CANADA EMISSIONS REDUCTION INNOVATION NETWORK (CERIN) PUBLIC REPORT

1. PROJECT INFORMATION:

Project Title:	Dry Gas Seal to Utility Gas Booster Compressor Skid
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:	December 2023

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 gas capture systems on our centrifugal compressor Dry Gas Seal (DGS) primary vents. TC Energy is therefore piloting different DGS Primary Vent conservation solutions at select compressor stations. The purpose of the *Dry Gas Seal to Utility Gas Booster Compressor Skid* pilot project is to evaluate whether the Booster Compressor skid solution is a technically and commercially acceptable vent conservation solution at remote sites primarily powered with an existing power generator. If proven to be viable, this solution would be the most cost-effective DGS primary vent conservation solution piloted by TC Energy to date.

The scope of the pilot project is to procure and install a Booster Compressor equipment package skid that will capture and recompress the DGS Primary Vent gas and inject it into the onsite, lower pressure, Utility Gas system. The Utility Gas system supplies Fuel Gas for the existing on-site primary power generator and boilers. This pilot project was still underway when this report was written and will be completed in December 2023. The Booster Compressor Skid is being installed at a TC Energy Compressor Station in Northern Alberta.

To prove that the Booster Compressor solution is technically and commercially viable, several desired outcomes have been defined and will be evaluated throughout the course of the project. At this time, all desired outcomes have either been met, or are on track to be met, by the end of the project. These desired outcomes, and the results of their evaluation, are summarized below:

Desired Outcome	Evaluation Summary
Total Gas Consumption and Utility Gas Reliability Maintained	Engineering checks have already proven that the Utility Gas System can consume 100% of the DGS Primary Vent Emissions without operational upset. The Utility Gas System operation will be monitored during commissioning and post-installation to ensure that it is unaffected by the installation of the Booster Compressor Skid.
Backpressure Control and Dry Gas Seal Reliability Maintained	Engineering checks have proven that the Booster Compressor skid equipment package will impose an acceptable level of

	backpressure on the Dry Gas Seals, as defined by the DGS Original Equipment Manufacturer (OEM).
Specifications and Standards Compliance	The Booster Compressor skid equipment package was reviewed in detail, and it is compliant with TC Energy and industry standards and specifications.
Project Cost-Effectiveness	The pilot project total costs are currently forecasted to be $500k less per compressor than the project costs for the next most cost-effective known DGS Primary Seal vent gas conservation solution for natural gas transmission compressor stations.

If all the desired outcomes of the pilot project are met, TC Energy will use the project learnings to scope out and plan a potential Dry Gas Seal Vent conservation program at multiple sites with existing, on-site primary power generators. If successful, this program could have the potential to abate between 10k-15k tCO_2e/year of methane emissions in TC Energy's Canada Gas Operations.

The learnings from this pilot project will also have industry-wide benefits. It will provide industry with a cost-effective solution to conserve Dry Gas Seal primary vents instead of destroying (combusting) them at natural gas transmission compressor stations.

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3. KEY WORDS

DGS Compressor Vent Utility Conservation

4. APPLICANT INFORMATION:

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5. LEAD CONTRIBUTING PARTNER INFORMATION:

Organization:	Flowserve Corporation
Representative Name:	John Sears
Title:	Director, Product Management
Representative Contact Information:	Mobile number: (403) 669-8869 Email: jsears@flowserve.com

6. PROJECT PARTNERS

We would like to graciously thank all the stakeholders and partners who played a pivotal role in ensuring the pilot is safely and 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, Flowserve who supplied the Dry Gas Seal Vent Booster skid, thank you for your expertise and support during the procurement and design process. We look forward to continuing to work with you through construction and commissioning.

Our engineering service provider, WSP, who is completing detailed design for the project, thank you for designing the integration of the Booster skid into the existing compressor station.

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 vents.

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 vents.

Dry Gas Seals are mostly found in centrifugal compressors. Their primary function is to prevent the product natural gas from escaping the body of the compressor around the rotor shaft. Without Dry Gas Seals installed, the natural gas undergoing compression would escape into the shaft bearings and eventually into the atmosphere. The orange components labelled "Shaft Seal" in Figure 1 below are the Dry Gas Seals on this example diagram of a centrifugal compressor:

