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PROJECT FINAL REPORT

AHRI Project 8001/GTI PROJECT NUMBER 20894

Technical Feasibility Study Carbon Monoxide Sensing Safety Systems for Appliances

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The results within this report relate only to the items tested.

Table of Contents

Tables

Figures

Executive Summary

Carbon monoxide (CO) sensors are commonly used for industrial applications and for whole-house alarms and systems. The U.S. Consumer Product Safety Commission (CPSC) is considering CO sensors on various types of gas appliances for both safety and operational control. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) to advise and/or respond to the CPSC, funded research to develop an understanding of the types of CO sensor technology available, to establish a technical baseline for considering the practical feasibility of integrating CO sensors into gas appliances, and to identify critical areas needing further development or research.

After surveying appliance manufacturers, GTI determined the types of environments and conditions under which a CO sensor must operate in gas-fired appliances and compared this information for currently available CO sensor technology.

Based on the available literature and test data, current designs of CO sensors would be unable to operate in the combustion chamber or the flue of a gas-fired appliance for an extended period of time for use as a safety or combustion control device.

- Sensor range, maximum sensor value, accuracy and voltage are not limitations for the usage of CO sensors with gas-fired appliances.
- Temperature and humidity operating limits prevent the use of current CO sensor technology in the flue or combustion chamber of gas-fired appliances.
- CO sensor poisoning due to flue gas contaminants prevent the use of current CO sensor technology in the flue or combustion chamber of gas-fired appliances.
- The existing life span of CO sensors studied is currently less than 6 years, short of the 20 year life expectancy of many gas-fired heating appliances.

Based on the available literature and testing data, extensive research is required before current designs of CO sensors would be able to operate in the combustion chamber or the flue of a gas-fired appliance for a length of time for use as a safety or combustion control device.

Recent papers published from CO sensor research reveal a trend toward development of SMO (semiconductor) or EC (electrochemical) sensors using different materials or chemicals on very small surfaces. Smaller surfaces improve heating and cooling times and reduce the power requirements. The research is in early-stage development and does not address technical issues for gas-fired appliances safety applications.

Economic drivers for CO sensor research in 1999 were the need for improved cost, selectivity and sensitivity. Extensive CO sensor research has resulted in improved selectivity, accuracy and cost. Similar economic drivers could be established to encourage CO sensor research to improve operational life, resistance to poisoning, and to minimize the effects of temperature and humidity.

Background

Carbon monoxide (CO) sensors are currently available for industrial applications and for whole-house alarms and systems. The industrial sensors typically require periodic calibration. The whole-house sensors typically have a relative short (3-5 year) life, and then need to be replaced. Neither of these characteristics is suitable for a gas appliance safety sensor that must operate with little or no maintenance over the multi-year life of a product. The U.S. Consumer Product Safety Commission (CPSC) staff have suggested that consideration be given to a requirement for CO sensors on various types of gas appliances. In order to advise and/or respond to the CPSC, the industry needs to have a good understanding of the types of sensor technologies that already exist, the issues that prevent them from being applicable to long-term appliance use, and potential improvement opportunities with the technology that would make them applicable.

This project conducted by the Gas Technology Institute, GTI, for the Air-Conditioning, Heating, and Refrigeration Institute, AHRI, provides information on the characteristics of existing CO sensors, the feasibility and limitations of their application as safety controls on gas appliances, and identifies areas of development that can potentially resolve current technical issues and limitations to CO sensors.

Objective

The objective of this project is to provide a technical baseline for considering the practical feasibility of applying CO sensor safety systems to gas appliances as well as identifying critical areas needing further development or research. It will identify the nature of the environment of the application and the specific needs of CO sensors that could be considered for safety systems on an appliance.

Task 1 - Identify Application Parameters

Objectives

- Identify the environment and conditions that would exist for a CO sensor applied on an appliance. This would be done by communication with all appropriate AHRI sections.
- Identify minimum performance and operating characteristics for a CO sensor in the intended application with respect to accuracy and reliability, calibration requirements, durability and service life, relative initial and operating cost etc.

Approach

In accordance with the objectives of Task 1, existing performance data on selected gas-fired residential equipment were evaluated. From this evaluation a survey was developed for appliance manufacturers designed to define the types of environments and conditions under which a CO sensor must operate in gas-fired appliances (Appendix A: Carbon Monoxide Sensing Safety Systems for Appliances Manufacturers Survey). The survey was distributed to selected AHRI subcommittees including: furnace and boilers, water heating and space heaters.

