Document Title:	Assessment of Portable HAZMAT Sensors for First Responders
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Document No.:	246708
Date Received:	May 2014
Award Number:	2010-IJ-CX-K024

Assessment of Portable HAZMAT Sensors for First Responders

DOJ Office of Justice Programs
National Institute of Justice
Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE)

NLECTC
Sensor, Surveillance, and
Biometric Technologies
Center of Excellence

March 1, 2012

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UNCLASSIFIED

This project was supported by Award No. 2010-IJ-CX-K024, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect those of the Department of Justice.

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1.0 EXECUTIVE SUMMARY

The National Institute of Justice (NIJ) Sensor, Surveillance, and Biometric Technologies (SSBT) Center of Excellence (CoE) has undertaken an assessment of portable hazardous material (HAZMAT) sensors to determine if commercially available devices exist that meet the full range of requirements. When emergency first responders respond to an accident or disaster scene, they often do so without any knowledge of whether they may be entering an area that has potentially harmful or deadly chemical hazards. A small, portable, wearable, and unobtrusive gas detector that could identify and quantify a wide range of hazardous gases would aid the first responders by indicating whether they might inadvertently be entering a hazardous area. The detector would identify and quantify the hazard, allowing first responders to quickly take measures to protect themselves and those around them. By continuously monitoring the atmosphere, the device may also be able to indicate that a clandestine laboratory is in the area by identifying solvent vapors and chemicals typically used in certain illegal operations (e.g., drug manufacturing).

Commercially available equipment used for gas detection ranges from small units that can detect only a single gas to devices that can sample, detect, and identify a wide range of hazardous gases. The technologies used for gas detection determine the abilities of the detector as well as the size and weight of the equipment. Small, wearable gas detectors tend to be able to only detect a small number of gases or gas types, while the detectors that are able to detect and identify a wide range of gases tend to be too large and heavy to be used unobtrusively (and require technical training).

It is the conclusion of the CoE that there **does not exist** a commercial off-the-shelf (COTS) device that meets the first responder needs in full. This effort has not been able to identify any commercially available equipment that is unobtrusive and able to detect a wide range of gases. This report identifies many commercially available gas detectors, discusses the sensing technologies used by them, and highlights devices of note that meet a significant subset of the technology requirements.

2.0 INTRODUCTION

NIJ has identified a technology need for an unobtrusive, wide spectrum portable HAZMAT sensor for use by first responders. This requirement was called out by the Sensor & Surveillance Technology Working Group (TWG). This report is an assessment of commercially available HAZMAT sensor devices that might be utilized by first responders, with the end goal of determining whether:

1. A commercial sensor system meets the stated technology need requirements
   OR
2. Further research and development (R&D) is needed to produce such a system.

As will be discussed in more detail throughout the report, it is the conclusion of the CoE that there **does not exist** a commercial off-the-shelf (COTS) device that meets the needs in full. As a result, further R&D is needed to produce such a system.

2.1 TWG Technology Need - Detection of Hazardous Conditions for First Responders

- **Issue:** Emergency first responders often arrive at accident and disaster scenes without any knowledge of potential deadly hazards. First responders need a way to determine whether they might be inadvertently entering a hazardous area while performing emergency services.
- **Desired Outcome:** A small detector, attachable to the officer's belt if possible, which will warn of multiple types of hazards.
- **Note:** If possible, systems capable of detecting illicit substances will be included in the investigation and related capabilities highlighted in device synopses
- **Note:** Existing chemical detection systems are likely to be larger than belt-worn; size and/or ergonomics of available devices will be summarized

2.2 About NIJ SSBT CoE

The NIJ SSBT CoE is a center within the National Law Enforcement and Corrections Technology Center (NLECTC) System. The Center provides scientific and technical support to NIJ’s R&D efforts. The Center also provides technology assistance, information, and support to criminal justice agencies. The Center supports the sensor and surveillance portfolio and biometrics portfolio. The Centers of Excellence are the authoritative resource within the NLECTC System for both practitioners and developers in their technology area(s) of focus. The primary role of the Centers of Excellence is to assist in the transition of law enforcement technology from the laboratory into practice by first adopters.

3.0 REQUIREMENTS

The goal of this effort is to investigate and identify commercially available products that are able to detect, identify, and quantify a wide range of toxic gases in real time. The ideal detector would also be small enough to be worn on a continuous basis by first responders, be unobtrusive to the first responder, and require minimal technical training to operate. The device should also trigger alarms when a toxic gas is detected, and when the levels of a toxic gas reach preset threshold levels [preferably below the levels which would be Immediately Dangerous to Life or Health (IDLH)] so that first responders may take immediate and specific actions to safeguard their own safety and the safety of those around them. In addition, the ideal detector would also alert the wearer of potentially illegal activities within the area, such as the clandestine production of methamphetamine, by detecting the presence of volatile chemicals and solvents commonly used in such activities.

It is expected that a wearable gas detector would be able to detect gases in the vicinity (as opposed to a stand-off system, which can monitor the atmosphere from a distance). These detection systems use an array of technologies to detect the target gases, and in some cases separate the gases to aid in identification and quantification. Detection may rely on physical properties such as size of gas molecules (as in ion mobility spectroscopy), optical characteristics of gas molecules (optical spectroscopy), or chemical characteristics (such as catalytic bead detectors, or colorimetric detection). Separation of gases relies almost exclusively on gas chromatography (GC). Separation of the gases can aid in identification by measuring the time needed to elute from the GC, and separate the target gases from each other as well as potential interferences before detection (see Section 5.11).

Unambiguous identification and quantification of unknown gases is not a terribly difficult matter for a well equipped chemical lab that specializes in such matters. However, the size, power requirements, and delicate components used in laboratory equipment make mobile applications very difficult and personal use nearly impossible. Commercial, wearable gas detectors tend to either detect single gases that are a known hazards in the environment (e.g., H_2S in the petroleum industry), specific types of gases [e.g., Volatile Organic Compounds (VOCs) in the coatings industry], or properties of the atmosphere [e.g., lower explosive limits (LEL) in the mining industry]. These commercial detectors rely on having previously identified specific potential hazards within the constraints of the surroundings. This information may not be available to first responders when they come to a potentially hazardous scene.

While first responders may be aware of the industries and services within the vicinity that produce and use hazardous materials, it would be an immense undertaking to identify all hazardous materials which may be produced, used, stored and transported through specific locations. Release of hazardous gases (by either accidental release, neglect of equipment or procedures, or intentional release) poses a threat to first responders and the public in general. It is imperative that unknown gases present be identified and quantified as quickly as possible so that first responders can be equipped with the necessary protective gear and so that proper procedures may be implemented to ensure public safety. Small, wearable gas detectors, which would be able to detect, identify, and quantify a wide range of toxic gases and would notify the wearer before concentrations become dangerous, would be of great benefit so that the use of

Personal Protection Equipment (PPE) and procedures, specific for the hazard identified, could be expedited.

For purposes of the Technology Need, the desired device would be able to detect hazardous chemicals in near-real time. Given all of the variables and operational scenarios, it is difficult to assign a specific response threshold without defining many other variables. However, for qualitative evaluation purposes, a response time of less than 10 seconds at concentrations that pose immediate danger to the first responder has been used as a guide.

The NIJ SSBT CoE has not identified any commercially available gas detector that is able to meet all the criteria mentioned above. Detectors small enough to be worn are typically single gas detectors, which are intended for use where there is a known hazard (such as H_2S in petroleum refineries), or the detectors are able to detect a small number of gases (typically up to five). Detectors that are able to identify a wider range [although not necessarily all of the Toxic Industrial Chemicals (TICs) listed in Table 4.0-1] of unknown gases tend to be larger in size (about the size of a shoe box and larger) and, at best, would be highly inconvenient to carry around and operate on a continuous basis. A sample list of commercially available gas detectors is listed in Table 6.1-2.[1, 2]

4.0 HIGH INTEREST CHEMICALS

Ideally, a small, unobtrusive wearable detector would be capable of detecting, identifying, and quantifying a large number of gases, including industrial gases, chemical warfare agents, and gases which may indicate the presence of potentially illegal activities. The ideal detector would be able to warn the wearer of potential hazardous conditions before the concentrations would be considered threatening. In addition, the detector would be easily maintained, have a long life, and be insensitive to interfering gases. With the current state of technology, detection, identification, and quantification of any and all gases would pose an impossible challenge to incorporate into a small wearable detector. Even with a subset of chemicals in a much smaller list of highly hazardous compounds, it is difficult to uniquely identify individual compounds with a small portable device.