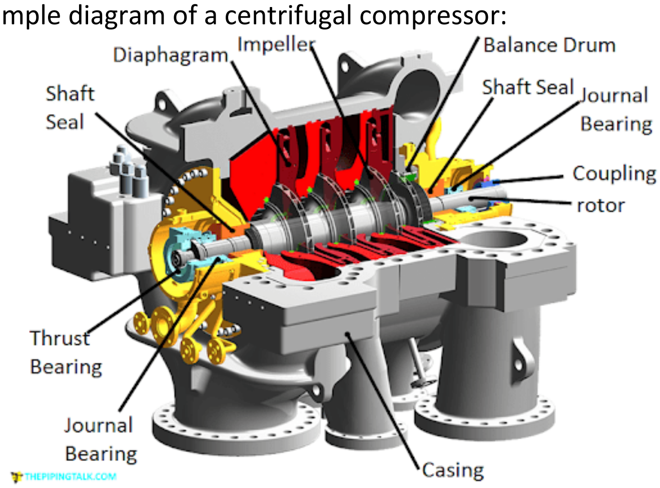

Figure 1: Centrifugal Compressor Cut-Away Diagram (Optimization and selection of the multi-objective conceptual design scheme for considering product assembly, manufacturing and cost)

Destruction is one available option for addressing DGS Primary Vent emissions. TC Energy has already successfully piloted the installation of an Enclosed Vapor Combustor (EVC), which was partly funded by CanERIC. Conservation is another option for eliminating methane emissions from the DGS Primary Vent. TC Energy is exploring and piloting multiple solutions to determine a strategy for conserving the vent gas instead of destroying (combusting) it. Available options are dependent on whether a given Compressor Station is primarily powered using on-site power generation or utility power.

At sites primarily powered by utility power, 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 is currently being explored through a separate feasibility study partly funded by CanERIC.

At sites powered by an existing on-site power generator only, an additional 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 funded by CanERIC and is the subject of this report.

One benefit of injecting vent gas into the Utility Gas piping system is a reduction in project cost per compressor of ~$500k compared to injecting vent gas into high pressure piping which would require a higher compression ratio. Using this method at TC Energy's Canada Gas Operations sites powered by existing on-site power generators could abate ~10-15k tCO2e/year of DGS vent emissions.

Project Specific Information

The scope of the *DGS Vent to Utility Gas Booster Compressor Skid* pilot project is to design, procure and install a booster compressor equipment package skid that will recompress the DGS Primary Vent gas and inject it into the Utility Gas piping system. When completed, this pilot project is expected to abate 510 tCO2e of natural gas emissions each year. Figure 2 below is a high-level, process flow diagram sketch showing the entire scope of the project:

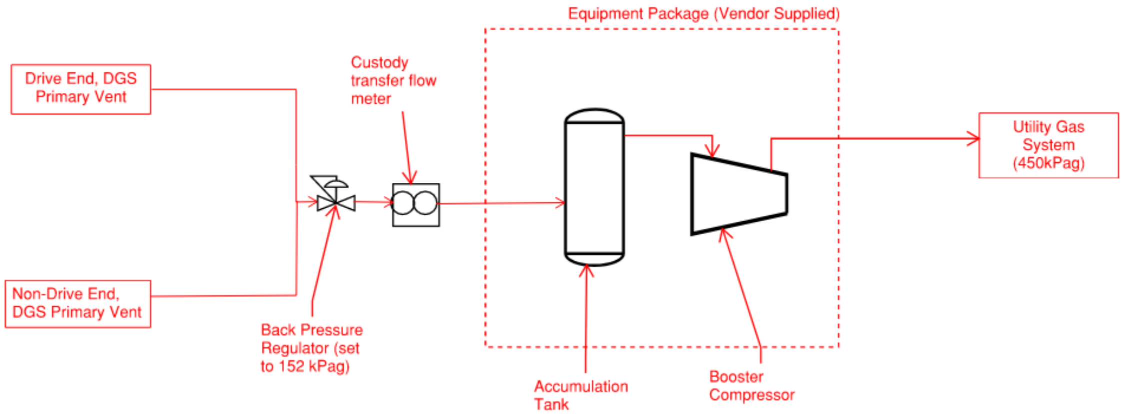

Figure 2: Pilot Project Process Flow Diagram

The purpose of the *DGS Vent to Utility Gas Booster Compressor Skid* pilot project is to move the Technology Readiness Level (TRL) of the equipment package skid from a TRL 8 to TRL 9. This will be accomplished by installing the equipment package at an operating compressor station and prove that it meets operational requirements. The expected outcomes of the pilot project that will move this equipment package to TRL 9 are as follows:

- **Gas Consumption and Utility Gas Reliability:** Prove that the Utility Gas system can consume 100% of the DGS Primary Vent Emissions without operational upset.
- **Backpressure Control and Dry Gas Seal Reliability:** Prove that the Booster Compressor skid equipment package would not impose an unacceptable level of backpressure on the Dry Gas Seals, as defined by the DGS Original Equipment Manufacturer.
- **Specifications and Standards Compliance:** Evaluate the Booster Compressor skid equipment package vendors and ensure that they are compliant with applicable TC Energy and industry standards and specifications.
- **Project Costs:** Validate the project costs and confirm that this project type is more economic than reinjecting into high pressure piping.

