CLEAN RESOURCES FINAL PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	**Improving Technologies for Detecting Submerged Oil**
Alberta Innovates Project Number:	AI 2617
Submission Date:	3/29/2023
Total Project Final Cost:	$1,867,711.90 ($940,000 initial budget)
Alberta Innovates Funding:	$297,000
AI Project Advisor:	Dallas Johnson

2. APPLICANT INFORMATION:

Applicant (Organization):	**C-FER Technologies (1999) Inc.**
Address:	3712 Roper Road NW, Edmonton, Alberta, T6B 3T9
Applicant Representative Name:	Corey Drake
Title:	Research Engineer, PEng
Phone Number:	1-587-754-2339 x342
Email:	c.drake@cfertech.com

3. PROJECT PARTNERS

Please provide an acknowledgement statement for project partners, if appropriate.

RESPOND BELOW

C-FER would like to thank the JIP members (Enbridge Pipelines, TCEnergy, TransMountain Pipeline, BC Oil and Gas Commission), grant providers (Alberta Environment and Protected Areas), and other government agencies (Alberta Innovates, PrairiesCanada) who provided funding for this project. Without these funds, the project would not have been able to take place.

A. EXECUTIVE SUMMARY

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

RESPOND BELOW

Historically, pipeline developments from Alberta to tidewater have been significantly delayed due to concerns regarding the impact of oil leaks on the environment. Oil leaks inland can threaten aquatic habitats and municipal drinking water supplies; as such, it is imperative to minimize the environmental exposure of leaks by locating and recovering the spilled product as quickly as possible. Furthermore, when oil leaks into a waterbody, it can interact with numerous environmental factors that can, in some cases, cause the oil to become submerged and/or sunken. Methods for detecting floating oil are well established; however, few have addressed the complexities in detecting submerged oil in terms of the quantity and location of the oil below the water surface.

This project was completed as a Joint Industry Project (JIP), comprised of pipeline operators, and government agencies. The JIP was consulted throughout each of the Milestones to ensure the technologies selected, and the procedures followed for testing were in alignment with expectations.

Given the aforementioned challenges, the main objectives of this JIP were to:

- Establish a new capacity to evaluate submerged oil detection technologies;
- Support technology vendors in demonstrating and commercializing new solutions;
- Assist pipeline operating companies in selecting the best available technologies for their application; and
- Reduce the impact of leaks through rapid and reliable detection of submerged crude oil products.

This project carried out a meso-scale evaluation of various technologies typically used for the detection of submerged oil. These technologies included various point sensors, fluorometers, and sonar-based sensors. Results from these initial tests show that some of the sensors were able to detect trace amounts of submerged oil in flowing water. The learnings from these tests will allow industry and government agencies to make more informed decisions on which sensors to use for emergency response and monitoring plans. The results are also beneficial to the participating vendors who provided technology, as they allow for either optimization or validation of their design for submerged oil detection.

B. INTRODUCTION

Please provide a narrative introducing the project using the following sub-headings.

- **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

RESPOND BELOW

Effective leak detection and spill response systems are often the main focus of the objections to new pipeline developments. Regulators and governments in Canada and the United States require that operators demonstrate their ability to detect and respond to leaks to prevent significant environmental impacts. The technologies tested in this project could be a critical component of these systems.

The need for improved techniques for detecting and responding to leaks was recognized by The Royal Society of Canada's report *The Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments* wherein they recommend that "special skills and equipment are needed both now and to be developed for inland or offshore oil spill responses under cold and harsh conditions" (2015).

A recent report entitled *uSCAT Technical Reference Manual – Underwater Seabed Cleanup Assessment Technique for Sunken Oil* by Coastal and Ocean Resources of Victoria, BC, provides an overview of the types of technologies and procedures that can be used to detect submerged oil based on field experience (2018). The authors of this report confirm that there is a need to develop methods to assess these technologies under controlled conditions.

The results from this project can be used to improve the design, deployment, and operation of technologies to detect submerged oil in inland waterways and marine environments. The technologies evaluated can be used to monitor for submerged oil at critical locations, such as pipeline water crossings, to rapidly detect leaks and activate emergency response procedures. These technologies can also be used after leaks have been identified in order to rapidly and reliably locate spilled products that have become submerged or settled to the bottom of waterways so that they may be quickly cleaned up and removed from the environment.

New and refined technologies to detect submerged oil will be a critical tool for pipeline operators and spill responders. They could be deployed as part of an active monitoring program in critical water crossings.

This technology could also be deployed during spill cleanup operations to increase the effectiveness of oil recovery operations.