The following tables were originally developed by NATO's International Task Force-25 (ITF-25). The list classifies hazard indices of Toxic Industrial Chemicals (TICs) based on the compounds availability, toxicity, and volatility.[3] This table was produced in the framework of potential terrorist activities; however release of any of these chemicals by any means (accidental or otherwise) would also result in similar HAZMAT situations and responses. The common name and Chemical Abstracts Service (CAS) number is provided.

Table 4.0-1: High Hazard Index Chemicals

Chemicals	CAS Number	Chemicals	CAS Number
Ammonia	(7664-41-7)	Hydrogen chloride	(7647-01-0)
Arsine	(7784-42-1)	Hydrogen cyanide	(74-90-8)
Boron trichloride	(10294-34-5)	Hydrogen fluoride	(7664-39-3)
Boron trifluoride	(7637-07-2)	Hydrogen sulfide	(7783-0604)
Carbon disulfide	(75-15-0)	Nitric acid, fuming	(7697-37-2)
Chlorine	(7782-50-5)	Phosgene	(75-44-5)
Diborane	(19287-45-7)	Phosphorus trichloride	(7719-12-2)
Ethylene oxide	(75-21-8)	Sulfur dioxide	(7446-09-5)
Fluorine	(7782-41-4)	Sulfuric acid	(7664-93-9)
Formaldehyde	(50-00-0)	Tungsten hexafluoride	(7783-82-6)
Hydrogen bromide	(10035-10-6)		

Table 4.0-2: Medium Hazard Index Chemicals

Chemicals	CAS Number	Chemicals	CAS Number
Acetone cyanohydrin	(75-86-5)	Methyl chlorosilane	(993-00-0)
Acrolein	(107-02-8)	Methyl hydrazine	(60-34-4)
Acrylonitrile	(107-13-l)	Methyl isocyanate	(624-83-9)
Allyl alcohol	(107-18-6)	Methyl mercaptan	(74-93-1)
Allylamine	**(**107-11-9)	Nitrogen dioxide	(10102-44-0)
Allyl chlorocarbonate	(2937-50-0)	Phosphine	(7803-51-2)
Boron tribromide	(10294-33-4)	Phosphorus oxychloride	(10025-87-3)

Chemicals	CAS Number	Chemicals	CAS Number
Carbon monoxide	(630-08-0)	Phosphorus pentafluoride	(7647-19-0)
Carbonyl sulfide	(463-58-1)	Selenium hexafluoride	(7783-79-1)
Chloroacetone	(78-95-5)	Silicon tetrafluoride	(7783-61-1)
Chloroacetonitrile	(107-14-2)[1]	Stibine	(7803-52-3)
Chlorosulfonic acid	(7790-94-5)	Sulfur trioxide	(7446-11-9)
Diketene	(674-82-8)	Sulfuryl chloride	(7791-25-5)
1,2-Dimethylhydrazine	(540-73-8)	Sulfuryl fluoride	(2699-79-8)
Ethylene dibromide	(106-93-4)	Tellurium hexafluoride	(7783-80-4)
Hydrogen selenide	(7783-07-5)	n-Octyl mercaptan	(111-88-6)
Methanesulfonyl chloride	(124-63-0)	Titanium tetrachloride	(7550-45-0)
Methyl bromide	(74-83-9)	Tricholoroacetyl chloride	(76-02-8)
Methyl chloroformate	(79-22-1)	Trifluoroacetyl chloride	(354-32-5)

Table 4.0-3: Low Hazard Index Chemicals

Chemicals	CAS Number	Chemicals	CAS Number
Allyl isothiocyanate	(57-06-7)	Ethyleneimine	(151-56-4)
Arsenic trichloride	(7784-34-1)	Hexachlorocyclopentadiene	(77-47-4)
Bromine	(7726-95-6)	Hydrogen iodide	(10034-85-2)
Bromine chloride	(13863-41-7)	Iron pentacarbonyl	(13463-40-6)
Bromine pentafluoride	(7789-30-2)	Isobutyl chloroformate	(543-27-1)
Bromine trifluoride	(7787-71-5)	Isopropyl chloroformate	(108-23-6)
Carbonyl fluoride	(353-50-4)	Isopropyl isocyanate	(1795-48-8)
Chlorine pentafluoride	(13637-63-3)	n-Butyl chloroformate	(592-34-7)
Chlorine trifluoride	(7790-91-2)	n-Butyl isocyanate	(111-36-4)
Chloroacetaldehyde	(107-20-0)	Nitric oxide	(10102-43-9)
Chloroacetyl chloride	(79-04-9)	n-Propyl chloroformate	(109-61-5)
Crotonaldehyde	(123-73-9)	Parathion	(: 56-38-2)
Cyanogen chloride	(506-77-4)	Perchloromethyl mercaptan	(594-42-3)
Dimethyl sulfate	(77-78-1)	sec-Butyl chloroformate	(17462-58-7)
Diphenylmethane-4.4'-diisocyanate	(101-68-8)	tert-Butyl isocyanate	(1609-86-5)
Ethyl chlroroformate	(541-41-3)	Tetraethyl lead	(78-00-2)
Ethyl chlorothioformate	(2941-64-2)	Tetraethyl pyroposphate	(107-49-3)
Ethyl phosphonothioic dichloride	(993-43-1)	Tetramethyl lead	(75-74-1)
Ethyl phosphonic dichloride	(1066-50-8)	Toluene 2.4-diisocyanate	(584-84-9)
		Toluene 2.6-diisocyanate	(91-08-7)

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[1] Note that the OSHA site has an incorrect CAS number for this chemical

5.0 INTRODUCTION TO GAS DETECTION TECHNOLOGIES

The types of sensors used by the detector and the characteristics of the sensor(s) determine the level of information that can be obtained on a given device. For example, some detectors are designed to detect and/or quantify the presence of only one specific gas (single gas detectors), while other detectors may be able to detect, identify, and quantify a limited number of unknown contaminates in a gas sample. There are several commercially available detectors that fall between these two extremes; some are able to detect the presence of several gases (or types of gases such as VOCs) but they are not able to provide specific identification and quantification. Other detectors use multiple sensors to detect the presence of several individual gases and/or gas types.

Some technologies listed are specifically sensors, while others are detection technologies that incorporate sensors as integral components to the detection technology along with electronics, optics, or other components that support the operation (not the signal processing) of the sensor(s). An example of the latter would be a gas detector that uses gas chromatography to initially separate gases in a sample before they are sent to the actual sensor for detection.

There are many products on the market that are able to detect and quantify specific gases, or classes of gases. For instance Gas Badge Plus (CO) can quantify the amount of CO in the atmosphere, but this is the only toxic gas it can detect (other Gas Badge Plus sensors exist for other single gas targets).[4] Other products can detect a wide range of chemicals (VOCs in particular) but are unable to identify specific gases, because of the detection method utilized. For example, the MiniRAE 3000 provides alerts when something is out of the ordinary in the environment, but does not provide specifics about the nature of the potential threat.[5] Because it cannot distinguish between different gases, quantification of unknown species is not possible because two chemicals may have different response characteristics for the particular detection method used.

