CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

## FINAL PROJECT REPORT

# Smart Shutoff Technology for Commercial and Residential Buildings

**July 2024 | CEC-500-2024-089**

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# ACKNOWLEDGEMENTS

GTI Energy appreciates support from Pacific Gas and Electric Company and Southern California Gas Company for providing the technical and operational expertise required to ensure this research's relevancy to California. Pacific Gas and Electric Company provided both a simulated building environment for testing and commercial and residential buildings for the demonstrations described in this report. Thanks also goes to the experts from Operations Technology Development (OTD), which provided subject matter expertise and direction during the project. In addition, GTI Energy appreciates the vendors that participated in the research, development, and deployment coordination for the project demonstrations, including Senet Inc., Semtech Corporation, Lorax Systems, Honeywell, New Cosmos, Heath Consultants, and eLichens.

# PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

*Smart Shutoff Technology for Commercial and Residential Buildings* is the final report for Contract Number PIR-19-003 conducted by GTI Energy. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

# ABSTRACT

This project provides California gas utilities with "smart" solutions to implement gas safety shutoff devices and sensors. Currently, gas infrastructure lacks the enhanced safety features needed to terminate the flow of gas in a building after detection of a hazardous incident such as a gas leak or fire. This project addresses the hurdles that exist in the implementation, integration, and data management of a smart safety system for utility gas customers.

A gas smart shutoff safety system consists of smart sensors, smart shutoff valves, network communication, and a software-user interface. These smart sensors detect both abnormal concentrations of gas (gas leak) and temperature (fire) and communicate hazard readings to the gas utility and emergency responders. Depending on the readings from these smart sensors, smart valves can either be actuated remotely or programmed to close if hazardous gas concentrations or high temperatures are detected. The valve closure stops the gas flow and reduces the threat of building fires or explosions.

The specific objectives of this project were to:

- Determine gas customer preferences with smart shutoff safety systems.
- Identify emerging gas concentration and temperature safety sensors and network communication practices and procedures.
- Integrate and test promising safety sensors and communication protocols to validate the performance of the gas smart shutoff system.
- Perform a pilot demonstration of a gas smart shutoff system for residential and commercial customers.

The project successfully demonstrated the safety system in both residential and commercial buildings during an initial installation. After more than six months had passed, the safety system was again exposed to hazards and the safety system successfully functioned as designed. All components of the safety system were improved as a result of this project, and these components are available for sale in the consumer market. Installation of this safety system on California buildings would improve gas safety.

**Keywords:** smart sensors, safety technology, gas, network communication, shutoff valves

Please use the following citation for this report:

Jarnecke, Dennis, Joe Carlstrom, Joseph Irwin, and Chris Ziolkowski. 2024. *Smart Shutoff Technology for Commercial and Residential Buildings*. California Energy Commission. Publication Number: CEC-500-2024-089.

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# Executive Summary

## Background

Gas leaks, fires, and explosions in buildings of all types are major concerns and can occur in California and throughout the United States. Research performed by New Cosmos Incorporated, a manufacturer of gas detectors, found 653 internet-documented gas incidents in the United States from 2010 to 2023 that resulted in 289 fatalities and 1204 injuries. Among those, 24 gas-related incidents occurred in California alone, resulting in 11 fatalities and 91 injuries. While it is difficult to estimate the overall cost of these incidents, all gas leaks impact life, property, and the environment. Therefore, more effective means are urgently needed to identify leaks before they become hazardous, to send alerts of those leaks to first responders, and to stop the release of further gas emissions into the environment. This research project presents a new smart technology to address these concerns in support of California's ambitious clean energy and climate mandates.

Current gas infrastructure lacks the enhanced smart safety features needed to detect hazards, alert emergency responders, and automatically shut off gas flow during incidents such as gas leaks or fires. Commercial stand-alone safety devices such as excess flow valves and indoor gas monitors are available, but they lack connectivity among emergency personnel, gas customers, and gas utility companies. Recent technology advancements in indoor methane sensors and wireless communication networks have allowed development of a safety system that can be installed in all buildings with gas service. The benefits of this safety system include decreased methane emissions, prevention of customer property damage and personal injury in the event of a hazard, and a decrease in incidents caused by gas leaks.

This project developed an integrated platform with smart hazardous detecting sensors, automated shutoff valves, two-way device communication, and a software user-interface that enhances gas safety for customers in California. A comprehensive gas smart shutoff safety system supports California's clean energy and climate goals by detecting a gas (methane) leak, restricting the flow of gas to a building, and alerting the gas utility to immediately respond to an emergency situation. The research for this project concludes that this gas safety system will provide a layer of safety protection not currently used in the gas industry and will save lives and property, while mitigating environmental impacts.

## Project Purpose and Approach

A comprehensive gas smart shutoff safety system was developed to alert first responders of a gas leak or fire in a building and to automatically shut off gas into that building. A technical approach was adopted, described in the following three tasks.

- **Customer Research and Product Discovery:** This task included customer research of California gas customers on gas safety concerns, attitudes on smart shutoff technology, and willingness to pay for such a system and for potential improvements to the system. Included in this task was a national and international search for gas safety system components.

- **Design, Specification, and Validation:** This task, which was based on customer research and product discovery findings, provided safety system requirements, specifications, and validation (testing) of the safety system components.
- **Utility Demonstration and Analysis:** This task required coordination with California gas utilities to gain subject matter expertise in safety system installation. Demonstrations were performed in select buildings.

The project required regular coordination with Southern California Gas Company (SoCalGas) and Pacific Gas and Electric Company (PG&E). PG&E provided a residential building in San Mateo, California, and a commercial building in Roseville, California, to install the pilot safety system and demonstrate the system's functionality in a live setting. At the time of initial installation, gas and heat hazards were applied to the smart sensors to confirm that the safety system functioned as designed. After the safety system was in place for over six months, the same hazards were again applied to the smart sensors to demonstrate the full function of the safety system. The system features that were demonstrated included:

- **Smart Sensors:** Each smart sensor provided an auditable alert to building occupants when a hazard was detected (gas leak or fire), as well as a digital alert sent over the wireless communication network to first responders and a viewable alert via a user interface dashboard.
- **Smart Valves:** The gas supply could be shut off by the smart valve, which was controlled remotely by the gas utility or by a pre-set hazard level provided by the smart sensors.
- **Wireless Communications:** The smart sensors, gas shutoff valve, and user interface were all connected via wireless communications. The communication network features low power consumption and can reliably send system data over long distances.
- **User Interface Software:** The user interface software allowed an end user to view the status and alerts of all smart devices, including the closing of smart valves.

## Key Results

This project successfully performed and tested a system that would improve gas safety for California gas utility customers. Customer research and online surveys were conducted at the beginning of the project. Results indicated that gas customers would trust and support a smart shutoff safety system if it is provided by a gas utility, has alerts for hazards, and can stop the flow of gas into a building.

As part of this research project, an in-depth search for required smart sensors, shutoff valves, communication networks, and software was conducted for integration with a building safety system tailored for gas utilities and their California customers. Various manufacturers and subject matter experts were interviewed, components were tested, and a prototype safety system was built.

Testing of the selected components was performed at GTI Energy's Chicago-area laboratories, and simulated environment testing was performed at SoCalGas and PG&E training centers to ensure that the safety system consistently functioned as designed. Valuable feedback was obtained from both utilities' subject matter experts. This related to the safety system's improved ability to detect gas hazards, send wireless alerts to the gas utility, be notified of alerts prior to the customer calling, automatically stop the gas flow to a building, and to evidence an overall improvement of natural gas safety for the industry. After successful testing and updated modifications, the safety system was made available for industry demonstrations that were performed at GTI Energy laboratories, industry conferences, and gas utilities upon their request.

The project successfully demonstrated how the use of a wireless communication network, smart sensors, smart valves, and a user interface software package could improve gas safety and provide reliable energy for customers in California. The safety system would reduce the amount of methane that escapes into the atmosphere by alerting a responder of a leak and shutting off the flow of gas.

Key demonstration results included:

- **Reliable Hazards Alert:** The smart sensors provided audible alerts and wirelessly transmitted data associated with hazard-level readings.
- **Reliable Communication:** The smart sensors wirelessly communicated alarm events and continued the alert until acknowledgement was received, and the smart device demonstrated functional modes of transmit, receive, and sleep.
- **Remote Disconnect:** Users could select a button on the user interface software to close the smart gas valve, which closed within 75 seconds.
- **Programmed Disconnect:** The gas valve was programed to stop flow if 20 percent of the lower explosive limit of gas or a temperature of 150 degrees Fahrenheit (65.6 degrees Celsius) was sensed. The valve closed within 75 seconds of the programmed hazard reading.
- **Device-to-Device Communication:** In the event of a hazard and no communication network is detected, the smart sensor wirelessly communicated the "close" command to the smart valve within 75 seconds.
- **Long Battery Life:** The use of the Long Range Wide Area Network (LoRaWAN®) communication network allows long battery life (10+ years) for smart safety system components.

The rate payer benefits of a gas smart shutoff system include the following:

- Ratepayers would have the necessary interventions in place to avoid potentially hazardous events posed by gas leaks and fires.
- The detection and intervention capabilities of this technology would protect both life and property.

- The technology would limit pipeline downtime and recovery costs from hazardous incidents, providing ratepayers access to safe and reliable energy.
- By establishing the foundation for gas smart shutoff requirements, the technology developers would have the framework for continued innovation in this emerging market, to improve customer satisfaction and lower costs.

## Knowledge Transfer and Next Steps

The primary audiences for technology and knowledge transfer are regulatory agencies and gas industry operators. GTI Energy implemented the following actions to make this research project information available to others.