An ongoing challenge is how to demonstrate the effectiveness of these technologies under real-world conditions, where historically this would require releasing hydrocarbon products into the environment. Even in controlled conditions, the impact of intentional releases into waterways is not acceptable. Currently, the only other option for demonstrating the performance of submerged oil and leak detection technologies is to apply them during actual leak events. However, leak events are extremely rare (fortunately) and are not well suited for "experimentation" since the conditions are not controlled, or even well understood. Thus, the results of testing during real-world leaks are of limited use. The results from these tests in controlled, near-real-world conditions are thus invaluable. They provide confidence that some of these systems can operate as required during actual leak events. Future work will be needed to test them under a broader range of conditions to help establish operational envelopes and optimal deployment strategies, and also to (potentially) help the vendors improve their technology.

C. PROJECT DESCRIPTION

Please provide a narrative describing the project using the following sub-headings.

- **Knowledge or Technology Description:** Include a discussion of the project objectives.
- **Updates to Project Objectives:** Describe any changes that have occurred compared to the original objectives of the project.
- **Performance Metrics:** Discuss the project specific metrics that will be used to measure the success of the project.

RESPOND BELOW

The objective of this project was to design and construct a facility capable of carrying out a near-real-world evaluation of technologies used for submerged oil detection. One of the key aspects of this facility was the requirement to be able to test with actual hydrocarbon products, instead of surrogate fluids. This was critical in understanding the sensor behaviour as it pertains to field deployments, as the weathering effects of oil can be appropriately replicated. The results of these tests can be used as a first step to inform operators and regulators and can act as a guide when determining what sensors may be best suited for these applications.

The following metrics were used to evaluate the success of the project:

- Number of technologies identified in the market scan
- Number of technologies tested in the Inland Waterway Simulator

D. METHODOLOGY

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

RESPOND BELOW

This project was structured into several tasks, with each task informing the decisions of the one to follow it. These are described below in the order they were carried out:

Task 1 – Define Technology Requirements

Task 1 consisted of identifying and defining explicit performance requirements by which to evaluate the candidate technologies. In this context, performance requirements refer to the collection of specifications describing the required functionality of a particular technology and formed the basis of the technology comparison described in subsequent tasks. The chosen technology requirements were focused on the technologies' operational capabilities.

To the extent possible, the performance requirements were expressed in terms that are consistent with relevant standards and recommended practices, such as DNVGL-RP-F302, API 1130, and API 1175. For example, performance metrics that are commonly referenced in the standards and recommended practices include sensitivity, accuracy, reliability, and robustness.

Task 2 – Review Technologies

Task 2 involved searching through public information (i.e. conference proceedings, web searches, communication with industry) to identify potentially viable commercial and pre-commercial technologies capable of detecting crude oil, as well as other hydrocarbon products, in inland waterways and marine environments. The identified technologies were evaluated by comparing their claimed performance capabilities (i.e. publicly available performance data) to the technology requirements described in Task 1.

The technologies were ranked using a detailed scoring process and presented to the industry-based Project Steering Committee (i.e. JIP members) to select five technologies that were deemed most likely to meet the specified technology requirements.

Task 3 – Test Facility Design and Setup

Task 3 consisted of developing a test plan for conducting large-scale laboratory tests to assess the performance of the candidate technologies. This required developing a detailed design of the test facility to effectively simulate submerged oil in a flowing water environment at a scale sufficient to accommodate commercial technologies. The test apparatus designed and operated by C-FER during this project is called the Inland Waterway Simulator (IWS).

The IWS was constructed with the goal of testing a wide range of oil leak detection technologies under near-real-world representative conditions. It was determined during the design process that a fully concrete structure, appropriately reinforced for the water loads, would be a suitable test material, provided it was lined with a waterproof barrier. The remainder of the flume (i.e. ducting and piping) was then constructed from stainless steel to prevent rusting and corrosion.

The IWS was also outfitted with a single centrifugal pump capable of 10,000 GPM flow rates, with up to 89-mm-diameter entrained solids. This pump was connected to a 125 HP motor / variable frequency drive (VFD) that allowed for the careful and repeatable control of flow rate. At a water depth of 1.5 m in the IWS, this resulted in maximum flow rate of 10,000 GPM; this translates to a maximum flow velocity of approximately 0.15 m/s in the IWS channel. Flow velocities in the piping and ducting would be considerably higher due to the reduced cross-sectional area.

