METHANE GAS DETECTION
BAST ASSESSMENT

STEP 1.2 of the
BAST DETERMINATION PROCESS

Office of Offshore Regulatory Programs

BAST DETERMINATION REPORT # 001
June 8, 2017

BSEE
Bureau of Safety and Environmental Enforcement

METHANE GAS DETECTION BAST ASSESSMENT
STEP 1.2 of the BAST DETERMINATION PROCESS

Prepared on August 31, 2016
Revised for Public Distribution on June 8, 2017

EXECUTIVE SUMMARY

The BAST Determination Process (BDP) provides BSEE with a structured methodology for assessing technology failures or improvements that would have a significant effect on personnel safety, health, or the environment. A flowchart of BSEE's BDP is provided on the last page of this report.

This BDP is being carried out to assess the feasibility of installing Methane Gas Detection (MGD) systems on oil and gas platforms in the U. S. Outer Continental Shelf (OCS) to avoid the risk of gas ingestion by helicopters.

This report presents the work and findings from Step 1.2 of the BSEE BDP, where a study by Price Waterhouse Coopers (PWC) was reviewed and the potential for safety improvement of OCS helicopter operations was analyzed. The availability of proven technology was investigated, a budget and timeframe for the entire BAST process was established, and a preliminary feasibility analysis was performed. The main conclusion is that use of MGD systems on OCS platforms is feasible (Step 1.3) and there is sufficient evidence to recommend continuing the process by establishing a Technology Improvement Objective (TIO) as stated in step 1.4 of the BDP.

Table of Contents

BACKGROUND

On August 26, 2014, a Safety Recommendation issued by the National Transportation Safety Board (NTSB) included five safety recommendations[1] to BSEE, one of which was to identify and develop a comprehensive system and procedures to mitigate the risk of ingestion of platform vented gases[2] by helicopters operating in the vicinity of offshore oil and gas facilities.

In response, BSEE funded Study No. 733 under the BSEE Technology Assessment Program (TAP), titled "***Aviation Safety Support Services for the Bureau of Safety and Environmental Enforcement***" [3]. The contractor, PWC, performed multiple tasks including Subtasks C.4.5.1, C.4.5.2 and C.4.5.3 (below) which apply to this BAST Assessment. Additionally BSEE engaged another company (Endyna) to provide a peer review of the conclusions of the PWC report[4]. The comments from the peer review were in general agreement with the conclusions of the original PWC report.

Subtask C.4.5.1 – ***review and assess helideck construction standards***: In this Subtask a review of current U.S. and international regulations and standards was performed addressing the placement of gas vents in relation to helidecks. Engineering studies should be commissioned to predict the theoretical concentration of APG (Associated Petroleum Gases) that may be present in an APG vapor cloud based on computational fluid dynamics (CFD) gas dispersion modelling. A comprehensive examination of U.S. regulatory agencies and statutes revealed that there are no regulatory requirements or guidance promulgated by these agencies for mitigation of hazards posed by APG. However, it was noticed that the recommendations provided in API 14-J: Recommended Practice for Design and Hazard Analysis for Offshore Production Facilities, 2nd Edition (May 2001) and the draft version of API RP 2L-1: Recommended Practice for Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms, 4th Edition (May 1996, Reaffirmed January 2012) are sufficiently comprehensive to ensure that hazards presented by APG are considered and mitigated. Additionally it was noted that placement of helidecks, cranes, living accommodations and flare discharge locations varies widely from one OCS facility to another.

Subtask C.4.5.2 – ***technical analysis***: As discussed in this Subtask, the maximum permissible concentration of hydrocarbon gas within the helicopter operating area is 10% of the lower flammable limit (LFL). According to the report, the LFL for methane is 4.4% by volume; thus 10% of the LFL for methane is 0.44%. Additionally, as mentioned in the report, this low methane concentration (0.44%) has the potential to cause helicopter engines to surge and/or flameout. Based on PWC findings regarding the threat posed by vented gas, it was concluded that until a CFD gas dispersion model is constructed for each facility, in accordance with the

[1] NTSB recommended to USCG to work with BSEE to identify and develop comprehensive systems and procedures to mitigate the risk of ingestion of raw gas discharges, such as methane, by helicopters operating in the vicinity of offshore oil platforms: http://www.ntsb.gov/safety/safety-recs/recletters/A-14-069-070.pdf

[2] For this report references made to gas detection or MGD are understood to refer to methane and one or more of the other APG.

[3] https://www.bsee.gov/sites/bsee.gov/files/reports/safety/task-5-study-on-effects-of-combustible-gas-on-helicopter-operations-v2-1.pdf

[4] https://www.bsee.gov/endyna-peer-review-comments-on-the-bsee-pricewaterhousecoopers-pwc-study-of-effects-on-combustible

recommendation included in Subtask C.4.5.1, helidecks should be considered contaminated with APG whenever the wind direction is within 10 degrees of the platform's designated flaring/venting critical wind zone and the facility is cold venting APG.

Subtask C.4.5.3 - ***monitoring and warning systems***: This part of the study identified and evaluated the following: (1) technologies to monitor combustible gases that could adversely affect helicopter operations in the vicinity of an OCS facility; (2) how a sensor for vented gas can be devised/installed around the helidecks to advise pilots of the quality of the environment they intend to fly through on takeoff and landing; and (3) mitigation strategies such as installing diffusers or other systems on vent stacks that would reduce the risk of methane or combustible gases.

The PWC report concluded that several mature hydrocarbon gas detection technologies were being used in offshore, petrochemical, and other hydrocarbon facilities that could also address concerns with the helicopter engine safety issue. Furthermore, the study showed (1) that installation of point and open-path gas detectors could be installed on the helideck perimeter and in the path from the APG source (e.g. boom) to the helideck and (2) that installation of a helideck visual warning indication system as discussed in the draft version of API RP 2L-1: Recommended Practice for Planning, Designing, and Constructing Heliports for Fixed Offshore Platforms, 4th Edition (May 1996, Reaffirmed January 2012), should be considered. More information on these monitoring technologies is provided later in this report.

In summary, the PWC report recommended that, in order to minimize or eliminate the risks presented to helicopter operations due to the release of methane or other combustible gases on OCS facilities BSEE should explore the use of methane gas detection devices as a way to provide early warning to helicopter pilots and facility personnel.

In review of PWC's report and based on the findings made in this document, the Office of Offshore Regulatory Programs (OORP) finds support for proceeding to the next step of the BDP.

RECOMMENDATION

As provided in the supporting documentation below, it has been determined by the Chief of OORP that there is sufficient safety justification to recommend that the Director initiate ***Step 1.3*** of the BDP. In Step 1.3, the Director reviews the findings from this document and decides whether to proceed with Step 1.4 of the BDP or whether an alternative course of action outside the BDP should be pursued (e.g., safety alert, research, revision of inspection procedures, etc.).

DOCUMENTATION

I. SAFETY ISSUE

The purpose of Step 1.2 of the BSEE BDP is to analyze the incidents of concern, similar events and whether a BAST Determination has the potential to identify technological solutions that would mitigate the safety issue identified in Step 1.1 of the BDP. The primary incidents of concern to BSEE include:

> Two helicopter incidents (2011 and 2013) which resulted when methane gas was vented from a facility and ingested into the turboshaft engines of the helicopters during takeoff; resulting in the ditching of the two aircraft.

