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CERIN Canadian Emissions Reduction Innovation Network

CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	Compressor Station (CS) and Equipment Blowdown Feasibility Study
Emissions Reduction Scope/Description:	Feasibility study for developing high-level concepts for the capture/destruction of vented methane during planned and unplanned blowdown events at compressor stations.
Applicant (Organization):	TC Energy – NOVA Gas Transmission Ltd. (NGTL)
Project Completion Date:	March 31st, 2023

Disclaimer: This report is based on theoretical abatement options. It does not consider process conditions and risks nor site-specific conditions. Applicability of any specific abatement solution discussed in this report needs to be evaluated on a case-by-case basis.

TC Energy

2. EXECUTIVE SUMMARY:

This report investigates practical compressor station modifications in Canada's gas natural gas transmission industry which can be implemented to eliminate or reduce methane emissions during planned and unplanned gas blowdown events in order to achieve Environment and Climate Change Canada's (ECCC) objectives under its proposed regulatory framework for reducing oil and gas methane emissions.

Planned blowdowns are scheduled blowdowns of the compressor station facility to facilitate repairs, pipe additions, or maintenance with potential release of hydrocarbon emissions. For the purposes of this feasibility study, planned compressor station 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. **Unplanned blowdowns** involve emergency evacuation of natural gas release to prevent damage to people, the environment, or equipment.

Categories for Managing Blowdown 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.

The scope of this study is to develop conceptual designs that outline best methane abatement technology solutions during a planned or unplanned compressor station blowdown. Mott MacDonald evaluated one specific compressor station selected by TC Energy ("*Site A Compressor Station*"), for reference purposes, to develop industry-established solutions to abate methane emissions. The key metrics considered during evaluation was the quantification of methane abated (tCO2e) for each methane abatement option along with practical feasibility at planned and unplanned blowdown events.

The following modifications were proposed by the consulting vendor (i.e., Mott MacDonald):

- Accumulator vessel (e.g., a 'harp' system), outside station boundary that the station 'blows down' into,
- Transfer compression package, purchased from vendor, to re-inject into pipeline, and
- Incineration or flare package to destroy residual gas inventory that could not be captured in accumulator.

To be suitable for unplanned/ESD outages, all options must comply with the maximum allowable time prescribed in TC energy's internal standards for blowing down a compressor station.

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For planned blowdown events, this report recommends installation of transfer compression to eliminate methane emissions.

For unplanned or emergency shut down (ESD) blowdown events, this report concludes that detailed hydraulic sizing is required to estimate the reduction of methane emissions. However, this report does recommend a collection of options be evaluated (see modifications proposed above) and describes them qualitatively for a future study.

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3. KEY WORDS:

Blowdown, abatement, feasibility, study, facility

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6. PROJECT PARTNERS:

As part of TC Energy's quest to achieving Net Zero by 2050, we would like to graciously thank all the stakeholders and partners who played a pivotal role in executing the Compressor Station and Equipment Blowdown Feasibility Study.

First, our grant funding partners, Canadian Emissions Reduction Innovation Consortium (CanERIC) and Petroleum Technology Alliance Canada (PTAC), who have provided this platform and opportunity. Thank you for your support in making this feasibility study become a reality in advancing our understanding of methane abatement options for compressor station blowdown events.

Our independent consultant, Mott MacDonald who completed the feasibility study and provided technical recommendations for concepts of proof.

Mott MacDonald would like to thank the following vendors for their sizing, pricing, and expertise, which was essential to the development of this report:

- Compass Energy Systems Ltd. (Compass)
- Bidell Gas Compression Ltd.
- Total Combustion Inc. (TCI)
- MRC Global

A. INTRODUCTION

Company Information

TC Energy is one of North America's leading energy infrastructure companies with operations in natural gas, oil, and power industries. TC Energy builds and operates safe and reliable energy infrastructure, including our 93,300 km network of natural gas pipelines, which supplies more than 25 percent of the clean-burning natural gas consumed daily across North America to heat homes, fuel industries, and generate power.

At TC Energy, we recognize 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 greenhouse gas (GHG) emissions intensity from its operations 30 per cent from a 2019 baseline by 2030 and to position the company to achieve net-zero emissions from our operations by 2050. The company's GHG Emissions Reduction Plan shares five key focus areas and a roadmap to support achieving net-zero by 2050.

In TC Energy's GHG emissions reduction plan, eight percent of our emissions are associated with venting and other emissions. Vented emissions are controlled releases of natural gas during operations and maintenance activities. Examples of vented emissions include pipeline or compressor blowdowns and purging, while other emissions* include flaring and aircraft and fleet vehicle transportation owned and leased by the company. This feasibility study report strictly focuses on compressor station blowdowns.

