Enbridge Consent Decree – Civil Action No. 1:16-cv-914
Independent Third Party Review and Evaluation of Enbridge Submittal: Section G Paragraphs 81,82, and 83
Report on Feasibility of Installing an Alternative Leak Detection System at the Straits of Mackinac

Amended

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The United States
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O.B. Harris, LLC, the appointed Independent Third Party (ITP) under the Enbridge Consent Decree (CD) (Civil Action No. 1:16-cv-914) has prepared this report at the request of the Environmental Protection Agency (EPA) and pursuant to CD requirements. In assessing Enbridge's compliance with the requirements contained in the CD, the ITP has in part relied on data and information supplied by Enbridge. The ITP, though, cannot be responsible for any errors or omissions in this report that are a result of errors or omissions in the data and information provided by Enbridge. This report, and the assessment reflected herein, supersedes any report relating to the subject matter hereof previously prepared by the ITP.

To the extent in this report that the ITP finds that Enbridge is in compliance with, or not in compliance with, the CD requirements addressed by this report, such finding is for the sole purpose of informing the EPA of the ITP's independent conclusions. The EPA remains, in all circumstances, the party which will officially determine whether Enbridge is in compliance with, or is not in compliance with, the CD.

Notice of Amendment

On February 19, 2018 the ITP published its review and evaluation of the *Report on Feasibility of Installing an Alternative Leak Detection System at the Straits of Mackinac* (*ALD Straits Report*).

Following publication of the ITP report, Enbridge provided clarifications regarding the definition of abnormal operating conditions, sensitivity values in Appendix 2, and the PCRI document discussed in Appendix 2.

This amended report restates the original report, but with the following sections revised to reflect the clarifications provided by Enbridge:

- Definitions
- Appendix 2: Fiber Optic Cable – Distributed Acoustic Sensing
- Appendix 2: Fiber Optic Cable – Distributed Temperature Sensing
- Appendix 2: Negative Pressure Wave

This amended report supersedes the original report in its entirety.

Definitions[1]

Item	Definition
ALD	Alternative leak detection
AOC[2]	Abnormal operating condition. Defined by Enbridge to include: • Transient operations • Column Separation conditions • Batch operations • Instrumentation failure • Communications failure • PLC failure • SCADA failure • Presence of pipeline pigs • Ancillary software process failure
API	American Petroleum Institute
API RP	API Recommended Practice
CD	Consent Decree. *United States of America v. Enbridge Energy, Limited Partnership, et al; Civil Action No. 1:16-cv-914*. Defined in the CD to include "this Decree and all Appendices attached hereto (listed in Section XXV [of the Consent Decree])."
CD ¶	Consent Decree Paragraph. Paragraph is defined in the CD as "a portion of this Decree identified by an Arabic numeral." The ¶ symbol is not used to note paragraphs from any other document.
CPM	Computational pipeline monitoring. A technology that uses computer software to monitor and process real-time values of pressure, temperature, flow, and fluid properties to identify leaks.
Column Separation	Defined in the CD as "the condition where a pipeline segment is not entirely filled with liquid or is partly void."
DAS	Distributed acoustic sensing. A technology whereby fiber optic cable is used to sense acoustic vibration as an indication of a leak.
Day	Defined in the CD as "a calendar day unless expressly stated to be a business day. In computing any period of time under this Consent Decree, where the last Day would fall on a Saturday, Sunday, or U.S. federal holiday, the period shall run until the close of business of the next business day."
DTS	Distributed temperature sensing. A technology whereby fiber optic cable is used to detect temperature and uses temperature differential as an indication of a leak.
DVN-GL RP	DVN-GL Recommended Practice

[1] Definitions from the CD are found in CD ¶10.
[2] This definition is from the *ALD Straits Report*, is specific to abnormal operating conditions in the leak detection system, and is an elaboration upon the definition of 'robustness' found in API 1130, Annex C. This definition is materially different from the PHMSA definition found at 49 C.F.R. § 195.503, which applies to a broader set of conditions found in pipeline operations.

Item	Definition
Effective Date	Defined in Section XVII of the CD as "the date upon which this Consent Decree is entered by the Court or a motion to enter the Consent Decree is granted, whichever occurs first, as recorded on the Court's docket." The Effective Date for this CD is May 23, 2017.
ELDER	External Leak Detection Experimental Research. A facility created through a pipeline operator JIP to evaluate in-soil external leak detection technology.
Enbridge	Defined in the CD to include "Enbridge Energy, L.P., Enbridge Pipelines (Lakehead) L.L.C., Enbridge Energy Partners, L.P., Enbridge Energy Management, L.L.C., Enbridge Energy Company, Inc., Enbridge Employee Services Canada Inc., and any of their successors and assigns."
EPA	Environmental Protection Agency. Defined in the CD to include "any of its successor departments or agencies."
External Leak Detection	Refers to technologies that are physically located outside the pipe and are used to detect pipeline leaks.
FOC	Fiber optic cable
FOSA	Fiber Optic Sensing Association
HSC	Hydrocarbon sensing cable. A class of technology where a special cable is placed in the pipeline trench alongside the pipe.
Hybrid LDS	An Enbridge-specific LDS implementation that integrates negative pressure wave, statistical flow, and volume balance measurements.
ILI	In-line inspection
ITP	Independent Third Party. CD Section J outlines the responsibilities of the ITP. O.B. Harris, LLC serves as the ITP for this CD.
JIP	Joint industry project. A project typically funded by multiple entities within a given industry to advance the development or application of technology. Also referred to as a joint industry partnership and joint industry program.
Lakehead Plan	The *Corrective Action Plan*, and its subsequent revisions, submitted by Enbridge to PHMSA in response to PHMSA's August 1, 2012, amendment to its *Corrective Action Order* of July 30, 2012, in case CPF No. 3-2012-5017H.
LDS	Leak detection system
MBS MBS LDS	Material Balance System MBS Leak Detection System Defined in the CD as "the computational pipeline monitoring system used by Enbridge to detect leaks or ruptures in the Lakehead System."
NGL	Natural gas liquid
PHMSA	Pipeline and Hazardous Materials Safety Administration. Defined in the CD to include "any of its successor departments or agencies."
PLC	Programmable logic controller
PRCI	Pipeline Research Council International

Item	Definition
RTTM	Real-time transient model. A type of CPM system that uses real-time measurement of pressure, temperature, fluid properties, and similar properties to determine whether the operating state of the pipeline is normal or abnormal, potentially representing a leak condition.
Section (of CD)	Defined in the CD as “a portion of the Decree identified by a Roman numeral.”
SCADA	Supervisory Control and Data Acquisition System. Defined in the CD as having the “same meaning as defined by C.F.R § 195.2” which defines it as “computer-based system or systems used by a controller in a control room that collects and displays information about a pipeline facility and may have the ability to send commands back to the pipeline facility.”
Steady-State	Defined in the CD as “the pipeline hydraulic condition that exists when all pipeline operating parameters remain nearly constant over time.”
VST	Vapor sensing tube. A class of technology that detects the presence of hydrocarbon vapor in the air.