- The 2011 incident (**NTSB-CEN11LA252**[5]) involved a Bell 206L-3, N32041 at Main Pass 61A on March 24th, resulting in the helicopter engine losing power after the pilot heard a loud bang. The pilot performed a successful autorotation to the water. The occupants escaped with minor injuries. The NTSB attributed this incident to engine compressor stalling resulting from ingesting methane gas during takeoff.
- The 2013 incident (**NTSB CEN13FA491**[6]) involved a Bell 407, N53LP, at Ship Shoal 208H on August 13th,where shortly after takeoff the pilot reported hearing a loud bang and then losing engine power. The pilot executed a successful water entry. All occupants exited with only minor injuries. The exact cause of this accident remains undetermined, but records indicate that the facility involved vented significant amounts of methane throughout the day of the accident.

II. BAST STEP 1.2 ASSESSMENT AND FINDINGS

The findings made under Step 1.1 provided sufficient evidence that a safety issue exists and that initiating Step 1.2 of the BDP was necessary to further assess the issue and determine whether technology exists that can resolve or lessen the risks of this safety issue. Step 1.2 of the BDP requires an assessment of the following:

- **Technology Failures:** Were the incidents (technology failures or near-misses) caused by a failure or gap in the use of technology?
- **Potential for Safety Improvement:** Could the use of new technology have prevented or minimized the specific safety issue or increased safety across the OCS?
- **Availability of Proven Technology:** Is there sufficient information to establish the existence of technologies that are currently available?
- **BSEE Resources:** What are the expected costs and resources necessary from BSEE to perform this BD and the anticipated timeframe for completion?
- **Economic Feasibility:** Is it likely that the benefit of better performing technologies will justify the implementation cost?

Technology Failures and Potential for Safety Improvement

Methane is a colorless, odorless gas that is lighter than air and extremely flammable. It is a natural byproduct of oil and gas production that may be vented or flared to the atmosphere (along

[5] http://www.ntsb.gov/_layouts/ntsb.aviation/brief2.aspx?ev_id=20110329X54044&ntsbno=CEN11LA252&akey=1

[6] http://www.ntsb.gov/about/employment/_layouts/ntsb.aviation/brief2.aspx?ev_id=20130815X95202&ntsbno=CEN13FA491&akey=1

with other APGs) to control a sudden over pressurization within a production or drilling system. The release of natural gas by flaring and venting is an essential practice in oil and gas production. The availability of a flare or a vent boom ensures that natural gas can be safely disposed of during emergency and shut down situations.

When vented, produced gas can drift over the helideck (depending on wind speed/direction) where it can be ingested by a helicopter during take-off or landing and potentially cause the engine to surge (over speed) or fail (flameout). Although many offshore facilities place vent/flare booms as far away from helidecks as practical, many remain within close proximity to the helidecks and can pose a danger of vented gas reaching the helideck in high enough concentrations to pose a risk to helicopter traffic.

Figure 1, below depicts a platform with produced gas venting from the boom passing from right to left (wind driven) over the helideck. The concentration of vented gas above a helicopter or in the direction of flight may pose a potential danger to the helicopter and crew, as well as to the offshore installation and personnel from a crash.

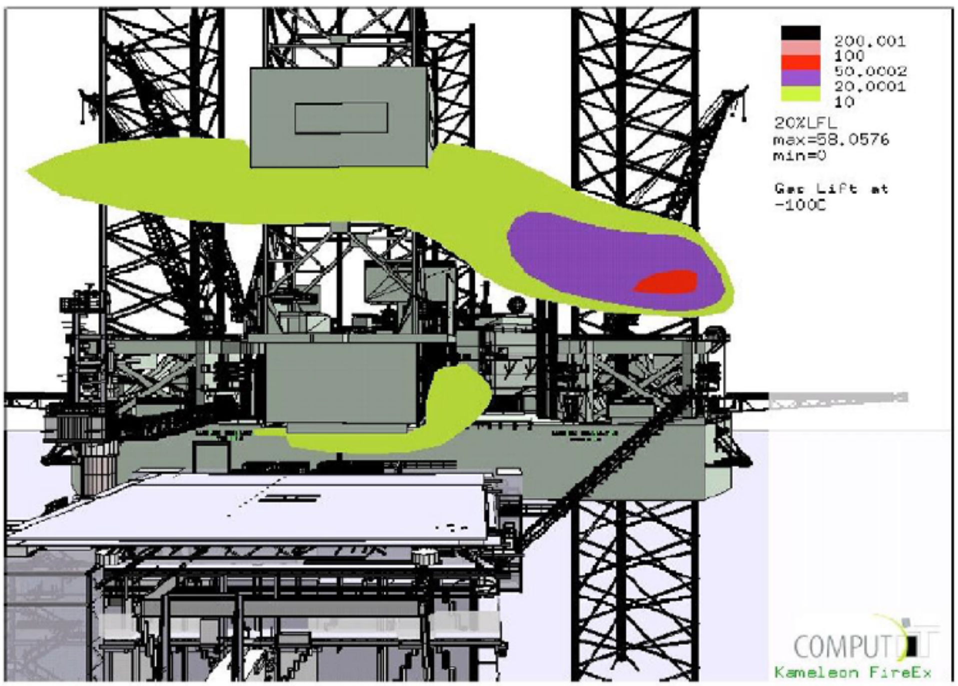


Figure 1: CFD Gas Dispersion Model[7]

To prevent gas ingestion by the helicopter, the PWC report, Task C.4.5, subtask C.4.5.3 (a), recommends[8] placement of a gas detection system in the area around the helideck. It also states that placing such systems in the vicinity of the helideck may be feasible if the detector system

[7] Taken from the PWC TAP Report No. 733, Task C.4.5. (Page 31, (Fig. 6)): https://www.bsee.gov/sites/bsee.gov/files/reports/safety/task-5-study-on-effects-of-combustible-gas-on-helicopter-operations-v2-1.pdf

[8] http://www.bsee.gov/uploadedFiles/BSEE/BSEE_Newsroom/Publications_Library/Publications_and_Studies/2015_Aviation_Study/Task%205%20-%20Study%20on%20Effects%20of%20Combustible%20Gas%20on%20Helicopter%20Operations%20v2%20(1).pdf

could be calibrated to 10% LFL of methane or lower without degrading the detection capability of the system or generating a nuisance caused by false alarms. Selecting the most effective gas detection system will be critical to ensuring helicopter safety. Depending on the type of system selected, a further means of improvement is to provide a helicopter pilot with real time information, concerning the wind direction and speed, temperature, and air quality in the immediate areas around the helideck to make a well-informed decision on whether to initiate an approach to land or takeoff from the platform.

BSEE's assessment concluded that use of gas detection technologies can mitigate the inherent danger of the emergency release of gas to approaching or departing helicopters. Such systems would need to be located either;

- on the helicopter or
- in the vicinity of the methane gas source and/or the region between the source and helideck.

Availability of Proven Technology

As part of the BAST Assessment, BSEE performed market research on a wide variety of commercially available gas detection systems and met with multiple Original Equipment Manufacturers (OEMs) whose systems appeared the most fit-for-service for OCS operations. Consistent with the findings of the PWC TAP No. 733 Report, BSEE found numerous MGD systems that appear capable of warning OCS helicopter pilots of the presence of methane gas clouds in the vicinity of the helideck during landing or take off. The following systems were found to be the most relevant:

Point Detection

Point detectors are generally small, compact devices, which are easily transported and installed. Point detectors work on various principles, including; chemical reaction, electrical resistance, and optical. Some optically-based detector systems are susceptible to contamination, rain or fog.