Sector Introduction

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% reduction by 2030 relative to 2012. This proposed framework further provides a case for testing methane abatement technologies. Some of the proposed source-by-source approaches that directly relate to this feasibility study are as follows (reference the conservation/fuel combustion below):

Hydrocarbon Gas Conservation and Destruction Equipment:

- Conservation equipment would be required to operate at 98%+ efficiency,
- Destruction equipment would be required to operate at a 99%+ control efficiency, and
- Fuel combustion would be required to meet a 95% control efficiency.

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.

* Note that other emissions specifically aircraft and fleet vehicle transportation were not considered as part of the CS & Equipment Blowdown feasibility study.

Traditional blowdowns in the transmission sector are the intentional release of natural gas into the atmosphere for the purposes of depressurizing a volume of pipe in an emergency or for necessary maintenance work. Depressurization can be achieved through any combination of the following blowdown practices below:

Categories for Managing Blowdown 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.

Although only planned blowdowns are considered in the proposed regulatory framework at this time, TC Energy also considered the abatement of unplanned venting.

The scope of this study is to develop design concepts that outline best technology solutions during a planned or unplanned compressor station and/or equipment blowdown.

Project Specific Information

The goals of this methane emission abatement study are:

1. Present current research technologies,
2. Present industry-established technologies, and
3. For a single TC Energy compressor station ("*Site A Compressor Station*"):
    - Determine which industry-established technologies are feasible for the specific station.
    - Present two combinations† of station modifications and their overall effect‡ on abatement.

B. METHODOLOGY

Note: Mott MacDonald reviewed and summarized technologies that are not commonly applied within the gas transportation (transmission) industry, to determine if any are applicable to compressor station blowdowns. This is shown below in *Section C.1 - Current Research Technologies*.

Mott MacDonald evaluated one specific compressor station selected by TC Energy (Site 'A' Compressor Station), for reference purposes, to develop industry-established solutions to abate methane emissions. Generic Solutions were investigated that were not bound by any specific site parameters. Design concepts are presented below in *Section C.2 - Industry-Established Solutions*.

TC Energy determined a single key performance indicator (KPI) of methane abatement (units of tCO2e abated). Mott MacDonald developed a site-specific preliminary design in support of this metric,

† One combination for planned outages, and one for unplanned/emergency shutdown (ESD) outages.
‡ The overall effect is quantified as a key performance indicator (KPI).

incorporating industry-established solutions that were determined to be practical. The preliminary design, and KPI, follow in *Section C.3 - Site A Compressor Station*. In addition to the quantification of methane abated (tCO2e) metric, there may be other station specific considerations in determining applicability of a technology.

At the Site A Compressor Station, throughout this report, site-specific considerations will be shown in gray text.

C. PROJECT RESULTS AND KEY LEARNINGS

1. Current Research Technologies

Considering the three categories of blowdown practices noted in *Section A - Sector Introduction*: Venting, Methane Conservation and Methane Destruction, a hierarchy of reducing emissions would be to:

1. Minimize or eliminate venting of CH_4 (as it has higher GHG potential than CO_2),
2. Minimize flaring which destroys CH_4, but produces CO_2 which also has GHG potential impacts, and
3. Maximize methane conservation, both reducing GHG emissions and conserving useable gas.

Emissions reduction strategies can either 'reduce/eliminate at source' or 'reduce emission to atmosphere'.

1.1. Reduction at Source

Designing to eliminate the causes of venting is a methane conservation strategy: preventing the methane being emitted in the first place. It entails a root cause analysis approach to finding sources of vented gas at plant and modifying ways of operating existing equipment to avoid venting.

Mott MacDonald identified some actions that could reduce venting at the source. However, many of these actions are not practical for in-service operating assets. These actions include re-positioning isolation valves to reduce pipeline length and therefore volume of gas to be vented; reviewing the logic and timing of blowdowns to determine if some blowdown events could be eliminated; keeping equipment pressurized when safe to do so and safe re-start is possible to avoid venting; identifying and sealing leaks and fugitive emissions sources throughout the compressor station as part of the Leak Detection and Repair (LDAR) Program; identifying and replacing problem or aged equipment (for further details for all actions, see *Section C.2 - Industry-Established Solutions*).

While precedents exist among industry emissions reduction programs in the oil and gas industry (upstream, midstream, and downstream), TC Energy's target of 30% reduction in GHG emissions intensity from 2019 baseline by 2030 would necessitate aiming for the highest reductions possible for the investment made, in the shortest timeframe. Root-cause-analysis approaches and practicality aspects are considered unlikely to yield the desired reductions in this timeframe. Further evaluation needs to be completed.