Executive Summary

The Independent Third Party (ITP) for the Enbridge Consent Decree (CD), O.B. Harris, LLC, was engaged effective January 11, 2017. The role of the ITP pursuant to the CD is to conduct a comprehensive verification of Enbridge's compliance with the requirements of the CD.[3]

On November 19, 2017, Enbridge submitted the *Report on Feasibility of Installing an Alternative Leak Detection System at the Straits of Mackinac* (*ALD Straits Report*). As required by CD Paragraph (¶) 132.b, the ITP has reviewed and evaluated the *ALD Straits Report*. On January 3, 2018, the Environmental Protection Agency (EPA) requested the ITP to prepare and provide a written report of its evaluation of the *ALD Straits Report.*

The CD requires that, within 180 Days of the CD Effective Date (May 23, 2017), Enbridge submit a report regarding the feasibility of installing an alternative leak detection (ALD) system at the Straits of Mackinac. Enbridge is required to:

- Evaluate the following leak detection technologies:
  - Fiber optic cable (FOC) (acoustic and temperature)
  - Vapor sensing tube (VST)
  - Negative pressure wave
  - Hydrocarbon sensing cable (HSC)
- Evaluate the:
  - Potential effectiveness of the technology in detecting leaks and ruptures of different sizes.
  - Practicability of deploying the technology in the Straits of Mackinac.
  - Practicability of long-term operation and maintenance of the technology.
  - Net present cost of the technology, taking into account the initial capital cost to install the technology and the annual expense to operate and maintain the technology.
- Compare the relative performance of each of the evaluated technologies with respect to any other factors Enbridge may decide to add to its analysis.
- Evaluate the risks and benefits of each technology in the Straits of Mackinac versus the risks and benefits of continuing to rely solely upon the Material Balance System (MBS) Leak Detection System (LDS) and those systems that Enbridge is required to implement under the CD.

[3] CD ¶125.

In conducting its analysis and assessment of Enbridge's *ALD Straits Report*, the ITP applied the following standards that are described in the CD:

1. Evaluate whether Enbridge's *ALD Straits Report* is complete and complies with the prescriptive requirements of the CD.[4]

2. Assess whether the results, findings, and conclusions presented in the *ALD Straits Report* are supported by the facts and best engineering judgment.[5]

The ITP evaluated the *ALD Straits Report* and finds that Enbridge's *ALD Straits Report* meets those two standards. The facts, details, and evaluations presented in Enbridge's ALD Straits Report are consistent with the ITP's understanding of the state of LDS technology currently available in the relevant marketplace. As such, the ITP concludes that Enbridge's conclusions in the ALD Straits Report are indicative of the application of best engineering judgment related to the technologies evaluated as they exist at the time of the report.

The ITP finds that the *ALD Straits Report* complies with CD ¶81-83.

[4] CD ¶132.b.
[5] CD ¶134.e.

Introduction

The Independent Third Party (ITP) for the Enbridge Consent Decree (CD), O.B. Harris, LLC, was engaged effective January 11, 2017. As required by CD Paragraph (¶) 132.b, the ITP has reviewed and evaluated the Enbridge *Report on Feasibility of Installing an Alternative Leak Detection System at the Straits of Mackinac* (*ALD Straits Report*) that Enbridge submitted on November 19, 2017.

Subsequent to the November 19, 2017 *ALD Straits Report* submission, on January 3, 2018, the Environmental Protection Agency (EPA) requested that the ITP evaluate the *ALD Straits Report* and prepare this report. In accordance with CD ¶132.b, this report is due within 45 Days of the EPA's request or Monday, February 19, 2018, the first Day following Saturday, February 17, 2018.

Summary of the Consent Decree Requirements

CD Section VII.J, ¶132.b requires that the ITP review and evaluate all proposed plans, reports, and other deliverables that Enbridge is required to submit to the EPA under the CD. CD ¶132.b also provides that the ITP shall review and evaluate the completeness of the Enbridge submittal and its compliance with requirements of the CD. CD ¶134.e requires that the ITP assess whether Enbridge submittals are supported by the facts and best engineering judgment. CD ¶132.b states that, if the EPA requests, the ITP is to submit to the EPA a written report of its evaluation within 45 Days of the request.

CD Section VII.G, ¶81 requires that, within 180 Days of the CD Effective Date (May 23, 2017), i.e., no later than November 19, 2017, Enbridge submit to the EPA the *ALD Straits Report*.

CD ¶81 requires evaluation of:

- Fiber optic cable (FOC) - acoustic.
- FOC - temperature.
- Vapor sensing tube (VST).
- Negative pressure wave.
- Hydrocarbon sensing cable (HSC).

CD ¶82 requires, for each of the technologies identified in CD ¶81, that the *ALD Straits Report*:

- Evaluate the potential effectiveness of the technology in detecting leaks and ruptures of different sizes.
- Evaluate the practicability of deploying the technology in the Straits of Mackinac.
- Evaluate the practicability of long-term operation and maintenance of the technology.
- Evaluate the net present cost of the technology, taking into account the initial capital cost to install the technology and the annual expense to operate and maintain the technology.

CD ¶83 requires, for each of the technologies identified in CD ¶81, that the *ALD Straits Report*:

- Compare the relative performance of each of the evaluated technologies with respect to each of the factors enumerated in CD ¶82.
- Compare the relative performance of each of the evaluated technologies with respect to any other factors Enbridge may decide to add to its analysis.
- Evaluate the risks and benefits of each technology in the Straits of Mackinac versus the risks and benefits of continuing to rely solely upon the Material Balance System (MBS) Leak Detection System (LDS) and those systems that Enbridge is required to implement under the CD.

Summary of Enbridge *ALD Straits Report*

The *ALD Straits Report* contains the major sections listed in Table 1.

