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January 30, 2019

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Combined Quarterly Progress Report and Annual Project Report Entitled "iPIPE – intelligent Pipeline Integrity Program," Contract No. G-046-88; UND Project – Fund 43500-UND0022445; EERC Funds 23121 and 23211

Attached is a combined quarterly progress and annual project report on the subject project for the periods of October 1, 2018 – December 31, 2018, and June 20, 2018 – December 31, 2018, respectively.

If you have any questions, please contact me by phone at (701) 777-5260 or by e-mail at jalmlie@undeerc.org.

Sincerely,

Jay C. Almlie
Principal Engineer
Mid/Downstream Oil & Gas Group Lead

JCA/kal

Attachment

IPIPE – INTELLIGENT PIPELINE INTEGRITY PROGRAM

Combined Quarterly Progress Report and Annual Project Report

(for the periods of October 1, 2018 – December 31, 2018 and June 20, 2018 – December 31, 2018, respectively)

Prepared for:

Karlene Fine

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600 East Boulevard Avenue, Department 405
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Contract No. G-046-88

Prepared by:

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January 2019

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BACKGROUND

During a May 2017 meeting with North Dakota pipeline operators, Governor Doug Burgum challenged industry to apply advanced technologies to eliminate pipeline leaks in North Dakota. In response to the Governor's challenge, industry chose a proactive path and engaged in a 3½-year program to advance development and application of emerging technologies that will prevent and detect pipeline leaks. The program intends to assist in the development of multiple emerging technologies to prevent and detect pipeline leaks by engaging with technology providers to refine not-yet-commercial products specifically for buried gathering pipelines in North Dakota, and then demonstrate technology application on working gathering pipelines.

The goal of this project is to develop and demonstrate cutting-edge technology that can prevent and/or detect gathering pipeline leaks. This goal will be supported by accomplishment of the following objectives:

- Select the most promising emerging (near-commercial) technologies for demonstration.
- Assist technology providers in refinement of their products.
- Demonstrate multiple technologies on working gathering pipelines.
- Document results of technology demonstrations.
- Facilitate adoption of technologies into North Dakota pipeline operations.

Multiple demonstrations of emerging technologies on working pipelines will simultaneously assist technology providers in refining designs, pave a path toward full commercialization in the North Dakota market, prepare pipeline operators for adoption of the new tools, and improve the performance and economics of gathering pipeline operations in North Dakota. With demonstrated success, additional consortium members (pipeline operators) will join the effort, thus enabling field testing of more technologies and further proliferating new technology among all pipeline operators.

Founding members of the industry-led consortium include Hess Corp., Equinor, Oasis Midstream Partners, Goodnight Midstream, ONEOK, Andeavor, Whiting Petroleum, and DCP Midstream. The consortium has asked the Energy & Environmental Research Center (EERC) to manage the program on its behalf. As such, the EERC submits a quarterly report and an annual report on behalf of the members of the iPIPE consortium.

The following quarterly report summarizes the program activities from October 1, 2018, through December 31, 2018. After the quarterly report, an annual report is included within this same document and summarizes program progress from June 20, 2018, through December 31, 2018.

QUARTERLY PROGRESS REPORT
(October 1, 2018 – December 31, 2018)

ACCOMPLISHMENTS DURING REPORTING PERIOD

- Program-Level Activities
  - Program Briefings
    - EERC staff presented an introduction to iPIPE at the Rocky Mountain Environment, Health, and Safety Peer Group meeting in Denver on October 25, 2018.
    - EERC and Hess Corp. staff presented an update on iPIPE progress to Governor Doug Burgum's staff and to Lieutenant Governor Brent Sanford in Bismarck on December 6, 2018.
    - EERC staff presented an update on iPIPE progress to the Oil and Gas Research Council (OGRC) in Bismarck on December 18, 2018.
  - Member Recruitment
    - Whiting Petroleum has joined the consortium as a founding member, with financial investment equal to all other founding members.
    - DCP Midstream has joined the consortium as a founding member, with financial investment equal to all other founding members.
    - The program is in discussion with a number of companies regarding new member participation. Some of these companies have approached the EERC regarding membership requirements and benefits, while others have been approached by the EERC and/or existing consortium members. Three of these companies do not currently have operations in North Dakota. We believe this demonstrates the state of North Dakota's national leadership in pipeline safety.
  - Program Media Mentions
    - iPIPE has now been highlighted in more than 35 public media or related articles. For a listing of known articles, please refer to Appendix A.
- Technology Selection
  - On October 30 and 31, 2018, iPIPE held a 2-day technology selection event in Williston, North Dakota. At the technology selection event, nine companies offering emerging technologies presented half-hour summaries of their respective submitted proposals. The iPIPE Executive Committee interviewed each presenting team, then selected technologies that the committee deemed most promising. The Executive Committee selected four technologies in which to invest, for a total of $1 million investment for 2019 codevelopment activities. Companies selected for possible demonstration and codevelopment activities in 2019 included the following:
    - Insitu, Inc.
    - Satelytics, Inc.
    - Southwest Research Institute
    - Direct-C Monitoring Services, Inc.
  - Following the technology selection event, iPIPE authorized the EERC to attempt to contract with each of the four selected technology providers in accordance with a defined negotiation plan drafted by the EERC and approved by the iPIPE Executive Committee. The EERC began contract negotiations with each of the four companies immediately following approval

of that plan in November. Negotiations with all four technology providers are ongoing at the time of this report.

- During this reporting period, the EERC continued its worldwide search for companies offering emerging technologies (not yet commercial) to improve gathering pipeline leak detection and gathering pipeline leak prevention. A wide range of technologies is continuously investigated, explored, and considered. These technologies included a vast spectrum of unique approaches such as direct measurement technologies, remote sensing technologies, nanotechnology sensors, self-healing technologies, multisensor fusion technologies, advanced cathodic protection technologies, and miniaturized inline inspection technologies.

- Demonstration Execution – Satelytics
  - Satelytics completed its satellite data collection program on October 17. By the end of October, Satelytics had analyzed all data captured for iPIPE in 2018 for hydrocarbon leak detection. Satelytics attempted to identify hydrocarbon leaks, equipment encroachment, land movement, vegetation changes, and water quality near gathering pipelines within a target area. Satellite images captured and hydrocarbon alerts were delivered to iPIPE members, as shown in Table 1.

Table 1. Satellite Image Capture and Hydrocarbon Alert Dates

Tasked Image 1	Analysis 1	6/7/18	6/10/18
Tasked Image 2	Analysis 2	6/14/18	6/18/18
Tasked Image 3	Analysis 3	6/25/18; 6/30/18	6/27/18; 7/3/18
Tasked Image 4	Analysis 4	7/4/18	7/8/18
Tasked Image 5	Analysis 5	7/7/18	7/10/18
Tasked Image 6	Analysis 6	7/12/18	7/16/18
Tasked Image 7	Analysis 7	7/17/18	7/18/18
Tasked Image 8	Analysis 8	7/23/18	7/25/18
Tasked Image 9	Analysis 9	7/30/18; 8/2/18	7/31/18; 8/6/2018
Tasked Image 10	Analysis 10	8/6/18; 8/7/18	8/8/18
Tasked Image 11	Analysis 11	8/12/18	8/14/18
Tasked Image 12	Analysis 12	8/21/18	8/23/18
Tasked Image 13	Analysis 13	8/30/18	9/1/18
Tasked Image 14	Analysis 14	9/5/18	9/6/18
Tasked Image 15	Analysis 15	9/18/18; 9/28/18	9/19/18; 9/30/18
Tasked Image 16	Analysis 16	10/17/18	10/18/18

  - Project update meetings were held on October 2, 2018, and October 23, 2018, as the Satelytics project completed its 2018 demonstration activities. Satelytics staff and iPIPE members participated in each via a WebEx conferencing service hosted by the EERC.
  - Satelytics provided to iPIPE membership a final report on the iPIPE demonstration of its "Constant Vigilance" asset-monitoring technology (focused on hydrocarbon leak detection efficacy) on October 31, 2018. In summary, Constant Vigilance hydrocarbon leak detection proved effective within iPIPE's 1000-square-mile area of interest. As is the nature of machine learning, the algorithm's efficacy improved during the course of the project and is expected to continue improving with additional data capture.