Extensive computational fluid dynamics (CFD) work was completed to ensure fully developed flow was achieved in the flow channel. This required several iterations of the ductwork design to achieve the desired results. Ultimately, a custom flow diverter was designed to address the issues associated with optimizing mass balance of fluid into the channel. Additionally, several configurations of turning vanes in the U bend were modelled and optimized to assess the ideal spacing to improve mass flow balance.

Task 4 – Technology Testing

Prior to testing with an actual hydrocarbon product, a dye test was first completed to visualize the flow within the channel. This was accomplished by adding pool dye into the tank at the outlet end of the channel, while the pump was running at approximately 10,000 GPM. The results from the dye flow test were used to validate the results from the CFD modelling that C-FER performed during the design phase. This dye test confirmed that the IWS generated laminar, fully developed flow along the latter third of the channel where the sensors were to be installed. A photo of the dye flow test is shown in Figure 1.

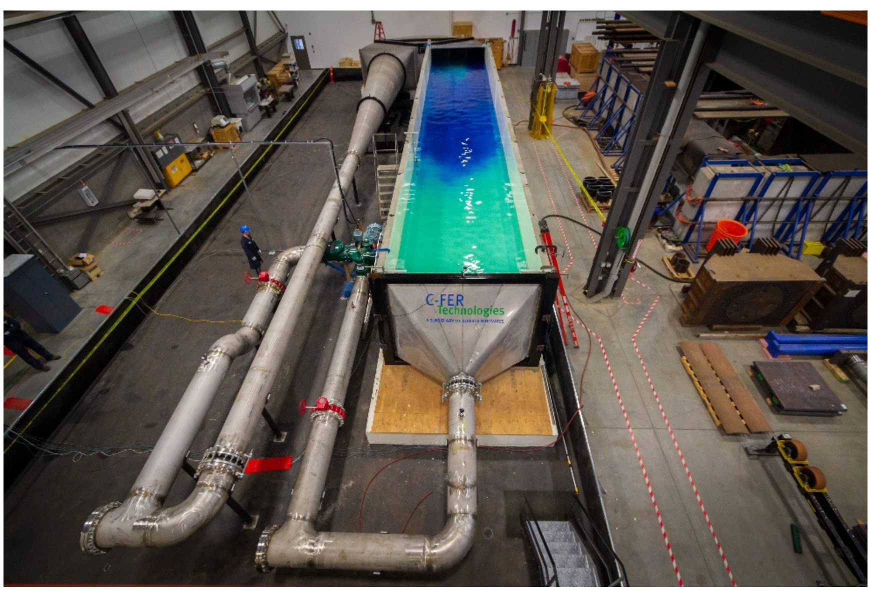

Figure 1 Flow Test in IWS

Dilbit was identified as a key product of interest given its prevalence in pipeline networks throughout Alberta, including along several water crossings where submerged oil could result from a pipeline leakage event. Therefore, it was selected as the product for testing.

To simulate the process whereby oil becomes submerged in nature, an oil particle aggregate (OPA) was prepared. A 20 L pail of dilbit was mixed with 5.0 wt. % of sediment to achieve the desired OPA mixture. During testing, it was observed that the oil mixture was not adequately submerging in the IWS; as such, the decision was made to add additional sediment (an additional 5.0 wt. %) to promote the submergence of the oil during testing. This increase in sediment allowed for adequate submergence of the dilbit during these initial demonstration tests.

The dilbit was contained in a 20 L pail and carefully (and gradually) injected into the IWS by C-FER personnel using a peristaltic pump. The injection tubing was placed near the outlet duct to facilitate suction into the piping. Figure 2 shows the injection location in the IWS.

