CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	Methane Destruction for Pipeline Blowdowns (Portable Incineration)
Emissions Reduction Scope/Description:	Methane Destruction through Incineration
Applicant (Organization):	TC Energy – NOVA Gas Transmission Ltd. (NGTL)
Project Completion Date:	March 31st, 2023

2. EXECUTIVE SUMMARY:

Pipeline blowdowns are an important part of TC Energy's natural gas operating practices which allow for the safe execution of pipeline repairs and maintenance activities. During a pipeline blowdown, an isolated pipeline segment is fully depressurized by venting the natural gas in the pipeline to atmosphere. In many instances, TC Energy owned-and-operated portable transfer compressors can reduce the volume of natural gas vented to atmosphere by redirecting the natural gas from the isolated pipeline segment to another pressurized segment elsewhere on the pipeline system. However, technical, and logistical constraints prevent these compressors from depressurizing the pipeline segment fully and therefore, a residual volume of gas remains in the pipe that has been traditionally vented to atmosphere.

The use of portable incineration technology is one potential option for abating the emissions associated with this residual volume of gas. By converting the methane that would otherwise be vented to atmosphere into carbon dioxide by means of combustion, the greenhouse gas (GHG) emissions associated with pipeline blowdowns can be significantly reduced. NOVA Gas Transmission Ltd., (NGTL) an affiliate of TC Energy, conducted incineration pilot projects to test the feasibility of portable incineration technology for pipeline blowdown emissions abatement. The incineration pilots tested two types of incinerators at three pipeline blowdown events to understand the following:

1. Understand the duration of incineration compared to a 'traditional' pipeline blowdown,
2. Trial different incineration vendors to understand technical differences and capabilities,
3. Validate methane destruction efficiency,
4. Verify that the portable incinerators can handle the pipeline volumes specified,
5. Determine the heat radiance and noise measurements of the incinerators,
6. Understand the requirements of transportation, mobilization, installation, and de-mobilization of incineration equipment,
7. Determine the ease of use in the field by operations teams, and
8. Understand safety and risk considerations.

Incinerators from Total Combustion Inc. (TCI) were used for Pilots #1 and #2. Incinerators from Questor Technology Inc. (QTI) were used for Pilot #3. For each pilot, incinerators were installed and connected to the blowdown valve riser on the pipeline to the incinerator using temporary piping. A separator tank was installed at each pilot between the pipeline and the incinerator(s) to mitigate any liquids or debris in the gas that could cause a safety hazard. Stack testing was performed to determine the combustion and methane destruction efficiencies, and heat radiance and noise testing were conducted to evaluate the heat and noise released from each incinerator.

The combustion efficiencies were found to be 99.9% for both TCI and QTI Incinerator units and the methane destruction efficiency was found to be 99.9% for all pilots. Noise testing indicated increased levels of noise during incineration activity ranging from 65.2 dBA to 102.5 dBA depending on the number and type of incinerators running as well as the distance to the incinerators. For reference to everyday life, 65 dB is comparable to piano practice, while 102.5 dB is comparable to a blender or factory noise. Valuable information on duration of an incineration event as well as complexities related to project planning and risk and safety were also gathered.

In conclusion, the incineration pilot projects successfully demonstrated that portable incineration technology is a viable option to mitigate pipeline blowdown emissions. The learnings from executing these pilots can be applied to future incineration events at TC Energy to further streamline the process and reduce incineration event duration and cost while maximizing emissions savings. It is recommended that incineration technology be explored as a means to mitigate methane emissions from other TC Energy facilities such as compressor stations, meter stations or pig barrels in the future.

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3. KEY WORDS:

Pipeline Blowdown Incineration Methane Destruction

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6. PROJECT PARTNERS:

We would like to graciously thank all the stakeholders and partners who played a pivotal role in ensuring the incineration pilots were safely and successfully executed.

First, our grant funding partners, Canadian Emissions Reduction Innovation Consortium (CanERIC) and Petroleum Technology Alliance Canada (PTAC), who provided this platform and opportunity. Thank you for your support in making these incineration pilots become a reality in advancing our blowdown management strategy.

Our incineration vendors, Total Combustion Inc. (TCI) and Questor Technology Inc. (QTI), who supplied the incinerators and provided continuous technician support throughout the duration of each incineration. Thank you for your expertise and support as we incorporate new GHG emissions reductions practices into our operations.

Our pipeline maintenance service vendor, MAXX North America (MAXX NA), who supplied the P-tank, fire watch, and monitored the pressure drop. Thank you for your expertise during each incineration pilot project, and for the safe execution of each incineration pilot project from start to finish.

Our on-site testing vendor, AGAT Laboratories, who completed stack testing to validate the combustion efficiency of the incinerators at Pilot #2. Our research vendors, starting with Southern Alberta Institute of Technology (SAIT) who completed the radiant heat and noise measurements of the incinerators, and verified the combustion efficiency from AGAT Laboratories' stack testing. Additionally, SAIT completed the stack testing at Pilot #1. The University of Waterloo's Professor Kyle Daun who assessed the radiant heat loading of the surroundings by each incinerator.

Lastly, to all the internal teams in TC Energy, from Operations to Indigenous Relations who engaged on these incineration pilot projects, thank you for your continued support, collaboration, and buy-in. These incineration pilots have provided valuable operational and performance information to help TC Energy build out a long-term strategy to abate methane emissions from pipeline blowdowns.

A. INTRODUCTION

Company Information

TC Energy has one of North America's largest energy infrastructure portfolios with operations in natural gas, liquids, power, and energy solutions. TC Energy builds and operates safe and reliable energy infrastructure, including a 93,300 km network of natural gas pipelines which supplies more than 25 per cent of the clean-burning natural gas consumed daily across North America to heat homes, fuel industries, and generate power.