- **Utilities:** Gas utilities were informed about this project through co-funding, participation via Operations Technology Development meetings, quarterly report updates, project proposals, relevant conferences, online publications, and direct involvement in the project.
- **Industry:** Industry was notified about this project through industry-specific conferences, technology advisory committee meetings, participation in project demonstrations, and online publications. Conferences and webinars where GTI Energy presented this project include: GTI Tech Talk, Western Energy Institute, National Association of Pipeline Safety Representatives, American Gas Association, Southern Gas Association, Internet of Things World Conference, GTI Public Interest Advisory Committee, and Operations Technology Development meetings.
- **Project Vendors:** Project vendors communicated the results of this project to their customers and provided project information on their respective websites.

Several gas utilities, including Consolidated Edison, Inc., in New York, led the industry by working with state regulators, obtaining rate case funding, and implementing similar technologies, as demonstrated during this project. Other gas utilities were investigating how to effectively use this technology and discussed their plans with GTI Energy. GTI Energy is and remains available to meet with any stakeholder and gas utility to further promote adoption of this technology.

# CHAPTER 1: Introduction

Gas hazards are typically detected in a building only when someone smells a gas odorant. That person then communicates the hazard information, which is relayed to gas utility first responders. There is a historic issue where many root-cause investigations of gas incidents reveal a communication breakdown in the reporting of the hazard to the gas utility. When the gas utility is contacted with the location of the gas smell, a first responder is dispatched to investigate. Based on this investigation, the first responder at the site must sometimes manually shut off gas service until the building's gas piping or appliances are repaired. In some circumstances, there may be limited access to the manual gas valve shutoff location, a context where a smart valve would be especially useful. A comprehensive gas smart shutoff safety system (CGSSSS) is needed to automate the process, which both improves safety and reduces gas emissions into the environment.

The CGSSSS can be compared with a building's circuit breaker, which is a safety system that detects an electrical hazard and curtails the flow of electricity to the building's wires and appliances. However, currently there is no similar safety system when there is a hazard in a building's gas pipes or associated appliances. As with electricity, a qualified person such as a gas utility employee was the customer's preference to both set up and maintain a gas safety system. Also, whenever gas is detected in a building there is a need to quickly stop the flow of gas at the building's source, typically at the gas utility-owned piping. Gas utility practices are to shut off gas at the meter set assembly location, which can be either inside or outside of the building. Current industry practice requires that, whenever the odorant in gas is smelled by a person, the gas utility dispatches an employee to investigate. The CGSSSS designed as part of this project detects gas before a customer can smell it and automatically alerts the gas utility.

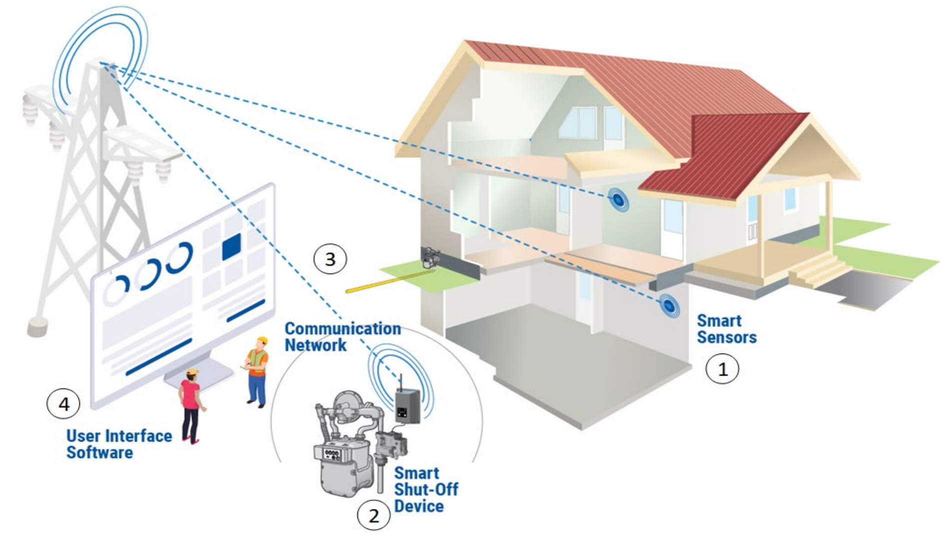
The CGSSSS supports California's ambitious clean energy and climate mandates by automatically detecting gas (methane) leaks and wirelessly alerting gas utilities to investigate, reducing the amount of methane that escapes to the atmosphere, either by alerting the gas utility or by shutting off the flow of gas to stop the leak. A CGSSSS paired with smart sensors (such as methane and fire sensors) would improve safety by alerting the customer and first responders of hazards in a building and stopping the flow of gas into that building. Recent advancements in technology pertaining to indoor methane sensors and wireless communication networks have allowed the development of a CGSSSS that can be installed in all buildings with gas service. The presence of a safety system ultimately provides customer security, since a gas leak can be detected and addressed before anyone can even smell it.

In the gas safety system developed for this project, smart sensors were deployed in both residential and commercial buildings to detect potential hazards involving gas piping or appliances. These smart sensors transfer data via a secure wireless communication network to a host server. The data stored on the host server can be viewed on a computer or a smart phone through a software user interface. The software provides information about the hazard levels detected by the smart sensors and allows the user to intervene by remotely actuating the safety shutoff valve to stop the flow of gas into the building before hazardous levels become too dangerous. In addition, the safety system can be programed to automatically shut off gas to a building when an identified hazard threshold is detected.

The goal of this project was to research, develop, test, and implement a CGSSSS for residential and commercial gas customers. The safety system comprises four major components, shown in Figure 1 for a residential building and in Figure 2 for a commercial building.

**Figure 1: Residential Building CGSSSS**

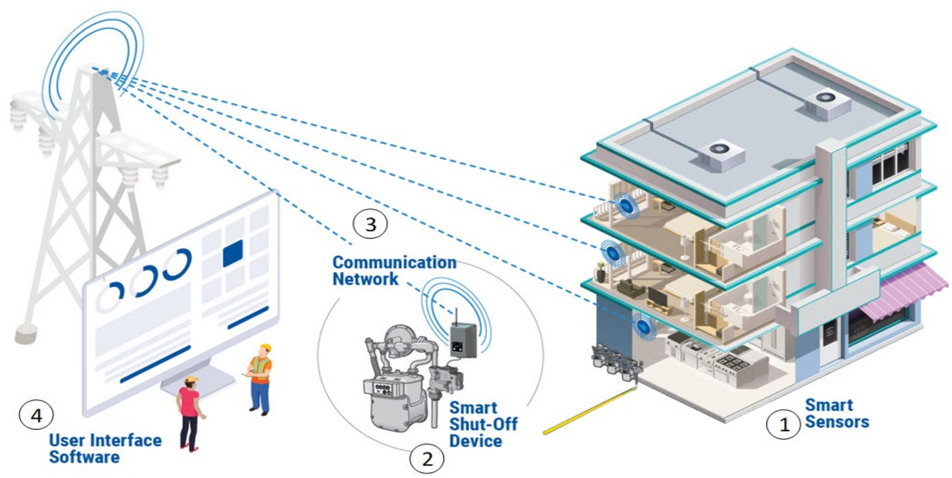
1. Smart Sensors
2. Smart Shutoff Valve
3. Communication Network
4. User Interface Software




Source: GTI

**Figure 2: Commercial Building CGSSSS**

1. Smart Sensors
2. Smart Shutoff Valve
3. Communication Network
4. User Interface Software




Source: GTI

# CHAPTER 2: Project Approach

## Approach

The project kickoff began with the development of a technical advisory committee, which consisted of industry experts, consultants, and manufacturers with gas safety experience for buildings. Several meetings and interviews were held to gather input and chart the project direction. Marketing research was subcontracted by Travis Research and Simple Opinions to obtain California customer input into the gas safety system concept and to provide overall project direction.

The marketing research for the project was divided into two phases: a Phase 1 qualitative approach and a Phase 2 quantitative approach. The Phase 1 approach provided project input by conducting in-depth interviews with gas utility professionals in California (Phase 1A) and by conducting focus groups with a diverse group of California gas customers (Phase 1B). A total of three one-on-one 30-minute phone interviews were conducted among executives at gas utilities in California as part of Phase 1A. A total of four focus groups, lasting two hours each, were conducted among California residents as part of Phase 1B. Each focus group had six participants and was divided into four demographic sessions: low income, homeowners, building tenants, and commercial property owners.

The information collected in Phase 1 was used to improve the questions used in Phase 2. The Phase 2 approach collected information by sending out online surveys to various demographics with gas service in California. The following distribution completed the online surveys.

- There were 198 total business property owners who completed the online surveys.
    - 98 were residential investment property owners.
    - 78 were commercial property owners.
    - 22 were renters.
- There were 436 total residential dwellers who completed the online surveys.
    - 217 were homeowners.
    - 59 were renters.
    - 160 were a mix of renters and homeowners living in disadvantaged areas.

Based on the marketing research, the project team drew the following conclusions about the CGSSSS:

- **Strong Appeal and Interest:** Customers viewed the safety system as highly appealing, unique, and providing peace of mind.
- **Worth Paying for:** Customers felt the safety system was worth paying for, including the equipment and a monthly monitoring fee. Commercial building owners with tenants were willing to pay more.

- **Gas Utility Company's Responsibility:** Customers expected the gas utility company or a qualified person to install and maintain the system. The customers expressed a lack of knowledge about gas and were uncertain about their abilities to install or maintain a safety system. Their interest decreased if they were responsible for the safety system.
- **Benefits the Gas Utility Company:** Customers expressed a positive perception of the gas utility if this safety system were to be offered by the utility to improve gas safety.
- **Commercial Building Owners Were the Best Prospects:** While all customers were interested, owners of buildings with tenants were the most interested and were willing to pay the most for the safety system.