  - Using data from the soil and water sampling completed during the previous reporting period, Satelytics refined its brine alert algorithms during the months of October and November. Satelytics provided to iPIPE membership a final report on the development of brine detection algorithms on December 17, 2018. In summary, algorithms were developed to detect brine in soil. These algorithms will benefit from further data capture and analysis. This is the nature of machine learning algorithms.
  - In December, the EERC began drafting a final report on the EERC's independent evaluation of Satelytics technology applied to gathering pipelines. An executive summary of the independent evaluation report is included in the annual report portion of the current combined report to the North Dakota Industrial Commission (NDIC). The full report will be shared with iPIPE members upon completion.
- Demonstration Execution – Ingu Solutions
  - During this reporting period, an additional six of the planned 15 tests of the Pipers™ technology were completed on various operating pipelines volunteered by Hess, Equinor, Goodnight Midstream, Oasis Midstream Partners, and Andeavor. In total, 12 tests have now been completed on a wide variety of gathering pipeline configurations. Tests were conducted as summarized in Table 2. This table represents the complete set of pipelines planned for demonstration activities in North Dakota. Discussions are ongoing to complete up to two additional tests out of state with a potential new iPIPE consortium member. If executed, these tests are planned to be completed during the first quarter of 2019.
  - Ingu Solutions has submitted an individual test report on each of the runs listed in Table 2, except those performed in December. Those reports are expected in January 2019. The detailed reports provided to iPIPE members indicate that certain functions of Pipers were validated during the course of this project. Perhaps the most significant result is that automated data analysis was improved as a result of this project.
  - In December, the EERC began drafting a final report on the EERC's independent evaluation of Pipers technology applied to gathering pipelines in North Dakota. An executive summary of the independent evaluation report is included in the annual report portion of the current combined report to NDIC. The full report will be shared with iPIPE members upon completion.

Table 2. Pipers Demonstrations

1	Hess Corp.	6", nonmetallic, crude oil	8/20/18
2	Equinor	8", metallic, crude oil	7/17/18–7/18/18
3	Equinor	6", nonmetallic, produced water	12/3/18–12/8/18
4	Goodnight Midstream	6", nonmetallic, produced water	8/21/18
5	Hess Corp.	6", metallic, high-pressure natural gas	9/18/18
6	Goodnight Midstream	6", nonmetallic, produced water"	10/18/18
7	Oasis Midstream Partners	4", nonmetallic, produced water	10/16/18
8	Equinor	8", nonmetallic, produced water	9/12/18
9	Andeavor	6", metallic, crude oil	12/3/18–12/7/18
10	Oasis Midstream Partners	6", metallic, crude oil	9/11/18
11	Hess Corp.	6", metallic, crude oil	12/5/18–12/6/18
12	Hess Corp.	6", nonmetallic, crude oil	12/5/18

MEMBERSHIP AND FINANCIAL INFORMATION

The original budget proposed to the NDIC Oil and Gas Research Program (OGRP) is $3,714,000, as shown in Table 3. Table 4 presents an expected budget and actual expenses incurred by the program to date.

Table 3. iPIPE Original Budget

Sponsors	2018	2019	2020	2021	Total
NDIC – Cash	403,320	405,226	393,454	398,000	1,600,000
Industry – Cash	264,000	450,000	450,000	450,000	1,614,000
Industry and Technology Provider – In-Kind	125,000	125,000	125,000	125,000	500,000
Total	**792,320**	**980,226**	**968,454**	**973,000**	**3,714,000**

Table 4. iPIPE Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 12/31/18		Balance Remaining of Expected Budget
NDIC Share – Cash	1,600,000		541,519	**1,058,481**
Industry Share – Cash	2,152,000*		254,370	**1,897,630**
Industry – In-Kind	250,000	*Hess*	*96,879*	**0****
		Andeavor	*12,600*	
		Oasis	*19,620*	
		Goodnight	*6,800*	
		Equinor	*32,310*	
		TOTAL	168,209	
Technology Providers – In-Kind	250,000	*Satelytics*	*320,650*	
		Ingu	*88,266*	
		TOTAL	408,916	
Total	**4,252,000***		**1,373,014**	**2,956,111***

* These expected budget figures are each increased by $538,000 over the figures presented in the last quarterly report to NDIC because of the addition of two new consortium members. Each new consortium member committed to $269,000 contributed in program membership fees through 2021.

** The program has already exceeded the budgeted amount of in-kind cost share by $77,125, only 6 months into the 42-month program.

To date, CY2018 program membership dues have been collected from all six original members of the iPIPE consortium. Invoices for CY2019 membership dues were sent in December 2018 and are payable in January 2019.

The program continues to solicit additional members to contribute to this program. As additional members join the program, Table 4 will be updated to show the additional financial resources brought to the program.

Project progress, as represented by the project schedule presented in the original NDIC OGRP proposal, is shown in Figure 1.

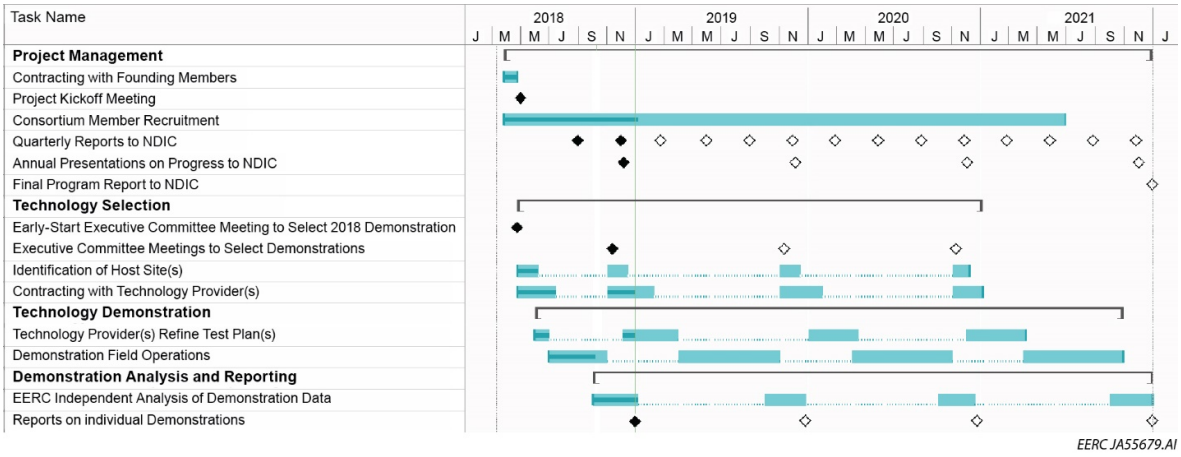

Figure 1. Project progress.