TC Energy recognizes the importance of addressing climate change and the significant undertaking to transition to a low-carbon future. In 2021, TC Energy announced targets to reduce GHG emissions intensity from its operations by 30 per cent (from a 2019 baseline) by 2030 and to position the company to achieve net-zero emissions from its operations by 2050. The company's GHG Emissions Reduction Plan shares five key focus areas and a roadmap to support its position to achieve net zero emissions by 2050.

Sector Introduction

Vented emissions are controlled releases of natural gas and other vapors during operation and maintenance. In general, pipeline blowdowns involve the intentional release of natural gas (methane) into the atmosphere and are performed as part of normal operating practice where depressurization of a pipe segment is required for operational, safety or maintenance reasons. At TC Energy, eight percent of reported emissions are associated with methane venting and a large portion of these vented emissions can be attributed to pipeline blowdowns.

Pipeline depressurization can be handled through any combination of the following practices:

- **Venting:** the intentional and controlled release of hydrocarbon gas.
- **Methane Conservation:** recovery of hydrocarbon gas for use as fuel, for sale, for process gas, for injection back into the pipeline system, or held in storage for later use.
- **Methane Destruction:** the conversion of hydrocarbons contained in hydrocarbon gas to carbon dioxide, along with other molecules, for a purpose other than to produce energy.

In November 2022, the Government of Canada released a proposed regulatory framework to amend the existing federal regulations for methane emissions from the oil and gas sector to achieve at least a 75 per cent reduction by 2030 relative to 2012 emissions levels. Some of the proposed regulatory framework's source-by-source approaches that would impact pipeline blowdowns and vented emissions are as follows:

Planned Blowdowns:

- Hydrocarbon emissions associated with planned pipeline blowdown activities would be controlled by routing gas to a capture system for beneficial use, destruction or by implementing practices that re-route or avoid the need to blowdown gas. In certain cases, a company's alternative approach that achieves equivalent reductions may be considered.

Hydrocarbon Gas Conservation and Destruction Equipment:

- Destruction equipment would be required to operate at a 99%+ control efficiency.

Given both industry and government imperatives to reduce methane emissions, particularly those resulting from pipeline blowdowns, there is a strong push to develop processes and implement technologies that will help to mitigate pipeline blowdown emissions.

Project Specific Information

TC Energy has used internally owned-and-operated portable transfer compressors as the primary source of methane conservation on its pipeline blowdowns for several decades. However, TC Energy owned-and-operated portable transfer compressors are not designed to achieve full depressurization of a pipeline segment due to limitations associated with machinery horsepower. Therefore, a residual volume of gas remains in the pipe and is vented to atmosphere to achieve full depressurization. For this research project, TC Energy elected to study methane destruction, by means of portable incinerators, to mitigate the emissions associated with the residual gas in the pipeline at three locations on its NOVA Gas Transmission Ltd. (NGTL) system.

Portable incinerators have been a prevalent methane mitigation technology in the oil and gas sector for many years. TC Energy was interested in piloting incinerators on our own pipeline blowdowns to better understand how this technology could potentially be used to mitigate pipeline blowdown events across our Canadian natural gas pipeline system. If determined successful, portable incineration technology would be an additional tool available to mitigate methane emissions resulting from pipeline blowdowns. Incineration technology could also be evaluated, in the future, to mitigate methane releases from blowdowns at facilities such as compressor stations.

TC Energy's primary intent in exploring this technology was to reduce methane emissions across our pipeline systems to help meet TC Energy's corporate sustainability targets. Understanding the applicability of this type of technology to our operations will also better position TC Energy to support the Government of Canada's climate change goals.

TC Energy conducted three separate incineration trials: two trials using Total Combustion Inc. (TCI) incinerators and one trial using an incinerator unit from Questor Technology Inc. (QTI). The incinerators were used to combust the residual gas left in the pipeline section once the initial depressurization with a TC Energy owned-and-operated portable transfer compressor was complete.

The goals and proposed outcomes of the incineration pilots were meant to prove the following:

1. Understand the duration of incineration compared to a 'traditional' pipeline blowdown,
2. Trial different incineration vendors to understand technical differences and capabilities,
3. Validate methane destruction efficiency,
4. Verify that the portable incinerators can handle the pipeline volumes specified,

5. Determine the heat radiance and noise measurements of the incinerators,
6. Understand the requirements of transportation, mobilization, installation, and de-mobilization of incineration equipment,
7. Determine the ease of use in the field by operations teams, and
8. Understand safety and risk considerations.

B. METHODOLOGY

I. Site Selection

TC Energy selected specific sites where pipeline blowdowns were expected to take place and where an incineration activity could be accommodated by both TC Energy internal resources and the incineration vendors. The selected TC Energy sites were all valve sites within Alberta with varying proximities to landowners and communities. Above-ground valve sites are safety critical isolation points installed along our pipeline system. The valves are normally open, but when a section of pipeline requires maintenance, operators close the valves to isolate that section of the pipeline. This variety allowed us to understand the differences in environmental (visual and noise) impacts on the surroundings. *Table 1* outlines details of the three pilot sites for this project.

Table 1: Pilot site details

Pilot No.	Site Name	Approximate Location	Site Features
Pilot #1	Site A	Northern Alberta: Grand Prairie area	Remote site, no nearby landowners
Pilot #2	Site B	Southern Alberta: Bragg Creek area	Close proximity to landowners and busy provincial highway
Pilot #3	Site C	Northern Alberta: Edson area	Rural community, close proximity to landowners

II. Equipment Selection

The size and number of incinerators were determined based on pipeline parameters unique to each blowdown event. The following parameters were provided by TC Energy to the incineration vendors for each blowdown event:

- Available outage duration,
- Diameter of pipe,
- Length of pipe isolated,
- Pipe wall thickness, and
- Expected starting pressure following completion of depressurization by a portable transfer compressor.