After performing a North American search, GTI Energy subcontracted with Energy Experts International (EEI) to perform an international search for potential components and obtain information on available gas safety systems. GTI Energy identified several technologies to incorporate into a safety system. Consolidated Edison (ConEd), the gas utility in New York, implemented a pilot of installing indoor methane detectors that provide audible alerts to customers and send those alerts through an existing advance meter infrastructure system to the gas utility. The ConEd safety system pilot does not incorporate smart valves, so a gas utility employee still needs to be dispatched to investigate and shut off gas to the building if required. The ConEd safety system detects gas leaks before a customer can smell it and found gas leaks that originated outside a building and migrated inside. National Grid, also in New York, performed significant research incorporating indoor methane detectors and the Lorax Systems smart shutoff valve with the Long Range Wide Area Network (LoRaWAN®) wireless communication network. National Grid's research successfully performed operability tests verifying the LoRaWAN® capabilities with the smart valve and various smart sensors (for example, for methane, flood, over-pressure).

The international research by EEI identified five gas utilities with remotely monitored gas safety systems (with shutoffs) in Japan, Spain, Korea, Italy, and Ukraine. Similar safety systems are in development in the Czech Republic and Colombia. Cadent, a gas utility in the United Kingdom, has a remote methane monitoring pilot. In Japan, Spain, and Italy, the shutoff valve is integrated into the gas smart meter. In Korea and Ukraine, the safety system has a stand-alone valve. In all these systems, the methane sensors do not communicate directly with the shutoff valve; the shutoff valve is controlled remotely by the gas utility, which raises concerns about fail-safe contingencies if there is an external communication failure. In these utility-operated shutoff systems, the gas utility owns the safety system. In Spain, Italy, and Ukraine, there is no additional charge for remote methane monitoring and shutoff. In Japan and Korea, there is a fee-based system. Many of these gas utilities promote the safety features of remote methane monitoring and shutoff as part of plans to transition to intelligent gas networks and smart gas grid concepts. The LoRaWAN® communication network is becoming the preferred safety system choice due to its cost, dependability, and low power consumption, which allows for battery-powered sensors. The gas smart meter is the preferred shutoff for remotely activated safety systems, although it protects only the low-pressure premise piping system.

The project team interviewed various manufacturers and gas utilities during the national and international product research. Based on this information, the team identified components and safety system features to demonstrate in the project. After a one-year period of research, the selected components were integrated into the safety system and testing began to create a prototype system.

Based on the customer and product research, the following manufacturers and vendors were selected:

- **Senet Incorporated:** The owner company of the LoRaWAN® Wireless Communication Network selected for the project. Research conducted during the project indicated that this newer wireless communication network could provide long battery life, deep signal penetration, and overall better performance for wireless smart sensors as compared to existing communication networks traditionally used by utilities.
- **Semtech Corporation:** The silicon chip maker for the LoRaWAN® Wireless Communication Network. The manufacturer created a prototype LoRaWAN® microchip for the smart sensors and smart valves used as part of this project.
- **Lorax Systems:** The manufacturer of the gas "stand alone" LoRaWAN® smart valve and user interface software.
- **Honeywell:** The manufacturer of the LoRaWAN® smart meter with integrated shutoff valve and user interface software.
- **New Cosmos/Heath Consultants**: The manufacturer and distributor of the LoRaWAN® gas leak detector.
- **GlobalSat WorldCom:** The manufacturer of the LoRaWAN® fire alarm.

## Component Selection

The CGSSSS design selected for the project consists of four main components, as shown in Figure 1 and Figure 2: (1) smart sensors, (2) smart valve, (3) wireless communication network, and (4) user interface software.

1. **Smart Sensors:** These battery-powered devices can be placed either inside or outside a structure to "sense" the environment for both normal and abnormal conditions. Smart sensors may monitor methane, smoke, carbon monoxide, floods, temperatures, and other conditions. When a smart sensor such as a methane detector identifies an abnormal condition, the sensor sends an alert (audible and electronic) that transmits data wirelessly. The alert data is stored on a server and is viewable from user-interface software. GTI Energy performed research on various smart sensors. The methane detector, sometimes referenced as an indoor gas detector or a remote methane detector (RMD), is the key sensor for the safety system. The New Cosmos DeNova Detector, shown in Figure 3(a), was selected as the methane detector and the GlobalSat LS-134 Heat Detector, shown in Figure 3(b) was selected as the fire sensor. Both of these smart sensors passed laboratory testing, and versions

of the products were already available on the wireless communication network selected for the project.

**Figure 3: (a) DeNova Detect Gas Detector, (b) GlobalSat LS-134 Heat Detector**

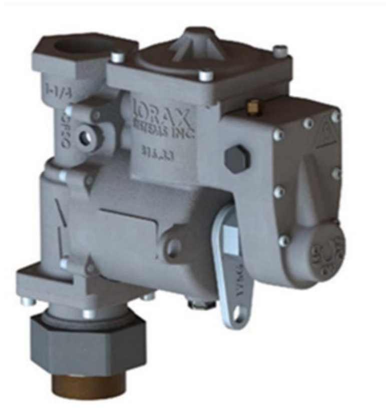

Source: New Cosmos


Source: GlobalSat

2. **Smart Valve:** An automatic safety valve is placed on a gas service pipe as close to the source as possible and can receive an electronic signal over the wireless communication network to stop gas flows into a building. GTI Energy performed testing and selected the Lorax Systems Meter Valve, shown in Figure 4(a), as the stand-alone, smart-valve option. Lorax Systems was the only manufacturer found during the product research that manufactured a stand-alone smart valve that can be placed on a gas service pipe with maximum operating pressure of 175 pounds per square inch gauge (psig). Lorax Systems' unique product and experience with creating automatic valves made the company a good fit for the project. In addition, GTI Energy tested both diaphragm and ultrasonic smart meters with an internal valve able to receive an electronic signal to shut off the gas. There are several manufacturers of smart meters with shutoff abilities. The Honeywell American Meter AC-250NXS smart meter, shown in Figure 4(b), was selected for the project as a low-pressure (less than 10 psig) smart valve option to stop the flow of gas. This product was selected based on Honeywell's commitment to the LoRaWAN® network, as demonstrated by its design of a LoRaWAN®-enabled smart meter for the project.

   Since an indoor gas leak can be difficult to find without proper equipment, it is important to stop the flow of gas before the first responder enters the building. The placement of the smart shutoff valve for a building is an important decision, especially in situations where a high-pressure gas pipe enters a building or the gas service regulator is inside a building. The Lorax Systems smart valve can be installed on the high-pressure pipeline that is upstream of the gas service regulator, so if there was a gas leak on the regulator, closing the valve would stop gas flows to the regulator. The Honeywell smart meter must be installed on the low-pressure pipe located downstream from the gas service regulator. Therefore, if there was a leak on the regulator, closing the valve inside the meter would not stop further gas flow to the regulator.

**Figure 4: (a) Lorax Systems Meter Valve, (b) Honeywell AC-250NXS Smart Meter**



Source: Lorax Systems


Source: Honeywell

3. **Wireless Communication Network:** The network allows the smart sensors, smart shutoff valves and user interface software to communicate back and forth wirelessly through a cloud server. The research revealed that low-power, wide area network (LPWAN) technology has been used to apply similar gas safety systems in Europe and Asia. The feedback was that these communication networks are easy to deploy, reliable, ideal for battery-operated sensors, and easy to use to complement other communication networks. They also cost less to install and maintain when compared with other communication networks. GTI Energy performed significant research on existing and available communication networks that could potentially work with a CGSSSS. The LoRaWAN® (an LPWAN network) was selected for the project. The decision was based on a comparison of communication networks, which showed that the LoRaWAN® communications network had several advantages: flexibility, ability to deploy, customer control, longevity of service contracts (20 years), an architecture for long battery life, affordability compared with other networks, high reliability, and compatibility with existing utility communication systems. Since LoRaWAN® is designed for smart sensors with batteries, many of the sensor manufacturers have been designing their devices to work on this communication network. During the product research, it was discovered that the Lorax Systems smart valve was already designed to work on the LoRaWAN® communication network and that the Honeywell smart meter was being updated to work on this network. Figure 5 illustrates a typical temporary installation of the LoRaWAN® Tektelic Gateway, antenna, and associated network equipment.

**Figure 5: Temporary LoRaWAN® Tektelic Gateway and Antenna Setup**

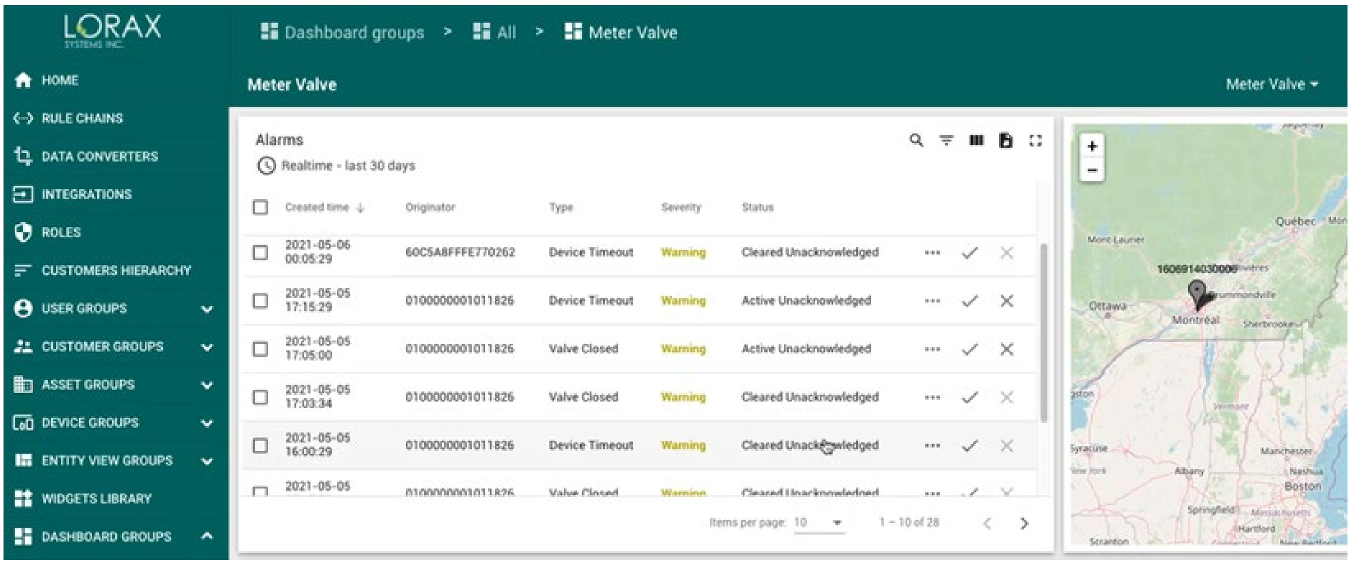
Source: PG&E

4. **User Interface Software:** This software connects all the safety system components and shares the status of the smart sensors and the smart valve on a viewable dashboard. Lorax Systems uses an open source internet of things (IoT) platform called ThingsBoard, which is programmed into the Lorax Valve Control Platform (shown in Figure 6) that is used to remotely operate the smart valve and connect the sensors; this application was used in the residential and commercial demonstrations for the safety system. The Thingsboard platform is an out-of-box, licensed software built for an IoT network to securely identify smart devices and control the sending and receiving of data to those smart devices. Thingsboard is an open-source IoT platform for data collection, processing, and visualization, and it can be used on any Windows-based computer with internet access.