The response time of detectors (i.e., how quickly the device can measure the type and quantity of a threat) is dependent on the type of detector technology and the device engineering. However, even within the same technology, manufacturing conditions, precision, and variables can have a large impact on response characteristics. In general, technologies that are less specific have faster response times than technologies that are able to differentiate between unknown gases. For instance, Photo Ionization Detectors (PIDs) typically have very short response times, but they are unable to identify unknown gases. Gas chromatography technologies have longer response times (several minutes) but they have the potential to identify a wide range of unknowns. Sometimes response times are limited by operational requirements, for instance the determination of lower explosive limits (LEL) by catalytic bead sensors require a flame arrestor to keep the flames from propagating from the sensor to the outside atmosphere, however the flame arrestor reduces the speed that flammable gasses can diffuse to the sensor. Concentration of the target gases is another variable that can affect response time. Sensors may utilize a permeable membrane to help improve the specificity of the target gas, but the membrane reduces the rate of diffusion of the target gas. Higher concentrations of the target gas in the atmosphere will allow a faster response time by reducing the time needed for a detectable amount of gas to reach the sensing element. For purposes of the Technology Need, the desired device would be able to detect hazardous chemicals in near-real time. Given all of the variables and operational scenarios, it is difficult to assign a specific response threshold without defining many other variables. However, for qualitative evaluation purposes, a response time of less than 10 seconds at concentrations that pose immediate danger to the first responder has been used as a guide.

NOTE: The SSBT CoE has not conducted any laboratory or field testing to verify the performance or features of specific devices or detection technologies. Assessments are based on subject matter expertise, available literature, and vendor materials.

5.1 Combustion Sensors (Catalytic Combustion; Catalytic Bead Sensors)

Combustion Sensors are used for the detection of combustible hydrocarbon gases. These sensors use a wire that has a small amount of catalyst (often in the form of a small bead) on the surface. The catalyst allows hydrocarbons to ignite at lower temperatures than would normally be necessary. This allows localized ignition of flammable gases on the catalyst, causing the catalyst and the supporting wire to heat up. The increased temperature of the wire affects the electrical conductivity of the wire. Electrical conductivity of the wire is then typically measured by a component known as a Wheatstone bridge.[6,7]

The change of electrical conductivity is dependent on the temperature change of the wire. This, in turn, is dependent on the concentration of a specific flammable gas in the sample. While this property will allow the quantification of the concentration of a known gas, it will not allow for the identification and quantification of an unknown gas. This is because different flammable gases will provide different amounts of heat when burned. Therefore these sensors are not able to distinguish between low levels of a gas that produces a large amount of heat when burned, and high levels of another gas which produces a small amount of heat when burned. Even with known gases, quantization requires the use of correction factors to account for the different amounts of heat produced by different gases.

Conceptually, the response time should be very fast; dependent mainly on how fast the temperature of the wire changes when a combustible gas is encountered. However, since the gas is ignited on the catalyst, there needs to be a flame arrestor in the diffusion path to prevent the flame from propagating and potentially acting as an ignition source for combustible gases in the atmosphere. Therefore diffusion of gases through the flame arrestor will increase the response time. Typical response times tend to be in the range of 20 to 30 seconds.[12]

The operation of the sensors is dependent on the ignition of a hydrocarbon on the catalyst surface in an oxygen containing atmosphere. Therefore these sensors may not function properly in low oxygen environments, and they are susceptible to reduced sensitivity due to catalyst poisoning by trace amounts of certain gases. Some of the more common catalyst poisons are silicone, halocarbons, and metallo-organic compounds.

Suitability: Combustion sensors are not suitable for the Technology Need because they are unable to identify or quantify unknown gases. Response times may be slightly too slow for real-time monitoring.

5.2 Colorimetric Sensors

Colorimetric detection depends on the gas of interest chemically reacting with an agent that has been impregnated into a support (paper, for instance). The reaction can be specific for only one gas, or for a class of gases. Some detection systems use multiple "cassettes" to detect several gases, such as the Chameleon by Morphix Technologies.[8] The Chameleon also reduces the ambiguity of observing a color change by using cassettes where only half the exposed area changes color. The contrast between the different colors makes it easier to identify a change. See Section 6.2.3 for more details on the Chameleon.

Although many detectors require that the observer visually observe the color change, some detectors (See section 6.2.2, Dräger CMS) use an optical electronic system to read the color change.[9] Detectors that use visual observation require that the observer take time to make a dedicated observation. These detectors tend to be single use type detectors, and only the chemical or group of chemicals that the detector is designed for will be detected. Even though some colorimetric devices can be used to quantify a gas, first responders tend to use colorimetric methods for confirmation of the presence of a hazardous gas or for qualitative analysis, not quantification.[10]

Response times of colorimetric sensors depend on the rate of reaction of the target gas with the color-changing material. These reactions are typically fast, leading to fast response times on the order of several seconds. Although this is typical, the response time is dependent on the chemistry involved. For example, color change detection of chemical warfare agents by enzymatic techniques used by military test papers can take as much as 15 minutes.[11] Also note that in some cases it is necessary for the operator to setup and initiate sampling (such as in colorimetric tubes). Preparation and sampling may take considerably more time than the color change chemistry involved.

Suitability: Colorimetric Sensors are not suitable for the Technology Need because they are only able to detect a limited selection of pre-determined target gases. Many of the COTS devices also require dedicated inspection or operation by the user. Depending on the engineering implementation, certain sensors may be too slow for real-time monitoring.

5.3 Electrochemical Sensors

Electrochemical detection relies on the ability of target gas molecules to be oxidized or reduced at the surface of an electrode. This reaction creates a small electric current that can be detected and measured. Specificity to a target gas is provided by optimization of the electrochemistry and/or the incorporation of filters that only allow the target gas to cross or chemically react with interference gases. Other than the specificity that they are designed for, electrochemical sensors do not provide further identification, however quantification of the target gas can be determined by the electrical current produced.[7,12]

Even though electrochemical sensors are designed for a single gas or type of gases, there is the potential to have interfering gases (such as hydrogen). Electrochemical sensors also have a short shelf life, and operate on a narrow temperature range. Sensor lifetimes will be shortened in very dry and hot environments.[7]

Response times of typical electrochemical sensors are on the order of less than a minute. However, response times are highly dependent on the engineering of the sensor, and a trade-off is often required between sensitivity, target gas specificity and sensor lifetimes. For instance, the rate of diffusion and specificity of the target gas is dependent (in part) on the characteristics of the gas permeable membrane. A more highly permeable membrane will allow for faster response times, but may allow the water in the electrolyte to evaporate faster to the environment and reduce the sensors lifetime. [13]

Suitability: Electrochemical Sensors are not suitable for the Technology Need because they are only able to detect a limited selection of pre-determined target gases. Depending on the engineering implementation, certain sensors may be too slow for real-time monitoring.

5.4 Thermal Conductivity Sensors

Thermal conductivity sensors operate by monitoring changes in the ability of a sample to remove heat from a heated wire as the sample passes over the wire, typically through the use of a device known as a Wheatstone bridge. The Wheatstone bridge compares the electrical conductivity of a heated wire (which is exposed to the sample) to the electrical conductivity of a second heated wire which is exposed to a gas that does not contain the sample (a reference flow). Comparing the conductivities of the sample and the reference provides a sensitive method of detecting the presence of gaseous contaminants. Thermal conductivity sensors are very sensitive to changes in sample composition, however they are unable to identify or quantify an unknown constituent.[14,15] Because of these properties, these sensors are often used in conjunction with a separation method, such as gas chromatography.

Thermal conductivity sensors require that only a temperature change of the sensing wire be determined by a change in the electrical conductivity of the wire. Thus, response times tend to be very short, some on the order of fractions of a second.[16] In general, the fast response times coupled with insensitivity to particular gases make them good choices for sensors in detection methods that separate gases before they are detected (e.g. gas chromatography).

Suitability: Thermal Conductivity Sensors are not suitable for the Technology Need because they are unable to identify unknown gases.

