Comparison of Available Portable Combustible Gas and Hydrogen Sensors

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

June 2011

FOREWORD

This report documents a comparison of currently commercially available portable equipment that can be used to sense/detect the presence of hydrogen and/or combustible gases in the air. Available devices, identified via a literature search, were compared and ranked based on a common set of ranking criteria and an objective rating system for each criterion. The devices were rated against each criterion based on data contained in manufacturer literature.

This document is intended as a reference for the Federal Motor Carrier Safety Administration in evaluating available equipment that might be used by agency inspectors to search for fuel leaks from commercial vehicles powered by hydrogen. In the context of this report, the presence of hydrogen detected in a concentration greater than 25 percent of the lower flammable limit (LFL) of hydrogen in the air would be considered a leak.

Such a search would most likely be done in the context of a roadside vehicle inspection conducted in accordance with the North American Standard Inspection Procedures. In accordance with current inspection procedures, a fuel leak would be grounds to declare a vehicle out of service for a safety violation.

Given that hydrogen is a colorless, odorless gas, it is unlikely that any vehicle inspector could identify a small leak (as defined above) from a hydrogen fuel system without the aid of detection equipment.

NOTICE

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16. Abstract

This report documents a comparison of currently commercially available portable equipment that can be used to sense/detect the presence of hydrogen and/or combustible gases in the air. Available devices, identified via a literature search, were compared and ranked based on a common set of ranking criteria and an objective rating system for each criterion. The devices were rated against each criterion based on data contained in manufacturer literature.

This document is intended as a reference for the Federal Motor Carrier Safety Administration in evaluating available equipment that might be used by agency inspectors to search for fuel leaks from commercial vehicles powered by hydrogen, in the context of safety inspections carried out in accordance with the North American Standard Inspection Procedures.

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SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	Millimeters	mm
Ft	Feet	0.305	Meters	m
Yd	Yards	0.914	Meters	m
Mi	Miles	1.61	Kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
Ac	acres	0.405	Hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME	1000 L shall be shown in m³	
fl oz	fluid ounces	29.57	Milliliters	mL
Gal	gallons	3.785	Liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		MASS		
Oz	ounces	28.35	Grams	g
Lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
Fc	foot-candles	10.76	Lux	lx
Fl	foot-Lamberts	3.426	candela/m²	cd/m²
		Force and Pressure or Stress		
Lbf	poundforce	4.45	Newtons	N
lbf/in²	poundforce per square inch	6.89	Kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	millimeters	0.039	inches	in
M	meters	3.28	feet	ft
M	meters	1.09	yards	yd
Km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
Ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
G	grams	0.035	ounces	oz
Kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8c + 32	Fahrenheit	°F
		ILLUMINATION		
Lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		Force & Pressure Or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009)

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LIST OF ABBREVIATIONS AND SYMBOLS

Acronym	**Definition**
CO	carbon monoxide
CO_2	Carbon dioxide
CSA	Canadian Standards Association International
FMCSA	Federal Motor Carrier Safety Administration
H_2S	hydrogen sulfide
LCD	liquid crystal display
LED	light emitting diode
LFL	lower flammable limit
NH_3	ammonia
NO_2	nitrogen dioxide
PPM	parts per million
SO_2	sulfur dioxide
UL	Underwriters Laboratories
USB	universal serial bus

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EXECUTIVE SUMMARY

PURPOSE

This report is intended to provide a review and comparison of commercially available devices that could be used by commercial vehicle inspectors to detect hydrogen leak from vehicles fueled by hydrogen. It is being published as part of a project to develop hydrogen safety training materials targeted toward commercial vehicle operators and commercial vehicle safety inspectors. This project is part of the Federal Motor Carrier Safety Administration's (FMCSA) ongoing efforts to ensure the safety of commercial vehicle operations as hydrogen begins to play a larger role as a future transportation fuel.

The North American Standard Inspection Procedures designate the fuel system on a commercial vehicle as a critical safety component and specify that any leak in a vehicle fuel system would be grounds to put the vehicle out of service. For this report, the presence of hydrogen detectable in a concentration greater than 25 percent of the lower flammable limit of hydrogen in the air would be considered to constitute a fuel leak from a hydrogen fuel system. Since hydrogen is a colorless and odorless gas, small leaks, as defined here, are generally not detectable by human senses alone. To aid commercial vehicle inspectors in the detection of hydrogen leaks, some type of portable chemical detector will likely be required.

The devices compared in this report are intended to represent a broad cross section of commercially available off-the-shelf devices that would be readily available to most users at the time of publication and does not necessarily provide a complete or comprehensive list of such devices.

PROCESS

To identify devices for comparison, the authors interviewed maintenance managers at five transit agencies that currently operate hydrogen fuel cell buses to identify any devices used for leak detection in their maintenance programs. They also conducted a literature search on the Internet and a review of catalogs from industrial supply houses. The authors identified 15 separate devices from 11 different manufacturers that can sense the presence of hydrogen in the air. These devices fall into two broad categories: hydrogen detectors and combustible gas detectors. All of these devices are small enough to be hand held and are battery operated. The authors also identified additional hydrogen sensors intended to be permanently mounted in a building and connected to grid power, but these were not included in the analysis.

The authors used manufacturer literature to identify relevant characteristics of each device for comparison. As necessary, the authors also contacted customer service and/or technical support from the device manufacturer or sales outlet to answer specific questions not covered in the available literature. The authors did not purchase any devices or conduct any side-by-side testing.

Each device was characterized based on 17 different parameters, roughly evenly divided between characteristics related to cost of ownership and other operational considerations and characteristics related to the ability of the device to correctly identify a hydrogen leak.