Using the above information, the incineration vendors were able to calculate a total volume of gas to be incinerated as well as an expected duration to incinerate the gas given a certain quantity and type of incinerators. TCI was responsible for providing incineration equipment for Pilots #1 and #2. QTI was responsible for providing incineration equipment for Pilot #3. *Table 2* shows a subset of the pipeline parameters provided to the incinerator vendors for each of the pilots as well as the quantity and type of incinerators recommended for use by the vendors given the allowable outage duration. For more information surrounding the summary of results for each incineration pilot, refer to *Table 3.*

Table 2: Pipeline parameters provided to incineration vendor and recommended incinerator type and quantity

Pilot No.	Site Name	Diameter of Pipe	Length of Pipe Isolated	Starting Pressure	Incinerator Vendor	Incinerator Type	Quantity
Pilot #1	Site A	NPS 20	30 km	2757 kPag	TCI	Dual 4800	2
Pilot #2	Site B	NPS 36	21.5 km	650 kPag	TCI	Dual 4800	3
Pilot #3	Site C	NPS 36	15.2 km	672 kPag	QTI	Q-5000	1

TCI's Dual 4800 mobile stack trailer units (see *Figure 1*) include a self-contained stainless-steel stack with a manual ignition system, single inlet dual stack trailer, waste gas inlet flame arrestor and venturi aspirated burners. The design of the TCI incinerators does not utilize any type of insulating material and therefore was expected to give off radiant heat.

Figure 1: Total Combustion Inc. Dual 4800 Incinerator Unit

The design of the QTI Q-5000 incinerators (see *Figure 2*) utilizes refractory material and are insulated on the inside. The incinerators are lined with ceramic fiber modules to help prevent high skin temperatures on the steel shell and ensure that sufficient heat is retained in the combustion chamber. QTI's vortex generating burner provides a draw for both air and low-pressure waste gas. Additionally, the vortex provides sufficient mixing of reactants and an increased residence time for the combustion reaction to occur.

Figure 2: Questor Technology Inc. Q-5000 Permanent Incinerator Units at a Rail Car Loading Facility in Edmonton

III. Equipment Layout and Deployment

In addition to incinerator equipment provided by the incineration vendors, auxiliary equipment was needed to connect to and operate the incineration equipment at all three pilot sites. The auxiliary equipment was provided by MAXX NA and included:

- Temporary piping, including fittings,
- Separator tank (P-tank),
- Pressure gauges, and
- Adaptors to connect temporary piping to the blowdown risers.

In order to mitigate potential heat and fire risks resulting from incineration, a fire suppression skid, additional water truck and fire crew were present at each pilot. Access matting was also used at each pilot to provide safe access to the valve site, provide a stable, level ground for the incinerator equipment to sit on, and to shield the ground from radiant heat during the incineration activity. Access matting for the purposes of radiant heat protection would not be required if the ground is considered non-flammable (i.e. dirt). For these pilots, the ground was covered in grass which is considered flammable and therefore matting was required to shield the ground from the incinerator heat.

The incinerators were required to be placed a certain distance away from flammable areas, tanks, and other equipment. The required minimum distance from the incinerators to the pipeline tie-in point was 50 meters. The separator tank was required to be positioned a minimum of 25 meters away from the incinerators. To ensure the safe operation of the equipment, the incinerators were required to be a minimum of 20 meters away from any overhead power lines, trees or other flammable, heat-sensitive areas.

Incinerators must also be spaced a certain distance from each other. For TCI incinerators, a 20-meter exclusion zone was recommended based on a side-by-side configuration (see *Figure 3*). This means that the incinerators must be placed a minimum of 20 meters apart from each other. For QTI, the Q5000 incinerators must be placed a minimum of approximately 2 meters apart from each other. The differences in spacing between TCI and QTI incinerators can be attributed to the insulation on the incinerator. TCI incinerators are not insulated and therefore give off more radiant heat and are required to be spaced further apart, this ensures they are drawing cold air rather than warm, used air. QTI incinerators are insulated and therefore can be placed much closer together. For Pilot #3, where a QTI incinerator was used, the 2-meter requirement did not apply since only a single incinerator was brought to site.

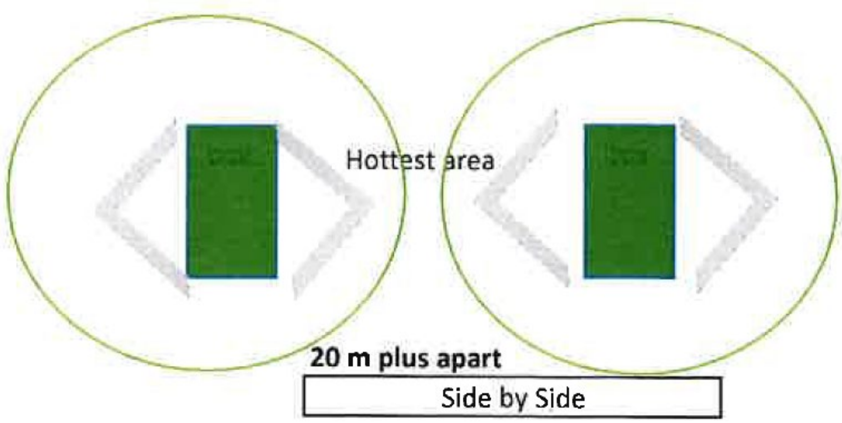

Figure 3: Total Combustion Inc.'s Suggested Lease Configuration for Dual 4800 Incinerators Placed Side-by-Side (implied circles are at a 10-meter radius)

Based on the spacing requirements, TC Energy worked together with equipment vendors to determine an optimal site layout for the incinerators and auxiliary equipment for each pilot site while ensuring the safety of the operating team and mitigating any risks. Equipment was deployed and installed as per the agreed upon site layout by all parties prior to and during the project planning phases.

