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Framework for Verifying and Validating the Performance and Viability of Leak Detection Systems for Liquid and Natural Gas Pipelines

Debrief Presentation

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Challenge

Existing Documentation

Is largely focused on conventional leak detection technologies including, but not limited to, Computational Pipeline Monitoring (CPM) systems

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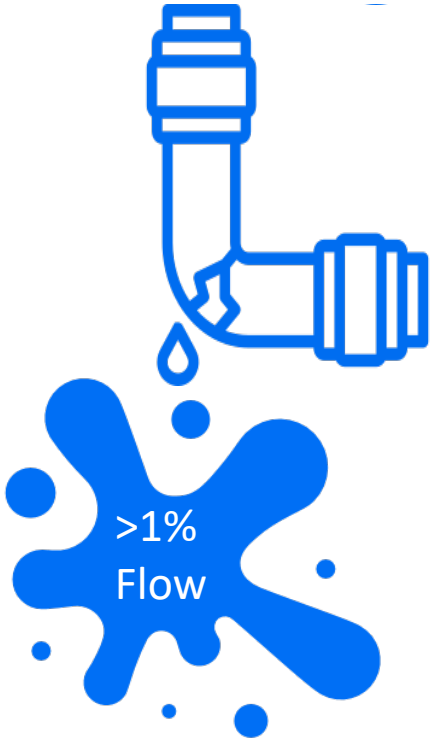
Lack of Public Documentation Focusing on External Leak Detection Systems

The challenge was to develop a framework capable of addressing this information gap.



Objective

To develop a framework that can be used by pipeline operators to identify and evaluate candidate External Leak Detection (ELD) systems intended for possible deployment on onshore transmission pipelines, and to assist operators in making an informed technology selection.

This framework covers the identification, evaluation, and selection of ELD technologies for onshore gas and liquid hydrocarbon transmission pipelines prior to field deployment. It does not address the following topics:

- Evaluating leak detection performance for systems intended for deployment at pump or compressor stations, valve stations, and tank farms.
- Evaluating leak detection performance of systems currently deployed on existing pipelines.
- Evaluating ELD sensor functionality for uses other than leak detection, such as third party intrusion monitoring, ground movement monitoring, and distributed strain monitoring.
- Evaluating sensor installation procedures.

Stakeholders

The framework is intended to be used by pipeline operators
to assist with the process of evaluating and comparing ELD technologies for possible deployment on their pipelines

ELD technology vendors could also use the framework
to focus their research and developments efforts such that they are able to provide operators with pertinent data that will better assist with making decisions regarding implementing their ELD technology.

Framework Summary

Technology Performance – provides guidance for defining specific ELD performance requirements

Technology Screening – provides guidance for identifying and comparing candidate commercial systems

Technology Characterization – provides guidance on consolidating performance data for the preferred technology vendors, identifying information gaps, and addressing gaps

Technology Evaluation and Selection – provides guidance to assist the operator in arriving at a final technology selection.