The authors rated each device using a set of six standard criteria chosen as relevant to the task of identifying hydrogen leaks from commercial vehicles during roadside inspection. For each criterion, the authors created an objective rating scale to rank each detector. Using the rating scale, each device was given a rating from 1 to 5 on each criterion, with 1 being the lowest score and 5 being the highest score. The authors also assigned each criterion a weighting factor from 0 percent to 100 percent, with the total of all weighting factors adding up to 100 percent. Using the weighting factors and individual criteria rankings, each device was given an overall weighted numerical score for comparison.

STUDY FINDINGS

Each of the portable combustible gas detectors compared here achieved an overall weighted rating between 3.0 and 4.2 out of 5.0 (the highest possible rating), and each of the portable hydrogen detectors achieved an overall weighted rating between 3.1 and 3.7.

The three highest rated detectors, which achieved overall weighted ratings between 4.0 and 4.2, were all combustible gas detectors. All of these detectors have low purchase costs (less than $350), and all have similar detection capabilities. The only differences between them are maintenance and calibration requirements, as well as battery life.

The next four highest rated detectors, which achieved overall weighted ratings between 3.6 and 3.7, were all hydrogen detectors. In comparison to the three highest rated detectors these hydrogen detectors were rated lower overall because they are more expensive to purchase and operate and because they have lower utility (i.e., they can only be used to detect leaks from hydrogen-fueled vehicles and not other alternative-fuel vehicles). These hydrogen detectors have the advantage of a liquid crystal display (LCD) display, which gives more accurate information about the actual level of gas detected than the progressive light emitting diode (LED)/Tone display on the most highly rated detectors, but this advantage was outweighed in the ranking process by their higher cost and lower utility.

Of the four lowest rated detectors, three were combustible gas detectors and one was a hydrogen detector. The lowest rated hydrogen detector has identical detection capability as the other hydrogen detectors, but significantly higher purchase and operating costs, as well as shorter battery life.

Of the three lowest rated combustible gas detectors, all were given lower ratings than other detectors because of the broad range of gases detected (including CO and/or CO_2), which could increase the possibility of false-positive detection of hydrogen leaks in a typical automotive environment. One also has high purchase and operating costs compared to the other combustible gas detectors, and the other two have much shorter battery lives.

Please note that the choice of criteria weighting factors may significantly affect the outcome of the analysis (i.e., determination of the highest rated detectors). To the extent that the overall ratings here are influenced by the authors' subjective choice of criteria weighting factors, they should be considered illustrative. Readers are encouraged to evaluate the authors' choice of criteria weighting factors; those readers who disagree with the emphasis implied by the author's choice of weighting factors are encouraged to define their own weighting factors and use them, along with the criteria ratings, to develop their own overall weighted ratings.

Also note that, based on the rating criteria and weighing factors used in this report, the theoretically "best" detector for use by commercial vehicle inspectors to detect leaks from hydrogen and other alternative fueled vehicles would have all of the following attributes: 1) low cost (less than $500); 2) a narrow range of combustible gases detected (to include hydrogen, methane, and propane, but not carbon monoxide or carbon dioxide); and 3) an LCD display of the actual concentration of gases detected. None of the detectors identified for this project have all three of these attributes. The highest rated detectors have low cost and the correct range of detected gases but do not have an LCD display. There are detectors available (at a range of costs) that include an LCD display, but all of these detectors either have too narrow a range of detected gases (hydrogen only) or too broad a range (to include carbon monoxide and/or carbon dioxide).

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1. INTRODUCTION

In 2007, the Federal Motor Carrier Safety Administration (FMCSA) published three documents relating to the use of hydrogen fuel in commercial vehicles:[1]

- *Guidelines for the Use of Hydrogen in Commercial Vehicles.*
- *Changes to Consider in Federal Motor Carrier Safety Regulations and North American Standard Inspection Procedures to Accommodate the Use of Hydrogen as an Alternative Fuel in Commercial Vehicles.*
- *System Safety Plan for Commercial Vehicles Using Hydrogen as an Alternative Fuel.*

These documents were developed as part of the President's Hydrogen Fuel Initiative, and were intended to help FMCSA pursue its mandate to ensure the safety of commercial vehicle operations as hydrogen begins to play a larger role as a future transportation fuel.

This report is part of a follow-on effort designed to implement some of the recommendations made in the above noted documents, specifically the development of hydrogen safety training materials targeted toward commercial vehicle operators and safety inspectors.

The North American Standard Inspection Procedures designate the fuel system on a commercial vehicle as a critical safety component and specify that any leak in a vehicle fuel system would be grounds to put the vehicle out of service. A fuel leak in a diesel fuel or gasoline fuel system is easily detected with human senses alone, via visual cues (wetting or puddles) and/or by smell. Hydrogen, however, is a colorless, odorless[2] gas. Very large leaks may be detectable by a hissing sound, but small leaks are generally not detectable by human senses alone. To aid commercial vehicle inspectors in the detection of hydrogen leaks, some type of portable chemical detector will likely be required.

This report is intended to provide a review and comparison of commercially available devices that could be used by commercial vehicle inspectors to detect hydrogen leaks. To identify devices for comparison, the authors interviewed maintenance managers at five different transit agencies that currently operate hydrogen fuel cell buses, to identify any devices used for leak detection in their maintenance programs. They also conducted a literature search on the Internet and a review of catalogs from industrial supply houses. The authors identified 15 separate devices from 11 different manufacturers that can sense the presence of hydrogen in the air. All of these devices are small enough to be hand held and are battery operated. The authors also identified additional hydrogen sensors intended to be permanently mounted in a building and connected to grid power, but these were not included in the analysis.

