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CERIN Canadian Emissions Reduction Innovation Network

CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	Dry Gas Seal to Power Generator Feasibility Study
Emissions Reduction Scope/Description:	Dry Gas Seal Vent Abatement
Applicant (Organization):	TC Energy – NOVA Gas Transmission Ltd.
Contract Project Completion Date:	March 31st, 2023
Actual Estimated Project Completion Date:	May 2023

TC Energy

2. EXECUTIVE SUMMARY:

TC Energy recognizes the importance of addressing climate change and the significant undertaking to transition to a low carbon future. In 2021 we released our GHG emissions reduction plan which includes goals to:

- Reduce GHG emissions intensity from our operations 30 % by 2030, and
- Position to achieve zero emissions from our operations, on a net basis, by 2050.

The GHG emissions reduction plan shares five key focus areas and a roadmap to support its position to achieve net zero emissions by 2050. One of these key focus areas is to modernize our existing systems and assets, including reduction of methane emissions.

One significant opportunity for methane emissions reduction is to implement vent capture systems on our centrifugal compressor dry gas seal (DGS) primary vent emissions. TC Energy is therefore piloting different DGS primary vent conservation solutions at select compressor stations. The purpose of the *Dry Gas Seal to Power Generator Feasibility Study* was to evaluate whether a DGS to power generator system is a technically and commercially acceptable vent conservation solution for all TC Energy compressor stations.

The scope of the potential pilot project considered by the feasibility study is to design and install a system that will capture the DGS primary vent for use elsewhere within the station. The system would control the vent flow so that a steady supply of fuel is provided to a newly installed power generator, with no recompression required. To ensure a steady supply of fuel, make-up gas from the existing fuel gas system would be used when required. The power generator would then power an existing, non-critical load on-site. Any excess gas would be directed to an enclosed vapor combustion unit (EVC).

To prove that the proposed Dry Gas Seal to Power Generator System is technically and commercially viable, several desired outcomes were evaluated through desktop analysis. All the desired outcomes have been met. These desired outcomes, and the results of their evaluation, are summarized below:

Desired Outcome	Evaluation Summary
Process Safety and Reliability Maintained	An alternative analysis and a What-If Process Hazard Analysis (PHA) were completed on multiple electrical load design options for the power generator. All load options could be powered by the power generator without affecting the safety or reliability of the facility. A Hazard and Operability Analysis (HAZOP) was also conducted on a draft mechanical and process design and found that the system could be safely and reliably designed.

Consistent Fuel Supply to the Power Generator with Minimal Make-Up Gas Required	A Stirling Engine power generator was selected and sized to closely match the estimated vent flow. The power load was optimized during the feasibility study and was estimated to require a minimal amount of make-up gas. This resulted in the lowest amount of the net post-project emissions.
Acceptable Backpressure Levels on the Dry Gas Seals	Engineering checks have proven that the proposed system will impose an acceptable level of backpressure on the dry gas seals, as defined by the Original Equipment Manufacturer (OEM), with only minor modifications to the DGS support system.
Low Post-Project Net Emissions	The proposed system would result in an 86% net tCO2e reduction in emissions. It was recommended to include an EVC in the system to consume any gas vented over the normal maximum DGS vent flow.
Specifications and Standards Compliance	The equipment in the proposed system was found to be compliant with TC Energy and applicable industry standards and specifications.
Project Cost-Effectiveness	The Class 5 cost estimate for this potential pilot is about ≈$1.4M and was deemed to be financially feasible. The lifecycle maintenance for the proposed system was found to be minimal (Less than $5k per year).

Since the desired outcomes have been met, the next step would be to use the feasibility study learnings to implement a DGS to power generator pilot project. If the pilot project is successful, a potential program could be developed which would abate approximately 500 tCO2e/year of methane emissions per compressor in TC Energy's Canada Gas Operations.

The learnings from this feasibility study will also have industry-wide benefits. It will provide industry with a cost-effective solution to conserve primary vent emissions instead of destroying (combusting) them at natural gas transmission compressor stations without an existing primary power generator. This will enable industry to comply with Environment and Climate Change Canada's *Proposed regulatory framework for reducing oil and gas methane emissions to achieve 2030 target*. This framework seeks to eliminate all facility venting where possible.

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3. KEY WORDS

DGS Compressor Vent Generator Conservation

4. APPLICANT INFORMATION:

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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 feasibility study was successfully executed.

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 advancing our emissions reduction strategy.

Secondly, thank you Flowserve, for supplying a sample proposal, drawings, and technical specifications for the Dry Gas Seal Power Generation Skid. Thank you for your expertise and support during the feasibility study.