Figure 4 shows the typical incineration schematic for each pilot project. It shows the delineation of equipment and tie-in responsibilities between the incineration vendor, pipeline maintenance service vendor, and TC Energy.

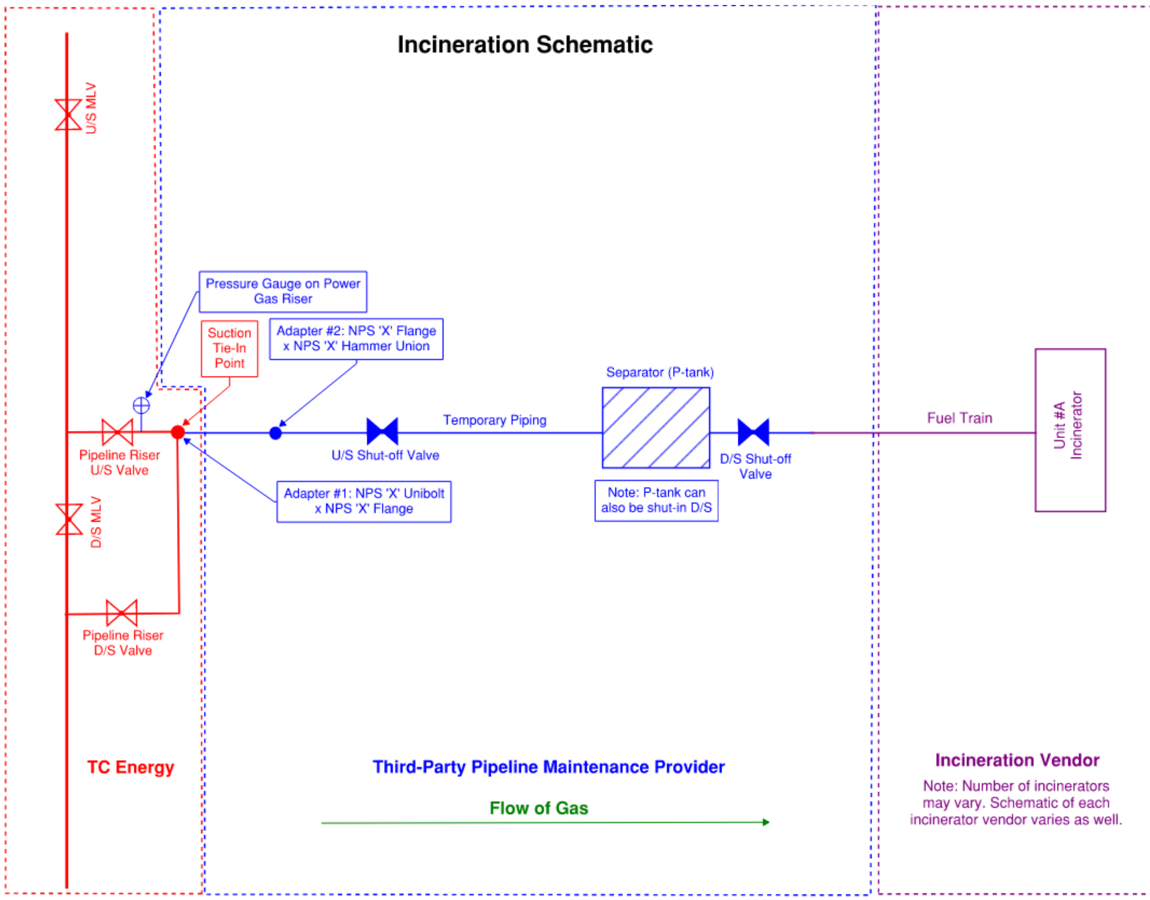

Figure 4: Typical Incineration Schematic

Additional photographs showing the equipment setup for each of the pilots can be found in *Appendix A*.

IV. Incineration

Once all incineration and auxiliary equipment was set up on site and all safety checks were completed, the incineration event was ready to begin. Note that a TC Energy owned-and-operated portable transfer compressor was used prior to each incineration event to depressurize the pipeline segment as much as possible prior to the incineration event. The start pressures for each of the pilots are shown in *Table 2*.

To begin the incineration, the blowdown valve connected to the blowdown riser (i.e., pipeline riser upstream valve) was slowly opened to allow the gas from the pipeline segment to flow through the separator tank and then to the incinerator. The flow of gas to the incinerators varied slightly between TCI and QTI as follows.

TCI – Pilots #1 & #2

A globe valve at the inlet of each incinerator skid was used to manually regulate the natural gas flow into the incinerator by TCI's technicians. Propane pilot gas was used to light the incinerators for start-up. The incineration then continued until the pipeline segment was depressurized.

QTI – Pilot #3

The Q-5000 incinerator was equipped with two inlet manifolds that supplied gas from the pipeline to the incinerator burners. A fuel train with propane pilot gas was used to light the incinerators for start-up. Once the pilot was lit, the inlet manifold valves were opened, and incineration of the pipeline gas began, and the pipeline was depressurized.

To ensure continuous operation of the incinerators during the pilots, TC Energy, the incinerator vendors, and the pipeline maintenance service vendor, MAXX NA, provided technician crews to supervise the incineration event for its entire duration. Crews worked shifts with a 30-minute overlap to ensure a seamless transition between shifts. Daily reports were created by TC Energy at the end of each shift, documenting the planned emergency procedure, start to end pressure, photos, and any noteworthy events during the shift.

For each pilot, pressure readings were taken every 30 minutes upstream of the separator tank which allowed for monitoring of the pipeline depressurization during the incineration event.