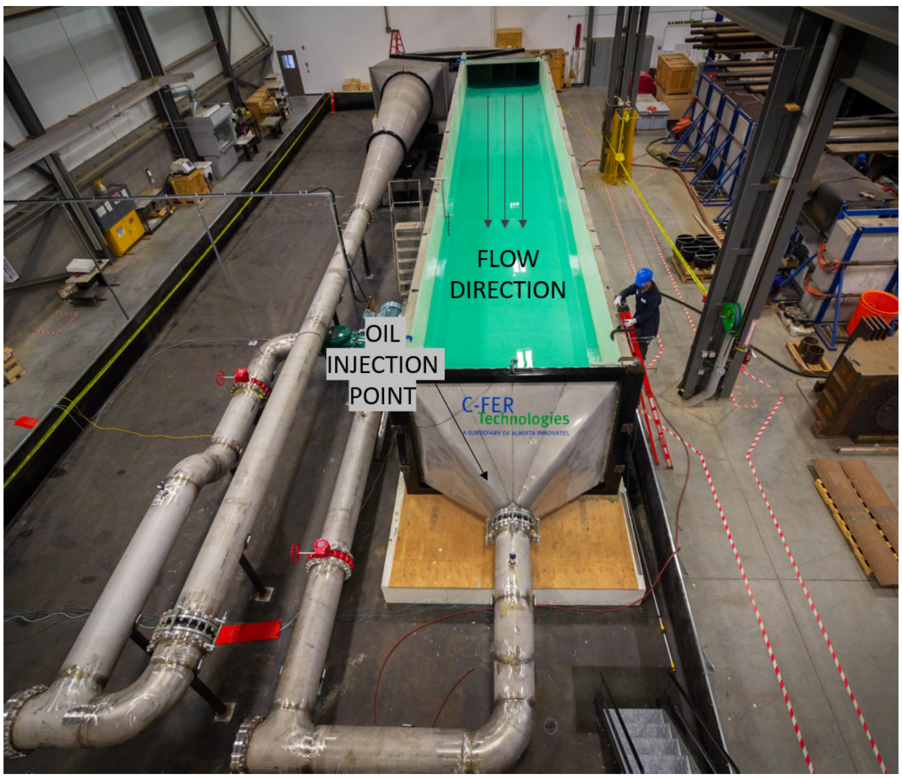

Figure 2 Oil Injection Point in IWS

The dilbit was injected in stages and circulated in the IWS for at least one hour between successive injections. Water samples were also taken at regular intervals as a means of comparison between what the vendors reported detecting and the actual water chemistry at a given point-in-time.

Task 5 – Analysis and Reporting

Task 5 involved interpreting the test results and providing the operators with compiled information comparing the performance of the candidate technologies under various test conditions. The candidate technology vendors were also provided with test data for their individual technologies following testing. This was done to allow them the opportunity to validate and perhaps improve (in some cases) their products. A detailed technical report summarizing the test procedure and vendor performance was provided to the JIP members.

E. PROJECT RESULTS

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- Describe the importance of the key results.
- Include a discussion of the project specific metrics and variances between expected and actual performance.

RESPOND BELOW

Milestone 1 – Technology Requirements and Review

The project target was to identify more than 20 technology vendors to be considered for testing; ultimately, 22 vendors were identified, which exceeded the project target. C-FER was then able to screen these vendors and selected a total five sensors to test. Of these, four vendor sensors were ultimately evaluated. Originally, the test plan had a total of five sensors included, but one of the sensors malfunctioned immediately prior to testing, and the schedule did not permit a replacement to be sent to C-FER in time (note that the technology provider was located in the UK).

Milestone 2 – Test Facility Design

There were significant challenges faced in the design and construction of the IWS. Several CFD runs were completed to ensure fully developed, laminar flow was present in the channel where the sensors were to be installed. This was critical to ensure all sensors were evaluated without any sort of bias in the results. Ultimately, a custom flow diverter was designed and fabricated to overcome the initial issues with mass flow balance into the channel.

The flow channel was comprised of several key sections: the concrete channel, the pumping system and associated piping, the flow expansion cone, the flow diverter, and the u-bend.

The concrete channel was constructed from pre-cast sections, engineered to accommodate the hydrostatic water loads present. A total of 10 individual trenches were assembled together to achieve the desired length of 20 meters. The trenches were sealed using butyl tape at the joints, and sprayed with a waterproof polyurea coating.

The pumping system was selected based on the required flow rates in the channel. The original design included two pump skids, but due to budget constraints, this was reduced to a single pump configuration. However, the piping system was designed in such a way that a second pump could be added in a parallel configuration at a later date, to effectively double the flow rate of the system. The pump selected was a centrifugal, solids handling pump from Pioneer Pumps that was capable of flow speeds up to 10,000 GPM. It was controlled via a 125 HP motor connected to a VFD to allow for variable flow rates, if required during testing.

The ducting components (expansion cone, flow diverter, and u-bend) were all extensively modelled using CFD analysis to determine the ideal geometries, given the space constraints in the laboratory. This required several iterations of the design, but ultimately allowed for fully developed flow in the channel. The ducting was engineered by C-FER and fabricated by a subcontractor from stainless steel.

Milestone 3 – Setup, Testing, Analysis, and Reporting

There were several key elements involved in the IWS test setup, as outlined in this subsection.

To collect water samples during testing, a water sampling tube, constructed of stainless-steel tubing, was installed in the main tank. The sampling location was approximately 0.8 m from the bottom of the tank and centered east to west. It was also positioned directly below the sensors so as not to affect the oil flowing towards them. Once the IWS was full, water was siphoned through the sampling tube to a valve that could be actuated as needed for water sampling. Before each sample was taken, the line was purged of any stagnant water to ensure a representative sample of the water was taken at the correct point in time.