FUTURE ACTIVITIES

The planned activities for the next quarter are detailed below:

- Program Level Activities
  - On January 8, 2019, EERC staff will present a high-level summary of iPIPE activities to the American Petroleum Institute (API) – Williston Chapter in Williston, North Dakota.
  - On January 18, 2019, EERC staff will present a high-level summary of iPIPE activities to NDIC in Bismarck, North Dakota.
  - On February 26, 2019, EERC staff will present a high-level summary of iPIPE activities to the 2019 North Dakota Reclamation Conference in Dickinson, North Dakota.
  - On February 12, 2019, iPIPE will hold its Winter 2019 members meeting. iPIPE members will discuss upcoming demonstration needs, program financial status, program membership recruitment, and strategies to maximize program impact.
  - iPIPE will continue to solicit additional consortium members, following up on several open discussions.
- Technology Selection
  - The EERC will continue to research and evaluate potential new and emerging technologies for consideration by iPIPE. The EERC will contact several potential candidates for the next technology selection event and will solicit proposals from select technology providers. This is a continuous task that will continue until the next iPIPE technology selection event, anticipated in early October 2019.

- Demonstration Execution – Satelytics, Phase II
  - The EERC's independent evaluation report on Satelytics will be completed and made available to iPIPE membership. An executive summary of this report is offered in the annual report section of this document.
  - The EERC and Satelytics will complete definition of detailed scope of work for 2019 Satelytics Phase II.
  - The EERC will also complete contracting with Satelytics for 2019 work.
- Demonstration Execution – Ingu Solutions
  - The final report on the North Dakota portion of Ingu Solutions fieldwork will be completed and made available to iPIPE membership. An executive summary of this report is offered in the annual report section of this document.
  - Ingu Solutions will complete the initial scope of work by completing one more demonstrations on a DCP Midstream natural gas liquids pipeline in Oklahoma. The results of this test will be made available to iPIPE membership, but no additional final report will be provided.
- Demonstration Execution – Direct-C
  - The EERC and Direct-C will complete definition of detailed scope of work for 2019 Direct-C work.
  - The EERC will also complete contracting with Direct-C for 2019 work.
  - Direct-C will ship a quantity of sensors to the EERC to facilitate lab work scheduled to begin in first quarter of 2019.
  - The EERC will begin laboratory testing of a variety of configurations of Direct-C sensors in a variety of representative conditions.
- Demonstration Execution – Insitu
  - The EERC and Insitu will complete definition of a detailed scope of work for 2019.
  - The EERC will also complete the definitized contract with Insitu for 2019 work, which will include a detailed scope of work.
  - Insitu will begin negotiations with the Federal Aviation Administration to facilitate beyond visual line-of-sight (BVLOS) flight operations over oil fields in North Dakota.
  - Insitu will begin internal preparations to move flight equipment and radar support equipment to North Dakota in support of BVLOS operations planned for summer 2019.
- Demonstration Execution – Southwest Research Institute (SwRI)
  - SwRI will propose a new scope of work to include aerial demonstration (flight operations) of its sensor suite, as requested by iPIPE. If the approach is accepted by iPIPE, contracting for that scope of work will commence.

ANNUAL PROJECT REPORT
(June 20, 2018 – December 31, 2018)

PROJECT OVERVIEW

The intelligent Pipeline Integrity Program (iPIPE) was founded in May 2018 by a core group of pipeline operators that quickly grew to eight founding consortium members. Cost match for the initial investment by the first six consortium members was provided by the North Dakota Industrial Commission (NDIC) in the amount of $1.6 million for the period of June 20, 2018, through December 31, 2021.

Initial program operations began in May 2018, before NDIC commitment. The goal of the early start to the program was to make an immediate impact to the state of technology available to contribute positively to gathering pipeline integrity in the state of North Dakota and beyond. The program's Executive Committee met on May 1, 2018, to evaluate a number of proposals submitted to the Energy & Environmental Research Center (EERC) by providers of applicable emerging technologies to address improvements in gathering pipeline leak prevention and gathering pipeline leak detection. Each technology provider presented its approach to the iPIPE Executive Committee. The Executive Committee then selected two technologies for codevelopment efforts and funding in 2018 and asked the EERC to contract with these technology providers on behalf of the consortium. The two technologies selected for demonstration and codevelopment activities in 2018 were Satelytics, Inc., of Toledo, Ohio, and Ingu Solutions of Calgary, Alberta, Canada.

The EERC coordinated all field-based demonstration and codevelopment activities with the technology providers and with consortium members who volunteered operating gathering pipelines on which the selected technologies could be demonstrated and improved. Demonstration and codevelopment activities for Satelytics began on June 1, 2018, and continued through October 17, 2018. Demonstration and codevelopment activities for Ingu Solutions began on July 17, 2018, and continued through December 8, 2018. Summaries of the EERC's evaluation of each technology codevelopment effort are provided below.

SUMMARY OF INGU SOLUTIONS ACTIVITIES

Pipers™ Sensor Description

Pipers is an emerging technology developed by Ingu Solutions, which claims that it is an affordable and easy-to-deploy screening tool that identifies risks and performance issues in pipelines, especially suitable for small-diameter (less than 8") pipelines. According to Ingu Solutions, the technology detects and locates leaks, defects, magnetic features, and restrictions in all pipelines, with no interruption of service. Pipers sensors can be deployed in two ways: free-floating (FF-Pipers) or in combination with a cleaning pig (CP-Pipers).

Pipers sensors employ acoustic leak detection and claim an excellent signal-to-background noise ratio, allowing for accurate detection of leaks. The reduction in background noise is achieved

by the free-floating nature of the Pipers sensors, which are weighted to be neutrally buoyant in the pipeline liquid and therefore experience greatly reduced background noise attributable to scraping and/or rolling along the pipeline.

Using the metal magnetic memory method, Pipers sensors attempt to identify pipeline sections exhibiting significant metal loss. With baseline measurements, Pipers report the axial and radial magnetic profile along the pipeline. Subsequent measurements indicate differences in the profile measured along the pipeline as well as changes in the profile over time.

Pipers sensors employ a tiny sensor and power package, mounted on a small circuit board inside a hermetically sealed sphere. As of the date of this report, Ingu Solutions has two variants: one measuring 1.5" and one measuring 2.2" in diameter. Each variant possesses capabilities of acoustic leak detection, magnetic feature identification, high-resolution pressure and temperature sensing, and position sensing via an inertial measurement unit (IMU). Information summarizing each Piper form factor is presented in Table 5. A photograph of the 1.5" Mini-Pipers is presented in Figure 2.

Table 5. Physical Specifications of Pipers Configurations

FF-Mini-Pipers, CP-Mini-Pipers	1.5"	2.5 hr	435 psig	−4°–140°F	Pressure Leak detection Flow dynamics Magnetic features Isometry/piggability
FF-Pipers, CP-Pipers	2.2"	24 hr	1450 psig	−4°–176°F	Pressure Leak detection Flow dynamics Magnetic features Isometry/piggability

Figure 2. 1.5" Mini-pipers sensors.

Development/Demonstration Goals, Objectives, and Overview

To accelerate full commercialization, Ingu Solutions expressed a desire to further enhance and automate the data analysis process, including employment of machine learning algorithms. At the start of this iPIPE project, data analysis required significant manual effort. Many data analysis algorithms were still under development. Ingu Solutions believed that obtaining more data from operations in live pipelines in as many different conditions as possible would broaden data sets upon which automated processes for their data analysis could be developed.

Volunteers from iPIPE membership stepped forward to offer pipelines upon which the Pipers could be demonstrated. The array of pipelines on which Pipers were demonstrated is shown in Table 6. The locations of these pipeline segments is shown in Figure 3.