Results

Nine surveys were returned that provided information on four types of gas-fired equipment, as summarized in Table 1.

Table 1. Responses to CO Survey from AHRI Member Companies

Type of Gas-Fired Equipment Manufacturer	Number of Responses
Boilers	4
Furnaces	4
Water Heaters	2
Infrared Heaters	1

Infrared heater, water heater, boiler, and furnace manufacturers' responses to determine CO sensor operating criteria did not vary significantly enough to warrant separate criteria for types of residential gas-fired equipment. Hence, a single set of criteria was established. Based on the responses to the surveys, the following set of criteria in terms of the minimal operational characteristics and environmental conditions that CO sensors must conform to operate in gas-fired equipment is identified in Table 2.

Table 2. CO Sensor Criteria Based on Surveys

Criteria	Range
Temperature	-40 to 500 deg F
Humidity	Up to 100%
Normal CO Sensor Range	0 to 400 ppm
Maximum CO Sensor Value*	3000 ppm
Lifespan	20 years
Accuracy	5%
Electrical Voltage	24 VAC

* Maximum CO Sensor Value – Value the CO sensor could be exposed to for less than 5 minutes during initial start up of unit

Several respondents noted the CO sensor would need to be impervious to different contaminants that could be caused by condensate in the flue or household cleaning/maintenance products. Identified contaminants include but are not necessarily limited to chlorides, phosphates, out gassing of binders, manufacturing oils and hydrochloric, carbonic, hydrofluoric, nitric and sulfuric acids.

Task 2 – Literature Survey and Analysis

Objectives

- Identify current commercially available CO sensor technologies.
- Compare and tabulate pertinent performance characteristics for each technology. Characteristics of interest include but are not limited to: detection accuracy and reliability; calibration requirements; service life; under current test conditions and environments as well as specific conditions and environments for the application under study.
- Analyze results of survey and identify any technical deficiencies in achieving needed performance and operating characteristics.

Approach

The literature survey and analysis focused on updating previous CO sensor studies, identifying the current "state of the art", and technology trends in CO sensor design over the next ten years.

In 1996, the Gas Research Institute, GRI, published a report entitled "Test Protocols for Residential Carbon Monoxide Alarms, Phase I, Final Report" (GRI-96/055). Section 4 of that report included a detailed analysis of commercial CO sensor technologies available at that time as well as ongoing research efforts through 1996. The report also included extensive references to patents and publications on CO sensor technologies, sensor performance, research efforts, and sensor limitations. The report concluded that no commercially available CO sensor technology met all technical requirements for carbon monoxide alarms. CO sensors would need to meet stringent requirements, especially sensitivity, selectivity, poisoning, and expected life to be successfully applied to gas appliance safety circuits.

In 2003, the Gas Technology Institute, GTI, performed a literature review of existing CO sensor technology to investigate CO sensors and approaches to implementing them on a fan-assisted Category I furnace. Based on conclusions found in the previous GRI report, GTI focused its efforts on advances since 1996 in semiconductor, electrochemical, and infrared CO sensor technologies. The literature review uncovered several potentially attractive CO sensor technologies for further investigation, including:

- Solid State Ceramic
- Copper Oxide with Alkaline Metal
- Tin Oxide in a Sensor Array with Signal Processing
- Tin Oxide with Platinum or Palladium Doping
- Multi-Sensor System with Sigma Delta Signal Processing
- Catalytic Bead Sensor with Platinum wire
- Gallium Lead Diode Laser Absorption Sensor
- Zirconia Sensor

The evaluation included technical performance requirements, economic parameters, CO sensor performance, and recommendations for future research on CO sensors. Table 3 summarizes the status of CO Sensor technology in 2003.

Table 3 Results of 2003 GTI CO Sensor Investigation

Type	Supplier	Sensor Element	Status
Catalytic Bead	Nemoto	Platinum/Alumina/Catalyst	Available
MOS*	Figaro	SnO_2/RuO_2/Charcoal	Available
MOS	Figaro	SnO_2/Pd/Ir doping	Available
IR	Comag IR	"SmartScan" Infrared	Available
Electrochemical	Sixth Sense	"SureCell" 3-electrode	Available
Catalytic Bead	Tokyo Gas	Platinum/Alumina/Catalyst	Field Trials
MOS	Los Alamos National Laboratory	Ceramic/Noble Metal	Patent Applied For
MOS Sigma Delta Processing	U. of Pavia	Multi-Sensor	Laboratory
MOS Micro-fabrication	EVE Group	SnO_2/Pd doping	Laboratory
MOS/Processing	U. of Barcelona	SnO_2 Array	Laboratory
Mid-IR BRD	Stanford U.	Quantum Cascade Laser	Laboratory
Electrochemical	Loughborough U.	Nafion/Pt/Au	Laboratory
IR	Stanford U.	GaSb Diode Near IR Laser	Laboratory
MOS	Osaka Gas	CuO/Na_2CO_3 doping	Laboratory