V. Stack, Noise and Heat Radiance Testing

Stack Testing & Combustion Efficiency

The efficiency of the incinerator was determined by means of stack testing performed by SAIT for Pilot #1 and a third-party vendor, AGAT laboratories for Pilot #2. Stack testing was not available for Pilot #3. SAIT collected the required data by using a probe inserted directly into the combusted flow at the top of the incinerator stack. AGAT collected data by collecting samples of the combusted gas and analyzing the gas in a laboratory setting after the incineration activity. Although the two vendors used different methodologies to confirm the stack testing results, both methodologies gave reliable results.

Noise Testing

Noise testing was performed at all pilots to gather environmental sound measurements at several points around the test site before and during the incineration activity to understand potential impact to nearby residents and site workers. SAIT performed this testing using a SoundPro Sound Level Meter Series 1-1/3.

Heat Radiance Testing

Heat radiance was measured by SAIT at Pilots #2 and #3 using the following FLIR cameras:

- FLIR TG297 thermal imaging camera
- FLIR GFX320 optical gas imaging (OGI) camera

Heat measurements were taken at various points on the incinerator stacks as well as the surrounding areas around the incinerator stacks. The images and data collected by SAIT were sent for further analysis to the University of Waterloo.

C. PROJECT RESULTS AND KEY LEARNINGS

Project Results and Discussion

Each of the conducted pilots provided valuable information that supported the goals and outcomes of this research project. A summary of the key parameters and results obtained from each of the pilots is shown in *Table 3*. *Table 4* shows the results of the noise data collection specifically.

Table 3: Summary of Results for Pilot #1, Pilot #2, and Pilot #3

Parameter	Pilot #1	Pilot #2	Pilot #3
Type of Incinerator	TCI Dual 4800	TCI Dual 4800	Questor Q-5000
Quantity of Incinerators*	Two (2)	Three (3)	One (1)
Start volume	170 e^3m^3	95 e^3m^3	75 e^3m^3
Start pressure	2,757 kPag	650 kPag	672 kPag
End pressure	5 kPag	5 kPag	0.5 kPag
Depressurization time	35.75 hours	23.5 hours	48.5 hours
Expected duration if vented without incineration†	1 hour	30 minutes	30 minutes
tCO2e if vented	3,190 tCO2e	1,610 tCO2e	1,210 tCO2e
tCO2e from incineration ‡	460 tCO2e	230 tCO2e	170 tCO2e
Emissions savings	2,730 tCO2e	1,380 tCO2e	1,040 tCO2e

* For TCI's incinerators, two (2) Dual 4800 incinerators corresponds to 4 incinerators total, while three (3) Dual 4800 incinerators corresponds to 6 incinerators total.
† Note that traditionally, the expected duration to vent the residual gas is following the pulldown compressor without the utilization of incineration.
‡ For each of the pilots, propane pilot gas was used during operation. Only emissions resulting from the combustion of natural gas in the incinerators are considered here.

Table 4: All Pilots Noise Testing Results

Pilot No.	Distance [§]	Before Operation [**] Day 1	During Operation [††] Day 2	During Operation Day 3
Pilot #1	Within 10 m	Data not collected	65.6 dB – 102.5 dB [‡‡]	N/A
	Between 10 - 20 m			
	Between 20 - 50 m			
	Between 50 - 75 m			
	Beyond 75 m			
Pilot #2	Within 10 m	45.5 dB – 52.5 dB	81.0 dB – 91.8 dB	N/A
	Between 10 - 20 m	46.0 dB – 54.2 dB	76.6 dB – 86.5 dB	
	Between 20 - 50 m	44.2 dB – 53.2 dB	68.4 dB – 81.2 dB	
	Between 50 - 75 m	Data not collected	59.8 dB – 71.9 dB	
	Beyond 75 m			
Pilot #3	Within 10 m	30.7 dB – 63.6 dB	62.5 dB – 72.3 dB	71.8 dB – 80.4 dB
	Between 10 - 20 m		58.4 dB – 65.2 dB	66.3 dB – 77.9 dB
	Between 20 - 50 m		52.3 dB – 77.5 dB	62.5 dB – 78.4 dB
	Between 50 - 75 m		49.6 dB – 79.0 dB	58.1 dB – 80.1 dB
	Beyond 75 m		42.4 dB – 57.3 dB	45.3 dB – 59.9 dB

As noted in *Table 3*, Pilot #1 used two (2) pairs of Dual 4800 incinerators while Pilot #2 used three (3) pairs. It is evident that the depressurization rate at Pilot #1 was significantly higher despite having fewer incinerators on site. TCI indicated that their incinerators are capable of operating at a range of flow rates. On the top end of the flow rate, the units burn hotter and were louder whereas on the lower end of the flow rates, the units were quieter and not as hot. At the Pilot #1 event, the incinerators were operating close to the top end of their range allowing the pipeline to depressurize at a faster rate. The incinerators at Pilot #2 were operating at a lower flow rate and therefore the pipeline depressurization was slower. The site location was in a populated area and, therefore, a lower flow rate was used as it minimized the noise level exposure in the nearby vicinity. Comparatively, it took 10 hours to depressurize from 650 kPag to 5 kPag at Pilot #1 and 23.5 hours to do the same at Pilot #2, though it is important to note that the pipeline sizes were different for each of the pilots (see *Table 2* above). The differences in flow rate are also reflected in the differences in noise levels (see *Table 4* above) between these two pilots. Higher flow rates in Pilot #1 contributed to higher noise levels compared to the relatively lower flow rates in Pilot #2 with lower noise levels. Only one incinerator pilot, Pilot #3, was conducted with a QTI Q-5000 incinerator and therefore no similar comparison can be made for this research project on flow rate ranges for this type of equipment.

