**ODYSSIAN TECHNOLOGY**
*A Technology Development and Innovation Company*

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# FINAL REPORT

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## SBIR PHASE I

## "Smart Pipeline Network – Seal Sensor System"


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**DISCLAIMER**

Final Report

SBIR PHASE I

## 1.0 PHASE I PROGRAM INTRODUCTION

Leak detection within the national pipeline network has long been recognized as a much-needed capability to reduce the loss of high value product, improve public safety, and to reduce the emissions of environmentally damaging substances.

In recent years, greater emphasis has been placed on the reduction of green house gas emissions in an attempt to address global warming. Natural gas contains a high concentration of methane gas, which is one of the most potent green house gas elements. Leakage of toxic and hazardous liquids into the environment often results in the long-term contamination of ground soil, and in some cases, results in the contamination of aquifers and waterways that are key to sustaining the local habitat. Consequently, the U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA), as well as various industry associations such as the Pipeline Research Council International (PRCI), have embarked upon extensive research and development programs aimed at establishing capability to pin point the location of pipeline leakage in real time.

Multiple technologies are being explored that offer various levels of leak detection capability, each with its own set of limitations. Aerial surveillance using advanced optical and computational techniques is being developed. This technology indirectly detects leaks by identifying plumes of airborne dispersed particles using LIDAR (Laser Imaging Detection and Ranging) systems and by detecting resulting vegetation damage using hyper spectral image analysis, which can occur as soon as two weeks after the leak begins. While one could focus on the shortcomings of each technology including the negative effects of cloud and snow cover, Odyssian Technology believes that the correct approach to eradicating or significantly reducing pipeline leaks is a *smart pipeline system* that has a collection of diverse (and evolving) technologies all integrated within a distributed, yet common communication and control platform.

Odyssian Technology was awarded programs for submitted proposals to all three of the DOT PHMSA SBIR topics (in solicitation DTRT57-12-R-SBIR1) to allow for development of a comprehensive set of technologies that will be needed to realize a national smart pipeline system. Technology that is unique to Odyssian Technology was adapted for point-of-source leak detection and state-of-the-system health monitoring of the pipeline seals, pipe repairs, and cased pipes. The three separately proposed SBIR programs are configured to be independent of each other. Yet each provides an important aspect or component of the integrated *Smart Pipeline Network*. In summary, the three related proposed programs that were awarded are distinguished as follows:

1. Focus Area 1 (PH1) – Seal Sensor System: is to develop smart seals capable of leak progression detection and monitoring proper sealing force.

2. Focus Area 2 (PH2) – Pipe and Repair Sensor System: is to develop concepts for smart pipe and smart pipe repair sensor systems capable of detecting leaks and monitoring structural integrity.
3. Focus Area 3 (PH3) – Cased Pipe for Monitoring & Sensor System: is to develop new casement and internal support structure concepts that will allow for continuous real time monitoring and network communication along the entire length of the cased pipelines.

The technology developed in these PHMSA SBIR programs take advantage of recent technology advances and shifts in affordability of technology to develop and demonstrate what Odyssian believes will be our future national *Smart Pipeline Network*. Such technology advances include the advent of nano-scale and thin and thick film materials in conjunction with micro machining techniques that allow for the development of very small sensors and multifunctional systems having intrinsically embedded sensing functionality. These small devices and materials are being used to develop highly engineered smart systems that are capable of sensing their environment and often responding to such stimulus.

Odyssian Technology has developed smart pipe and smart seal technology, originally targeted for use on airborne high-energy chemical laser systems. This DOT PHMSA SBIR program further developed and adapts this technology for use on pipelines to allow for the pinpoint location of leaks and in some cases emerging leaks (detecting an imminent leak before leakage occurs). The shift in affordability and proliferation of wireless and wired communication networks makes more feasible a S*mart Pipeline Network* that provides real-time operational status of pipeline transmission, distribution, and remote facility systems. Communication and signal conditioning circuitry was developed that is integrated within the system to provide a sensor network capable of pinpointing the location of progressing leaks through fittings, joints, valves, pipe, pipe repairs, etc.

As described in the PH3 Focus Area #3 solicitation, the current configuration of cased pipes present a challenge to using pipeline monitoring technologies. Internal support structures within cased pipe are circumferential, blocking access and impeding utilization of the interior space. As with the smart seal and smart pipe technology, Odyssian Technology is uniquely qualified to develop new cased pipe concepts for use in a smart pipeline system. Odyssian Technology has an active patent on structures having internal (truss) support structures with integrated sensors and electronics. This technology and expertise, which is described in Odyssian Technology's proposal to Focus Area #3, was used to develop cased pipe concepts that support monitoring and integrated pipeline sensing.

In Odyssian Technology's related PHMSA SBIR programs to develop *smart seal* (PH1)and *smart pipe and smart pipe repair* (PH2) technology for the pipeline industry, technology was adapted and further developed that was originally developed for the U.S. Department of Defense (DOD) Missile Defense Agency (MDA). This includes smart piping system technology that was developed for the MDA Airborne Laser (ABL) system to detect leak progression of harmful chemicals that are within the ABL high energy laser system. Such technology includes novel seals and piping that detect impending leaks using highly integrated point-of-source leak detection sensors. A wireless Zigbee sensor network was used to communicate state-of-the-system or containment status of the ABL Smart Piping System. This technology has been developed and demonstrated in a laboratory setting through funding under MDA Phase I and Phase II Small Business Innovation Research (SBIR) programs.

This PHMSA SBIR is focused on the development of a *Pipe and Repair Sensor System*. When combined with the Seal Sensor System and Cased Pipe for Monitoring and Sensor System (separate projects), this technology will allow for a comprehensive Smart Pipeline Grid having integrated sensor networks that provide for continuous real-time monitoring of leaks and system health. Design concepts for pipe and pipe repair having integrated leak detection sensors were developed for use with oil and gas (O&G) pipeline systems. Concepts and designs were developed for a networked sensing system capable of sensing the pinpoint location of a leak or impending leak, as well as monitoring structural health through impact detection. The Phase I scope included developing Pipe and Repair Sensor System technology for liquid petroleum-based pipeline systems, with the goal of having Phase II expand the scope to include development of a system for use with natural gas.

Once developed, the oil and gas pipe/repair sensor network will be useful for pipeline operators to continuously monitor for leaks and impacts within the pipeline system. Other commercial applications will include gasoline stations, oil storage facilities, methane plants, oil and gas transportation, and offshore oil rigs.

## 2.0 EXECUTIVE SUMMARY

The Pipeline Research Council International (PRCI) provided support to this SBIR program by providing input and advice on the needs and issues related to leak detection within the pipeline industry. It's membership also provided support by identifying applications, as well as reviewing and commenting on Odyssian's conceptual designs. PRCI formed a group within its membership, called the PRCI Smart Pipeline Steering Committee. Collectively and individually, members of this group helped to define the application and scope of the smart system that would be developed and demonstrated. Deliberation over whether to focus on pipeline facilities or long-run pipeline considered such factors as remoteness, the likelihood of a leak, the length of time to detect a slow leak, the type of fittings, and the consequence of a leak. While it was recognized that facilities had many more threaded or flanged fittings than long run piping systems, it was decided to focus on long-run pipe because of the greater likelihood of a leak occurring in a remote area and being undetected for a longer period of time. Later in the program, there became a more expressed desire from the committee to develop technology that has application within pipeline facilities because of the greater amount of flanged fittings. Discussions near the end of the program with PRCI members indicated that for facilities the following is needed,

1. Smart mechanical seals for use on pumps and compressors
2. Smart spiral wound flange gaskets that can sense leaks.

The selected product type to be sensed was refined liquid petroleum, with specific interest given to gasoline. Odyssian Technology proposed this product type to allow use of its proprietary fuel sensor, which lends itself well to integration within smart devices. Members of the PRCI committee accepted the selection of refined liquid product, specifically gasoline. This is because when water is involved, gasoline can be more damaging than oil because it seeps through the ground more quickly and mixes in with water, making it harder to remove. Gasoline also gives off more dangerous fumes and can ignite more easily than crude oil.

Based upon the initial pipeline application and product selection, design concepts were developed for smart seals for use in long-run Oil and Gas (O&G) pipeline systems. Long-run pipeline systems typically have impressed current cathodic protection (ICCP) systems to prevent corrosion of the steel pipe. Near the beginning of the program, Odyssian Technology established a relationship with Garlock Pipeline Technologies (GPT), a major producer of voltage isolating gaskets. An operating group of GPT, which is formerly Pikotek, collaborated with Odyssian Technology to develop a smart seal.

Initial seal concepts had conventional layouts that were tailored for a bolted flange fitting on a 4-inch pipe. Early conceptual designs included embedded sensing circuits having novel a novel sensing technology called Dispersion Media Sensing (DMS). Initial seal concepts had multiple modes of sensing to minimize the likelihood of a false possible or negative. This included the use of dispersion media sensing (DMS) along with micro-electromechanical systems (MEMS) pressure sensors. In this dual-mode sensing scheme, a leak is detected directly (DMS) and indirectly (MEMS). A conclusive leak would have sensory alarms from both the indirect and direct sensors.

Garlock's Pikotek Very Critical Services (VCS) seal was used as a model from which a smart seal was developed and prototyped (see http://www.gptindustries.com/product/vcs). This seal was selected because it is a voltage isolation seal, and because its basic construction made initial prototyping relatively easy and inexpensive. Design concepts of the smart seal were developed using the same basic general construction arrangement used in the VCS seal. This included having a stainless steel core, a conventional GRE sheet on one face, and an electronic GRE face on the other face. The electronic GRE made up the sensor circuits needed to detect a leak and to detect earth movement or an impact.

A prototype of the smart seal was developed and tested. This seal, called the sensorSEAL™ , was developed having four types of sensors. This included micro-electromechanical-systems (MEMS) pressure sensors, reactive fuel sensor, an accelerometer, and a sensor O-ring. The MEMS and reactive sensor are for detecting the leakage of gasoline and other fuel hydrocarbons, the accelerometer is for detecting impact and earth movement and the sensor O-ring is for sensing sealing force. The reactive fuel sensor is proprietary to Odyssian Technology and was modified to improve its use in the smart pipeline system components, include the sensorSEAL™. The sensor O-ring is a proprietary seal made by Odyssian Technology that through special material formulation and algorithms have been shown to detect in changes sealing force or compression. Commercial-off-the-shelf (COTS) MEMS pressure sensors and accelerometers where used to detect pressure buildup from leaks and vibration from impacts, respectively. Testing was performed to establish alarm threshold values, condition the sensors, and to calibrate the MEMS pressure sensors.

## 3.0 SUMMARY OF WORK PERFORMED

This program included the following tasks. A summary of work performed under each task is provided in the subsequent subsections.

The work plan of this program included the following four tasks;

Task I – Application and Concept Study

Task II – R&D, Prototype, and Lab Scale Evaluation

Task III – In-field Evaluation Planning

Task IV – Preliminary Cost and Market Analysis

Task V – Program Management & Reporting

### *Task I – Application and Concept Study*

The Pipeline Research Council International (PRCI) in conjunction with Odyssian Technology established the Smart Pipeline Steering Committee, which was made up of several PRCI members to provide support to this SBIR program. This committee, which was made up of key PRCI members who could eventually be users of the Smart Pipeline Network, was formed to provide assistance in identifying applications for the smart pipeline technology, to identify potential issues , and to review concepts. During the Application Study with PRCI members, a broad system level approach was taken that considered the cased pipe for smart pipeline (this program's focus), as well as the related sensor seal and pipe & repair applications (other related SBIR programs).

*APPLICATION STUDY*

During the Application Study, multiple discussions were held with PRCI staff and members on the need for leak detection and the areas of greatest opportunity. Below is a list of some of the application concepts that were identified during these discussions

1. ISOLATED CASED PIPE SPACERS – Development of cased pipe spacers that not only provide full axial access for routing optical fiber, wires, probes, etc, but also provides voltage isolation of the carrier pipe.
2. STRUCTURAL CASED PIPE SPACEERS – Interest was expressed in seeing the development of smart pipe spacers for use with larger transmission pipes that carry relatively high force loads. These smart spacers would be more structural than the non-metallic voltage isolation spacers.
3. EXPLOSION PREVENTING CASED PIPE SPACERS – There is a need for cased pipe spacers having embedded sensors that can detect the leakage or buildup of explosive substances. During this program a cased pipe explosion occurred due to the leakage of natural gas from the carrier pipe.
4. ENCASED INSULATED PIPE SPACER – There is an interest in developing dual walled pipe having embedded sensors, where the outer wall is an encasement that shields insulation from the weather. The embedded sensor network would detect moisture intrusion and monitor pipe temperature and insulation performance. This need could be met by developing spacers having embedded sensors that are designed to secure insulation jackets.

5. FLANGE LEAK DETECTION – Development of seals for flanged connections having embedded leak detection sensors that are part of a sensor network.
6. FLANGE TORQUE SENSING – Development of flange seals having sealing force sensing capability that verifies proper tightening of the bolts. It has been stated that a majority of leaks across flange seals is the result of improper installation and tightening.
7. PIPE COATING SENSING – Development of embedded sensor networks that monitor the integrity of pipe coatings and heat-shrinkable sleeves used to cover uncoated portions of the pipe having welded joints.
8. HYDROGEN SULFIDE – Development of small embedded sensing technology that is capable of detecting leakage of Hydrogen Sulfide ($H_2S$) across seals. $H_2S$ is a colorless and very poisonous flammable gas.
9. WATER CROSSING – There is a need to monitor water crossing pipe due to the high consequence of failure. Interest was expressed to develop a water crossing smart piping system that can detect impacts from debris and pipe rising, which can occur during flooding.
10. COMPOSITE WRAP REPAIR SENSING – Develop a way to monitor the sealing and structural contribution of composite wrap repairs. The sensorSLEEVE™ developed during this program could house strain and leak detection sensors to monitor composite repair. In this application, the sensorSLEEVE shell would not have to be designed to be a secondary containment structure because of the presence of the composite wrap repair. The shell would be a lower cost and lower weight design that only provides an electronic enclosure to shield the sensor circuitry and to be a collector of leaking substance to ensure contact with the sensors.
11. SMART MECHANICAL SEAL – Develop a mechanical seal for use in compressor and pump stations that detects leaks and monitors the health of the bearings by measuring vibration levels.
12. SMART WELL-SITE SEALS – Develop sensor system that is highly integrated within the well-site piping system to monitor temperature, strain, and containment.
13. SMART ISOLATION GASKETS – Develop flange isolation gaskets with embedded leak detection sensors for use on cathodically protected piping systems. Particular interest in using on flanged isolation fittings that are in remote areas where leaks may go undetected.
14. SMART ELASTOMERIC SEALING – Further develop elastomeric material and algorithms that can be used to sense sealing force. This technology was invented by Odyssian Technology for use in elastomeric O-rings (patent pending). Characterize behavior and performance of various forms.
15. NATURAL GAS – Interest was expressed in seals having natural gas leak detection. It was learned that the leakage of natural gas is the prevalent of all leaking substances. Develop smart seals for natural gas that are wireless for easier installation in facilities and plants that have a large number of seals.

The results of the application study are summarized in Figure 1. As shown, this project focused on developing leak and impact detection for pipeline systems containing refined petroleum product, specifically gasoline. The application was initially defined to be long run transmission pipelines.

While it was recognized that facilities had many more threaded or flanged fittings than long run piping systems, it was decided to focus on long-run pipe because of the greater likelihood of a leak occurring in a remote area and being undetected for a longer period of time. As recommended by the committee, further development is needed to develop and demonstrate smart pipe and sealing systems that are specifically designed for pipeline facilities because of the greater amount of flanged fittings. PRCI members indicated that facilities would best benefit from the following;

1. Smart mechanical seals for use on pumps and compressors
2. Smart spiral wound flange gaskets.

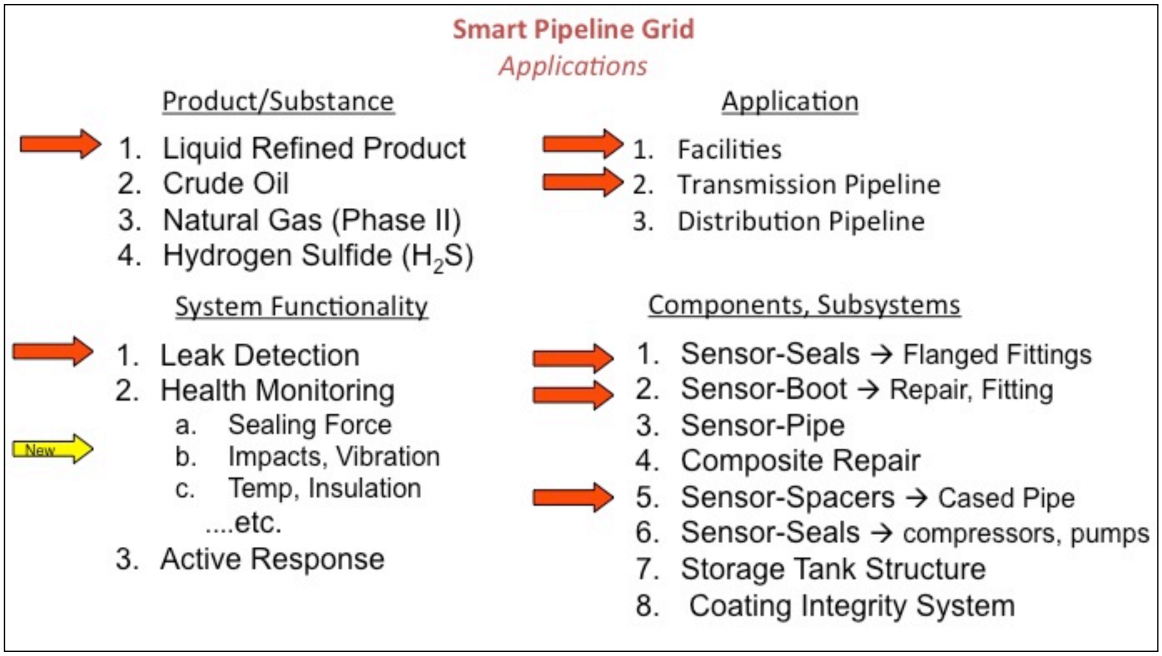



*Figure 1 – Odyssian Technology and the PRCI Smart Pipeline Steering Committee defined the scope of the application, product to be contained, functionality of sensor system, and what type of components would be further developed and demonstrated.*

Also shown in Figure 1, is the selection of components or subsystems that would be part of the initial smart pipeline prototype system. The components selected for the prototype system include; (1) smart seals for use in flanged fittings, (2) smart sensor-spacers for use in cased pipe, and (3) sensor-boots or sensor sleeves for use over repaired pipe, fittings, valves, welded joints, etc. The product selected for leak detection is refined liquid petroleum product, specifically gasoline.