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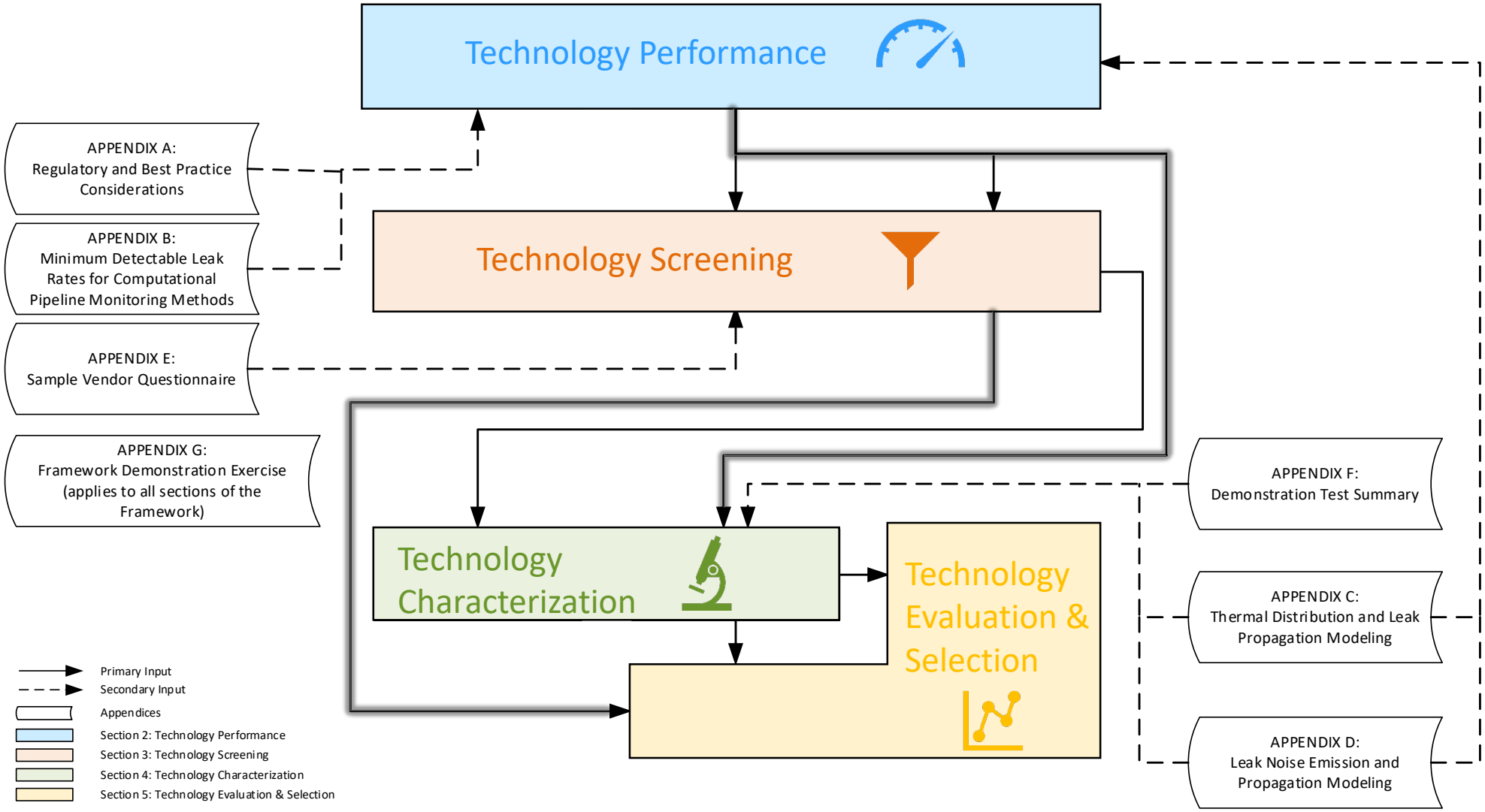
Framework Flowchart



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Technology Performance

Performance Requirements

Metric → **KPI** → **Target**

Metric	KPI	Target
Accuracy	Leak rate	0.5 LPM
Sensitivity	Leak pressure	0.1% flow
Reliability	Leak volume	
Robustness		

Application Environment

Locations + Operating States → Application Environment Parameters (AEP)

- Soil density
- Driving pressures
- Commodity Temperature

Parameter Selection & Characterization

Sensing Mechanisms
- Temperature
- Vibration/Acoustics
- HC (vapor/liquid)
- Strain

→ **AEP Impact**

Soil density	HIGH IMPACT
Driving pressures	HIGH IMPACT
Commodity Temperature	LOW IMPACT

→ Final List of Important AEPs

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Technology Screening

Market Survey

Identify viable technologies for consideration → Screen them based on their ability to meet the performance requirements

Vendor Questionnaire

Develop questionnaire Based on the performance requirements and AEPs → Vendor responses are interpreted and organized into discrete performance claims

Technology Comparison

Compare technologies using a consistent and objective process →

Evaluation Matrix
- Define score criteria (performance requirements)
- Compare against vendor performance claims
- Multiply by importance weighting

→ Shortlist of candidate vendors for further evaluation

Technology Characterization

Performance Data Characterization

Supporting Data Sources
Field scale testing
Large scale laboratory testing
Bench scale laboratory testing
Numerical & analytical modeling

Confidence Scores
Based on the type of supporting data

Relevance Scores
Based on level of consistency between the supporting data and the AEPs

→ Data Quality Score

Information Gaps

Minor Gaps
The performance claim is sufficiently supported to justify taking the information at face value
(HIGH DATA QULITY SCORES)

Moderate Gaps
Caution should be exercised before relying on the performance claim. Could potentially be addressed by either supplementing or validating existing data
(MODERATE DATA QUALITY SCORES)