Table 1: *ALD Straits Report* major sections and summaries

Report Section	Section Title (summary listed below as needed)
Section 1	**Nomenclature and Abbreviations**
Section 2	**Preface**
Section 3	**Executive Summary** The *ALD Straits Report* provides an evaluation of the alternative leak detection (ALD) technologies specified in the CD. Additionally, the report states that digital acoustic sensing (DAS), digital temperature sensing (DTS), VST, and HSC technologies were not specifically tested in underwater application, but that they were tested in water saturated environments with the results used formulate the technology evaluations. A table is included at the end of section 3 that provides a summary of the evaluation results.
Section 4	**Evaluation Criteria** Section 4 provides a description of the evaluation criteria used by Enbridge. Those criteria are summarized in Appendix 1 of this ITP report.
Section 5	**Evaluation of Alternative Leak Detection Systems for the Straits of Mackinac** Section 5 provides Enbridge's detailed evaluation of the CD prescribed technologies. This evaluation is summarized in Appendix 2 of this ITP report. In section 5.4 (Negative Pressure Wave), Enbridge describes their implementation of a commercial hybrid system that includes both negative pressure wave analysis and statistical flow measurement. The evaluations in the report in subsequent sections refer to the hybrid system as "hybrid LDS."

Report Section	Section Title (summary listed below as needed)
Section 6	**Enbridge's Current Leak Detection Methods and Systems at the Straits of Mackinac** Section 6 describes Enbridge's multiple layered LDS including: • Computational pipeline monitoring (CPM). • Video and physical surveillance. • Controller monitoring. • Sensor-based leak detection. Additionally, the *ALD Straits Report* describes two sensor-based leak detection tools currently in use: • Smartball in-line inspection (ILI) • Infra-red cameras
Section 7	**Technology Performance Comparison against the Identified Factors** Section 7 provides an overview of the relative performance of the evaluated technologies. Further, the Report states: "The recommended technology for implementation as an [ALD] from those assessed in this report, is the [h]ybrid LDS that integrates pressure wave technology with flow measurements. DAS Technology also shows some promise, but will require further investigation."
Section 8	**Risks and Benefits of Adding Alternative Leak Detection Systems versus Current Leak Detection Systems at the Straits** Section 8 describes the risks and benefits of the evaluated technologies used in combination with the current Enbridge LDS.
Section 9	**Next Steps for Evaluations** Section 9 describes the next steps for implementation and evaluation of LDS for the Straits. Enbridge states they are in the final stages of assessment of the hybrid LDS, and are completing the development of hybrid LDS alarm assessment and response procedures. The Report describes continuing evaluations of DAS. Section 9.3 introduces "A commercial hydrophone-based strike detection technology" that is being evaluated for detection of anchor strikes.
Section 10	**Enbridge's Plans to Enhance Monitoring at the Straits** Section 10 describes Enbridge's plan for implementation of ALD at the Straits. Enbridge states their plan to place: • The hybrid LDS into operation by Q3 2018. • A new generation of thermal cameras into operation by Q1 2018. A commercial automatic identification system is also described that can alert vessels in a predefined zone to not drop their anchors.
Section 11	**Conclusions** Section 11 states the following conclusions: • DTS, VST, and HSC technologies are not suitable for application at the Straits of Mackinac and will not be further tested or pursued at this time. • Hybrid LDS is the most suitable option, and Enbridge is planning to place this technology into operation at the Straits of Mackinac. • Enbridge plans to continue assessment of DAS and hydrophone technologies.

Analysis of the Enbridge *ALD Straits Report*

Scope

In conducting its analysis and assessment of Enbridge's *ALD Straits Report*, the ITP applied the following standards that are described in the CD:

1. Evaluate whether Enbridge's *ALD Straits Report* is complete and complies with the prescriptive requirements of the CD.[6]

2. Assess whether the results, findings, and conclusions presented in the *ALD Straits Report* are supported by the facts and best engineering judgment.[7]

Enbridge included in the *ALD Straits Report* a description of its ship broadcast system (notifying ships to not drop anchor) and its hydrophone system (listening for anchor strikes). The ITP views these technologies as damage prevention, not pipeline leak detection, and thus, arguably, outside the scope of CD ¶81-83.

The *ALD Straits Report* describes the existence of infrared cameras at a land-based facility, and expresses the intent to upgrade those cameras to newer thermal imaging technology. The ITP does not see this technology as relating to ALD in the Straits of Mackinac. The cameras are near the shore; however, the *ALD Straits Report* clearly states that the infrared/thermal camera system is used to monitor the facility.[8] It is the view of the ITP that the cameras are not pipeline leak detection, rather they are facility leak detection, and that is the cameras are outside the scope of CD ¶ 81-83.

The ITP's review and analysis did not include an independent search for or evaluation of other technologies that might have applicability to the Straits of Mackinac.

Analysis of *ALD Straits Report*

The ITP considers the on-going ALD program implemented by Enbridge at the Straits of Mackinac to be comprehensive, addressing a broad range of technologies that are used for leak detection or are being actively evaluated by industry. Pipeline leak detection is an evolving science with new technologies frequently entering the market.

The *ALD Straits Report* was submitted by Enbridge to the EPA on November 19, 2017, 180 Days following the CD Effective Date, as required by CD ¶81.

Completeness and Compliance with Prescriptive Requirements

Table 2 (next page) summarizes the manner in which the *ALD Straits Report* satisfactorily addressed the individual CD requirements.

[6] CD ¶132.b.
[7] CD ¶134.e.
[8] *ALD Straits Report*, page 35

Table 2: CD requirements addressed in the *ALD Straits Reports*

CD ¶	Requirement	Addressed as	*ALD Straits Report* Location
81	Evaluation of fiber-optic cable (FOC) – acoustic	FOC – distributed acoustic sensing (DAS)	Section 5.1, beginning page 12
81	Evaluation of FOC – temperature	FOC – distributed temperature sensing (DTS)	Section 5.2, beginning page 16
81	Vapor sensing tube (VST)	VST	Section 5.3, beginning page 19
81	Negative pressure wave	Negative pressure wave	Section 5.4, beginning page 22
81	Hydrocarbon sensing cable (HSC)	HSC	Section 5.5, beginning page 24
82	Evaluate the potential effectiveness of the technology in detecting leaks and ruptures of different sizes.	Potential effectiveness of the technology in detecting leaks and ruptures of different sizes	First subsection (5.x.1) for each of the technologies addressed in CD ¶81 (See NOTE 1 on the next page)
82	Evaluate the practicability of deploying the technology in the Straits of Mackinac	Practicability of deploying the technology in the Straits of Mackinac	Second subsection (5.x.2) for each of the technologies addressed in CD ¶81 (See NOTE 1)
82	Evaluate the practicability of long-term operation and maintenance of the technology	Practicability of long-term operation and maintenance of the technology	Third subsection (5.x.3) for each of the technologies addressed in CD ¶81 (See NOTE 1)
82	Evaluate the net present cost of the technology, taking into account the initial capital cost to install the technology and the annual expense to operate and maintain the technology	Net present cost of the technology	Fourth subsection (5.x.4) for each of the technologies addressed in CD ¶81 (See NOTE 1)
83	Compare the relative performance of each of the evaluated technologies with respect to each of the factors enumerated in CD ¶82.	Technology performance comparison against identified factors	Section 7, page 30
83	Compare the relative performance of each of the evaluated technologies with respect to any other factors Enbridge may decide to add to its analysis.	Technology performance comparison against identified factors, specifically “Recommendation for the Straits”	Section 7, page 30