   ThingsBoard has a history of being used for smart metering and collecting data for improving energy efficiency. For smart metering, the software allows the collection of energy usage data and has a customized dashboard with reporting functions, data analyses, and alarms for abnormalities. The software allows a dashboard of maps, filters, and selectable locations to obtain information in a geographic territory. The dashboard displays real-time data from multiple sources throughout a geographic territory. The software has the ability to obtain information over multiple communication network servers, to integrate that data, and to provide customized dashboards.

Honeywell has a customized user interface software called Connexo NetSense, which was demonstrated using the Honeywell smart meter. Connexo NetSense is a web-based, head-end system that enables data collection flexibility from multiple networks. The Honeywell software is currently used to obtain data from electric, gas, and water meters. For this project, both Lorax Systems and Honeywell customized their software for a dashboard that includes the latest password protection protocols.

**Figure 6: Lorax Valve Control Platform**




Source: Lorax Systems

## Safety System Function

The New Cosmos DeNova Detect Methane Detector is a battery-powered device that provides methane concentration data via the LoRaWAN® network. The device remotely sends an alarm when the methane level meets or exceeds 10 percent of the lower explosive limit (LEL). The National Fire Protection Association (NFPA) 715 standard and the Underwriters Laboratory 1484 standard both require that the detector begin alerting at the 10-percent LEL. The methane sensor continues to monitor methane levels and send these readings to a cloud server. The user interface software displays the alerts on a dashboard; a user can remotely close the smart valve from the dashboard. For this project's demonstration, the user interface software was programed to automatically close the smart valve if a 20-percent LEL or higher reading was detected.

The second sensor selected for the project was the GlobalSat LS-134 Heat Detector. The GlobalSat alert level is governed by the NFPA 72 standard and sends an alarm once 150 degrees Fahrenheit (°F) (65.6 degrees Celsius [°C]) is detected. That alarm data is transferred to the cloud server via the LoRaWAN® network and displayed on the software's dashboard. For this project's demonstration, the user interface software was programed to automatically close the smart valve when 150°F (65.6°C) was detected. Two specific smart sensors were used in the demonstration systems in the field pilots for this project, although other sensors on the market could also be integrated into the system in a similar way and provide other relevant data. They can detect, for example, building hazards, carbon monoxide, flooding, or dangerous gas pressures.

## Demonstration Plan

A milestone was reached after all the CGSSSS components were successfully tested, both individually and as part of an integrated system. All the components were verified in a laboratory before the project began. The next task was to perform a demonstration of the technology in both a residential building and a commercial building. Arrangements were made to hold simulated demonstrations for SoCalGas and PG&E experts, and then to install the safety system in the buildings. Two LoRaWAN® gateways and antennas were installed at the SoCalGas and PG&E training centers. The CGSSSS was successfully demonstrated in simulated settings for the utilities' subject matter experts; these were performed either on gas meter assembly mock-ups or in buildings used to train employees. Details of the simulated demonstrations performed at the gas utility training centers are shown in Table 1. These simulated demonstrations with the gas utility subject matter experts provided feedback to assist with the preparations to install the safety system on a residential building and on a commercial building in the PG&E service territory; these details are shown in Table 2.

**Table 1: Project Simulated Demonstration Details**

| Demo Date | Gas Utility Location | Solution Type and Dashboard | Numbers and Types of Smart Sensors Assigned to Smart Valve or Smart Meter | Number of Gateways/ Antennas |
|---|---|---|---|---|
| 06/28/22 | SoCalGas, Pico Rivera, CA | Lorax Systems | 1 – New Cosmos RMD<br>1 – GlobalSat Fire Alarm | 2 (1 roof and 1 ground) |
| 09/12/22 | SoCalGas, Pico Rivera, CA | Honeywell | 1 – New Cosmos RMD<br>1 – GlobalSat Fire Alarm | Same installed on 06/28/22 |
| 09/28/22 | PG&E, Winters, CA | Lorax Systems and Honeywell | 1 – New Cosmos RMD (Lorax)<br>1 – GlobalSat Fire Alarm (Lorax)<br>1 – New Cosmos RMD (Honeywell)<br>1 – GlobalSat Fire Alarm (Honeywell) | 2 (1 roof and 1 ground) |
| 04/13/23 | TECO, Tampa Bay, FL | Lorax Systems and Honeywell | 1 – New Cosmos RMD (Lorax)<br>1 – GlobalSat Fire Alarm (Lorax)<br>1 – New Cosmos RMD (Honeywell)<br>1 – GlobalSat Fire Alarm (Honeywell) | Public LoRaWAN® network used |

**Table 2: Project Residential and Commercial Demonstration Details**

| Demo Date | Gas Utility | Solution Type and Dashboard | Numbers and Types of Smart Sensors Assigned to Smart Valve or Smart Meter | Number of Gateways/ Antennas |
|---|---|---|---|---|
| 07/26/22 | PG&E, residential customer, San Mateo, CA | Lorax Systems | 1 – New Cosmos RMD<br>1 – GlobalSat Fire Alarm<br>Note: Added 2 more RMDs per NFPA 715. Added 2 fire alarms in the same location as the additional RMDs. | 1 (roof) |
| 11/30/22 | PG&E, commercial customer, Roseville, CA | Lorax Systems | 3 – New Cosmos RMD<br>2 – GlobalSat Fire Alarm<br>Note: Added 1 more fire alarm at a later date. | 1 (ground) |

Source: GTI

## Demonstration Procedure

Each simulated demonstration was successfully performed with two separate CGSSSS solutions: one centering on the use of the Lorax Systems Meter Valve and the other incorporating the Honeywell American Meter AC-250NX. Both systems were equipped with one New Cosmos DeNova Detect indoor methane detector and one GlobalSat fire alarm. Both systems utilized LoRaWAN® connectivity by way of two Kona Macro gateways installed on the premises, which used AT&T cellular connectivity as a backhaul. The simulated demonstrations successfully illustrated that a gas leak or a fire in a building can be detected by smart sensors, alerts can be wirelessly communicated to first responders, and the gas can be shut off to the building either by a programmed hazard-level setting or remotely by the gas utility. Each simulated demonstration was conducted on a single day with a combination of onsite and virtual participation by subject matter experts and stakeholders.

A fully functioning prototype of the CGSSSS was installed in a residential building in San Mateo, California, and a commercial building in Roseville, California, to demonstrate that the safety system functioned properly, improved safety, and was available and ready for production. The residential and commercial building demonstrations used only the Lorax Systems solution since the Honeywell smart meter was not approved for customer use with live gas at the time of the demonstrations. A demonstration was held on the day of the safety system installation and on the day of removal at both the residential and the commercial building locations. The CGSSSS demonstration included monitoring of the system by both the project team and the customers while it remained in place in the buildings for more than six additional months. During the monitoring period, the smart devices provided regular updates, indicating that they were functioning properly and that no hazards were observed in the buildings.

During the installations on the buildings, the project team educated the participants regarding the fundamental mechanical operation of system components, the enhanced safety features, the LoRaWAN® wireless communication network, and the cloud-based headend dashboards. Each demonstration successfully satisfied the following exit criteria:

- All participating attendees were able to view the vendor-specific headend dashboard to see each component, the component status, the normal status, the hazards introduced, the gas disconnection, and system reset.
- Participating members were able to view the dashboard buttons, including the remote disconnect button; when selected, the button caused the Lorax Systems smart valve to close. The demonstration also included the process of manually resetting the smart valve and viewing its open status on the dashboard (normal status).
- The New Cosmos indoor methane detector was exposed to methane exceeding 20-percent LEL (with sample gas), and participants were able to hear the audible alarm, see the hazard alert on the dashboard, and observe the automatic disconnection of gas from the Lorax Systems smart valve. The demonstration also included manually resetting the smart valve and viewing the smart valve open status on the dashboard (normal status).
- The GlobalSat sensor was exposed to 150°F (65.6°C) with heat (heat gun) and participants were able to hear the audible alarm, see the hazard alert on the dashboard, and then see the automatic gas disconnection. The demonstration of the Lorax Systems smart valve included manually resetting the smart valve and viewing the smart valve open status on the dashboard (normal status).
- For the demonstrations, the Lorax Systems smart valve and the New Cosmos indoor methane detector contained the new prototype Semtech microchip, which allowed device-to-device (D2D) communications. In locations where the LoRaWAN® network could be turned off, the D2D feature was demonstrated. Without the network, the indoor methane detector successfully communicated with the smart valve and automatically closed the valve when the 20-percent LEL was exceeded.

All simulated demonstrations repeated the same steps with the Honeywell smart meter, which uses the Connexo NetSense Cloud Platform.

# CHAPTER 3: Results

GTI Energy tested and validated each of the CGSSSS components to verify functionality and adherence to the minimum specifications determined during the product research tasks. Testing was performed on the smart sensors, smart valve, wireless network, and user interface software. After testing each component individually, all the components were tested together to verify their functionality in an integrated safety system. The results were first verified during testing of the project; those results were then discussed with attendees of both the simulated demonstrations and the residential and commercial building demonstrations.

