Utilizing Distributed Fiber Optic Sensing Systems to Detect Leaks and Ground Movement and Prevent Damage to Pipelines

This paper contains four sections outlining how distributed fiber optic sensing (DFOS) can be used to monitor pipeline conditions (leaks, pig tracking, hot tap/valve detection, and geologic disturbances) and heat tracing as well as detecting third-party intrusions (TPIs) to help prevent leaks occurring via accidental or deliberate damage. The first section explains the technology behind DFOS; the second section explains challenges facing the pipeline industry; the third section explains how DFOS can help solve these challenges; and the fourth section provides recommendations for Congress and the Executive Branch.

I. What is Distributed Fiber Optic Sensing (DFOS)?

Distributed fiber optic sensing (DFOS) systems are a sensor technology used around the world to constantly and consistently monitor terrestrial and subsea pipelines and power cables, international borders, critical infrastructure, power stations, telecom networks, railways, roads, and bridges. DFOS systems connect laser interrogator units (IUs) to a fiber optic cable, converting the fiber to an array of distributed sensors. The fiber becomes the sensor, and is a cost-effective method for monitoring long distance infrastructure assets while reducing the cost of asset ownership by 1) providing operating risk mitigation to operators and the public and 2) making operations more efficient. Often the fiber optic cable investment is multi-use, exists already, provides data communications along the infrastructure, and can be easily transformed to sense for safety and efficiency. For example, along a pipeline, all facilities, such as pumping stations or valve sites, can be connected with a high bandwidth fiber optic network that is simultaneously acting as a sensing array.

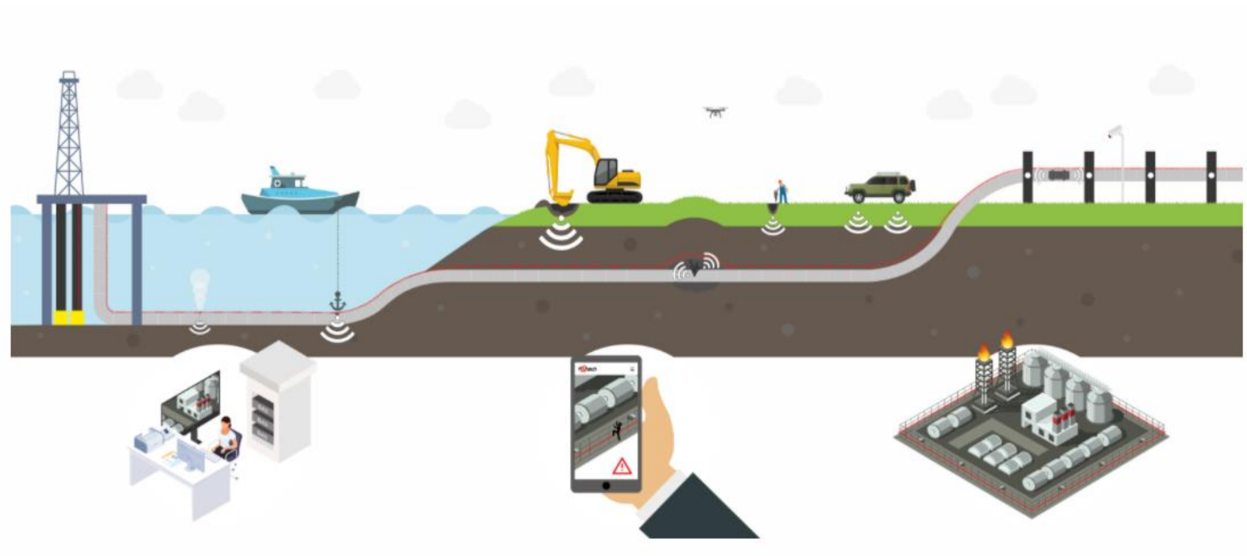
More specifically, DFOS systems consist of a fiber optic cable, IUs, and intelligent monitoring software. The IU emits pulses light thousands of times per second within the fiber optic cable. Changes in vibrations/acoustics, temperature, or strain at or near the fiber optic cable are identified and classified in real time by intelligent monitoring software, which then alerts the operator of the system with what the disturbance is and precisely where it is located. Patterns of acoustic behavior can be detected to identify unique occurrences such as digging, walking, vehicles, liquid and gas leaks.