The end pressure for each of the pilots did not reach 0 kPag. This is because when the pipeline segment to be depressurized is at a very low pressure, it becomes harder for the incinerator units to efficiently

[§] For pilot #3, distance from 1 combustor stack.
[**] For pilot #3, baseline measurement in pre-operations.
[††] For pilot #3, on Day 2, the incinerator was operating with 1 valve open (fuel), the other valve was off. During Day 3, the incinerator was operating with 2 valves open (fuel). Additionally, the firetruck was parked in the 50m – 75m zone, engine was always running during July 16 and 17, and may have contributed to the noise levels.
[‡‡] No baseline data was collected before the operation. Sound levels reported here are a combination of both the incineration equipment and background noise.

burn the waste gas. For each pilot, TCI on-site operators have been instructed to have the inlet pressures ranging from 14 kPa to 21 kPa (2 psig to 3 psig), which was being controlled into each incinerator(s). Additionally, for the QTI unit, increased pilot gas must be used to ensure the incinerator continues to run and the depressurization rate decreases significantly. This means that the depressurization rate in the pipeline becomes very slow when the pipeline reaches very low pressures. When this point is reached, the incinerators are shut off and the incineration activity is considered complete. The residual gas in the pipeline must then be vented to atmosphere. Note that the volume of residual gas remaining in the pipeline is calculated using the end pressure and pipeline volume; two differently sized pipeline segments will have different residual volumes even at the same end pressures.

Table 5 shows the results of the combustion efficiency and methane destruction efficiency. Combustion efficiency is defined as the amount of methane converted to carbon dioxide while the methane destruction efficiency is defined as the amount of methane destroyed/incinerated versus total methane.

Table 5: Performance Metrics for Pilot #1, Pilot #2, and Pilot #3

Parameter	Pilot #1	Pilot #2	Pilot #3
Combustion Efficiency	Inconclusive	99.9%	N/A
Methane Destruction Efficiency	99.9%	99.9%	99.9%

The methane destruction efficiency was 99.9% for all of the pilots; this was congruent with the expected results as each of the vendors had indicated that their equipment was capable of reaching this efficiency rate. The combustion efficiency was measured for Pilots #1 and #2 for TCI Incinerators. For Pilot #1, the combustion efficiency was inconclusive. One reason for this is that the equipment used for the collection of data for Pilot #1, a probe inserted into the stream of burned gas, may have been affected by the high temperatures of this gas stream making the data collection challenging and potentially skewing the results. A different data collection methodology was used for Pilot #2 and the results aligned with the expectation of 99.9% combustion efficiency.

Stack testing was not performed for Pilot #3 with the QTI equipment because QTI had already received a verification statement from an accredited body in accordance with ISO 14034:2016 – Environmental Technology Verification (ETV), which recognizes the verification of performance of innovative environmental technologies. This certification verified Questor's Q-5000 performance claims of > 99.99% combustion efficiency.

Project Learnings

The pilots represent typical pipeline blowdown events for TC Energy in terms of start pressures and volumes. For each of the pilots, significant emissions savings were achieved when employing incineration practices compared to venting the residual gas to atmosphere. These emissions savings occurred with an additional 24 to 48 hours of depressurization time when compared to venting residual gas after the use of TC Energy owned-and-operated portable transfer compressors.

The incineration events at each pilot also provided insights and operational experience with two incinerator vendors, Total Combustion Inc., and Questor Technology Inc. This data is useful as TC Energy looks to further its methane emissions reduction efforts by mitigating pipeline blowdown emissions specifically. Key learnings from the pilots are highlighted below.

Planning and Stakeholder Engagement

Executing a successful incineration activity at a pipeline blowdown event takes a significant amount of planning and coordinating with both internal and external stakeholders. The project team leading these coordination efforts must have a fulsome understanding of both the additional equipment and personnel and account for the additional time this type of activity adds to a pipeline blowdown project. Technical engineering resources should be engaged at the onset of the project to ensure the correct pressure ratings and operating conditions are verified prior to the equipment being deployed. Additionally, hazard identification sessions and risk assessments should be conducted and documented with all relevant stakeholders to ensure that any potential risks and hazards are mitigated as much as possible.

Controlling Flow to Incinerators

Operational experience from Pilots #1 and #2 suggests that it may be possible to achieve faster depressurization by increasing the flow rate to an incinerator. However, this approach impacts noise and heat radiance in the surrounding areas. Both of these factors need to be considered prior to increasing the flow rates. Additionally, the flow rates should never exceed the rated capacity of the incinerator units as this could lead to safety concerns and visible flame.

Safety

Given the nature of incineration activities, risk of excessive heat and/or fire should always be considered. Personnel should stay clear of the high heat exclusion zones unless absolutely necessary for incinerator operation. Only trained personnel may enter the exclusion zone during operation to adjust the incinerator equipment.

For each of these pilots a fire watch crew and additional water trucks were brought to each site to mitigate this risk. The fire watch crew is expected to monitor the temperature of the areas surrounding the incinerator and act to suppress any excessive heat radiance. For this research project, the temperature of the matting surrounding the incinerators was monitored by the fire watch crew every 30-45 minutes and mats were hosed down with water as necessary if the temperatures were deemed too high. Heat scans on the matting showing a temperature of 80°C or higher would warrant preventive action by the fire crews and the mats would be hosed down with water. If continued excessive heat is witnessed, the incinerator units should be shut down until the cause for excessive heat is determined and the site and project teams are all deemed safe to continue incineration.

D. BROADER IMPACT TO INDUSTRY

As discussed in the *Sector Introduction*, the new proposed methane regulatory framework released in November 2022 is expected to drive more stringent requirements with regards to emissions from pipeline blowdowns. Companies that perform pipeline blowdowns as part of their operating practices will need to evaluate and adopt new and innovative ways to mitigate the methane emissions associated with these types of blowdowns. This research project has shown that using incineration could be one potential method to reduce methane emissions associated with pipeline blowdowns.