## Smart Sensor Results

Indoor gas detectors are small alternating-current-powered or battery-powered devices used to detect gas (methane), which may be present in both residential and commercial buildings. One of the keys to achieving full customer adoption of indoor gas detectors is product reliability and accuracy. Two concerns with these detectors are false positive rates and sensitivity to chemicals other than methane. A false positive is a test result that mistakenly gives a positive reading when there is an alert without the presence of a combustible gas. False or nuisance alarms can cause unnecessary panic and generate inappropriate responses. Over time, repeated false or nuisance alarms may cause consumers to ignore alarms because of a suspicion that they are not real.

Interviews with gas utility experts showed that false positives were a major concern that must be addressed as part of this project. Indoor gas detectors are commercially available; however, there is evidence that some indoor methane or combustible gas detectors may respond with an unacceptable number of false positives. As required by industry standards, these devices are designed to sound an alarm at or above 10 percent of the LEL of methane. LEL is the lowest concentration of a gas (percentage by volume in air) below which a flame will not spread in the presence of ignition sources including arcs, flames, or heat.

A total of 21 brands of indoor gas detectors was tested at GTI Energy. Indoor gas detectors were purchased from home improvement stores and online through several vendors. Each indoor gas detector was placed in a test chamber, as shown in Figure 7, and exposed to multiple products and chemicals, as listed in Table 3; these were then tested for false alarms. The duration of exposure during each test was 15 minutes unless the alarms sounded earlier. Ethanol, acetone, and paint thinner were tested at a calculated 25 percent and 12 percent LEL. These percentages represented potential exposure situations in a building. Other products and chemicals used typical amounts that represented potential spills in a home.

**Figure 7: Gas Detector Test Chamber**

Source: GTI

**Table 3: List of Products and Chemicals Tested**

| Test Material | Typical Use or Application |
|---|---|
| Methane | Natural gas |
| Propane | Liquefied petroleum gas |
| Ethanol | Alcohol |
| Acetone | Fingernail polish remover |
| Paint Thinner | Oil-based paint and cleaners |
| Laundry Detergent | Clothes washing machines |
| Stain Remover | Clothes washing machines |
| Cyanoacrylate Adhesive | Household gluing tasks |
| Bathroom Cleaner | Toilet and shower cleaning |
| Home Dry-Cleaning Kit | Clothes dryer machines |
| Fabric Freshener | Household cleaning tasks |
| Aerosol Hairspray | Personal grooming |
| Furniture Polish | Household cleaning tasks |
| Bleach | Clothes washing machines |
| Household Ammonia | Household cleaning tasks |
| Duster Spray | Computer cleaning spray |

| Test Material | Typical Use or Application |
|---|---|
| Disinfectant Spray | Household cleaning tasks |
| Oven Cleaner | Household cleaning tasks |
| Rust Stain Remover | Household cleaning tasks |

Source: GTI

Based on what was currently available on the market, and with input from industry subject matter experts and gas consumers, GTI created a list of minimum smart sensor specifications for verification and testing. Several of these are shown in Table 4.

**Table 4: Minimum Smart Sensor Specifications**

| # | Requirement | System Information Notes |
|---|---|---|
| 1 | Battery power (all smart sensors) | In a situation of power loss, the system still needs to function to provide safety to the building occupants. |
| 2 | 10-year lifetime (all smart sensors) | This is a minimum requirement based on industry needs and what is available on the market. |
| 3 | Minimum calibration needs (all smart sensors) | The sensor needs to be user friendly and reliable, with no device errors. |
| 4 | Threshold alarm of 10 percent or less LEL methane in air | This is the current standard for NFPA 715, which was updated during the project. |
| 5 | No response to acetone or ethanol. No false positive hazard alerts for any smart sensor. | The customer research has indicated a concern by the gas utilities of having to visit customers to investigate false positive alarms. |
| 6 | UL 1484 compliant | This is the current global standard for indoor gas detector certification. |
| 7 | NFPA compliant (temp/fire sensor only) | The National Fire Alarm and Signaling Code (NFPA 72). |
| 8 | Audible alarm for consumer (all smart sensors) | This is a minimum sensor requirement to ensure communication to the customer. |
| 9 | Capability to communicate information back to a gas utility (all smart sensors) | This is a minimum safety requirement for the system. |
| 10 | Heartbeat signal showing health of device and battery once per day (all smart sensors) | This is a minimum sensor requirement to ensure that the system is functioning properly. |
| 11 | Communication of threshold alarm within 30 second (all smart sensors) | This is a minimum sensor requirement to ensure that the system is functioning properly. |

| # | Requirement | System Information Notes |
|---|---|---|
| 12 | End of life signal (all smart sensors) | This is a system requirement to ensure that the owner is aware and takes corrective action. |
| 13 | FCC compliant (all smart sensors) | This is a requirement for all electronic devices. |
| 14 | No impact from humidity; 85 percent at an ambient temperature of 86°F (30°C) (all smart sensors) | This is a minimum sensor requirement to ensure that the system is functioning properly. |
| 15 | Temperature operating range from 32°F (0°C) and 120°F (49°C). Temperature (fire) sensors need to be functional at higher temperatures, per NFPA 72. | This is a minimum sensor requirement to ensure that the system is functioning properly. |

Source: GTI

Manufacturer brands from New Cosmos, CNIguard and eLichens displayed in Figure 8 had excellent performance in testing at GTI Energy laboratories. They had no false positives, and they met the minimum smart sensor specifications. CNIguard's GasMarshall and eLichens' Avolta methane detectors are available on the market and were validated to meet the minimum specifications tested. The New Cosmos devices are one of the most widely used in the gas industry. All three gas-detector models successfully transmitted correct methane alerts through the LoRaWAN® communication network, and those alerts were viewable on the user interface software of the Lorax Valve Control Platform. All models were able to send alerts and function properly with the safety system.

**Figure 8: (Left) New Cosmos's DeNova Detect, (Center) CNIguard's GasMarshal, (Right) eLichen's Avolta**


Source: New Cosmos Presentation


Source: CNIguard Presentation


Source: eLichens Presentation

It was learned during product research that a new Semtech microchip was being introduced that allowed for device-to-device capabilities, meaning that a smart device could wirelessly send a command to another smart device without the LoRaWAN® network. If the LoRaWAN® gateways stopped working due to events such as fires or earthquakes and there was a gas leak or fire in a building, the smart sensors would send a signal directly to the smart valve to disconnect the gas. Lorax Systems, Honeywell, and New Cosmos created a prototype with the new microchip for this project. The new microchip was installed in the Lorax Systems smart valve, the Honeywell smart meter, and the New Cosmos DeNova Detect, allowing D2D communication. As a result, the simulated demonstrations and the actual building demonstrations successfully demonstrated the D2D communication feature.

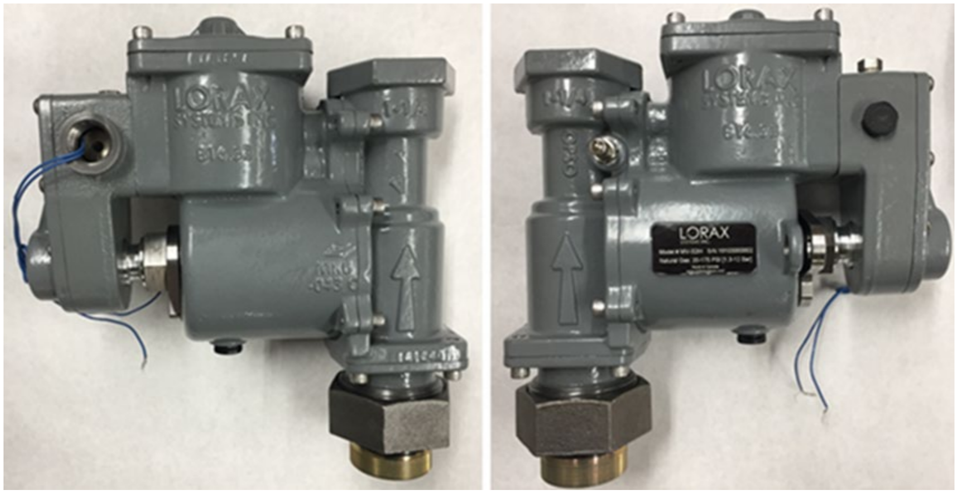
The GTI Energy project team originally worked with indoor gas detector manufacturers to integrate a temperature (fire) sensor into their devices that alerted at temperatures identified by the standard NFPA 72 to indicate a fire in a building. The temperature of 150°F (65.6°C) alarm level was selected based on the standard. There are existing LoRaWAN®-enabled fire alarms on the market that functioned better, so the team decided to use a stand-alone fire detector for the demonstrations instead of integrating this feature into an existing indoor methane detector.

The GlobalSat LS-134 fire alarm, shown in Figure 3, is available on the market to function on the LoRaWAN® communication network. It can be triggered by either an elevated temperature or the presence of smoke. The GlobalSat device was designed with fire detection as its primary function, and comparative testing indicated that its response was much quicker than using secondary sensors within the indoor gas detectors. The response time of the thermal shock test was under one minute for all three samples tested. The GlobalSat devices were selected to integrate with the CGSSSS for the demonstration. When connected to the Lorax Valve Control Platform, they functioned successfully. The GlobalSat devices also successfully sent out both audible and digital alarms when exposed to 150°F (65.6°C), a temperature alert was verified in the software, and the smart valve closed.

## Smart Valve Results

The Lorax Systems smart valve is the only smart valve available on the market designed for higher-pressure gas upstream of the gas service regulator. The Lorax Systems smart valve shown in Figure 9 underwent a series of tests to validate the valve's design and performance in accordance with American Society of Mechanical Engineers (ASME) standard B.16.33 (Manually Operated Metallic Gas Valves for Use in Gas Piping Systems up to 175 psig). In addition, the project team performed several supplemental tests to evaluate the valve's performance as part of the overall safety system; these are shown in Table 5. The Lorax meter valve successfully passed all the tests and was selected for the demonstrations in both the residential and commercial buildings.