1.2. Reduction of Emission to Atmosphere

This entails the following unit operations be performed on the blown down gas:

<u>**Capture-Store-Conserve:**</u>

Methane Conservation, is highly dependent upon finding a beneficial use for the methane, either on plant (e.g., as fuel gas) or in the local community/local industry. Due to the remoteness of most compressor station installations, beneficial use cases that serve local community heating needs or use of methane as feedstock for local industry were discounted. The most viable conservation option was to re-inject methane into existing pipeline flow so emissions instead become useable gas.

For **Capture-Store-Reinject** to be viable, the concept chosen must:

- Physically capture the compressor plant inventory (high volume of gas) within blowdown duration (requirement proposed by TC Energy of 7 minutes to 15 minutes),
- Store the inventory for a longer duration (typically hours) needed to re-inject that gas back into pipeline, with a dedicated re-injection package undertaking that duty,
- Segregate the stored inventory from the compressor station for the re-injection duration, preserving the safety objective of depressurization of station, and
- Where a residual volume of methane remains in station inventory, include a means of destruction so system is operationally ready for next blowdown.

For **Capture-Store-Reinject**, concepts that were discounted:

Metal-Organic Framework to capture emitted molecules:

- Primarily for CO_2 capture from waste streams e.g. flue gas; dominant species is not CH_4,
- Nascent technology going from lab to field; would require customized molecule/lattice that adsorbs CH_4,
- Ejectors/eductors that 'suck' lower pressure gas into a faster-moving gas stream, and
- For capture of smaller quantities of low-pressure streams (e.g., dry seal gas from compressors, flare header gases). Not suitable for capturing blowdown (large) inventory which starts off at high pressure.

Hence the concept elaborated in further sections consists of the following elements:

- Accumulator vessel (e.g., a 'harp' system), outside station boundary that station 'blows down' into,
- Compression package, purchased from vendor, to re-inject into pipeline, and
- Flare package to destroy residual gas inventory that could not be captured in accumulator.

2. Industry-Established Solutions

Industry-established solutions are presented below, with design considerations per CSA Z662, *Oil and Gas Pipeline Systems*, and, referenced there-in, ASME B31.3, Process Piping (ASME B31.8, *Gas Transmission and Distribution Piping Systems*, was also considered). These options are generic and will not address all code requirements; they should be evaluated on a site-specific basis. In addition, many of these actions are not practical for in-service operating assets (i.e., mainline compressor unit control modifications and accumulators).

Each of the considerations for the solutions presented below is independent and can be separated from all other solutions with two complications.

1. The accumulator will require a method of depressurization to allow for subsequent utilization of the accumulator (e.g., by incineration or transfer compression); all such methods are excluded from the accumulator section but appear elsewhere (see *Section C.2.1*, *Section C.2.2*, *Section C.2.4,* and *Section C.2.5*), and
2. In detailed design, hydraulic modeling will require specifying which of the modifications are included or excluded (i.e., "stacked" solutions) on a case-by-case basis.

One factor essential to all options is blowdown duration for unplanned or emergency shutdown (ESD) outages. Mott MacDonald relied upon API 521, *Pressure-Relieving and Depressuring Systems*, which allows for a 15-minute blowdown duration[§], whereas TC Energy generally requires compressor station blowdowns to occur in 5 to 7 minutes.

2.1. Mainline Compressor Unit Control Modifications

In a typical compressor station ESD event, the compressor units receive a shutdown signal from the station programmable logic controller (PLC), then the units shut down, then the station inlet- and outlet-valves close. More investigation needs to be done to determine how the mainline compressor unit control modifications would impact in-service operations.

A proposed modification to this control sequence for non-emergency shutdowns is as follows. The station inlet-valve closes, the compressor suction pressure drops and begins to run in recycle, then the discharge valve closes. This modification "starves" the unit, i.e., suction pressure is reduced below normal operation. Any detailed evaluation should use process analysis software, e.g., Aspen HYSYS, and include participation by compressor unit vendors. Ultimately, a detailed evaluation would quantify a time-delay between closing the station inlet valve(s) and closing the station outlet valve(s). This time delay would be perhaps a few seconds. While NPS 24 to NPS 48-yard valves require 30 to 45 seconds to fully operate (respectively), the time delay would create a staggered effect between the inlet and outlet valves.

Note: the above consideration/evaluation must occur on a site-specific basis and should not occur without customary industry considerations (e.g., review of the new and advanced isolation valve logic, safety system review, path to pump logic, etc.).

