

RESEARCH PERFORMANCE PROGRESS REPORT

SUBMITTED TO:

U. S. Department of Energy
National Energy Technology Laboratory

WORK PERFORMED UNDER AGREEMENT: DE-FE0029020

PROJECT TITLE:

Smart Methane Emission Detection System Development

SUBMITTED BY:

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SUBMISSION DATE: October 30, 2019

DUNS NUMBER: 007936842

RECIPIENT ORGANIZATION:

Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238

PROJECT/GRANT PERIOD:

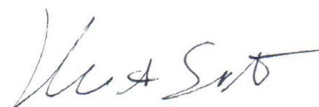
October 1, 2016 through December 31, 2019

REPORTING PERIOD END DATE:

September 30, 2019

REPORT TERM OR FREQUENCY: Quarterly

SIGNATURE OF SUBMITTING OFFICIAL:


Heath S. Spidle

ACCOMPLISHMENTS

What was done? What was learned?

Activities during this quarter focused on data collection and adaptation of the SLED/M algorithm for drone operation. During this period, we collected methane leak aerial data using cameras mounted on a DJI Matrice M600 Pro platform.

- **What are the major goals of the project?** The major objective of this DOE research project is to develop an autonomous, real-time methane leak detection technology, the SLED/M, which applies machine learning techniques to passive optical sensing modalities to mitigate emissions through early detection. The goal during Phase 1 was to develop the prototype methane detection system with integrated optical sensors and the embedded processing unit. The goal for Phase 2 was to integrate and field-test the prototype system, and then demonstrate the capabilities to DOE. The goal for Phase 3 will be to adapt the system developed under previous phases for use on a mobile aerial drone platform.

To accomplish these goals, SwRI has identified a comprehensive schedule with milestone dates for important activities that will evidence progress on the project. The milestone schedule, with actual completion dates, is shown below.

| Phase | Milestone Description | Verification Method | Planned Completion | Completion Date |
|-------|---------------------------------|---------------------|---|---------------------------|
| 1 | Prepare and Submit the PMP | Delivery to DOE | 10/29/16 | 10/29/2016 |
| 1 | Update PMP with DOE Comments | Delivery to DOE | 12/2/16 | 11/16/2016 |
| 1 | Update the Data Management Plan | Delivery to DOE | 12/16/16 | 12/16/2016 |
| 1 | Develop the Algorithm | Assessment Results | 9/15/17 (revised per PMP submitted on 6/13/17) | 9/15/17 |
| 1 | Develop and Assemble Prototype | Testing Results | 9/22/17 (revised per PMP submitted on 6/13/17) | 9/22/17 |
| 2 | Integrate and Test Prototype | Testing Results | 9/15/18 | 9/15/18 |
| 2 | Demonstrate the System to DOE | Demonstration | 9/15/18 | 9/28/18 (via test report) |
| 3 | Deployment of System to Drone | Testing Results | 1/10/18 | 3/06/19 |
| 3 | Develop Drone Algorithm | Assessment Results | 6/1/18 | 8/06/19 |
| 3 | Detection of Methane from Drone | Demonstration | 12/30/19 | |

| Number | Task/Subtask | Deliverables | Completion Date | Revised Date |
|--------|--------------|---|-----------------|--------------|
| Pd6 | 4.0 | Mechanical Drawings | 1/26/18 | 6/30/18 |
| Pd7 | 5.0 | Electrical Drawings and System Design Document | 1/26/18 | 6/30/18 |
| Sd1 | 6.0 | System Test Plan, System Test Report, Updated Drawings, Updated Software Executable and Source Code | 4/20/18 | 9/15/18 |
| | 8.0 | System Test Plan, System Test Report, Updated Drawings, Updated Software Executable and Source Code | 12/30/19 | |

What was accomplished under these goals?