*Figure 2: Photograph of a flange that has been leaking long enough to cause extensive corrosion.*

The need for a smart seal is well illustrated by the spill that occurred in June of 2012 on the Athabasca pipeline due to a failed flange gasket. It was estimated by Enbridge, the pipeline operator, that approximately 61,000 gallons of heavy crude oil leaked from a flanged gasket at a pumping station located about 15 miles southeast of Elk Point Alberta. More information is provided online, including the following website;

**http://metronews.ca/news/edmonton/269475/pumping-station-leaks-230k-litres-of-oil/**

Figure 2 shows a photograph of a flanged connection that was leaking for a prolonged period of time, causing extensive corrosion.

*CONCEPT STUDY – SEAL SENSOR SYSTEM*

Conceptual designs were developed for a seal sensor system for use in Smart O&G Pipeline Network. The results of the Application Study, which was performed with input from members of the Pipeline Research Council International (PRCI), provided a basis from which to develop the conceptual designs. Results of this task showed greatest need for leak detection in long run pipeline systems where a small leak in a remote area may occur for a prolonged period of time before being detected.

Smart pipe features suitable for use with oil & gas (O&G) were identified. Unlike smart pipe that Odyssian Technology developed for use on an airborne high-energy laser system, weight is not as much of a concern for on-land pipe and the use of impact tolerant carbon steel pipe is the mainstay of the O&G pipeline system, particularly for long run transmission pipelines that transport liquid product. Another unique feature or attribute of the piping systems used in O&G when compared to airborne piping systems was the use of coatings and impressed current cathodic protection (ICCP) to prevent corrosion of the carbon steel pipeline structures.

The first few seal concepts that were developed have a conventional seal layouts design for a flange fitting on a 4-inch pipe. These initial designs included embedded sensing circuits that relied upon a novel sensing scheme called dispersion media sensing (DMS).

Some of the smart seal concepts have multiple modes of sensing to minimize the likelihood of a false possible or false negative. This included embedding dispersion media sensing (DMS) along with micro-electromechanical systems (MEMS) pressure sensors. In this dual-mode sensing scheme, a leak is directly detected for the DMS and indirectly detected from the MEMS pressure sensors.

Figure 3 shows a smart seal design concept that includes dual-mode sensing using DMS and MEMS. This smart seal also has two seals, an inner spring energized seal and an outer O-ring. The leak detection sensor circuit, having dispersion media sensing and MEMS pressure sensors, is located between the seals to provide for leak progression detection. This is when a leak is detected prior to leaking outside the containment system. If the primary spring energized seal where to fail, the sensing system would identify its failure while the secondary seal, the O-ring, continued to contain the fluid. In most instances a leak will result in an ancillary effect of increased pressure within the area that the leak occurs. In the case of the smart seal used in O&G pipelines, the containment pressure of the liquid hydrocarbon product is at much higher than the pressure outside the primary seal. When a secondary seal is used, such as shown in this concept the pressure between the primary and secondary seal would be the atmospheric pressure at the time of installation.

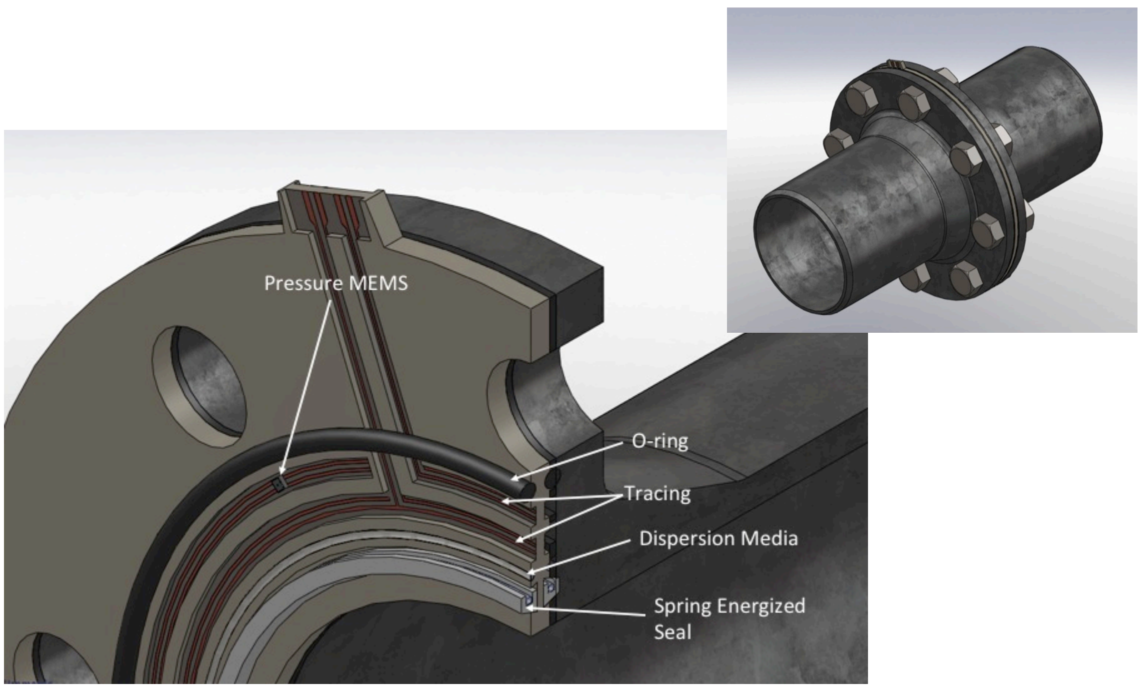


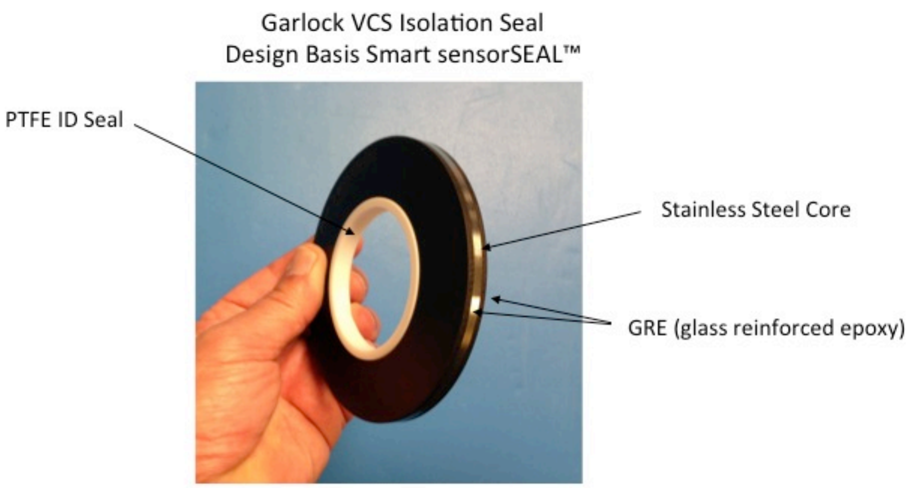

*Figure 3: Concept for a sensorSEAL™. Shown is a concept that has redundancy in sealing surfaces with the leak detection sensors placed between the seals to provide capability to sense an impending leak before a leak occurs. Two modes of leak detection are used, both direct and indirect.*

This initial concept that makes use of DMS was developed before the selection of gasoline as the liquid product. Once gasoline was selected as the liquid to be sensed, Odyssian Technology developed smart component concepts (smart seals included) that used Odyssian's reactive fuel sensor in place of the less proven DMS approach.

Once the collaboration arrangement was established with Garlock, Odyssian Technology was provided samples of different types of Garlock seals that are currently sold for use in O&G applications. Odyssian Technology evaluated each type of seal for ease of sensor integration. The seal selected for use as a standard for development of the smart seal is Garlock's Pikotek Very Critical Service (VCS) seal (see http://www.gptindustries.com/product/vcs). This type of seal, which is shown in Figure 4, was selected because it is a voltage isolation seal, which fits the long-run pipeline application. These seals are used in long-run pipeline systems at voltage isolating flanged connections. The other reason for selecting the Pikotek VCS seal as the baseline model, is because its construction is made up of a stainless steel carrier with electrically insulating glass reinforced epoxy (GRE) sheets on each face of the seal. The GRE is the same material as used on printed circuit boards, thus making the introduction of electronic sensor circuitry much easier. Also, the stainless steel core provides the thickness needed to embedded higher profile sensors, which was achieved by milling out cavities in the core to house the sensors.

The design of the voltage isolating sensorSEAL™ was developed having structural components that are similar to the Garlock VCS seal. This smart seal design, which is shown in Figures 6 thru 8, includes a stainless steel core, a conventional GRE on one face, and an electronic GRE (eGRE) on the other face. The eGRE on one side of the seal contains all of the sensors and electronic circuits needed. This smart seal concept, which was fully designed and prototyped, has four types of sensors. These include micro-electromechanical-system (MEMS) pressure sensors, reactive fuel sensors, an accelerometer, and a sensor O-ring. As previously stated, the MEMS pressure and reactive fuel sensors are for detecting the leakage of gasoline and other fuel hydrocarbons. The accelerometer is for detecting impact and earth movement. And, the sensor O-ring is for sensing sealing force.

Figure 5 shows a solid model design of the sensorSEAL™. This design has several novel features. The white seal is a PTFE ID (inner diameter) seal, which is unique to Garlock. The cut-out design feature that allows for passage of the bolts through the seal is novel. This design allows for the use with flanges of a varying bolt design and eases installation. It also allows for either raised face flanges or flat-faced flanges. Another unusual feature is the way the seal extends out beyond the diameter of the flanges. This was done initially to create space for placement of the sensor node (sNode) electronics, which was desirable for the 'above ground' version of the sensorSEAL™. By incorporating the sNode electronics onto the above ground sensorSEAL the need for a separate enclosure for sNode electronics is eliminated and more importantly, the need to route wire between seal and the node is eliminated. This feature of extending out beyond the seal proved to be useful for the 'below ground' version of the sensorSEAL™ as well. It provided ample space for placement of electrical connectors that connect the seal to the above ground sNode and allowed routing of the seal circuitry outside the compression zone of the seal. In future designs, the extent of how far the seal protrudes beyond the flange will likely be reduced and optimized.




- GRE provides voltage isolation
- GRE made from same material (FR4) as Printed Circuit Boards

*Figure 4: Garlock Pipeline Technology (GPT) Pikotek VCS Seal. This isolation gasket was used as the baseline or reference model from which the sensorSEAL prototype was developed and prototyped.*

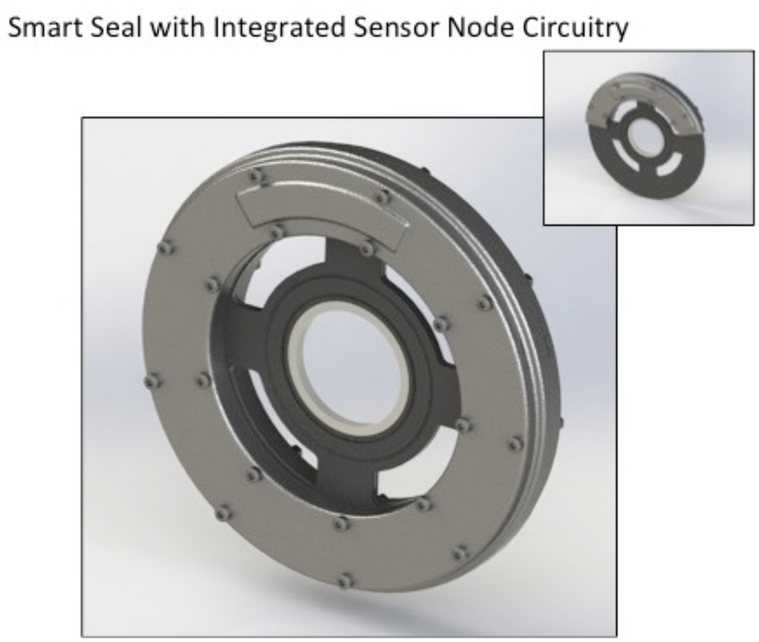



*Figure 5: Design of the voltage isolation sensorSEAL™. This seal was designed to be used with either a raised face or flat faced flange. The outer carrier structure of the seal provides space outside of the seal's compression zone for placement of electronics, connectors, sensors, etc.*

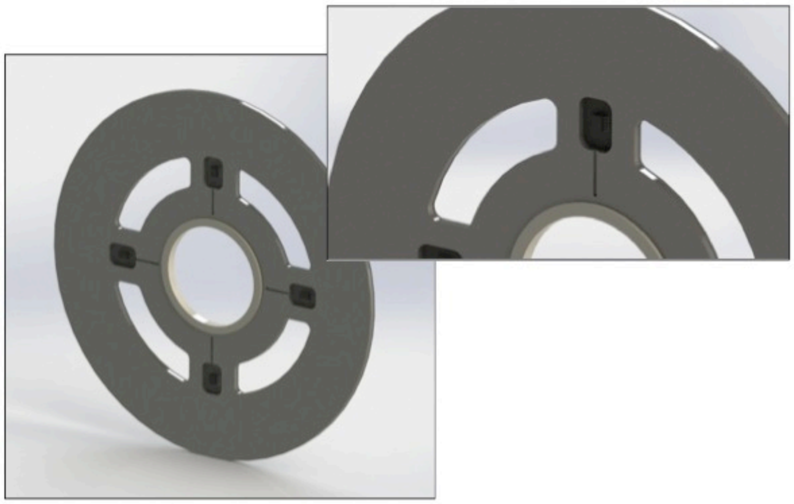


*Figure 6: Core of sensorSEAL™. Shown are the sensor cavities and channels machined out to support the embedded sensor system.*

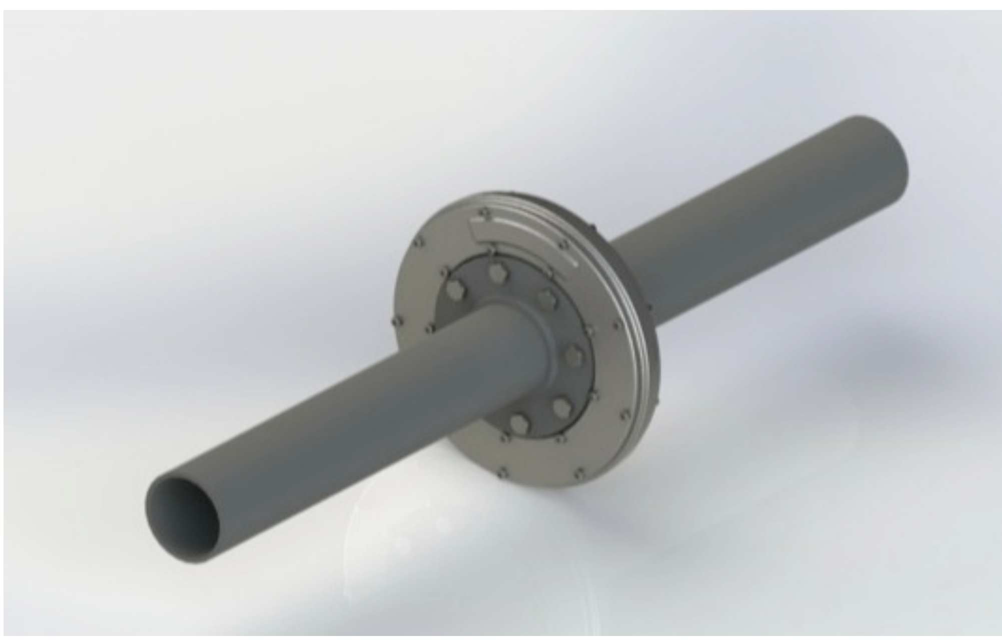


*Figure 7: Voltage isolation sensorSEAL™ installed in a flanged fitting.*

Figure 5 shows the sensorSEAL having the outside seal covers attached. These covers go over the portion of the seal that extends out beyond the flange. The purpose of the covers is to provide a sealed enclosure for the electronic circuitry. The small illustration in the top right of this figure shows that the covers on each side are made in two pieces to allow insertion of the seal in-between the flanges of in-place flange connection. Once in the seal is installed between the flanges, the cover is attached to the other half of the seal.

The design model in Figure 6 is provided to give a view of the stainless steel core. As shown, this core has four cavities hogged or cut out to provide space for the sensors. The sensors are the only components on the side of the eGRE that mates up against the core. The rest of the components are on the other side of the eGRE. Also shown in this figure, are four channels that travel radially inward from the sensor cavities. These channels are on both sides of the core to connect to leak path ring channels that are on the outer surface of both the eGRE and GRE. When a leak occurs, the leaking liquid passes the ID seal and enters the leak path ring channel, and then enters one or many of the channels that are cut-out in the core. The liquid then enters one or multiple sensor cavities. Each cavity contains a MEMS pressure sensor and a Reactive Fuel Sensor.

Further testing and validation is needed to test how effectively the leaking liquid travels through the leak paths to the sensors. Testing needs to be done using the variety of hydrocarbon liquids that are transported through O&G transmission pipelines. Designs need to optimized to ensure the leak paths are adequately sized with all the needed venting paths to ensure ease of flow.

Figure 7 shows a design model of he sensorSEAL installed in a flanged pipe. This design is a 4-inch steel pipe with appropriately sized flanges and seal. As shown in the figure, at this size of pipe and flange, the seal extends out beyond the flange a noticeably large amount. Because a prototype was being made and there existed uncertainty about the space needed under the seal covers for wiring and electronic modules, the radial dimension beyond the flange was made larger than what will be seen in final production versions of the sensorSEAL. Also, it should be noted that as the size of the pipe increases, the radial dimension of the seal beyond the flange will be a much smaller portion of the overall radial dimension of the seal. One unmentioned advantage of the seal extending beyond the flange is that the seal will be easily recognizable as a smart seal from a distance.