To contain the vapours during testing, the tank was covered in a polyvinyl chloride (PVC) tarp, with a pass-through for connection to a blower system. As a secondary safety feature, a lower explosion limit (LEL) monitor was also installed adjacent to the vendor sensors inside the tank to monitor explosive gas concentrations. In the event these concentrations ever approached explosive limits, a relay would cut power to all sensors in the tank. During testing, the LEL never exceeded 0%.

A mounting bracket constructed from 80/20 aluminum was also installed in the downstream third of the IWS tank. Sensors were installed based on the specifications provided by each of the vendors. The results of the flow test showed fully developed flow in the tank; as such, the positioning of east to west was not critical to sensor performance. In the event that any of the sensors were knocked loose or became detached from the mounting bracket during testing, a steel mesh grate was installed at the outlet end of the tank to prevent any items from being pulled into the pump while it was running. Despite this, it was deemed important that each of the sensors were also positioned at the same position north to south in the IWS (and were, thus, also exposed to the approximately the same flow and test conditions). In addition to the vendors sensors, an underwater action camera (Akaso V50X) was also installed by C-FER to provide video footage during testing. This video provided a secondary verification (in addition to the water samples collected) that oil was present near the sensors during testing.

The dilbit was contained in a 20 L pail and carefully (and gradually) injected into the IWS by C-FER personnel using a peristaltic pump. This type of pump was selected due to its suitability for pumping of high viscosity fluids with moderate flow rates. The dilbit pump flow rate was maintained between 250 and 500 mL/min, depending on the volume of product being injected. The injection tubing was placed near the outlet duct to facilitate suction into the piping. A total of 7 dilbit injections were completed.

The results from this initial test show that trace amounts of submerged oil (ppm level) can be detected in flowing water at speeds up to 0.2 m/s and water depths of 1.5 m by some of the technologies tested. Figure 3 shows an anonymized plot of vendor data, indicating a clear trend in signal corresponding to the dilbit injections. Conversely, Figure 4 shows a plot of vendor data that exhibited a weaker signal response that did not exceed the alarm threshold of the sensor.

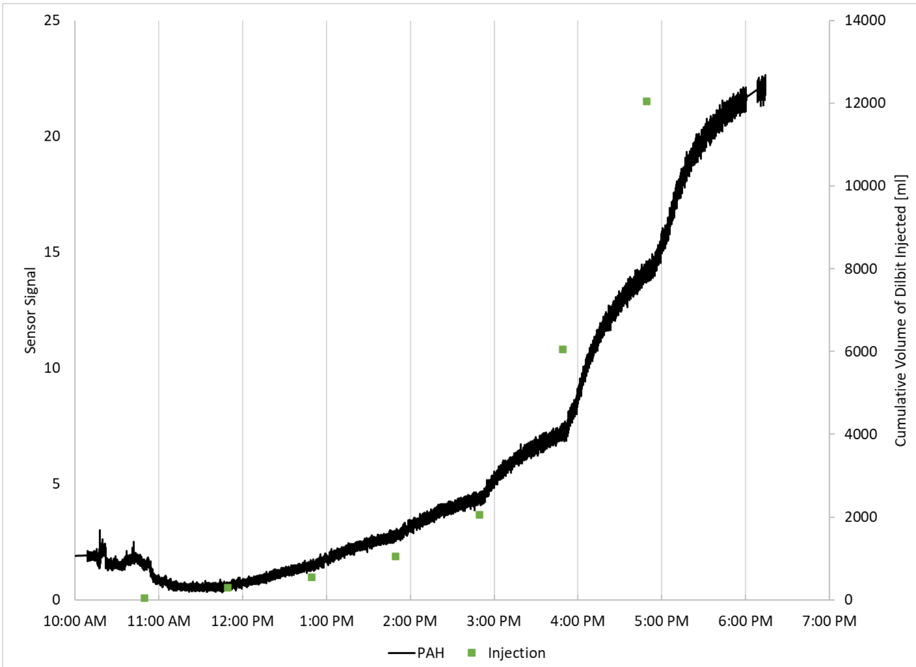

Figure 3 Sample Vendor Data – Strong Signal

Figure 4 Sample Vendor Data - Weak Signal

This information can assist operators and emergency responders in selecting the most appropriate equipment for the job and for operational constraints.