Refined Aerial SLED Algorithm

- During this reporting period, SLED/M was further trained and refined for increased reliability using a large portion of the data collected during Phase 1, Phase 2, and Phase 3. The embedded deployment platform speed was increased to 10x the frame rate from the Phase 2 system. Figure 1 shows SLED/M running from aerial platform.
- During this reporting period, SLED/M qualitatively evaluated Phase 3 images, and initial aerial results look very good, as shown in Figure 2, Figure 3, and Figure 4.
- During this reporting period, quantitative evaluation was started over 226 Validation directories with a mixture of Methane, No-Methane and other various substances that could cause false positives. These metrics will be gathered and evaluated to choose the final model for Phase 3, and made available in the final report.



Figure 1. DJI Matrice 600 Pro carrying the OGI camera for data collection



Figure 2. SLED/M methane detection from aerial platform

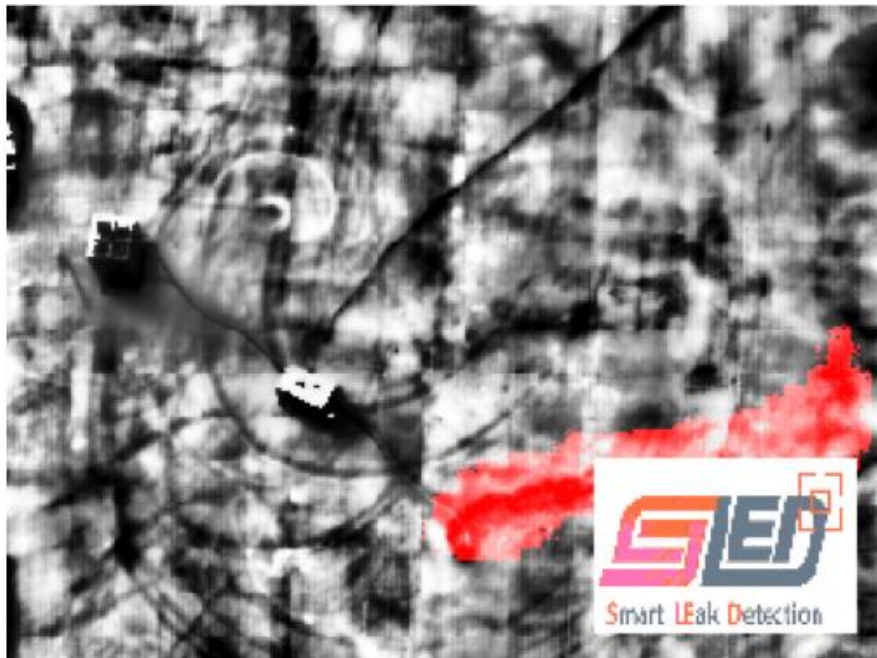


Figure 3. SLED/M methane detection from aerial platform

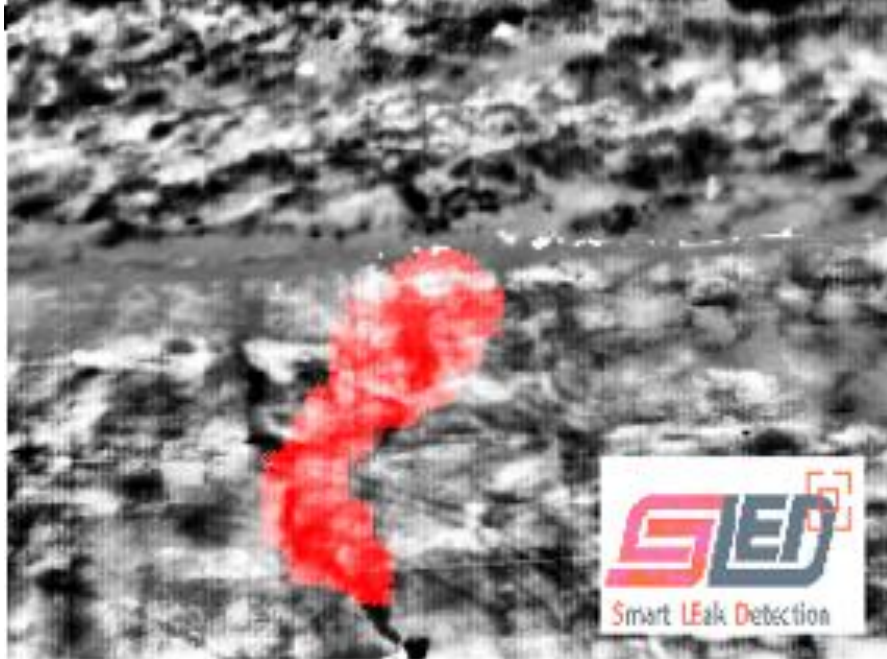


Figure 4. SLED/M methane detection from aerial platform

What opportunities for training and professional development has the project provided?

FAA UAS pilot training and license

How have the results been disseminated to communities of interest?

- With the concurrence of the DOE PM, Mr. Joseph Renk III:
 - Maria Araujo presented at the Western Regional Gas Conference in San Diego, CA on August 30, 2017 with a presentation titled “Bringing Smarts to Methane Emissions Detection: An Update on the DOE Smart Methane Emissions Project.”
 - Daniel Davila presented at the Machine Learning for Oil and Gas Conference in April 2018 with presentation titled “Enabling Edge Solutions with Deployable Machine Learning.”
 - Maria Araujo presented at the Pipeline and Energy Expo in Tulsa, OK in April 2018 with a presentation titled “Automated Leak Detection Using Machine Learning and Multi-Platform Remote Sensing.”
 - Maria Araujo presented at the World Gas Conference in June 2018 with a presentation titled “Real-Time Automated Methane Leak Detection Using Remote Sensing and Machine Learning on the Edge.”
 - Maria Araujo presented at the American Gas Association Conference in June 2018 with a presentation titled “Using Remote Sensing and Machine Learning for Automated Methane Leak Detection.”