Table 6. Final Reduced Set of Pipers Demonstrations

1	Hess Corp.	6", nonmetallic, crude oil	8/20/18
2	Equinor	8", metallic, crude oil	7/17/18–7/18/18
3	Equinor	6", nonmetallic, produced water	12/3/18–12/08/18
4	Goodnight Midstream	6", nonmetallic, produced water	8/21/18
5	Hess Corp.	6", metallic, high-pressure natural gas	9/18/18
6	Goodnight Midstream	6", nonmetallic, produced water	10/18/18
7	Oasis Midstream Partners	4", nonmetallic, produced water	10/16/18
8	Equinor	8", nonmetallic, produced water	9/12/18
9	Andeavor	6", metallic, crude oil	12/3/18–12/7/18
10	Oasis Midstream Partners	6", metallic, crude oil	9/11/18
11	Hess Corp.	6", metallic, crude oil	12/5/18–12/6/18
12	Hess Corp.	6", nonmetallic, crude oil	12/5/18

To account for the three remaining unfulfilled pipeline demonstrations for which the consortium was not able to find suitable volunteer pipelines, Ingu Solutions agreed to perform up to two additional demonstrations on natural gas liquids lines owned by DCP Midstream, an iPIPE member that joined the program toward the end of 2018. These tests are scheduled to be completed during the first quarter of 2019.

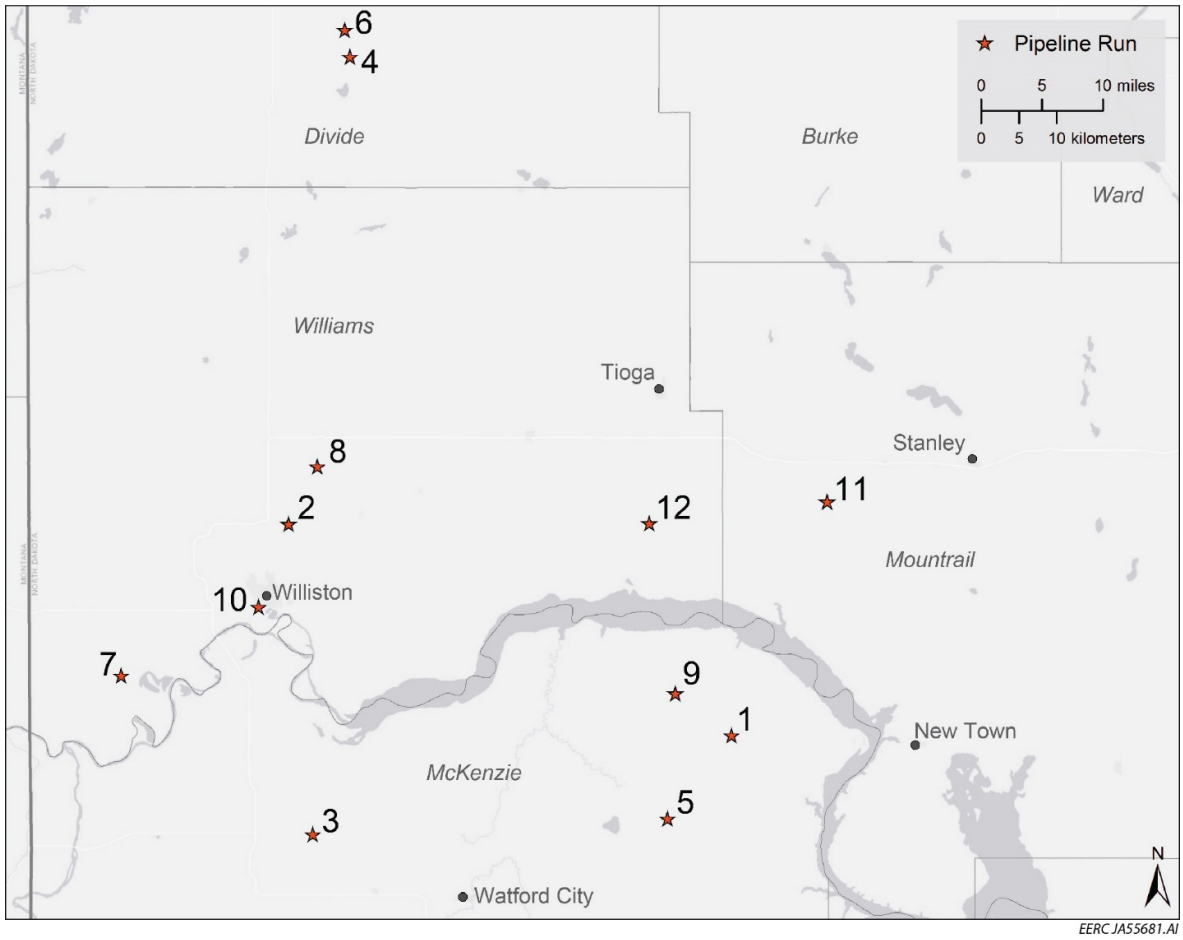

Figure 3. Location of all North Dakota pipeline tests of Pipers technology.

Discussion of Project Results

A large amount of data was generated as a result of the multiple demonstrations conducted within this project. Ingu Solutions reported that the company was very pleased to obtain these data, as it facilitated its efforts to automate the algorithms used to analyze the data. This was a declared primary goal of the project and, as such, served to advance the technology toward commercial applicability.

Additionally, the project yielded a great deal of operational and logistical lessons for both Ingu Solutions and the pipeline operators who may eventually consider commercial utilization of the Pipers technology. Each demonstration exposed Ingu Solutions staff to new and unique pipeline equipment configurations, which required on-the-fly changes to each planned execution. Ingu Solutions now has a much greater depth of understanding of the myriad configurations of gathering pipeline equipment suites in North Dakota. Each demonstration also illustrated for pipeline operators the amount of forethought and planning required to successfully employ Pipers as an inline inspection tool for gathering pipelines.

At the start of the project, Ingu Solutions asserted that simple modifications could be made to nearly any pipeline to facilitate launch and retrieval of Pipers. It is the EERC's opinion that this was proven through 12 demonstrations on unique pipeline equipment configurations. Only time constraints precluded implementation of suitable modifications to facilitate launch and retrieval of Pipers in any pipeline system considered for this project. With these learnings, participating pipeline operators and Ingu Solutions both have a clearer notion of what is required to overcome delays that may preclude use of Pipers on any considered pipeline.

Ingu Solutions analyzed every Pipers run completed as part of this project. Its acoustic analyses did not find signs of leaks in any of the pipelines (and, to be clear, no leaks were expected), but analyses of acoustic, magnetic flux, accelerometer, pressure, and temperature measurements did highlight other useful information for pipeline operators. Because of the difficulties in creating such leaks without risk to the environment, because of the compressed time frame available to put this scope of work in place, and because iPIPE members were just beginning to learn how to engage in the activities of this program, no leaks were simulated to test this capability of Pipers. If another project were pursued by iPIPE, the EERC recommends that controlled pipeline leaks be created in a safe manner to validate this function of Pipers.

EERC Assessment of Pipers Development Progress

Pipeline operators reported to the EERC that they felt that the Pipers demonstrations helped them to understand the requirements of utilizing Pipers on a variety of their pipeline configurations. This was therefore a valuable project. One pipeline operator discovered that Pipers may serve additional purposes not highlighted by Ingu Solutions. With this information, it seems that Pipers development is proceeding along a productive pathway.