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[1] These documents can be found at: www.fmcsa.dot.gov/facts-research/art-public-reports.asp.

[2] Natural gas, which is also used as a transportation fuel, is also a colorless, odorless gas in its natural state. However, natural gas utilities generally add sulfur-based odorants specifically to aid in the detection of leaks. The most likely use of hydrogen as a transportation fuel will be to power a hydrogen fuel cell engine. Current generation fuel cells are very sensitive to sulfur poisoning, limiting the use of natural gas odorants for hydrogen fuel.

The devices compared in this report are intended to represent a broad cross section of commercially available off-the-shelf devices that would be readily available to most users at the time of publication, and do not necessarily represent a complete or comprehensive list of such devices.

The authors used manufacturer literature to identify relevant characteristics of each device for comparison. As necessary, the authors also contacted customer service and/or technical support from the device manufacturer or sales outlet to answer specific questions not covered in the available literature. The authors did not purchase any devices or conduct any side-by-side testing.

2. SUMMARY OF AVAILABLE PORTABLE DETECTORS

The portable detectors identified in the literature review fall into two broad categories: hydrogen detectors and combustible gas detectors. Hydrogen detectors are designed to detect only hydrogen, while combustible gas detectors are designed to detect a wide range of combustible gases, including hydrogen. The typical range of substances that can be detected by a combustible gas detector includes acetone, acetylene, benzene, butane, ethanol, gasoline, hexane, hydrogen, industrial solvents, methane, paint thinners, propane, natural gas, and naphtha. Some combustible gas detectors can also detect some or all of the following additional gases: carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), chlorine, nitrogen dioxide (NO_2), ammonia (NH_3), and hydrogen sulfide (H_2S).

The literature search identified nine portable combustible gas detectors and six portable hydrogen detectors. See Figure 1 for photos of six typical units. All of these devices are small enough to be hand carried, and all are battery operated.

Figure 1. Typical Portable Combustible Gas and Hydrogen Detectors

The characteristics of each of these 15 devices are summarized in Table 1 through Table 4. Table 1 summarizes the purchase cost and operational considerations for the combustible gas detectors, and Table 2 summarizes the detection capabilities and user interface for these devices. Table 3 summarizes the purchase cost and operational considerations for the hydrogen detectors, and Table 4 summarizes the detection capabilities and user interface for these devices.

Table 1. Available Portable Combustible Gas Detectors—Purchase Cost and Operational Considerations

Model	Gases Detected*	Cost	Warranty	Expected Life	Maintenance	Calibration	Training	Battery Life	Ruggedness	Comments
Bacharach Informant 2	Combustible Gas	$340	1 yr including sensors	5 yr	None	None	<1hr	4–5 hrs on 4 AAs	No information available	20” flexible probe, rubber boot w/MagLite
Bacharach Leakator 10	Combustible Gas	$290	1 yr	5 yr	Replace sensor tip every 12–18 mos	None	<1hr	30 hrs on 5 C batteries	No information available	20” flexible probe; never tested on hydrogen
Bacharach Leakator Jr.	Combustible Gas	$230	2 yr	Unknown	None	None	<1hr	14 hrs on 4 AAs	No information available	12” flexible probe
BW Technologies GasAlert Quattro	Combustible Gas + O_2, CO, H_2S, SO_2, Cl, NO_2, NH_3, CO2	$995†	2 yr, including sensors	Unknown	None	Every 6 mos	<1hr	14 hrs on AA alkaline; 20 hrs on rechargeable	Built in concussion proof boot	–
Honeywell, Lumidor Impact	Combustible Gas + O_2, CO, H_2S, SO_2, Cl, NO_2, NH_3, CO_2	$925	2 yr instru-ment; 1 yr cartridge	Unknown	Replace cartridge (1 yr warranty)	Every 6 mos	<1hr	17 hrs on 4 AA; 10 hrs on rechargeable	Waterproof, dustproof, weatherproof	Calibration history, gas/event log data available on software
Honeywell MicroMAX Pro	Combustible Gas + O_2, CO, H_2S	$2,171	Lifetime, excluding 2-yr sensors	Unknown	Replace sensors (2 yr warranty)	Bump test before use, calibration every 6 mos	<1hr	13 hrs, included rechargeable, or 3 AAA	No information available	–
MSA Altair 4 Multigas	Combustible Gas + O_2, CO, H_2S	$978‡	2 yr	Unknown	None	Bump test before every day's use, calibrate when fails	<1hr	16 hrs on rechargeable; 4 hr charge time	10 foot drop test, water/dust proof	MotionAlert if no motion for 30 seconds, data logging
TIF Instruments 8800	Combustible Gas + ethane, CO, H_2S, Cl	$165	1 yr	Unknown	None	None	<1hr	4 hrs, rechargeable batteries	No information available	15” flexible probe
TIF Instruments, 8800A	Combustible Gas + ethane, CO, H_2S, Cl	$190	1 yr	Unknown	None	None	<1hr	4 hrs, rechargeable batteries	No information available	–

* Standard combustible gases detected: acetone, acetylene, benzene, butane, ethanol, gasoline, hexane, hydrogen, industrial solvents, methane, paint thinners, propane, natural gas, naptha.

† Included calibration kit; ‡ Includes calibration kit and bump test kit.