There were some challenges observed with the use of sonar systems in the IWS. After reviewing the data, there was a large amount of noise present and any clear indications of oil droplets could not be discerned from the data. It is unclear whether this was due to reflections of the acoustic signal in the tank, entrained air in the water flow, pump vibrations, or a combination thereof. This suggests that for future tests, noise isolation will have to be taken into account when evaluating these systems.

Both fluorometers evaluated in the test performed very well, and were able to detect trace amounts of dilbit in the tank. As for the point sensor, the detection threshold was not as clear, but data showed potential signs of dilbit detection. Further evaluations would need to be carried to assess the alarm thresholds for this particular system.

F. KEY LEARNINGS

Please provide a narrative that discusses the key learnings from the project.

- Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

RESPOND BELOW

There were several key learnings from this project, which are summarized below:

- From the design aspect, one key learning was the requirement for higher flow rates. Although the flow velocity of 0.2 m/s is representative of a slow moving stream, there is value in testing under higher flow conditions as this will have an impact on sensor performance. This could be achieved with the addition of a second pump skid, or a converging channel in the tank to reduce the cross sectional flow area.
- There are vendor sensors and technology available that can detect the presence of trace amounts of submerged dilbit in flowing water under some real-world conditions. In some cases, the performance of these sensors outperformed the results from analytical lab instruments.
- With a sufficient amount of sediment, dilbit is able to submerge under flowing conditions in a short period of time. This assumes that the product has weathered sufficiently, and it has mixed with sediment in the waterway.
- There is a strong need to further assess the performance of these and other technologies, under more varied and extreme testing conditions. This may include (but is not limited to) introducing the presence of organic matter, highly turbid waters, higher flow rates, turbulent flow, and different hydrocarbon products.
- Although each of the technologies were in the later stages of TRL development, not many of them had experience with the detection of dilbit, specifically. Given the prevalence of dilbit in Alberta

pipeline networks, further work should be conducted to assess the sensor responses to dilbit versus other hydrocarbons products such as light oils and crudes

These learnings can help industry and regulatory agencies better select which technologies to use in the detection and mapping of submerged oil. These sensors could easily be integrated into existing emergency response plans to further supplement the equipment currently being used. A detailed technical report was provided to the JIP members (industry/government/regulators) to allow them to make more informed decisions when it comes to vendor selection and to help guide further research.

G. OUTCOMES AND IMPACTS

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Project Outputs:** List of all obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the project. As appropriate, include attachments.

RESPOND BELOW

The outcomes of this project will provide useful information for industry and government, as well as the various technology providers. Although these initial tests focused on a single oil product (dilbit) and flow regime, the results show a high potential for the detection of trace amounts of submerged hydrocarbon products under these conditions. Some of the sensors used in these tests have been evaluated for the performance of other crude oil products, but their performance with regards to the detection of submerged dilbit was unknown. The results from these tests provide technology vendors with additional data on their system performance and allow them to expand their offerings to industry. These technologies provide the opportunity to decrease the overall risk of a spill, by means of early detection and tracking, if it is applied correctly and under the right conditions in the field.

For the Clean Energy Metrics, the target of three tests was exceeded (with a total of seven discrete leak events actually completed). Each leak event evaluated the lower limit of detection for each of the systems in a staged manner. This eliminated the costly requirement to remediate the test tank between leak events and also allowed for a broad spectrum of leak volumes to be evaluated from as low as 50 mL up to

12 L. This effectively proved the performance of the sensors tested and outlined some potential areas for improvement. Furthermore, this project allowed for the development of a standard test procedure to evaluate the performance of submerged oil systems. This procedure covers the processes for commissioning the flow channel to ensure flow characteristics are met, preparing the hydrocarbon product, properly injecting the product to ensure mixing, and conducting a detailed water sampling program/video monitoring program to validate data obtained from the sensors tested.

As for the Program Specific Metrics, each of these targets were met. As noted, there was a technical issue with one of the sensors during commissioning, and the timeline did not allow for a replacement to be sent from the UK in time for testing. Therefore, a total of 22 vendors were identified during the market search (exceeding the target of 20), but only 4 sensors were evaluated during the project as opposed to the original target of 5. Ultimately, C-FER was still able to include technologies across a spectrum of categories (i.e. point sensing, sonar, and fluorometry) in this initial testing and demonstration project.

There are no further project outputs to report on at this time; however, note that C-FER has submitted an abstract to be presented in an upcoming international conference relating to oil spills and marine protection. In this manner, C-FER intends to help ensure the learning are shared.