B. METHODOLOGY

The pilot project is being executed according to TC Energy's internal project delivery standard. At the time of writing this report, the pilot project is still underway, and will be completed by the fall of 2023. A description of the pilot project's execution plan is provided below.

Project Location

The project is being executed at a TC Energy Compressor Station in northern Alberta, Canada. The project will install the booster compressor equipment package on the Dry Gas Seal Primary vent for one of the station's centrifugal compressors. Details of the centrifugal compressor, Dry Gas Seal and Utility Gas System are as follows:

Table 1: Compressor and Utility Gas Details

Parameter	Value
Centrifugal Compressor Manufacturer & Power Output	General Electric (GE); 31 MW
Compressor Seals Type	Dry Gas Seal
Dry Gas Seal Primary Vent Backpressure Regulator Set Point	152 kPag
Utility Gas System Design Pressure	450 kPag
Power Generators with Fuel Gas supply from Utility Gas System	Qty 2; 1280 HP
Boilers with Fuel Gas supply from Utility Gas System	Qty 2; 20000 BTU

This site was chosen because of its remote location and existing on-site, primary power generators. The compressor unit was chosen as it has a higher level of DGS primary vent emissions compared to other TC Energy compressors in Canada.

Main Project Deliverables

The main deliverables for this pilot project are as follows:

1. Front End Engineering and Design

This deliverable comprised writing a Design Basis Memorandum (DBM). The DBM describes the process flow of the project, ensuring that the Utility Gas system can consume all the DGS vent gas without issue. It also contains design criteria, specifications, standards, and other requirements for the other engineering disciplines.

2. Major Equipment (Booster Compressor Skid) Procurement

This deliverable included a competitive equipment package Request for Quotation (RFQ) with multiple vendors for the Booster Compressor Skid. The best technical and commercial proposal was selected for contract award. During the RFQ process the vendor's proposal was evaluated to ensure that it complied with TC Energy and industry standards and specifications. After contract award the equipment package was designed and will be fabricated with multiple quality checks and vendor document reviews.

3. Detailed Design, Fabrication and Construction

After the DBM was created and the Booster Compressor Skid contract awarded, the project awarded a contract to an Engineering Service Provider (ESP), in this case WSP. WSP will complete all detailed design deliverables, including Issued for Construction drawings. After detailed design is complete, the project will procure the remainder of the materials, fabricate the connecting piping spools and complete field construction.

4. Commissioning

After completion of field construction, the newly installed equipment package, process piping, and equipment will be tested to ensure that everything functions as designed. Flowserve and TC Energy technicians will complete the commissioning tests.

5. Post-Installation Monitoring

After commissioning is complete the newly installed system will be monitored to ensure that it is operating correctly and that all the DGS Primary Vent Gas is captured and reinjected into the Utility Gas system.

Project Schedule

The project's milestone schedule is as follows (cells highlighted in green are completed milestones as of the date of this report):

Table 2: Project Schedule

Milestone	Date Complete
Design Basis Memorandum Complete	Complete
Booster Compressor Equipment Package RFQ Issued	Complete
Booster Compressor Equipment Package Contract Award	Complete
Detailed Design Start	Complete
CanERIC Funding Agreement Complete	March 31, 2023
Detailed Design Complete	April to June 2023
Construction and Commissioning Complete	October to December, 2023
Post-Installation Monitoring Period	December 2023 to December, 2024

Evaluation of Project Outcomes

The desired project outcomes and their post-project evaluation methodologies are described in Table 3 below.

Table 3: Project Outcomes Evaluation Methodology

Desired Outcome	Evaluation Methodology
Gas Consumption and Utility Gas Reliability: Prove that the Utility Gas system can consume 100% of the DGS Primary Vent Emissions without operational upset.	1. Calculate the minimum, normal and maximum Utility Gas flows using vendor data for the equipment supplied by the Utility Gas system. 2. Pull the DGS vent flows from the existing orifice meters on the DGS vent lines. 3. Confirm that there are no operational scenarios where the DGS vent flow is higher than the Utility Gas consumption. 4. Evaluate how well the gases mix at the injection point to confirm that gas odorization levels do not change and that Utility Gas composition is unaffected. 5. Conduct a Hazard and Operability (HAZOP) study on the full design. 6. Monitor the Utility Gas System operation during commissioning and post installation to ensure that it is unaffected by the installation of the Booster Compressor Skid.