Ingu Solutions stated that the real-world operations experience provided by this project was invaluable. The multiple Pipers runs helped Ingu Solutions anticipate a broad variety of pipeline configurations that may be encountered in the future so that options for launch and retrieval can be confidently offered for nearly any situation. Ingu Solutions also obtained a large quantity of data upon which improvements to analytical routines could be made. However, the EERC was not able to evaluate the efficacy of these improvements, given the brief nature of this project.

A summary of progress is presented in Table 7.

Table 7. Summary of Progress Made Toward Commercialization for Gathering Pipelines

Field Operations	The EERC believes that the area of greatest progress made during 12 Pipers runs was in development of a greatly increased understanding of logistics and hardware required to accomplish Pipers launch and retrieval from myriad pipeline hardware configurations and pipeline operational procedures. Ingu Solutions proved a willingness and ability to suggest or even fabricate modifications that would enable launch and retrieval of Pipers to each pipeline on which they were demonstrated.
Leak Detection	Ingu Solutions examined all data obtained from the iPIPE runs for indications of pipeline leaks. None were found, but if no leaks were present, it is difficult to prove whether the analytics are performing adequately. A possible next step for Ingu Solutions participation in iPIPE is to work closely with iPIPE members to create representative simulated pipeline leaks to validate the leak detection capabilities of Pipers.
Pipeline Depth Measurement	Pressure measurements recorded by Pipers clearly demonstrated their ability to record actual installed pipeline depth along a pipeline route.
Other Analytical Insights	This brief project did not facilitate a thorough evaluation of all the advertised capabilities of Pipers. Joint inspection, wall thickness changes, and metal pipe stress exposure all require repeated Pipers runs to monitor for small changes in magnetic flux. What was demonstrated during this brief project was the baseline measurement gathering that Pipers can achieve. It would be insightful to repeat many of these pipeline segments next year or after to determine changes in magnetic flux signals and to determine what those changes actually mean for pipeline health.
Ingu Solutions Postinspection Reports	Although Ingu Solutions postinspection reports provide substantive, detailed insights into buried pipeline characteristics, they are written in a very customized fashion for each pipeline. The EERC believes that this will need to be standardized and automated to achieve prolific utilization across hundreds of pipeline systems. Pipeline operators would likely use these reports as quick references to document pipeline health and will not value them as much if each one presents unique information that requires time-consuming digestion.

SUMMARY OF SATELYTICS ACTIVITIES

Satelytics is a data and analytical platform that promises to automate broad monitoring of large systems of liquids gathering pipelines. Satelytics employs machine learning algorithms to automatically analyze large amounts of optical, multispectral, and hyperspectral data from satellites, commercial airliner overflights, drone overflights, and fixed sensors to produce alerts on various changes of interest to the pipeline operator. Satelytics employs a Web-based interface as a data-rich information delivery system. Via this interface, current and historical alert locations and details can be displayed, before-and-after comparisons over a time span within the project can be observed, data can be downloaded to support field actions, and feedback can be provided to continuously improve the performance of the algorithms employed.

Satelytics provides a variety of analytical tools to the pipeline operator, including temperature analyses, chemical analyses, leak detections, and change detections. Change detections are further categorized as vegetation changes or encroachment changes. Encroachment changes are further categorized as surface disturbance, vehicle, structure, water, road, facility, shed, or other.

Scope of Work

iPIPE contracted with Satelytics to provide a two-pronged scope of work. The first task was to demonstrate and refine the existing capabilities of the "Constant Vigilance" asset-monitoring function, which includes leak detection and change detection analyses. The second task was to develop an algorithm that specifically targeted brine spill detection. Although Satelytics claims broad functionality, iPIPE efforts focused tightly on leak detection. As such, only the technical functions related to leak detection were evaluated by iPIPE.

The scope of work required satellite data from a 1000-square-mile area of North Dakota selected by iPIPE members to include gathering pipeline assets of a majority of iPIPE members. That area is shown in Figure 4. The monitored pipeline assets comprised over 2000 miles of gathering pipelines.

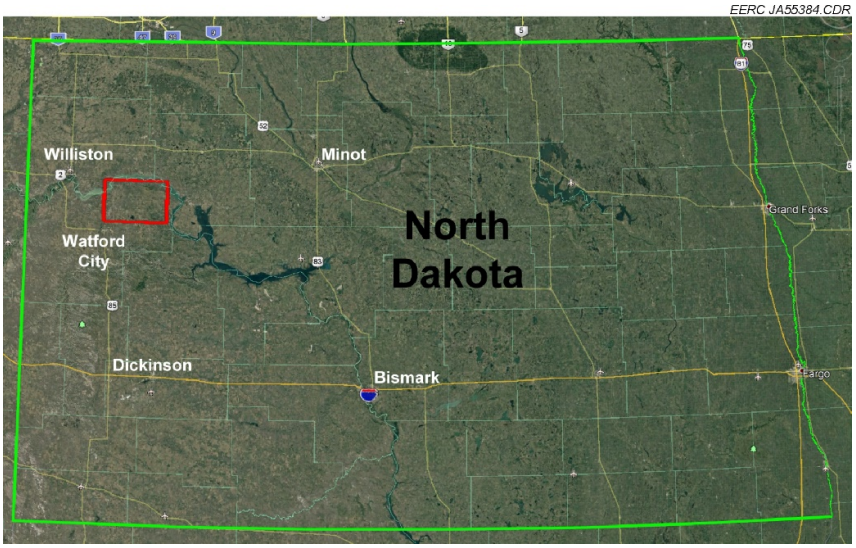

Figure 4. Area of interest for iPIPE's Satelytics project.

Multispectral and optical sensor data were obtained by Satelytics from a variety of satellite and aerial image providers to feed data to the Satelytics algorithms. Initial data were obtained at project inception to provide a baseline set of data against which successive sets of satellite imagery could be compared. Sixteen additional sets of images were then obtained, with a goal of weekly image capture and immediate analysis. Cloud cover and other factors resulted in an extension of this 4-month capture window.

Project operations can be summarized as follows:

- Satelytics collected baseline imagery, then aimed for subsequent weekly image captures and analysis.

- Satelytics trained iPIPE members in operating the *Satelytics.io* interface during weekly WebEx meetings. These meetings also served to inform iPIPE members of project progress and as a forum for Satelytics to gather suggestions for product improvements.

- Satelytics notified iPIPE members immediately upon completion of each new image analysis, which triggered field teams to investigate each hydrocarbon alert provided by Satelytics. This was referred to as "ground truthing" during the project.

- Based on their investigations, iPIPE field teams provided feedback on each alert to Satelytics. This information was used by Satelytics to train the machine learning algorithms to distinguish true hydrocarbon signatures from other misleading signatures.

- During the Constant Vigilance phase of development work, three iPIPE member companies created six simulated leaks at wellsites to evaluate Satelytics' ability to affirmatively identify actual hydrocarbon and produced water signatures.

- Satelytics led a soil- and water-sampling effort to provide valuable data to new algorithms being developed to distinguish brine signatures from hydrocarbon signatures.

- Satelytics compared performance of the brine algorithm against known benchmarks, establishing a baseline upon which future work can be based.

Project Results

Hydrocarbon Alerts Accuracy

A primary task assigned to the EERC was to independently evaluate the accuracy of hydrocarbon alerts provided by Satelytics' Constant Vigilance algorithms. A summary of over 3000 alerts provided to iPIPE members between June 1, 2018, and October 17, 2018, is shown in Table 8. iPIPE informed Satelytics very early in the project that the iPIPE member resources required to ground-truth all alerts would be too costly to justify at this early point of the development effort, so iPIPE members decided to focus on only leak detection alerts. By the end of the contracted period of performance, Satelytics provided 176 alerts of possible hydrocarbon leak detections.

iPIPE members were able to ground-truth only 104 of 176 (59%) leak detection alerts provided. This is not a reflection on anything within Satelytics' control. Rather, it is largely a function of iPIPE members learning how to engage with technology providers during the early portion of summer 2018 development efforts. Satelytics stated that this feedback greatly assisted in training their machine learning algorithms and the accuracy with which they identified spill signatures.