5.5 Semiconductor Sensors

Semiconductor sensors have a thin layer of a metal oxide on top of a nonconductor. The metal oxide is semiconducting and is able to absorb oxygen from the air. The presence of the oxygen on the surface of the metal oxide increases the electrical conductivity of the semiconducting oxide. The amount of oxygen on the surface is constant as long as target gases are not present, but when the sensor is exposed to a sample containing the target gas, the gas replaces some of the oxygen absorbed on the surface of the semiconductor. This absorption changes the electrical resistance of the sensor. Semiconducting sensors have long lives, high sensitivity, and a wide operating temperature; they are not specific, sensitive to humidity, and subject to sensitivity loss due to poisoning.[6, 7]

Response times of semiconductor sensors are dependent on the design requirements of the sensor based on the target gas properties. Response times are typically in the range of 20 to 90 seconds.[17]

Suitability: Semiconductor Sensors are not suitable for the Technology Need because they are only able to detect a limited selection of pre-determined target gases. Response times may be slightly too slow for real-time monitoring.

5.6 Photo Ionization Detectors (PIDs)

PIDs shine UV light through a gas sample to eject electrons from target gas molecules (ionize the gas molecules). The ionized gases are then collected on charged grids and produce an electrical current.[15] The amount of current is proportional to the amount of gas in the sample. The specific energy of the UV light used determines whether the detector can be used for more specific gases with low ionizing energies (such as toluene vapors or benzene vapors) or for a more broad detection of gases to include gases with higher ionizing energies. Reducing the energy of the UV light will increase the specificity to gases with lower ionization potentials, reducing the number of potential gases. Gases with higher ionization potentials are typically not detected (hydrogen sulfide and CO, for example). Also note that PID detectors do not destroy the sample, and the gases can be collected for further analysis if needed.[5,18]

Response times of PIDs tend to be fast, on the order of 3 seconds.[19] Detection is fast because it is based on the fast processes of gas ionization by UV, collection of ion, and electrical current produced by the collected ions.

Suitability: PIDs are not suitable for the Technology Need because they are unable to identify or quantify unknown gases and are unresponsive to gases with high ionization potentials.

5.7 Flame Ionization Detectors (FIDs)

FIDs operate in a similar method as PIDs, except they use a flame to supply the energy needed for ionization of the gas molecules. FIDs are able to detect a wider range of gases, but again, there is no identification of unknown gases. In addition to the VOCs, they are able to detect gases with higher ionization potentials, such as methane. FIDs use a combustible gas (typically hydrogen) to produce the ionizing flame; therefore the combustible gas is a consumable and must be supplied. FIDs also require oxygen to operate. Typically oxygen is supplied from the atmospheric air. In low oxygen containing atmospheres, it may be possible to supply oxygen to the apparatus. Flame arresting frits can be incorporated to explosion proof the equipment, although it may still not be desirable for some extremely hazardous environments.[18]

The detection principles of FIDs are very similar to the detection principles of PIDs (Section 5.6). Even slow FIDs have a response time on the order of a second.[20]

Suitability: FIDs are not suitable for the Technology Need because they are unable to identify or quantify unknown gases.

5.8 Flame Photometry

Flame Photometry burns a sample in a hydrogen flame. Target gases in the sample are burned and they produce chemical species which give of specific wavelengths of light at high temperatures. The intensity and wavelength of light given off are then analyzed to detect chemical species associated with classes of chemicals (such as chlorine in chlorinated solvents).[21] Because the sample is burned to detect chemical species, the original gas that produced the chemical species cannot be identified. Also, since the unknown gas is destroyed, further analysis is not possible.

Response range is highly dependent on concentration; at low concentrations of the target gas, multiple measurements may be necessary to improve the detection reliability. Typical response times are still short, on the order of a few seconds up to 30 seconds for H_2S.[22]

Suitability: FIDs are not suitable for the Technology Need because they are unable to identify or quantify unknown gases.

5.9 Ion Mobility Spectroscopy (IMS)

Ion Mobility Spectroscopy ionizes gases (often by the use of radioactive beta emitters) which are then accelerated in a weak electrical field toward a collection plate. The mass of the ions determines the speed that the ions move toward the collection plate, and therefore the time it takes to reach the collection plate.[23] This allows differentiation between chemical species that have different masses in a gas sample. While it is possible to significantly narrow the possibilities of potential unknowns based on mass, it would not be truly unambiguous since different gases may have the same molecular weight.

Response times are dependent on the formation, diffusion, and collection of ions; all of which are relatively fast processes. The response times of COTS are typically on the order of several seconds.

Suitability: Ion Mobility Spectroscopy technologies have the potential to meet a large portion of the Technology Need. However, they are unable to differentiate between gases that have the same molecular mass. In addition, current COTS devices are too large and bulky to be worn and used unobtrusively.

5.10 Light Absorption Based Detectors

Light absorption based detectors use the interactions between light and the target gases to detect (and in most cases quantify) the gases within the sample. Different methods used are typically described by the wavelengths used during the analysis. For instance, visible absorption techniques use wavelengths of light that the human eye can see. Chlorine (which is seen as a green gas) would be detectable by visible absorption methods. The amount of light that is absorbed in a sample can be used to determine the amount of target gas in the sample. Other absorption methods use wavelengths of light that are not detectable by the human eye – ultraviolet (UV) and infrared (IR).

Absorption based methods fall into two broad categories; dispersive and non-dispersive. Dispersive techniques use optical components to spatially separate the different wavelengths of light so that each wavelength (or small range of wavelengths) can be used for sensing. With dispersive methods, the sample is often “scanned” by changing the wavelength of light that the sample is exposed to. Using this information, it is possible to create a graph that shows the absorption characteristics of a sample. The time required to completely scan a sample can take from several seconds to several minutes depending on the range and the resolution required. Spectrums can be used for the identification of unknown gases, and in some cases can unambiguously determine the identification of a gas.

5.10.1 Non-Dispersive Spectroscopy

Non-Dispersive methods typically use a single wavelength or small range of wavelengths to investigate a sample. Light sources may be light emitting diodes (with narrow wavelengths) or filtered conventional light sources. The time required for analysis is short compared to dispersive methods, and non-dispersive methods may be able to quantify the amount of known target gases (in the absence of interference gases). However, since only a narrow range of wavelengths is used, non-dispersive methods are typically unsuited for identification of unknown gases. One major exception to this rule is the use of Fourier Transform Infrared Spectroscopy (FTIR), where a broad band light source (contains all the wavelengths intended to create a spectrum) is used. Even though the light is not dispersed by an optical component, a spectrum is able to be obtained because of equipment design and mathematical manipulation of the signals obtained. FTIR is discussed in more detail below.

Response times of non-dispersive spectroscopy techniques are based on optical sensors and are fast compared to other sensing technologies. In principle, response times can be less than a second; however response times are highly dependent on concentration and response times are often increased by the necessity for additional data acquisition to improve detection reliability. Response times of COTS tend to be on the order of 10 to 60 seconds.

Suitability: In general Non-Dispersive Spectroscopy techniques are not suitable for the Technology Need because they are unable to identify or quantify unknown gases; a potential exception is FTIR (see section 5.10.3). Response times may be slightly too slow for real-time monitoring.

5.10.2 Dispersive Spectroscopy

The actual sensors used in light absorption equipment typically do not make a distinction between the different wavelengths (or color) of light, they only detect and quantify the amount of light that reaches the sensor and produce an electrical signal which is proportional to the amount of light detected. For instance, in order to tell the difference between a gas that absorbs red light and another gas that absorbs blue light it would be necessary to only shine red or blue light on the samples. The red gas would allow the red light to easily pass through the sample (resulting in little or no change in the intensity of light reaching the sensor) and the blue gas would absorb a significant amount of red light (resulting in a significant change in the intensity of light reaching the sensor). The opposite would be true if a blue light were used; with the red gas producing a strong signal, and the blue gas producing little or no signal.

If a white light source is used (typical incandescent bulbs for instance), then all the colors of the rainbow are available for detection. The main issue is separating colors (or wavelengths of light) from each other. Prisms have been used in the past to produce a separation (or dispersion) of light, but a more favorable method of dispersing light is by the use of diffraction gratings. Dispersing the light allows a sample to be "scanned" by different wavelengths of light. The amount of light absorbed by the sample at any specific wavelength is then monitored by the sensor. Creating a graph of the amount of light absorbed vs. the wavelength will create what is known as a "spectra" of the sample.