- Heath Spidle presented at the ASME Robotics for Inspection and Maintenance Forum with presentation titled “Case Study: Real-Time Detection of Small Hazardous Liquid Pipeline Leaks Using Remote Sensing and Machine Learning.”
- Maria Araujo presented Phase 2 results at the CH4 Connections conference in Ft Collins, CO.
- Maria Araujo presented at the EUCI Methane Emissions Symposium 2019, in San Diego, CA.
- Maria Araujo presented at Cleantech Innovation Showcase, in Seattle, WA.
- Heath Spidle presented at Energy Drone Coalition 2019, in Houston TX.
- Heath Spidle presented at Addressing the Nation’s Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting in Pittsburgh, PA.
- Heath Spidle presented at CH4 Connections, Ft Colling CO.
- Heath Spidle exhibited at Environmental Partnership 2019 Annual Conference, in Houston TX.
- The team is also looking at additional conferences/venues to divulge this work.
 - Heath Spidle will be presenting at 2019 Natural Gas STAR & Methane Challenge Workshop in Pittsburgh PA.
- Additionally, several high-level articles regarding the work being done on this project were published and aired on television. Some references are noted below:
 - <https://pgjonline.com/2017/10/02/teaching-technology-solution-finds-small-pipeline-leaks/>
 - <https://www.talkingiotinenergy.com/single-post/2017/06/08/Machine-learning-improves-oil-and-gas-monitoring>
 - <https://www.asme.org/engineering-topics/articles/energy/machine-learning-applies-pipeline-leaks>
 - <http://www.naturalgasintel.com/articles/108067-texas-laboratory-developing-methane-leak-detection-system-for-doe>
 - http://www.rigzone.com/iPhone/article.asp?a_id=147295
 - <http://www.klrn.org/blogs/station-news/swri-developing-smart-technology-to-detect-methane-leaks/>
 - <http://www.oilandgaslawyerblog.com/2017/02/high-tech-detect-pipeline-leaks.html>
 - <https://www.ksat.com/news/swri-working-on-oil-and-gas-leak-detection>
 - https://www.wvnews.com/news/wvnews/netl-southwest-research-institute-develops-new-methane-detectors/article_1605789b-8875-5fff-9bb0-d434245bb1ba.html
 - <https://video.klrn.org/video/march-14-2019-tech-detects-methane-gas-leaks-wxb80n/>

What does SwRI plan to do during the next reporting period to accomplish the goals?