Thank you to Siemens Energy for providing feedback on how the proposed system would impact their compressor package which was chosen for the feasibility study.

Also, thank you Qnergy and Clear Rush Co. for participating in the HAZOP and providing technical clarifications on your Stirling Engine power generator and Cube Enclosed Vapor Combustor, respectively.

Our engineering service provider, WSP, who completed the technical and commercial evaluations for the feasibility study, thank you for providing your technical expertise and robust analysis of the potential Dry Gas Seal to Power Generator System.

Lastly, to all the internal teams in TC Energy, thank you for your continued support and collaboration. This pilot has and will continue to provide valuable information to help TC Energy build a long-term strategy to abate methane emissions from dry gas seal primary vent emissions.

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 % 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 greenhouse gas (GHG) emissions intensity from its operations by 30 % (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

One of TC Energy's key focus areas for GHG emissions reduction is to modernize our existing systems and assets, which will lead to a reduction of methane emissions. One significant opportunity for methane emissions reduction is to abate methane emissions from our centrifugal compressor dry gas seal (DGS) primary vent emissions.

DGS primary vent emissions can either be destructed (combusted to yield gases with lower global warming potential) or conserved. With support from CanERIC, TC Energy has already successfully piloted the installation of an Enclosed Vapor Combustor (EVC) System (CERIN project title: *Enclosed Combustor Testing at TC Energy*) and is installing these units on Coastal GasLink facilities. TC Energy is also exploring and piloting multiple solutions to determine a strategy for conserving the vent gas. Available options are dependent on whether a given Compressor Station is primarily powered using an on-site power generator or utility company power lines.

At sites primarily powered by utility power and seldom running a generator, the known options for gas conservation at compressor stations are as follows:

- **High Pressure Reinjection**: The vent gas can be recompressed and injected into high pressure piping. This has been successfully piloted by TC Energy already outside of the CanERIC program.
- **New Power Generator Consumption**: The vent gas can be routed at low pressure to a new power generator with a low fuel gas supply pressure requirement. This concept has been explored through a feasibility study partly funded by CanERIC and is the subject of this report.

At sites powered by an existing on-site power generator only, a more cost-effective option for gas conservation is as follows:

- **Low Pressure Reinjection (Booster):** The vent gas can be recompressed and injected into a lower pressure utility gas piping system that supplies fuel gas for the existing on-site power generator and boilers. TC Energy's pilot project for this option is being partly funded by CanERIC and will be complete by the fall of 2023. (CERIN Project Title: *Dry Gas Seal to Utility Gas Booster Compressor Skid*)

TC Energy's interest in a system that feeds the vent gas to a new power generator is the elimination of recompression costs that are present in the high-pressure reinjection option. The DGS to power generator system could provide a more cost-effective dry gas seal vent conservation option than the other known options at compressor stations primarily powered by utility power.

Project Specific Information

The scope of the *Dry Gas Seal to Power Generator Feasibility Study* was to assess the technical and commercial feasibility of designing and installing a new system that would capture the DGS primary vent gas. It will then control the vent flow so that a steady supply of fuel is provided to a newly installed power generator, with no recompression required. The power generator will then power an existing, non-critical load on-site. Figure 1 below is a high-level, process flow diagram sketch showing the entire scope of the proposed system:

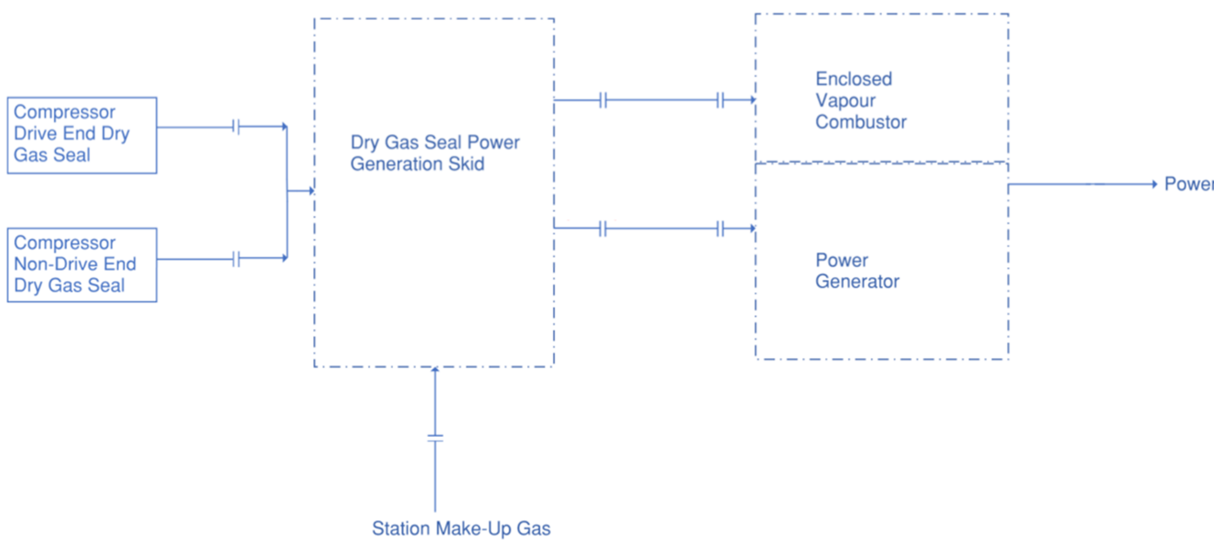

Figure 1: Feasibility Study High-Level Process Flow Diagram

The various components of the proposed system are described below:

- **Dry Gas Seals**: The compressor selected for this feasibility study has two dry gas seals in total, one on its drive end and one on its non-drive end. These seals vent natural gas by design.
- **Dry Gas Seal Power Generation Skid:** This skid provides back pressure control on the dry gas seals and controls the vent gas flow to the power generator. It ensures that the power generator always has enough gas to power the chosen electrical load, using station make-up gas as required to

supplement the vent gas flow. If the vent gas flow goes over the normal maximum flow, then the skid directs any excess vent gas to the EVC to be consumed.

- **Enclosed Vapor Combustor:** The EVC is included in the process to consume any excess vent gas flow in abnormal operating conditions. This will ensure no DGS vent gas is vented to atmosphere.
- **Power Generator:** The power generator combusts the DGS primary vent gas and is sized to consume up to the normal maximum vent flow. It generates electricity from the gas combustion reaction, which is supplied to an existing, non-critical electrical load on-site.

To assess the technical and commercial feasibility of the proposed Dry Gas Seal to Power Generator System, several desired outcomes were evaluated during the feasibility study. If the desired outcomes were met, then the system would be deemed feasible to design and install in a pilot project. The desired outcomes assessed during the feasibility study were as follows:

- **Process Safety and Reliability Maintained:** Confirm that the new, proposed system would have no impact on the process safety or reliability of the compressor station.
- **Consistent Fuel Supply to the Power Generator with Minimal Make-Up Gas Required:** Assess whether the system could be optimized so that an insignificant amount of make-up gas would be consumed.
- **Acceptable Backpressure Levels on the Dry Gas Seals:** Prove that the Dry Gas Seal to Power Generator System would not impose an unacceptable level of backpressure on the dry gas seals, as defined by the DGS Original Equipment Manufacturer (OEM).
- **Low Post-Project Net Emissions:** Estimate the project's net tCO2e reduction considering all the Scope 1 and Scope 2 emissions abated and produced by the new system. Confirm that the proposed system's net tCO2e reduction is greater than 85%.
- **Specifications and Standards Compliance:** Evaluate the Dry Gas Seal Power Generation Skid, power generator and Enclosed Vapor Combustor and ensure that they are compliant with applicable TC Energy and industry standards and specifications.
- **Project Cost Effectiveness:** Validate the project and lifecycle costs and confirm that this project type is economic.

B. METHODOLOGY

Feasibility Study Scope

The feasibility study was completed by WSP with input from TC Energy Subject Matter Experts and the equipment manufacturers: Flowserve, Clear Rush Co., and Qnergy. A sample compressor was chosen as an example site for the feasibility study, ensuring that it was representative of a typical site in TC Energy's Canadian natural gas footprint. Details of the centrifugal compressor and dry gas seal selected as a sample site for the feasibility study are as follows:

Table 1: Compressor Details

Parameter	Value
Centrifugal Compressor Manufacturer & Power Output	Cooper-Bessemer Rotating (Siemens Energy); 14.1 MW
Seals Type	Dry gas seal
Normal Maximum Dry Gas Seal Vent Flow (Both seals combined)	2.6 scfm
Dry Gas Seal Pressure Safety Valve Setpoint	30 psig

WSP completed the following activities during the feasibility study:

1. **Equipment Package Request for Information**
   WSP prepared a technical request for information (RFI), including a process condition sheet and specifications for the Dry Gas Seal Power Generation Skid, power generator, and Enclosed Vapor Combustor. This RFI was then sent to Flowserve who provided a sample proposal complete with draft engineering drawings and technical specifications. WSP then completed a technical and commercial evaluation on the sample proposal.