Three complexities of this modification are described below:

[§] *API 521 allows a 15-minute duration for cases where flame-jet impingement is not a credible scenario. This case is typically applicable to gas transmission facilities.*

#1. Recycle

As the unit begins to starve, the unit- or station-recycle system will begin to flow. For this modification to provide maximum abatement, the recycle system must be sized to trip the compressor on low-suction pressure as gas flows from the recycle operation to the system outlet. This is accomplished by ensuring the cold-recycle aerial gas aftercoolers are sized appropriately. If not sized appropriately, the unit will trip on high-discharge temperature instead. Brownfield station modifications would be required for existing stations that lack cold-recycle coolers, or those that are not adequately sized for the purpose described above.

#2. Unit Backflow

After the unit fully starves and before the compressor shutdown occurs (regardless of whether the trip occurs on low suction pressure or high discharge temperature), the station outlet-valve must close. Otherwise, when the unit shutdown occurs, gas might free flow backwards across the unit**, negating any savings. Control of this system, to prevent backwards free flow, could be implemented with a simple programmable timer, with the timing determined by detailed transient hydraulic analysis of the valve closure and compressor trip.

#3. Unit Trip

Compressor unit "trips" are designed by compressor manufacturers (typically as a safety mechanism, and not intended to be relied upon by cascading events unknown at the time of manufacture). As such, relying upon these trips for additional purposes is not strictly within the manufacturer's design intent. Compressor manufacturers should be consulted to warrant operation described here, due to equipment risk, safety risks, etc. Their participation may also yield synergies of cost and/or additional methane abatement.

Based on the Site A Compressor Station, Mott MacDonald modeled simplified hydraulic operation of this modification. While the NPS 48 station inlet and outlet-valves take approx. 45 seconds to operate, compressor unit 'B7' would starve in approximately 0.6 seconds, reducing the suction-side pressure and abating 0.5 tonne CH_4 per ESD-blowdown event. Because of the magnitude of the starvation time, very fast, the compressor was assumed to run at its normal operating speed throughout the event; a simplifying assumption.

Due to the scope and schedule of this feasibility project, Mott MacDonald did not consider use of the recycle system nor develop the timing for the transient interplay between the compressor shutdown and the station outlet-valve operation (i.e., did not quantify the "few seconds" of the time delay). The site-specific compressor operating envelope was used to develop a baseline, conservative estimate of abatement mass. Fully evaluating these limitations within a detailed design project will yield an increase in the abatement mass (not a decrease).

** *Unit installations typically include a discharge check valve to address this consideration. And, depending on configuration, this consideration may extend to the unit (hot) recycle system as well. Backwards free-flow is a consideration for centrifugal units more-so than reciprocal units.*

In this analysis, free-flowing high-pressure discharge gas is modeled as flowing into the high-pressure side of the pipeline (i.e., through the station outlet-valve). However, another option was initially considered: flow into the low-pressure side of the pipeline would also be possible (with station modifications). In that option, there would be a slight increase in the mass of methane abated. However, that increase is marginal, and the station modification includes installation of an additional line from the unit discharge to the station inlet. This option's KPI would be based upon only the margin, thus it was rejected outright.

2.2. Mainline Compressor Cold-Recycle Modifications

Most compressor stations with cold-recycle can run for some amount of time (or indefinitely, at partial load) in "complete" cold-recycle, meaning the station isolation valves are closed, and the unit is running in recycle (without gas flow out of the recycle system).

In this modification, an additional small discharge line (e.g., NPS 4) with control valve is routed from inside the recycle system (on the discharge side) to the low-pressure side of the pipeline. This line would allow discharge pressure to enter the pipeline until either zero flow in the line, or until compressor shut down. The free-flow in this line would reduce mass of gas in the recycle system (both in the recycle piping and in the station's inlet-side piping), yielding methane abatement.

At Site A Compressor Station, this modification would require separating the cold-recycle system and the station outlet with a proposed NPS 48 valve. For the unplanned/ESD combination only, the small discharge line would also be sized to maximize flow in a short amount of time (so as not to extend the ESD event duration too significantly). For the planned or unplanned combination, sizing of the small discharge line would also depend on the amount of time that the cold-recycle system can run before compressor shut down. As this requires detailed hydraulic analysis (rather than preliminary), it is not included within the KPI evaluation *Section D - Project and Technology Key Performance Indicators* of this report. It is recommended for further study.

2.3. Accumulators (Pipe-Type Holders)

In a typical compressor station ESD event, gas free flows from compressor station piping to atmosphere. A proposed piping modification is to free-flow a portion of that gas to an accumulator and vent the remainder of the station gas to atmosphere. The gas in the accumulator would be stored until it could be compressed and re-injected into the mainline or incinerated. The accumulator itself has a number of design considerations, as seen below.