Major Gaps
The performance claim should not be relied upon. Best addressed by generating new data or replacing irrelevant data
(LOW DATA QUALITY SCORES)

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Technology Evaluation & Selection

Updated Performance Claims

Testing & Modeling
Information gaps are addressed

→

- **Confirmed** — Original claim is valid
- **Rejected** — Update the claim

} Update Confidence & Relevance Scores

- **Inconclusive** — Claim remains unchanged

} Use Previous Confidence & Relevance Scores

Modified Score Criteria

Revisit & Redefine Previous Score Criteria
Testing might reveal new ELD system capabilities or limitations (not always necessary)

Modified Evaluation Matrix

Previous Evaluation Matrix
The evaluation matrix defined in the "Technology Characterization" section

+ **Updated Performance Claims**

+ **Modified Score Criteria**

+ **Information Quality Factors**
Normalized information quality scores

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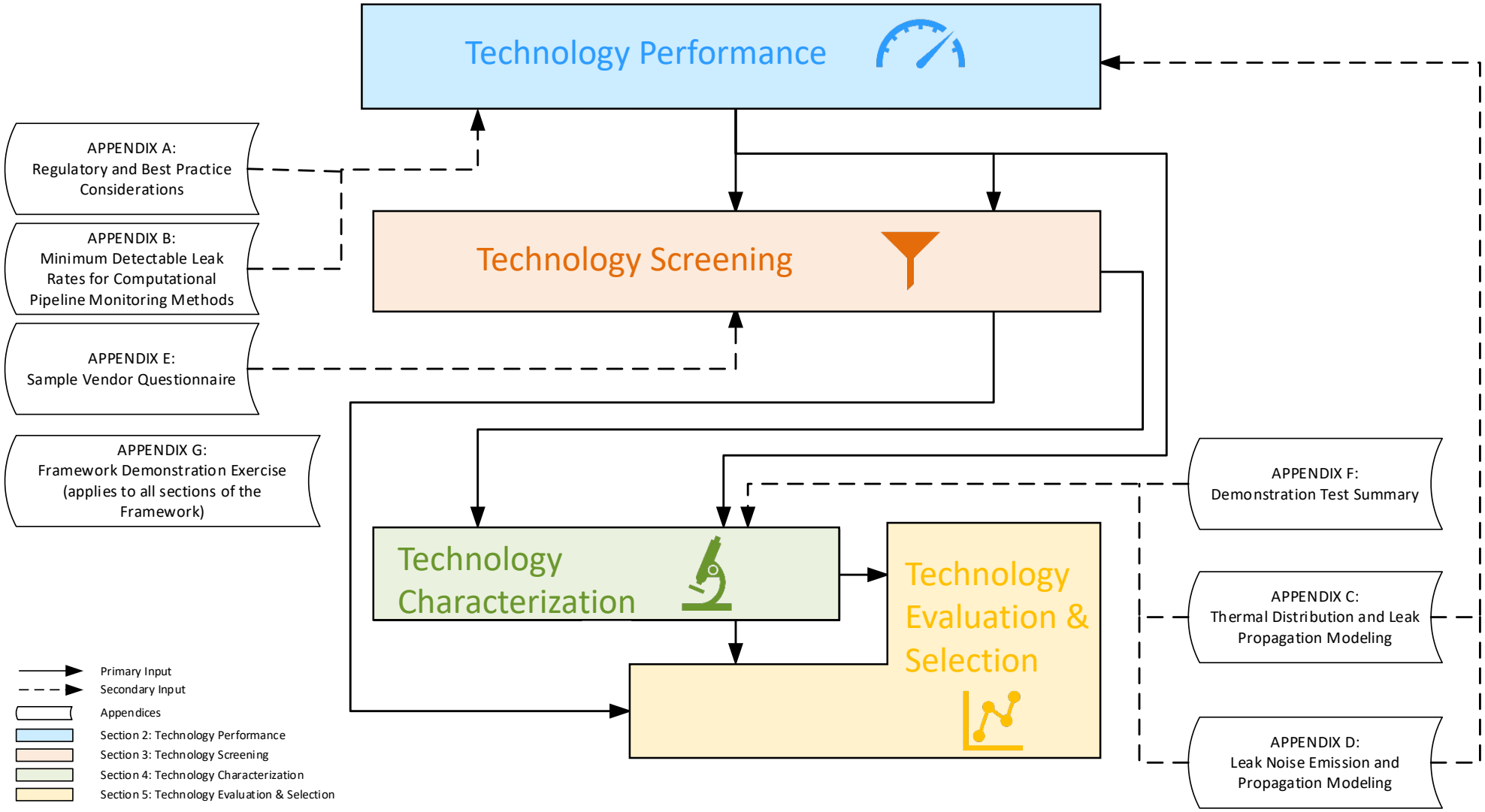
Framework Flowchart