As indicated above, spectroscopy is not limited to the visible portion of the light (i.e., electromagnetic) spectrum. Ultraviolet light and infrared light spectroscopy are also used for detection and identification of samples. The equipment used for ultraviolet spectroscopy is very similar to the equipment used for visible spectroscopy and therefore it is not uncommon to have one piece of equipment that measures both ultraviolet and visible spectra (often abbreviated UV-Vis spectroscopy). Infrared spectroscopy (IR), on the other hand, requires significantly different light sources, optics, and sensors to measure the infrared spectra. However, the IR spectra can be extremely useful for identifying unknown gases, especially gases of organic compounds.[15, 24]

Response times of dispersive systems are comparatively slow and dependent on the necessary wavelength range and how fast the spectra can be collected. In addition to the scan speeds, comparison of the collected sample to a database of known spectra for sample identification is dependent on the algorithms used for comparison.

Suitability: Dispersive Spectroscopy instruments (especially IR devices) have the potential to meet a large portion of the current Technology Needs as they may be able to detect, identify, and quantify many different gases. However, the current COTS devices are too large and bulky to be worn and used unobtrusively. Current systems will also have too long of a response time for real-time monitoring.

5.10.3 FTIR

Technically, FTIR is a non-dispersive technique because the broad wavelength light from the source is not separated into individual wavelengths; however absorption spectra are still able to be obtained because of engineering and equipment design, and a mathematical technique known as Fourier Transformation. FTIR produces the same information as dispersive IR, but in a much shorter timeframe. The IR light in the FTIR is modulated by the use of a Michelson Interferometer. The modulation is different for different wavelengths at different times during the analysis. The signal received (known as an interferogram) is then mathematically converted to the typical spectra. FTIR analysis depends heavily on precise measurements of the distances between components of the Michelson Interferometer during analysis.[24] The possibility of misalignment of the optical components for portable equipment would seem to make portable FTIRs less rugged than other detection methods.

Response times of FTIR instruments are comparatively fast to optical dispersion methods, but still slower than most other methods. A sample is often scanned multiple times so that an average of several scans can be used to improve detection reliability. Also, for identification purposes, time will be required to compare the obtained spectra to a database of known spectra. The amount of time required will be dependent on the total number of spectra in the database and the algorithms used for comparison. COTS devices typically have response times of 1 to several minutes, but note that this is dependent on the concentration of the target gas; higher concentrations will produce more reliable spectra with fewer scans.

Suitability: FTIR devices have the potential to meet a large portion of the Current Technology Needs as they may be able to detect, identify, and quantify many different gases. However, the current COTS devices are too large and bulky to be worn and used unobtrusively. Current systems will also have too long of a response time for real-time monitoring.

5.10.4 Photoacoustic IR Spectroscopy

Photoacoustic IR Spectroscopy is a detection method used in IR spectroscopy. Instead of measuring the absorbance of light, the amount of sound produced by the absorption is measured. Sound is produced because the sample is exposed to an on/off beam of light (typically by the use of a shutter system, or a chopper). When the sample absorbs the light, it heats up and expands; when the light is taken away, the sample cools and contracts. This expansion/contraction cycle of the sample produces sound at the same frequency as the light source. This technique is good for weakly absorbing samples because it is easier to detect and measure a weak signal than it is to measure a small difference between two strong signals as in absorption spectroscopy.[15]

Response times of photoacoustic IR devices will be dependent on whether the detector is dispersive or non-dispersive in nature. These devices are optical in nature and would be expected to have similar response times to the more conventional analogs (10-60 seconds for non-dispersive methods, a minute or more for FTIR methods; and dependent on concentration).

Suitability: Photoacoustic IR Spectroscopy devices have the potential to meet a large portion of the current Technology Needs as they may be able to detect, identify, and quantify many different gases. However, the current COTS devices are too large and bulky to be worn and used unobtrusively. Response times may be too slow for real-time monitoring.

5.11 Gas Chromatography

Gas Chromatography (GC) in and of itself is not specifically a detection technology, however it allows for the separation of gases for further analysis. This method uses a thin tube which may have the inner surface coated with a specific chemical, or filled with “packing”. Tubes in this manner are known as Chromatography Columns, or simply columns. When a gas sample is passed through the column, the packing will retard (slow down) the flow of specific types of gases through the tube. The gases are then detected at the columns exit by a gas sensor. The amount of time that it takes a gas to traverse the length of the column is called the retention time. Even gases within a specific chemical group may have different retention times. The retention time of an unknown gas can be cross-referenced with retention times of known gases to make an initial identification. Since the gases are not destroyed during GC, further analysis may be possible after the sample has undergone separation (for instance, infrared spectroscopy or IMS).[15]

Response times of GC methods depend mainly on the amount of time required to provide good separation of the gases. This is dependent on the particular gas (some gases will elute slower than others) and the composition of the chromatography column. Typical COTS devices have response times of a minute in the best case scenario to more than three minutes.

Suitability: Gas Chromatography technologies have the potential to meet a portion of the Technology Need. However differentiation between gases depends upon choice of column packing and the current technology of COTS devices makes them too large and bulky to be worn and used unobtrusively. Current systems will have too long of a response time for real-time monitoring.

6.0 COMMERCIALLY AVAILABLE DETECTORS

6.1 Market Survey

The following table is a list of commercially available products that are able to detect hazardous gases in normal atmosphere. Critical parameters of a detector for use as an unobtrusive, wearable, detector are that the device be small and light weight. Surveying the table indicates that the smaller and lighter detectors tend to be single gas detectors, detectors with exchangeable sensors for different gases, or detectors requiring the operator to either observe a color change or even to initiate and carry out sample collection (e.g. detection tubes). Detection technologies that have the potential to identify a large number of unknown gases tend to be large (at least one dimension longer than 1'), and heavy (typically from several pounds to 25 lbs).

It should be noted that products that contain the colorimetric detection tubes are not listed because manufacturers often prepare "kits" of tubes by selecting detection tubes for gases and gas types and packaging them together for specific potentially hazardous environments.

Much of the information in this table was culled from the Responders Knowledge Base,[1] Guide for the Selection of Chemical Equipment for First Responders,[2] as well as manufactures' literature and websites.

Table 6.1-1: Market Survey Technology Abbreviations

Technology	Abbreviation	Technology	Abbreviation
Colorimetric	Co	Electrochemical	EC
Catalytic Combustion	CB	Thermal conductivity	TC
Flame Photometry	FP	Gas Chromatography	GC
Photo ionization	PID	Flame ionization	FID
Surface Acoustic Wave	SAW	IR Absorption	IR
Ion Mobility Spectroscopy	IMS	Semiconductor	SC
		Photoacoustic IR	PIR

- **Manufacturer** – Product Maker

- **Size** – Dimensions in inches

- **Weight** - In pounds

- **Operation Time** – Amount of time the detector is able to be continuously operated on new or fully charged batteries.

- **Response Time** – Length of time in seconds that it takes the detector to respond after exposure to a target gas.

- **TIC/TIM detected** – The number of TICs (from the ITF-25 list) and Toxic Industrial Materials (TIMs) that the detector could potentially detect either inherently, by the use of additional gas specific sensors (or by exchanging sensors) with other sensors on the unit. Many of the values were obtained from Responder Knowledge Base (RKB). However, if they were not reported by the manufacturer, values were based on the perceived ability of the detection technology to detect TICs. Measured as 0, 1, 2, or Multiple (M). Note that most detectors could at least be configured to detect hydrogen sulfide, carbon monoxide, and LEL, even if not all of the gases at once.

- **Nonspecific Identification** – Refers to the potential of the device to detect and identify a significant number of gases from the TIC list without resorting to sensor exchange or attachments designed for specific gases. (i.e. will the detector "as is" be able to detect and identify a large range of TICs?)
    - Mainly and information gathered from RKB, manufacturers' literature and websites as well as abilities of detection technology used.
    - Reported as Yes, No, and S (smaller, but significant, number of TICs expected to be able to be identified).