Table 8. Summary of Provided Alerts

	Alerts
Total Alerts	**3113**
Leak Detection Alerts	176
Change Detection Alerts	2937
Vegetation	34
Encroachment	2903
Surface Disturbance	1384
Other	749
Vehicle	353
Structure	215
Water	143
Road	47
Facility	11
Shed	1

Although statistically inconclusive because of limited sample size, it could be stated that a general trend is observable in the hydrocarbon alerts as a function of time. Figure 5 shows the hydrocarbon alerts resulting from each successful satellite image capture. There appears to be a decreasing trend in hydrocarbon alerts that could possibly be attributed to the algorithms "learning" to distinguish actual spills from other anomalous signatures. The jump witnessed in early August was due to a mutual agreement to expand the buffer area around pipeline centerlines from 50 to 300 feet on each side of the centerline, thus increasing the area under most intense scrutiny for leak detection analysis. It is worthy of mention that when no feedback was provided to other algorithms within the Constant Vigilance suite, this same diminishing trend was not evident. This further suggests that the machine learning algorithms require data to improve their accuracy.

Identification of an Actual Hydrocarbon Spill

It is promising that Satelytics identified an actual, unanticipated hydrocarbon spill during the project. Triggered by a Satelytics hydrocarbon alert, a Hess field team investigated a signature at a site known as AN-Lone Tree 152-95-1207H-1. Hess reported that there appeared to be a spill, leak, or spray that likely originated at a valve set on a crude oil sales pipeline. Hess estimates that 25 gallons of crude oil was discharged from the valve set and deduced that the cause was a gauge failure. Identification of a very small, 25-gallon hydrocarbon leak is an achievement worthy of note.

Results of Simulated Leaks

Satelytics was able to identify two of six simulated produced water or crude oil spills deployed by members of iPIPE. It is hoped that these simulated spills helped to improve the performance of the Constant Vigilance algorithm. Continued work during Phase II efforts scheduled for 2019 will perhaps allow iPIPE and Satelytics to measure that improvement.

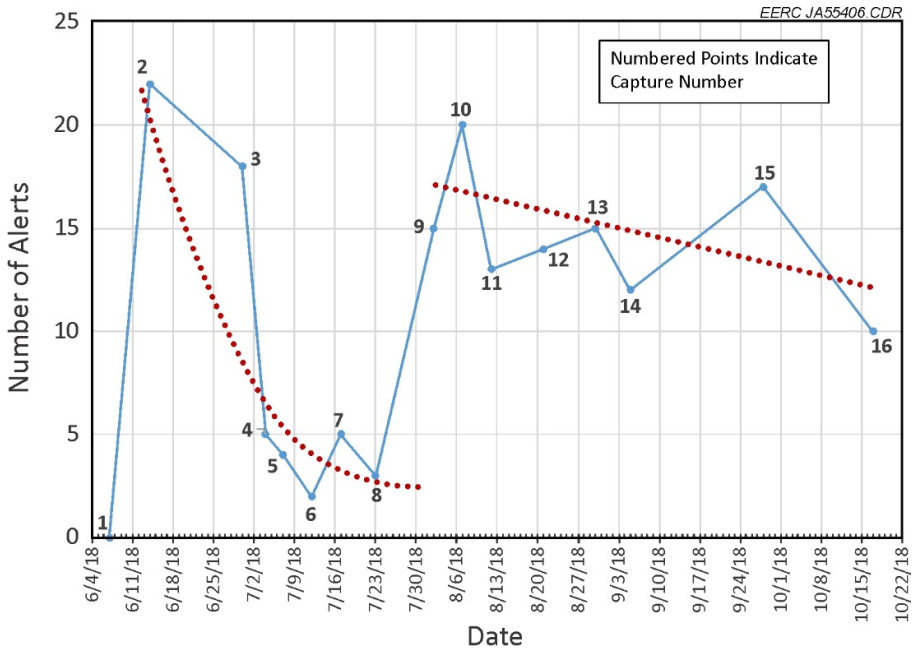

Figure 5. Apparent trend possibly indicating efficacy of machine learning algorithms.

Brine Alerts Algorithm Development

Satelytics and iPIPE collaborated to measure a suite of constituents in soil and in water using remotely acquired satellite imagery, calibrated with laboratory results from actual soil and water samples. The primary focus was to identify and quantify constituents related to salinity. Satelytics and the EERC collected a total of 27 surface water samples and 32 surface soil samples from various sites within the area of interest over four sampling dates (8/29/2018, 9/5/2018, 9/11/2018, and 10/4/2018).

After receiving soil and water sample results from the lab, Satelytics calculated all summary statistics for each of the constituents analyzed for soil and water. Constituent candidates for development were chosen by number of samples, range of laboratory values, and distribution of sample values. Satelytics chose calcium as highest ranked in these three categories.

With this limited data set, development of the calcium-based algorithm was begun. Satelytics believes that initial tests of the algorithm are promising but offered no resulting alerts, so no evaluation of alert efficacy is possible. Satelytics will integrate data sets acquired during upcoming 2019 activities into further development of the calcium-based algorithms. Table 9 details the specific data ranges of interest for continued development of calcium-based algorithms. Satelytics has stated that other constituents may also be considered if results warrant.

Table 9. Summary of Gaps in Training Data for Calcium-Based Algorithms

	Calcium in Water	Calcium in Soil
Data Needed	<20 mg/L 50–150 mg/L >200 mg/L	<10 g/kg >30 g/kg

satelytics.io Interface Improvements

Extensive interaction with the *satelytics.io* interface resulted in iPIPE users developing a list of suggested improvements they felt might improve the functionality of the interface. Satelytics was able to address many of these by making significant improvements to the Web-based interface.

EERC Analysis of Factors Impacting Efficacy of Satellite Data Capture

The ability to detect releases soon after inception relies on sensitivity of the satellite imaging and image analysis systems, satellite availability, and adequate viewing conditions.

Remote Sensing Resolution

Acquiring and transmitting sensor data is only one step of the remote sensing process. Another step involves extracting information out of sensor data by analysis or interpretation. Resolution can greatly influence what can be extracted from sensor data. Analysis can compensate, to some extent, for insufficient resolution. For example, if an image lacks sufficient detail to reveal the condition of a tiny area of interest, analysis might be able to infer its condition from changes in the area of interest and conditions surrounding it. Interpretation based upon past experience and scientific knowledge permit analysts to infer more information.

However, this approach must be executed with care. Subtle changes, changes that are not unique, or changes that can result from multiple conditions reduce the specificity and reliability of the conclusions from the analysis. Ultimately, greater resolution is desirable because it eases the demands on analysis of inference from contextual information and avoids related extrapolative errors.

Satellite Availability

Satelytics analyzed images from four constellations of satellites. Only three of these were actively employed after baselines were achieved. These included the following:

- Landsat 7 and 8, which individually possess 16-day cycles but as a team pass over the area of interest every 8 days.
- Sentinel 2A and 2B, which have 10-day individual cycles but as a team pass over the target area every 5 days.
- Pleiades 1A and 1B which, together, can revisit the area of interest daily.