*Metallic Oxide Sensors

In 2003, GTI determined that current MOS, electrochemical and catalytic technologies, low cost CO sensors at the time were not yet suitable for widespread application to gas appliance safety circuits in the US. GTI noted at the time, that in light of recent market introduction of CO sensors in appliances in Asia and the US, and CPSC laboratory investigations, further investigation into the performance of MOS, catalytic bead, and electrochemical CO sensor technologies were warranted.

CO Sensor Literature Review Results

The information collected from research papers over the past ten years, the previous work by GRI, interviews with sensor manufacturers and published sensor product literature show that the predominant technologies in use and the number of CO sensor manufacturers has changed somewhat over the past five years, while the research focus in the development of CO sensors has not changed significantly in the past ten years.

CO Sensor Technologies

As detailed by Galatsis et al (2008), the majority of CO sensor fall into three categories: metal oxide or semiconductors (SMO), electrochemical (EC) and infrared or optical (IRO). SMO sensors were derived from the same category as MOS sensors given in Table 3, but referring to these sensors as semiconductor sensors has become standard within the industry. The acronyms used were changed from those used by Galatsis to maintain consistency within this report.

SMO sensors have a small heated element that cause oxidizing gases such as CO to react with a metal oxide film. The film's conductivity is measured and is proportional to the gas concentration. SMO sensors tend to be small, reliable, durable and inexpensive, but have poor gas selectivity and can be influenced by temperature and humidity, which could be an issue for flue gas sampling.

EC sensors have an electrode in contact with a liquid electrolyte. Sample gas is diffused into the electrolyte which changes the electrical potential of the electrode proportionally to the gas concentration. EC sensors tend to be small, but can have poisoning and temperature issues.

IRO sensors have an optical sensor that changes in light transmission properties based on the concentration of sample gas present. IRO sensors tend to be small, low power consumption, good selectivity and have longer life spans compared to other sensors. However, IRO sensors are not as common as the other types, generally cost more and have slower response times.

The following table from Galatsis et al (2008) gives a comparison of the three sensor types.

Table 4. CO Sensors Technologies from Galatsis et al (2008).

Comparison of Three Gas-Sensing Technologies with Respect to Desirable Carbon Monoxide Domestic and Vehicle Air Quality Monitoring Criteria

Criteria	Infra Red—Optical	Electrochemical	Metal Oxide
Cost	<US$15	<US$10	<US$5
Life time	>6 years	2–5 years	>6years
Sensitivity	Very good	Very good	Very good
Selectivity	Excellent	Very good	Poor
Response time	Seconds	Seconds	Seconds
Size	Medium	Medium	Small
Ease of use	Good	Excellent	Excellent

Another sensor type is Pellistors or Ceramic Beads. A catalytic pellistor use ceramic beads with a catalyst that changes in resistance when exposed to different sample gases that are oxidized by the catalyst. Thermal conductivity pellistors have measureable changes in heat loss based on the concentration of sample gas oxidized. Pellistors tend to drift, become poisoned, require maintenance every few months and are primarily designed for detecting combustible gases. Because CO and air have very similar thermal conductivities, Pellistors don't work well with CO. For these reasons, Pellistors are not generally used for CO detection.

CO Sensor Manufacturers

A study conducted by GTI (2004) for investigating the use of CO sensors in residential furnaces, gave a list of manufacturers of CO sensors, presented in Table 5. The table lists the sensors types in accordance with Galatsis (2008) where the following of acronyms are used:

- SMO for Semiconductor/Metal Oxide sensors
- EC for Electrochemical sensors
- IRO for Infrared/Optical sensors

Table 5. CO Sensors Manufacturers from GTI (2004).

Manufacturer	Sensor Type
City Technology LTD	SMO
COMAG IR	IRO
Figaro	SMO
Nemoto	Catalytic Bead
Sixth Sense	EC

The 2004 GTI report compiled a table of manufacturers, sensor type, products and application. The table showed that semiconductor/metal oxide sensor technology dominated products and research in 2004. New updated summary information has been compiled through manufacturer interviews and reviews of product literature in the following table.