CD ¶	Requirement	Addressed as	*ALD Straits Report* Location
83	Evaluate the risks and benefits of each technology in the Straits of Mackinac versus the risks and benefits of continuing to rely solely upon the MBS LDS and those systems that Enbridge is required to implement under the CD.	Risks and benefits of adding alternative LDSs versus current LDSs at the straits	Section 8: • Page 31 • Table 9, pages 32-33

NOTE 1: Section 5 of the *ALD Straits Report* is organized by the technologies evaluated, such that section 5.x would relate to the technology. The subsections under section 5.x (e.g., 5.x.1, 5.x.2) would be the evaluation requirement specified in the left most column of this table.

Supported by the Facts and Best Engineering Judgment

As part of evaluating Enbridge's *ALD Straits Report* the ITP undertook a search to identify the current state of technology being deployed offshore (i.e. subsea) to monitor for, identify, and raise an alarm of a leak or rupture in a subsea pipeline.

LDS technologies often are classified into two broad categories of internal or external systems. The technology underpinning both internal and external types of LDSs is rapidly advancing and maturing. These advancements are being driven primarily by the oil and gas industry extending their exploration and production operations into deeper offshore waters and harsher environmental climates such as the Arctic.

Internal systems monitor various operational parameters within a pipeline such as:

- Pressure.
- Temperature.
- Flow.
- Fluid properties.

CPM systems using specifically designed software will compare these parameters to a set of established normal conditions. When those conditions are exceeded, the systems will notify an operator or raise an alarm, indicating the system is operating outside normal parameters and that a leak might exist in the system. Internal systems of this type can quickly detect large leaks or ruptures, typically on the order of 1% or greater of the normal flow rate, but tend to have limited ability to detect smaller, chronic leaks. [9]

External systems are systems that measure one or more physical properties (for example, temperature, sound, light, and similar factors) outside a pipeline. These systems include, as delineated in the CD, FOCs, VTSs, and HSTs.

[9] Guidance Note. *Leak Detection Based Pipeline Integrity Systems*. TUV NEL Ltd. 2010.

These types of external systems, in general, can more quickly detect and locate small leaks below the minimum thresholds of internal LDSs. However, that each of these technologies has limitations is recognized within the industry. The ITP's research into the limitations in deploying each of these technologies in a marine environment, such as the Dual Pipelines the cross the Straits of Mackinac, aligns with the limitations described in Enbridge's *ALD Straits Report*, including:

- Robustness.
- Maintainability.
- Need for a high level of maintenance support.
- Overall complexity.

In early 2017, the Fiber Optic Sensing Association (FOSA) was established as a non-profit organization with the mission of educating industry, government, and the public on the benefits of fiber optic sensing. The FOSA website (https://www.fiberopticsensing.org/) includes a number of vendor technical papers that describe the technologies and their applications. The ITP believes that the formation of FOSA supports the ITP's conclusion regarding the rapid evolution of fiber optic technologies.

As an example of the interest in these technologies and their application in the offshore environment, in 2014, DNV-GL facilitated an industry led joint industry project (JIP) to evaluate the various types of LDSs being supplied and used in the offshore sector of the oil and gas industry. Participants to the JIP included:

- Oil and gas operators, including:
  - BP.
  - ENI Norge.
  - Petrobras.
- Suppliers, such as:
  - NAXYS.
  - SonarDyne.
  - Kongsberg Maritime.
  - Norbit Subsea.
  - KSAT.
  - Miros.

The JIP was completed in 2015, and from the results of the JIP, DNV-GL revised their Recommended Practice DNV-GL-RP-F302 *Offshore Leak Detection* (*DNV-GL RP-F302*).[10] *DNV-GL RP-F302* describes a process an operator may wish to use to assess, evaluate, and then decide on the type of LDS they may wish to deploy on a given subsea structure, including pipelines. The process described in *DNV-GL RP-F302* is very similar to the process outlined in the CD and the process Enbridge employed in analyzing various ALD systems.

While both types of LDSs (i.e. internal and external) are advancing, one study published in 2016 found that internal systems (i.e. CPM systems that Enbridge already has in place at the Straits) continue to comprise about 40% of all LDSs being deployed.[11] A separate study of both internal and external LDSs noted that while mass/volume balance systems are a preferred solution, these systems are a considered a mature technology and they did not expect this type of technology to advance and/or be deployed in the future at the same rate as external based LDSs.[12]

In 2014, a study of both internal and external LDSs used in the offshore upstream oil and gas industry was published in the *Australian Journal of Basic and Applied Sciences*.[13] The study evaluated various internal or computational based pipeline monitoring systems as well as external systems including:

- Liquid sensing systems.
- Fiber optic systems.
- Vapor sensing systems.
- Acoustic emission systems.

The 2014 Australian study used criteria similar to those required by the CD, as well as those criteria Enbridge applied in the *ALD Straits Report*. The 2014 study came to similar conclusions as those stated in Enbridge's *ALD Straits Report* concerning the technologies of FOCs, vapor, and liquid sensing cables, namely:

- Their sensitivity and accuracy for identifying and locating leaks was high to very high.
- Their robustness or propensity to being damaged was rated as low (i.e. they were susceptible to being damaged).
- Their costs to install were high to extremely high.
- Their complexity was assessed to be complicated to very complicated.
- The need or effort to maintain them was all rated as being very high.

[10] DVN-GL Recommended Practice F302: *Offshore Leak Detection* Det Norske Veritas Germanischer Lloyd. April 2016.
[11] *Oil and Gas Pipeline Leak Detection Equipment Market to Reach US$3.65B by 2021*. Transparency Market Research. November 2017.
[12] *Leak Detection Systems Global Market 2016-2021*. Prakash, J, et. al. June 2017.
[13] *A Feasibility Study of Internal and External Based System for Pipeline Leak Detection in the Upstream Petroleum Industry*. FaniSulaimi, M., et. al. Australian Journal of Basic and Applied Science. March, 2014.