#1. Design Code Selection and Design Code Considerations

The accumulator may be fabricated from pipe and fittings (under ASME B31.3, *Process Piping*[††]), or as a pressure vessel (under ASME Sect. VIII Div. 1, the *Boiler and Pressure Vessel Code*). The specific code

[††] *CSA Z662 requires use of CSA B51, Boiler, Pressure Vessel, and Pressure Piping Code, which in turn requires use of ASME B31.3.*

required is based on the installation country's requirements and owner's preference (Canadian Z662 allows use of either code). Mott MacDonald also considered ASME B31.8, *Gas Transmission and Distribution Piping Systems* (which is not required but contains additional information for bottles and pipe-type holders not present within the required codes). The remainder of these design considerations attempt to avoid being specific to any one code.

Some design codes will require accumulators be buried; others omit buried/exposed requirements entirely.

Over-pressure protection (OPP) of an accumulator must include thermal relief. Pipe routing to tie the accumulator to existing yard piping would need to be reviewed within a process hazard analysis (PHA) to ensure any additional OPP consideration can be ruled non-credible (i.e., with competent tie-in locations, it's likely OPP does not need to consider run-away compression or other cases of significant size, as these cases must be handled by the station's existing OPP and safety systems).

At Site A Compressor Station, Mott MacDonald assumed a pipe-type B31.3 design, which included meeting the station design pressure (9560 kPag) and includes thermal relief OPP.

#2. Separation from Compressor Station, Fencing, and Footprint

Gas transmission compressor stations must evacuate gas to the extents of the station limits during an ESD event. As such, the accumulator must reside outside the extents of station limits. The accumulator must be within an enclosed, fenced area. The pressure-retaining components of an accumulator may have clearance requirements to other structures. If a pipe-type accumulator is designed similar to a "finger-type slug catcher" then these clearances can become the basis for footprint required. Additionally, the outermost border of an accumulator will have additional clearance requirements to the accumulator's fence line, anywhere from (approximately) 5 meters to 30 meters. The fencing requirement, and the clearance requirements (for both pressure-retaining components and fencing), should be evaluated when deciding whether or not to use an existing easement for an accumulator.

At Site A Compressor Station, Mott MacDonald used 2.3 meters clearance between the pressure-retaining components of the accumulator, and 8 meters clearance between the pressure-retaining components and fence line, and, due to these requirements, developed a facility-style accumulator (not parallel with the existing mainline corridor easement).

Because of these requirements, accumulators are typically installed on property under exclusive use or exclusive control by the operating company.

#3. Hydraulic Sizing

At the start of the ESD event, after the station is shut-in, gas should free flow from the station piping to the accumulator piping. This free flow is limited by gas velocity and should not exceed owner's limits for pipelines of similar construction. The accumulator's hydraulic sizing will necessarily require all piping design considerations to be evaluated, including but not limited to hydraulic shock (i.e., water hammer).

At Site A Compressor Station, Mott MacDonald modeled a proposed NPS 36 segment of piping to free-flow from the station to the accumulator. The rate-limiting factor was the gas velocity limit of 21 m/s, controlled by a proposed NPS 16 globe control valve. The transient free-flow pressure analysis "settled out" after a few minutes, and the vast majority of mass flow occurred in less than a minute.

The accumulator's actual (water-filled) volume can be set to any size, limited only by available space and funding. The pressure at which the station and accumulator equalize will be a function of the relative volume of the accumulator compared to the combined volume of the station and accumulator[‡‡].

At Site A Compressor Station, Mott MacDonald set the volume at approximately 50% of the station volume. The transient pressure analysis combined total volume (approximately 150%), and approximately one-third of the gas was abated. The accumulator pipe size was NPS 48, selected to match the station[§§]. This option abates 13 tonnes CH_4 per accumulation event.

Use of multiple, transiently staged accumulator tanks were also considered, but this did not yield a significant abatement savings when compared to the total installed cost.

#4. Availability

The accumulator is only available when the pressure in the accumulator is less than the shut-in station and is unavailable when the station shut-in pressure matches the accumulator pressure. The accumulator will become unavailable before the entire station is depressurized. As such, an accumulator system is a "first resort" option for an ESD-blowdown event, and "last resort" options must still be included in station design (e.g., venting to atmosphere).

At Site A Compressor Station, the accumulator could be depleted by a transfer compressor, the compressor's low-suction pressure trip will be used as the accumulator's "empty" pressure. See *Section C.2.4* for details.