Adequate Viewing Conditions

Although many factors can contribute to target view obstruction, weather conditions over the target are the most prominent reason. In assessing the effect of weather on target observation, climatological data from five weather-reporting stations surrounding the area of interest over the test period were obtained. The major conclusion that can be drawn from analysis of these data is that the June–September season represents the period of lowest cloud cover for the area of interest. The potential effect on satellite-based reconnaissance is that cloud cover will likely significantly reduce the opportunity to acquire images in winter months versus summer months. Figure 6 exhibits image capture failure rates at different amounts of maximum cloud cover, based on data derived from the schedule of successful captures attained during this 2018 project.

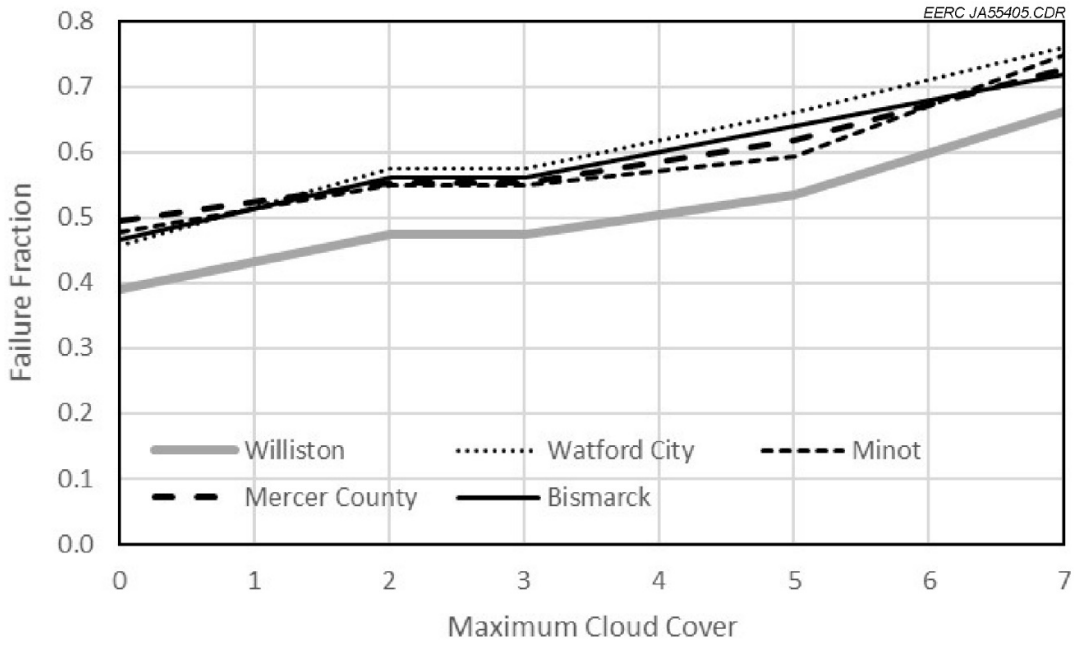

Figure 6. Failure at different cloud cover.

Capture Schedule Performance

In general, it could be said that July performance was close to the intended schedule and superior to biweekly aerial scheduling. On the other hand, when capture intervals exceeded a week, acquisition frequency was only marginally better than aerial patrols and, late in the test period, might have been marginally worse, depending on the extent that ground and water sampling delayed the observation.

Additionally, it is recognized that when the area of interest is eventually expanded beyond the 1000-square-mile area employed during this iPIPE effort, the odds of cloud cover affecting at least a part of the area of interest increase significantly. It is likely that in a commercial application

of this technology, the capture rules would be modified to accommodate frequent partial captures, thus achieving improved capture frequency.

EERC Assessment of Satelytics Technology

The iPIPE Satelytics project was an excellent start to what is hoped to be a long series of iPIPE-funded technology development efforts. Satelytics embraced the nature and mission of iPIPE. Satelytics seemed to treat this brief project as an opportunity to learn more about industry's needs, then adapt its product, and advance it toward commercial readiness. Real progress was made along that path during this project.

Table 10 summarizes (in order of relative importance assigned by the EERC) specific observed strengths of this technology and a few iPIPE observations on areas that iPIPE believes Satelytics should focus effort to make this product ready for commercial liquids gathering pipeline commercialization. Satelytics has been selected for a second phase of the project, during which additional progress toward commercialization specifically for liquids gathering pipelines will be made.

Table 10. Summary of EERC Evaluation of Satelytics Performance and Its Commercial Readiness

Promising Aspects	Aspects That Require Further Development Before Full Commercial Implementation
• Constant Vigilance algorithms identified an actual, unrecognized leak. This was a convincing, unplanned demonstration of the efficacy of this approach to leak detection. • The Satelytics team was highly responsive to interface improvement suggestions. Many improvements were quickly made to the interface upon suggestion by iPIPE members. These improvements resulted in significant functionality improvements. • Constant Vigilance algorithms produced a diminishing number of alerts as time progressed, possibly indicating efficacy of machine learning. Trends indicate that over time, Constant Vigilance algorithms will continue to improve their accuracy. • Although not yet adapted to distinguish between hydrocarbon and brine signatures, Constant Vigilance algorithms were able to identify both hydrocarbon and brine signatures. Not enough data were generated during the course of the project to assign values to the success rate of each leak type category, but leaklike events were identified.	• Cloud cover presents a major impediment to Satelytics' satellite-based imagery analysis approach. Satelytics must incorporate other forms of spectral data (such as those available from aerial platforms flying under cloud cover) to overcome this. It is anticipated that winter months will present additional challenges to the Satelytics approach in North Dakota, and possibly other climatological regions, because of cloud cover trends and snow cover. • Constant Vigilance cannot yet distinguish between hydrocarbon and brine leaks. An effort is under way to improve this functionality. • Mobile functionality of the *satelytics.io* interface must improve to optimize use by field teams. When field teams are dispatched, they will want to carry critical alert information with them on their mobile devices and will want to report (including photographic data) within this mobile interface to document resolution or to trigger further remediation action.

TECHNOLOGY SELECTIONS FOR 2019 CODEVELOPMENT ACTIVITIES

On October 30 and 31, 2018, iPIPE's Executive Committee entertained presentations from nine providers of emerging technology. From this group, the Executive Committee selected four technologies for possible codevelopment activities in 2019, including:

- *Satelytics, Inc.* – uses machine learning algorithms (artificial intelligence) to identify pipeline leaks using large sets of data from satellites, drones, and commercial aircraft. This will continue a second phase of work previously funded during 2018.

- *Insitu, Inc.* – uses drones flying beyond visual line of sight (BVLOS), multiple sensors, and advanced analytics to identify pipeline leaks over large areas of operation.

- *Southwest Research Institute (SwRI)* – uses commercial-off-the-shelf (COTS) cameras and machine learning algorithms to instantly identify hydrocarbon leaks.

- *Direct-C* – uses film-embedded nanocomposites to instantly directly measure hydrocarbon and saline leaks.

CONCLUSION

iPIPE has already demonstrated impressive results in advancing truly emerging technologies for pipeline leak prevention and pipeline leak detection toward commercialization. The consortium members have expressed pleasant surprise at the productive collaboration made possible by iPIPE. Where business-competitive concerns are not present, a great amount of information on issues related to pipeline integrity has been shared in an effort to advance the technologies selected for codevelopment toward commercialization.