During the next reporting period, SwRI will:

- Collect algorithm performance metrics, accuracy and false positive (FP) rate
- Integrate the development model with drone platform for real time performance testing.

PRODUCTS

What has the project produced?

Publications, conference papers, and presentations:

- **Journal publications -**
 - Teaching Technology: Solution Finds Small Pipeline Leaks, Pipeline and Gas Journal. October 2017, Vol. 244, No. 10.
 - Machine Learning Applies to Pipeline Leaks, American Society of Mechanical Engineers (ASME). August 2017.
 - Machine learning improves oil and gas monitoring, Talking IoT in Energy, June 2017.
- **Books or other non-periodical, one-time publications –**
 - Nothing to Report During This Period.
- **Other publications, conference papers and presentations -**
 - Maria Araujo presented at the Western Regional Gas Conference in San Diego, CA on August 30, 2017 with a presentation titled “Bringing Smarts to Methane Emissions Detection: An Update on the DOE Smart Methane Emissions Project.”
 - Daniel Davila presented at the Machine Learning for Oil and Gas Conference in April 2018 with presentation titled “Enabling Edge Solutions with Deployable Machine Learning.”
 - Maria Araujo presented at the Pipeline and Energy Expo in Tulsa, OK in April 2018 with a presentation titled “Automated Leak Detection Using Machine Learning and Multi-Platform Remote Sensing.”
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 - Heath Spidle presented at the ASME Robotics for Inspection and Maintenance Forum with presentation titled “Case Study: Real-Time Detection of Small Hazardous Liquid Pipeline Leaks Using Remote Sensing and Machine Learning.”
 - Maria Araujo and Daniel Davila presented at the CH4 Connections in Fort Collins, CO and had a booth showcasing the SLED/M technology.
 - Maria Araujo presented at the EUCI Methane Mitigation Symposium in San Diego, CA showcasing the SLED/M technology.
 - Maria Araujo presented at Cleantech Innovation Showcase, in Seattle, WA showcasing the SLED/M technology.
 - Heath Spidle presented at Energy Drone Coalition 2019, in Houston TX and had a booth showcasing the SLED/M technology.

- **Website(s) or other Internet site(s) –**
 - <https://www.spe.org/en/ogf/ogf-article-detail/?art=3639>
 - <https://pgjonline.com/2017/10/02/teaching-technology-solution-finds-small-pipeline-leaks/>
 - <https://www.talkingiotinenergy.com/single-post/2017/06/08/Machine-learning-improves-oil-and-gas-monitoring>
 - <https://www.asme.org/engineering-topics/articles/energy/machine-learning-applies-pipeline-leaks>
 - <http://www.naturalgasintel.com/articles/108067-texas-laboratory-developing-methane-leak-detection-system-for-doe>
 - http://www.rigzone.com/iPhone/article.asp?a_id=147295
 - <http://www.klrn.org/blogs/station-news/swri-developing-smart-technology-to-detect-methane-leaks/>
 - <http://www.oilandgaslawyerblog.com/2017/02/high-tech-detect-pipeline-leaks.html>
 - <https://www.ksat.com/news/swri-working-on-oil-and-gas-leak-detection>
 - https://www.wvnews.com/news/wvnews/netl-southwest-research-institute-develops-new-methane-detectors/article_1605789b-8875-5fff-9bb0-d434245bb1ba.html
 - <https://video.klrn.org/video/march-14-2019-tech-detects-methane-gas-leaks-wxb80n/>

- **Technologies or techniques** – A technique for autonomously detecting methane using MWIR cameras and machine learning is currently under development, with promising results.