*CONCEPT STUDY – NETWORK TOPOGRAPHY*

A conceptual design of the network topography was developed for a long run pipeline having impressed current cathodic protection (ICCP). This topography, which is shown in Figure 8, has a two level network topography that includes multiple lower level microprocessor-based sensor networks integrated to a higher level TCP/IP – based network. The microprocessor-based sensor networks communicate via a wired network using a controller area network (CAN) protocol or via a wireless network using the Zigbee® protocol. The network topography design is for a voltage-isolated section of piping having a rectifier station for its impressed current cathodic protection (ICCP) system and a flanged fitting having with a smart voltage-isolating gasket.

Each 40 foot pipe segments has a sensor node (sNode) to support all sensor circuits associated with its pipe segment. The sNodes provide signal processing and conditioning and have a micro controller, CAN controller, and wireless modules to support networked data communication to the integration node (iNode). Each microprocessor-based sensor network has multiple sNodes that communicate to one supervisory iNode. The iNodes are the master controllers on the sensor networks and are coupled to a single board computer (SBC) to provide connectivity between the lower level microprocessor-based sensor network and the upper level TCP/IP network. The iNodes have multiple responsibilities including communicating to the multiple sNodes that are a part of its lower level microprocessor network, as well as controlling data handling and transfer between the SBC and the sNodes. The SBC's of each sensor network is responsible for communication to a cloud-based host server and for providing local data storage and management, as well as providing the option to connect locally to the sensor network associated with the SBC. When connected locally a computer device, such as a laptop or smart phone, plugs into the SBC via an Ethernet cable to establish a peer-to-peer connection to the SBC. The webpage of the SBC are accessed much like other internet devices (i.e., routers, wireless access points, etc.) by entering the unique SBC Internet Protocol (IP) address into the address line of a web browser, such as Internet Explorer or Fire Fox.

The energy source needed to power the network comes from the same energy source that feeds the Rectifier Station. Rechargeable batteries are used to provide back up power in the event of lost power. The design includes both wired and wireless networked communication. Similar to security systems, the smart pipeline will operate over a wired network and the wireless networked communication will be used only when connectivity of the wired network is lost.

This particular design shows sensors embedded within heat shrinkable sleeves that go over the welded joints of long run pipelines. These sensors monitor the integrity of the sleeve and pipe.

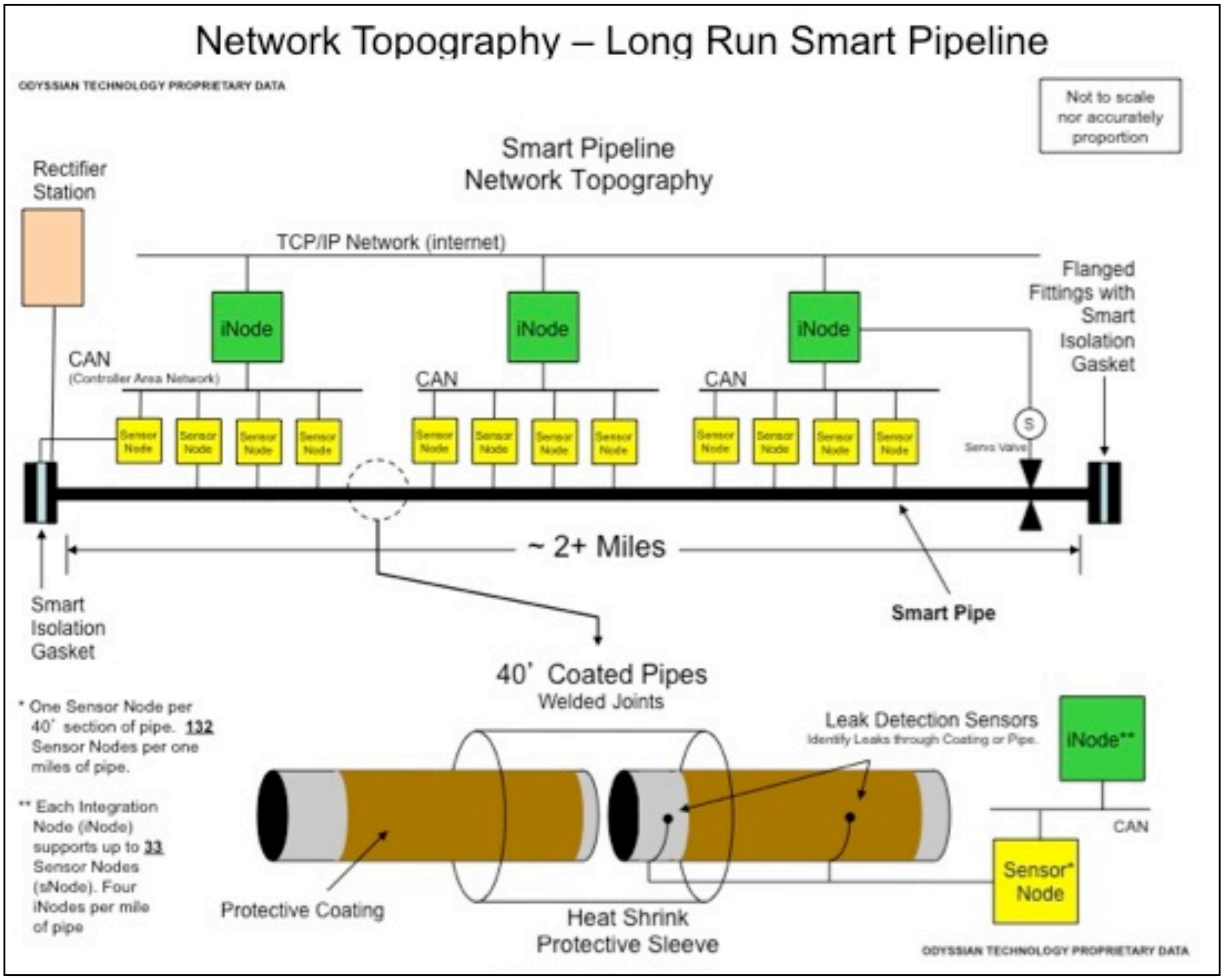



*Figure 8: Network Topography Concept. This concept was developed to help communicate to the PRCI Smart Pipeline Steering Committee how a smart pipeline network could be set up for long run pipeline applications. Shown is a topography that includes multiple sensor area networks made up of a master node or integration node (iNode) that serves up to 33 sensor nodes (sNodes). The sensor area networks are integrated via a TCP/IP (internet) network.*

## *Task II – R&D, Prototype, and Lab Scale Evaluation*

### *SENSOR RESEARCH AND DEVELOPMENT*

Odyssian Technology choose to further develop and prototype a sensorSEAL™ having a reactive fuel sensor. To accomplish this Odyssian Technology enhanced a reactive fuel sensor that it had developed years earlier. The reactive sensor was modified to be mountable to a printed circuit board (PCB) and packaged for improved containment of the sensing element. Figure 9 shows three test sensors that are mounted to a small PCB having connection leads. These specimens were tested by exposing them to mid-grade unleaded gasoline while taking electrical readings using the multi-meter shown in the figure.

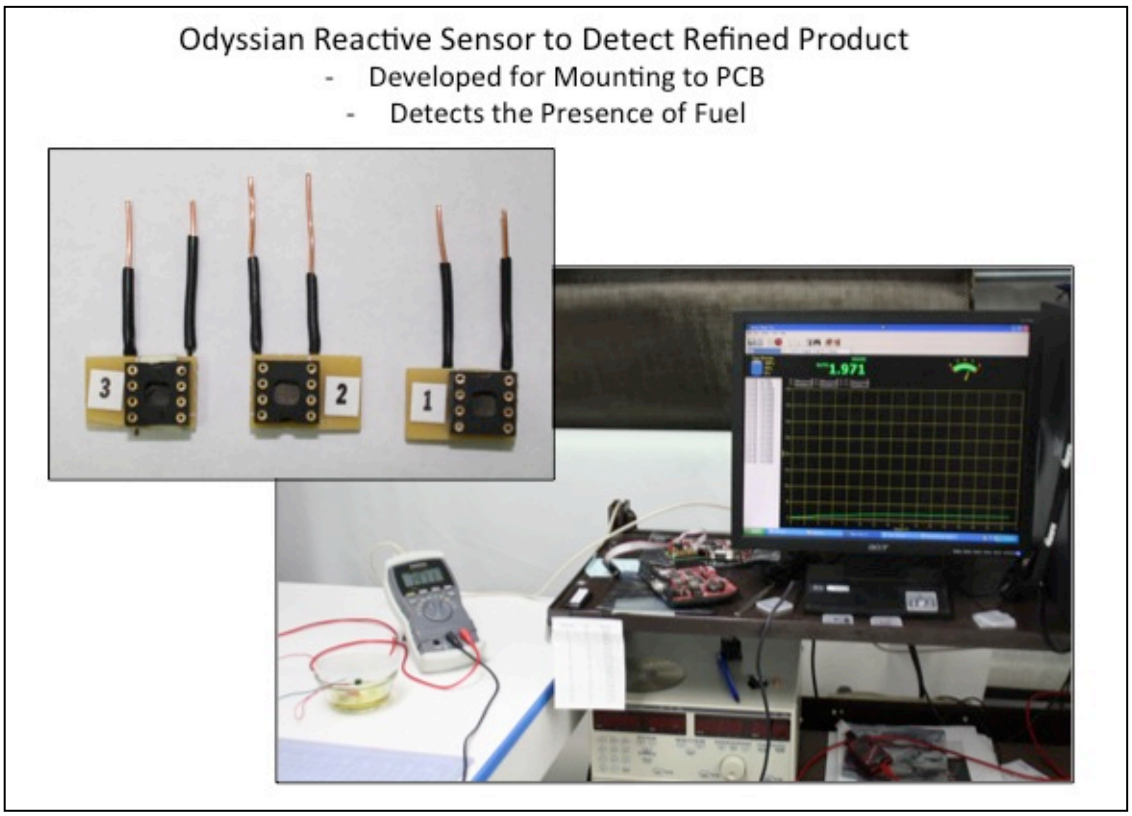



*Figure 9: Odyssian Technology's Reactive Gasoline Sensor and initial test set-up. Odyssian Technology developed a sensor that detects the presence of gasoline and other hydrocarbons. During this program this sensor was further improved upon by making it mountable to a printed circuit board. Shown are three sensor test specimens and the initial test set-up used to test and verify sensor response.*

Testing included exposing the reactive fuel sensor to gasoline vapor, to a single drop of liquid gasoline, and then completely saturating the sensor in liquid gasoline. The results showed a noticeable response when exposed to vapor and extreme responses when exposed to a single drop and when saturated. Figure 10 shows the response of the fuel sensor when saturated in gasoline. As shown, the sensor reaches 1M-Ohm resistance in a little over 8 minutes. Figure 11 shows the response of the sensor when exposed to gasoline vapor. This data shows a significant response is achieved over a longer period of time. Testing showed that the sensor's first 'at-rest' (no gasoline present) electrical signature is different then the at-rest electrical signature of the sensor after it had been exposed to gasoline This showed that there is a need to condition the sensor by exposing it to gasoline prior to its first use. Testing also included exposing the reactive sensor to other hydrocarbons and it was found that the sensors are capable of detecting a few of these other hydrocarbons. This testing is inconclusive and requires further research.

Lab evaluations included observing if there was a noticeable change in the reactive sensor's sensing element after repeated exposure to gasoline. Visual inspection suggests that the element may be used multiple times without noticeable degradation, but <u>further testing of the Reactive Fuel Sensor is needed to conclusively determine it's useful life</u>.

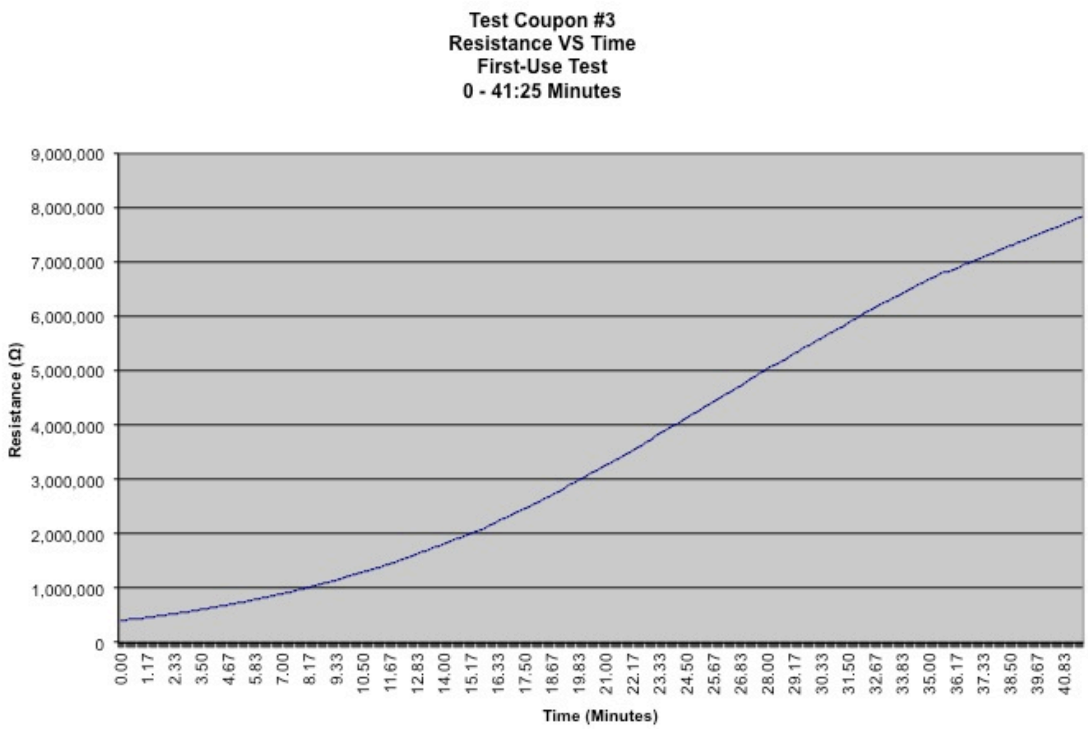



*Figure 10: Odyssian Technology has developed a proprietary multi-use sensor that responds to the presence of various hydrocarbon substances including gasoline. Further research is needed to understand what the sensor is capable of sensing under various conditions, and over repeated use.*

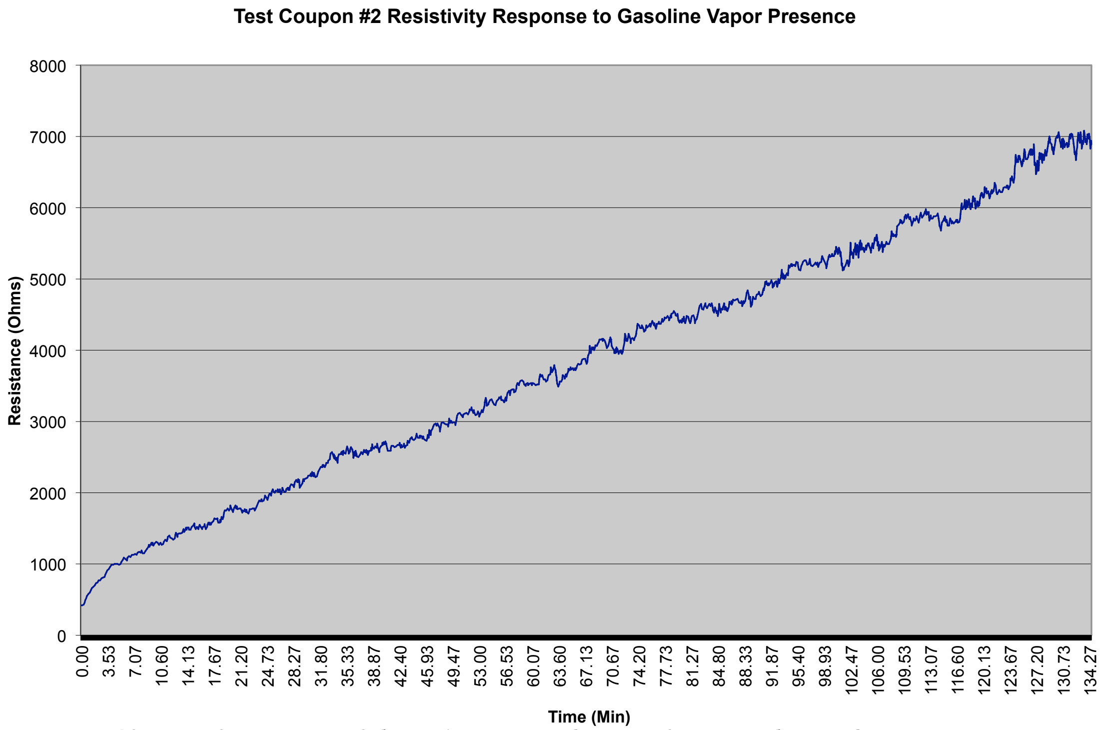



*Figure 11: Shown is the response of Odyssian's reactive fuel sensor when exposed to gasoline vapor over time. This data implies that this sensor technology would be able to sense a gasoline leak without coming into contact with liquid gasoline. Additional characterization and formulation optimization is required to complete development of the sensor system.*

Odyssian Technology conducted tests on the Reactive Fuel Sensor beyond exposure to gasoline. The findings are very preliminary, but results to date show that the Reactive Fuel Sensor responses to other liquid hydrocarbons-based products including acetone. The sensors were shown to respond to acetone vapor as well. <u>Further research is required to test the Reactive Fuel sensors when exposed to other gas and liquid hydrocarbon-based products</u>. The Reactive Fuel Sensor, if shown to be effective in sensing a broad array of hydrocarbon-based products, could be a very valuable sensing technology for monitoring the health of the pipeline system. This sensor is made from a material that may be better for use in the harsh O&G operating environment.