Table 6.1-2: Commercially Available Detectors

Product	Detection Technology	Manufacturer	Size (Inches)	Weight (Pounds)	Training (hrs)	Operation Time	Response Time (s)	TIC/TIM detected	Nonspecific Identification
SABRE 4000	IMS	Smiths Detection	14.5" x 4.0" x 4.5"	7	< 8	---	10 to 30	M	S
Multi-Sensor Gas Detector Array	IMS, EC, PID, SC	Airsense Analytics	8" x 15" x 4"	8.4	---	---	> 60	M	S
Gastec Tubes and Kits	Co	Gastec	Tubes and Kits	---	---	NA	---	M	No
Dräger Tubes and Kits	Co	Dräger Safety, Inc.	Tubes and Kits	---	---	NA	> 60	M	No
Morphix Chameleon	Co	Morphix	Small: Worn on Arm	0.125	0	NA	---	M	No
ToxiRAE 3	EC	RAE Systems Inc.	3.4" x 2.2" x 0.8"	0.22	---	2 yrs	> 12	Two	No
ALTAIR® 4X Multigas Detector	EC, CB	MSA - The Safety Company	4.4 x 3.0 x 1.31	0.5	<4	24 hrs	10 to 30	M	No
QRAE Plus Hand Held 4 Gas Monitor	EC, CB	RAE Systems Inc.	4.5" x 3" x 1.8"	0.94	< 4	8 hrs	> 60	M	No
iTX Multi-Gas Monitor	EC	Industrial Scientific Corporation	4.75" x 3.19" x 1.68"	1.2	< 4	---	---	M	No
M40 Multi-Gas Monitor	EC	Industrial Scientific Corporation	4.3" x 2.5" x 1.37"	0.53	< 4	8 hrs	10 to 30	Two	No
Dräger Pac III Monitor Single-Gas	EC	Dräger Safety, Inc.	2.6" x 4.6" x 1.3"	1.1	< 4	---	30 to 60	M	No
Gas Badge Plus	EC	Industrial Scientific Corporation	3.2" x 1.9" x 1.1"	0.16	---	---	5 to 10	M	No
Gas Badge Pro	EC	Industrial Scientific Corporation	3.2" x 2.0" x 1.1"	0.19	---	---	5 to 10	M	No
GasAlert 100	EC	BW Technologies by Honeywell	1.0" x 1.5" x 2.3"	0.063	---	100 days	---	Two	No

Product	Detection Technology	Manufacturer	Size (Inches)	Weight (Pounds)	Training (hrs)	Operation Time	Response Time (s)	TIC/TIM detected	Nonspecific Identification
Genesis Portable Gas Monitor	EC	Thermo Electron Corporation	2.3" x 3.7" x 6"	1	< 8	---	30 to 60	M	No
GT CO2 Portable Gas Monitor	EC	Thermo Electron Corporation	10" x 6" x 5"	4.95	< 8	---	> 60	M	No
IQ-250 Single Gas Detector	EC	International Sensor Technology	6.3" x 3" x 4"	1.4	---	---	30 to 60	M	No
MultiCheck 2000 Multi-Gas Monitor	EC	Quest Technologies, Inc.	6.9" x 3.4" x 2"	1.32	<4	---	> 60	M	No
PAC 5000 Single Gas Detectors	EC	Dräger Safety Inc.	1.5" X 1.5" X .75"	0.22	0	8 hrs	10 to 30	Two	No
PAC 7000 Single Gas Detectors	EC	Dräger Safety Inc.	2.5" X 3.3" X 1"	0.22	0	8 hrs	30 to 60	M	No
Sensit®Gold CGI	EC	J And N Enterprises, Inc.	11.5” x 3” x 2.32”	1.2	---	16 hrs	---	Two	No
T40 Rattler Single-Gas Monitor	EC	Industrial Scientific Corporation	3.75" x 2.3" x 0.75"	0.2	---	500 hrs	---	Two	No
VRAE Hand Held 5 Gas Surveyor (Model 7800 Monitor)	EC	RAE Systems Inc.	8.3" x 3" x 1.9"	1.25	< 4	> 8 hrs	> 60	M	No
4000 Series Portable Gas Analyzers	EC	Interscan Corporation	7" x 4" x 8.9"	4.5	0	10 hrs	10 to 30	M	No
GasAlert Micro5 PID	EC, PID	BW Technologies	5.7" x 2.9" x 1.5"	0.82	< 4	---	---	M	No
MicroFID II	FID	Photovac, Inc.	13" x 12" x 3"	11	---	15 hrs	---	M	No
TVA-1000B (FID or FID/PID)	FID or PID	Thermo Electron Corp.	13.5" x 10" x 3.2"	12.32	< 8	< 8 hrs	<5	M	No
AP4C	FP	Proengin SA	13.75" x 5.5" x 3.75"	4.5	<4	8 hrs	5	M	No
TIMs Detector (M629 E00 001)	FP	Proengin SA	13.75" x 5.5" x	4.5	< 4	< 8 hrs	<5	M	No

Product	Detection Technology	Manufacturer	Size (Inches)	Weight (Pounds)	Training (hrs)	Operation Time	Response Time (s)	TIC/TIM detected	Nonspecific Identification
			3.75"						
Chemical Agent Monitor (CAM-2)	IMS	Smiths Detection	15.5" x 6" x 3"	4	< 8	8 hrs	> 60	M	S
ChemPro100	IMS	Environics USA Inc.	4" x 9" x 2"	1.8	< 4	8 hrs	10 to 30	M	S
LCD Series	IMS	Smiths Detection	7.5" x 3.5" x 1.6"	1.2	< 4	---	5 to 10	M	No
RAID-XP Nuclear & Chemical Detector	IMS	Bruker Daltonics	9.6" x 6.5" x 11.0"	15.4	< 8	---	10 to 30	M	No
Dräger X-am 7000	IR, PID, CB, EC	Dräger Safety	5.9" x 5.6" x 3"	2.4	< 4	8 hrs	---	M	No
GasAlertMicro 5 Series	PID or IR	BW Technologies	5.7" x 2.9" x 1.5"	0.82	< 4	---	---	M	No
Dräger X-am 2000 Personal 2,3 or 4 gas Monitor	EC, CB	Dräger Safety	1.9" X 5" X 1.2"	0.47	< 4	---	10 to 30	M	No
Dräger X-am 5000 Multigas Monitor	EC, CB	Dräger Safety	2.5" X 4.5" X 1.5"	0.47	None	8 hrs	10 to 30	M	No
GasAlertMax Multi-Gas Detector	EC, CB	BW Technologies	1.6" x 3.0" x 5.9"	1	----	10 hrs	---	M	No
GasAlertMicroClip	EC, CB	BW Technologies by Honeywell	4.2" x2.4" x1.1"	1	---	8 hrs	---	Two	No
Dräger MiniWarn Multi-Gas Detector	EC, CB	Dräger Safety, Inc.	3.1" x 5.6" x 2.3	1	< 4	8 hrs	60	M	No
Target Multi Gas Detector	EC, SC, CB	Enmet Corporation	5.9" x 4.5" x 1.8"	2	< 8	16 hrs	30 to 60	M	No
Omni-4000 Gas Detector	EC, CB, IR	Enmet Corporation	7.6" x 4.7" x 2.3"	4.84	<4	8 hrs	30 to 60	M	No
Gas-Sentry Chemical Detector	EC, TC, CB	Bascom-Turner Instruments, Inc.	7.25" x 3.62" x 1.7"	1.25	< 4	24 hrs	10 to 30	M	No