- **Inventions, patent applications, and/or licenses**
 An initial disclosure about the technology was made here <https://www.netl.doe.gov/node/2228> on December of 2016. It was determined that enough information about the technology was made public prior to the filing of the patent application that the application would be rejected under 35 U.S.C. § 102 and the decision was made not to proceed with the application.

- **Other products** - Nothing to report during this reporting period.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS (optional)

Who has been involved?

What individuals have worked on the project?

The following individuals were the main contributors to this project during this reporting period:

1. **Name:** Heath Spidle
 - a. **Project Role:** PI
 - b. **Nearest person month worked:** 3
 - c. **Contribution to Project:** Mr. Spidle oversees the project and technical direction. He participated on the simulated tests and holds periodic meetings with the project team. Mr. Spidle also assisted with tests performed and algorithm development during this reporting period.
 - d. **Funding Support:** N/A
 - e. **Collaborated with individual in foreign country:** No
 - f. **Country(ies) of foreign collaborator:** N/A
 - g. **Travelled to foreign country:** No
 - h. **If traveled to foreign country(ies), duration of stay:** 1 week
2. **Name:** Austin Dodson
 - a. **Project Role:** Developer
 - b. **Nearest person month worked:** 1
 - c. **Contribution to Project:** Mr. Dodson assisted with tests performed and camera driver development
 - d. **Funding Support:** N/A
 - e. **Collaborated with individual in foreign country:** No
 - f. **Country(ies) of foreign collaborator:** N/A
 - g. **Travelled to foreign country:** No
 - h. **If traveled to foreign country(ies), duration of stay:** N/A

What other organizations have been involved as partners?

There are no other planned partner organizations besides the cost share partners.

Have other collaborators or contacts been involved?

No other collaborators or contacts have been involved. However, a variety of potential industry partners have been in contact with interest in commercializing SLED/M.

IMPACT (optional)

What is the impact of the project? How has it contributed?

With the approval of the DOE, the team has already been engaging in conversations with oil and gas companies about how the SLED/M technology could potentially improve their efficiency and safety and help in the reduction of methane emissions through early detection of methane leaks. The Smart Methane Leak Detection System (SLED/M) is an autonomous, reliable, real-time methane leak detection technology that utilizes machine learning techniques and a commercial-off-the-shelf (COTS) optical sensor to mitigate emissions through early detection. SLED/M can monitor various regions of a pipeline facility and easily integrate with existing and new suites of natural gas mitigation technologies.

| Feature | Details |
|---|--|
| Low False Alarm Rates | Less than 0.5% (number of events incorrectly classified as leaks). |
| Autonomous Detection | No need for a human to be in the loop <ul style="list-style-type: none">• Minimizes human error• Minimizes response time to a leak event (early detection)• Reduces operational costs• Operates at the edge – no need for video streaming to the cloud or to a central facility |
| Works with Existing Operator-Owned MWIR Cameras | <ul style="list-style-type: none">• SLED/M has been shown to work with MWIR cameras from multiple manufacturers• SLED/M can be integrated with existing operator-owned equipment |
| Near Real-Time Detection | The time between acquiring data and obtaining an output from the system is only a few seconds |
| Non-Intrusive, Passive Technology | No need to retrofit existing equipment and facilities. The proposed technology is passive in nature, thus eliminating safety and operational restrictions. |
| Reliable Detection | Ability to detect methane leaks that could go unnoticed by current technologies |

What is the impact on the development of the principal discipline(s) of the project?

The development of the SLED/M technology allows for mitigation of fugitive emissions via the early detection of methane leaks. The technology is real-time and autonomous, thus allowing for facilities to be monitored with minimal human resource involvement and, therefore, reducing the overall monitoring costs and improving the reliability of detections.

What is the impact on other disciplines?

The technology being developed in this project has a variety of applications beyond methane emissions monitoring, such as carbon monoxide monitoring; agricultural land use analysis and crop prediction; water management and soil moisture analysis; natural hazards monitoring and prediction; and ecosystem monitoring and conservation.

What is the impact on the development of human resources?

Nothing to Report.