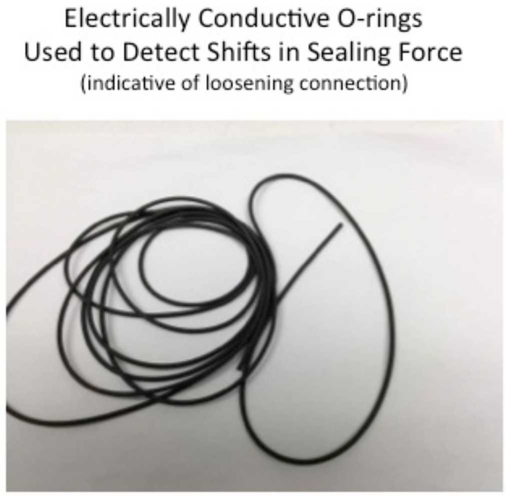



*Figure 12: Sensor O-ring. Odyssian Technology has developed for the MDA a smart seal having sensor O-rings that were used to sense changes in sealing force, while at the same time acting as a sealing component. This same technology has been explored for use in O&G seals. Preliminary testing has shown that the O-ring material does change electrical readings when compressed, but additional characterization, material formulation and optimization, and algorithm development is required.*

Figure 12 shows a photograph of some of the O-ring material that was tested during this program for use in creating a sensor O-ring. The sensorSEAL design has a sensor O-ring on the eGRE face of the seal to detect changes in sealing force. The purpose of this sensor system is to identify if a bolt has loosened on the flanged fitting. Odyssian Technology in a past program with the Missile Defense Agency developed and demonstrated a sensor O-ring that could detect the loosening of bolts when the flange had a four-bolt configuration. Preliminary testing of the sensor O-ring materials provided insight into the electrical properties and behavior of various different material formulations. The behavior characteristic of the sensor O-ring was investigated and consideration was given to how this technology may be applied to O&G pipeline systems. Initial data and investigation shows great promise for the likelihood of being able to develop sensor O-rings for larger flanged fittings used in O&G pipelines. <u>Further development is needed to develop the material formulations, electronic circuitry and algorithms for the various flange bolt patterns that are used in O&G pipeline systems.</u>

The prototype of the sensorSEAL™ uses two types of commercially available sensors. These include the MEMS pressure sensor shown in Figure 13 and one of the accelerometers shown in Figure 14. The MEMS pressure sensor is a sensor made by GE that is used widely in systems that monitor automotive tire pressures. The photographs in Figure 14 shows two accelerometers that were used in the smart pipeline network prototypes. The accelerometer shown on the left was used in the sensorSEAL. This accelerometer is a MEMS accelerometer capable of detecting vibration is the X and Y axis.

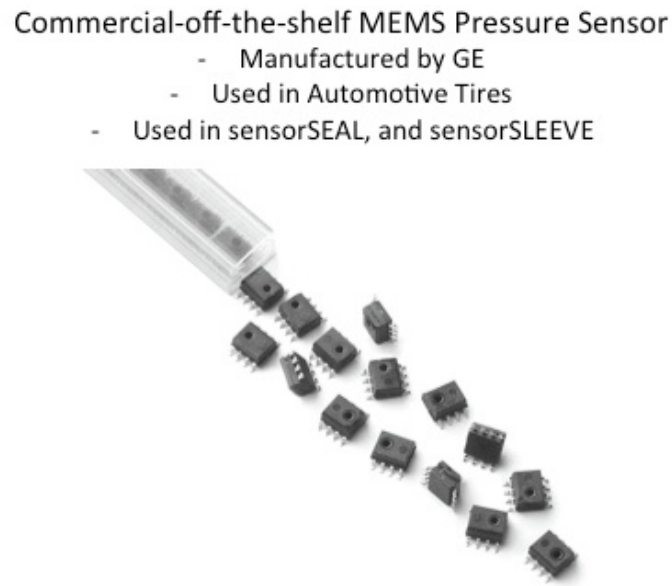



*Figure 13: Shown is the response of Odyssian's reactive fuel sensor when exposed to gasoline vapor over time. This data implies that this sensor technology would be able to sense a gasoline leak without coming into contact with liquid gasoline. Additional characterization and formulation optimization is required to complete development of the sensor system.*

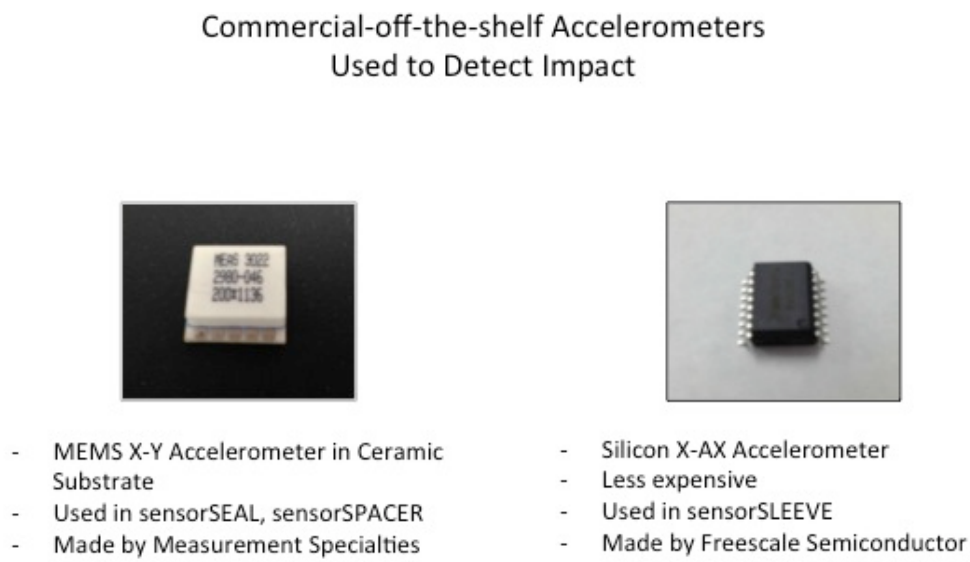



*Figure 14: Commercial –off-the-shelf accelerometers were used to detect impact and earth movement. The accelerometer shown on the left is a more expensive MEMS accelerometer capable of detecting vibration in the x and y directions.*

*PROTOTYPE SYSTEM DEVELOPMENT*

The smart pipeline network system, which is referred to as the sensorPIPELINE™ , includes a cloud-based controller that is capable of monitoring a large collection of sensor networks. Such a system will ultimately be a provide real time monitoring of the pipeline systems, both long run O&G pipeline and discrete O&G pipeline facility piping systems. Figure 16 shows a schematic of a notional cloud based system that is capable of monitoring large pipeline installations. It is envisioned that this system, which takes advantage of the internet infrastructure, will be a non-biased service that monitors the integrity of our nations pipeline system. As shown in Figure 15, this system will service multiple control centers made up of both private and government entities. The sensorPIPELINE system will have a control architecture involving lower level sensor networks that are integrated within higher-level Internet networks. In the event of lost connectivity the sensor networks will continue to collect status data at the local level. Once connectivity is regained, the master data bases within the internet network will be updated with status data that occurred during the lost connection. As shown, each sensor network is made up of multiple sensor nodes (a.k.a. sNodes) that connect to the various sensor components within the network. The sNodes within each of the sensor networks communicates to a master node, referred to as an integration node (a.k.a. iNode), which is coupled to a single board computer (SBC) (each SBC has a subNet server) . This iNode/SBC acts as the local data management device and provides a gateway to the TCP/IP Internet network.

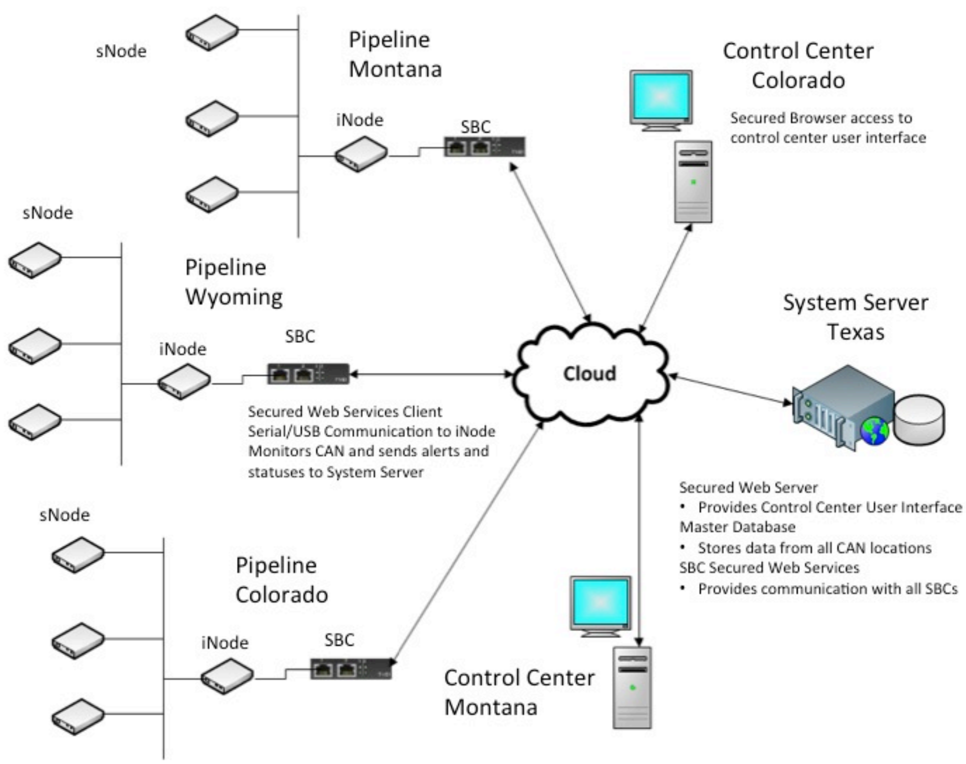



*Figure 15: Topography of the sensorPIPELINE™ Network. As shown, the sensorPIPELINE™ system has web-based controls.*

### sensorPIPELINE™ Subnet Server

The purpose of the iNode/SBC (a.k.a Subnet Server) is to configure and control the sensorPIPELINE CAN network. The Subnet Server is also responsible for managing local storage of data and for transferring sensor data to the centralized cloud database. A Subnet Server is a small credit card size single board computer (SBC) utilizing a low power ARM8 processor. The SBC has serial port communication capability to the CAN (controller area network) sensor network and TCP/IP access to the Internet. The SBC runs a version of Linux called Ubuntu and is configured with a MySQL database engine for local data storage.

A control and communication software application written in C was developed to manage the serial communication with the CAN sensor network. The C application sends configuration commands to the CAN network and receives back sensor state data that is both stored locally in the MySQL database and forwarded onto the centralized database in the cloud. Communication with the cloud is through REST style web service calls. The C application makes secured https/ssl web service calls to the sensorPIPELINE centralized cloud system utilizing a Linux library called cURL. Through this web service interface the C application receives configuration information and sends out sensor data.

During normal operation the C application simply receives a continuous stream of sensor data from the CAN network, performs sensor specific data conversions, determines status of each sensor (normal, caution, or alarm), locally stores the sensor data and then forwards the sensor data to the cloud in real time. The normal operating mode of the C application can be interrupted by commands placed in its processing queue in the cloud. The C application periodically queries the cloud though the web service interface for new commands to execute. Any new commands found are executed and when there are no more commands in the queue the C application will return to the normal mode of receiving a continuous stream of sensor data.

The C application stores the last configuration commands and other state information so that in case of local power loss the system can return to the last operating state when power is restored. In addition, the C application continues to operate even if communication with the cloud is lost or interrupted. Any sensor data stored locally will be sent onto the cloud system when Internet communication is restored.

### sensorPIPELINE™ Cloud System

The purpose of the cloud system is to report on the health status of the overall system, to report on the status of individual CAN sensor networks through their local Subnet Server, manage the configuration of all devices within the system, and to store sensor history data sent from the installed base of Subnet Servers. There are two types of software applications in the cloud, the web user interface and the REST style web services.

The purpose of the web user interface is to provide users with:

- A quick means of monitoring overall system health
- The ability to monitor the state of specific SubNet Servers
- A mechanism to configure all devices within the sensorPIPELINE system
- Mapping capabilities to assist in locating specific devices within the system
- A means to review and export sensor history data

The web interface is designed to be accessed by web browsers such as Internet Explorer, Chrome, Safari, and Firefox. Screen shots of the web user interface are shown in the Appendix I.

The web user interface allows access to system features through secured https/ssl communication. The web interface is written primarily in PHP, jQuery, and CSS. It features secured login authentication and uses roles to give individual users controlled access to specific features of the system. As shown in the screen shots in the Appendix, navigation through the web user interface is designed to be simple allowing the user to quickly see the state of the system and if required take action when the system is in the caution or alarm state. Mapping features make use of the Google Maps jQuery API.

The other software developed for the cloud is the REST style web services interface allowing machine-to-machine communication between the cloud and each installed Subnet Server. The web service interface is also accessed through secured https/ssl communication. Each Subnet Server is uniquely identified and access to the web services requires secured login authentication. The Subnet Servers use the web services interface to retrieved commands and configuration data and to send sensor history data to the cloud for long-term storage. The web services interface is also written in PHP and messages are passed in JSON format.

Both the user web interface and the web services utilize a MySQL database for storage of data and the Apache2 web server. The current system runs within a Linux operating system known as Ubuntu. The components of the cloud system are designed to work with other common cloud services for load balancing and scaling so as the system grows in size it is easy to add resources to handle demand. In addition the design of the system allows for the use of virtual cloud resources and allows for easy maintenance, backup and recovery options.

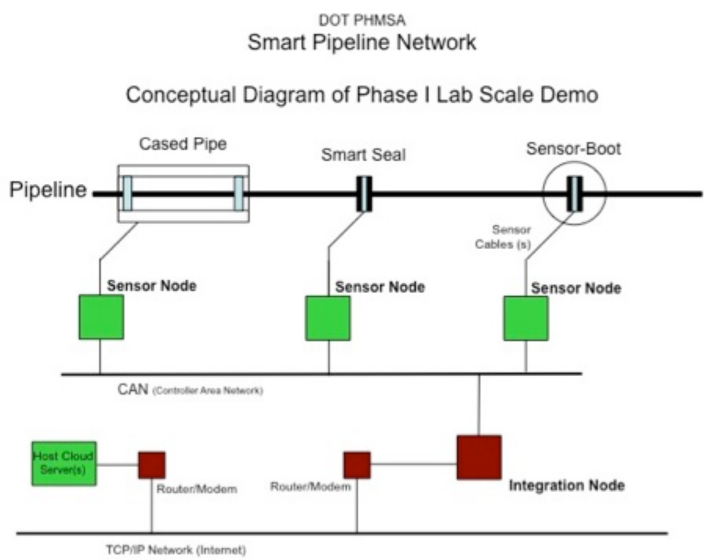



*Figure 16: Topography of the Prototype Network.*

To demonstrate the sensorPIPELINE a prototype was designed and developed that includes the web-based controls for the full operational system. Figure 16 shows a schematic of the prototype demonstration system and its components. The difference between the full system and this prototype system is the limited number of smart components and their sNodes, as well as the limited number of sensor networks and their iNodes. The prototype system will include only one small sensor network and its iNode. This small sensor network is wired using a controller area network (CAN) and includes a sensorSPACER™, a sensorSLEEVE™, and a sensorSEAL™ (developed under this program).

## sensorPIPELINE™ Web User Interface

As previously stated, screen shots of the web user interface are shown in the Appendix I. This interface was designed to provide a simple and easy-to-understand graphic user interface (GUI). To simplify information displayed, one of three status conditions of the user network is displayed using color. The three possible conditions are 'green (okay)', 'amber (caution)', and 'red (alert)'. Sensor threshold values are defined for the two levels of alarms. An example of a caution alarm may be when a Reactive Fuel Sensor detects a low level of gasoline vapor, but has not detected liquid gasoline. The caution alarm tells the operator that a problem may be developing, which under some operating procedures may lead to a higher level of observation and system assessment.

As shown in the screen shots in Appendix I, the menu buttons on the left side were made large to ease their use when the screen is being displayed on a mobile device with a small display. The first screen once logged onto the site is 'health SUMMARY'. This page is designed to be simple with only the 'green' or okay alarm status displayed during normal operating conditions when no alarms have occurred. If an alarm ha occurred, this page lists only those components (i.e., sensorSEAL, etc.) with an alarm condition. If the operator desires to see more information for those components that have tripped an alarm, there is a link on the component name that cause the system to display the detailed information on this component. The operation may also click on the map link to see geographic location of the components with an alarm.

The 'component STATUS' link shown on the left, will display a list of all of the components within the user's network. If a user needs additional information the component and map links can be clicked. The next available link in the left menu area is the 'geographic MAP'. This link will display the map of where a component is located that has an alarm condition. The next link in the left menu is 'performance HISTORY'. This screen shows graphical displays of the user's pipeline network performance. Shown in this screen is a pie chart that shows the health status of a user's pipeline network by indicating the percent of operating hours that the system had a normal, caution or alert status. There is a link in the bottom right corner to get performance history information by SubNet or by individual sensor networks within the users network. Some users may have a pipeline network that is made up of multiple SubNets (each sensor network has one subnet server).

The last link is 'system SETUP'. Access to this portion of the site is limited to only those users with responsibility for system set up. Senior system analysts may also have certain access privileges to this portion of the website. Several sub-links are provided under the system setup link, which includes subNet setup, iNode setup, sNode setup, Host server setup, messaging setup, and user setup. The ability to send commands to specific sensor networks are under the subNet server link, which would be made available to senior system analyst who may need to query system information to trouble shoot system problems and to validate alarm states.

**sensorSEAL™**

Figure 17 shows A photographs of the above ground sensorSEAL™ that was developed and prototyped. This photograph shows the complete seal assembly, less the seal covers Figure 18 Shows the eGRE that was bonded to the core to the make the seal shown in Figure 17. All of the sensors, electronic components, and tracings are outside the compression area of the seal.