In a short amount of time, iPIPE has garnered significant attention in the news media and among pipeline operators across the nation. Over 35 articles have been published about iPIPE in publications across the country. An assortment of potential new consortium members have approached iPIPE about membership. Petroleum business trade organizations have also approached iPIPE to explore ways to assist in promotion of the program.

iPIPE has been a highly novel and highly successful initiative. It has served to demonstrate North Dakota leadership on the important topic of gathering pipeline integrity. It stands as a model program for state government cooperation with industry to address the topic of responsible promotion of oil and gas resource development.

APPENDIX A

PARTIAL LISTING OF iPIPE MEDIA MENTIONS

Partial List of Articles Highlighting iPIPE

Title	Date	URL
Industry responds to governor's initiative to improve pipeline technology; Program funding approved by North Dakota Industrial Commission		https://www.ndoil.org/industry-responds-to-governors-initiative-to-improve-pipeline-technology-program-funding-approved-by-north-dakota-industrial-commission/
Satelytics Selected to Participate in the Intelligent Pipeline Integrity Program (iPIPE)	5/18/2018	https://mailchi.mp/satelytics/satelytics-chosen-to-participate-in-ipipe-project?e=922473135e
ND implements intelligent pipeline project	5/22/2018	http://northamericanshalemagazine.com/articles/2380/nd-implements-intelligent-pipeline-project
North Dakota Governor Doug Burgum provides remarks this morning at the Williston Basin Petroleum Conference in Bismarck, thanks Hess and the industry for innovation through iPIPE program.	5/23/2018	https://twitter.com/HessCorporation/statuses/999315208261853185
North Dakota Pipeline Leak Detection Initiative Announced	5/25/2018	https://extension.psu.edu/north-dakota-pipeline-leak-detection-initiative-announced
New consortium sets goal of improving pipelines	5/26/2018	https://www.mrt.com/business/oil/article/New-consortium-sets-goal-of-improving-pipelines-12941971.php
Industry Responds To Governor's Initiative To Improve Pipeline Technology; Program Funding Approved By North Dakota Industrial Commission	5/26/2018	https://www.oilandgasonline.com/doc/industry-governors-initiative-pipeline-program-north-dakota-industrial-commission-0001
New consortium sets goal of improving pipelines	5/27/2018	https://www.timesunion.com/business/oil/article/New-consortium-sets-goal-of-improving-pipelines-12941971.php
Principal Engineer Jay Almlie discusses the iPipe Program on Energy Matters Radio	5/31/2018	https://www.youtube.com/watch?v=ZQuwsK0z2aM
North Dakota selects Ingu Solutions for demonstration of cutting-edge leak detection and prevention technology for oil and gas pipelines	5/31/2018	https://ingu.co/ipipe/
Leak Detection Project Kicks Off This Summer	6/1/2018	https://myemail.constantcontact.com/Here-are-the-week-s-top-North-Dakota-energy-stories-.html?soid=1102657032033&aid=NpwT2Ynl17c
How a Canadian solution to detecting pipeline leaks is being used in North Dakota	6/5/2018	https://www.bnnbloomberg.ca/video/how-a-canadian-solution-to-detecting-pipeline-leaks-is-being-used-in-north-dakota~1410402
iPIPE Program helps solve pipeline leaks in ND	6/6/2018	http://www.kfyrtv.com/content/news/iPIPE-Program-helps-solve-pipeline-leaks-in-ND--484747291.html
Startup uses small sensors to check North Dakota oil pipes	6/10/2018	https://www.alvareviewcourier.com/story/2018/06/10/interesting-items/startup-uses-small-sensors-to-check-north-dakota-oil-pipes/37406.html
Sensors to monitor oil, brine gathering lines coming to ND	6/12/2018	https://www.westfargopioneer.com/news/science-and-nature/4459638-sensors-monitor-oil-brine-gathering-lines-coming-nd
Pipe sensors to monitor gathering lines	6/12/2018	https://bismarcktribune.com/business/local/pipe-sensors-to-monitor-gathering-lines/article_cd64586c-1d52-52df-83e6-b661d3b95f0a.html
Startup uses small sensors to check North Dakota oil pipes	6/21/2018	https://www.apnews.com/9d65538034a24711a4a84d4e2bb38efe

Continued . . .

Partial List of Articles Highlighting iPIPE (continued)

Title	Date	URL
Startup Uses Small Sensors to Check North Dakota Oil Pipes	6/21/2018	https://www.usnews.com/news/best-states/north-dakota/articles/2018-06-21/startup-uses-small-sensors-to-check-north-dakota-oil-pipes
Startup uses small sensors to check North Dakota oil pipes	6/21/2018	https://m.washingtontimes.com/news/2018/jun/21/startup-uses-small-sensors-to-check-north-dakota-o/
iPIPE: Taking a bite out of leaks	6/25/2018	http://blogs.und.edu/und-today/2018/06/taking-a-bite-out-of-leaks/
iPIPE: Taking a Bite Out of Leaks	6/29/2018	http://www.northdakotaagconnection.com/story-state.php?Id=688&yr=2018
Industry demonstrates commitment to stopping pipeline leaks	7/17/2018	http://northamericanshalemagazine.com/articles/2444/industry-demonstrates-commitment-to-stoping-pipeline-leaks
Testing of New Pipeline Inspection Device Begins in Bakken	7/18/2018	https://www.spe.org/en/ogf/ogf-article-detail/?art=4404
Testing of New Pipeline Inspection Device Begins in Bakken	7/18/2018	https://www.spe.org/en/print-article/?art=4404
6 companies collaborating on pipeline leak detection	8/15/2018	https://www.willistonherald.com/news/companies-collaborating-on-pipeline-leak-detection/article_bbce3194-a098-11e8-8bac-1b765123019e.html
Burgum highlights oil industry's progress, challenges at ND Petroleum Council's annual meeting in Fargo	9/25/2018	https://www.governor.nd.gov/news/burgum-highlights-oil-industry%E2%80%99s-progress-challenges-nd-petroleum-council%E2%80%99s-annual-meeting
Burgum highlights oil industry's progress, challenges at ND Petroleum Council's annual meeting in Fargo	9/25/2018	https://votesmart.org/public-statement/1287849/burgum-highlights-oil-industrys-progress-challenges-at-nd-petroleum-councils-annual-meeting-in-fargo#.XDz9tVxKjmE
The Digital Oilfield: How digital technologies are changing the oil industry in ND and nationwide	9/30/2018	http://www.prairiebusinessmagazine.com/business/energy-and-mining/4506605-digital-oilfield-how-digital-technologies-are-changing-oil
Progress for Partners Key to Energy & Environmental Research Center		https://www.ndliving.com/content/progress-partners-key-energy-environmental-research-center
API Banquet salutes stars of Bakken oil and gas	11/19/2018	https://www.willistonherald.com/news/api-banquet-salutes-stars-of-bakken-oil-and-gas/article_a006f78e-eb98-11e8-a353-abe9fc1170fc.html
Energy Matters: iPIPE receives Industry Innovation Award	12/3/2018	https://www.youtube.com/watch?v=L2lEr2Xu4aw
Energy Matters with iPIPE	12/12/2018	https://www.satelytics.com/blog/oil-gas-solutions/2018-energy-matters-with-ipipe/
Developing Technology to Prevent Pipeline Leaks	1/3/2019	https://mydigitalpublication.com/publication/?i=547462&p=&pn=#{%22issue_id%22:547462,%22page%22:34}
Innovative Pipeline Consortium Marks New Highlights	1/8/2019	http://undeerc.blogspot.com/2018/12/innovative-pipeline-consortium-marks.html
2018 State of the State Address	1/23/2019	https://www.governor.nd.gov/events/2018-state-state-address