Pipeline operators should consider the impacts of incorporating such practices into their normal pipeline blowdown operations. The increase in time and resources to execute incineration activities safely and successfully must be considered in addition to the impacts on customers of extended blowdowns/outages. Building expertise with technical and operational experts in-house as well as building relationships with incinerator vendors is crucial to being able to expand incineration practices across a large pipeline system footprint.

E. PROJECT AND TECHNOLOGY KEY PERFORMANCE INDICATORS

Organization: TC Energy	Current Study	Commercial Deployment Projection
Project cash and in-kind cost ($):	$535,621.62	Under development
Technology Readiness Level (Start/End):	9	9
GHG Emissions Reduction (tCO2e abated):	5,150 tCO2e	Under development
Estimated GHG abatement cost ($/tCO2e):	$104/tCO2e	Under development
Jobs created or maintained:	N/A	TBD

Note: Commercial Deployment Projection over a five-year period is still under evaluation by TC Energy.

F. RECOMMENDATIONS AND NEXT STEPS

Next Steps & Recommendations

The information gathered from these pilots has shown that portable incinerators are a suitable option for abatement of residual pipeline blowdown gas. The learnings from this pilot have given TC Energy confidence that incineration can be a viable way to decrease emissions associated with pipeline blowdowns. Through these learnings, TC Energy expects that the process to complete an incineration activity can be further streamlined and completed at a lower cost. This will ensure that the maximum quantity of emissions are abated safely at the lowest possible cost. Following the completion of this research project, TC Energy developed an internal operating procedure outlining the step-by-step tasks required for a Project Manager to successfully execute this work. Internal teams are working on developing a plan for potential wider adoption of this technology across our operating footprint.

Further investigation into how this technology could apply to compressor stations and smaller volume applications (e.g., pig barrels and/or in-line inspections, small diameter laterals, etc.) will also be considered in the future and may be presented as a secondary phase to this project.

G. APPENDICES

Appendix A – Photos of Incineration Setup for Each Pilot

Incinerator & Equipment Set Up – Pilot #1

The incinerator and associated equipment set-up and take down took place on October 1st, 2021. For this project, matting was already in place (see *Figure 5)* from the pulldown activity completed on the NPS 20 Pilot #1 line several days prior. Set up would have taken approximately one extra day if matting had not already been on site.

Figure 5: Set-up of Total Combustion Inc.'s Incinerators for Pilot #1.

Incinerator & Equipment Set Up – Pilot #2

The incinerator and associated equipment setup took place on June 10th, 2022. For this pilot, matting was set-up the week prior (see *Figure 6*).

Figure 6: TCI Incinerators being set up on site. Matting had been installed several days prior.

Incinerator & Equipment Set Up – Pilot #3

The incinerator and associated equipment set up took place on July 15th, 2022. Matting was set-up the previous day (see *Figure 7*).

Figure 7: Questor incinerator being set-up on site. Matting had been installed the day prior to equipment set-up.

Connection Points – Pilot #1

The connection point to the pipeline was located at the valve site. The suction was connected to blowdown valve NPS 10 unibolt riser (see *Figure 8*) by means of an NPS 10 unibolt x NPS 10 flange adaptor.

Figure 8: Tie-in point for Pilot #1.

Connection Points – Pilot #2

The connection point to the pipeline riser was located at the valve site. The suction was connected to blowdown valve NPS 12 unibolt riser (see *Figure 9* for the equipment set-up photo) by means of a NPS 12 unibolt x NPS 10 flange adaptor.

Figure 9: During equipment set-up of Pilot #2. The NPS 12 blowdown riser on the right served as the connection point for the temporary piping to the P-tank and then incinerators.