**sensorSEAL™**

*Figure 17: sensorSEAL. Shown is the completed above ground sensorSEAL without the seal covers.*

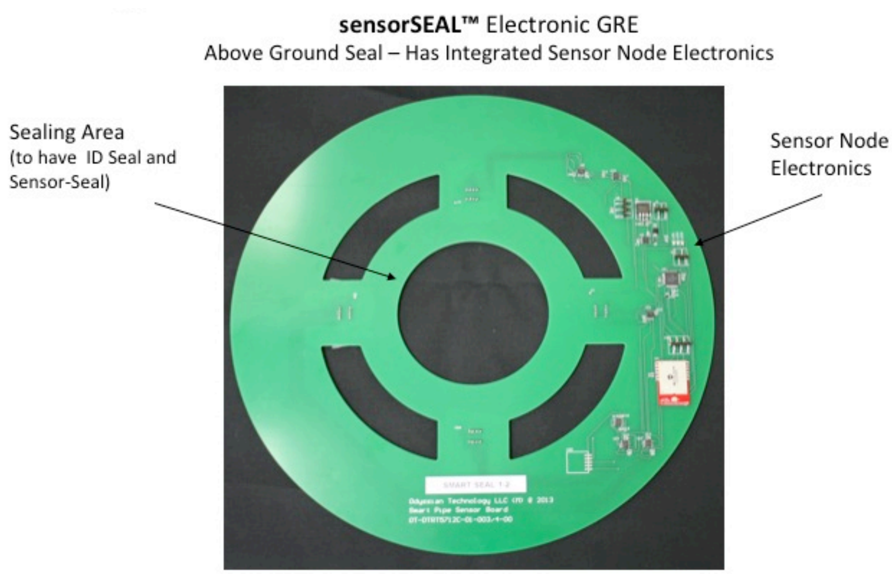



*Figure 18: eGRE for Above Ground Wireless sensorSEAL. This eGRE has the sNode circuitry integrated withuin the seal.*

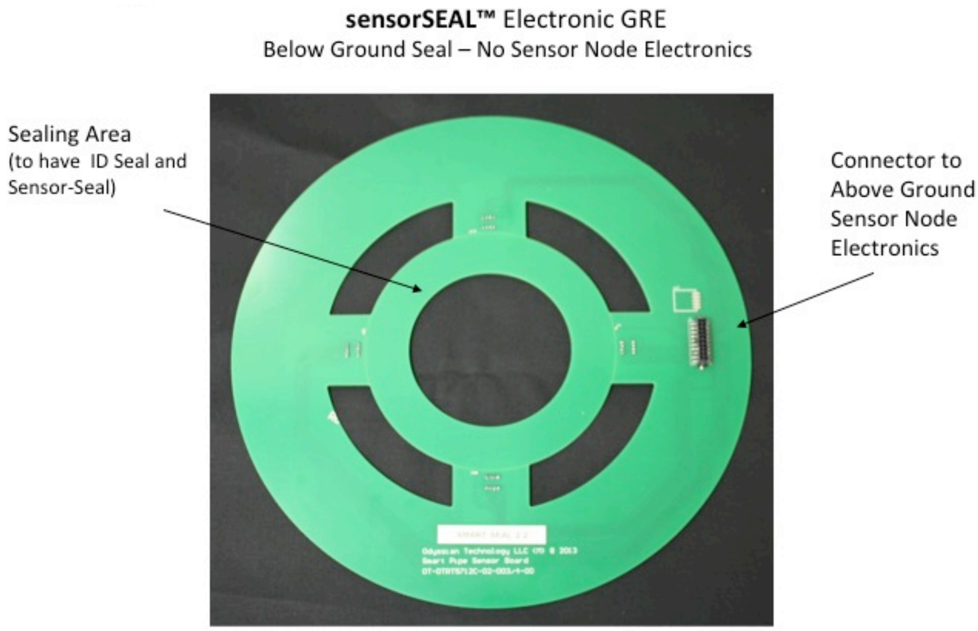



*Figure 19: eGRE for Below Ground sensorSEAL. This eGRE has the sNode circuitry integrated withuin the seal.*

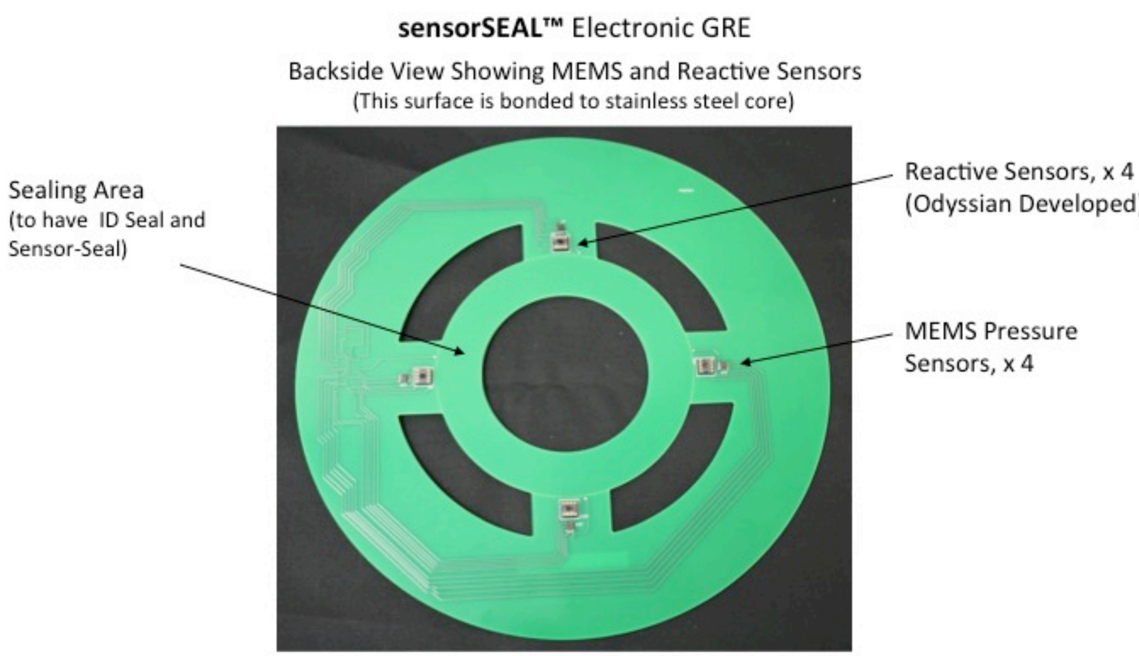



*Figure 20: eGRE. Shown is the backside view of the eGRE which shows the reactive and MEMS sensors in four locations. This is the side of the eGRE that is bonded to the stainless steel core*

The photograph of Figure 19 shows the outer face (not bonded to core) of the below ground eGRE. As shown, there are no electronic components. These reside above ground in the sNode enclosure. This eGRE has only sensors and the connector that connects the sensor cable. The sensor cable enters a sealed flex conduit, which is routed up through the ground to the pipe mounted sNode enclosure. Figure 20 shows the backside view of this eGRE. The backside of the eGRE for the below ground and above ground seals are identical if the electrical tracings are ignored. Essentially all this is on this side of the eGREs are the reactive and MEMS sensors. This is the side of the GRE that is bonded to the stainless steel core. The sensors are seated within the sensor cavities that are milled out of the core. Pressure sensitive adhesive film was used to bond the eGREs to the core. Film was used in place of the conventional paste to ensure that resin did not flow into the flow channels or sensor cavities. Additional testing and manufacturing optimization is needed to ensure a robust bond is achieved using materials and processes that protect the integrity of the sensors and electronics.

The photographs in Figure 21 show the prototype below ground sensorSEAL™. Next to the sensorSEAL is its sNode. The sensors inside the sensorSEAL includes four reactive fuel sensors, four MEMS pressure sensors, an accelerometer, and a sensor O-ring. The sensorSEAL sensors and sNode are part of a sensor network that includes two other sensor laden components, each with its own sNode. These other components are a sensorSLEEVE™ and sensorSPACER™ (developed under the related SBIR programs). The sensor network has a master node, called the integration node or iNode. The iNode is connected to a single board computer (SBC). The iNode and SBC together provide a gateway between the microcontroller based sensor network and the Internet. Together the iNode and SBC acts as a subnet server that provides connectivity to a web-based master control system within the Cloud. Figure 22 shows pictures of the prototyped sNode and iNode.

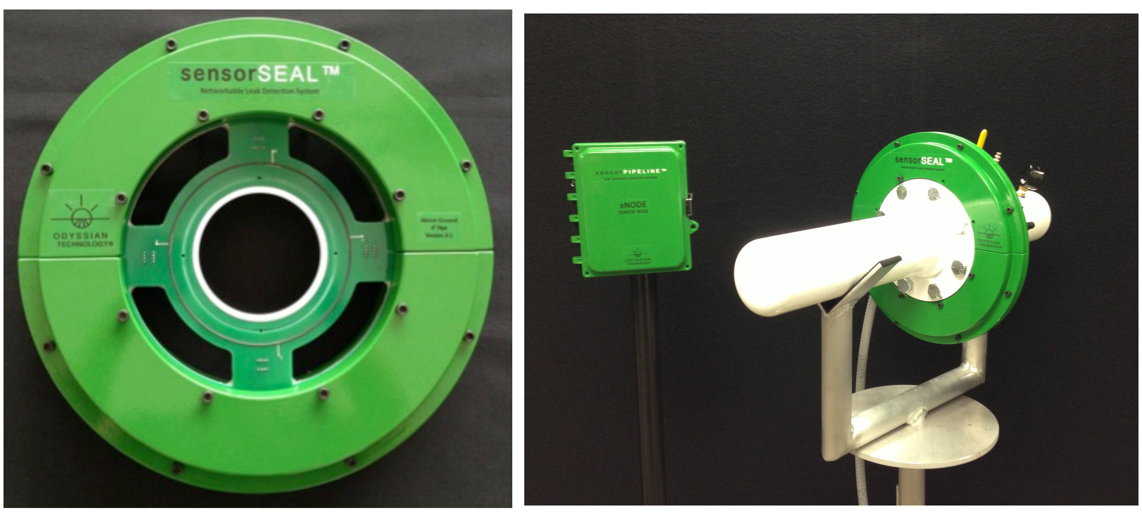



*Figure 21: Photograph of the Prototype sensorSEAL™*

Sensor NODEs (sNode)


Integration NODE (iNode)


*Figure 22: Shown are the sensor node (sNode) and integration node (iNode). Each sensor-laden device (i.e., sensorSEAL, etc.) on the sensorPIPELINE system has a dedicated sNode. Each sensor network, which has multiple sNodes has a single iNode that acts as the master node and is coupled to a single board computer (SBC).*

*Task III – In-field Evaluation Planning*

The in-field evaluation plan includes those activities that are believed to be necessary to validate this technology in an operational setting. To adequately validate this technology the following activities are required;

1. Continue to characterize the sensor suite to better understand the performance limits
2. Conduct in-field site surveys to better understand the operational environment and installation implications.
3. Select a demonstration site by identifying an operational pipe that will be repaired using composite wrap repair methods.
4. Work with the pipeline operator and composite repair company to have a sensorSEAL installed. The sensorSEAL should be located in an area with adequate physical access and internet connectivity
5. Perform and report multi-year system performance testing and evaluation.

It is preferred that this in-field evaluation be performed on an operational system. But, if pipeline operators are unwilling or unable to put the sensor system on an operation system, then the contingency plan is to simulate such an environment by installing a sensorSEAL in a controlled area, such as at Odyssian Technology's research facility, or other available test facility that is recommended by the PHMSA customer.

*Task IV – Preliminary Cost and Market Analysis*

Current system estimates are based on prototype cost at minimum order and developmental cost Projected Future Cost Estimates assume large quantity orders and less engineering time. Installation and maintenance costs have not been reviewed. These numbers will be formulated during the in-field evaluation.

| **Smart Pipeline Network - Seal Sensor System** | |
|---|---|
| Above Ground Seal | |
| Current Cost Estimates | Projected Future Cost Estimates |
| $10,272.13 | $5,136.06 |
| Below Ground Seal | |
| $7,742.15 | $3,871.08 |

## MARKET ANALYSIS SUMMARY

Odyssian Technology has developed a set of patented technologies for application in the oil and gas pipeline industry referred to as: (1) Smart Pipe and Repair, (2) Smart Seals and Gaskets, and (3) Case Piping. The purpose of this customized market research report was to identify potential target markets for the smart seal, discuss competing technologies, and provide data that would assist in understanding how to penetrate the Oil and Gas industry. Sources of potential funding for continued technology development were also identified.

LEAK DETECTION SYSTEMS

In the Oil and Gas industry, the market opportunity for leak detection exists because of a number of federal regulations. Most recently, the Pipeline Safety Improvement Act of 2006 encouraged the continued study of pipeline safety and security practices and mandated a leak detection study. In 2007, this study was commissioned by the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) and was issued in 2012 as the Leak Detection Study. Three types of leak detection systems (LDS) were defined and categorized in this report: (1) visual inspection techniques; (2) instrumented monitoring of internal pipeline conditions; and (3) external, instrumentation for detecting leaked hydrocarbons. This comprehensive study defines a leak detection system (LDS) as having three components, all of which must be considered: Personnel, Procedures, and Technologies.

According to operators, "false alarms" are a major concern and are not the result of the LDS not functioning properly. False alarms reflect the fact that normal operational changes on or near the pipeline can cause exactly the same physical effects that the LDS uses to detect leaks. "It is an inherent difficulty with any technology that relies upon any physical side effect of a leak for its detection." Another issue mentioned was that external systems are often quite complex and are difficult to select, engineer, and deploy.

Data on pipeline incidents collected by the Department of Transportation provided an additional perspective on why leak detection systems are viewed as having three components (Personnel, Procedures, and Technologies). Of 5,610 onshore spills reported as *significant* between 1993 and 2012, the main causes were corrosion (19%) and third party generated spills such as those that occur during excavation (22.5%). The primary causes of *serious* incidents occurring during this period resulted from incorrect operation (12.4%) and excavation (33.2%).

A final conclusion was that "Leak detection system complexity or high cost does not necessarily translate to better performance. Without a focus on all three: technology, people and procedures, a single "weak link" can render the overall system useless. In particular even very simple technologies can be very effective, if they are backed up by highly skilled operators and well-designed procedures. Design choices need to be balanced with available and committed operating and maintenance resources."

It appears from the detailed discussion in the Leak Detection Study of how the oil and gas industry operates, that the appropriate focus for Odyssian might be areas of high environmental sensitivity. "Pipelines often have relatively short sections where leak detection is far more critical than in others. Examples include: river crossings (even small emissions are carried long distances); road crossings (vibration, immediate contact with moving machinery); hospitals, schools and other low-mobility areas (limited escape capability). There is a need for a certified, *dedicated point solution* that is predesigned and pre-configured for each of these common situations."

COMPETING PRODUCTS

Competing approaches for leak detection were reviewed including: Computational Pipeline Monitoring (CPM), acoustic leak detection, remote sensing using air platforms, strain sensors, pressure and temperature sensors, Supervisory Control and Data Acquisition (SCADA) Pressure Point Analysis, and External Sensors. A summary table briefly describes how each contrasting technique works, provides illustrative names of companies that provide that approach and provide additional information that highlights the value proposition. In pursuing the Oil and Gas industry it will be important that Odyssian contrast the feature, advantages, and benefits of its technology relative to other solutions that exist. If the Odyssian system can greatly reduce false positives, this should be highlighted.

## OTHER INDUSTRIES WHERE LEAK DETECTION IS IMPORTANT

Apart from the oil and gas industry, it is reasonable to assume that leak detection in other industries is important. A quick review of leak detection in the water, wastewater, renewable and alternative energy industries was provided. In a study conducted by The Fredonia Group, it was projected that the demand for water and wastewater pipe in the U.S. is estimated to rise 5.8 percent annually to $19.6 billion in 2014. Advances will reflect renewed activity in the residential building construction sector, the growing obsolescence of sewer and drainage systems and upgrades of municipal water systems. Another study conducted by Frost and Sullivan indicated that the global leakage levels of water average 25-30 percent. In areas where water is treated as a precious commodity the interest in leak detection is highest. For example, the Las Vegas water district implemented a PermaLog remote leak detection system.

Specialty pipelines are required for renewable and alternative energy substances as their chemical composition is often corrosive or destructive to the existing, conventional pipeline infrastructure. A 2010 report prepared by SBI Energy estimates that the total global market for specialty pipelines will show year over year increases of 30% through 2015. A summary of the growth rate of pipelines needed for the transport of carbon dioxide, ethanol, biodiesel, biogas, and biomethane are included.

Leak detection is also an issue with pipes that carry water, wastewater, and alternative fuel. However, just as with the oil and gas industry, it is suspected that there are selective areas along the distribution network where an alternative to current methods may be required. To determine the specific niche where Odyssian's technology will be valued, will require primary market research. This section of the report concludes with an illustrative approach for collecting feedback from individuals who are responsible for leak detection in highly sensitive areas such as river crossings, road crossing, hospitals, and schools. Sample questions are included.

## SEALS MARKET

Odyssian anticipates using a licensing strategy to bring its patented products to market. Therefore, in this section insight was provided into selected players that manufacture mechanical seals. Of particular interest is EnPro Industries, a leading manufacturer of high-performance industrial seals, bearing, and compressor components. Since 2003, EnPro has made 28 acquisitions including Pipeline Seal and Insulator Inc. (PSI). " The company complements Garlock's Pikotek line of products offered to the oil & gas production market, providing it with a more comprehensive offering in this space, and 2) it represents Garlock's initial presence in water and wastewater transmission, a market that is likely to grow in the coming years due to the need to replace aging infrastructure throughout the U.S. and Europe." A summary of sealing product segment subsidiaries is included which highlights whether sales to OEMs and/or aftermarket.

Highlights from a 2010 Frost and Sullivan report on the global mechanical seals market are also included. The top three players: EagleBurgmann, FlowServe, and John Crane account for 74.8% of the global mechanical seals market.

POTENTIAL SOURCES OF FUNDING

Odyssian is looking for additional sources of funding to continue the maturation of its technology. Although the technology has been tested and has performed well in laboratory environments, it needs to be tested in the field. Within the Small Business Innovation Research (SBIR) program, it was recommended that Odyssian reach out to the Department of Energy SBIR Program Manager, Manny Oliver. In addition other initiatives conducted at the National Energy Technology Laboratory (NETL) may be appropriate. Other initiatives funded through the Department of Defense, the Environmental Protection Agency, and the Department of Transportation were discussed.