A summary of the metrics are shown below:

Clean Energy Metrics (Select the appropriate metrics from the drop down list)			
Metric	**Project Target**	**Commercialization / Implementation Target**	**Comments (as needed)**
# field pilots/demonstrations	3	Prove the performance of oil detection technologies for end users	A total of 7 controlled releases were completed
# New policies created	1	Establish standard testing procedure to assess new technologies	1 new procedure was developed to evaluate submerged oil detection technologies

Program Specific Metrics (Select the appropriate program metrics from the drop down list)			
Metric	**Project Target**	**Commercialization / Implementation Target**	**Comments (as needed)**
Land and Biodiversity Program Metric	Identify 20+ technology vendors for end users to consider	Increase awareness of available technologies and inform vendors of end user requirements	A total of 22 vendors were identified during the market survey
Land and Biodiversity Program Metric	Demonstrate performance of at least 5 vendors in full scale tests	De-risk implementation of technologies for end users	The test plan had originally included 5 different sensors. However, one of these sensors malfunctioned during commissioning and time did not permit for repair (vendor was based overseas). Therefore, only 4 sensors were evaluated

H. BENEFITS

Please provide a narrative outline the project's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- **Building Innovation Capacity:** Describe the project's contribution to the training of highly qualified and skilled personnel (HQSP) in Alberta, their retention, and the attraction of HQSP from outside the province. Discuss the research infrastructure used or developed to complete the project.

RESPOND BELOW

The results from this project have several benefits, which are summarized below:

Economic

<u>Benefits to Technology Vendors</u>

For vendors with fully developed products, this project allowed them to evaluate and improve upon the technologies they are currently selling, thereby improving the efficiency and value for their clients. For vendors in earlier development stages of their product, this provided an opportunity to test their concepts in a controlled, representative environment. Through rigorous testing, vendors were able to prove their technologies to the end users (i.e. operators) and potentially expand current markets for their technologies.

<u>Benefits to Industrial End Users</u>

The industry representatives involved in this project received a detailed report outlining the performance of each of the technologies evaluated. The goal is to assist the operators to improve upon their existing emergency response plans and reduce the cost of spill cleanups through earlier detection and tracking.

<u>Benefits to Regulators and Governments</u>

Identifying technologies that could be used for submerged oil detection in environmentally sensitive areas will assist regulators and governments in understanding what level of leak detection is practical to protect critical water bodies. This information could be used to direct new regulations or legislation to support

Alberta's leadership position in responsible energy development. Demonstrating this leadership will help to secure public support for pipelines to transport Alberta oil to foreign markets.

Investment Attraction

In an effort to maximize the knowledge transfer and identify the most promising technologies, C-FER included technologies offered by vendors outside of Alberta. By communicating the need for these technologies in Alberta to technology vendors from around the world, there is potential for vendors based in the rest of Canada or internationally to expand manufacturing and distribution operations into Alberta. Furthermore, the IWS could facilitate opportunities for collaboration amongst vendors, academia, and industry from around the world that could lead to establishing new companies in Alberta.

Environmental

Submerged oil detection technologies will support two of the four themes of the Water Innovation Project (WIP):

Theme 2 Healthy Aquatic Ecosystems – Improving leak detection technologies will help to minimize the impact of liquid hydrocarbon spills in aquatic environments by providing earlier detection of leaks to minimize the spill volume. Using these technologies following spill events will help to locate submerged oil to improve the recovery of spilled oil and to minimize unnecessary cleanup activities that could cause further harm to the environment.

Theme 4 Water Quality Protection – Using proven oil detection technologies to plan and execute spill cleanups will make it easier, faster, and less costly to recover spilled hydrocarbon products from the environment. This will minimize near-term impacts of spills on municipal water supplies and long-term impacts on ecosystems.

Social

Improving the ability to detect submerged oil will help to respond to spills in inland waterways more rapidly and assist spill response personnel in focusing cleanup efforts on where submerged oil is found. This will reduce the environmental impact of spills in waterways and will assist authorities in making decisions as to when cleanup activities are complete and when water use from affected sources can resume.

The technologies tested in this project can help to reduce loss of petroleum products and limit environmental impacts during spill events. It is difficult to quantify the impact since it will depend on the scale of the spill and the degree that it impacts communities and the environment. For instance, during the 2016 oil spill in the North Saskatchewan River near Maidstone, Saskatchewan, water intakes for North Battleford, Prince Albert, and Melfort (over 300 km downstream of the release) were shut-in for several months as authorities assessed the potential for oil to foul the water supplies. Reliable technologies that could show that submerged oil was not present at the water intake locations might have allowed authorities to re-open these water supplies much sooner. Media reports indicate that Husky provided North Battleford with more than $3 million to compensate for the cost of trucking water to the city while the water intake was shut-in. The total cost of the cleanup is reported to be $107 million, but lawsuits by First Nations affected by the spill are still pending.