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Framework Demonstration

Demonstration Scenario Description

Introduces and describes a hypothetical pipeline (the demonstration pipeline) which will be the basis of the demonstration exercise

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Technology Performance → Defines specific ELD performance requirements for the demonstration pipeline

Technology Screening → Identifies candidate commercial ELD systems capable of meeting the defined performance requirements

Technology Characterization → Consolidates the performance data and identifies information gaps which are addressed through the demonstration test

Technology Evaluation & Selection → A final technology selection is made

Demonstration Scenario Description

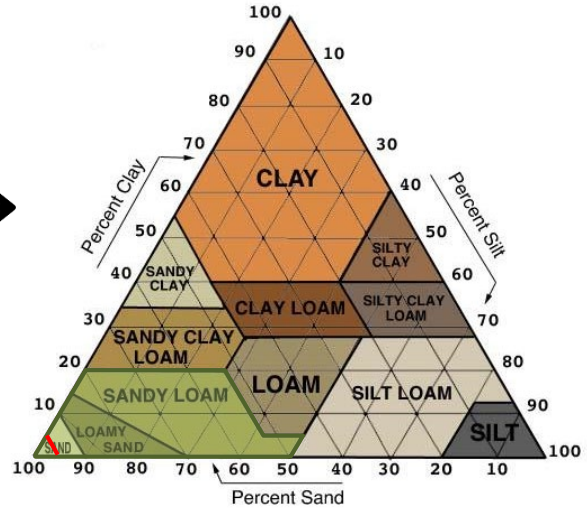
Demonstration Pipeline

Deployment Environment

Subsurface pipeline deployed in
Sandy soil with minimal silt and clay

Deployment Stage

Legacy pipeline (as opposed to
new construction)