#5. Appurtenances for Operations, Maintenance, Corrosion Control, and Process Considerations

Accumulators should be designed with these topics in mind. Air evacuation and gas purging taps, sloped piping for liquid collection, low point drains for liquid collection, thermal relief valves, and hydraulic shock should all be incorporated. The rapid depressurization at the beginning of the transient event may

‡‡ At Site 'A' Compressor Station, Mott MacDonald used 345 kPag for the accumulator's starting pressure.

§§ At Site 'A' Compressor Station, at this time, NPS 48 pipe is not available to meet the -50° F MDMT requirement of assets installed in cold climates, as the specific plate steel required for milling is not available in-industry. These issues would need addressed during project execution.

incur significant Joule-Thompson cooling effect, although this is temporary[***]. These considerations are fully defined in the applicable codes and must be incorporated within detailed design.

The accumulator would always remain pressurized during operation, even when empty[†††]. However, due to the sheer amount of accumulator piping, cathodic protection should be sized as defined in applicable codes. Even designs capable of in-line inspection (ILI) might be desirable.

At Site A Compressor Station, the design is not ILI-capable, and the proposed accumulator is buried (not above ground).

2.4. Transfer Compression

A gas reservoir (either a compressor station's shut-in piping gas or accumulator gas) may serve a local beneficial use on a site-by-site basis. However, transfer compression from the reservoir to the low-pressure side of a pipeline adjacent to the facility, or to another non-isolated part of the facility, is typically more feasible and a cheaper option among more compressor stations (TC Energy operates a fleet of portable transfer compression and is familiar with third party vendors of these solutions).

Mott MacDonald focused heavily on this option, assuming a permanent installation. To best ensure the objectives of the Environment and Climate Change Canada (ECCC) regulatory framework are met, also, selected an electric motor drive (EMD) compressor to eliminate exhaust emissions. This will require utility/mains power and will not be a portable unit. More investigation needs to be done to determine the practicality of installing a permanent transfer compression installation.

Additional design considerations are below:

#1. Code-Required Safety Systems

Gas compressors with prime-mover sizes at-or-above 750kW (1000bhp) are, essentially, the compressors of compressor "stations", and must be designed and constructed with ESD-capable safety systems and additional safety system instrumentation. As the proposed ECCC regulatory framework will likely be applicable to compressors of this size, any "large" transfer compressor would repeat the exercises of this feasibility project effort, merely on a smaller scale. This recursive requirement adds significant design complexity, and for the purposes of this report, it was assumed that transfer compressors would be limited to sizes smaller than 750 kW to eliminate it.

#2. Station Hydraulic Model

When the transfer compressor initially operates, it compresses gas from the reservoir (e.g., subterranean accumulation of oil and gas) into to the pipeline mainline's low-pressure side of the mainline valve (MLV). After some amount of time, the transfer compressor will shut down on low suction pressure. At Site A Compressor Station, Mott MacDonald set the low suction pressure

*** *The Joule-Thompson effect would be greatest at the beginning of the transient event when station shut-in pressure free-flows into accumulator empty pressure.*

††† *At Site 'A' Compressor Station, Mott MacDonald used 345 kPag for the accumulator's empty pressure.*

requirement at 345 kPag. After shutdown of the transfer compressor, the reservoir will be at low pressure. The pipeline mainline pressure will not be appreciably affected and will remain at its operating pressure. This is due to the large volume of the pipeline section. Once the mainline compressor (not the transfer compressor) is running, the gas transferred from the reservoir to the low-pressure side of the MLV would then flow through the station inlet valve and be compressed by the mainline compressor to pipeline high-pressure. Because the size of transfer compression is significantly lower than mainline compression, the mainline compressor is expected to accommodate this additional throughput load.

Routing the transfer compressor discharge into the pipeline's low-pressure side ensures the transfer compression can be as effective as possible (reducing the compressor's required pressure ratio). Opportunities to route to other low-pressure systems (e.g., nearby pipelines) should be evaluated on a site-specific basis.

At Site A Compressor Station, a 700-kW unit was sized by a transfer compressor vendor using site-specific hydraulic conditions. In the case that the accumulator station modification is also installed, the transfer compressor would pull down the accumulator alone in approximately 5.3 hours and would pull down the balance of the station piping in just over 10 hours. In the case that the accumulator station modification is not installed, the transfer compressor would pull down the entire station in under 16 hours.

#3. Compressor Skid Hydraulic Model

Due to the large compressor pressure ratio required, transfer compressor offerings by industry-established vendors are typically reciprocating units. A pressure-reducing control valve is installed on the suction-side of the compressor to further lessen the pressure ratio requirement (and drive shaft torque requirement, load steps, etc.). At Site 'A Compressor Station, the setpoint was 1210 kPag. This control valve causes the compressor suction pressure to be far lower than it would otherwise be. This control valve also creates a hydraulic simplification when determining the duration that transfer compression runs: the compressor throughput is constant so long as the upstream pressure reservoir is above the setpoint.