Table 2. Available Portable Combustible Gas Detectors—Detection Capability and User Interface

Manufacturer Model	Gases Detected*	Sensor Type	Precision	Minimum Detection†	Sensitivity Adjustment‡	Potential for False Positive	Audible§	Visual**	Comments††
Bacharach Informant 2	Combustible Gas	Heated diode semicondu	Not available	50 ppm	Automatically adjusts to background [2]	Broad range of automotive gases detected	Progressive Ticking	Dual 6 Progressive LEDs	UL Listed for Class 1 Div 1 Group D
Bacharach Leakator 10	Combustible Gas	Heated diode semicon-ductor type	+/-20 ppm	20 ppm	None	Broad range of automotive gases detected	Progressive Ticking	10 Progressive LEDs	UL Listed, CE Marked, Class 1, Division 1, Group A B C D
Bacharach Leakator Jr.	Combustible Gas	Metal Oxide sensor	+/ 20 ppm	20 ppm	User selection of either 20 ppm or 50 ppm	Broad range of automotive gases detected	Progressive Tone	LED	UL Listed for Class 1 Div 1 Group A, B, C, D
BW Technologies GasAlert Quattro	Combustible Gas + O_2, CO, H_2S	Catalytic sensor	1% LFL	440 ppm	None	Broad range of automotive gases detected	Single Tone	LEDs; LCD–% LFL	CSA approved, Class 1, Div 1, Groups C/D, Class 2, Div 1, Group G
Honeywell Lumidor Impact	Combustible Gas + O_2, CO, H_2S, SO_2, Cl, NO_2, NH_3, CO_2	Electro-chemical sensor	+/- 3%	880 ppm	None	Broad range of automotive gases detected	Two tone	LED; LCD–% LFL	UL Listed for Class 1 Div 1 Group A, B, C, D
Honeywell MicroMAX Pro	Combustible Gas + O_2, CO, H_2S	Diffusion and built in pump sampling systems	2% LFL	880 ppm	None	Broad range of automotive gases detected	Single Tone	LED; LCD–% LFL	UL listed for use in Class I, II, III Division I, Groups A, B, C, D, E, F, G
MSA Altair 4 Multigas	Combustible Gas + O_2, CO, H_2S	Catalytic sensor	1% LFL	400 ppm	None	Broad range of automotive gases detected	Single Tone	LED; LCD–% LFL	UL Listed for Class 1 Div 1 Group A, B, C, D
TIF Instruments 8800	Combustible Gas + ethane, CO, H_2S, Cl	Customer service had no information	Not available	500 ppm	User adjustable dial	Broad range of automotive gases detected	Progressive Tone	None	UL Listed for Class 1 Div 1 Group A, B, C, D

Manufacturer Model	Gases Detected[*]	Sensor Type	Precision	Minimum Detection[†]	Sensitivity Adjustment[‡]	Potential for False Positive	Audible[§]	Visual[**]	Comments[††]
TIF Instruments 8800A	Combustible Gas + ethane, CO, H_2S, Cl	Customer service had no information	Not available	500 ppm	User adjustable dial	Broad range of automotive gases detected	Progressive Tone	6 Progressive LEDs	UL Listed for Class 1 Div 1 Group A, B, C, D

[*] Standard combustible gases detected: acetone, acetylene, benzene, butane, ethanol, gasoline, hexane, hydrogen, industrial solvents, methane, paint thinners, propane, natural gas, naptha.

[†] Minimum Detection: For all combustible gas detectors except MSA Altair 4, minimum detection capability is based on detection of methane. For the Altair 4, it is based on detection of pentane.

[‡] Sensitivity Adjustment: USER ADJUSTABLE DIAL = Dial on device can be moved from low to high sensitivity, but there are no markings indicating actual minimum detection level at any dial setting. The Bacharach Informant 2 automatically zeroes at the detected gas level after 5 seconds to allow user to find the leak source by identifying the area with highest concentration as the device is moved around a space.

[§] Audible Signal: SINGLE TONE = same tone regardless of gas concentration detected; PROGRESSIVE TONE/TICKING = tone and/or click rate changes depending on gas concentration detected.

[**] Visual Signal: LED = All LED(s) light if any amount of gas is detected; PROGRESSIVE LED = Number of LEDs lit is proportional to gas concentration detected; LCD–% LFL = Actual gas concentration detected (% lower flammable limit) is shown on liquid crystal display; LCD─PPM = Actual gas concentration detected (ppm) is shown on liquid crystal display.

[††] Standards Organizations: UL = Underwriters Laboratories (US); CE Marked = Certification that the product meets European Union consumer safety, health, or environmental regulations; CSA = CSA International (Canada) Notes about Figures and Tables.

Table 3. Available Portable Hydrogen Detectors—Purchase Cost and Operational Considerations

Manufacturer Model	Gases Detected*	Cost	Warranty	Expected Life	Mainte-nance	Calibration	Training	Battery Life	Ruggedness	Comments
ATEQ H6000	Hydrogen	$6,000	1 yr	Unknown	None	None	<1hr	8 hrs, rechargeable removable battery pack	No information available	USB port
H2Scan Model 500	Hydrogen	$3,925	1 yr	10 yrs	None	Every 12 mos	<1hr	10 hrs on rechargeable, 4-hr charge time with included charger	Water resistant	
Kanomax S200	Hydrogen	$945	1 yr	Unknown	Replace sensor every year	Every 12 mos	<1hr	4 hrs on rechargeable battery, or wall power	No information available	Remote sensor capability
RKI Instruments Eagle 2	Hydrogen	$2,270†	2 yrs, 1 yr for sensors	Unknown	Replace sensors when needed	Every 6 mos	<1hr	16 hrs on 4 C batteries	Waterproof, chemical resistant	5-ft hose, 128-ft pump range, data logging, button toggle b/w LEL/VOL
Sensistor H2000-C Plus	Hydrogen	$15,000	2 yrs, 1 yr for sensors	Unknown	None	Before every use	<1hr	4 hrs on rechargeable battery, or wall power	No information available	
US Industrial 7200P	Hydrogen	$1,973†	1 yr	10 yrs	None	Every 3 mos	<1hr	10 hrs on rechargeable, built in battery charger	No information available	5-ft probe cable

* Standard combustible gases detected: acetone, acetylene, benzene, butane, ethanol, gasoline, hexane, hydrogen, industrial solvents, methane, paint thinners, propane, natural gas, naptha.