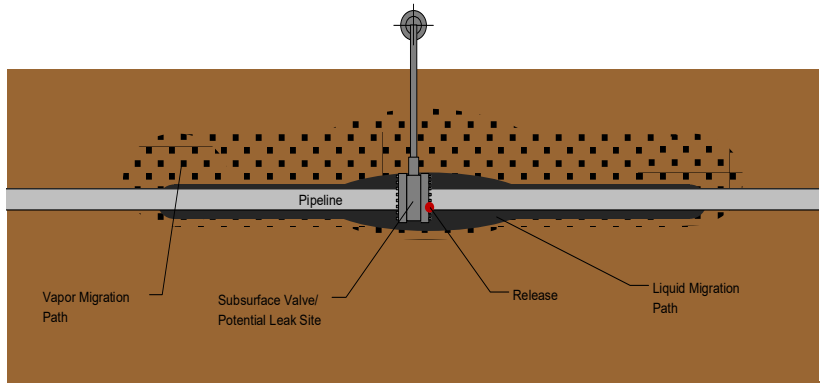
Construction Specs

24 inch OD
3/8 inch wall thickness

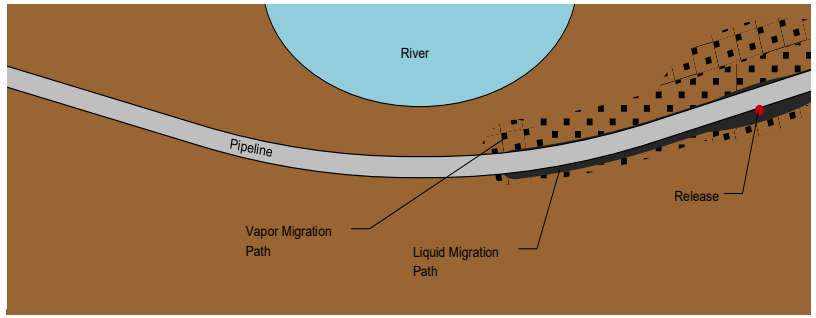
Operation Specs

Liquid HC (dilbit)
50 to 500 psi operating pressure

ELD Deployment Configurations



High Leak Probability Areas



High Consequence Areas

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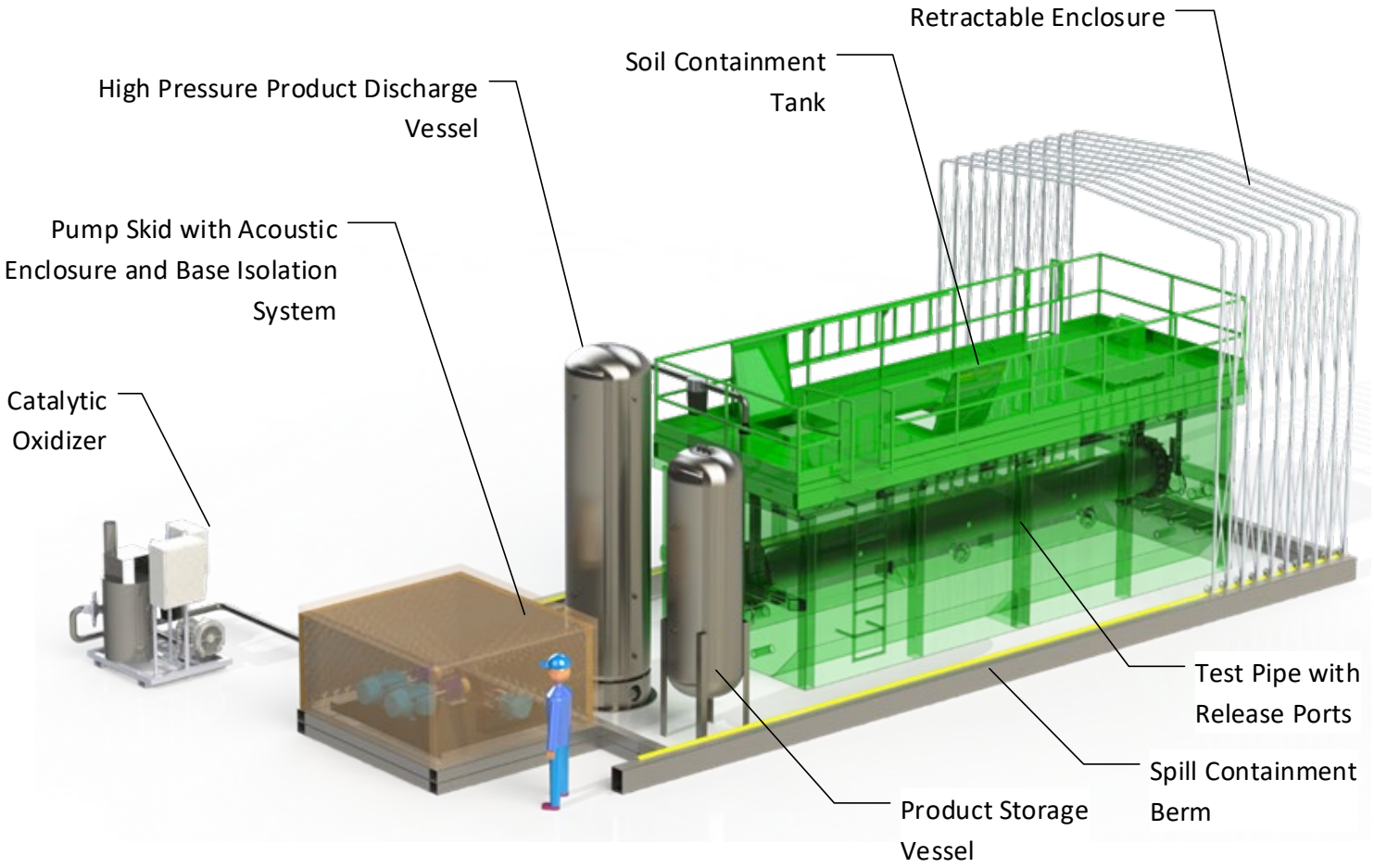
Demonstration Scenario Description

External Leak Detection Experimental Research (ELDER) Apparatus



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Technology Performance Demonstration

Operating Areas

Area 1: Near or at a sub-surface component having an increased likelihood of producing a leak
Area 2: Near or at an HCA where leakage would be of relatively high consequence to the environment

Operating States

Normal: characterized by normal or steady-state operating conditions
Shut in: characterized by very low to no net flow of product