Building Innovation Capacity

The project had an Innovation Focus by demonstrating and developing new technologies, and developing best practices for detecting submerged oil, including the selection and deployment of technologies in partnership with operating companies, technology vendors, and researchers. The construction of a new testing facility to conduct controlled hydrocarbon releases in flowing water will create a new Innovation Platform where equipment vendors, operators, regulators, and academia can test new concepts and refine the performance of commercial technologies. This will also increase the Innovation Capacity in leak detection by creating experts in this emerging field and increasing the collective knowledge of the challenges of detecting submerged oil, which should lead to concepts for new technologies.

I. RECOMMENDATIONS AND NEXT STEPS

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- Describe the potential partnerships being developed to advance the development and learnings from this project.

RESPOND BELOW

The results from these initial demonstration tests suggest that there are further evaluations that should be carried out to assess instrument performance in detecting submerged oil. There is a need to evaluate more technologies and determine the operating envelope(s) where each technology can best be deployed. Additionally, more test conditions should be varied. For example, it would be beneficial to carry out more testing under higher flow speeds to assess performance in higher-rate flood conditions. As the residence time of the oil near the sensor may be lower, this could potentially impact sensor performance. Additionally, these higher velocities may generate more turbulence, which could weather the product more rapidly. This may lead to accelerated submergence, and potentially impact the size and shape of the submerged oil droplets. Future testing could also be completed in conjunction with an assessment of submerged oil containment and filtration technologies, and could assess the impact of a range of water conditions (turbid, presence of organic matter, suspended solids, etc.). A multi-tiered research program could assess the weathering behaviour of various petroleum products in flowing water, the ability for sensors to detect these products under high and low flow velocities, and the ability to filter and or contain the submerged oil product.

This initial series of demonstration tests confirmed that the IWS is capable of evaluating the effectiveness of submerged oil detection technology. Further testing will be required to fully understand and optimize the performance of various technologies for deployment by both government and industry in response to spill events.

C-FER is actively marketing this new Canadian-based testing facility to regulators, industry, and key stakeholders that would have an interest in oil spill testing. We are also looking into other areas, such as microplastics detection, protection of water intakes, as well as the evaluation of other novel technologies, that could be used for the enhancement and protection of waterways.

J. KNOWLEDGE DISSEMINATION

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

RESPOND BELOW

A technical report was provided to the JIP members involved in the project. This report summarized the test procedures used, provided an assessment of each of the technologies evaluated, and highlighted key areas where further testing can be carried out to improve emergency response.

Each of the vendors who participated in the project will receive a copy of their data, as well as a log of the leak events completed. C-FER is currently working with these vendors to discuss performance and potential ways these technologies can be improved. This will ultimately lead to a better product for both the vendor, as well as industry.

Additionally, C-FER has submitted an abstract (pending acceptance) for an international conference to present on this project. The white paper and accompanying presentation will be focused on the testing methods used to evaluate the selected technologies

K. CONCLUSIONS

Please provide a narrative outlining the project conclusions.

- Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

RESPOND BELOW

During this project, C-FER designed and built a custom full-scale experimental facility in Edmonton, Alberta, known as the Inland Waterway Simulator (IWS). The IWS facilitates the carefully controlled, measured, and safe experimental testing of various leak detection and spill response technologies at representative full-scale conditions. As such, it provides a unique, controlled test environment to accurately evaluate submerged-oil leak-detection technologies. Following construction of the IWS, C-FER completed a series of initial demonstration tests to confirm operation of the IWS, and then evaluated several different technologies. Initial leakage events were carried out in the IWS to evaluate the performance of four submerged oil detection sensors during a series of demonstration tests.

These initial demonstration tests were carried out under controlled real-world-representative conditions with a single constant flow rate of 0.2 m/s and water depth of 1.5 m. The four sensors were installed in the IWS at the same distance from the inlet in a region of fully developed, laminar flow. The results from these initial flow tests show that there is a high probability of detecting submerged oil droplets with some of the selected technology, even in low concentrations. The data from these tests were shared with each of the vendors who participated to allow them to better understand the capabilities of their systems and ultimately make improvements, so they are better suited for real-world deployments. Finally, a detailed test procedure was developed from this project, which can be used for subsequent evaluations of similar scope.

The results from these tests show that there is a high potential for these sensors to work in the field, and further work should be carried out to characterize performance under a broader range of conditions. This may include testing these systems with the presence of organic matter, under turbulent flow conditions, and with a wider range of hydrocarbon products.