**Smart Pipeline Network Seal Sensor System**
Preliminary Cost and Marketing Analysis

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In the Oil and Gas industry, the market opportunity for leak detection exists because of a number of federal regulations. Most recently, the Pipeline Safety Improvement Act of 2006 encouraged the continued study of pipeline safety and security practices and mandated a leak detection study. In 2007, this study was commissioned by the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) and was issued in 2012 as the Leak Detection Study. Three types of leak detection systems (LDS) were defined and categorized in this report: (1) visual inspection techniques; (2) instrumented monitoring of internal pipeline conditions; and (3) external, instrumentation for detecting leaked hydrocarbons. This comprehensive study defines a leak detection system (LDS) as having three components, all of which must be considered: Personnel, Procedures, and Technologies.

According to operators, “false alarms” are a major concern and are not the result of the LDS not functioning properly. False alarms reflect the fact that normal operational changes on or near the pipeline can cause exactly the same physical effects that the LDS uses to detect leaks. “It is an inherent difficulty with any technology that relies upon any physical side effect of a leak for its detection.” Another issue mentioned was that external systems are often quite complex and are difficult to select, engineer, and deploy.

Data on pipeline incidents collected by the Department of Transportation provided an additional perspective on why leak detection systems are viewed as having three components (Personnel, Procedures, and Technologies). Of 5,610 onshore spills reported as *significant* between 1993 and 2012, the main causes were corrosion (19%) and third party generated spills such as those that occur during excavation (22.5%). The primary causes of *serious* incidents occurring during this period resulted from incorrect operation (12.4%) and excavation (33.2%).

A final conclusion was that “Leak detection system complexity or high cost does not necessarily translate to better performance. Without a focus on all three: technology, people and procedures, a single “weak link” can render the overall system useless. In particular even very simple technologies can be very effective, if they are backed up by highly skilled operators and well-designed procedures. Design choices need to be balanced with available and committed operating and maintenance resources.”

It appears from the detailed discussion in the Leak Detection Study of how the oil and gas industry operates, that the appropriate focus for Odyssian might be areas of high environmental sensitivity. “Pipelines often have relatively short sections where leak detection is far more critical than in others. Examples include: river crossings (even small emissions are carried long distances); road crossings (vibration, immediate contact with moving machinery); hospitals, schools and other low-mobility areas (limited escape capability). There is a need for a certified, *dedicated point solution* that is predesigned and pre-configured for each of these common situations.”

## COMPETING PRODUCTS

Competing approaches for leak detection were reviewed including: Computational Pipeline Monitoring (CPM), acoustic leak detection, remote sensing using air platforms, strain sensors, pressure and temperature sensors, Supervisory Control and Data Acquisition (SCADA) Pressure Point Analysis, and External Sensors. A summary table briefly describes how each contrasting technique works, provides illustrative names of companies that provide that approach and provide additional information that highlights the value proposition. In pursuing the Oil and Gas industry it will be important that Odyssian contrast the feature, advantages, and benefits of its technology relative to other solutions that exist. If the Odyssian system can greatly reduce false positives, this should be highlighted.

## OTHER INDUSTRIES WHERE LEAK DETECTION IS IMPORTANT

Apart from the oil and gas industry, it is reasonable to assume that leak detection in other industries is important. A quick review of leak detection in the water, wastewater, renewable and alternative energy industries was provided. In a study conducted by The Fredonia Group, it was projected that the demand for water and wastewater pipe in the U.S. is estimated to rise 5.8 percent annually to

$19.6 billion in 2014. Advances will reflect renewed activity in the residential building construction sector, the growing obsolescence of sewer and drainage systems and upgrades of municipal water systems. Another study conducted by Frost and Sullivan indicated that the global leakage levels of water average 25-30 percent. In areas where water is treated as a precious commodity the interest in leak detection is highest. For example, the Las Vegas water district implemented a PermaLog remote leak detection system.

Specialty pipelines are required for renewable and alternative energy substances as their chemical composition is often corrosive or destructive to the existing, conventional pipeline infrastructure. A 2010 report prepared by SBI Energy estimates that the total global market for specialty pipelines will show year over year increases of 30% through 2015. A summary of the growth rate of pipelines needed for the transport of carbon dioxide, ethanol, biodiesel, biogas, and biomethane are included.

Leak detection is also an issue with pipes that carry water, wastewater, and alternative fuel. However, just as with the oil and gas industry, it is suspected that there are selective areas along the distribution network where an alternative to current methods may be required. To determine the specific niche where Odyssian's technology will be valued, will require primary market research. This section of the report concludes with an illustrative approach for collecting feedback from individuals who are responsible for leak detection in highly sensitive areas such as river crossings, road crossing, hospitals, and schools. Sample questions are included.

SEALS MARKET

Odyssian anticipates using a licensing strategy to bring its patented products to market. Therefore, in this section insight was provided into selected players that manufacture mechanical seals. Of particular interest is EnPro Industries, a leading manufacturer of high-performance industrial seals, bearing, and compressor components. Since 2003, EnPro has made 28 acquisitions including

## 4.0 SIGNIFICANT FINDINGS, PROBLEMS, TRENDS & IT'S IMPACT ON FURTHER DEVELOPMENT

The preliminary market analysis and relatively recent pipeline accidents emphasizes the need to establish continuous real time monitoring of pipeline integrity. In particular, there is a growing awareness of the hazards and environmental impacts of small leaks that are currently undetectable. Multiple technical solutions are being explored for improving leak detection, yet most are not focused on continuous real time monitoring capable of pinpointing the source of leaks or the precise location of damaging impacts. Meanwhile, information technology and the associated networking infrastructure needed for a Smart Pipeline Network continues to proliferate. The trend is that many consumer and industrial products are increasingly taking advantage of the benefits of being networkable devices. It has become evident to most consumers that significant advances are made when information and communication systems, as well as sensor-laden devices are networked using well-established Internet protocols.

While networkable smart systems continue to evolve and become evermore affordable, there appears to be reluctance by the O&G pipeline operator community to embrace smart pipeline technology that will provide significant insight into the magnitude of leaking systems. The current market dynamics appear to provide inadequate financial incentive for the pipeline operators to incur the significant cost of correcting unsatisfactory containment conditions of some of the aged pipeline infrastructure. The enforcement of federal laws and subsequent regulations may be needed to provide the incentive to adopt smart pipeline and other leak preventative technologies. The Pipeline and Hazardous Material Safety Administration (PHMSA) will most likely have to continue to be the primary source of funding to continue the advancement of smart pipeline technology until the time that regulatory consequences are high enough to provide the incentive needed.

The time required to achieve adequate market demand will depend upon how incentivized the pipeline industry becomes, as well as what perception the pipeline industry has toward the level of technology maturation of the smart pipeline technology. Further federal funding is needed to characterize and validate the technology to the level needed to entice early adopter's.

## 5.0 FURTHER DEVELOPMENT NEEDED

While great progress was made under this SBIR program, further research is needed to test, characterize, and validate the DMS technology on the many fluid compositions that are transported within O&G pipelines. Also, the current design of the sensorSEAL relies upon leaking product reaching the sensors by traveling through channels in the core. Further testing and validation is needed to test how effectively the leaking liquid travels through the channels to the sensors. Testing needs to be done using the variety of hydrocarbon liquids of varying viscosity that are commonly transported through O&G transmission pipelines. Designs need to optimized to ensure the leak paths are adequately sized with all the needed venting paths to ensure ease of flow.

The sensorSEAL benefits from the use of Odyssian's Reactive Fuel Sensor, which is made of a fracture tough material. Lab evaluations conducted during this program included observing if there was a noticeable change in the reactive sensor's sensing element after repeated exposure to gasoline. Visual inspection suggests that the element may be used multiple times without noticeable degradation, but further testing of the Reactive Fuel Sensor is needed to conclusively determine it's useful life. In addition, Odyssian Technology conducted tests using the Reactive Fuel Sensor to sense the presence of hydrocarbon-based liquids other than gasoline. The findings are very preliminary, but results to date show that the Reactive Fuel Sensor responds to other liquid hydrocarbons including acetone. Further research is required to test the Reactive Fuel Sensors to determine what other liquid hydrocarbon-based products it is capable of sensing.

Initial data and investigation shows great promise for the likelihood of being able to develop sensor O-rings for larger flanged fittings used in O&G pipelines. Further development is needed to develop the material formulations, electronic circuitry and algorithms for the various flange bolt patterns that are used in O&G pipeline systems.

Further development is also needed to commercialize the smart pipeline technology. Specifically, the components (sensorSEAL, etc.), sensors, and the cloud control networking require further evaluation and demonstration to characterize and validate the technology. Engineering and manufacturing development and validation is needed to demonstrate consistent product performance and to prove adequate in-field operation. Sensors need to undergo prolonged testing under environmental and operational conditions to prove adequate life-cycle performance.

Further research is needed into available and emerging thin and thick film sensors having an extremely small form factor that are capable of detecting the wide array of hydrocarbons that are transported within the O&G transmission pipelines.

Lastly, PRCI expressed that there is a need to develop smart mechanical seals for use on compressor and pump stations. It was pointed out that a majority of leaks within an O&G facility occur due to failure of mechanical or dynamic seals.

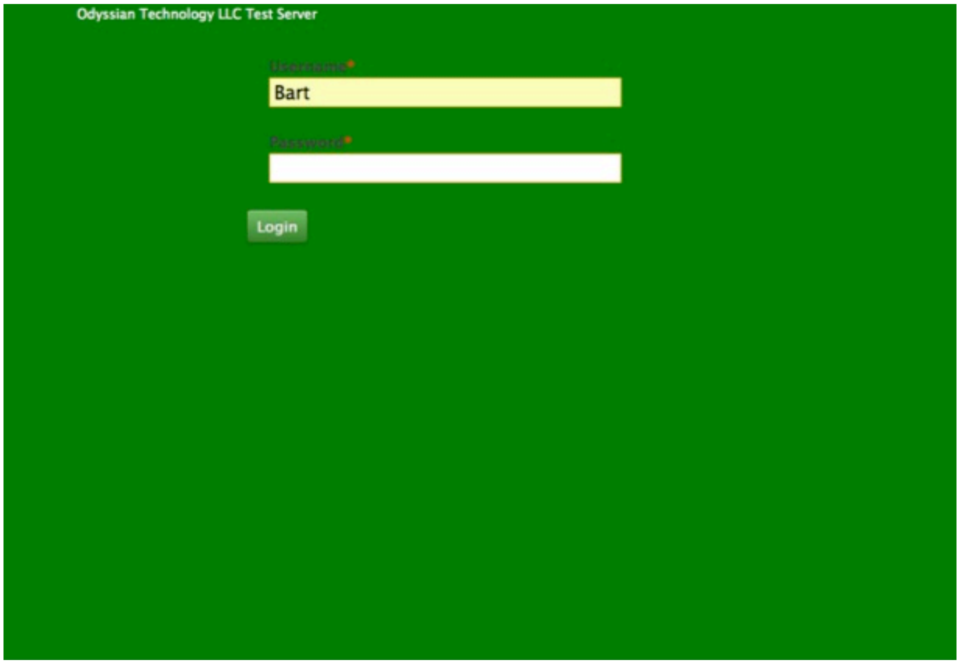
## 6.0 REQUIRED GOVERNMENT ASSISTANCE

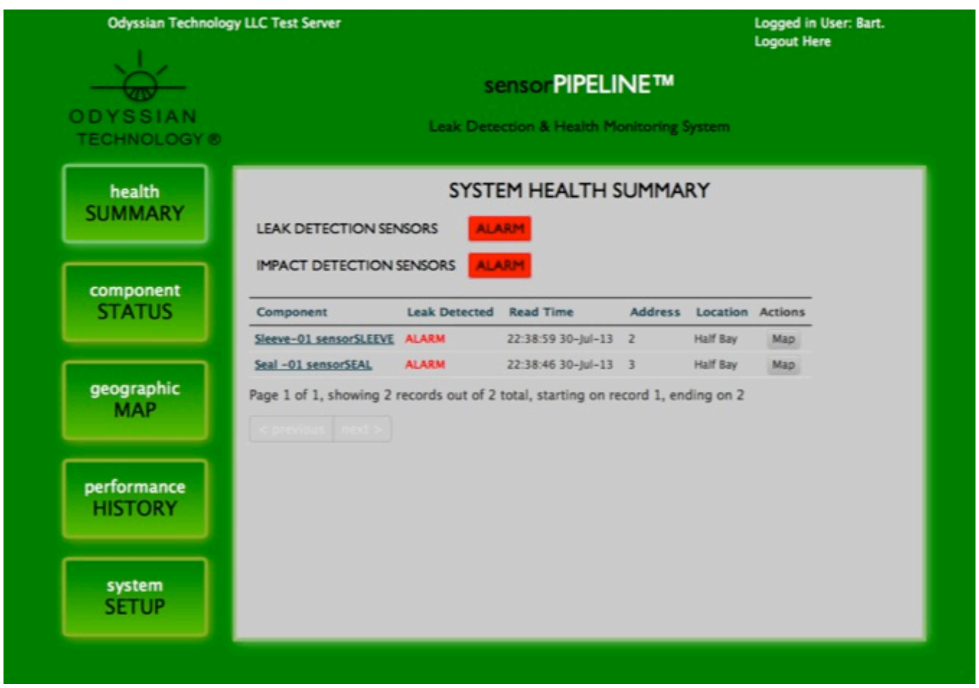
Government assistance is needed to establish and enforce regulations that will incentivize the O&G pipeline industry to adopt and promote smart pipeline and related technology.

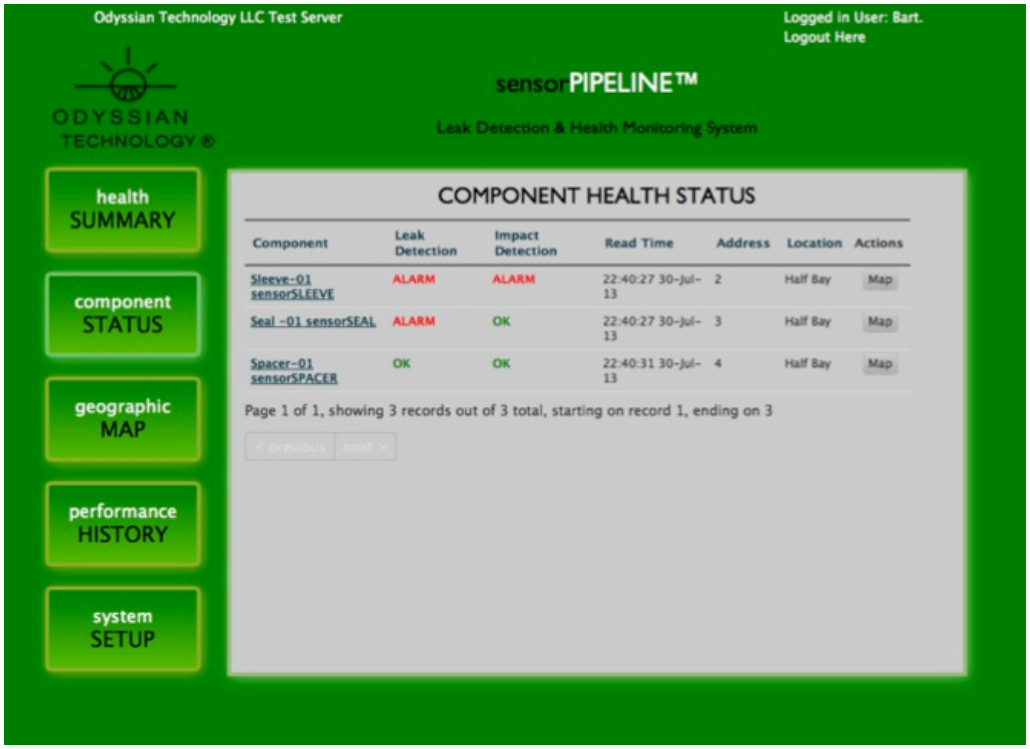
Additional government funding is needed to further develop, characterize, and validate the smart pipeline network sensorSEAL and related technology. Mechanical seals are a great source of leaks and further funding is needed to develop smart mechanical seals that detect leaks and monitor performance. Small sensors that lend themselves to integration within components of the smart pipeline (i.e., smart pipe, etc.) need to be further developed, tested, and validated.

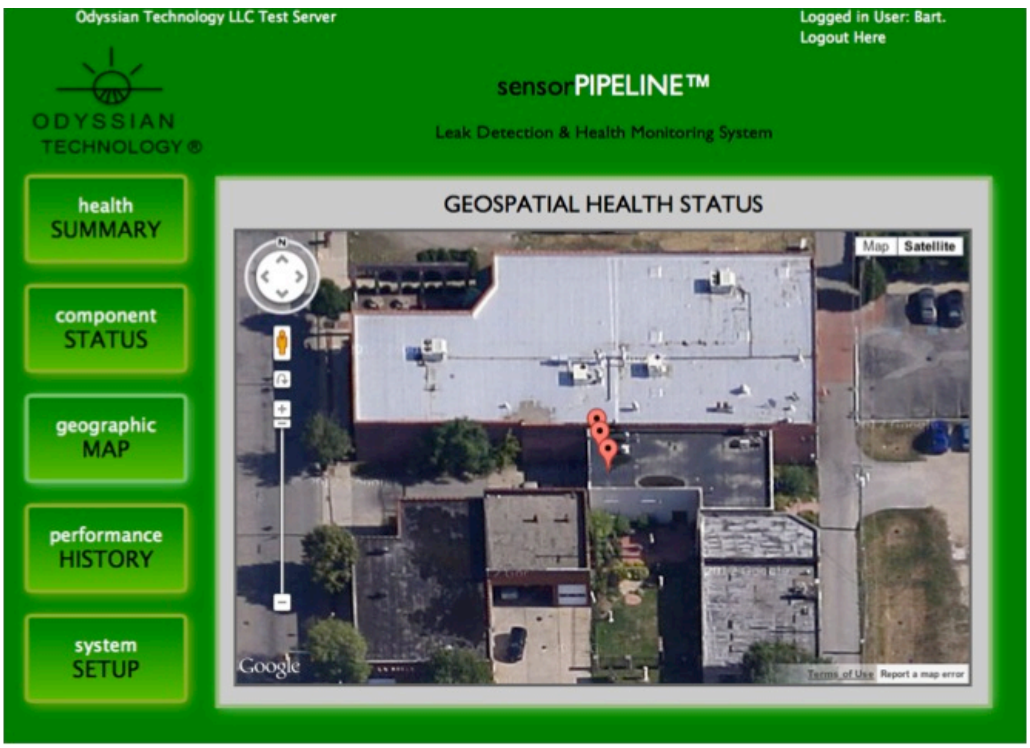
Odyssian Technology's ROM estimate is that approximately $3M to $3.5M over 3 years is needed for adequate development, testing, and validation of sensorSEAL and the development of smart mechanical seals.