† Includes calibration kit.

Table 4. Available Portable Hydrogen Detectors—Detection Capability and User Interface

Manufacturer Model	Gases Detected*	Sensor Type	Precision	Minimum Detection†	Sensitivity Adjustment‡	Potential for False Positive	Audible§	Visual**	Comments††
ATEQ H6000	Hydrogen	Customer service refused to give information	Not available	50 ppm	None	Only sensitive to hydrogen	Single Tone	2 LEDs; LCD–PPM	CE Marked
H2Scan Model 500	Hydrogen	Semiconductor sensor	15 ppm	15 ppm	None	Only sensitive to hydrogen	None	4 Progressive LEDs; LCD–PPM	UL Listed-not certified for hazardous locations
Kanomax S200	Hydrogen	Semiconductor sensor	+/- 10%	0–5000 ppm	None	Gas-specific sensors	None	LCD–PPM	None
RKI Instruments Eagle 2	Hydrogen	Thermal conductivity sensor	+/- 5% total scale	400 ppm	None	Also detects gas/natural gas	Single Tone	LED; LCD–% by volume	UL Listed for Class 1 Div 1 Group A, B, C, D
Sensistor H2000-C Plus	Hydrogen	Heating element with hydrogen screen	0.5 ppm	10 ppm	None	Hydrogen filter ensures hydrogen specific detection	Single Tone	LEDs; LCD–PPM	CE Marked
US Industrial 7200P	Hydrogen	Solid state device, no need for replacement	+/- 5% total scale	400 ppm	None	Gas-specific sensors	Single Tone	LED; LCD–% LFL or PPM; Analog meter	UL Listed-No manufacturer data beyond that

* Standard combustible gases detected: acetone, acetylene, benzene, butane, ethanol, gasoline, hexane, hydrogen, industrial solvents, methane, paint thinners, propane, natural gas, naptha.

† Minimum Detection: For all combustible gas detectors except MSA Altair 4, minimum detection capability is based on detection of methane. For the Altair 4 it is based on detection of pentane.

‡ Sensitivity Adjustment: USER ADJUSTABLE DIAL = Dial on device can be moved from low to high sensitivity, but there are no markings indicating actual minimum detection level at any dial setting. The Bacharach Informant 2 automatically zeroes at the detected gas level after 5 seconds to allow user to find the leak source by identifying the area with highest concentration as the device is moved around a space.

§ Audible Signal: SINGLE TONE = same tone regardless of gas concentration detected; PROGRESSIVE TONE/TICKING = tone and/or click rate changes depending on gas concentration detected.

** Visual Signal: LED = All LED(s) light if any amount of gas is detected; PROGRESSIVE LED = Number of LEDs lit is proportional to gas concentration detected; LCD–% LFL = Actual gas concentration detected (% lower flammable limit) is shown on liquid crystal display; LCD–PPM = Actual gas concentration detected (ppm) is shown on liquid crystal display.

†† Standards Organizations: UL = Underwriters Laboratories (U.S.); CE Marked = Certification that the product meets European Union consumer safety, health, or environmental regulations; CSA = CSA International (Canada) Notes about Figures and Tables.

In addition to manufacturer name, model, and range of gases detected, for each device the following characteristics are summarized in the tables:

- PURCHASE COST AND OPERATIONAL CONSIDERATIONS: purchase cost, length of standard warranty, expected life, maintenance requirements, calibration requirements, amount of training required for users, battery life, ruggedness of the device, and comments.
- DETECTION CAPABILITIES AND USER INTERFACE: sensor type, precision, minimum detection capability and whether or not it is user adjustable, potential for false positive hydrogen readings, the kind of audible and visual signal given if gases are detected, and listing or approval by any standards organizations.

As shown, the cost of the combustible gas detectors ranges from $165 to $2,171. Hydrogen detectors are typically more expensive, with prices ranging from $945 to $15,000. Manufacturers typically provide a 1- or 2-year warranty, but several provide lifetime warranties. Most manufacturers do not provide an estimate of expected life, but those that do list either 5 or 10 years.

Based on manufacturer information, 10 of the devices require no routine maintenance, while 5 devices require the user to replace a cartridge or sensor every 1 to 2 years. Five of the combustible gas detectors require no calibration, while four require calibration every 6 months. Several of these devices also require a "bump test" before every use.[3] Only one of the hydrogen sensors did not require regular testing or calibration. The other hydrogen sensors require calibration at intervals ranging from before every use, to every 3 months, to every 12 months. Review of the manufacturer literature indicates that all of these devices are easy to set up and use. The authors estimate that training for new users will take less than 1 hour for each device.

There is a wide range of battery types used in the various devices, including standard AAA, AA, and C batteries, as well as purpose-built rechargeable battery packs. Several devices come with rechargeable batteries and a wall charger, and several devices include a built-in charger. Battery life before replacement or charging ranges from 4 to 30 hours.

Some, but not all, devices are described by the manufacturer as "water resistant" or "water proof," "dust proof," "weather proof," "concussion proof," and/or "chemical resistant."