Examples of Point detection systems:

- **Catalytic Detectors**: Heating of an electrical wire responds to an influx of combustible hydrocarbon gas by increasing the temperature and resistance of the sensing element.
- **Electrochemical Detectors**: The equipment undergoes a chemical reaction producing a current that is directly proportional to the concentration of gas present.
- **Infrared Point Detectors**: Measures the attenuation of an infrared beam identifying the presence of methane gas.

Open Path Detection

Open Path detectors operate by measuring the attenuation of an optical beam of light by a vapor cloud between the transmitter and receiver over a large area. An open path detector is effective over distances of up to 985 feet, however practical detection is less than 328 feet to ensure accuracy and reduce nuisance alarms. This operational feature makes this type of detector ideal for perimeter monitoring. However, like all optically-based detector systems, they are susceptible to contamination, rain or fog.

Example of Open Path detection systems:

- **Infrared Open Path**: A hydrocarbon gas detector consisting of a transmitter and receiver with the capability to detect methane between 0 - 5,000 parts per million (ppm).

Hydrocarbon Gas Imaging

These systems are quite new and similar to forward-looking infrared technology. With this technology it is possible to actually 'see' a vapor gas cloud in real time. This technology has the ability to distinguish between the vapor gas cloud and the surrounding humid environment. Optical reflective technology makes imaging possible to actually see the vapor gas cloud in real time. These technologies have been used in onshore oil and gas operations.

Examples of Hydrocarbon Gas Imaging systems:

- **Gas Cloud Imaging (GCI)**: GCI is video camera that monitors, quantifies and displays gas leaks in real time. It uses hyperspectral imaging technology to provide real-time images of multi-gas compositions (methane, ethane, etc.) and estimates volumes.
- **Optical Gas Imaging (OGI)**: The OGI camera works by using spectral wavelength filtering and an array of infrared detectors to visualize the infrared absorption of hydrocarbons and other gaseous compounds. Gas absorbs radiant energy at the same waveband that the filter transmits to the detector, thus imaging gas and its motion.

Based on BSEE's assessment, there are multiple commercially available technologies that can be used singularly or in combination to provide the detection and reporting of methane gas in the open air as related to the safety issue. Additional information on these technologies can be found in Appendix A.

Acoustic Detection

Acoustic detectors operate by measuring the acoustic (sound) signal that results when pressurized gas leaks from a component. This acoustic signal occurs due to turbulent flow when pressurized gas moves from a high-pressure to a low-pressure environment across a leak opening (U.S. EPA, 2003a)[9]. The acoustic signal is detected by the analyzer, which provides an intensity reading on the meter. These detectors do not measure leak rates, but provide a relative indication of leak size measured by the intensity of the signal.

Examples of Acoustic detection systems:

- **FlexSonic**: A non-contact gas leak detector that recognizes unique sound "fingerprints." It analyzes up to 24 discrete ultrasonic bands.
- **GSD600**: The meter emits a frequency tone when gas is detected. The frequency of the beep coincides with the concentration of the gas.

BSEE Resources

As part of this Step 1.2, BSEE made an assessment of the time, effort and resources needed by the agency to complete all three stages of this BAST Determination. This internal assessment

[9] https://www.epa.gov/sites/production/files/2016-06/documents/ll_dimcompstat.pdf

allowed BSEE to conclude that all necessary resources in terms of budget and expertise are present internally to allow the continuation of the process to completion.

Feasibility Analysis

Part of the BDP is to determine the anticipated cost to industry to adopt technologies necessary to significantly reduce or eliminate the safety issue. This Feasibility Analysis (FA) is less detailed than the more complete Benefit-Cost Analysis which will be performed in Stage 3 of the BDP. This FA determines the range of costs needed to purchase/lease, install, and maintain various proven technologies, as well as any training needed for personnel to operate such technologies. Additionally, this FA also looks into benefits (cost savings) that may be experienced by the industry due to the avoidance of accidents/incidents.

For the FA the following assumptions were applied:

- MGD technologies were applied only to current OCS facilities with; 1) helidecks, 2) vent/flare booms and 3) active production.
- OCS facilities were designated as:
  1. High volume/high traffic requiring a more advanced MGD system, or
  2. Low volume/low traffic requiring a simple MGD system.

The FA calculations were performed as follows:

- Various technologies were used in the calculations related to costs and benefits achieved.
- Some of the calculations (Cases 1 -5) assumed that the same MGD technology was used on all 412 OCS facilities requiring MGD systems.
- Some of the calculations (Cases 6 and 7) assumed that different technologies would be used on different facilities (high volume/high traffic and low volume/low traffic facilities). We assumed that 10 - 20 % of the facilities would use more sophisticated technology and that 80 - 90 % of the facilities would adopt less advanced MGD systems.

For details on the FA see ***Appendix B. Feasibility Analysis.***

III. RECOMMENDATION

Based on the information provided above, BSEE finds that use of MGD systems on OCS facilities is feasible (Step 1.3) and that sufficient justification is available to continue to Step 1.4 (establish the Technology Improvement Objective) of the BDP. BSEE does not think an alternative course of action outside the BDP (e.g. safety alert, research, revision of inspection procedures, etc.) is an appropriate way to address this safety issue at this time.

APPENDIX A. METHANE GAS TECHNOLOGIES SUPPORTING DATA

During Step 1.2 of the Assessment, BSEE evaluated commercially available MGD systems and met with the OEMs and equipment distributers to discuss the technologies found most applicable to OCS operations and helicopter engine safety. This Appendix serves to provide additional information on each of the technologies previously mentioned in this BAST Assessment.

Point Detection

Although point detectors are best applied to confined spaces such as pump and compressor rooms, there may be consideration for open space applications when the point detector can be installed in close proximity to the methane source (flare/vent boom) or impact point (perimeter of helideck).

Point detectors are generally small, compact devices which are easily transported and installed and that work on various principles, including; chemical reaction, electrical resistance and optical detection. Point detectors can be mobile handheld units for remote, as-needed use or fixed for continuous use. The detection chamber is small, ranging in length from less than an inch to multiple inches, and must be installed in the immediate vicinity (e.g., within inches) of the area to be evaluated. In some cases, point detectors require physical contact with the element (methane gas) to be measured.

Point detection systems may be used in offshore oil and gas operations, floating production storage and offloading vessels, tankers, onshore oil and gas terminals, refineries, Liquefied Natural Gas and Liquefied Petroleum Gas bottling plants, gas compressor/metering stations, gas turbine power plants and coating plants.

Major OEMs of point detectors include Honeywell, Tyco, and Simtronic.

Examples of Point Detection Systems, Applications and Operational Considerations:

1) **Catalytic Sensor**: A catalytic gas detector works by the electrical heating of a wire. Current is passed through the wire so it reaches a temperature of 932-1022 °F at which point oxidation of a gas readily occurs. The change in resistance in the sensor is proportional to the volume fraction of the hydrocarbon gas in air and is converted to an analog voltage signal which is then displayed on an indicator or used to activate an alarm.

   Range of Concentration (detection across flammability range): Output change is linear for most gases, up to and beyond 100% of the Lower Explosive Limit (LEL). Response time is a few seconds to detect alarm levels which occur at approximately 20% LEL.

   Application: Potential leakage points such as pumps and compressors.

Operational Considerations: Easy to install, calibrate, and use. Once in place, the detectors can operate for years with only minimal maintenance consisting of periodic gas calibrations to verify operational status. Because the catalytic combustion reaction is non-selective, catalytic detectors can be used for monitoring several target gases across a wide range of applications. Advances in material processing have yielded measurable improvements in the tolerance of catalytic detectors to high temperatures.