Table 6. Current CO Sensor Manufacturers

Manufacturer	Sensor Type	Products	Applications
City Technology LTD*	EC	Sensors	Gas Sensors
Comag IR	IRO	Sensors/Alarms	HVAC control, ventilation
E2V**	SMO, EC, IRO	Sensors	Gas Sensors
Figaro	SMO, EC	Sensors	Gas Sensors
FiS Inc	SMO	Sensors	Gas Sensors
Kidde	EC	Sensors/Alarms	Nighthawk brand residential CO alarms
KWJ Engineering Inc	EC	Sensors	Gas Sensors
Monox***	NA	Sensors	Gas Sensors
Nemoto & Co., LTD	EC	Sensors	Sensors for residential use and boilers
Quantum Group Inc	IRO	Sensors	Sensors for Costar brand CO Alarms

*Acquired by Honeywell in 2006, included Sensoric and Sixth Sense products
**Acquired Microchemical MiCS in 2007
***Part of Invensys Sensor Group, sensor type not available on website

The majority of the manufacturers in Table 6 are strictly sensor manufacturers that develop and sell sensors for use in other manufacturers' products to monitor CO concentrations. The exceptions are Comag IR and Kidde who manufacture their own sensors for installation in their products for HVAC and ventilation control, and CO alarms respectively. According to their website, the sensors made by Quantum are used in the Costar® brand of CO alarms, but information is not given to confirm if Costar® and Quantum are commonly owned or an exclusive manufacturer.

The sensor type information in Table 6 when compared to in Table 5 shows a shift from semiconductor/metal oxide sensors to electrochemical sensors. Separate conversations with representatives from City Technology (2010) and Figaro (2010) confirm the shift in last five years to electrochemical sensors. City Technology is not currently manufacturing any semiconductor sensors, choosing to focus entirely on their electrochemical designs. A sales engineer from Figaro stated the reason for their shift from semiconductor to electrochemical was the market's interest in sensors that require less power.

CO Sensor Research

The literature review looked at research in CO sensor design and development over the last ten years. The review found that a vast majority of funded CO sensor research centered on ambient monitoring of CO levels as used in typical residential CO alarms. An exception in the research was Folch et al. (2007) which focused on multi-gas sensor for combustion control for boilers.

The review identified poisoning due to corrosive contaminants in the flue gas and matching the life of the sensor to the life to the appliance are major technical hurdles in CO sensor development. These findings corroborate concerns identified by the manufacturers in the Task 1 survey. Though these issues have been discussed in several of the references listed for this report, the emphasis of the research has been improving sensor accuracy and sensitivity, selectivity, and cost, as detailed in a review of sensor research by Azad et al (2000) and shown in the work of Liao et al (2008), Sberveglieri et al (1998), Hoefer et al (2001) and others listed in the Reference section for this report. As in Pfefferseder (2001), either sensor life has been based on the typical battery life of CO alarms or it is accepted that the CO sensor must be tested and/or replaced ever five years or so. The acceptance, especially in Japan, that CO sensors have to be checked and/or replaced ever five years was expressed by the engineer from Figaro (2010).

Detailed by Willett (1999), the economic drivers in CO sensor research in 1999 were the need for improved cost, selectivity and sensitivity, which is reflected in the research from the literature review for the past ten years. According to Figaro, if the economic drivers were to emphasize improved resistance to poisoning and increased sensor life, then improvements in these characteristics for CO sensors would be addressed and improved. But as the past ten years of research has shown, at least 10 to 15 years of work may be necessary to achieve and validate significant improvements in these areas.

The most recent papers published for CO sensor research reveal a trend toward development of SMO (semiconductor) or EC (electrochemical) sensors using different materials or chemicals on very small surfaces. Depending on the researcher, terms like micro machined, micro platforms, nanoparticles or nanowire sensors have been used to describe these new sensors. As explained by Yamazoe (2009), these sensors use the same basic principles as SMO and EC sensors, but use the smaller surfaces to improve heating and cooling times and reduce the power requirements. Yamazoe (2009) also states that another trend in sensor development is the process of using a more theoretical approach to designing sensors instead of an empirical approach where different materials and surface designs are just tested and compared. In the theoretical approach, the design of a sensor takes into account the physical properties of different semiconductors and electrolytes and the chemical properties of the gas to be measured. Using this method leads to more research in exotic materials and substrate designs for sensors. Examples include gold nanoparticle decorated GaN nanowires studied by Berven et al (2008), gold on nanotubes studied by Penza et al (2009), platinum nanoparticles on polymer electrolytes studied by Chou et al (2009), porous silicon films with aluminum backing studied by Martinez et al (2008), zeolites on micro machined thin films studied by Yasuda et al (2009), and micro machined sensors with temperature control studied by Lombardi (2009).