There are four basic types of DFOS systems:

1. **Distributed Acoustic Sensing (DAS)**
   DAS systems convert fiber optic cable into a series of thousands of sensitive microphones or vibration sensing locations. Using specially developed algorithms it is possible to listen to, track, detect and pinpoint various activities and events along assets, including vehicle and foot traffic, digging, tunneling, seismic activity, rock falls, and landslides. DAS can also be used for asset condition

monitoring by detecting events such as pipeline leaks or broken rails, and much more.

2. **Distributed Temperature Sensing (DTS)**
   DTS is a fiber-optic sensing technology for measuring temperature profiles along fiber-optic sensor cables installed near linear assets as well as on two- or three-dimensional objects. Major applications of DTS are leak detection at pipelines and storage tanks, fire detection in tunnels and buildings, power cable monitoring, and monitoring of industrial equipment such as ovens and reactors and oil and gas production.
3. **Distributed Strain Sensing (DSS)**
   DSS is a fiber optic sensing technology that measures changes to strain at all points along the length of a fiber optic cable. DSS is commonly used for monitoring large structures where changes in strain may be indicative of impending failure. Pipelines, dams, levees, bridges, tunnels, roadways, and power cables are all structures that can benefit from DSS monitoring. Similarly, industrial process monitoring, as well as pipeline deformations, tunneling, and landslides can be detected by DSS measurements.



II. Pipeline Challenges in the United States

There are more than 2.8 million miles of pipelines in the U.S. that move more than 16 billion barrels of hazardous liquids and gases every year. These pipelines are geographically widespread, running through remote regions and densely populated regions, from Arctic Alaska to the Gulf of Mexico. While pipelines are the safest way to transport energy products like natural gas, crude oil, and other fuels, because they carry volatile, flammable, or toxic materials, they have the potential to injure the public, destroy property, and damage the environment.

Over 98% of these pipelines are made of steel, which are vulnerable to corrosion. Pipeline operators use a range of technologies to protect steel pipes from corrosion, but these can degrade over time. The National Transportation Safety Board highlighted aging pipelines as a particular concern in its 2019-2020 *Most Wanted List of Transportation Safety Improvements*. Natural forces, such as floods and earthquakes, can also damage pipelines. And leaks, or uncontrolled pipeline releases, can also be caused by third-party excavations that are improper or unauthorized, mechanical failures, control system failures, operator errors, and malicious acts.

High-profile incidents such as the 2010 San Bruno pipeline explosion that killed 8 and injured 60, the 2018 landslide in Marshall County, WV that caused a newly installed natural gas pipeline to rupture and explode, and the 2019 Keystone pipeline rupture that caused over 383,000 gallons of oil to contaminate surrounding wetlands in North Dakota underscore the impact of problems caused when pipelines fail.

According to Pipeline and Hazardous Materials Safety Administration (PHMSA) statistics, while there was a steady decline of pipeline incidents between 2009 and 2013, since then the average incident count increased and recently shows that incidents continue.

PHMSA Pipeline Incidents: (2002-2021)
Incident Type: Serious **System Type:** (All Column Values) **State:** (All Column Values)

Calendar Year	Number	Fatalities	Injuries
2002	36	12	49
2003	61	12	71
2004	44	23	56
2005	38	16	46
2006	32	19	34
2007	42	15	46
2008	36	8	54
2009	46	13	62
2010	34	19	103
2011	31	11	50
2012	28	10	54
2013	24	8	42
2014	27	19	94
2015	26	9	48
2016	38	16	86
2017	23	7	30
2018	36	6	78
2019	25	11	35
2020	27	15	40
2021	26	11	31
Grand Total	**680**	**260**	**1,109**

III. How Can DFOS Solve These Challenges?

Pipeline operators carefully build, maintain, and monitor the integrity and security of their pipelines. They invest in employee training and actively work to prevent corrosion and mechanical and human error. In addition, they engage with the construction industry through such programs as the ‘Dial-before-you-dig’ 811 phone number service, to prevent unintentional damage to lines due to excavation activity. However, PHMSA’s data showing no clear improvement trend in reducing the number of pipeline incidents, particularly in light of increasingly aging pipelines, emphasizes that more needs to be done.