2.5. Flaring/Incineration

Mott MacDonald initially investigated combustion of methane into carbon dioxide, as the global warming potential (GWP) of CH_4 is 28 times higher than that of CO_2. This investigation resulted in evaluating the design requirements of API 537 for flares/incinerators, combustion efficiency, and discussions with a vendor in industry.

Conversion of CH_4 is essentially limited by combustion efficiency. Inefficient combustion will not convert as much CH_4 to CO_2, incomplete combustion will yield carbon monoxide, and higher combustion temperatures will yield nitrogen oxides. While some high-pressure flares have been shown to achieve over 98% efficiency, the industry-average efficiency is 92% (half of flares installed are less efficient). To best ensure the objectives of the ECCC proposed regulatory framework is met, open flaring was rejected, and enclosed multi-burner flares are recommended (i.e., incinerators). Incinerators are generally more efficient and were evaluated in the intent of the ECCC framework. At Site A Compressor Station, the proposed incinerator efficiency is 99.8%.

For this equipment, emissions stack testing, noise testing, and unique hazards must be considered. These hazards are summarized in the following table below (see *Table 1*).

Table 1: Risks and Hazards from an Incineration Project

Risk/Hazard	Description	Mitigation Action
Inclement Weather: Rain	Rain does not affect the operation of the incinerators and they can be safely operated in rainy conditions.	Monitor equipment operation and ensure no abnormal conditions occur.
Inclement Weather: High Winds	Flame may be drawn out of the top of the incinerator.	Cease operations until it is safe to resume.
Inclement Weather: Lightning	Incinerators not to be operated in lightning conditions.	Procedures in Safety Management Plan to be followed. Cease operations.
High Noise Levels	Noise levels can reach over 100dB.	Adequate hearing protection required for all personnel on site.
High Heat Levels	Radiant heat from incinerator units increase temperature at ground level.	Personnel to remain at a safe distance to incinerators. Design must ensure nearby surface temperatures are safe, and/or locate incinerator away from other areas of the facility.
Leak in Connections	Leak found in any part of the system during incineration pilot.	Leak checks to occur on defined interval. If leak is found during operation, cease operation and fix leak before resuming.
Disturbance to Neighboring Landowners	Noise, light, heat from incinerators may be a disturbance to nearby landowners.	Notifications of the incineration operations and impacts sent to landowners in advance. Land team will notify of any landowner complaints that require further project action.
Congested Site	Pipe, hoses, and cables will be required as incinerator connections, there may be limited vehicle access and space to maneuver.	All personnel and visitors to be made aware of equipment on site and sign on to JSA. Any visitor vehicles should be parked at separate site. Routing of pipes, hoses, and cables to be designed to minimize impact.

For unplanned/ESD blowdown events, unfortunately, incineration was determined to be not feasible, as the flow rates required to quickly evacuate a station for safety reasons are significantly higher than the flow rates appropriate for incineration; further, fuel gas combustion pressures are significantly lower than station pressures.

At Site A Compressor Station, one of the largest commercially available (and stock) gas incinerator designs[‡‡‡], if used, would require approximately 9 hours to incinerate the accumulator gas, if the station were modified to include an accumulator, and approximately 18 hours to incinerate the balance of station piping gas. If an accumulator were not installed, incineration of the station piping would occur in approximately 24 hours.

[‡‡‡] *TCI recommend their largest unit, TCI-6000 w/ inlet NPS 3, diameter 2.8 meters, height 11.4 meters. The equipment datasheet was used to develop the durations in this estimate.*

Mott MacDonald assumed the proposed incinerator would be located on newly acquired fee property (approximately 0.4 acres) that would adjoin the existing compressor station.

3. Site A Compressor Station

This station was selected for site-specific evaluation because it was close to Calgary to allow for site visits and/or any measurements needed. The station's essential parameters were used throughout this report:

Parameter	Pressure
Existing Suction-Side	6,900 kPag (MOP)
Existing Discharge Side	8,690 kPag (MOP)
Proposed Accumulator	50 kPag (empty) 3,760 kPag (full)

MOP = Maximum Allowable Pressure
Design pressure of all piping above: 9,560 kPag

3.1. Preliminary Design

For planned outage events, the transfer compressor alone would be sufficient to abate all methane emissions. At Site A Compressor Station, Mott MacDonald recommends this option, as it will be evaluated later in this report to have the best KPI.