After evaluating several external leak detection and internal LDSs, the 2014 study concluded that the system rated highest, and the one that should be deployed by the project, was an internally based real-time transient model (RTTM). In its evaluation of four internal and four external based LDSs, the RTTM was given an overall score of 348 out of a possible 400 total points. The system that scored second, or next highest, was the negative pressure wave system with a total of 323 points.

Enbridge notes in section 6.1.1 of the *ALD Straits Report* that the current primary system installed on Line 5 is a "[RTTM that] uses enhanced statistical methods for leak identification." Enbridge's *ALD Straits Report* also notes that Enbridge is assessing and planning to put into production on Line 5 a negative pressure wave system to complement the current RTTM.

Findings

The ITP evaluated the *ALD Straits Report* and finds that Enbridge's *ALD Straits Report* meets the following standards:

- Enbridge's *ALD Straits Report* is complete and complies with the prescriptive requirements of the CD.
- The results, findings, and conclusions presented in the *ALD Straits Report* are supported by the facts and best engineering judgment.

The facts, details, and evaluations presented in Enbridge's *ALD Straits Report* are consistent with the ITP's understanding of the state of LDS technology currently available in the relevant marketplace. As such, the ITP finds that the *ALD Straits Report* is complete. The ITP also finds that the *ALD Straits Report* complies with the requirements of CD ¶81-83.

The ITP also finds that Enbridge's evaluations are supported by facts and that Enbridge's conclusions in the *ALD Straits Report* are indicative of the application of best engineering judgment related to the technologies evaluated as they exist at the time of the report.

The ITP further finds that the state of the technologies evaluated is rapidly evolving and that Enbridge's commitment to continue its evaluation of DAS technology is consistent with good industry practice.

List of Information Considered

The EPA requested that the ITP apply CD ¶133.a and identify all information considered by the ITP, identify all persons interviewed by the ITP, and summarize all relevant oral communications.

Federal Documents and Regulations

Consent Decree: *United States of America v. Enbridge Energy, Limited Partnership, et al*; Civil Action No. 1:16-cv-914.

Industry Standards and Papers

A Feasibility Study of Internal and External Based System for Pipeline Leak Detection in the Upstream Petroleum Industry. FaniSulaimi, M., et. al. Australian Journal of Basic and Applied Science. March, 2014.

DNVGL Recommended Practice F302: *Offshore leak detection*. DNVGL. April 2016.

Guidance Note. *Leak Detection Based Pipeline Integrity Systems*. TUV NEL Ltd. 2010

Leak Detection Systems Global Market 2016-2021. Prakash, J, et. al. June 2017.

Oil and Gas Pipeline Leak Detection Equipment Market to Reach US$3.65B by 2021. Transparency Market Research. November 2017.

American Petroleum Institute Recommended Practice 1130: *Computational Pipeline Monitoring for Liquids*. American Petroleum Institute. April 2012.

Enbridge Documents

Report on Feasibility of Installing an Alternative Leak Detection System at the Straits of Mackinac, Version 1.0. Enbridge. November 19, 2017.

Appendix 1

The following sections of this appendix provides an explanation of the evaluation criteria used by Enbridge as described in the Evaluation Criteria section of the *ALD Straits Report.*

Potential Effectiveness of the Technology in Detecting Leaks and Ruptures of Different Sizes

This section of the *ALD Straits Report* references the American Petroleum Institute Recommended Practice 1130*, Computational Pipeline Monitoring for Liquids* (*API RP 1130*) as the basis for performance criteria. While the *API RP 1130* performance criteria are intended for CPM systems, Enbridge has expanded their use to the additional ALD technologies evaluated in the *ALD Straits Report*.

Table 3 summarizes the evaluation criteria and terminology used by Enbridge in the *ALD Straits Report*.

Table 3: Terms and definitions for evaluation criteria

Term	Definition
Technical Performance, reference *API RP 1130,* Annex C.	
Sensitivity	The composite measure of the size of leak that a system is capable of detecting and the time required for the system to issue an alarm in the event that a leak of that size should occur. Metrics may include: • Sensitivity related to leak flow rate (i.e., the size of a leak detected as a percentage of nominal flow). • Sensitivity as response time or time taken to first alarm (i.e., the time taken by the system to detect the leak).
Reliability	A measure of the ability of an LDS to render accurate decisions about the possible existence of a leak on the pipeline, while operating within an envelope established by the LDS design. Reliability is measured by the number of false alarms (i.e., reporting a leak when no leak exists).
Accuracy	The ability to determine: • The location of the leak. • The leak flow rate. • The total leak volume.
Robustness	A measure of the LDS ability to continue to function and provide useful information: • In changing conditions of pipeline operation. • In conditions where data is lost or suspect. The *ALD Straits Report* specifically mentions that robustness can be a measure of the system's ability to function and provide useful information even under abnormal operating conditions including: • Transient operations and Column Separation conditions. • Batch operations. • Instrumentation failure, communications failure, programmable logic controller(PLC) failure, Supervisory Control and Data Acquisition (SCADA) failure, and ancillary software process failure. • Presence of pipeline pigs.

The *ALD Straits Report* defines a qualitative metric representing the best estimate of the overall effectiveness based on the four *API RP 1130* criteria as applied to two detection cases:

- A rupture – defined as a structural loss of containment where the pipeline is no longer operable
- A leak – defined as a loss of containment where the pipeline is still operable, but a range of fluid loss occurs.

Table 4 summarizes qualitative metrics of effectiveness.

Table 4: Definitions for qualitative metrics of effectiveness

Term	Definition
High	Indicates that the technology has a high likelihood of being effective for the defined detection cases.
Medium	Indicates that the technology may be effective for the defined cases.
Low	Indicates that the technology would not be expected to be effective for the defined detection cases.

Practicability of Deploying the Technology in the Straits of Mackinac

Table 5 summarizes the criteria for evaluating whether construction practices are readily available to safely complete installation of the technology in the Straits of Mackinac, including:

- Ease of sensor installation.
- Ease of hardware installation.
- Installation of any additional infrastructure requirements.