2) **Infrared Sensor**: An infrared point sensor is a point gas detector operating on the principle that raw gas such as methane absorbs infrared energy at certain wavelengths. The amount of absorption is proportional to the concentration of gas present in the measuring path.

   Range of Concentration (detection across flammability range): Toxic gases are measured in the low ppm range. Flammable gases are measured in the 0 - 100% LEL range.

   Applications: Potential leakage points such as pumps and compressors.

   Operational Considerations: Detectability of gases is poor when the contrast with the background is poor. Heavy fog and rain reduces detection range. Technology is suitable only for large leaks, not small leaks.

3) **Semiconductor Sensor:** Semiconductor sensors detect gases by a chemical reaction that takes place when the gas comes in direct contact with the sensor. Tin dioxide is the most common material used in semiconductor sensors. The electrical resistance in the sensor is decreased when it comes in contact with the monitored gas. This change in resistance is used to calculate the gas concentration. Semiconductor sensors are commonly used to detect hydrogen, oxygen, alcohol vapor, and harmful gases such as methane and carbon monoxide.

   Range of Concentration (detection across flammability range): The resistance of the tin dioxide is typically around 50 kilo ohms (kΩ) in air but can drop to around 3.5 kΩ in the presence of 1% methane.

   Application: Potential leakage points such as pumps and compressors.

   Operational Consideration: Because the sensor must come in contact with the gas to detect it the semiconductor sensors work over a smaller distance than ultrasonic detectors.

Open Path Detection

Open path detectors operate by measuring the attenuation of an optical beam of light by a vapor cloud located between the transmitter and receiver. An open path optical beam measures an infinite number of points along the sensor path.

Usually, there are separate transmitter and receiver units at either end of a straight beam path. Alternatively, the source and receiver are combined, and the beam bounces off a retroreflector at the far end of the measurement path. The presence of a chosen gas (or class of gases) is detected from its absorption of a suitable infrared wavelength in the beam. The quantity of gas intercepted by the beam is then inferred from the ratio of the signal losses at the measurement and reference wavelengths.

Open path detectors are effective over a long distance with typical coverages up to 985 feet. Practical effective detection limits are less than 328 feet to ensure accuracy and reduce nuisance alarms. This operational feature makes these types of detectors ideal for perimeter monitoring. However, like all optically-based detector systems, they are susceptible to contamination, rain or fog.

Major OEMs of open path detectors include Honeywell, Tyco, and Simtronic.

Example of Open Path Detection System, Applications and Operation Considerations:

1) **Infrared Detectors**: IR gas detectors operate by the physical principle that raw gas such as methane absorbs infrared energy at certain wavelengths.

   The open-path IR gas detector is similar to a conventional optical beam smoke detector in appearance and configuration. It works by measuring the attenuation of IR by a vapor cloud between the transmitter and receiver over a large area (line of sight). The optical beam measures the total amount of gas present in the sensor path as if a row of point-type detectors had been placed end to end in a line. This provides rapid gas leak detection for flammable gases at concentrations comparable to the LFL (typically a few percent by volume).

   Range of Concentration (detection across flammability range): Capable of detecting combustible gases and vapors ranging from 0.1% - 5% LFL over line-of-sight from 23 ft. - 650 ft.

   Application: Open path detection systems are widely used in the petroleum and petrochemical industries (e.g., in offshore oil and gas operations, floating production storage and offloading vessels, tankers, onshore oil and gas terminals, refineries, LNG/LPG bottling plants, gas compressor/metering stations, gas turbine power plants, and coating plants).

Operational Considerations: Gas to be detected must pass through the sampling path and must be infrared active (e.g. a hydrocarbon). Rain, fog or high humidity in the measurement path can reduce the strength of the received signal, so it is customary to make simultaneous measurements at one or more reference wavelengths. Other considerations include: routine calibration to a different gas is impractical (not suitable for multiple gas applications), a relatively large amount of gas is required for response testing, ambient temperature limit of detector use is 160°F, and infrared source is not replaceable in the field.

Hydrocarbon Gas Imaging

Hydrocarbon Gas Imaging systems use a video camera with hyperspectral imaging that monitors, quantifies and displays gas leaks in real time. Hyperspectral imaging, like other spectral imaging, collects and processes information from across the electromagnetic spectrum to obtain the spectrum for each pixel in the image of a scene. Using this imaging technology, it is possible to actually 'see' a vapor gas cloud in real time. It is also possible to compare the gas cloud to the surrounding humidity.

These systems are used in onshore oil and gas operations. The Environmental Protection Agency (EPA) and State regulatory agencies require these for gas compressor/metering stations and for some gas turbine power plants.

Major OEMs of Hydrocarbon Gas Imaging include Rebellion, Bertin, and FLIR

Examples of hydrocarbon gas imaging systems, applications and operation considerations:

1) **Gas Cloud Imaging (GCI)**: The GCI system utilizes a thermographic camera (also called an infrared camera or thermal imaging camera) to form a thermal image using infrared radiation operating in wavelengths as long as 14,000 nanometer (nm). The video camera takes real-time images of at least 20 types of gases for continuous monitoring of potential raw gas leaks. It can instantly detect what gases are leaking and how much is being leaked. GCI allows the user to assess the situation before exposing anyone to a potentially lethal situation. State regulators in Wyoming[10], Ohio[11], California[12], Pennsylvania[13], and Colorado[14] recommend or make use of GCI in oil and gas production operations.

   Range of Concentration (detection across flammability range): Not applicable.

[10] http://deq.wyoming.gov/media/attachments/Air%20Quality/New%20Source%20Review/Guidance%20Documents/5-12-2016%20Oil%20and%20Gas%20Guidance.pdf

[11] http://epa.ohio.gov/Portals/27/genpermit/RSCompGP20170217Final.pdf

[12] http://www.conservation.ca.gov/index/Documents/2016-06%20DOC%20fines%20oil%20operator%20$75%2C000.pdf

[13] http://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Permits/gp/MethaneRegulations.pdf

[14] https://www.colorado.gov/pacific/cdphe/AIMM

Application: GCI can be installed up to 405 feet away from a raw gas source and has the capability to detect large gas clouds. The system can pan 180 degrees, has an operational radius of 360 degrees, and can detect gas at a distance of up 5600 feet from the source.

Operational Considerations: Each GCI frame views 4-million pixels. No light source is required for it to operate. GCI is self-calibrating and works well in light rain. GCI has been tested on drilling rigs under normal field operating conditions including; humidity, water vapor, salt spray, vibrations and dense fog.

2) **Optical Gas Imaging (OGI)**: OGI operates much like a consumer video camcorder and provides a real-time visual image of gas emissions or leaks to the atmosphere. The OGI camera works by using spectral wavelength filtering and an array of infrared detectors to visualize the infrared absorption of hydrocarbons and other gaseous compounds. As the gas absorbs radiant energy at the same waveband that the filter transmits to the detector, the gas and motion of the gas is imaged. EPA recommends the use of OGI in onshore oil and gas production operations in their recently proposed rule: Greenhouse Gas Reporting Rule[15]: Leak Detection Methodology Revisions and Confidentiality Determinations for Petroleum and Natural Gas Systems.

   Range of Concentration (detection across flammability range): Not applicable.

   Application: Large gas clouds, unmanned platforms, and pipelines.

