO. Investigation found a shrink-wrap machine on the loading dock in a remote part of the plant pumping out 150 ppm CO in the worker breathing zone.

- **Clues:** Printed circuit board plant
- **Toxic Sensor:** 35-45 ppm reading on CO
- **LEL:** no reading on LEL
- **PID:** no reading on PID
- **Tubes:** 50 ppm reading on CO tube



★ =CO from shrink wrap machine

Proper Calibration Eliminates a Phantom Negative Alarm

A customer using a PID in a styrene plant complained of frequent “negative” alarms when using the PID in the plant. When observed in their calibration lab their calibration procedures seemed appropriate. When walking through the plant with the PID it seemed that the “negative” alarms came when a breeze blew through the open air plant. When checked with a PID calibrated outside of the plant it was determined that the entire plant (including the

calibration lab) had a background of 5-10 ppm of styrene. When the clean wind blew through the plant the PIDs tried to read lower than zero prompting the “negative” alarm. Charcoal filters were an easy solution to provide clean, zero air for the PIDs. But “zero gas” could also have been used.

Calibration Mistakes

Negative Alarms

Typically negative alarms are caused by zeroing when a background is present and then going to a cleaner environment. As there is no such thing as a “negative CO” the detector usually gives some sort of “NEG” or “Negative” alarm.

Startup Zero

Some detectors zero at start-up, so starting in “clean” air is always a good idea for all detectors.

Zeroing near running engines

Internal combustion engines that are running (like in engine bay) generate CO and sometimes SO₂. Elevated levels can be found long after an engine has been shut down. Clean outdoor air is often the best solution for this problem.

My detector failed calibration, what next?

If any sensor fails calibration in a detector, and any remedial steps don’t address the problem, then the sensor needs to be replaced or the detector repaired and recalibrated before use. Any detector that has failed calibration and has not been repaired should not be used. Any detector that has failed calibration has been repaired and subsequently passed calibration is safe for use. If any sensor in a multi-gas detector has failed, then the entire detector should be put out of service until it can be fully repaired and calibrated because all of the sensors may be needed to solve a particular gas detection challenge.

- “Only my oxygen sensor failed calibration, can I still use it?”

NO

Calibration or Die!

The importance of calibration for handheld gas and vapor detectors cannot be under-emphasized because many gas sensors fail to an unsafe state. The only way to assure that many sensors are working correctly is to apply a gas to them to “calibrate” them.

About the Author

Christopher Wrenn is the Vice President of Americas Sales for AEssense Corp., a Silicon Valley developer and manufacturer dedicated to providing innovative technological solutions for plant growers worldwide. Previously Chris was Sr. Director of Sales and Marketing for Environics USA, a provider of sophisticated gas & vapor detection solutions for the military, 1st responder, safety and homeland security markets. Chris was also a key member of the RAE Systems team, helping to grow RAE's revenues from \$1M/yr to nearly \$100M/yr in the above mentioned markets.

Chris has extensive experience teaching gas and vapor detection and has been a featured speaker at more than 100 international conferences. He has written numerous articles, papers and book chapters on gas/vapor detection. Mr. Wrenn has received the following awards:

- 2011 “Outstanding Project Team Award,” in recognition of outstanding service and dedication to the Real Time Detection Registry Team presented by the AIHA (American Industrial Hygiene Association) President
- 2015, received the James H. Meidl “Instructor of the Year” award at The Continuing Challenge, Sacramento, CA presented by CA State Fire Marshal
- 2016, received the “Level A Award” from the International Hazardous Materials Response Team Conference “For your Leadership Service and Support to the Hazardous Response and Training Program.”