Table 5: Definitions for evaluations of deployment practicability

Term	Definition
Easy	Deployment can be completed with a minimum amount of construction effort and/or consistent with Enbridge's current asset and infrastructure.
Feasible	Deployment can be completed with some construction effort and/or with Enbridge's current asset and infrastructure modifications.
Difficult	Deployment can be completed with an extensive amount of construction effort (routine and non-routine) and/or with Enbridge's current asset and infrastructure modifications. New construction methods may need to be invented or borrowed from industries where contractors are not familiar with pipeline construction.
Impractical	Deployment is not feasible with current construction methods available in industry. New methods must be invented or borrowed from industries where contractors are not familiar with pipeline construction.

Practicability of Long-term Operation and Maintenance of the Technology

Table 6 summarizes the following criteria for evaluating practicability of long-term operations and maintenance including:

- The general durability of sensors.
- Sensor susceptibility to damage.
- On-going sensor maintenance required to maintain functionality.

The practicability of integrating the technology into pipeline operations is also incorporated into the criteria.

Table 6: Definitions for evaluations of operation and maintenance practicability

Term	Definition
Easy	The technology is durable, can be easily integrated into operations and requires minimal maintenance to provide value for leak detection.
Feasible	The technology can provide value[14] for leak detection, but only with considerable effort and ongoing maintenance.
Difficult	With a significant amount of effort, the technology may provide limited functionality and limited value for leak detection.
Impractical	The technology is not durable, and/or cannot be integrated into operations, and/or requires significant maintenance.

Net Present cost of the Technology

The *ALD Straits Report* defines net present cost as a composite metric including capital installation cost and annual operating/maintenance cost. Enbridge states that they used a 20-year operating period as the basis to determine the net present cost. Enbridge states that they do not have experience installing cable-based ALD technologies underwater, and, as a result, costs were estimated using land project experience and adjusting for a hypothetical installation on Line 5 in the Straits of Mackinac. Therefore, the estimated costs are described as conceptual estimates. The ITP did not attempt to evaluate Enbridge's cost estimates.

Table 1 of the *ALD Straits Report* provides the definition of this metric as shown in Table 7 below:

Table 7: Net present cost as presented in Table 1 of the *ALD Straits Report*

Net Present Cost	Capital Installation Cost (CAP)	20 year operating and maintenance Cost (OM)
$: 1MM – 4MM	$ CAP: 1MM – 2MM	$ OM: 50k – 2MM
$$: 4MM – 8MM	$$ CAP: 2MM – 4MM	$$ OM: 2MM – 4MM
$$$: 8MM – 16MM	$$$ CAP: 4MM – 8MM	$$$ OM: 4MM – 8MM
$$$$: 16MM – 40MM	$$$$ CAP: 8MM – 20MM	$$$$ OM: 8MM – 20MM
$$$$$$: > 40MM	$$$$$ CAP: >20MM	$$$$$ OM: > 20MM

[14] The ITP interprets Enbridge's use of the term "value" to mean "incremental effectiveness."

Appendix 2

The following sections of this appendix provide a summary of the Evaluation of Alternative Leak Detection Systems for the Straits of Mackinac section of the *ALD Straits Report –.*

Fiber Optic Cable – Distributed Acoustic Sensing

General
• DAS fiber-optic cables are placed in the trench with an underground pipeline and can detect leaks by detecting acoustic signatures. • Sensor information is provided to software that analyzes the signal. • The technology has the additional benefit of providing intrusion monitoring for security and detecting theft. • Technology was tested for land-based applications and was not tested for underwater implementations. • Given the lack of maturity and inconsistent performance of the land-based testing, installing a fiber optic cable underwater was not deemed to be a reasonable step. • This technology is new in the pipeline industry.

Potential Effectiveness of Determining Leaks of Different Sizes	
Sensitivity	• The External Leak Detection Experimental Research (ELDER) facility testing demonstrated that the technology was able to detect most of the simulated leaks created in various operating conditions, at various placements, and in dry soil. • Performance at the ELDER facility varied greatly by vendor. • Leak detection times ranged from seconds to minutes. • Successful leak detection in dry soil ranged, on average, from 0.9% to 95%, depending on the vendor. • The technology also was able to detect most of the simulated leaks in a water saturated environment. • Although no underwater testing or pilots were performed, Enbridge determined that "in principle" acoustic monitoring for off shore leaks or anchor strikes has the potential to be established with DAS technology.
Reliability	• After extensive tuning, the DAS technology was relatively reliable with a limited number of few false alarms every month. • However, as water is a great transmitter of sound, any source of sound under water or on the surface would impact performance. • Additional tuning required in noisy areas might result in degraded sensitivity.
Accuracy	• The system was able to locate events within 10 meters. • The system is unable to estimate the volume leak rate.
Robustness	• DAS is expected to be functional under most pipeline abnormal operating conditions (AOCs). • Cable integrity is expected to be robust when properly installed. • Performance is not dependent on the position of the fiber-optic cable because detection does not require contact with the leaked product. This provides some installation flexibility.

Overall Effectiveness Consideration for Detecting Leaks Underwater

- Relative effectiveness – **MEDIUM**
- DAS should "in principle" be able to detect underwater leaks with a detection time of seconds to a few minutes.
- Performance might be degraded by extraneous noise that would have to be tuned out.
- Line 5 caries natural gas liquids (NGL) in addition to oil products. The behavior of NGL leaks and the performance of DAS NGL leak detection has not been tested.
- The industry does not have a repeatable and reliable method to test or measure sensitivity of DAS after installation underwater.

Overall Effectiveness Consideration for Detecting Ruptures Underwater

- Relative effectiveness – **MEDIUM to HIGH**
- Highly dependent upon:
  - Installation design and execution.
  - Vendor maturity.
- The industry does not have a repeatable and reliable method to test or measure sensitivity of DAS after installation underwater.

practicability of deploying the Technology in the Straits of Mackinac

- Relative practicability – **DIFFICULT**
- Requires installation of an FOC adjacent to the underwater pipeline.
- Installation may require installation in a conduit or use of armored cable.
- The Straits of Mackinac are 6.5 kilometer in length. FOCs can be fabricated in lengths of up to 8 kilometers making one continuous installation possible.
- Conduit is typically fabricated in shorter lengths, but may be connected in the field using mature and reliable methods.
- It is expected that specialized methods are required to install FOC underwater, requiring contractors familiar with marine construction and underwater FOC implementation.

Practicability of Long-term Operation and Maintenance of the Technology	
Operation	• The impact to operations is expected to be moderate. • Enbridge has small land-based pilot projects, but does not currently operate DAS systems in a production role. • Procedures would need to be developed to calibrate, assess, and maintain the system.
Maintenance	• The impact to maintenance is expected to be moderate. • The system requires periodic integrity recertification. • Underwater FOCs have a design life of 25 years.
Relative Practicability	**FEASIBLE**

Net Present Cost of the Technology

- Conceptual estimate – **$15MM**
- Annual operating costs are not expected to be a significant portion of the overall cost.
- Cost of any required repairs could be significant at approximately $500k per location.