The minimum detection limit for eight of the devices ranges from 400 parts per million (ppm) to 880 ppm. The minimum detection limit for the other seven devices ranges from 0 ppm to at least 50 ppm. The precision of the reading varies by device from +/- 1 percent to +/- 10 percent. Two of the combustible gas detectors include a dial that the user can turn to adjust the sensitivity of the device from "low" to "high." However, when doing so there is no indication to the user as to how this adjustment changes the minimum detection limit. A third combustible gas detector has a feature that allows the user to select either 20 ppm or 50 ppm as the minimum detection limit.

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[3] A "bump test" is defined by the manufacturer as a quick test of the unit's calibration using a small gas canister containing a specific pre-mixed gas sample. Units that "fail" the bump test must be calibrated using a more elaborate procedure.

A fourth combustible gas detector indicates that gas is detected, but then automatically zeroes to the sensed level of gas after 5 seconds. The purpose of this feature is to allow the user to identify the source of a leak by identifying the area with the highest gas concentration as the device is moved around. With all of the other combustible gas detectors and hydrogen detectors, the user cannot adjust the sensitivity.

Virtually all of the devices provide both an audible and visual indication when gas is detected. One combustible gas detector provides an audible signal only, and one hydrogen sensor provides a visual signal only. Audible signals are either a steady-state tone or a ticking sound. With both tones and ticking, the indication can be a single tone or a progressive tone. Devices with a single tone produce the same sound regardless of the concentration of gas detected. For devices with a progressive tone, the tone or ticking rate changes progressively as higher concentrations of gas are detected.

Most of the devices also have one or more light emitting diodes (LED) that light up when gas is detected. As with the audible signals, LEDs can be either single indication or progressive; with progressive LEDs, the number of LEDs lighted is proportional to the concentration of gas detected.

Four of the combustible gas detectors and all of the hydrogen detectors also have a liquid crystal display (LCD), which is used to indicate the actual concentration of gas detected. Detected concentration is indicated as parts per million, percent by volume, or percent of lower flammable limit (LFL).[4]

Of the 15 hydrogen and combustible gas detectors identified in the literature, 14 are listed or approved by a U.S., Canadian, or European standards organization. All of the combustible gas detectors and one of the hydrogen detectors are specifically listed for use in Class 1/Division 1/Group A–D hazardous environments, per the National Electrical Code.[5]

[4] The Lower Flammable Limit (LFL) is the minimum concentration of gas that can ignite. LFL varies by substance. The LFL of hydrogen in the air is 4 percent by volume, or 40,000 ppm.

[5] Class 1/Div 1 environments are defined as areas considered hazardous because flammable gases may be present in sufficient concentration to produce flammable or explosive mixtures under normal operating conditions. The group A–D designation addresses the types of gases that might be present, including hydrogen, acetylene, gasoline, methane, and other typical automotive combustible gases.

3. COMPARISON OF AVAILABLE PORTABLE DETECTORS

The 15 portable detectors identified in the literature were compared using a set of six standard criteria, chosen as relevant to the task of identifying hydrogen leaks from commercial vehicles during roadside inspection. For each criterion, the authors created an objective rating scale by which to rank each detector. Using the rating scale, each device was given a rating from 1 to 5 on each criterion, with 1 being the lowest score and 5 being the highest score. The authors also assigned each criterion a weighting factor from 0 percent to 100 percent, with the total of all weighting factors adding up to 100 percent. Using the weighting factors and individual criteria rankings, each device was given an overall weighted numerical score for comparison.

3.1 EVALUATION CRITERIA

Two types of criteria were used to rank the devices: economic factors and factors relating to the ability of the device to accurately detect a hydrogen leak.

The following discusses the criteria used, the rationale for their choice, and the rating scale used for each.

3.1.1 Economic Factors

The first economic factor used for comparison is purchase cost for the device. Devices costing less than $500 were given a ranking of 5, devices costing more than $5,000 were given a ranking of 1, and devices with prices in between these extremes were given a proportional numerical ranking between 1 and 5.

The second economic factor used for comparison was maintenance and calibration requirements, because the need to implement regular maintenance and replacement, as well as the need to conduct periodic calibration, will significantly affect ongoing operating costs for the use of these devices. Devices for which the manufacturer has indicated no need for calibration and no need for regular scheduled maintenance were given a rating of 5. Devices that must be calibrated more often than annually and/or that have components (sensors, cartridges) which must be replaced at least annually were given a rating of 1. Devices that need to be calibrated every 2 years and/or which have components that need to be replaced every 2 years were given a rating of 3. Other devices were given proportional numerical ratings between these extremes.

The third economic factor used for comparison was battery life, since the amount of time that a device can operate between battery changes or charging will affect both operating costs and practical reliability in the field. Devices with advertised battery life greater than 25 hours were given a rating of 5. Devices with advertised battery life less than 5 hours were given a rating of 1. Devices with advertised battery life of 15 hours were given a rating of 3; other devices were given proportional numerical ratings between these extremes.

3.1.2 Factors Relating to Detection Capability

The first detection capability factor used for comparison was the minimum detection limit of the devices. The LFL of hydrogen is 4 percent by volume in the air, or 40,000 ppm hydrogen in the air. When implementing a sensor-based detection program for gaseous fuels, it is typical to set two levels of alarm, with the first warning triggered when sensors detect a gas level equivalent to 25 percent of LFL. The second, more severe level of alarm is triggered when sensors detect a gas level equivalent to 50 percent of LFL.[6] Consistent with this practice, for this report the authors adopted as the definition of a "leak" any detected concentration of hydrogen greater than 25 percent of the LFL of hydrogen in the air.