2. **Mechanical and Process Simulation and Preliminary Design**
   WSP created a redline, draft process flow diagram, and piping & instrumentation diagram. They then completed a process simulation to identify any process flow issues with the proposed system. WSP also participated in a HAZOP analysis by a 3rd party facilitator to ensure there were no process safety or reliability issues with the proposed system.

3. **Electrical Preliminary Design and Alternative Analysis**
   WSP created draft single line electrical diagrams for multiple electrical load options to be powered by the new power generator. WSP then assessed each load option for constructability station reliability, and make-up gas usage. Their assessment also included the completion of an Electrical Process Hazard Assessment What-If Analysis. The results of this alternative analysis were used to identify a preferred electrical load for the sample site.

4. **Project and Lifecycle Cost Estimate**
   WSP completed a Class 5 estimate (+50 %/-30 %) for a potential pilot project installation of the proposed system at the sample site. They also completed estimates of the lifecycle maintenance required for the proposed system.

5. **Net Emissions Abatement Calculations**
   WSP completed net emissions abatement calculations. These calculations considered the following:
   - Abatement of Scope 1 DGS vent methane emissions (-tCO2e)
   - Abatement of Scope 2 electricity grid power generation combustion emissions (-tCO2e)
   - New Scope 1 combustion emissions from the power generator and the EVC (+tCO2e)

   The results of these emissions abatement calculations were also used to inform the electrical alternative analysis described above.

Feasibility Study Outcomes Evaluation

The desired feasibility study outcomes and their evaluation methodologies are described in Table 2 below.

Table 2: Study Outcomes Evaluation Methodology

Desired Outcome	Evaluation Methodology
Process Safety and Reliability Maintained: Confirm that the new, proposed system would have no impact on the process safety or reliability of the compressor station.	1. Review the proposed design of the new system and compare it to the existing system to identify any potential impacts on equipment and processes. 2. Identify and review the electrical design options to determine the safest load configuration for the new system. 3. Conduct HAZOP and electrical What-If PHA sessions to identify any potential safety or reliability risks associated with the proposed system. Develop mitigation measures to address any identified risks.
Consistent Fuel Supply to the Power Generator with Minimal Make-Up Gas Required: Assess whether the system could be optimized so that an insignificant amount of make-up gas would be consumed.	1. Select and size a power generator that closely matches the estimated vent flow. 2. Analyze the required make-up gas consumption and total emissions of different power outputs. 3. Optimize the power output of power generator to consume the most vent flow,

	minimize the amount of make-up gas that would be required, and reduce the post-project net emissions.
Acceptable Backpressure Levels on the Dry Gas Seals: Prove that the Dry Gas Seal to Power Generator System would not impose an unacceptable level of backpressure on the Dry Gas Seals, as defined by the DGS Original Equipment Manufacturer.	1. Confirm the required maximum inlet pressure with the vendor for the DGS Power Generation skid, power generator, and EVC. 2. Confirm with the OEM directly that the required maximum inlet pressure for the DGS Power Generation skid does not exceed the OEM's specified allowable backpressure for the dry gas seals. 3. Model the overall process in HYSYS to confirm that the sum of the numerous pressure drops in-between the backpressure regulator and the power generator and EVC is not too high.
Low Post-Project Net Emissions: Estimate the project's net tCO2e reduction considering all the Scope 1 and Scope 2 emissions abated and produced by the new system. Confirm that the proposed system's net tCO2e reduction is greater than 85%.	1. Measure the DGS primary vent flow at various compressor suction pressures. 2. Create a trend of DGS vent flow vs suction pressures. 3. Calculate an estimated, total, 2022 yearly DGS vent flow using the trend equation and real suction pressures during 2022. Convert to tCO2e using measured gas density and a Global Warming Potential of 28:1 for methane. 4. Calculate the kWh generated by the power generator for various load options. Convert the kWh produced into Scope 2 electricity generation emissions abated using Alberta Tier's High Performance Benchmark forecast. (tCO2e/kWh produced). 5. Calculate the Scope 1 combustion emissions produced by the power generator and EVC for various load options.