   Operational Considerations: The detection capability is based on a variety of factors such as detector capability, gas characteristics of the leak, optical depth of the plume and temperature differential between the gas and background. The system is also sensitive to ambient conditions around the equipment that is being monitored. The larger the temperature differential between the leaking gas and the contrasting background (e.g., sky, water or equipment), the easier the leaking gas is to see. The apparent temperature of the sky, a commonly used background, is also highly dependent on weather conditions such as cloud cover, ambient temperature and relative humidity. The effectiveness of an OGI instrument is dependent on the training and expertise of the operator.

Acoustic Detection

Acoustic detectors operate by measuring the acoustic (sound) signal that results when pressurized gas leaks. This acoustic signal occurs due to turbulent flow when pressurized gas moves from a high-pressure to a low-pressure environment across a leak opening (U.S. EPA, 2003a)[16]. Since most high-pressure gas leaks generate sound in the ultrasonic range of 25

[15] https://www.federalregister.gov/articles/2016/01/29/2016-01669/greenhouse-gas-reporting-rule-leak-detection-methodology-revisions-and-confidentiality?utm_campaign=subscription+mailing+list&utm_medium=email&utm_source=federalregister.gov#h-14

[16] https://www.epa.gov/controlling-air-pollution-oil-and-natural-gas-industry

kiloHertz (kHz) - 10 megaHertz (MHz), the sensors are able to easily distinguish these frequencies from background acoustic noise which occurs in the audible range of 20 Hertz (Hz) - 20 kHz.

Major OEMs of acoustic detectors include Honeywell, Tyco, and KRN.

Example of an Acoustic Detection System, Application and Operation Consideration:

1) **Acoustic Leak Detectors (ALD)**: The acoustic signal (resulting from high-pressure, turbulent flow released to a low-pressure environment) is detected by the analyzer which provides an intensity reading on the meter. Acoustic detectors do not measure leak rates but provide a relative indication of leak size measured by the intensity of the signal (or how loud the sound is).

   Range of Concentration (detection across flammability range): Not applicable.

   Application: ALD are mounted to the structure on waveguides and transform acoustic waves to electronic voltage signals, which are amplified, filtered, and processed to determine energy content.

   Operational Considerations: Generally, two types of acoustic leak detection methods are used; high frequency and ultrasound. High frequency acoustic detection is best applied in noisy environments where the leaking components are accessible to a handheld sensor. Ultrasound leak detection is an acoustic screening method that detects airborne ultrasonic signals in the frequency range of 20 kHz - 100 kHz and can be aimed at a potential leak source from a distance of up to 100 feet.

APPENDIX B. FEASIBILITY ANALYSIS

The purpose of this feasibility analysis (FA) is to evaluate whether commercially available technologies exist and are functional for use on the OCS, and to measure the potential benefits and impacts to industry and the environment by requiring the use of such technologies to prevent methane gas ingestion by helicopters. This analysis takes into consideration technical, operational, economic and other factors to determine the possible positive/negative outcomes of requiring companies to use MGD technologies on facilities where vented methane from flare/vent booms could endanger helicopter landing and take-off.

This FA includes two analyses, 1) a Technological and Operational Analysis and 2) an Economic Analysis. BSEE will use the outcomes of a future and more in-depth benefit-cost analysis to make a decision on if an MGD BAST policy will be issued. BSEE envisions the requirements for MGD implementation as having a positive impact on the safety of personnel and the environment, and this FA indicates a positive benefit will result from such implementation.

TECHNOLOGICAL AND OPERATIONAL ANALYSIS:

As previously mentioned, Appendix A of this Assessment analyzed technologies marketed as being able to detect, measure, and warn of the presence of methane and other gases. From these analyses, BSEE identified a number of technologies on the open market with applicability to OCS operations that could be installed at or near the point of methane gas release and/or at or near the helideck, individually or in combination, to provide early warning to helicopter pilots.

ECONOMIC ANALYSIS:

BSEE analyzed the application, use and cost of multiple technologies that appear to be fit-for-service for OCS operations through a structured Economic Analysis Methodology. This analysis was for a 10-year period and assumed that the equipment life is also 10 years with the exception of the handheld point detectors that were assumed as having a 5-year life. Other assumptions include:

- Number of helicopters ditched into the Gulf of Mexico during the years 2003-2012: 20
- Number of fatalities as a result of the 20 ditched helicopters: 26
- Average fatalities per ditched helicopter: 1.3
- Accidents that potentially will be avoided by using MGD technology over 10 years: 4
- Estimated fatalities avoided due to the use of MGD technologies over a 10-year period: 5.2
- Estimated value of a Statistical Life in millions of 2016 dollars: $9.6[17]

Figure 2 below shows the relation between helicopter accidents and fatalities verses the number of facilities worldwide (by region) for the period of 2003 – 2012[18].

[17] It is important to notice that what is involved in this number is not the valuation of life as such, but the valuation of reductions in risks. As stated in the US Department of Transportation document, VSL is "defined as the additional cost that individuals would be willing to bear for improvements in safety (that is, reductions in risks)." http://www.dot.gov/policy/transportation-policy/economy

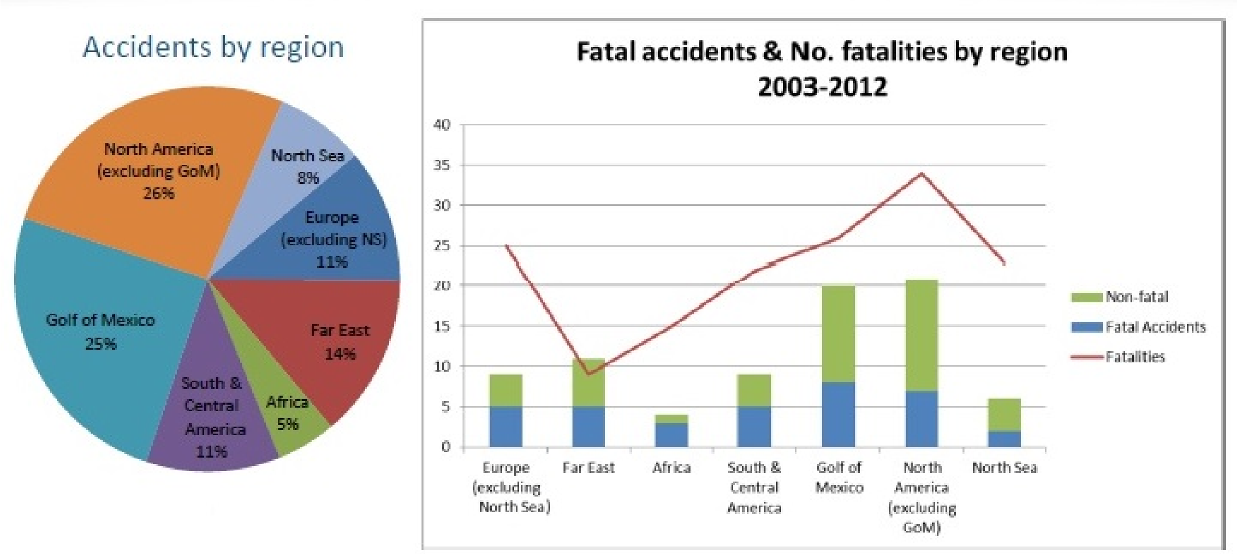


Figure 2: Fatal Accidents vs. Fatalities by Region 2003-2012

Table A below shows the calculation of the estimated benefits of adopting gas detection technologies in undiscounted 2016 dollars.