What is the impact on physical, institutional, and information resources that form infrastructure?

Nothing to Report.

What is the impact on technology transfer?

Commercial partners have expressed interest in commercializing the technology developed under this contract. SLED/M is garnering significant interest in industry due to:

- Its ability to operate autonomously
- Its use of COTS parts
- Its ability to detect methane that might go undetected by state-of-the-art OGI equipment
- Its ability to work with a variety of OGIs from different manufacturers

What is the impact on society beyond science and technology?

The byproducts of this project will allow for more effective mitigation of methane emissions, which are a major greenhouse effect contributor. By reducing fugitive methane emissions, climate change impacts caused by greenhouse gas emissions are also reduced.

What dollar amount of the award's budget is being spent in foreign country(ies)?

Nothing to Report.

CHANGES/PROBLEMS

SwRI does not anticipate any significant changes in the project or its direction. If this should occur, SwRI is fully aware of its responsibility to provide all relevant details, and to obtain prior written approval from the Contracting Officer.

Changes in approach and reasons for change –

Nothing to report during this reporting period.

Actual or anticipated problems or delays and actions or plans to resolve them –

Nothing to report during this reporting period.

Changes that have a significant impact on expenditures –

Nothing to report during this reporting period.

Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards –

Nothing to report during this reporting period.

Change of primary performance site location from that originally proposed –

Nothing to report during this reporting period.

SPECIAL REPORTING REQUIREMENTS

SwRI is not aware of any special reporting requirements in the award terms and conditions.

BUDGETARY INFORMATION

The cost status is provided on the next page. It identifies the baseline cost plan, actual incurred costs, and variance.

| Budget Reporting Quarter | Budget Period 2 | | | | | | | | | | | | | | | | | |
|-----------------------------|--------------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|--------------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|--------------------|---------------|
| | Q1 | | Q2 | | Q3 | | Q4 | | Q1 | | Q2 | | Q3 | | Q4 | | Q1 | |
| | 10/1-17 - 12/31/17 | | 1/1/18 - 3/31/18 | | 4/1/18 - 6/30/18 | | 7/1/18 - 9/30/18 | | 10/1-18 - 12/31/18 | | 1/1/19 - 3/31/19 | | 4/1/19 - 6/30/19 | | 7/1/19 - 9/30/19 | | 10/1-19 - 12/31/19 | |
| | Q1 | Total to Date | Q2 | Total to Date | Q3 | Total to Date | Q4 | Total to Date | Q1 | Total to Date | Q2 | Total to Date | Q3 | Total to Date | Q4 | Total to Date | Q4 | Total to Date |
| Budget Cost Plan | | | | | | | | | | | | | | | | | | |
| Federal Share | \$27,748 | \$545,155 | \$27,747 | \$572,902 | \$27,747 | \$600,649 | \$27,747 | \$628,396 | \$20,000 | \$648,396 | \$76,000 | \$724,396 | \$90,000 | \$814,396 | \$80,000 | \$894,396 | \$23,235 | \$917,631 |
| Non-Federal Share | \$0 | \$157,379 | \$0 | \$157,379 | \$0 | \$157,379 | \$0 | \$157,379 | \$0 | \$157,379 | \$21,692 | \$179,071 | \$21,692 | \$200,763 | \$21,692 | \$222,455 | \$7,233 | \$229,688 |
| Total Planned | \$27,748 | \$702,534 | \$27,747 | \$730,281 | \$27,747 | \$758,028 | \$27,747 | \$785,775 | \$20,000 | \$805,775 | \$97,692 | \$903,467 | \$111,692 | \$1,015,159 | \$101,692 | \$1,116,851 | \$30,468 | \$1,147,319 |
| Actual Incurred Cost | | | | | | | | | | | | | | | | | | |
| Federal Share | \$18,727 | \$478,174 | \$43,311 | \$521,485 | \$56,192 | \$577,677 | \$45,219 | \$622,896 | \$16,604 | \$639,500 | \$87,877 | \$727,377 | \$100,152 | \$827,529 | \$53,372 | \$880,900 | | |
| Non-Federal Share | \$4,682 | \$119,543 | \$10,828 | \$130,371 | \$14,048 | \$144,419 | \$12,960 | \$157,379 | \$0 | \$157,379 | \$0 | \$157,379 | \$54,203 | \$211,582 | \$0 | \$211,582 | | |
| Total Incurred Costs | \$23,409 | \$597,717 | \$54,139 | \$651,856 | \$70,241 | \$722,096 | \$58,179 | \$780,275 | \$16,604 | \$796,879 | \$87,877 | \$884,756 | \$154,355 | \$1,039,111 | \$53,372 | \$1,092,482 | | |
| Variance | | | | | | | | | | | | | | | | | | |
| Federal Share | \$9,021 | \$66,981 | -\$15,564 | \$51,417 | -\$28,445 | \$22,972 | -\$17,472 | \$5,500 | \$3,396 | \$8,896 | -\$11,877 | -\$2,981 | -\$10,152 | -\$13,133 | \$26,628 | \$13,496 | | |
| Non-Federal Share | -\$4,682 | \$37,836 | -\$10,828 | \$27,008 | -\$14,048 | \$12,960 | -\$12,960 | \$0 | \$0 | \$0 | \$21,692 | \$21,692 | -\$32,511 | -\$10,819 | \$21,692 | \$10,873 | | |
| Total Variance | \$4,339 | \$104,817 | -\$26,392 | \$78,425 | -\$42,494 | \$35,932 | -\$30,432 | \$5,500 | \$3,396 | \$8,896 | \$9,815 | \$18,711 | -\$42,663 | -\$23,952 | \$48,320 | \$24,369 | | |