Specifications and Standards Compliance: Evaluate the Dry Gas Seal Power Generation Skid, power generator and Enclosed Vapor Combustor and ensure that they are compliant with applicable TC Energy and industry standards and specifications.	1. Include all applicable industry and TC Energy specifications and standards in the RFI. 2. Verify that the proposed Dry Gas Seal to Power Generation Skid equipment package meets all applicable standards and specifications during the RFI review and HAZOP sessions. 3. Ensure that all documentation related to the Dry Gas Seal to Power Generation Skid, including technical data and drawings, follows the applicable standards and specifications.
Project Cost Effectiveness: Estimate the project and lifecycle costs and confirm that this project type is economic.	1. Complete redline, preliminary electrical, mechanical, civil, and process designs. 2. Use these designs to complete a Class 5 (+50 %/-30 %) project cost estimate. 3. Request the vendors to provide the lifecycle maintenance requirements for the DGS Power Generation skid, Enclosed Vapor Combustor, and power generator.

C. PROJECT RESULTS AND KEY LEARNINGS

The desired outcomes of the feasibility study have been evaluated with the results and key learnings described below. All desired outcomes have been met.

Process Safety and Reliability Maintained

Currently, the DGS system vents gas to the atmosphere without capturing, utilizing, or destroying it. Process changes are necessary to capture the vent gas, utilize the electrical power generated, and combust any excess gas in the EVC. The changes to the DGS vent process require a thorough technical evaluation, risk identification, and mitigation measures to ensure the continued safe and reliable operation of the compressor station. A mechanical and process design HAZOP and electrical design 'What If' session was conducted to address technical clarifications and safety hazards. The results of the sessions revealed several potential safety hazards that require proper design to ensure the proposed system is safe, reliable, and meets the necessary process safety standards.

The electrical design 'What If' session was conducted to review the potential electrical design options. The electrical design options were selected based on the power output expected from the power generator and their impact on the reliability and safety of the station. The options considered include:

- **Design Option 1:** Supply power to the DGS panel.
- **Design Option 2:** Supply power to glycol distribution pumps used for heat tracing and fuel gas heating.
- **Design Option 3:** Supply power to the outdoor yard lights.
- **Design Option 4:** Supply power to a UPS system.

Several risks were identified; however, all risks were identified as having a low probability of a minor impact on the compressor station's operation. It was determined that all options are technically feasible and pose a low risk to the safety and reliability of the compressor station. Several general recommendations were made to ensure safe operation of the proposed electrical system, including ensuring the power generation equipment was properly designed and installed, and incorporating the appropriate electrical equipment such as breakers and fused terminals. Ultimately, supplying the electricity to the outdoor yard lighting loads (Option 3) was deemed to have the least impact on the operation of the compressor station.

The HAZOP was conducted to review the draft mechanical and process design to determine whether deviations from the design or operational intent can lead to undesirable consequences, and whether the risks of those deviations meet the risk acceptance level. Several recommendations were made during the HAZOP:

- Ensure that PSVs are adequately sized and vented to atmosphere to a safe location.
- Ensure that the control valves fail to the correct position.

- Ensure all alarms and shutdowns are set appropriately.
- Ensure there are no issues with Joule-Thomson effect.

If designed correctly, it was determined that the proposed system does not impact the reliability of the compressor station. Therefore, the desired outcome of proving that the process safety and reliability of the compressor station can be maintained has been met.

Consistent Fuel Supply to the Power Generator with Minimal Make-Up Gas Required

During the evaluation process, three types of power generators were considered as options: Thermoelectric (TEG), Internal Combustion Engine (ICE), and Stirling Engine. It was determined that the Stirling Engine had the closest match between its fuel requirements and the available vent flow, thus requiring less make-up gas compared to the other two options and had the advantage of minimal maintenance requirements.

From the technical analysis, HAZOP, and PHA sessions; the yard lighting load and DGS panel was selected as the preferred load option. The individual yard lights can be combined to add up to the desired total connected load. Due to the fluctuation in gas flow from the dry gas seals, make-up gas is required to run the power generator at a constant load. The power load selected should be optimized to minimize the make-up gas required and total combustion emissions. Four lighting load combinations and their estimated make-up gas requirements were considered. Table 3below shows the estimated amount of make-up gas needed for a full year for each load option.

Table 3: Make-Up Gas Volumes

Load Option Number	Lighting Load (kW)	Make-up Gas Volume per Year (scf/year)
1	5.34	281,860
2	3.88	165,980
3	3.40	132,196
4	1.94	35,252

Based on the estimated DGS vent rate during different compressor operating conditions it was determined that Load Option 4 would require the least amount of make-up gas and thus the least amount of combustion emissions. To optimize the power load further, it is recommended that the DGS vent emissions be continuously monitored over a wide range of compressor operating conditions. Currently, there isn't an accurate meter installed on the DGS vent with continuous data logging. The vent rates were determined using discrete measurements taken with a Hi-Flow sampler during different operating conditions. With the actual vent rates known, the total connected load and required make-up gas can be further optimized. Based on the engineering work completed during the feasibility study, the desired outcome of proving that the power generator can be fed a constant supply of fuel gas while minimizing the required make-up gas has been met.