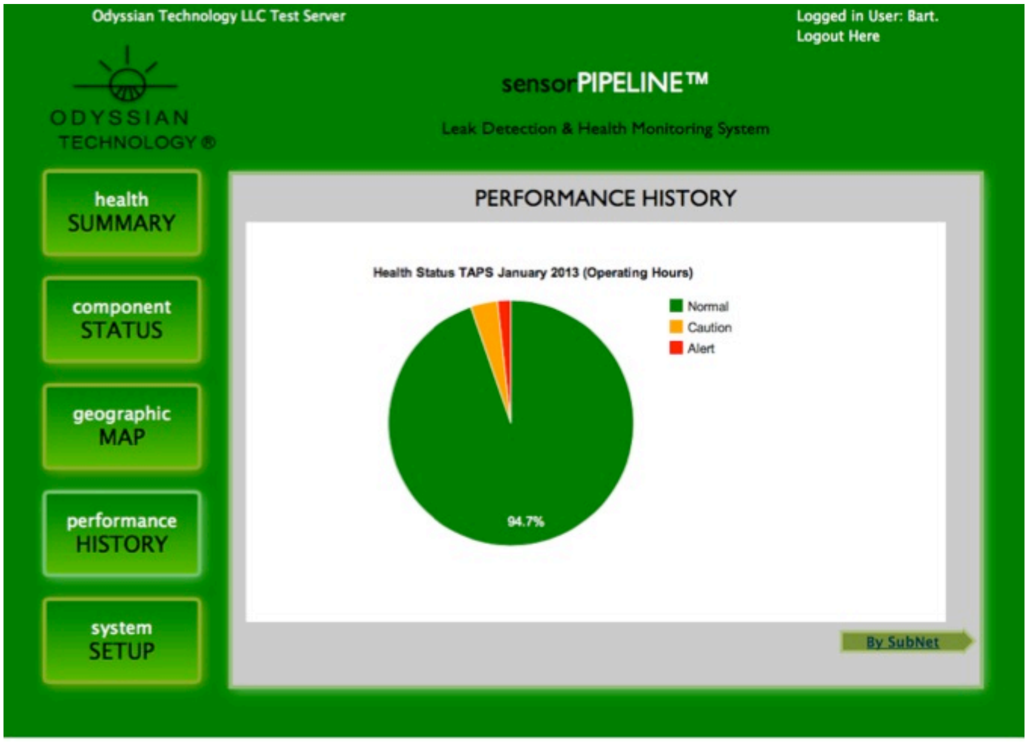
Appendix I: Screen shots of the **sensorPIPELINE™** webpages

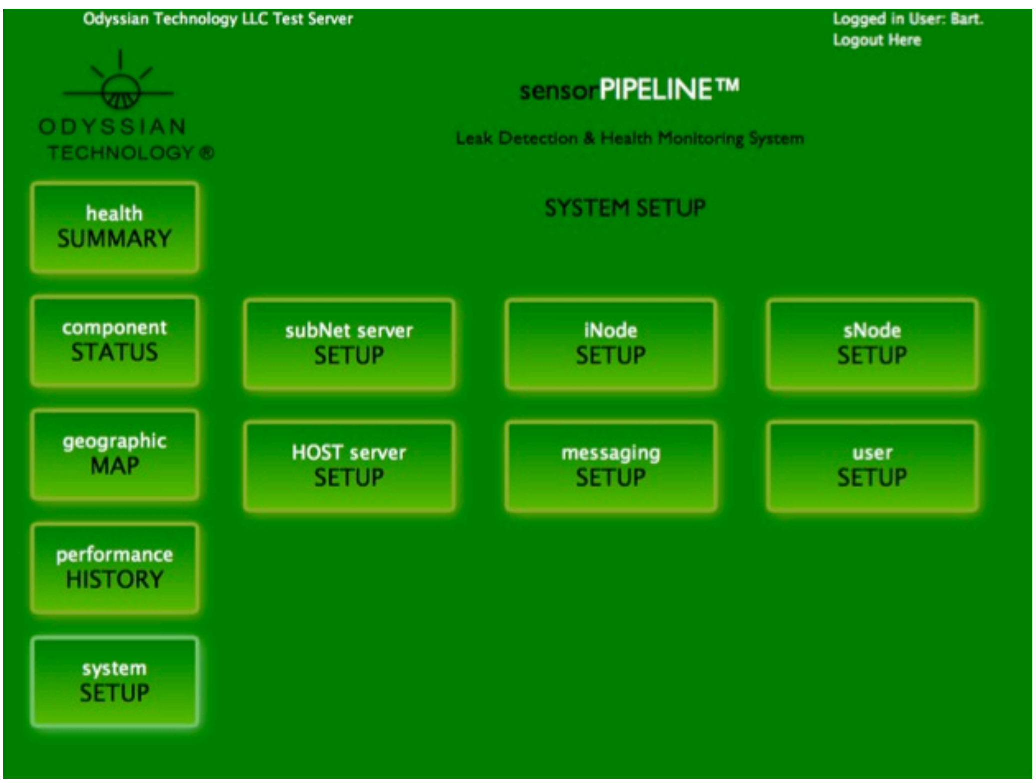


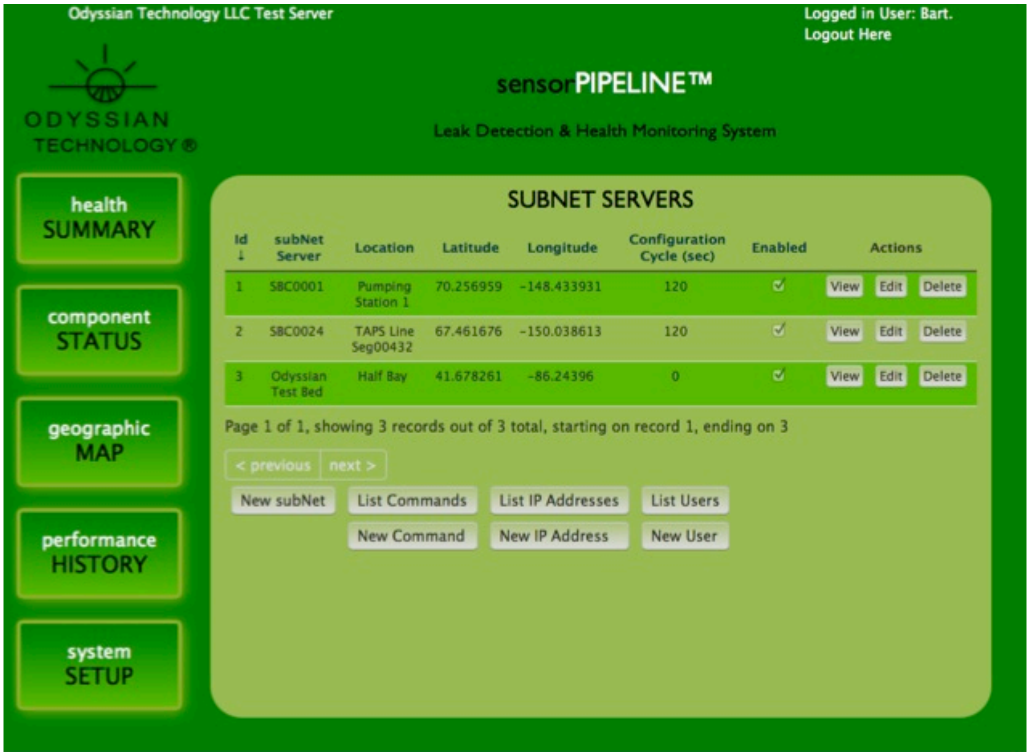



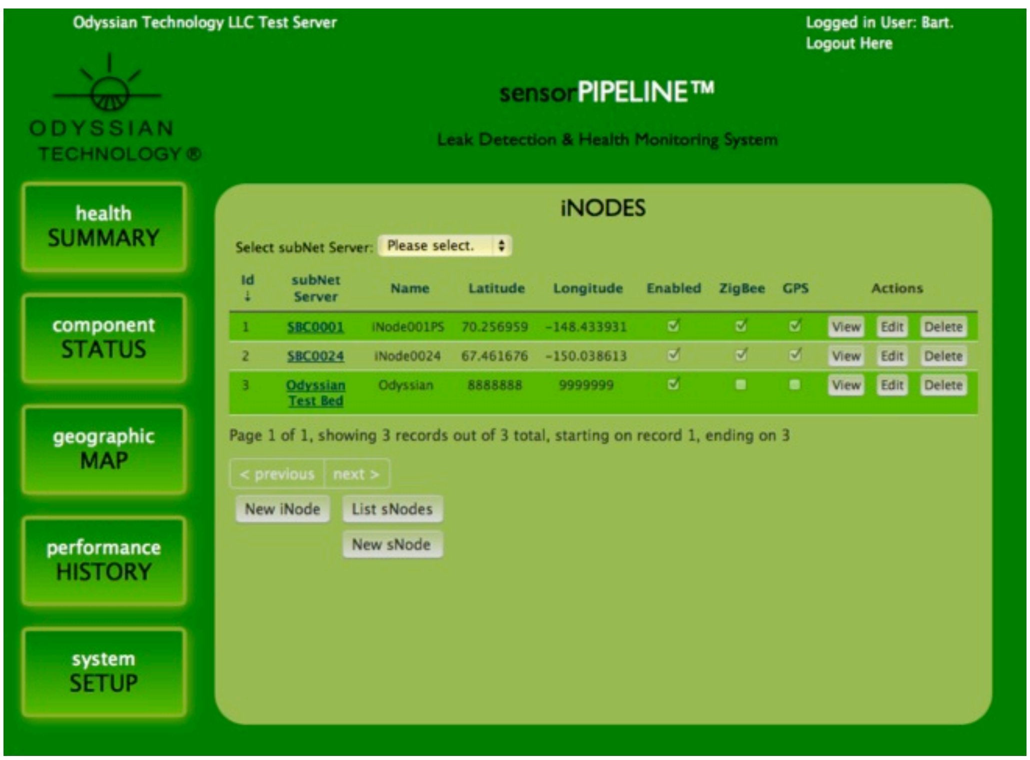

Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
COMPONENT HEALTH STATUS
Component
Leak Detection
Impact Detection
Read Time
Address
Location
Actions
Sleeve-01 sensorSLEEVE
ALARM
ALARM
22:40:27 30-Jul-13
2
Half Bay
Map
Seal -01 sensorSEAL
ALARM
OK
22:40:27 30-Jul-13
3
Half Bay
Map
Spacer-01 sensorSPACER
OK
OK
22:40:31 30-Jul-13
4
Half Bay
Map
Page 1 of 1, showing 3 records out of 3 total, starting on record 1, ending on 3
< previous
next >

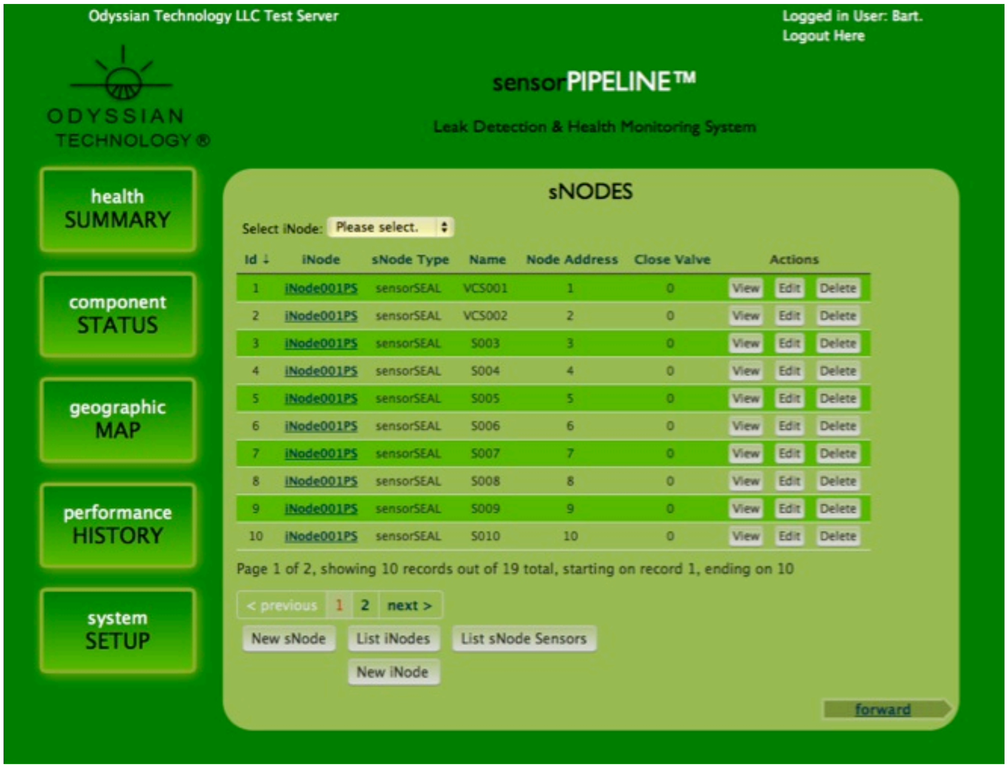

Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
GEOSPATIAL HEALTH STATUS
Map
Satellite
Google
Terms of Use
Report a map error


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
PERFORMANCE HISTORY
Health Status TAPS January 2013 (Operating Hours)
Normal
Caution
Alert
94.7%
By SubNet


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
SYSTEM SETUP
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
subNet server SETUP
iNode SETUP
sNode SETUP
HOST server SETUP
messaging SETUP
user SETUP


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN
TECHNOLOGY®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
SUBNET SERVERS
Id
subNet Server
Location
Latitude
Longitude
Configuration Cycle (sec)
Enabled
Actions
1 SBC0001 Pumping Station 1 70.256959 -148.433931 120 View Edit Delete
2 SBC0024 TAPS Line Seg00432 67.461676 -150.038613 120 View Edit Delete
3 Odyssian Test Bed Half Bay 41.678261 -86.24396 0 View Edit Delete
Page 1 of 1, showing 3 records out of 3 total, starting on record 1, ending on 3
< previous
next >
New subNet
List Commands
List IP Addresses
List Users
New Command
New IP Address
New User


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN
TECHNOLOGY®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
iNODES
Select subNet Server: Please select.
Id
subNet Server
Name
Latitude
Longitude
Enabled
ZigBee
GPS
Actions
1 SBC0001 iNode001PS 70.256959 -148.433931 View Edit Delete
2 SBC0024 iNode0024 67.461676 -150.038613 View Edit Delete
3 Odyssian Test Bed Odyssian 8888888 9999999 View Edit Delete
Page 1 of 1, showing 3 records out of 3 total, starting on record 1, ending on 3
< previous
next >
New iNode
List sNodes
New sNode


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
sNODES
Select iNode: Please select.
Id ↓ iNode sNode Type Name Node Address Close Valve Actions
1 iNode001PS sensorSEAL VCS001 1 0 View Edit Delete
2 iNode001PS sensorSEAL VCS002 2 0 View Edit Delete
3 iNode001PS sensorSEAL S003 3 0 View Edit Delete
4 iNode001PS sensorSEAL S004 4 0 View Edit Delete
5 iNode001PS sensorSEAL S005 5 0 View Edit Delete
6 iNode001PS sensorSEAL S006 6 0 View Edit Delete
7 iNode001PS sensorSEAL S007 7 0 View Edit Delete
8 iNode001PS sensorSEAL S008 8 0 View Edit Delete
9 iNode001PS sensorSEAL S009 9 0 View Edit Delete
10 iNode001PS sensorSEAL S010 10 0 View Edit Delete
Page 1 of 2, showing 10 records out of 19 total, starting on record 1, ending on 10
< previous 1 2 next >
New sNode
List iNodes
List sNode Sensors
New iNode
forward


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY ®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
HOST SETUP
Change to Scenario 1
Change to Scenario 2
Change to Scenario 3
Change to Scenario 4
Change to Odyssian Test Bed
Export System Data
Activate a Valve
Delete subNet Server Sensor History Data
Delete Cloud Sensor History Data


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY®
sensorPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
CONFIGURED EMAIL ALERTS
Id Recipient Email Alert On Time Interval Enabled Actions
2 Todd Pickard todd@creativemindscafe.com ALARM 00:00:15 View Edit Delete
Page 1 of 1, showing 1 records out of 1 total, starting on record 1, ending on 1
< previous next >
New Email Alert
List sNodes


Odyssian Technology LLC Test Server
Logged in User: Bart.
Logout Here
ODYSSIAN TECHNOLOGY®
smartPIPELINE™
Leak Detection & Health Monitoring System
health SUMMARY
component STATUS
geographic MAP
performance HISTORY
system SETUP
USERS
Id Username Role Created Modified Actions
1 todd admin 2013-05-15 21:58:29 2013-05-15 21:58:29 View Edit Delete
2 Bart admin 2013-05-15 22:01:50 2013-05-16 21:47:16 View Edit Delete
3 jimp admin 2013-05-20 23:46:56 2013-05-22 21:00:22 View Edit Delete
4 PHMSA admin 2013-05-25 09:16:29 2013-05-25 09:16:29 View Edit Delete
6 webserviceapi user 2013-06-13 20:04:19 2013-06-13 20:04:19 View Edit Delete
Page 1 of 1, showing 5 records out of 5 total, starting on record 1, ending on 5
< previous next >
New User

| | |
|---|---|
| Attachment J.1 (DEC 2010) | |
| **SUMMARY REPORT** | |
| Topic No: | DTRT57-12-C-10050 |
| Project Title: | Smart Pipeline Network – Seal Sensor System |
| Phase II: _______ Phase II B: ______ | |
| Firm Name | Odyssian Technology |
| Address: | 511 East Colfax Avenue |
| City, State, Zip: | South Bend, Indiana 46617 |
| To best of my knowledge and belief the data provided below is accurate, complete, and current as of the date of signature below. | |

PRINCIPAL INVESTIGATOR

Name Barton Bennett
Title Co-Founder & CTO

SIGNATURE: DATE JULY 25, 2013

Telephone No. 574-257-7555
E-mail Barton.bennett@odyssian.com

CORPORATE/BUSINESS OFFICIAL/
PROJECT DIRECTOR
Name Barton Bennett
Title Co-Founder & CTO

SIGNATURE DATE JULY 25, 2013

Telephone No. 574-257-7555
E-mail Barton.bennett@odyssian.com

**PERIOD OF PERFORMANCE: AUGUST 15, 2012 TO JULY 26, 2013**

The Pipeline Research Council International (PRCI) provided support to this SBIR program by providing input and advice on the needs and issues related to leak detection within the pipeline industry. It's membership also provided support by identifying applications, as well as reviewing and commenting on Odyssian's conceptual designs. PRCI formed a group within its membership, called the PRCI Smart Pipeline Steering Committee. Collectively and individually, members of this group helped to define the application and scope of the smart system that would be developed and demonstrated. Deliberation over whether to focus on pipeline facilities or long-run pipeline considered such factors as remoteness, the likelihood of a leak, the length of time to detect a slow leak, the type of fittings, and the consequence of a leak. While it was recognized that facilities had many more threaded or flanged fittings than long run piping systems, it was decided to focus on long-run pipe because of the greater likelihood of a leak occurring in a remote area and being undetected for a longer period of time. Later in the program, there became a more expressed desire from the committee to develop technology that has application within pipeline facilities because of the greater amount of flanged fittings. Discussions near the end of the program with PRCI members indicated that for facilities the following is needed,

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| **SUMMARY REPORT** | |
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| Phase II: _______ Phase II B: ______ | |
| Firm Name | Odyssian Technology |

3. Smart mechanical seals for use on pumps and compressors

4. Smart spiral wound flange gaskets that can sense leaks.

The selected product type to be sensed was refined liquid petroleum, with specific interest given to gasoline. Odyssian Technology proposed this product type to allow use of its proprietary fuel sensor, which lends itself well to integration within smart devices. Members of the PRCI committee accepted the selection of refined liquid product, specifically gasoline. This is because when water is involved, gasoline can be more damaging than oil because it seeps through the ground more quickly and mixes in with water, making it harder to remove. Gasoline also gives off more dangerous fumes and can ignite more easily than crude oil.