**Figure 9: Lorax Systems Smart Valve**




Source: Lorax Systems Brochure

**Table 5: Supplemental Tests Performed on Lorax Systems Smart Valve**

| Supplemental Test | Description | Lorax Meter Valve Evaluation Results |
|---|---|---|
| Operational Cycle Test | Verify valve's ability to operate repeatably at varying inlet pressures. | Passed |
| Reverse Flow Test | Pressurize valve outlet to 175 psig and monitor outlet for leak-through. | Passed |
| Outdoor Test | Install valve and operate periodically to monitor operational ability. | 8 months of operation, no issues to report |
| Pressure Test at 70°F (21°C) | Pressurize valve inlet to 7-psig and monitor outlet for leak-through. | Passed |
| Line Pressure Loss/ Momentary Closure Test | Simulate service line pressure loss by pressurizing the valve assembly and then vacating the service line. Monitor inter-stitial pressure over time to find how long the valve can be expected to remain open. | Passed |

Source: GTI

In the United States, the major smart meter manufacturers with integrated shutoffs are Itron, Honeywell, and Sensus. The Honeywell American Meter AC-250NXS smart meter selected for the project, shown in Figure 10, is a Class 250 diaphragm gas meter with an integrated communication module and a shutoff valve. The meter includes pressure and temperature sensors. This allows autonomous shutoff responses in the event of overpressurization, fire, and excess-flow incidents. Apart from traditional gas-metering data management, the Cat M1 communication module tested enables two-way communication that in turn enables remote shutoffs. The Honeywell smart meter was mechanically tested as part of the project; however, it could not be fully tested with the safety system since the LoRaWAN® version was not available at the time of testing. GTI Energy had a cellular-enabled AC-250NXS smart meter that remotely received a signal to close the integrated valve. The LoRaWAN® version was made available by the manufacturer in time to successfully demonstrate its integration into a safety system at the SoCalGas and PG&E facilities. The LoRaWAN® version of the AC-250NXS did not receive approval to be used with gas in time to be installed for the residential and commercial building demonstrations.

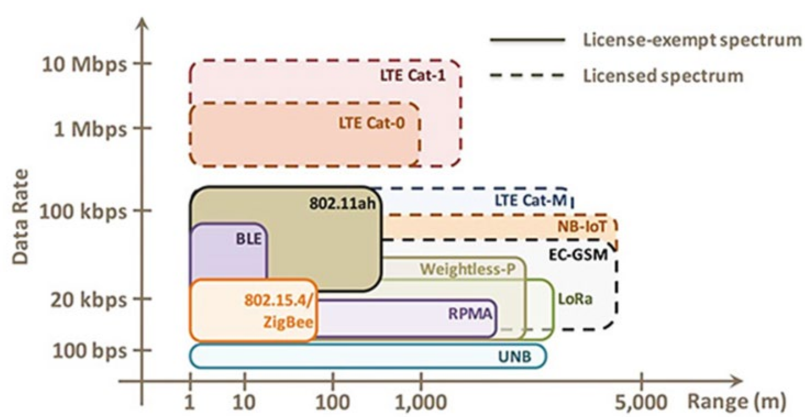
**Figure 10: Honeywell American AC-250NXS Smart Meter**

Source: Honeywell Brochure

## Wireless Communication Network Results

GTI Energy used the LoRaWAN® communication network for multiple projects. The advantage of this wireless network is its low power consumption, which ensures that battery-operated smart devices have a long life and securely transmit/receive data. Figure 11 provides an overview of various radio protocols currently available for consideration by gas utilities.

**Figure 11: Range and Rate Comparison of Wireless Technologies**




Source: GTI

Figure 11 shows the transmission ranges, data rates, and licensing requirements to use the spectrum. The communication network data requirements of gas utilities and the safety system are very similar, since only small amounts of data are required to be wirelessly transmitted (no audio, video, or large data files). The utility and safety systems send small packets of data at long intervals, requiring the price per packet to be small for the system to be economically feasible. Based on this consideration, LoRaWAN® emerged as one of the most promising communication technologies for both utilities and safety systems. A utility can install gateways and antennas to own the LoRaWAN® network or can use existing networks if available.

The LoRa® physical layer is designed with small data packets and low power operation. In the United States it is implemented in the 915 megahertz (MHz) unlicensed band (868 MHz in the European Union). This relatively low frequency provides better radio penetration into buildings and other structures, an important consideration for gas utility applications. The LoRaWAN® protocol layer is an open standard managed by the LoRa Alliance. Because it is an open standard, there are many interoperable hardware choices available, a large percentage of which are battery powered.

Table 6 provides a comparison of various wireless technologies. SigFox is a LPWAN that competes with LoRaWAN® and has many technological similarities. It has significant market deployment in the European Union, though less so in North America when compared with LoRaWAN®. SigFox fees and royalty network structures are more restrictive when compared with LoRaWAN®. SigFox sets up and maintains a coverage area and does not provide the option to self-provision a system.

**Table 6: Communication Network Comparison**

| | SigFox | LoRaWAN® | 2G | 3G | Wi-Fi |
|---|---|---|---|---|---|
| **Data Rate** | 0.3 kbps | 0.3 kbps to 50 kbps | 40 kbps to 500 kbps | 384 kbps to 168 Mbps | 11 Mbps to 72 Mbps |
| **Power** | 32 mA to 51 mA | 40 mA | 250 mA | 460 mA | 320 mA |
| **Urban Range** | 3 km to 10 km | 2 km to 5 km | 5 km to 8 km | 5 km to 8 km | 35 m to 70 m |
| **Rural Range** | 30 km to 50 km | 15 km | 50 km to 70 km | 50 km to 70 km | 140 km to 250 km |
| **Device Cost** | $13 | $15 | $14 | $35 | $12 |

bps = bits per second
kbps = kilobits per second
km = kilometers
m = meter
mA = milliampere
Mbps = megabits per second

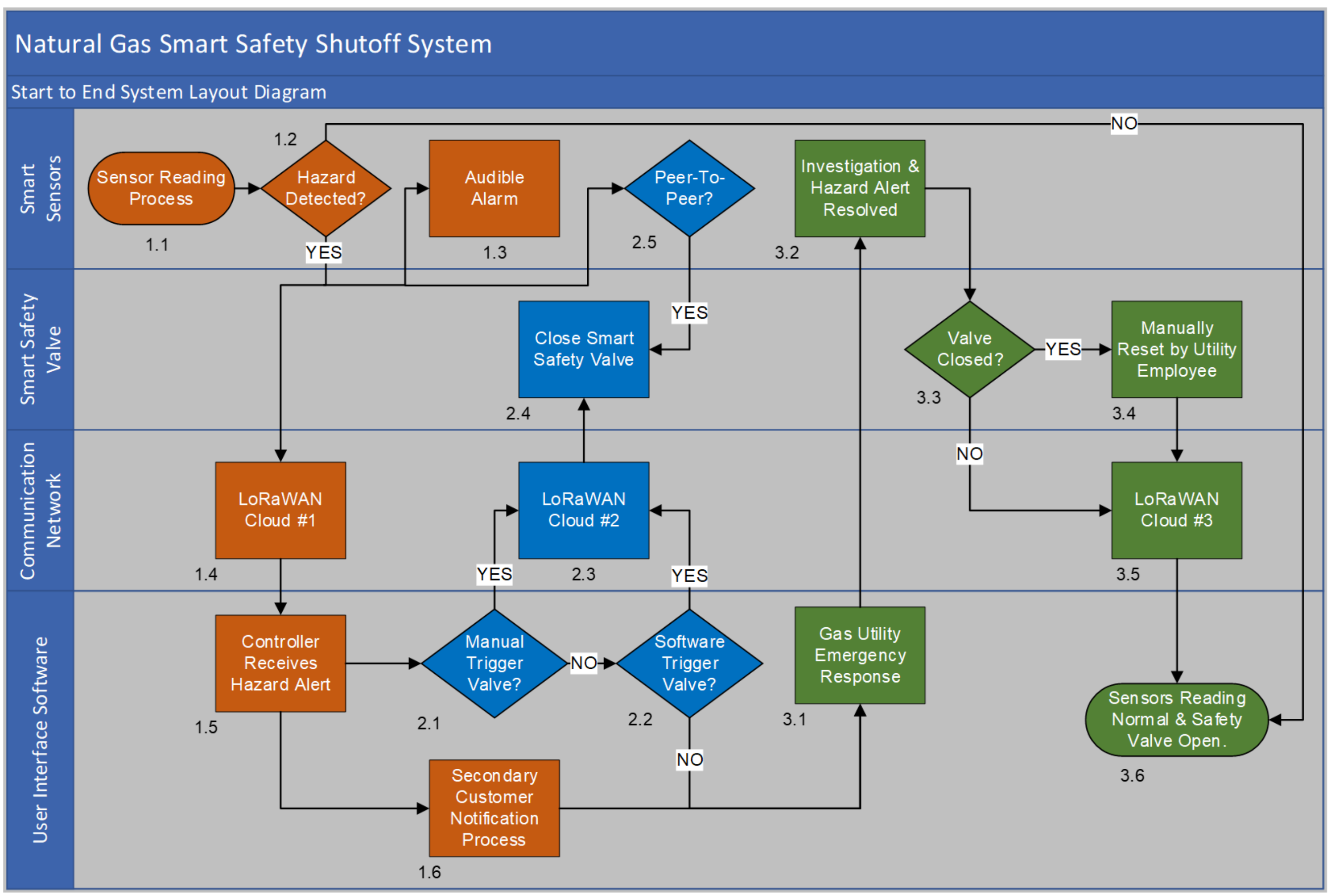
Source: GTI

The customer research tasks for this project determined that network and software cyber security is a concern for both gas utilities and gas customers. LoRaWAN® communication networks have security comparable to other networks, including individualized encryption for each smart device attached to the network. The feedback based on the research was that LoRaWAN® communication networks are easy to deploy, reliable, ideal for battery-operated sensors, and easy to use with other complementary communication networks, and they have lower installation and maintenance costs than other communication networks. The decision to use the LoRaWAN® network for this project was based on a comparison of communication networks where the LoRaWAN® communications network had advantages in flexibility, ability to deploy, ability for gas utility control, and service-contract longevity (20 years). Additional advantages identified were a "sensor centric" architecture for long battery life, affordability, high reliability, and complementary to existing utility communication systems. Since LoRaWAN® is designed for sensors with batteries, many of the sensor manufacturers have been designing their devices to work on this type of communication network. All the CGSSSS components were successfully tested to accurately and reliably transmit data using the LoRaWAN® communication network.