Acceptable Backpressure Levels on the Dry Gas Seals

The first step completed to determine the backpressure imposed on the dry gas seals from the proposed system was to identify the vendor's required minimum inlet pressures for the Dry Gas Seal Power Generation Skid, Enclosed Vapour Combustor, and power generator. These pressures can be found in Figure 2 below.

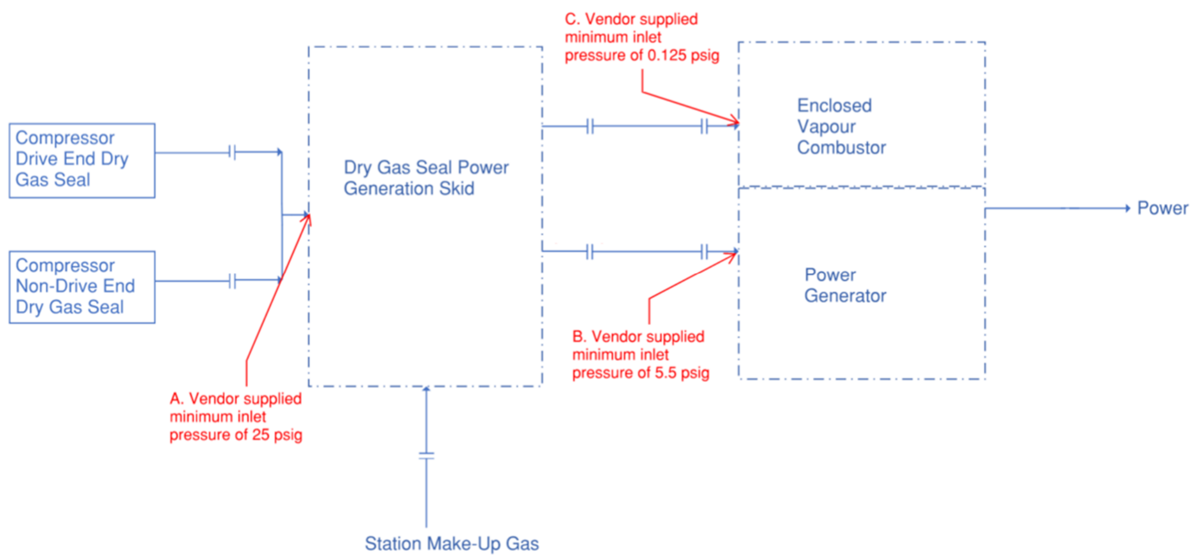

Figure 2: Vendor's Minimum Inlet Pressure

The required pressure at point A in Figure 2 would be the set point on the dry gas seal back pressure regulator in the Dry Gas Seal Power Generation Skid. This would also be the back pressure imposed on the dry gas seals.

To verify that this level of backpressure (25 psig) was acceptable, the OEM for the compressor (Siemens Energy) was asked to confirm if this level of backpressure was acceptable. Siemens confirmed that it would be acceptable, if a full engineering assessment on the dry gas seal system was completed to verify this and minor modifications were made to the dry gas seal system.

The overall system was then simulated in Aspen HYSYS to confirm that the specified level of backpressure was going to be high enough to overcome the pressure drop in the system between points A and B in Figure 2. The pressure drop could not be greater than the difference between the backpressure regulator, 25 psig, and the power generator's minimum inlet pressure, 5.5 psig. Therefore, the pressure drop would have to be less than 19.5 psig if the selected level of backpressure was to remain at 25 psig. The HYSYS simulation did confirm that the pressure drop between point A and B was less than 19.5 psig, in fact it was 15.76 psig.

Therefore, the desired outcome of confirming that the system would not impose an unacceptable level of backpressure on the dry gas seals has been met.

Low Post-Project Net Emissions

The net post project tCO2e/year was calculated by estimating the tCO2e for the following emission sources either abated or introduced by the project:

1. Scope 1 dry gas seal primary vent emissions abated.
2. Scope 2 power generation combustion emissions abated.
3. Scope 1 power generator and enclosed vapour combustor combustion emissions introduced.

Emission sources 2, and 3 above were calculated for different electrical load options to determine an optimal electrical load configuration that results in the lowest post-project net emissions.