All of the technologies published in these reports show potential for gas sensors including CO. These technologies, however, are still in early development stage and require at least five more years of research to resolve issues such as selectivity and cost before they could be ready for use in gas-fired applications. In addition, none of the listed research discusses sensor life beyond what is typical for the currently available sensors.

Analysis of the Use of CO Sensor in Gas-Fired Appliances

The project objective includes determining the technical feasibility of installing a CO sensor in the combustion chamber or flue of a gas-fired appliance. The literature review shows that the emphasis in the development and usage of CO sensors has focused on monitoring ambient levels of CO for safety or ventilation control, with minimal research on combustion control. The potential use of a CO sensor in a gas-fired appliance falls into the category of use as a combustion control, or least is exposed to the same environmental conditions as combustion control. Based on the surveys from AHRI member manufacturers of, the following set of criteria for the environmental conditions that the sensor could be exposed to is presented in Table 7.

Table 7. CO Sensor Criteria Based on Surveys

Criteria	Range
Temperature	-40 to 500 deg F
Humidity	Up to 100%
Normal CO Sensor Range	0 to 400 ppm
Maximum CO Sensor Value*	3000 ppm
Lifespan	20 years
Accuracy	5%
Electrical Voltage	24 VAC

* Maximum CO Sensor Value – Value the CO sensor could be exposed to for less than 5 minutes during initial start up of unit

Based on the literature review of CO sensor research over that past ten years and conversations with representatives from CO sensor manufacturers, each technology-type of CO sensor has limitations that currently prevent it from meeting the performance criteria listed in Table 7.

Several sources have studied if a sensor design is capable of producing an electrical signal based on CO concentration that could be used in appliance shut down. Research by CPSC (2001), CPSC (2004) and GTI (2004) in an environmental chamber with a controlled level of CO showed that different designs for electrochemical (EC), infrared (IRO), semiconductor (SMO) and catalytic sensors produce this type of electrical signal. As Figure 1 shows, the CO sensor tested by GTI (2004) has a consistent output signal as a function of CO concentration, both for increasing and decreasing levels of CO.

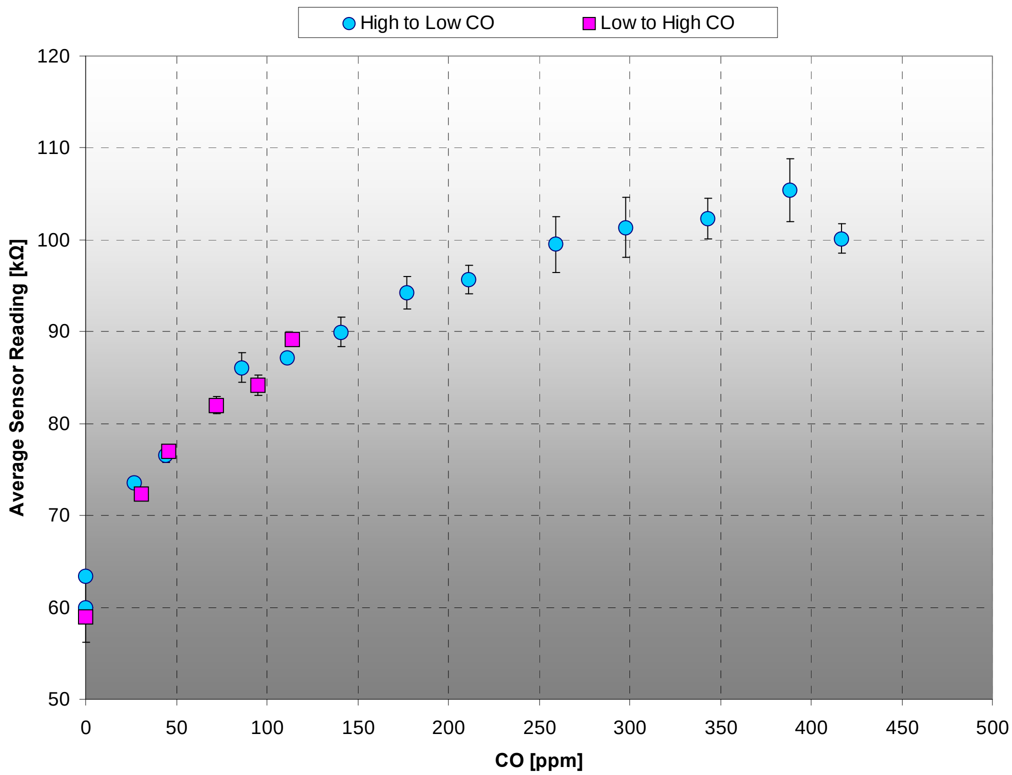

Figure 1. CO Sensor Reading as function of CO concentration GTI(2004).