TABLE A - Estimated Benefits	
Number of Avoided Downed Helicopters over 10 Years (due to the Implementation of MGD Technology)	4
Number of Helicopters Ditched in Water in GOM in 2003-12	20
Number of Fatalities from Those Ditched Helicopters	26
Estimated Fatalities Per Ditched Helicopter	1.3
Estimated Fatalities From Issue Over 10-Year Period	5.2
Estimated Value of a Statistical Life in Millions of 2016 Dollars	9.6
TOTAL BENEFIT IN FATALITIES AVERTED OVER 10 YEARS IN MILLIONS OF 2016 DOLLARS (Undiscounted)	**$ 49.920**
Loss of Helicopters at $2.6 million (assuming depreciation of 40%): 4 * $2.6 * 0.6 = $6.24 (Undiscounted)	**$ 6.240**
Averted Injuries Estimated as 25 percent cost of falalities in millions: 0.25 * $49.92 = $12.48 (undiscounted)	**$ 12.480**
Total Benefits (Undiscounted) in Millions	**$ 68.64**

For this preliminary estimate, if the total benefit of $68.64 million is equally divided over the 10 year period considered and then brought back to year 1 at discount rates of 7% and 3%, the following result will be achieved, as shown in Table B, below.

TABLE B - Benefits Discounted (Millions)										
Year	1	2	3	4	5	6	7	8	9	10
Cost Per Year	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86	$ 6.86
Benefit - Year 1 7% discount rate	**$ 51.58**									
Benefit - Year 1 3% discount rate	**$ 60.31**									

[18] http://aerossurance.com/helicopters/cap1145-survivability-stats/ - Figure 2 depicts a pie chart showing statistics related to all helicopter accidents by region while the bar chart shows total fatal accidents and number of fatalities per region.

In the GoM the size of and activity on drilling and production facilities varies. Of the 412 facilities with helidecks at the time of BSEE's assessment, the larger high-activity facilities may experience multiple helicopter landings/takeoffs per day whereas the smaller, low-activity facilities may experience a helicopter landing/takeoff as little as one per day or perhaps one every week or two. So, for the purpose of this analysis it was assumed an average of one flight per facility per day.

Using the discounted benefit estimates presented in Table B the feasibility analysis for seven cases was performed. These seven cases, summarized below, are presented in the following pages.

<u>Case 1 – Handheld Gas Detection:</u> A simple solution where a worker, using a handheld explosion proof detector, will check the perimeter of the helideck and remain in sight of the pilot prior to every helicopter landing and departure to warn the pilot of the presence of methane gas. For the calculations it was assumed that detectors would be changed after 5 years. Use of Handheld Gas Detectors on all 412 facilities was found to be feasible.

<u>Case 2 – Point Detection:</u> A simple solution where as many as three fixed (3) point detectors (any combination of infrared, acoustic, electrochemical, catalytic, etc.) are installed at the source and on or near the helideck between the gas source and helicopter and combined with a platforms existing wind sock (wind direction) and warning devices to provide the pilot with early indication of a vent release. For the calculations it was assumed that detectors would be changed after 5 years. Use of Point Detectors on all 412 facilities was found to be feasible.

<u>Case 3 – Open Path (Infrared) Detection:</u> Open Path (Infrared) Detectors are widely used by the petrochemical industry. It is a system where the equipment sends out a beam of infrared light, detecting gas anywhere along the path of the beam. The concentration of gas will be measured using a transmitter and receiver over a large area (line of sight). Use of Open Path (Infrared) Detection system on all 412 facilities was found to not be feasible due to its high costs.

<u>Case 4 – Hydrocarbon Gas Imaging Detection:</u> A solution where a Hydrocarbon Gas Imaging system is installed in the vicinity of the source and helipad and oriented to capture the entire area between the source and helipad to identify and warn the pilot of a gas cloud that has or may reach the helideck during landing and takeoff. Use of Hydrocarbon Gas Imaging on all 412 facilities was found to not be feasible; however it is possible to reserve this more sophisticated solution to busier, larger production facilities while using a simpler solution on smaller facilities. In the calculations for this case, the type of Hydrocarbon Gas Imaging system used was the Gas Cloud Imaging (GCI).

<u>Case 5 – Acoustic Detection:</u> Acoustic systems detect sound signals from pressurized gas leaking from a compartment. This acoustic signal occurs due to turbulent flow when pressurized gas moves from a high-pressure to a low-pressure environment across a leak opening. The acoustic signal is detected by the analyzer, which provides an intensity reading on the meter. These detectors cannot measure leak rates, but provide a relative indication of leak size measured by the intensity of the signal. Use of Acoustic Detection system on all 412 facilities was found to be feasible in terms of the costs incurred; however, this technology may not be suited for offshore facilities due to the possibility of false readings.

Case 6 – 10% of facilities use Hydrocarbon Gas Imaging (GCI) and 90% use Point Detection: A feasibility analysis of this hybrid solution was tested and proved to be economically feasible.

Case 7 – 20% of facilities use Hydrocarbon Gas Imaging (GCI) and 80% use Point Detection: A feasibility analysis of this hybrid solution was tested and proved to be economically feasible.

The tables presented in the following pages are a summary of the calculations performed for each of the 7 abovementioned cases. BSEE understands that other solutions may exist. This analysis was performed using different types of equipment to verify that feasible solutions do exist in the market.

The analysis was made assuming implementation in year 2019. This is just an estimate of when it would be possible to start using MGD technology after this BDP is completed. This is not a binding date and year 2019 was used for the purpose of the FA calculations only.

Case 1: Handheld Gas Detection

Table C: Handheld Gas Detector										
Year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Costs	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware Procurement, Set-up, monitoring and data storage	$2,500.00					$2,500.00				
Shipping	$100.00					$100.00				
Personnel - 1 person, 1hr/day (average), $28/hr*1.3(benefits), 365 days/year	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00	$13,286.00
Total Projected Costs	**$15,886.00**	**$13,286.00**	**$13,286.00**	**$13,286.00**	**$13,286.00**	**$15,886.00**	**$13,286.00**	**$13,286.00**	**$13,286.00**	**$13,286.00**
	Cost Per Facility	**Number of Facilities**	**Total Cost (Millions)**				**Estimated Net Benefits (Millions)**			
NPV over 10 years (at 7 percent discount rate)	**$104,301.14**	**412**	**$42.97**	**From TABLE B, Benefit at 7% discount Rate = $49.24 Million**			**$8.61**			
NPV over 10 years (at 3 percent discount rate)	**$121,575.03**	**412**	**$50.09**	**From TABLE B, Benefit at 3% discount Rate = $57.57 Million**			**$10.22**			

Cost of a handheld explosion proof detector (changed every 5 years).	$2,600
Worker checking the perimeter of the helideck for every landing and take off, estimated at 1hr/day, 365 days/year at $28/hr plus 30% benefits	$13,286.00

Summary: Assuming a simple solution, with a worker checking the perimeter of the helideck for gases using a handheld, explosion proof detector, the benefit for the industry (412 facilities), in terms of avoiding accidents, loss of property, fatalities and injuries is (at a discount rate of 3%/year) equal to $10.22 millions or $1.022 million/year.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 2: Point Detection (Infrared)