Performance Requirements

Performance Metrics	Performance Requirements by Application Environments			
	Pipeline Area 1 Operating State "Normal "	Pipeline Area 2 Operating State "Normal "	Pipeline Area 1 Operating State "Shut-in "	Pipeline Area 2 Operating State "Shut-in "
Sensitivity	Minimum detectable leak rate of <20 LPM (5.3 GPM)	Minimum detectable leak rate of <10 LPM (2.6 GPM)	Minimum detectable leak rate of <20 LPM (5.3 GPM)	Minimum detectable leak rate of <10 LPM (2.6 (GPM)
Reliability	<2 false alarms/year	<10 false alarms/year	<2 false alarms/year	<10 false alarms/year
Accuracy	None	Leak localization accuracy of <10 m (<32.8 ft)	None	Leak localization accuracy of <10 m (<32.8 ft)
Robustness				

Technology Performance Demonstration

Application Environment Parameters

AEPs	AEP Values by Application Environment			
	Pipeline Area 1 Operating State "Normal "	Pipeline Area 2 Operating State "Normal "	Pipeline Area 1 Operating State "Shut-in "	Pipeline Area 2 Operating State "Shut-in "
Minimum operating pressure	1379 kPa	1379 kPa	345 kPa	345 kPa
Maximum operating pressure	3447 kPa	3447 kPa	1379 kPa	1379 kPa
Estimated range of orifice diameters	1.27 – 3.81 mm	1.27 – 3.81 mm	1.27 – 3.81 mm	1.27 – 3.81 mm
Commodity Phase	Liquid	Liquid	Liquid	Liquid
Commodity Composition	Dilbit	Dilbit	Dilbit	Dilbit
Average soil temperature	6° - 20°C	6° - 20°C	6° - 20°C	6° - 20°C
Average commodity temperature	10 - 25°C	10 - 25°C	10 - 25°C	10 - 25°C
Soil Hydraulic Conductivity	$1x10^{-4}$ cm/s	$1x10^{-4}$ cm/s	$1x10^{-4}$ cm/s	$1x10^{-4}$ cm/s
Soil density	1700-1900 kg/m^3	1700-1900 kg/m^3	1700-1900 kg/m^3	1700-1900 kg/m^3
Soil porosity	45%	45%	45%	45%
Soil Moisture content	6-10%	6-10%	6-10%	6-10%

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Technology Screening Demonstration

Market Survey

5 Vendors were identified through the market survey

Vendor Questionnaire

A questionnaire was produced and distributed to the candidate vendors

Technology Comparison

2 Vendors were selected for further consideration

Vendor A
Acoustic based technology

Vendor B
Hydrocarbon Vapor Sensing Technology

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Technology Characterization Demonstration

Performance Data Characterization

Sample of Information Quality Scores

Performance Requirement	Vendor B				Vendor A			
	Performance Claim	Confidence Score	Relevance Score	Information Quality Score	Performance Claim	Confidence Score	Relevance Score	Information Quality Score
Minimum detectable leak rate of 20 LPM (application environment A)	0.001 LPM	3	3	9	1 LPM	4	2	8
Minimum detectable leak rate of 10 LPM (application environment B)	0.001 LPM	3	2	6	1 LPM	4	2	8

Information Gaps

Minor to Moderate Gaps

To address the information gaps, a large scale laboratory test (i.e. the demonstration test) which leverages C-FER's external leak detection experimental testing apparatus (ELDER) was designed and executed

→

Demonstration Test

AEPs relating to the soil properties, the commodity and the sensor deployment configuration were identified as being the primary source of low relevance scores. They were given particular attention in the design of the demonstration test

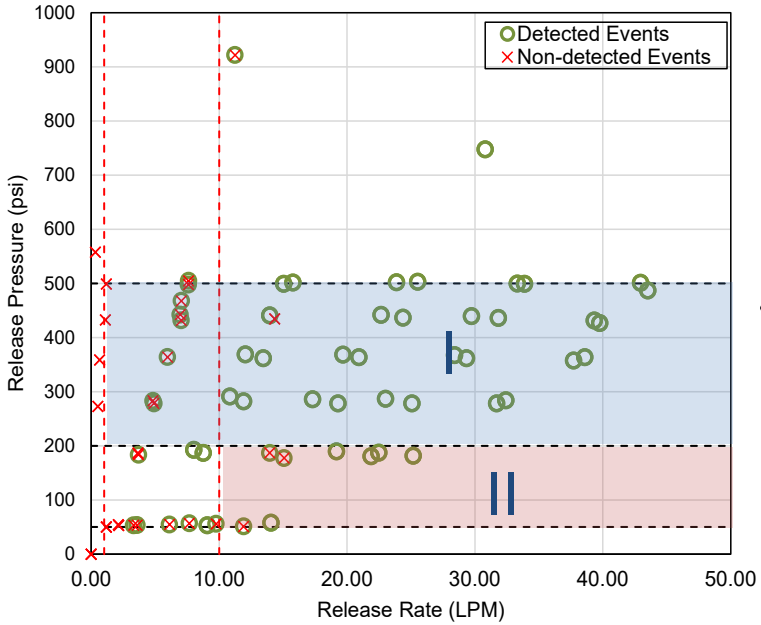
Technology Evaluation & Selection Demonstration