The variance for Fiscal Year 2019 Q4 is shown above.

For historical reference, below is the variance for Budget Period 1.

| Budget Reporting Quarter | Budget Period 1 | | | | | | | |
|-----------------------------|--------------------|---------------|------------------|---------------|------------------|---------------|------------------|---------------|
| | Q1 | | Q2 | | Q3 | | Q4 | |
| | 10/1-16 - 12/31/16 | | 1/1/17 - 3/31/17 | | 4/1/17 - 6/30/17 | | 7/1/17 - 9/30/17 | |
| | Q1 | Total to Date | Q2 | Total to Date | Q3 | Total to Date | Q4 | Total to Date |
| Budget Cost Plan | | | | | | | | |
| Federal Share | \$49,000 | \$49,000 | \$160,000 | \$209,000 | \$165,000 | \$374,000 | \$143,407 | \$517,407 |
| Non-Federal Share | \$39,345 | \$39,345 | \$39,345 | \$78,690 | \$39,345 | \$118,035 | \$39,345 | \$157,379 |
| Total Planned | \$88,345 | \$88,345 | \$199,345 | \$287,690 | \$204,345 | \$492,035 | \$182,752 | \$674,786 |
| Actual Incurred Cost | | | | | | | | |
| Federal Share | \$9,846 | \$9,846 | \$128,947 | \$138,793 | \$151,515 | \$290,308 | \$169,138 | \$459,446 |
| Non-Federal Share | \$2,461 | \$2,461 | \$32,237 | \$34,698 | \$37,879 | \$72,577 | \$42,284 | \$114,862 |
| Total Incurred Costs | \$12,307 | \$12,307 | \$161,184 | \$173,491 | \$189,394 | \$362,886 | \$211,422 | \$574,308 |
| Variance | | | | | | | | |
| Federal Share | \$39,154 | \$39,154 | \$31,053 | \$70,207 | \$13,485 | \$83,692 | -\$25,731 | \$57,961 |
| Non-Federal Share | \$36,884 | \$36,884 | \$7,108 | \$43,992 | \$1,466 | \$45,457 | -\$2,940 | \$42,517 |
| Total Variance | \$76,038 | \$76,038 | \$38,161 | \$114,199 | \$14,950 | \$129,149 | -\$28,671 | \$100,478 |