Product	Detection Technology	Manufacturer	Size (Inches)	Weight (Pounds)	Training (hrs)	Operation Time	Response Time (s)	TIC/TIM detected	Nonspecific Identification
Innova Type 1314 Multigas Monitor	PIR	California Analytical Instruments, Inc.	6.9"x 15.6" x 11.8"	30.8	< 8	---	30 to 60	M	No
MiniRae 2000	PID	RAE Systems, Inc.	8.2" x 3" x 2"	1.22	<4	---	5	M	No
PhoCheck 5000+	PID	ION Science Ltd	13.5" x 2.3" x 1.9"	1.3	< 8	---	< 5	M	No
ppbRAE 3000	PID	RAE Systems	10" x 3" x 2.5"	1.6	---	16 hrs	< 5	M	No
ppbRAE Plus	PID	RAE Systems	---	1.22	---	8 hrs	3	M	No
TLV Panther Gas Detector	PID	International Sensor Technology	9" x 4.5" x 5.4"	5.99	---	14 hrs	---	M	No
2020ppbPRO	PID	Photovac, Inc.	9" x 3" x 4.25"	1.9	<8	8 hr	3	M	No
MultiRAE Plus	PID , EC	RAE Systems	4.65" x 3.0" x 1.9"	1	< 8	---	> 60	M	No
MiniRAE 3000	PID	RAE Systems	---	---	---	---	3	M	No
MSA Sirius® Multigas Detector	PID, EC	MSA - The Safety Company	6.5" x 3.61" x 2.6"	1.45	<4	---	30 to 60	M	No
Portable FTIR DX-4030	FTIR	Gasmet Technologies Oy	15" x 14" x 6"	25	<4	---	5 to 10	M	Yes
AccuSense Chemical Recognition System	GC	SEER Technology, Inc.	17" x 4.5" x 11"	25	<4	8 hrs	60-180	M	S
Hand-Held Chemical Identifier	GC	D-tect Systems	16.25" x 7.75" x 9"	15.9	< 4	---	> 60	M	S
Voyager Portable Gas Chomatograph	GC	Photovac, Inc.	15.4" x 10.6" x 5.9"	15	> 8	> 8 hrs	> 60	M	S

Product	**Detection Technology**	**Manufacturer**	**Size (Inches)**	**Weight (Pounds)**	**Training (hrs)**	**Operation Time**	**Response Time (s)**	**TIC/TIM detected**	**Nonspecific Identification**
HGVI (Hazardous Gas and Vapor ID)	IMS, PID, SC	Smiths Detection	17” x 5.5” x 5”	7.5	< 8	8 hrs	< 5	M	S
MSA HAZMATCAD® and HAZMATCAD® Plus	SAW	MSA - The Safety Company	2.3" x 7.9" x 9.8"	3.13	---	8 - 12 hrs	20 to 120	M	No
GasID Partnership Package	FTIR	Smiths Detection	17.5" x 12" x 7.5"	25	< 8	< 8 hrs	> 60	M	Yes
MIRAN SapphIRe Portable Gas Analyzer	IR	Thermo Electron Corp	21.8" x 14.4" x 7.6"	24	<4	< 8 hrs	10 to 30	M	No
Ahura TruDefender FTG	FTIR	Ahura Scientific	11" x 4.4" x 2.1"	<3	< 8	4 hrs	30 to 60	M	Yes (**Head Gases**)

6.2 Devices of Note

Several COTS HAZAMT detectors have been identified that meet a significant number of requirements. Although these systems do not meet the full set of requirements defined by the NIJ Sensors & Surveillance TWG (see Section 3.0), they are noteworthy enough to warrant highlighting to first responders seeking to satisfy an immediate operational need.

NOTE: The SSBT CoE has not conducted any laboratory or field testing to verify the performance or features of specific devices or detection technologies. Assessments are based on subject matter expertise, available literature, and vendor materials.

6.2.1 Ahura TruDefender FTG

The Ahura TruDefender FTG is a rugged handheld FTIR spectrometer intended to be used for headspace gas identification in barrels, drums, bottles, and other chemical or solvent containers. FTIR spectroscopy is a highly selective method of identification of unknown gases, making the Ahura TruDefender FTG capable of identifying a wide range of headspace gases. The Ahura TruDefender FTG is also capable of identifying components in mixtures of headspace gases.[25,26] The Ahura TruDefender appears to require minimal training to set-up and operate. Some additional training may be required if data is to be exported for storage or further analysis. Response time is 30 to 60 seconds.[26] This is one of the shorter response times for FTIR devices, but note that the device is intended to measure highly concentrated gases, thus significantly reducing the response time.

Advantages:

- Light enough to be worn on the belt
- Multiple gases can be tested for simultaneously
- Potential identification of components of gas mixtures

Disadvantages:

- Size is on the larger side of what could be considered unobtrusive
- Device is intended for measurement for headspaces in chemical containers where gases tend to be much more highly concentrated than typical atmospheric safety threshold levels.
- Response time is slightly too slow for real-time monitoring

6.2.2 Dräger CMS

The Dräger CMS (Chip Measurement System) is a colorimetric system that uses an optical electronic system to detect a change in color of gas-specific chips. The use of an optical electronic system eliminates the potential for error due to operator judgment and allows for easy quantification of a gas. Each gas-specific Dräger CMS chip has 10 measurement capillaries. Information about the chip is read by the analyzer from a barcode printed on the chip. To make an individual measurement, the operator uses a four position slider switch to sequentially turn on the analyzer (runs a function test), perform a chip integrity test, and perform an individual measurement. After an appropriate measurement time, which is dependent on the specific gas and concentration, an acoustic signal is sounded and the measured value is displayed. Up to 50 results can be saved on the Dräger CMS.[9,27] The device appears to require minimal training. The main decision made by the user is the choice of gas to be detected. Response time is dependent on target gas and concentration, and can be as short as 30 seconds to as long as five minutes.[27]

Advantages:

- Small, light, and intuitive operation
- Bar code transfers all measurement data to the analyzer
- Able to measure several different gases

Disadvantages:

- Device is not intended to be operated continuously
- Operation requires dedicated actions by the operator during measurement
- Multiple gases cannot be measured simultaneously
- Response time is too slow for real-time monitoring

Figure 6.2.2-1: Dräger CMS
Courtesy of Dräger

6.2.3 Morphix Chameleon

The Morphix Chameleon is an arm-worn colorimetric device that uses exchangeable cassettes for the detection of gases. The cassettes utilize a technology where only half of the cassette changes color when the target gas is detected. This reduces the potential for error due to operator (observer) ambiguity. The device is light weight, and the positioning of the device allows for easy observation. Cassettes can be stored (unopened) for 24 months at room temperature and have a service life of 24 hours.[28,29] The Chameleon appears to be easily operated with minimal training, requiring the user to insert the desired cassettes and attach the device to the user. Periodic observation of the cassettes for color change is also required. Response times range from less than 30 minutes at dangerous concentrations for 8-hour exposure, to less than 5 minutes at IDLH concentrations.[28]

Advantages:

- Designed to be small and light enough to be worn on the arm
- Minimally invasive to the wearer
- Able to detect several different gases by cassette choice/exchange
- No power requirements

Disadvantages:

- Direct and dedicated observation of cassettes must be performed by observer
- Number of gases detected is limited to 10 because of cassette size
- Quantification (beyond lower threshold values) is not available or at least not easily performed (there may be the potential of quantification by the use of colorimetric comparison charts)
- Response time is too slow for real-time monitoring

**Figure 6.2.3-1: Chameleon
Courtesy of Morphix**

6.2.4 ToxiRAE 3

The ToxiRAE 3 detector is a single gas detector (CO or H_2S) that can provide 2 years of maintenance-free operation for initial activation. Response time is less than 12 seconds, and provides audible, visual, and vibrational alarms. The range of ToxiRAE 3 for H_2S is 0 to 100 ppm with a 0.1 ppm resolution, and for CO the range is either 0 to 500 ppm or 0 to 1999 ppm with a 1 ppm resolution for both ranges. Alarms differentiate between High, Low, Time Weighted Average (TWA), and Short Term Exposure (STEL) concentrations.[30] The device appears to require very little training to operate; essentially powering the device on and clipping it to the user.

Advantages:

- Designed to be small and light enough to be worn
- Minimally invasive to the wearer
- Up to 2 years continuous operation with supplied battery

Disadvantages:

- Only one gas detected (either CO or H_2S – chosen at purchase time).