## Safety System Component Integration Results

The user interface software for the CGSSSS integrates all its components for proper communication and function. Each smart device was connected to the LoRaWAN® wireless communication network and confirmed in the Lorax Valve Control Platform software. The safety system layout diagram in Figure 12 shows the start-to-end processes, connection relationships, and activities related to the safety sensors, smart shutoff valve, communication network, and user interface.

**Figure 12: CGSSSS Layout Diagram**




Source: GTI

The validation results of the complete operability of the CGSSSS are summarized using processes shown in Figure 12. The results for the safety system processes are divided into the red "Hazard Detection and Communication Process," the blue "Communication to Close the Smart Valve Process," and the green "Hazard Resolution Process." The Hazard Detection and Communication Process outlines processes for detecting hazards and notifying responders and customers. The Communication to Close the Smart Valve Process is the associated process for closing the valve. The Hazard Resolution Process is the vision for the safety system's coordination with gas utilities. The CGSSSS results were consistently demonstrated in both the GTI Energy laboratories, the simulated demonstrations, and in the residential and commercial building demonstrations. The data from the demonstrations indicated low latency of an average of fewer than 75 seconds for smart valve activation for both remote and D2D communication after a hazard had been detected. A detailed description of each numbered process can be found in the Final Software Design and Specification Report for the project.

## Residential and Commercial Building Demonstration Results

A detailed description of the demonstrations appears in the Field Demonstration Report. Both the residential and commercial CGSSSS demonstrations showed steps for installing the LoRaWAN® gateways and antennas, the Lorax Systems smart valve, multiple New Cosmos DeNova Detects, and multiple GlobalSat fire alarms. The CGSSSS was tested in front of an audience during initial installation and monitored for regular daily heartbeat signals from each smart component to ensure proper functioning for more than six months. The CGSSSS was tested again prior to removal.

The residential building demonstration was in PG&E's service territory in San Mateo, California. The Lorax smart valve was installed on the outside of the residential building and the antenna/gateway was installed on the roof. During the original installation, an indoor methane detector and a fire alarm were placed on the inside wall where the gas service pipe enters the building and where the gas dryer is located. The system was demonstrated during the installation using a sample can of methane spray and a heat gun to verify functionality after installation. The following performance metrics were observed on the user interface software dashboard: the methane alert, the methane LEL level, the fire alert, the valve status for a remote disconnect, and the valve status for closing due to hazard detection. The smart valve successfully closed when either the indoor methane detector or the fire sensor detected a hazard.

The residential building owner observed the demonstration on how the safety system works, the exposure of the smart sensors to the hazards, and the closure of the smart valve. The owner discussed the wireless communication box that was connected by a cable to the smart valve, and it was explained that, once a wireless network is determined by the gas utility, the box could be integrated into the smart valve, thereby eliminating the need for a cable connection. The owner was pleased with the demonstration and expressed confidence in how the system functioned.

At a later date, additional smart sensors were placed in the residential building near the gas furnace and the gas water heater. These additional indoor methane detectors were installed in accordance with NFPA 715, which requires placement between 3 feet and 10 feet of each gas appliance in a building and fewer than 12 inches from the ceiling. The residential GCSSSS installation and its associated smart sensors are shown in Figure 13, Figure 14, Figure 15, and Figure 16.

**Figure 13: PG&E Residential Building:**
**(Left) Lorax Systems Valve, (Right) Antenna/Gateway**

Source: GTI

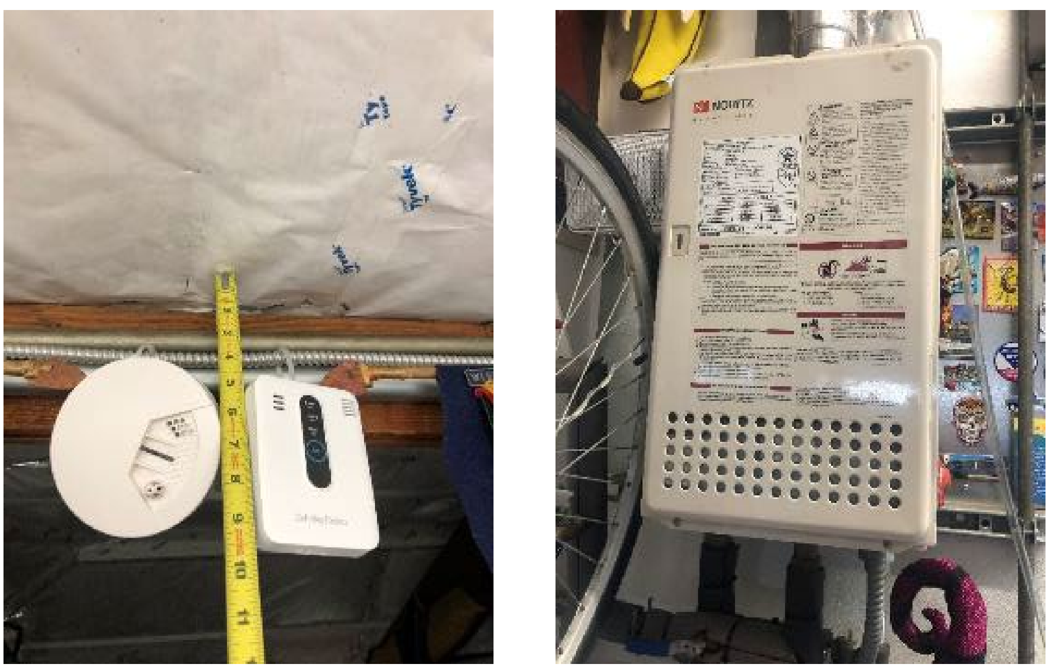
**Figure 14: PG&E Residential Building: (Left) Smart Sensors, (Right) Gas Dryer**

Source: GTI

**Figure 15: PG&E Residential Building:**
**(Left) Smart Sensors, (Right) Furnace**

Source: GTI

**Figure 16: PG&E Residential Building:**
**(Left) Smart Sensors, (Right) Gas Water Heater**



Source: GTI

The project team monitored the CGSSSS from July 26, 2022, until September 29, 2023. The monitoring results indicated the successful heartbeat of each smart component and no hazards. It was noted during the monitoring period that there was an unexpected battery drain on the Lorax Systems smart valve. An investigation concluded that the D2D firmware required updating. After the firmware was updated, a new battery was installed and no further issues were observed. Table 7 and Table 8 indicate the user interface dashboard testing results on the day the CGSSSS was removed from the residential building.

**Table 7: Residential Indoor Methane Detector Final Testing Results**

| Indoor Methane Detector | Time 20% LEL Detected | Time Valve Closed | Reaction Time (Seconds) |
|---|---|---|---|
| Gas Dryer | 9/29/2023 17:29 | 9/29/2023 17:30 | 44 |
| Gas Water Heater | 9/29/2023 17:24 | 9/29/2023 17:25 | 43 |
| Gas Furnace | 9/29/2023 17:16 | 9/29/2023 17:17 | 83 |

Source: GTI

**Table 8: Residential Fire Alarm Final Testing Results**

| Fire Alarm Location | Time Hazard Detected | Time Valve Closed | Reaction Time (Seconds) |
|---|---|---|---|
| Gas Dryer | 9/29/2023 18:02 | 9/29/2023 18:03 | 32 |
| Gas Water Heater | 9/29/2023 17:35 | 9/29/2023 17:36 | 43 |
| Gas Furnace | 9/29/2023 17:32 | 9/29/2023 17:33 | 52 |

Source: GTI

The commercial building demonstration was located in PG&E's gas service territory in Roseville, California. In the past, the commercial building had a leak on the service pipe and the underground gas service pipe was replaced. The Lorax smart valve was installed on the outside of the commercial building and the antenna/gateway was installed on the ground by the building (Figure 17 and Figure 18). The system was demonstrated using a sample gas can of methane spray and a lighter (fire) to prove its functionality. The following performance metrics were observed on the user interface software dashboard: the methane alert, the methane LEL level, the fire alert, the valve status for a remote disconnect, and the valve status for closing when a hazard was detected. The smart valve successfully closed when the indoor methane detector or the sensor detected a hazard.

Members from the California Energy Commission (CEC) and field employees from PG&E were onsite during the demonstration and participated in exposing each of the smart sensors to gas and fire hazards. The attendees agreed that these types of hazard alerts transmitted from a building would also allow more responsive prevention by stopping the flow of gas before accumulation, notifying an employee to investigate, and improving gas safety overall. As with the residential building demonstration, all attendees concluded that the safety system worked successfully and would reduce the likelihood of an incident if there were a gas leak or a fire in the building.

**Figure 17: PG&E Commercial Building:
(Left) Smart Valve, (Right) Gateway/Antenna Installation**

Source: GTI

**Figure 18: PG&E Commercial Building:
(Left) Smart Sensors at Basement Gas Service Entry, (Center) Smart Sensors Near Gas Water Heater, (Right) Smart Sensors at Inside Wall Service Entry**

Source: GTI

During the initial installation of the CGSSSS, three indoor methane detectors and three fire alarms were installed in the commercial building. The locations of these smart devices were:

- The basement where the gas service enters the building.
- The room where the gas water heater is located.
- Inside the building wall where the gas service pipe enters the building.