Table D: Point Detector

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Hardware	$450.00					$450.00				
Shipping	$100.00					$100.00				
Installation	$300.00					$150.00				
Software Maintenance & Upgrade	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Personnel	$480.00					$480.00				
Travel	$1,200.00					$1,200.00				
Total Projected Costs	**$3,330.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**	**$3,180.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**
	Cost Per Facility	**Number of Facilities**	**Total Cost (Millions)**				**Estimated Net Benefits (Millions)**			
NPV over 10 years with 3 detectors installed (at 7 percent discount rate)	**$30,717**	**412**	**$12.66**	**From TABLE B, Benefit at 7% discount Rate = $49.24 Million**			**$38.93**			
NPV over 10 years with 3 detectors installed (at 3 percent discount rate)	**$34,836**	**412**	**$14.35**	**From TABLE B, Benefit at 3% discount Rate = $57.57 Million**			**$45.96**			

Initial cost of a point detector (Installed). Changed every 5 years.	$2,530
Annual Maintenance	$800

Summary: Assuming a low cost solution, with 3 point detectors installed around the helideck to detect surrounding gas contamination, the benefit for the industry (412 facilities), in terms of avoiding accidents, loss of property, fatalities and injuries is (at a discount rate of 3%/year) equal to $45.96 millions or $4.596 millions/year.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 3: Open Path (IR) Detection

Table E: Open Path (IR) Detector System										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
Hardware	$15,000.00									
Hardware Maintenance	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00
Installation	$30,000.00									
System Testing	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00
Database Preparation	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
Personnel	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00
Travel	$5,000.00					$5,000.00				
Training	$2,500.00					$2,500.00				
Overhead	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Total Projected Costs	**$65,000.00**	**$12,500.00**	**$12,500.00**	**$12,500.00**	**$12,500.00**	**$20,000.00**	**$12,500.00**	**$12,500.00**	**$12,500.00**	**$12,500.00**
	COST Per Facility	**Number of Facilities**	**Total Cost (Millions)**				**Estimated Net Benefits (Millions)**			
NPV over 20 years (at 7 percent discount rate)	**$151,788**	412	$62.54	**From TABLE B, Benefit at 7% discount Rate = $49.24 Million**			**($10.95)**			
NPV over 20 years (at 3 percent discount rate)	**$168,796**	412	$69.54	**From TABLE B, Benefit at 3% discount Rate = $57.57 Million**			**($9.24)**			

Initial cost of an Open Path System including training (Installed). Includes costs of training and travel every 5 years.	$52,500
Annual Maintenance	$12,500

Summary: The benefit would be negative if all 412 facilities utilize a sophisticated and expensive gas detection system such as the Open Path System. However BSEE does not expect that use of this expensive system will be needed. There are other technologies available in the market that can guarantee reliable detection at a lesser cost.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 4: Hydrocarbon Gas Imaging (GCI)

Table F: Hydrocarbon Gas Imaging (GCI)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware Procurement, Set-up, monitoring and data storage	$160,000.00									
Shipping	$200.00									
Calibration	$5,000.00									
Software licensing	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00
Software Maintenance & Upgrade	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
System Testing	$3,500.00									
Automated video, email, text escalation alarms	$3,000.00									
Personnel	$5,000.00									
Travel	$1,300.00									
Training	$2,000.00									
Overhead	$4,000.00									
Total Projected Costs	**$220,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**
	COST Per Facility	**Number of Facilities**	**Total Cost (Millions)**				**Estimated Net Benefits (Millions)**			
NPV over 10 years (at 7 percent discount rate)	**$454,548**	412	$187.27	**From TABLE B, Benefit at 7% discount Rate = $49.24 Million**			**($135.69)**			
NPV over 10 years (at 3 percent discount rate)	**$500,300**	412	$206.12	**From TABLE B, Benefit at 3% discount Rate = $57.57 Million**			**($145.82)**			

Initial cost of a Hydrocarbon Gas Imaging (GCI) System including training (Installed)	$184,000
Annual Maintenance	$36,000

Summary: The benefit would be negative if all 412 facilities utilize a sophisticated gas detection system such as Hydroarbon Gas Imaging. However BSEE does not expect that all facilities will be implementing this system, which is expected to be used only on those busiest facilities with large production (up to 20% of total facilities).

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 5: Acoustic Detectors

Table G: Acoustic Detectors										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware	$15,000.00									
Installation	$30,000.00									
Database Preparation	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00
Personnel	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00	$3,000.00
Travel	$5,000.00					$5,000.00				
Training	$2,500.00					$2,500.00				
Overhead	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Total Projected Costs	**$59,000.00**	**$6,500.00**	**$6,500.00**	**$6,500.00**	**$6,500.00**	**$14,000.00**	**$6,500.00**	**$6,500.00**	**$6,500.00**	**$6,500.00**
	COST Per Facility	**Number of Facilities**	**Total Cost**				**Estimated Net Benefits (Millions)**			
NPV over 10 years (at 7 percent discount rate)	**$106,696**	412	$43,958,919	**From TABLE B, Benefit at 7% discount Rate = $49.24 Million**			**$7.63**			
NPV over 10 years (at 3 percent discount rate)	**$116,079**	412	$47,824,661	**From TABLE B, Benefit at 3% discount Rate = $57.57 Million**			**$12.48**			

Initial cost of an Ultrasonic System including training and travel (Installed). Training and travel costs ($7,500) incurred every 5 years.	$52,500
Annual Maintenance	$6,500

Summary: The benefit would be positive if all 412 facilities utilize acoustic detection. Even though the result is positive, BSEE does not expect this system to be used due to technology limitations. There are other technologies available in the market that can guarantee reliable detection and offer equal or even higher benefits.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 6: 90% Point Detector – 10% Hydrocarbon Gas Imaging (GCI)

The next two tables (Tables H and I) show the results of a combined solution, where 90% of the facilities will utilize a less sophisticated system, with 3 point detectors installed around the helideck and 10% of the facilities will utilize Hydrocarbon Gas Imaging.

Table H: Point Detector (at 90% of the facilities)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware	$450.00					$450.00				
Shipping	$100.00					$100.00				
Installation	$300.00					$150.00				
Software Maintenance & Upgrade	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Personnel	$480.00					$480.00				
Travel	$1,200.00					$1,200.00				
Total Projected Costs	**$3,330.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**	**$3,180.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**
	COST Per Facility	**Number of Facilities**	**Total Cost (Millions)**							
NPV over 10 years (at 7 percent discount rate)	**$30,717**	371	$11.40							
NPV over 10 years (at 3 percent discount rate)	**$34,836**	371	$12.92							

Table I: Hydrocarbon Gas Imaging (GCI) (at 10% of the facilities)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware Procurement, Set-up, monitoring and data storage	$160,000.00									
Shipping	$200.00									
Calibration	$5,000.00									
Software licensing	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00
Software Maintenance & Upgrade	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
System Testing	$3,500.00									
Automated video, email, text escalation alarms	$3,000.00									
Personnel	$5,000.00									
Travel	$1,300.00									
Training	$2,000.00									
Overhead	$4,000.00									
Total Projected Costs	**$220,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**
	COST Per Facility	Number of Facilities	Total Cost (Millions)							
NPV over 10 years (at 7 percent discount rate)	**$454,548**	41	$18.64							
NPV over 10 years (at 3 percent discount rate)	**$500,300**	41	$20.51							

Benefits	Sum of costs for a solution using 90% Point Detectors and 10% GCI (Millions)	Estimated Net Benefits (Millions)
From TABLE B, Benefit at 7% discount Rate = $49.24 Million	$30.03	$21.55
From TABLE B, Benefit at 3% discount Rate = $57.57 Million	$33.44	$26.87

Summary: Assuming a hybrid solution, with 10% of the facilities having a more sophisticated GCI system and 90% having a point detection system, the benefit for the industry (412 facilities), in terms of avoiding accidents, loss of property, fatalities and injuries is (at a discount rate of 3%/year) equal to $26.87 millions or $2.687 million/year.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Case 7: 80% Point Detector – 20% Hydrocarbon Gas Imaging (GCI)

The next two tables (Tables J and K) show the results of a combined solution, where 80% of the facilities will utilize a less sophisticated system, with 3 point detectors installed around the helideck and 20% of the facilities will utilize Gas Cloud Imaging.