Testing by CPSC and interviews with Figaro and City Technology show limitations in the performance of CO sensors based on environmental conditions. As stated by Galatsis (2008) and reflected in the data of CPSC (2001) and CPSC (2004), both SMO and EC sensor outputs were affected by temperature and humidity. For example, in the work by CPSC (2004), the EC sensor tested had a voltage output of about 1.4 volts at 64°F and 50% rh (relative humidity) compared to 2.1 for 70°F and 92% rh.

These limitations were also noted in interviews with Figaro and City Technology. According to Figaro (2010), their SMO sensors were limited to operating conditions without high heat or humidity due to a loss in accuracy and their EC sensor life span was reduced by high temperature operating conditions. A specific temperature limit was not given from Figaro, but the reason for the life span reduction in the EC sensors is due to evaporation or loss of the water in the sensor. Typically the water in the sensor lasts for seven years at room temperature, but decreases proportionally as the exposure temperature is increased. According to City Technology (2010), their EC sensor is limited to operating conditions at temperatures below 105°F and rh range of 15 to 90%. Based on the results from all the sources listed in the reference section of this report, none of the sensors listed were capable of operating for a significant amount of time in an environment greater than 300°F. This means, as currently designed, CO sensors would have to be placed in flue downstream of the heat exchanger in an appliance and could not be placed in the combustion chamber.

These results reflect the emphasis in CO sensor development on sensors for ambient monitoring and not combustion control. Typical conditions found in the flue of gas-fired appliances like furnaces and water heaters are known to have environmental conditions where humidity and flue gas contaminants could affect the performance or poison CO sensors. Without extensive life testing of the existing designs of CO sensors in an environment similar to that found in exhaust flue of gas-fired appliances, conclusions cannot be made about the ability of existing CO sensors to operate effectively to control gas-fired appliances.

Conclusions and Recommendations

A survey of selected AHRI appliance manufacturers established environmental and operating criteria under which a CO safety sensor must operate in gas-fired appliance.

- Temperature Range: -40 to 500 deg F
- Humidity Range: 0% to 100% rh
- Normal CO Sensor Range: 0 to 400 ppm
- Maximum CO Sensor Value: 3000 ppm
- Lifespan: 20 years
- Accuracy: ±5%
- Electrical Voltage: 24 VAC

A review of the literature and discussions with CO sensor manufacturers determined the following:

- Sensor range, maximum sensor value, accuracy and voltage are not limitations for the usage of CO sensors with gas-fired appliances.
- Temperature and humidity operating limits prevent the use of current CO sensor technology in the flue or combustion chamber of gas-fired appliances.
- CO sensor poisoning due to flue gas contaminants prevent the use of current CO sensor technology in the flue or combustion chamber of gas-fired appliances.
- The existing life span of CO sensors studied is currently less than 6 years, short of the 20 year life expectancy of some gas-fired appliances.

Table 8 gives a summary of the different issues for SMO, EC and IRO sensors usage in gas-fired appliances.

Based on the available literature and testing data, extensive research is required before current designs of CO sensors would be able to operate in the combustion chamber or the flue of a gas-fired appliance for a length of time to be used for safety or combustion control.

Recent papers published for CO sensor research reveal a trend toward development of SMO (semiconductor) or EC (electrochemical) sensors using different materials or chemicals on very small surfaces. Smaller surfaces improve heating and cooling times and reduce the power requirements. The research is in early-stage development and does not address technical issues for gas-fired appliances safety applications.

Table 8. CO Sensor Usage in Gas-Fired Appliances*

CO Sensor Usage in Gas-Fired Appliances*			
	SMO: Semicondutor /Metal Oxide	EC: Electrochemical	IRO: Infrared /Optical
Size	No Issues	No Issues	No Issues
Reliability	No Issues	No Issues	No Issues
Durability	No Issues	No Issues	No Issues
Cost	Potential Issues	Potential Issues	Issues
Temperature/Humidity Influenced	Potential Issues	Potential Issues	Insufficient Data
Selectivity	Issues	No Issues	No Issues
Poisoning	Issues	Potential Issues	Insufficient Data
Life	Issues	Issues	Potential Issues
Response Time	No Issues	No Issues	Potential Issues
Power Usage	No Issues	No Issues	No Issues

*Matrix based on usage in CO sensing on gas fired appliances and in comparison with each other type

Graphical representations of Table 8 are given in Appendix B.