Figure 6.2.4-1: ToxiRAE 3
Courtesy of RAE Systems

6.2.5 AccuSense

AccuSense chemical recognition system uses gas chromatography to separate chemicals and a proprietary thermal detection system to detect and quantify multiple chemicals nearly simultaneously. Unlike many other GC systems, AccuSense uses an on-board conditioning methodology so that treated ambient air can be used as a carrier gas instead of using a "consumable" carrier gas such as Argon or Nitrogen. AccuSense can be operated either by AC current, or by a rechargeable Li-Ion internal battery (8 hours).[31,32] For normal operations, the unit appears to require minimal interactions, however setting up may require compounds/database selection, connection to computer (by wire or wireless), and general software operation. Response times may vary depending on how fast the target gas elutes from the column, but the product typically operates on a 3 minute sample/analysis cycle.[33]

Advantages:

- Capability to detect and identify a wide range of chemicals
- Requires no consumables
- Can be operated continuously

Disadvantages:

- Device is too heavy to be worn
- Device is too large to be unobtrusive to operator
- Response time is too slow for real-time monitoring

Figure 6.2.5-1: AccuSense
Courtesy of SEER Technology

7.0 EMERGING/FUTURE TECHNOLOGIES

For miniaturizing a detector that would be able to detect, identify, and quantify unknown gases there appear to be two potential pathways:

1. Reduce the size of sensors of specific gases to the point that a large number sensors could be placed into a small size so that there are a large number of specific sensors; each able to detect a single gas
2. Reduce the size of technologies that are already inherently able to detect, identify, and quantify a large number of gases

7.1 Nanotechnology Based Sensors

In 2009, NNI released "Nanotechnology – Enabled Sensing" which outlines multiple research paths for reducing the size of current technologies, as well as examining novel technologies that may provide for a large number of sensors to be packaged in a smaller area. Single Wall Carbon Nanotubes, conducting polymers, and metal oxide nanowires are much smaller than conventional sensors, and have been used to detect a variety of gases. Progress is being made in improving sensitivity and selectivity of gas sensing nanomaterials. However, aside from a couple of single-chemical sensors (e.g., Nanomix carbon dioxide medical sensor), nanotechnology-based sensors are still predominantly at the laboratory proof-of-concept stage.

Presumably, if each sensor is able to detect a specific gas, then an array of sensors (each of which could detect a different gas) may be able to be manufactured which would be able to detect a large number of specific gases. Identification of the most beneficial technologies, fabrication of the sensor arrays, and materials to use for the identification of specific gases are some of the main hurdles of reducing the size of the sensor array.[34,35]

7.2 DHS "Cell-All"

A program called "Cell-All" is investigating the potential of using nanotechnology based gas sensors in cellular based phones. The detection system would have to be small, accurate, and draw only a small amount of power from the cell phones battery. The sensors currently under investigation are sensors base on new nanotube sensors developed by NASA and Synkera Technologies.

In September of 2011, DHS (in collaboration with NASA, Synkera Technologies, Qualcomm, and NC4) gave a Cell-All demonstration of a mock CO release at a Los Angeles Fire Department training facility.[36, 37]

7.3 MEMS Based FTIR

FTIR instruments are one of the main methods used by laboratories to identify chemicals, especially organic chemicals. These instruments are usually large and very sensitive to vibration and impact. One of the main issues is a component known as a Michelson Interferometer. A moveable mirror in the interferometer is used and must be moved and tracked with great accuracy and precision. Block Engineering is developing MEMS Technology in an attempt to significantly reduce the size of an FTIR instrument to approximately 8 inches long and ¾ inch in diameter by reducing the size of the interferometer. The ChemPen would perform the same function as larger FTIR instruments and is intended to identify all Chemical Warfare Agents and Toxic Industrial Chemicals under field conditions.[38,39]

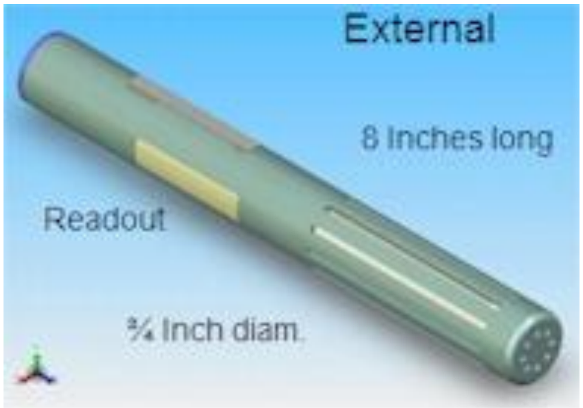

Figure 7.3-1: ChemPen Concept
Courtesy of Block Engineering

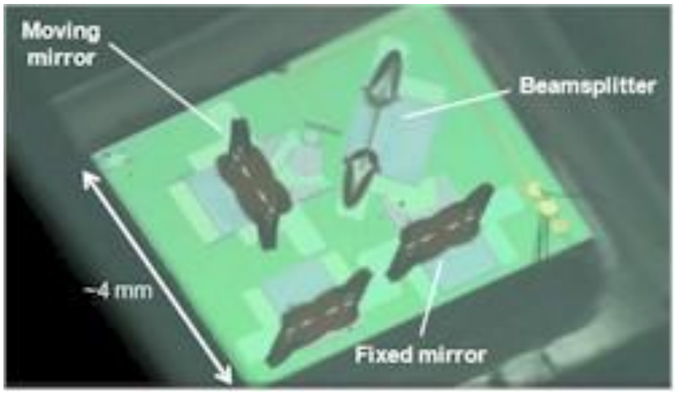

Figure 7.3-2: MEMS Based Interferometer
Courtesy of Block Engineering

8.0 CONCLUSIONS

It is the conclusion of the SSBT CoE that there does not exist a commercial off-the-shelf (COTS) device that meets the technology needs in full. As a result, further R&D is needed to produce such a system.

Several detectors have the potential to detect the presence of multiple TICs. However, most detectors incorporate sensors designed to detect a specific gas (e.g., electrochemical sensors), or use a technology that is able to detect a wide range of gases but is unable to identify an unknown gas (e.g., photoionization detectors). Of the detections technologies discussed above, only spectroscopic methods (particularly FTIR) and potentially GC and IMS have the ability to identify a large number of unknown gases (or at least a smaller but significant subset of TICs) in the atmosphere without having to change out components that are specific for particular gases. Unfortunately, because of equipment and engineering requirements, IR, GC, and IMS detectors also tend to be the larger of the listed technologies.

APPENDIX A: ACRONYMS, ABBREVIATIONS, AND REFERENCES

A.1 Acronyms and Abbreviations

ACRONYM	DESCRIPTION
AC	Alternating Current
AKA	Also Known As
CB	Catalytic Combustion
CMS	Chip Management System
CO	Carbon Monoxide
Co	Colorimetric
CoE	Center of Excellence
DHS	Department of Homeland Security
DOJ	Department of Justice
EC	Electrochemical
e-IC	Enterprise Integration Center
eV	Electron Volts
FID	Flame Ionization Detector
FP	Flame Photometry
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
H_2S	Hydrogen Sulfide
HAZMAT	Hazardous Materials
IDLH	Immediately Dangerous to Life or Health
IMS	Ion Mobility Spectroscopy
IR	Infrared
ITF	International Task Force
LEL	Lower Explosive Limit
M	Multiple
MEMS	Micro Electro-Mechanical Systems
NASA	National Aeronautics and Space Administration
NIJ	National Institute of Justice
NLECTC	National Law Enforcement and Corrections Technology Center

ACRONYM	DESCRIPTION
PID	Photoionization Detector
PIR	Photoacoustic IR
PPE	Personal Protective Equipment
R&D	Research and Development
RKB	Responders Knowledge Base
SC	Semiconductor
SSBT	Sensor, Surveillance, and Biometric Technologies
STEL	Short Term Exposure Limit
TC	Thermal conductivity
TIC	Toxic Industrial Chemical
TIM	Toxic Industrial Material
TWG	Technology Working Group
TWA	Time Weighted Average
UV	Ultraviolet
UV-Vis	Ultraviolet - Visible
Vis	Visible
VOC	Volatile Organic Compound

A.2 References

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