Fiber Optic Cable – Distributed Temperature Sensing

General
• DTS fiber optic cables functions as a sensor and records the temperature profile over time. • Software analytics determine if there is a leak. • The technology was tested for land-based applications. • The technology was tested in water saturated environments. • The effectiveness of DTS is highly dependent upon installation design and execution, as well as vendor maturity. • DTS was not tested underwater.

Potential Effectiveness of Determining Leaks of Different Sizes	
Sensitivity	• ELDER facility testing demonstrated the ability to detect some of the simulated leaks: – In various operating conditions. – At various sensor placements. – In dry soil. • Response times ranged from a few minutes to a few hours. • Successful leak detection ranged, on average, from 6% to 41% of simulated leaks. • Most of the simulated leaks in a water-saturated environment were undetected.
Reliability	• Enbridge's on land pilot showed false alarm count to be highly dependent on environmental conditions such as rain, water table, settling, and strain. • DTS may be susceptible to false alarms due to: – Normal temperature variations in the Straits of Mackinac. – Currents and scouring near the pipeline.
Accuracy	• The system was found to locate leaks within a few tens of meters. • The system is unable to estimate the leak volume or the leak rate. • Enbridge suspects that most leak alarms would be invalid.
Robustness	• DTS is expected to be functional under all pipeline AOCs. • Cable integrity is expected to be robust when properly installed.

Overall Effectiveness Consideration For Detecting Leaks Underwater
• Relative effectiveness – **LOW** • DTS requires usually more than 2 degrees C of temperature difference between the FOC and surrounding released product to alarm. • DTS effectiveness is highly leak-path dependent, requiring the FOC to be located very close to the pipeline. • In underwater conditions, the temperature difference will disappear more quickly, and therefore may not be sensitive to leaks.

Overall Effectiveness Consideration for Detecting Ruptures Underwater
• Relative effectiveness – **LOW** • DTS Effectiveness is not expected to change drastically for ruptures.

Practicability of Deploying the Technology in the Straits of Mackinac
• Relative practicability – **DIFFICULT** • DTS requires a FOC be installed very close to the underwater pipeline. • Installation may require installation in a conduit or use of armored cable. • The Straits of Mackinac are 6.5 kilometer in length. FOCs can be fabricated in lengths of up to 8 kilometers making one continuous installation possible. • Conduit is typically fabricated in shorter lengths, but may be connected in the field using mature and reliable methods. • It is expected that specialized methods are required to install FOC underwater, requiring contractors familiar with marine construction and underwater FOC implementation. • Enbridge currently has no procedures or specifications to safely secure an underwater cable on or near an underwater pipeline segment. • Retrofitting and working on the existing pipe has inherent risk.

Practicability of Long-term Operation and Maintenance of the Technology	
Operation	• Not material to the decision due to limited potential.
Maintenance	• Not material to the decision due to limited potential.
Relative Practicability	**FEASIBLE**

Net Present Cost of the Technology
• Conceptual estimate – **$15MM** • Annual operating costs are not expected to be a significant portion of the overall cost. • Cost of any required repairs could be significant at approximately $500k per location. • With good installation, repairs are expected to be required one every 10 years.

Vapor Sensing Tube

General
• VST technologies obtain gas samples from sensing tubes placed along the length of the pipeline. • Hydrocarbon vapors created during a leak permeate the soil and diffuse into the VST. • Once or twice a day, the contents of the tubes are purged, and a gas analyzer detects the presence of hydrocarbon vapors. • VST technology can be used on on-shore pipelines but its application for underwater pipelines is uncertain. • The technology was tested for land-based applications and was not tested for underwater implementation.

Potential Effectiveness of Determining Leaks of Different Sizes	
Sensitivity	• The technology was able to detect every simulated leak in ELDER facility testing. • Leak detection time ranges from hours to a full day for both dry and water saturated soil. • Testing in water saturated soil demonstrated that leak detection is very slow.
Reliability	• The frequency of false alarms requires further investigation. • Enbridge expects VST to not be effective for underwater leak detection, consequently, reliability would not be material to the decision.
Accuracy	• The system cannot estimate the leak volume or the leak rate. • Enbridge expects VST to not be effective for underwater leak detection, consequently, accuracy would not be material to the decision.
Robustness	• Varying pressures underwater may lead to failure of the sensing tube.

Overall Effectiveness Consideration for Detecting Leaks Underwater
• Relative effectiveness - **LOW** • VST is not identified as a viable underwater leak detection technology.

Overall Effectiveness Consideration for Detecting Ruptures Underwater
• Relative effectiveness – **LOW** • VST Lack of effectiveness is not expected to change for ruptures.

Practicability of Deploying the Technology in the Straits of Mackinac
• Relative practicability – **DIFFICULT** • VST installation requires a hollow tube filled with air be installed within a slotted conduit in close proximity to the underwater pipeline. • The VST custom tubes are typically fabricated in lengths of significantly less that a kilometer, making it difficult to install as a continuous construction across the 6.5 kilometer Straits of Mackinac. • It is unclear what the impacts of underwater pressure would be on the VST installation. • It is expected that specialized methods are required to install VST underwater, requiring contractors familiar with marine construction and underwater tube implementation. • Enbridge currently has no procedures or specifications to safely secure an underwater cable on or near an underwater pipeline segment.

Practicability of Long-term Operation and Maintenance of the Technology	
Operation	• Expect moderate impact to operations. • Procedures to calibrate, assess, and maintain the system would need to be developed. • Training would be required for personnel to perform assessment and maintenance. • Feasibility of underwater operation is uncertain.
Maintenance	• Expect impact to maintenance to be significant due to fragility of the sensing tube. • Likely that the technology would require frequent integrity recertification. • Significant potential for a failure that requires complete replacement of the system within 25 years or less.
Relative Practicability	**IMPRACTICAL**

Net Present Cost of the Technology
• Conceptual estimate – **$20MM** • Annual operating costs are not expected to be a significant portion of the overall cost. • Cost of any required repairs could be significant at approximately $500k per location. • Anticipate frequent repairs at a cost of $3MM per year. • Inspections of the VST by remotely operated vehicle may be performed at the same time as inspections of the pipeline.