Economic drivers in CO sensor research in 1999 were the need for improved cost, selectivity and sensitivity. Extensive CO sensor research has resulted in improved selectivity, accuracy and cost. Similar economic drivers could be established to encourage CO sensor research to improve operational life, resistance to poisoning, and to minimize the effects of temperature and humidity.

Improvements in these characteristics for CO sensors could be addressed and improved over the next 10 to 15 years. Extensive life testing would have to be included in the research before any conclusions could be made the use of any CO sensor in a gas-fired appliance.

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Appendix A: Carbon Monoxide Sensing Safety Systems for Appliances Manufacturers Survey

INTRODUCTION

Purpose of Survey

AHRI is funding the Gas Technology Institute to provide a technical baseline for considering the practical feasibility of applying CO sensor safety systems to gas appliances as well as identifying critical areas needing further development or research.

As part of the research, AHRI is soliciting member participation in this survey to:

- Identify the environment and conditions that would exist for a CO sensor applied on an appliance, and
- Identify minimum performance and operating characteristics for a CO sensor in the intended application.

Confidentiality

Results of this survey will be aggregated with others and used as basis for comparing commercially available CO Sensors, and identifying further development needs. Any information provided for this survey will be kept confidential by AHRI staff and contractor.

MANUFACTURER INFORMATION

Name:
Company:
Contact (Email or Phone):
Date:

QUESTIONS

1. Which of the following types of product do you manufacture and sell?

Priority	Type of Equipment Manufactured
	Furnaces
	Water Heaters
	Boilers
	Direct Heating Equipment
	Unit Heaters
	Infrared Heaters
	Vent Free Heaters

2. Define the range for the steady state operating environment and conditions CO sensors would be subjected to by your appliance when installed to monitor productions of combustion?

CO SENSOR OPERATING ENVIRONMENT AND CONDITIONS

	Operation Range		
	Steady State	**Min**	**Max**
Ambient Conditions			
Temperature (deg F)			
Humidity (%)			
Altitude* (ft)			
Appliance Conditions			
Flue Gas Temperature (deg F)			
Flue Gas Pressure (in. wc.)			
Flue Gas Flow Rate (cfm)			
Burner Firing Rate (BTU/hr)			
O_2 (%) or CO_2 (%) [circle]			
Carbon Monoxide** (ppm)			

*At what range of altitudes is the appliance designed to operate without adjustment

**Please provide CO values corrected to 3% O_2

3. During the first 15 minutes of a cold start up of the appliance, what is the peak CO emission that could occur for the type(s) of products that you manufacture? Is this a spike or a gradual ramp up?

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____

4. During the operation on your appliances, are you aware of any contaminants or pollutants that could be in the products of combustion that could affect a CO sensor?

5. New sources of natural gas are being introduced in the fuel supply in the US, including import LNGs and biogases. Are you aware of any issues concerning these fuels that could affect a CO sensor?