Twenty-five percent of LFL for hydrogen is 10,000 ppm. To be effective in identifying hydrogen leaks, a portable detector must, at a minimum, be able to detect this concentration of gas, so the rating scale was set to give a rating of 1 to any device whose minimum detection limit is greater than 10,000 ppm. Devices with minimum detection limit less than 1,000 ppm (less than 2.5 percent LFL for hydrogen) were given a rating of 5. It should be noted that the minimum detection limit for all devices compared here is lower than 1,000 ppm, and all devices were given a rating of 5 based on this criterion.

The second detection capability factor used for comparison was the range of gases that the device can detect. The authors judged that a detector which can detect the standard suite of combustible gases, to include hydrogen (see Section 2), would provide the greatest overall utility for commercial vehicle inspectors because it could be used to detect leaks from a range of alternative fuel vehicles, including those fueled by hydrogen, natural gas, and propane. Since only one of these alternative fuels would typically be present on any single vehicle, the ability of the detector to detect all of these combustible gases would not contribute significantly to the possibility of a "false positive" indication of a hydrogen leak based on detection of some other non-hydrogen gas.

With the exception of gasoline, the other combustible gases detected by a typical standard combustible gas detector also would not be expected to be present in significant concentration at the roadside or in an automotive service center and would therefore also not typically contribute significantly to the potential for a false positive indication of a hydrogen leak. While gasoline vapors could be expected to be present at the location of a commercial vehicle inspection, the odor threshold for gasoline is very low—approximately 0.025 ppm[7]—so that any gasoline vapors present in high enough concentration to contribute to a false positive indication of a hydrogen leak would be very easily detected by the inspector.

Given the above analysis, devices designed to detect the standard suite of combustible gases were given a rating of 5 on the criterion "gases detected." Devices designed to detect only hydrogen were given a rating of 3 because they would have less overall utility for a commercial vehicle inspector. Devices designed to detect the standard suite of combustible gases, as well as carbon monoxide (CO) and/or carbon dioxide (CO_2) were given a rating of 1; this was done because there are likely to be elevated levels of both CO and CO_2 in roadside locations and automotive service centers where commercial vehicle safety inspections typically take place, but these elevated levels could not be detected by the inspector based on visual or olfactory cues. As

[6] See: FMCSA-RRT-07-020, *Guidelines for the Use of Hydrogen Fuel in Commercial Vehicles*, November 2007, Chapter 5.

[7] Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, *Medical Management Guidelines for Gasoline* (www.atsdr.cdc.gov/MHMI/mmg72.html).

such, detectors that include CO and CO_2 in the list of detected gases would have a higher risk of false positive indication of a hydrogen leak.

The last detection capability factor used for comparison was how the device indicates to the user that gas has been detected (i.e., user interface). In this instance, the authors based the rating scale on the concept that to be of maximum use in identifying a "leak" that might be used to justify an out-of-service designation, the user would need to have a good indication from the device of the actual concentration of gas(es) detected.

This is an idea that was expressed by several transit bus maintenance managers interviewed during the project. These managers had used several of the combustible gas detectors compared here to help identify hydrogen leaks from fuel cell buses, and they expressed a lack of confidence in the utility of the devices because they could not tell how much gas they were detecting. This could be particularly problematic if the minimum detection limit is very low (100 ppm or lower, less than 0.25 percent LFL for hydrogen); a broad range of gases might be detected; and/or the user can adjust the sensitivity but only in relative terms (high to low).

With this feedback in mind, the authors rated a device as a 5 if it includes an LCD screen and provides a readout of the actual concentration of gas(es) detected. Devices that do not have an LCD screen but provide a progressive visual or audible signal (the signal changes in proportion to detected concentration) were rated 3. Devices that give the same visual/audible signal regardless of detected concentration were rated 1.

3.2 CRITERIA WEIGHING FACTORS

The authors used the following criteria weighting factors to rank the devices:

- Purchase Cost—15 percent.
- Maintenance and Calibration—10 percent.
- Battery Life—10 percent.
- Minimum Detection Limit—10 percent.
- Gases Detected—25 percent.
- User Interface—30 percent.

The above weighting factor percentages sum to 100 percent for all six evaluation criteria. Taken together, the economic factors are weighted at 35 percent of the total, and the factors related to detection capability are weighted at 65 percent. This weighting also puts a strong emphasis on reducing the potential for false positive indications of a hydrogen leak (i.e., Gases Detected and User Interface are together weighted as 55 percent of the total).

The chosen weighting factors are to a certain extent subjective, but they reflect the authors' judgment regarding the most important considerations related to detector choice, given the task at hand (i.e., detecting hydrogen fuel leaks in the context of commercial vehicle safety inspections).

3.3 OVERALL WEIGHTED RATING

To determine an overall weighted rating for each device, the rating given to the device for each of the six rating criteria was multiplied by the relevant criteria weighting factor and the results summed, in accordance with the following formula (Figure 2):

$$R_1 = \sum_{c=1}^{6} R_{1c} \times W_c$$

where: R_1 = Weighted rating of detector 1

$R_{1,c}$ = Rating of detector 1 on criterion C

W_c = Criteria weighting factor for criterion C

Figure 2. Formula for Determining an Overall Weighted Rating for Each Device.

The result is a weighted overall average rating between 1 and 5 for each device. Devices given a higher weighted rating are judged to be better than devices with a lower weighted rating, taking all of the rating criteria into account.

3.4 RESULTS: WEIGHTED AVERAGE RATING OF AVAILABLE DETECTORS

The individual criteria ratings and the overall weighted rating for each of the devices compared here are summarized in Table 5 through Table 8. Table 5 shows the economic factors that were the basis for the rating scale for both hydrogen and combustible gas detectors, and Table 6 shows the detection capability factors that were the basis for the rating scale. Table 7 shows the weighted average ratings for the nine brands of portable combustible gas detectors, and Table 8 includes the weighted average ratings for the six brands of portable hydrogen detectors.