As part of the demonstration, the project team monitored the CGSSSS by the project team from November 29, 2022, until September 12, 2023. The monitoring results indicated a successful heartbeat for each smart component, and no hazards were detected during the monitoring period. Table 9 and Table 10 show the user interface dashboard testing results on the day that the CGSSSS was removed from the commercial building.

**Table 9: Commercial Indoor Methane Detector Final Testing Results**

| Indoor Methane Detector Location | Time 20% LEL Detected | Time Valve Closed | Reaction Time (Seconds) |
|---|---|---|---|
| Basement | 9/12/2023 15:59 | 9/12/2023 16:00 | 45 |
| Gas Water Heater | 9/12/2023 15:56 | 9/12/2023 15:57 | 60 |
| Building Service Entry | 9/12/2023 15:46 | 9/12/2023 15:47 | 85 |

Source: GTI

**Table 10: Commercial Fire Alarm Final Testing Results**

| Fire Alarm Location | Time Hazard Detected | Time Valve Closed | Reaction Time (Seconds) |
|---|---|---|---|
| Basement | 9/12/2023 15:41 | 9/12/2023 15:43 | 143 |
| Gas Water Heater | 9/12/2023 15:33 | 9/12/2023 15:34 | 43 |
| Building Service Entry | 9/12/2023 15:20 | 9/12/2023 15:25 | 275 |

Source: GTI

# CHAPTER 4: Conclusion

GTI Energy successfully implemented and demonstrated various CGSSSS components, including smart sensors (methane and fire), smart shutoff devices, wireless communication networks, and user interface software. The project's technical advisory committee and national and international research provided the needed direction to determine the available features and components for successfully implementing both residential and commercial demonstrations in California. GTI worked with industry providers New Cosmos, Lorax Systems, Honeywell, Semtech, and Senet to make needed enhancements and modifications to their respective products and to ensure their integration into a successful working system prototype. This prototype was demonstrated in both residential and commercial installations. Two demonstration systems were developed around different vendors and served as proof of concept for a CGSSSS. One system centered on a smart shutoff valve by Lorax Systems, the Lorax Systems meter valve, and the other system centered on a Honeywell smart gas meter with a built-in shutoff valve (Honeywell American Meter AC-250NX). Both systems used a minimum of two smart sensor types, the New Cosmos indoor gas detector and the GlobalSat fire alarm. Multiple different smart sensors were integrated into the CGSSSS that can be programed to automatically shut off the smart valve according to assigned hazard levels. The LoRaWAN® wireless communication network was used, since it is an open ecosystem, meaning that other vendors can create LoRaWAN®-compliant devices that easily integrate into the CGSSSS (for example, flood, pressure, and seismic sensors).

The CGSSSS enables both the gas utility and the customer to remotely monitor for gas leaks or fires in a building and automatically shut off that building's gas flow. In both testing and demonstrations, the CGSSSS was shown to have the required performance capabilities to improve gas safety in buildings by alerting customers of a hazard, notifying the gas utility, and stopping the flow of gas. There were multiple utility demonstrations where both the Lorax Systems meter valve and the Honeywell American Meter AC-250NX successfully operated. The demonstrations showed the intended performances of the systems, including remote and D2D gas shutoffs to the building.

The market research performed for this project established customer need and preference for the gas utility to be responsible for a CGSSSS. There was strong appeal for a CGSSSS for California ratepayers, who appear willing to pay for this additional safety benefit. Building owners with tenants had the greatest interest in a CGSSSS and were willing to pay the most for the system's added security. The interest from California residents increased if insurance companies or the gas utility offered discounts for the CGSSSS installation and monitoring.

The associated cost of a CGSSSS for California ratepayers depends on multiple factors, including who owns the safety systems (utility, residents, or third party), volume of components ordered, wireless network setups, and ownership. Market research indicated that California gas customers are willing to pay an extra $100 to $750 for a CGSSSS. It is estimated that the initial installation of the CGSSSS would cost $500 to $800 per customer, with a $5 to

$10 monthly ongoing service fee per customer for monitoring and maintenance of the safety system. The project team managed temporary installations of the LoRaWAN® gateways and antennas for $1500 in equipment costs, with the capability of connecting to thousands of smart devices within range. In addition, there are associated network costs, similar to those for using a cellular network, for each gateway installed. The network costs can vary, based on whether an existing network is in an area or if it needs to be installed, who owns the network, and the number of smart devices connected. The CGSSSS could be installed and managed by the gas utility or a third party. The costs are justified by a reduction in natural gas incidents, injuries, and methane-related emissions.

The important aspect of this safety system is getting the smart sensor data to the gas utility first responders, who would then be sent to the address transmitted by the safety system. The software may be monitored by a third party that could contact the gas utility, or the software may additionally communicate directly with the gas utility's dispatch department. A typical gas utility dispatch department would have customized software and firewalls for security that could directly receive and send communications from thousands of smart sensors and smart valves installed throughout the utility's service territory. In addition, with regulatory approval, the implementation of this safety system could potentially reduce leak survey inspection requirements for indoor piping owned by a gas utility, which may result in cost savings for the ratepayers.

All of the technology demonstrated — including both hardware and software — is commercially available, so the next step would be for California's gas utilities to determine a path for implementation. For a gas utility to implement a CGSSSS within a designated service territory for multiple residential and commercial buildings, the infrastructure of smart sensors and smart valves would need to be installed within that territory. The communication network gateways (antennas) would need to be either already in place or installed, and the user interface software would need to gather all the initial system inputs to begin functioning. An option for deployment could be for a third party to deploy, set up, and perform all required ongoing maintenance.

Gas utilities would benefit from the expanded use of a CGSSSS by improving gas delivery for their customers, improving safety, and reducing emissions. Expanded CGSSSS pilots are needed to integrate the technology developed during this project into a gas utility's existing information technology and emergency-response processes.

In conclusion, this project was a demonstration of how existing smart sensor, smart valve, and wireless communication technologies can be adapted to the gas industry to both improve safety and reduce emissions. The CGSSSS system developed and demonstrated in this project is available and ready for deployment and integration into gas utility emergency-response processes. The recommended next step is for gas utilities to integrate these smart technologies into their existing infrastructure and emergency processes to reduce the risk associated with gas service to buildings in California. It is also recommended that gas utilities conduct small initial pilots to allow for the development of procedures and processes for widescale deployment of CGSSSS systems throughout their gas service territory.

# GLOSSARY AND LIST OF ACRONYMS

| Term | Definition |
|---|---|
| backhaul connectivity | The part of the network that communicates with the global internet. In LoRaWAN® the backhaul is typically responsible for delivery of traffic from a gateway to/from a LoRaWAN® network server (LNS). |
| bps | bits per second |
| °C | degrees Celsius |
| CEC | California Energy Commission |
| CGSSSS | comprehensive gas smart shutoff safety system |
| ConEd | Consolidated Edison (utility in New York) |
| D2D | device-to-device |
| D2D communication | Direct communication between a subset of devices, such as smart meters, smart valves, and smart sensors, that does not require a gateway connection. |
| D2D disconnect | The closing of a valve to stop the flow of gas, prompted by direct communication without the need for network connection. |
| EEI | Energy Experts International |
| °F | degrees Fahrenheit |
| FCC | Federal Communications Commission is the U.S. federal agency that regulates communications. |
| greenfield deployment | An entry and exit point for a network that data passes through. |
| heartbeat message | A message a device sends to the head end system to confirm its presence, status, and validate link quality. |
| indoor methane detector | Industry-referenced as: residential methane detector (RMD), remote methane detector (RMD), indoor methane detector, and natural gas detector (NGD). |
| IoT | Internet of Things is a network of physical objects that are embedded with technology that allows them to connect and exchange data with other devices or systems in the same network. |
| ISM band | Industrial, Scientific, and Medical band is the part of the radio spectrum reserved for industrial, scientific, and medical purposes. |
| kbps | kilobits per second |
| km | kilometers |
| latency | The time it takes data to transfer from its origin to its destination. |

| Term | Definition |
| --- | --- |
| LEL | Lower explosive limit is the lowest concentration of gas with potential to explode, with "X% LEL" meaning X% of the lower explosive limit. |
| LoRa® | Long Range; a spread spectrum radio frequency modulation technique invented by Semtech. |
| LoRaWAN® | Long Range Wide Area Network; a type of LPWAN protocol that uses LoRa® as its physical layer in the ISM band. It's an open standard that can be deployed in a variety of applications. |
| LPWAN | Low Power Wide Area Network; a wireless telecommunication wide area network designed for long range communication and low power consumption. |
| m | meter |
| mA | milliampere |
| Mbps | megabits per second |
| MHz | megahertz |
| NFPA | National Fire Protection Association |
| OTD | Operations Technology Development |
| PG&E | Pacific Gas and Electric Company |
| psig | pounds per square inch gauge |
| remote disconnect | A network-prompted closing of a valve to stop the flow of gas. |
| RMD | remote methane detector |
| SoCalGas | Southern California Gas Company |

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## Support Manufacturers

GTI Energy provided product testing and project management for all activities described in this report. Products and various product information were provided by the following companies:

- DeNova Detect, 2020–2023, www.denovadetect.com
- elichens, 2020–2023, www.elichens.com
- Honeywell, 2020 – 2023, www.honeywell.com
- Lorax Systems Inc., 2020–2023, www.loraxsystems.com
- Senet, 2020–2023, www.senetco.com

# Project Deliverables

The following reports and deliverables are available upon request by submitting an email to pubs@energy.ca.gov.

- Customer Research Plan (Phase 1 and Phase 2)
- Product Discovery Report
- Hardware Design and Specifications Report
- Software Design and Specifications Report
- Hardware Validation Report
- Software Validation Report
- Site Readiness Report
- Field Demonstration Plan
- Field Demonstration Report
- Technology/Knowledge Transfer Report
- Production Readiness Report