To estimate the Scope 1 yearly DGS primary vent flow abated, the vent flow was measured at various compressor suction pressures and rotations per minute (RPM). There was a positive correlation between the DGS vent rate and suction pressure, and a negative correlation between the vent rate and RPM, although the data exhibited significant variability. A trend was then developed, showing the relationship between primary vent flow and compressor suction pressure, DGS Vent Flow= ƒ(Suction Pressure). Real operational suction pressures throughout 2022 were then used in this function to estimate the total DGS primary vent flow in 2022 and tCO2e. The results of these calculations are as follows:

Table 4: Dry Gas Seal Primary Vent Emissions

Emission Source	Flow (scf per year)	tCO2e/year
DGS primary vent abated emissions	839,741	422

To estimate the Scope 2 utility power generation combustion emissions abated by the proposed system, WSP selected 4 intermittent lights loads and estimated the kWh of power that the lights would normally demand from the utility power source. The yearly power demand powered by the new system was then multiplied by the Alberta Technology Innovation and Emissions Reduction Regulation (TIER) High Performance Benchmark (HPB) to calculate the Scope 2 utility power generation combustion emissions abated by the proposed system. The results of these calculations are shown below:

Table 5: Scope 2 Power Generation Emissions

Load Option Number	Lighting Load (kW)	Power Demand per year (kWh/year)	Scope 2 Utility Power Generation Combustion Emissions Abated tCO2e/year (2025)
1	5.34	23,389	16.3
2	3.88	16,994	11.8
3	3.40	14,892	10.4
4	1.94	8,497	5.9

The new Scope 1 combustion emissions from the power generator were calculated using the manufacturer's published values at different power outputs. To ensure that no vent gas was ever vented to atmosphere, an enclosed vapour combustor was also recommended to be included in the design. The combustion emissions for this combustor were also calculated using stochiometric mass balances. The calculated new combustion emissions are as follows:

Table 6: Scope 1 New Combustion Emissions

Load Option Number	Lighting Load (kW)	New Scope 1 Combustion Emissions (tCO2e/year)
1	5.34	98.26
2	3.88	83.20
3	3.40	78.52
4	1.94	63.74

The net post-project emissions for each load options are as follows:

Table 7: Post-Project Net Emissions

Emissions Source	Emissions for each load option (tCO2e/year)			
	No. 1 (5.34 kW)	No. 2 (3.88 kW)	No. 3 (3.40 kW)	No. 4 (1.94 kW)
Dry Gas Seal Primary Vent Abated Emissions	-422	-422	-422	-422
Scope 2 Utility Power Generation Combustion Abated Emissions (2025)	-16.3	-11.8	-10.4	-5.9
Scope 1 New Combustion Emissions	+98.3	+83.2	+78.5	+63.7
Total Post-Project Net Emissions	-340.0	-350.6	-353.8	-364.2
% Net Emissions Reduction	81 %	83 %	84 %	86 %

As shown in Table 7, selecting an option with a lower electrical load results in the lowest amount of post-project net emissions. This is because a lower electrical load requires less make-up gas throughout the year when the DGS vent flow is lower than required. Load Option 4 has a net emissions reduction of 86%, which is greater than the study's goal of 85% net emissions reduction.

Specifications and Standards Compliance

A request for information (RFI) was issued to Flowserve for the Dry Gas Seal to Power Generator Skid equipment package. The RFI included all applicable industry and TC Energy specifications and standards.

After a detailed technical evaluation, it was confirmed that Flowserve's proposal met all the applicable specifications and standards. Therefore, the desired outcome of ensuring the Dry Gas Seal to Power Generator Skid equipment is compliant with industry and TC Energy standards and specifications has been met.

Project Costs

The Class 5 estimate for a potential DGS to power generator project is approximately $1.4M. The lifecycle maintenance required for the Dry Gas Seal to Power Generator System is also approximately $4.5k/year for 25 years.

After review of these estimates, it was confirmed that installing the Dry Gas Seal to Power Generator System is economically feasible. This will make it more economic for TC Energy to install DGS gas conservation solutions at sites with lower vent emission volumes.

Broader Impact to Industry Learnings and Beyond

While economic DGS vent destruction technologies are known, economic solutions for DGS gas conservation still needs to be developed. The Dry Gas Seal to Power Generator System provides industry with a more cost-effective solution to conserve DGS primary vent emissions. The learnings described in the sections above can be used by other oil and gas companies to help select and design their own low pressure DGS primary vent to power generator system. This will enable industry to comply with Environment and Climate Change Canada's *Proposed regulatory framework for reducing oil and gas methane emissions to achieve 2030 target* in a cost effective manner. This framework seeks to eliminate all facility venting where possible.