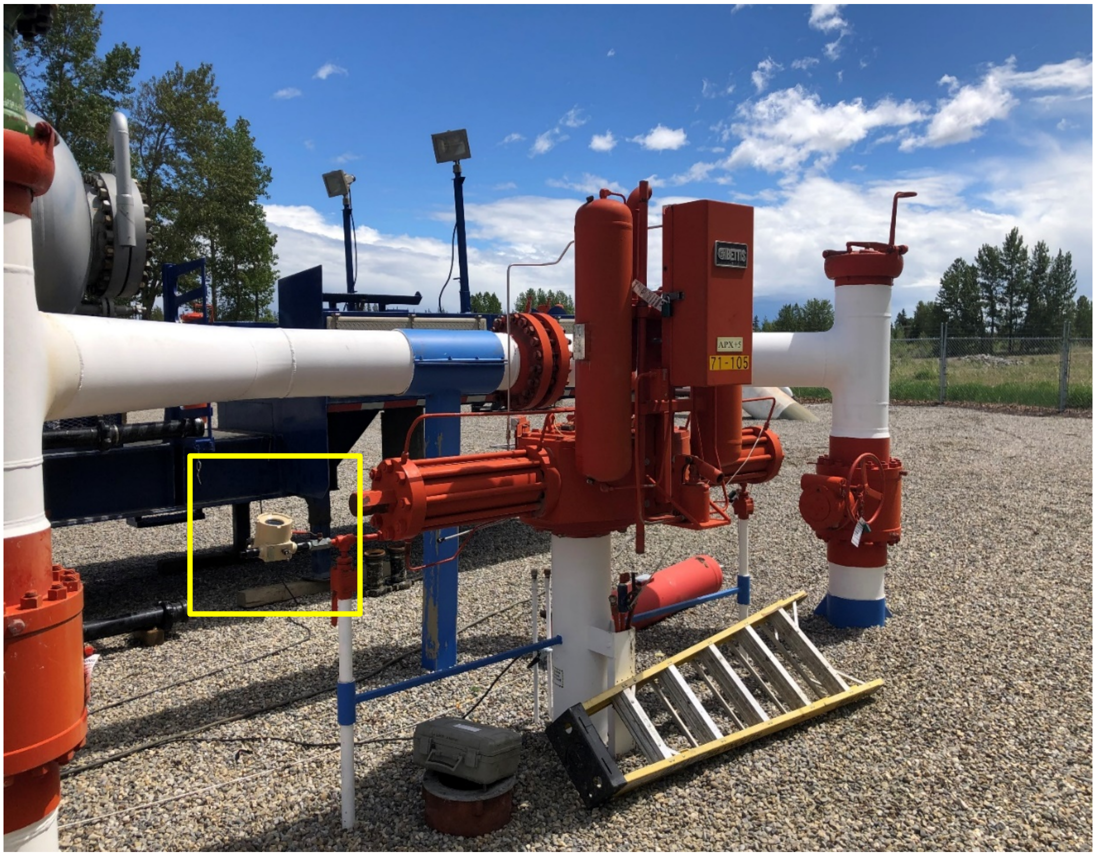

Figure 10: Pressure gauge located upstream of the separator tank which allowed for monitoring of the pipeline pressure during the incineration event.

Figure 11: NPS 3 NPT tapped flange connection. Tees from temporary piping to connect to each incinerator unit.

Connection Points – Pilot #3

The connection point to the pipeline riser was located at the valve site. The suction was connected to blowdown valve NPS 12 unibolt riser (see *Figure 12* for the pre-job photo, and *Figure 13* for the equipment set-up photo) by means of an NPS 12 unibolt x NPS 10 flange adaptor.

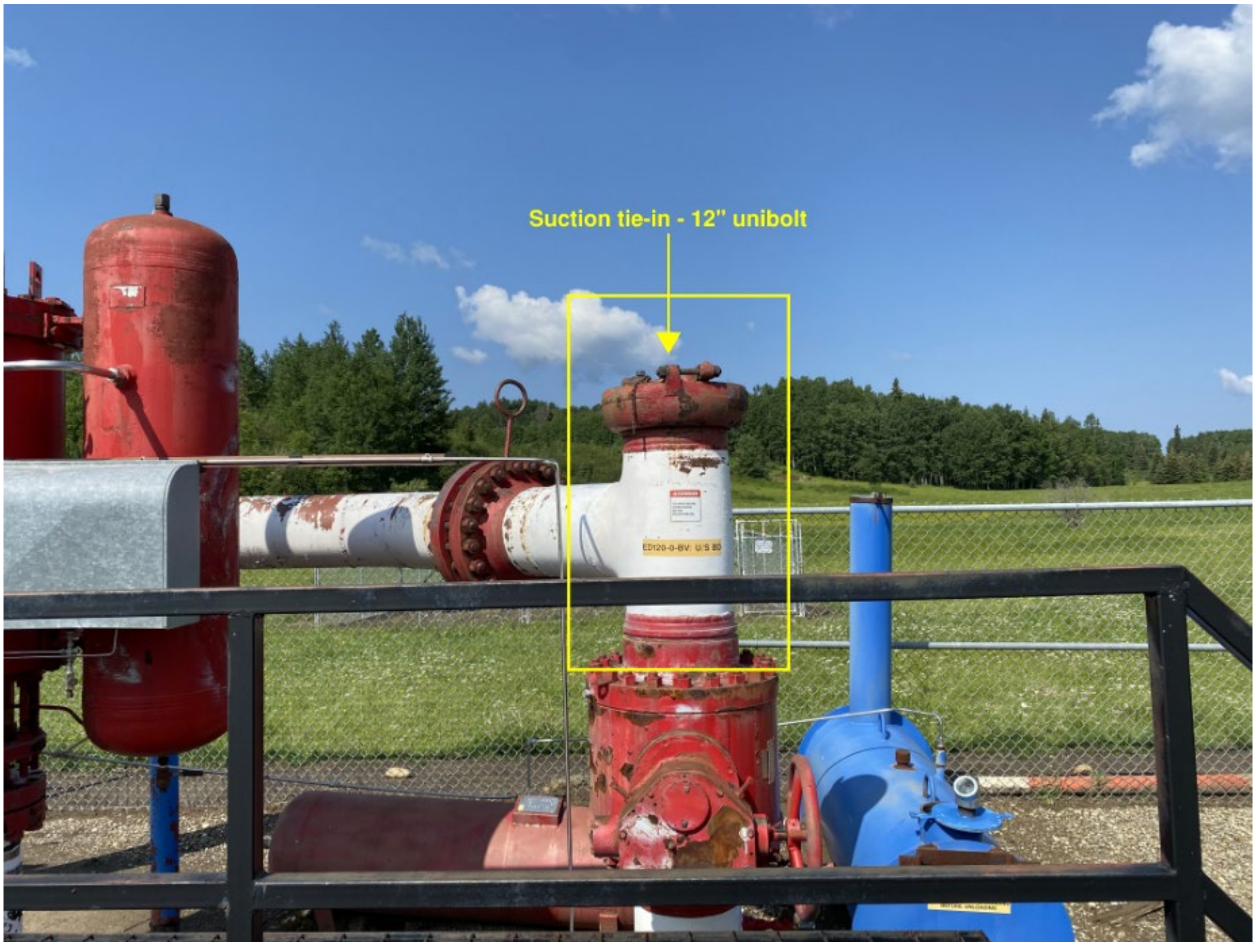

Figure 12: Pre-job photo of the Pilot #3 valve site. The NPS 12 blowdown riser above served as the connection point for the temporary piping to the P-tank and then incinerators.

Figure 13: During equipment set-up of Pilot #3 with temporary piping connecting from the P-tank (not in the picture – starting on the far left) to the pipeline riser (on the right).

Figure 14: NPS 4 and NPS 6 NPT tapped flange connection. Ties from temporary piping to connect to each incinerator unit.