Negative Pressure Wave

General
• Enbridge has implemented a commercial hybrid system that includes both negative pressure wave analysis and statistical flow measurements at the Straits of Mackinac. • Negative pressure wave was assessed in a Pipeline Research Council International (PRCI) study, *Field Testing of Negative–Wave Leak Detection Systems*[15], that was used as guidance by Enbridge. NOTE: While the PRCI document is referenced in the *ALD Straits Report*, Enbridge indicated to the ITP that Enbridge is prohibited from disclosing the PRCI document. As a result, the PRCI document was not provided to the ITP, and the ITP was unable to use the document in its evaluation of the *ALD Straits Report* (e.g., the PCRI report is not available in the public domain). • Negative pressure wave uses the following to identify a pipeline leak: – Pressure transmitters to detect transient pressure waves associated with the onset of a leak – Flow measurement to perform statistical volume balance – Combination of the above methods • The hybrid reduces uncertainty and enhances performance by leveraging the strength of each method. • The system is installed and fully functional. • Leak alarms are not yet being passed to the control center. • Reliability of the system is being actively monitored before full operational implementation.

Technical Performance	
Sensitivity	• Table 5 of the *ALD Straits Report* provides hybrid LDS performance. • Sensitivity ranges from 25 minutes to detect a 1.5 percent leak of 54 cubic meters per hour, to 2 minutes to detect a 40 percent leak of 1,440 cubic meters per hour.
Reliability	• The most recent reliability test, conducted for 70 days, showed that the hybrid LDS had zero false alarms.
Accuracy	• Both flow and negative pressure wave estimate leak location. • Negative pressure wave is expected to estimate location of the leak more accurately than the flow component. • Negative pressure wave does not estimate total volume lost or leak rate. • The flow measurement component estimates both total leak volume and leak rate.
Robustness	• The LDS is generally optimized for Steady-State operations. • Pressure wave is less effective at detecting leaks during transient operations. • Pipeline pigs have a degrading effect to the negative pressure wave component, increasing leak detection time. • Instrument outages of flow and pressure transmitters also degrade performance.

Overall Effectiveness Consideration for Detecting Leaks Underwater
• Relative effectiveness – **HIGH** • Expected to be effective for leak detection of 1.5 percent of the mainline flow rate and higher.

[15] PR-015-123713-R01: *Field Testing of Negative–Wave Leak Detection Systems*. Pipeline Research Council International.

Overall Effectiveness Consideration for Detecting Ruptures Underwater
• Relative effectiveness – **HIGH** • Expected to be very effective for rupture detection.

Practicability of Deploying the Technology in the Straits of Mackinac
• Relative practicability – **FEASIBLE** • Requires installation of special high fidelity pressure transmitters. • The technology can be retrofitted on an existing pipeline relatively easily. • The technology is suitable for high consequence areas and water crossings. • The technology is effective for segment lengths (distance between pressure transmitters) of less than 50 kilometers.

Practicability of Long-term Operation and Maintenance of the Technology	
Operation	• Impact expected to be low/moderate. • Training of alarm assessment and field maintenance personnel is needed. • Need to develop procedures to calibrate, assess, and maintain the system.
Maintenance	• The impact of maintenance is expected to be low. • Pressure sensors require a small amount of yearly maintenance to ensure calibration.
Relative Practicability	**EASY**

Net Present Cost of the Technology

• Conceptual estimate – **$15MM**
• Actual installation cost was **$1.1MM** for the Straits.
• Installation cost included vendor software, high fidelity pressure transmitters, and labor.
• Yearly cost of maintenance is approximately **$53k per year.**
  – $15-20k for software
  – $33k for internal labor

Hydrocarbon Sensing Cable

General
• An HSC involves a cable placed alongside an underground pipeline in the trench. • An HSC cable has electrical properties that change when the cable comes in contact with a liquid hydrocarbon. • Software processes the electrical signals to determine a leak. • The technology was tested for land-based applications and was not tested for underwater implementation. • Results of land-based testing suggested it would not be useful to undertake underwater testing.

Technical Performance	
Sensitivity	• ELDER facility testing showed that in dry soil, HSC was able to detect some of the simulated leaks, especially leaks that were close to the HSC sensor. • Detection success is highly dependent on the leak path. • Sensor placement is critical. • Leak detection response time was within 1.5 to 12 hours. • Successful leak detection ranged from 24% to 44% depending on the vendor. • For a water saturated environment, the technology was mostly unsuccessful.
Reliability	• Land-based installations have shown the system is prone to false alarms in high water table and in the presence of trace residual hydrocarbons.
Accuracy	• An HSC is unable to estimate the leak volume or the leak rate.
Robustness	• An HSC is expected to be functional under all pipeline AOCs. • Cable integrity is expected to be robust when properly installed.

Overall Effectiveness Consideration for Detecting Leaks Underwater
• Relative effectiveness – **LOW to MEDIUM** • A HSC requires direct contact with liquid hydrocarbon. • Underwater applications are challenging as current and water movement may change leak path avoiding contact with the HSC.

Overall Effectiveness Consideration for Detecting Ruptures Underwater
• Relative effectiveness – **MEDIUM** • A HSC is expected to be slightly more effective for rupture detection. • A large volume of release product may increase the probability of the HSC contacting the leak.

Practicability of Deploying the Technology in the Straits of Mackinac
• Relative practicability – **DIFFICULT** • Installation would require a custom cable with a slotted conduit installed in close proximity to the underwater pipeline. • The custom cables are typically fabricated in lengths significantly shorter than a kilometer, making it difficult to use a continuous construction method in the 6.5 kilometer Straits of Mackinac. • Construction requires a contractor familiar with: – Marine construction methods including safe excavation and deep-water dives. – Underwater testing and termination of the sensing cable.

Practicability of Long-term Operation and Maintenance of the Technology	
Operation	• The impact to operations is expected to be moderate. • Enbridge would need to develop procedures to calibrate, assess, and maintain the system.
Maintenance	• Impact to maintenance is expected to be significant, primarily due to the fragility of the conduit used to house the cable. • The technology is likely to require frequent integrity recertification using visual inspection by remotely operated vehicle. • The HSC will trigger an alarm upon contact with hydrocarbon from any source, including those other than a pipeline leak. • Any hydrocarbon sensed requires a diver to repair the affected segment.
Relative Practicability	**DIFFICULT**

Net Present Cost of the Technology
• Conceptual estimate – **$18MM** • Annual operating costs are not expected to be a significant portion of the overall cost. • Cost of any required repairs could be significant at approximately $500k per location. • Anticipate repairs required 3 times per year of operation at a cost of $3MM per year. • Inspections of the HSC by remotely operated vehicle may be performed at the same time as inspections of the pipeline.