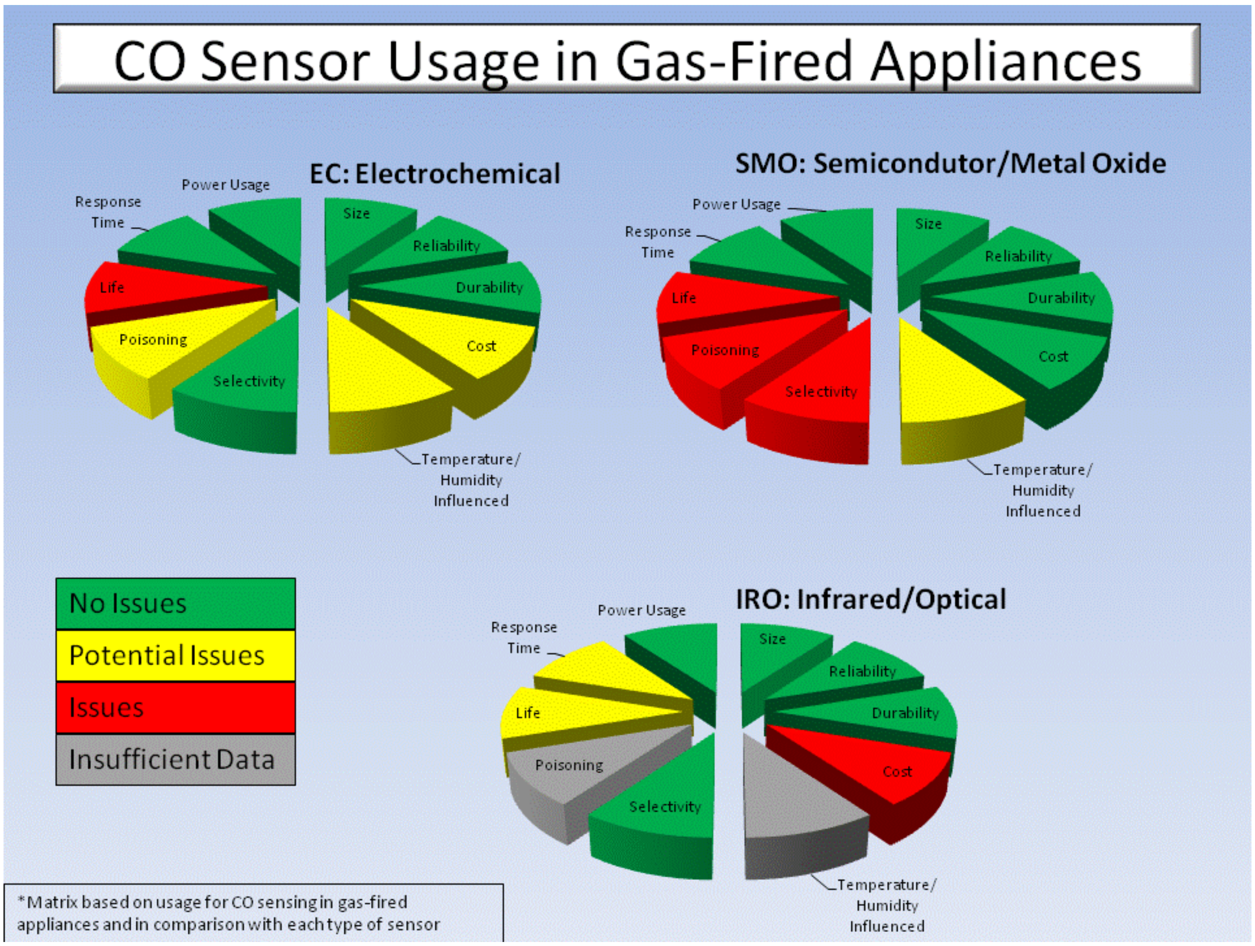
6. From the list of performance and operating characteristics for CO sensors, please comment on the characteristics that you feel are important or critical for evaluating potential sensor technologies. Express your comment in the following formats if possible: must be > X, should be < X, = X.

   Please review this list for its completeness and provide any missing information in the comments section of this survey.

	Important	Critical	Comment
Performance Operating Characteristic	✓	✓	
Example: Operation Temperature (in °F)		✓	***Up to550 °F***
Long-Term Stability (in years)			
Expected Life (in years)			
Life Extendibility (yes/no)			
Accuracy (in %)			
Detection Range (in ppm CO)			
Immunity to False Alarms (important or not)			
Sensitivity to Contaminants (important or not)			
Response Type (Non-linear or linear)			
Response Time (slow to fast or not important)			
Temperature and Humidity Variation			
Sensitivity Drift (in % over time)			
Zero Drift (important or not)			
Mode of Failure			
Battery Operable (yes/no)			
Electrical Signal Processing			
Serviceability (important or not)			
Operational Voltage (in volts)			
Maximum Current Consumption (in mA)			

8. Please write in any comments or suggestions you that have not been addressed in this survey.

Appendix B: Graphical Representations of Issues for CO Sensor Usage in Gas-Fired Appliances



CO Sensor Usage in Gas-Fired Appliances*

	SMO: Semicondutor /Metal Oxide	EC: Electrochemical	IRO: Infrared /Optical
Size	✓	✓	✓
Reliability	✓	✓	✓
Durability	✓	✓	✓
Cost	✓	⊘	✗
Temperature/Humidity Influenced	⊘	⊘	?
Selectivity	✗	✓	✓
Poisoning	✗	⊘	?
Life	✗	✗	⊘
Response Time	✓	✓	⊘
Power Usage	✓	✓	✓

*Matrix based on usage in CO sensing on gas fired appliances and in comparison with each other type

✓	No Issues
⊘	Potential Issues
✗	Issues
?	Insufficient Data