For unplanned/ESD blowdown events, assuming all recommended station modifications were installed, the sequence of transient hydraulic flows during an ESD event would be as follows:

Unit Control Mods --> Free-Flow Station Gas to Accumulator --> (Continue traditional ESD event) Vent Balance of Station Gas to Silencer

After the ESD event, the transfer compressor would move accumulator gas to the pipeline and/or this gas would be incinerated. If the accumulator were unavailable (i.e., if transfer compression were already running, and this ESD-blowdown event were subsequent to a prior event), station automated controls would need to detect this condition, and route subsequent unplanned/ESD blowdown gas to the station vent silencer. At Site A Compressor Station, Mott MacDonald recommends further study of the mainline compressor cold-recycle modifications (as described in *Section C.2.5* and *Recommendation E.6*) and detailed hydraulic design of all modifications. For the unplanned/ESD blowdown, the scope of this report is limited to describing the sequence of transient hydraulic operations, and Mott MacDonald cannot make an informed recommendation with the information available currently.

D. PROJECT AND TECHNOLOGY KEY PERFORMANCE INDICATORS

Mott MacDonald calculated the 'tCO2e abated' for each methane abatement option. The incinerator savings must be evaluated after converting CH_4 to CO_2, a factor of 2.75. TC Energy determined the KPI should be evaluated based on one (1) planned blowdown-per-year, and one (1) unplanned/ESD blowdown per year.

Two sets of KPI results are presented below: one (1) event-per-year and two (2) events-per-year. Because station modifications associated with unplanned/ESD blowdowns may also be used to mitigate emissions of planned blowdowns, the first set of results will apply to planned blowdowns only, and the second set of results will apply to planned and unplanned blowdowns.

At Site 'A' Compressor Station specifically, the maximum abatement amount is:

Potential for Emissions	Old Value		Conversion Factor		New Value
No Station Modifications	41 tonnes CH_4 per event	X	28 $CO2e/CH_4$	=	1148 tonnes CO2e/event

The methane abatement savings of each station modification can be calculated similarly:

Modeled Abatement	Old Value		Conversion Factor		New Value
Unit B7 Control Mods	0.5 tonnes CH_4 per event	x	28 $CO2e/CH_4$	=	14 tonnes CO2e/event
Accumulator	13 tonnes CH_4 per event	x	28 $CO2e/CH_4$	=	364 tonnes CO2e/event
Transfer Compressor (Preferred)	41 tonnes CH_4 per event	x	28 $CO2e/CH_4$	=	1148 tonnes CO2e/event
Incinerator	41 tonnes CH_4 per event	x	2.75 $CO2e/CH_4$	=	112.75 tonnes CO2e/event

Mott MacDonald recommends transfer compressor in the case of planned blowdowns. For unplanned/ESD blowdowns, Mott MacDonald recommends further study of the mainline compressor cold-recycle modifications (as described in *Section C.2.5* and *Recommendation E.6*).

Specific to Site A Compressor Station, this table has been populated for planned blowdown, one event per year, assuming transfer compression is the only station modification.

Organization:	**Current Study**	**Commercial Deployment Projection**
Project cash and in-kind cost ($)	$43,030 CAD	Under Development
Technology Readiness Level (Start/End):	9	Under Development
GHG Emissions Reduction (tCH_4/yr):	41	Under Development
Estimated GHG abatement cost ($/$tCH_4$)	$462,000	Under Development
Jobs created or maintained:	N/A	TBD

E. RECOMMENDATIONS AND NEXT STEPS

Mott MacDonald's recommendations for the feasibility study of methane abatement options are as follows:

1. Re-visiting any KPI that might be used within the ECCC proposed regulatory framework after it is finalized, and re-evaluating the items determined in this report against them (unknown at this time),
2. Investigating the factors that determined a company's specific unplanned/ESD blowdown duration, and evaluation of whether or not increasing the duration is safe and prudent,
3. Review of multi-variable approach and selection of specific combinations (i.e., there are many available choices for industry-established solutions, specific compressor stations, and both planned and unplanned philosophies),
4. A longer timeline for a more in-depth report,
5. A more thorough review of combustion vendors as other vendors of array-style combustors might be able to improve flow rates,
6. Further investigation into hydraulic analysis. The scope and schedule of this report precluded software hydraulic modeling, which is more visually intuitive and suitable to the iterative/revision design process, also a natural first step towards detailed design,
7. Developing additional graphics to represent the transient (chronological) changes and/or the carbon abatement amounts within the hydraulic system for any site-specific station modifications during detailed design, and
8. An economic analysis of capital-vs-annual costs; capital being the total installed cost of station modifications, annual being the carbon tax.