Based upon the initial pipeline application and product selection, design concepts were developed for smart seals for use in long-run Oil and Gas (O&G) pipeline systems. Long-run pipeline systems typically have impressed current cathodic protection (ICCP) systems to prevent corrosion of the steel pipe. Near the beginning of the program, Odyssian Technology established a relationship with Garlock Pipeline Technologies (GPT), a major producer of voltage isolating gaskets. An operating group of GPT, which is formerly Pikotek, collaborated with Odyssian Technology to develop a smart seal.

Initial seal concepts had conventional layouts that were tailored for a bolted flange fitting on a 4-inch pipe. Early conceptual designs included embedded sensing circuits having novel a novel sensing technology called Dispersion Media Sensing (DMS). Initial seal concepts had multiple modes of sensing to minimize the likelihood of a false possible or negative. This included the use of dispersion media sensing (DMS) along with micro-electromechanical systems (MEMS) pressure sensors. In this dual-mode sensing scheme, a leak is detected directly (DMS) and indirectly (MEMS). A conclusive leak would have sensory alarms from both the indirect and direct sensors.

Garlock's Pikotek Very Critical Services (VCS) seal was used as a model from which a smart seal was developed and prototyped (see http://www.gptindustries.com/product/vcs). This seal was selected because it is a voltage isolation seal, and because its basic construction made initial prototyping relatively easy and inexpensive. Design concepts of the smart seal were developed using the same basic general construction arrangement used in the VCS seal. This included having a stainless steel core, a conventional GRE sheet on one face, and an electronic GRE face on the other face. The electronic GRE made up the sensor circuits needed to detect a leak and to detect earth movement or an impact.

A prototype of the smart seal was developed and tested. This seal, called the sensorSEAL™ , was developed having four types of sensors. This included micro-electromechanical-systems (MEMS) pressure sensors, reactive fuel sensor, an accelerometer, and a sensor O-ring. The MEMS and reactive sensor are for detecting the leakage of gasoline and other fuel hydrocarbons, the accelerometer is for detecting impact and earth movement and the sensor O-ring is for sensing sealing force. The reactive fuel sensor is proprietary to Odyssian Technology and was modified to improve its use in the smart pipeline system components, include the sensorSEAL™. The sensor O-ring is a proprietary seal made by Odyssian Technology that through special material formulation and algorithms have been shown to detect in changes sealing force or compression. Commercial-off-the-shelf (COTS) MEMS pressure sensors and accelerometers where used to detect pressure buildup from leaks and vibration from impacts, respectively.

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| | Attachment J.1 (DEC 2010) |
| **SUMMARY REPORT** | |
| Topic No: | DTRT57-12-C-10050 |
| Project Title: | Smart Pipeline Network – Seal Sensor System |
| Phase II: _______ Phase II B: ______ | |
| Firm Name | Odyssian Technology |
| Testing was performed to establish alarm threshold values, condition the sensors, and to calibrate the MEMS pressure sensors. | |

Attachment J.2 JAN 2011

**PHASE I COMMERCIALIZATION REPORT**

| | |
|---|---|
| Topic No: | DTRT57-12-C-10050 |
| Project Title: | Smart Pipeline Network – Seal Sensor System |
| Firm Name | Odyssian Technology LLC |
| Address: | 511 East Colfax Avenue |
| City, State, Zip: | South Bend, Indiana 46617 |
| **Provide Narrative and Relevant Statistical Data.** | The 2012 Leak Detection Study conducted by the PHMSA points out that 44% of these old, over 170,000 miles, hazardous liquid pipelines are in High Consequence Areas — which means that peoples' lives are at risk if they leak or spill. Thus, it is important that leak detection systems are used to promptly identify when a leak has occurred so that appropriate response can be initiated quickly. Analysis of historical incident data reported by US pipeline operators allows calculation of the financial consequences of leak scenarios. US Pipeline & Hazardous Materials Safety Administration (PHMSA) data and statistics for distribution and transmission pipelines show 730 hazardous liquid pipeline accidents between Jan. 1, 2010, and August 2012 with 241 involving at least 10 bbl. Average cost/accident was $1,343,041. Average cost/bbl released was $4,263. This analysis excludes fines, damage to the company image, imprisonment, and other consequences more difficult to quantify. Costs include:<br><br>• Product loss.<br>• Property damage and repair.<br>• Emergency response.<br>• Environmental damage<br><br>It is known throughout the oil and gas industry that the multitude of pumping stations in the world experience huge problems with leaking flanges and mechanical seals. Some of these are slow leaks that go undetected due to no detectable loss in pressure. Many of these oil spills are not widely publicized because they are contained within the operations area. The high density of pumps and flange fittings at these facilities creates an environment for small continual leaks that often go undiscovered for long periods of time. This can amount to a substantial loss of product and as seen at the Elk Point Alberta, spill damage to the surrounding environment.<br><br>The Elk Point Alberta pumping station leak is an example of a large spill of approximately 61,000 gallons from a leaking flange that could have been detected and stopped with the implementation of the Seal Sensor System.<br><br>**http://metronews.ca/news/edmonton/269475/pumping-station-leaks-230k-litres-of-oil/**<br><br>The Smart Pipeline Network - Seal Sensor System provides a valuable solution. Not only is it a good replacement for the conventional mechanical seals but it can also be incorporated into the flange fittings. The Seal Sensor System will sense a loss of liquid or gas, drops in pressure and vibration. This system can be readily implemented into the multitudes of facilities by Odyssian Technology's installation and maintenance team and to immediately relay status and alerts of problem areas. This immediate leak detection |

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| | Attachment J.2 JAN 2011 |
| **PHASE I COMMERCIALIZATION REPORT** | |
| Topic No: | DTRT57-12-C-10050 |
| Project Title: | Smart Pipeline Network – Seal Sensor System |
| Firm Name | Odyssian Technology LLC |
| Address: | 511 East Colfax Avenue |
| | saves on the costly loss of product and environmental damage and Odyssian's installation and maintenance will cut the cost of expensive training and operator errors. |

Please describe the degree of interest made by third parties, other Federal agencies, state and local governments, as well as private enterprise, in acquiring the products or services developed under this contract.

Odyssian Technology expects to use a licensing strategy to bring its patented and proprietary products to market. Of particular interest is EnPro Industries, a leading manufacturer of high-performance industrial seals, bearing and compressor components. Galock's Pikotek a division of EnPro Industries has worked closely with Odyssian by providing existing technologies and substantial information of the current sealing method short falls and needs. Garlock has shown great interest in the Smart Pipeline Network - Seal Sensor System. Garlock which has indicated its willingness to conduct preliminary market research.

Please describe the potential market for the products or services developed under this contract for the purpose of applying it to other commercial markets.

Apart from the oil and gas industry, it is reasonable to assume that leak detection in other industries is important. The importance of leak detection in the water, wastewater, renewable and alternative energy industries is a growing concern. In a study conducted by The Fredonia Group, it was projected that the demand for water and wastewater pipe in the U.S. is estimated to rise 5.8 percent annually to $19.6 billion in 2014. Advances will reflect renewed activity in the residential building construction sector, the growing obsolescence of sewer and drainage systems and upgrades of municipal water systems. Another study conducted by Frost and Sullivan indicated that the global leakage levels of water average 25-30 percent. However, just as with the oil and gas industry, it is suspected that there are selective areas along the distribution network where an alternative to current methods may be required.

Additionally, areas where water is treated, as a precious commodity the interest in leak detection is highest. The Smart Pipeline Network – Seal Sensor System will lend itself well in sensing leaks, pressure variance, and vibration.

Specialty pipelines are required for renewable and alternative energy substances as their chemical composition is often corrosive or destructive to the existing, conventional pipeline infrastructure. A 2010 report prepared by SBI Energy estimates that the total global market for specialty pipelines, transport of carbon dioxide, ethanol, biodiesel, biogas, and bio methane, will show year over year increases of 30% through 2015.

The Smart Pipeline Network – Seal Sensor System lends itself well to new pipeline systems and could replace static seals currently in use. Use of Odyssian's Seal Sensor System will provide real time monitoring for point-of-source leak detection, resulting in the elimination of lost product, reduction in spillage, as well as the reduced need for fines and penalties.

Please describe the potential market for the products or services developed under this contract for the purpose of applying it to Government requirements.

The existence of a market depends upon the availability of funding and the ability of a provider to address the need in a cost-effective and approved way. The 2012 Leak Detection study concluded with a discussion of operator opinions regarding budgets for leak detection systems, which indicates that budgets are limited and driven be a desire to meet regulation. Technologists

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| | Attachment J.2 JAN 2011 |
| **PHASE I COMMERCIALIZATION REPORT** | |
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| Firm Name | Odyssian Technology LLC |
| Address: | 511 East Colfax Avenue |

included in this study indicated that regulations were key to enabling their technologies to be adopted.

- " The opinion of the large majority of interviewees was that that overall leak detection budgets are driven by an honest desire to meet regulations and industry standards, but no more. In order to secure a program budget from the board, a case has to be made that it is necessary to meet an external standard or obligation.
- The interviewees [which did not include representatives from the corporate risk analysis group] did not think that leak detection was a significant consequence mitigation measure at the corporate level.
- The personnel interviewed were given working budgets for a period of between on and five years. Therefore actual investment in leak detection has to be taken out of additional departmental responsibilities (metering, SCADA, Information Technology).
- They are all regularly asked to rank potential technical options in terms of costs and benefits. Despite this, a large number reported that even very cost-effective options are often excluded if they do not follow accepted internal procedures. Following a tried and tested approach is usually valued more highly than cost-benefit.
- Those included in the study indicated that their companies carried liability insurance specifically against "pipeline losses".
- The technology developers considered that regulation alone is largely responsible for the adoption of their products, at any price."

In the Oil and Gas industry, the market opportunity for leak detection exists because of a number of federal regulations. Most recently, the Pipeline Safety Improvement Act of 2006 encouraged the continued study of pipeline safety and security practices and mandated a leak detection study. In 2007, this study was commissioned by the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) and was issued in 2012 as the Leak Detection Study. Three types of leak detection systems (LDS) were defined and categorized in this report: (1) visual inspection techniques; (2) instrumented monitoring of internal pipeline conditions; and (3) external, instrumentation for detecting leaked hydrocarbons. This comprehensive study defines a leak detection system (LDS) as having three components, all of which must be considered: Personnel, Procedures, and Technologies. According to operators, "false alarms" are a major concern and are not the result of the LDS not functioning properly. False alarms reflect the fact that normal operational changes on or near the pipeline can cause exactly the same physical effects that the LDS uses to detect leaks. "It is an inherent difficulty with any technology that relies upon any physical side effect of a leak for its detection." Another issue mentioned was that external systems are often quite complex and are difficult to select, engineer, and deploy. Leak detection system complexity or high cost does not necessarily translate to better performance. Without a focus on all three: technology, people and procedures, a single "weak link" can render the overall system useless. In particular even very simple technologies can be very effective, if they are backed up by highly skilled operators and well-designed procedures. Design choices need to be balanced with available and committed operating and maintenance resources.

Odyssian Technology's Smart Pipeline Network System will not only satisfy current government regulations and requirements but it will exceed these requirements and will establish a standard for clean pipeline systems. Odyssian's plan to install, maintain and monitor the Smart Pipeline Network System will prevent costly maintenance error, damaging leaks, loss of product, loss of life, harm to the environment and fines and/or penalties. In light of the oil and gas industries current standard practice of merely

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| working to meet government requirements and regulations change will not occur without additional regulation. The Smart Pipeline Sensor Network System is a viable solution for leak detection suited for installation on both new and old pipelines. But just as has been seen with many other technologies and as was stated by the interviewees no change will be made within this industry without stringent requirements/regulations and shorter timelines to implement. These industries must not merely react to disasters but they must prevent them.<br><br>View of more oil spills since the 2010 Gulf of Mexico disaster that spilled 210,000,000 gallons of oil over an 87 day period.<br>http://www.huffingtonpost.com/2013/07/05/crow-reservation-gasoline-spill_n_3550728.html#slide=2097848 | |
| Patents & Patents Applied for have has been reported in accordance with H.12. | No Patents have been filed, as of yet, that have been developed from program related technology. Previously held patents related to the Smart Pipeline Network technology as listed below.<br><br>1. Seals with Integrated Leak Progression Detection<br>11/090,527<br>Granted/Registered –United States<br><br>2. Seals with Integrated Leak Progression Detection<br>08 727 381.9<br>Examination Report - Received European Patent Office – United States<br><br>3. Gaskets and Seals with Integrated Leak Detection Capabilities PCT/US09/65695<br>Examination Report Received – Patent Cooperation Treaty<br><br>4. Seals with Integrated Sensor<br>8,601,211<br>Granted/Registered–United States<br><br>5. Composite Repair for Pipe and Monitoring Assembly<br>13/396,294<br>Application Filed – United States<br><br>6. Compostie Repair for Pipes<br>8,113,242<br>Granted/Registered – United States |
| Have you issued a press release or media for publicity? | Odyssian Technology is in the process of updating its website. Upon completion of the website press releases will be issued. |
| | |

**Attachment J.3 (April 2010)**

**SBIR Phase I**
**CONTRACTOR REPORT OF GOVERNMENT PROPERTY**

**1. Contract Number:** DTRT57-12-C-10050

**2. Report Period Ending:** July 25, 2013

**3. Contractor (Name and Address)**
Odyssian Technology
511 East Colfax Avenue
South Bend, Indiana 46617

**4. Contracting Office (Name and Address)**
USDOT/RITA/Volpe Center
Contracts & Tech support Services
55 Broadway RVP-32
Cambridge, MA 02142-1001

**5. Name and location of Government-Owned, Contractor-Operated Plant (if applicable)**
NONE

**6. Any Government property located at a subcontractor's plant? ______ Yes X No. If yes, give the name and address of the subcontractor(s) on an attached sheet to this report.**

| 7. Property Class (See FAR 45.5) | Item/ Description | Unit Price In dollars | Quantity | Total Acquisition Cost | Invoice Date | Required for Phase II.B or Phase III (yes/no) |
|---|---|---|---|---|---|---|
| Plant Equipment | | | | | | |
| Special Test Equipment | | | | | | |
| Special Tooling | | | | | | |
| Materials in Stock | | | | | | |
| Other Real Property | | | | | | |

**NOTE: This report shall include all Government property (i.e., property furnished by the Government, or acquired or fabricated by the contractor or subcontractors). By signature hereon, the contractor's property administrator declares that the report was prepared from the contractor's records.**

**8. Typed Name of Contractor Property Administrator**

Susan Bennett

**9. Signature and Date**

S Bennett

DOT SBIR Phase I
Contract No: DTRT57-12-C-10048
DTRT57-12-C-10049
DTRT57-12-C-10050

Assertion of Data Rights

**Required Data Rights Assertion FAR 52.227-20**

| Technical Data to be Furnished With Restrictions* | Basis for Assertion** | Asserted Rights Category*** | Name of Entity Asserting Restrictions**** |
|---|---|---|---|
| Concepts, technology, and data related to multifunctional or smart seals, smart gaskets, rubber sealing sensors and custom pressure sensors. | Developed under non-federal funds | Limited Rights | Odyssian Technology |
| Concepts, technology, and data related to hydrocarbon sensing. | Developed under non-federal funds | Limited Rights | Odyssian Technology |
| Concepts, technology, and data related to sensors to detect leaks in water distribution, gasoline piping and storage tanks. | Developed under non-federal funds | Limited Rights | Odyssian Technology |
| Concepts, technology, and data related to multifunctional sandwich electronic structures including dual wall truss electronic piping. | Developed under non-federal funds | Limited Rights | Odyssian Technology |
| Concepts, technology, and data related to smart collar (sensor boot). | Developed under non-federal funds | Limited Rights | Odyssian Technology |

July 17, 2012

Odyssian Technology
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