Table 5. Economic Factors

Parameter	Rating Scale 1	Rating Scale 3	Rating Scale 5	Weighting Factor
Purchase Cost	> $5,000	$2,750	< $500	15%
Maintenance & Calibration	> Annual	Every 2 yrs	NONE	10%
Battery Life	< 5 hrs	15 hrs	> 25 hrs	10%

Table 6. Detection Capability

Parameter	Rating Scale 1	Rating Scale 3	Rating Scale 5	Weighting Factor
Gases Detected	Combustible Gas + CO, CO2	H2 ONLY	Combustible Gas	25%
User Interface	LED/TONE	Progressive LED/Tone	LCD -% LFL or PPM	30%
Minimum Detection	>10,000 PPM	5,000 PPM	<1,000 PPM	10%

Table 7. Weighted Average Rating of Portable Combustible Gas Detectors

Parameter	Bacharach Informant 2	Bacharach Leakator 10	Bacharach Leakator Jr	BW Tech. Gas Alert	Honeywell Lumidor	Honeywell MicroMax	MSA Altair 4	TIF 8800	TIF 8800A
Purchase Cost	5.0	5.0	5.0	4.5	4.6	3.5	4.5	5.0	5.0
Maintenance & Calibration	5.0	2.4	5.0	1.0	1.0	1.0	1.0	5.0	5.0
Battery Life	1.0	5.0	2.8	2.8	3.4	2.6	3.2	1.0	1.0
Gases Detected	5.0	5.0	5.0	1.0	1.0	1.0	1.0	1.0	1.0
User Interface	3.0	3.0	3.0	5.0	5.0	5.0	5.0	3.0	3.0
Minimum Detection	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
WEIGHTED AVERAGE RATING	**4.0**	**4.1**	**4.2**	**3.3**	**3.4**	**3.1**	**3.3**	**3.0**	**3.0**

Table 8. Weighted Average Rating of Portable Hydrogen Detector

Parameter	ATEQ H6000	H2Scan Model 500	Kanomax S200	RKI Eagle 2	Sensistor H2000-C	US Ind. 7200P
Purchase Cost	1.0	1.9	4.6	3.4	1.0	3.7
Maintenance & Calibration	5.0	2.0	2.0	1.0	1.0	1.0
Battery Life	1.6	2.0	1.0	3.2	1.0	2.0
Gases Detected	3.0	3.0	3.0	3.0	3.0	3.0
User Interface	5.0	5.0	5.0	5.0	5.0	5.0
Minimum Detection	5.0	5.0	5.0	5.0	5.0	5.0
Weighted Average Rating	3.6	3.4	3.7	3.7	3.1	3.6

As shown, each of the portable combustible gas detectors achieved an overall weighted rating between 3.0 and 4.2 out of 5.0 (the highest possible rating), and each of the portable hydrogen detectors achieved an overall weighted rating between 3.1 and 3.7.

The three highest rated detectors, which achieved overall weighted ratings between 4.0 and 4.2, were all combustible gas detectors. These sense only the standard range of combustible gases and have a progressive LED/Tone for signaling that gas was detected. These three detectors are all made by the same company (Bacharach); all of these detectors have low purchase cost (less than $350), and all have similar detection capabilities. The only differences between them are maintenance and calibration requirements, as well as battery life.

The next four highest rated detectors, which achieved overall weighted ratings between 3.6 and 3.7, were all hydrogen detectors that include an LCD display of the actual concentration of gas detected. In comparison to the three highest rated detectors, these hydrogen detectors were rated lower overall because they are more expensive to purchase and operate and because they have lower utility (i.e., they can only be used to detect leaks from hydrogen-fueled vehicles and not other alternative-fuel vehicles). These hydrogen detectors have the advantage of an LCD display, which gives more accurate information about the actual level of gas detected than the progressive LED/Tone display on the most highly rated detectors, but this advantage was outweighed in the ranking process by their higher cost and lower utility.

Three of the four lowest rated detectors were combustible gas detectors, and one was a hydrogen detector. The lowest rated hydrogen detector has identical detection capability as the other hydrogen detectors but significantly higher purchase and operating cost, as well as a shorter battery life.

The three lowest rated combustible gas detectors were all given lower ratings than other detectors because of the broad range of gases detected (including CO and/or CO_2), which could increase the possibility of false-positive detection of hydrogen leaks. One also has high purchase and operating costs compared to the other combustible gas detectors, and the other two have shorter battery life.

Please note that the choice of criteria weighting factors may significantly affect the outcome of the analysis (i.e., determination of the highest rated detectors). To the extent that the overall ratings here are influenced by the authors' subjective choice of criteria weighting factors, they should be considered illustrative. Readers are encouraged to evaluate the authors' choice of criteria weighting factors; those readers who disagree with the emphasis implied by the author's choice of weighting factors are encouraged to define their own weighting factors and use them, along with the criteria ratings, to develop their own overall weighted ratings.

Also note that, based on the rating criteria and weighing factors used in this report, the theoretically "best" detector for use by commercial vehicle inspectors to detect leaks from hydrogen and other alternative fueled vehicles would have all of the following attributes: 1) low cost (<$500); 2) a narrow range of combustible gases detected (to include hydrogen, methane, and propane but not CO or CO_2); and 3) an LCD display of the actual concentration of gases detected. None of the detectors identified for this project have all three of these attributes. The highest rated detectors have low cost and the correct range of detected gases but do not have an

LCD display. There are detectors available (at a range of costs) that include an LCD display, but all of these detectors either have too narrow a range of detected gases (hydrogen only) or too broad a range (to include CO and/or CO_2).

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