Table J: Point Detector (at 80% of the facilities)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware	$450.00					$450.00				
Shipping	$100.00					$100.00				
Installation	$300.00					$150.00				
Software Maintenance & Upgrade	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00	$800.00
Personnel	$480.00					$480.00				
Travel	$1,200.00					$1,200.00				
Total Projected Costs	**$3,330.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**	**$3,180.00**	**$800.00**	**$800.00**	**$800.00**	**$800.00**
	COST Per Facility	Number of Facilities	Total Cost (Millions)							
NPV over 10 years (at 7 percent discount rate)	$30,717	330	$10.14							
NPV over 10 years (at 3 percent discount rate)	$34,836	330	$11.50							

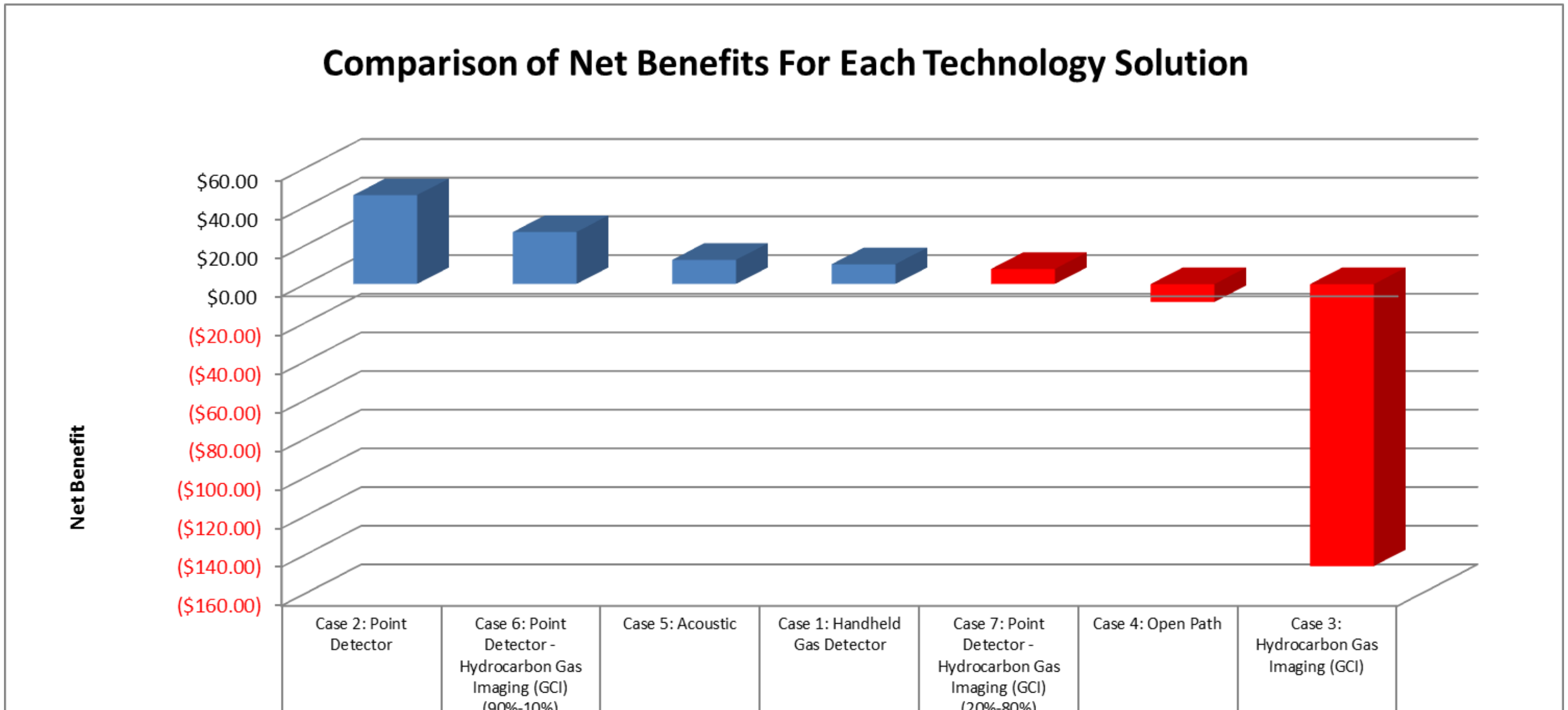
Table K: Hydrocarbon Gas Imaging (GCI) (at 20% of the facilities)										
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Hardware Procurement, Set-up, monitoring and data storage	$160,000.00									
Shipping	$200.00									
Calibration	$5,000.00									
Software licensing	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00	$30,000.00
Software Maintenance & Upgrade	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00	$6,000.00
System Testing	$3,500.00									
Automated video, email, text escalation alarms	$3,000.00									
Personnel	$5,000.00									
Travel	$1,300.00									
Training	$2,000.00									
Overhead	$4,000.00									
Total Projected Costs	**$220,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**
	COST Per Facility	**Number of Facilities**	**Total Cost (Millions)**							
NPV over 10 years (at 7 percent discount rate)	**$454,548**	82	$37.27							
NPV over 10 years (at 3 percent discount rate)	**$500,300**	82	$41.02							

Benefits	Sum of costs for a solution using 90% Point Detectors and 10% GCI (Millions)	Estimated Net Benefits (Millions)
From TABLE B, Benefit at 7% discount Rate = $49.24 Million	$47.41	$4.17
From TABLE B, Benefit at 3% discount Rate = $57.57 Million	$52.52	$7.79

Summary: Assuming a hybrid solution, with 20% of the facilities having a more sophisticated Hydrocarbon Gas Imaging System and 80% having a point detection system, the benefit for the industry (412 facilities), in terms of avoiding accidents, loss of property, fatalities and injuries is (at a discount rate of 3%/year) equal to $7.79 millions or $779,000/year.

Note: This is a preliminary analysis. Several indirect costs, which would increase the net benefit when an incident is avoided, are not being considered such as negative Public Relations due to the accident, interruption of production, investigation costs, recovery of equipment, penalties, etc.

Summarizing, there are several available technologies in the market that may be used as a safety device to detect gases in and around the helideck avoiding fatalities and costly accidents. Some of the technologies may not represent a feasible solution due to high costs. However, in this study BSEE has identified various solutions that are feasible and may, if implemented, represent an actual gain for the industry. The graph below shows a summary of the results of this analysis.



	Case 2: Point Detector	Case 6: Point Detector - Hydrocarbon Gas Imaging (GCI) (90%-10%)	Case 5: Acoustic	Case 1: Handheld Gas Detector	Case 7: Point Detector - Hydrocarbon Gas Imaging (GCI) (20%-80%)	Case 4: Open Path	Case 3: Hydrocarbon Gas Imaging (GCI)
Series1	$45.96	$26.87	$12.48	$10.22	$7.79	($9.24)	($145.82)

APPENDIX C: BSEE BAST Determination Process Flowchart