Remote-sensing technologies like DFOS are making it easier and more cost-effective for pipeline operators to continually monitor very long assets, inspect for problems, and proactively address potential concerns. DFOS has a well-proven capability of detecting smaller leaks faster, with high location accuracy, as well as providing early warning of pipeline intrusion threats on the right of way, typically before pipeline damage occurs. Compared with traditional leak detection, which is generally based on discrete point sensors, DFOS offers significant advantages in terms of having thousands of distributed sensors over the same monitoring span. This is why DFOS is able to provide an order of magnitude improvement in sensitivity (e.g. leaks an order of magnitude smaller can be detected in minutes) and accuracy (e.g. 5-50 ft location) compared to traditional leak detection technologies (miles) leading to lower overall spilled volumes. DFOS systems are also widely used to provide warning of ground movement through strain monitoring, which often lead to major pipeline failures, as well as seismic activity, which is currently being investigated by the California Energy Commission for natural gas infrastructure. In all, DFOS systems are estimated to be monitoring some 40,000 miles of pipelines around the world, but the US makes-up a tiny fraction of that monitored distance, mainly due to a lack of awareness and education about the benefits of the technology.

While the cost of retrofitting fiber on existing pipelines is practical, the technology lends itself easily to installation on new pipelines when the trench is open so the communications and sensing benefits of fiber optics can be made available at minimal expense. Often the cable can be pulled or jetted into a plastic conduit, which makes the installation highly efficient and robust. Fiber optics, which are known to continue to function with high reliability for decades with little maintenance, provide an excellent investment on new construction projects, considering the multi-use of communications and pipeline safety. The additional compliment of conduit pathways enables rapid and easy repairs to the fiber cable if required, in addition to possibly desired future fiber cable additions or replacement.

DFOS systems are resilient. In the event that a fiber optic cable is inadvertently cut, the remaining spans will continue to function and can easily be repaired. In the event of deliberate cable tampering, such as cutting, these systems immediately pinpoint where the cut is occurring so that intervention can occur without time-consuming, costly searches.

IV. FOSA Recommendations

FOSA supports PHMSA's goal to improve the safety of the Nation's 2.8 million miles of gas and liquid pipeline and recommends the following initiatives:

- Completion of the report required by the 2020 PIPES Act from the Secretary of Transportation on the R&D capabilities of the administration and the costs and benefits of developing an independent pipeline safety testing facility.
- Authorization and appropriation of sufficient funding for the design and development by PHMSA of a world-class pipeline Research, Development, and Testing (RDT) Facility at the Transportation Technology Center (TTC) in Pueblo, CO, to facilitate the demonstration and development of DFOS and other pipeline safety technologies.
- Timely promulgation of the final rule called for in Section 113 of the PIPES Act of 2020 (P.L. 116-260), Section 113 requires a final rule directing gathering, transmission, and distribution pipeline operators to conduct leak detection and repair programs that meet minimum performance standards and identify and repair or replace leaky pipes.
- Continue to encourage and fund the research and development of fiber optic retrofitting on existing 'brownfield' pipelines.
- Legislation and regulations to expand "Dig Once" policies to new pipeline construction projects requiring pipeline operators and third parties to assess the long-term costs/benefits of installing fiber optic infrastructure along open trenches in new pipeline construction projects with the added benefit of bringing broadband to rural and Native American communities.

About the Fiber Optic Sensing Association (FOSA)

The Fiber Optic Sensing Association (FOSA) is a non-profit organization composed of organizations that manufacture, install, test, evaluate, support or use fiber optic sensing systems and equipment. FOSA's mission is to educate industry, government, and the public on the benefits of fiber optic sensing and how it can be used to secure critical facilities, enhance public safety, and protect the environment.