D. PROJECT AND TECHNOLOGY KEY PERFORMANCE INDICATORS

Organization:	Current Project	Commercial Deployment Projection
Project cash and in-kind cost ($):	$158,494*	≈$1,400,000 per DGS vent source**
Technology Readiness Level (Start/End):	7	8
GHG Emissions Reduction (tCO2e/year abated):	N/A – Feasibility Study	≈500 tCO2e/year per DGS Vent Source;
Estimated GHG abatement cost ($/tCO2e):	N/A – Feasibility Study	≈$2,800 per DGS vent source***
Jobs created or maintained:	N/A – Feasibility Study	TBD**

* Please note that this was the cost of the feasibility study.
** Commercial deployment is still under development by TC Energy. TC Energy cannot guarantee that the project costs and GHG emissions reduction estimates will match actual commercial deployment, as they will likely vary, dependent on vent volumes and equipment types.
*** GHG abatement cost ($/tCO2e) is more representative of midstream economics and costs.

E. RECOMMENDATIONS AND NEXT STEPS

Further Testing Required

Based on the results of the feasibility study, it is recommended to execute a pilot project to further validate the desired outcomes through operational testing of the Dry Gas Seal to Power Generator System. The desired outcomes which would be validated through a pilot project are as follows:

Desired Outcome	Pilot Project Evaluation
Process Safety and Reliability Maintained: Confirm that the new, proposed system would have no impact on the process safety or reliability of the compressor station.	1. Implement the recommendations from the HAZOP and electrical What-If sessions during detailed design. 2. Conduct second HAZOP and electrical What-If sessions once the design is more finalized.
Consistent Fuel Supply to the Power Generator with Minimal Make-Up Gas Required: Optimize the system so that an insignificant amount of make-up gas would be consumed.	1. Install an accurate, continuous flow meter on the DGS primary vent to determine the actual vent flow rates, which will be used to size the power generator more accurately. 2. Further optimize the power output of power generator to consume the most vent flow, minimize the amount of make-up gas that would be required, and reduce the net, post-project emissions using a more sophisticated what-if goal seek analysis.
Acceptable Backpressure Levels on the Dry Gas Seals: Prove that the Dry Gas Seal to Power Generator system would not impose an unacceptable level of backpressure on the dry gas seals, as defined by the DGS Original Equipment Manufacturer.	1. Complete a full engineering assessment on the dry gas seals to confirm the level of backpressure is acceptable. 2. Implement the required modifications to the dry gas seal system that are identified by the full engineering assessment.
Low Post-Project Net Emissions: Confirm that the proposed system's net tCO2e reduction is greater than 85%.	1. Install an accurate, continuous flow meter on the DGS primary vent to determine the actual abated vent flow rates. 2. Install a watt-hour meter on the electrical power supply from the new power generator to accurately report on the actual, abated Scope 2 power generation combustion emissions. 3. Install an accurate, continuous flow meter on the supply lines to the power generator and enclosed vapour combustor to accurately

	report on the new post project combustion emissions.
Specifications and Standards Compliance: Evaluate the Dry Gas Seal Power Generation Skid, power generator and Enclosed Vapor Combustor and ensure that they are compliant with applicable TC Energy and industry standards and specifications.	1. Include all applicable industry and TC Energy specifications and standards in the project RFQ. 2. Verify that the proposed equipment packages meet all applicable standards and specifications during the RFQ review. 3. Ensure that all documentation related to the equipment packages follows the applicable standards and specifications through detailed vendor documentation reviews.
Project Cost Effectiveness: Estimate the project and lifecycle costs and confirm that this project type is economic.	1. Closely track the pilot project actual costs and compare to the past project cost actuals for high pressure reinjection.

Conclusion and DGS Program Next Steps

Since the desired outcomes have been met, the next recommended step is to use the feasibility study learnings to implement a DGS to power generator pilot project (as described in the "Further Testing Required" section above). If the pilot project is completed successfully, TC Energy may use the project learnings to scope out and plan a potential DGS vent conservation program at multiple sites without existing, on-site primary power generators. This program could have the potential to abate approximately 500 tCO2e/year of methane emissions per compressor in TC Energy's Canada Gas Operations. If this program is realized, it will help to advance TC Energy's GHG emissions reduction plan which includes a goal to reduce our methane emissions and meet Canada's methane reduction objectives.

F. APPENDICES

N/A