Updated Performance Claims

Vendor A - Performance Claim Evaluation

Experimentally derived Alarm Ratio (AR) as proxy to POD
Ratio of successfully detected releases to total releases

→ Alarm Ratio Threshold **90%**



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Performance Requirement		Associated Region(s)	AR (Claim Status)	Performance Claims	
No.	Description			Initial	Updated
1	Minimum detectable leak rate of 20 LPM (applies to application environment A)	I	83% (performance claim rejected)	1 LPM	6 LPM
2	Minimum detectable leak rate of 10 LPM (applies to application environment B)	I	83% (performance claim rejected)	1 LPM	6 LPM
3	Minimum detectable leak rate of 20 LPM (applies to application environment C)	II	81% (performance claim rejected)	10 LPM	14 LPM
4	Minimum detectable leak rate of 10 LPM (applies to application environment D)	II	81% (performance claim rejected)	10 LPM	14 LPM

Technology Evaluation & Selection Demonstration

Modified Evaluation Matrix

Previous Evaluation Matrix
The evaluation matrix defined in the "Technology Characterization" section

+

Updated Performance Claims

+

Modified Score Criteria

+

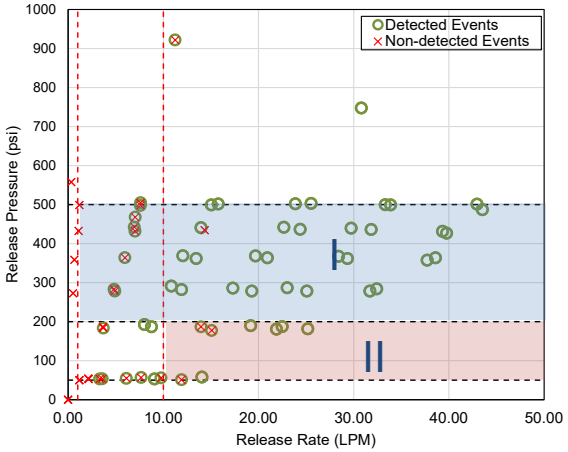
Information Quality Factors
Normalized information quality scores

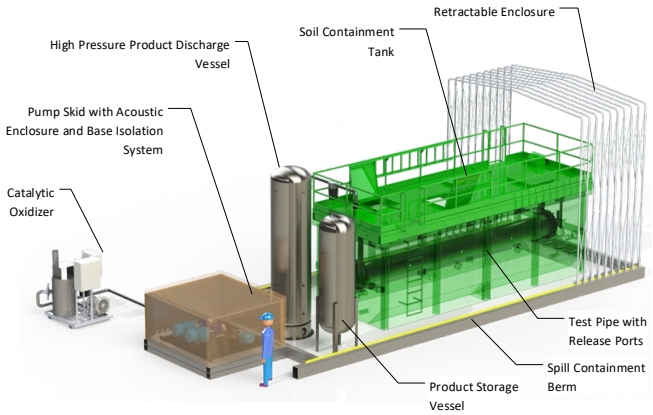
Completed in Technology Screening Section

Claims were updated with Laboratory test result

Score Criteria was not modified

Confidence and relevance scores were updated to reflect the new test data





Appendices Overview

Appendix A – Regulatory and Best Practice Considerations

Appendix B – Minimum Detectable Leak Rates for Computational Pipeline Monitoring Systems

Appendix C – Thermal Distribution and Leak Propagation Modeling

Appendix D – Leak Noise Emission and Propagation Modeling

Appendix E – Sample Vendor Questionnaire

Appendix F – Demonstration Test Summary

Appendix G – Framework Demonstration Exercise