Backpressure Control and Dry Gas Seal Reliability: Prove that the Booster Compressor skid equipment package would not impose an unacceptable level of backpressure on the Dry Gas Seals, as defined by the DGS Original Equipment Manufacturer (OEM).	1. Confirm the required maximum inlet pressure with the vendor for the Booster Compressor skid equipment package 2. Confirm with the OEM directly that the required maximum inlet pressure does not exceed the OEM's specified allowable backpressure for the Dry Gas Seals.
Specifications and Standards Compliance: Evaluate the Booster Compressor skid equipment package vendor offerings and ensure that they are compliant with TC Energy and industry standards and specifications.	1. Include specifications and standards in equipment package RFQ scope. 2. Conduct a full review of vendor's compliance with specifications and vendors through a Technical Bid Evaluation during the RFQ process.
Project Costs: Validate the project costs and confirm that this project type is less expensive than reinjecting into high pressure piping.	1. Monitor project cost actuals and total project cost forecast throughout the life of the project. 2. Confirm the project actuals at the end of the project and compare against past project actuals for the high-pressure reinjection solution.

C. PROJECT RESULTS AND KEY LEARNINGS

The desired outcomes of the pilot project have been evaluated with the results and key learnings described below. Please note that since the project is not complete at the time of writing this report, these results and learnings are preliminary in nature. At this time, all desired outcomes have either been met, or are on track to be met by the end of the project.

Gas Consumption and Utility Gas Reliability:

First, the project design team confirmed that the Utility Gas system could consume all the DGS Primary vent gas. The fuel consumption of the utility gas system was calculated for minimum, normal and maximum flow operating conditions. The Dry Gas Seal Primary vent measured readings were then pulled from continuously data logged orifice meters and the maximum observed flow was taken as the normal flow operating condition, while the minimum observed flow was taken as the minimum flow operating condition. The vendor specified maximum Dry Gas Seal Primary vent flow was the maximum flow operating condition. The result of this analysis is shown in Table 4 below.

Table 4: Dry Gas Seal and Utility Gas Flows

	Min	Normal	Max
Utility Gas flowrate (Sm3/hr)	29.3	203	643
Seal gas flowrate (Sm3/hr)	2.8	3.4	17

As shown in Table 4, the maximum seal gas flow rate is less than the minimum Utility Gas flow rate at a ratio of 1.7:1. This proves that the Utility Gas system can consume all the DGS Primary Vent gas in all operating conditions.

Next, the injection point was then assessed by WSP's Process Engineering team to confirm sufficient mixing of the two gas streams. Sufficient mixing of the two gas streams is required to ensure that the odorant added to the Utility Gas upstream of the injection point is fully mixed with the un-odorized gas from the Dry Gas Seal Primary Vent. Both gas streams have the same gas composition (pipeline grade quality gas), so mixing to ensure uniform gas composition downstream of the injection point was not a concern.

After the assessment of the injection point was complete, the project design team decided to add a static inline mixer at the injection point to ensure complete mixing of the two gas streams. A static inline mixer has no moving parts, with no required maintenance and is an inexpensive process device. Figure 3 below shows a cut-away image of an example static inline mixer:

Figure 3: Static Inline Mixer from Koflo

Finally, a Hazard and Operability (HAZOP) study was completed at the Issued for Review 45% stage of detailed design. The HAZOP was successfully completed with all process risks mitigated as acceptable.

Based on the engineering work completed at the time of this report, the desired outcome of proving that the Utility Gas system can consume 100% of the DGS Primary Vent Emissions without operational upset has been met. The reliability of the Utility Gas system will be unaffected by the introduction of the Dry Gas Seal to Utility Gas Booster Compressor system. The Utility Gas System and Dry Gas Seal System will be monitored remotely post installation through existing flow and pressure alarms to ensure that both systems are operating correctly and safely.

Backpressure Control and Dry Gas Seal Reliability

For the Dry Gas Seal system to be unaffected by the installation of the DGS to Utility Gas Booster system, the backpressure imposed by the Booster system must not be greater than the maximum allowable backpressure on the Dry Gas Seals, as defined by the Original Equipment Manufacturer (OEM).

After investigating the existing Dry Gas Seals Primary Vent process, the project design team identified that the primary line vent already had an existing, OEM designed, back pressure regulator set to 152kPag. Therefore, this value was taken as the design, maximum, allowable backpressure and provided to the Booster Compressor package vendor. The vendor confirmed that this was an acceptable inlet suction pressure for their package. The tie-in between the DGS Primary Vent and the Booster system has also been designed so that the vent gas will be automatically redirected to atmosphere if any issues arise with the Booster Compressor system. The details of the tie-in piping are shown in Figure 4 below. This design is not yet finalized and is only at the Issued for Review 45% complete stage.

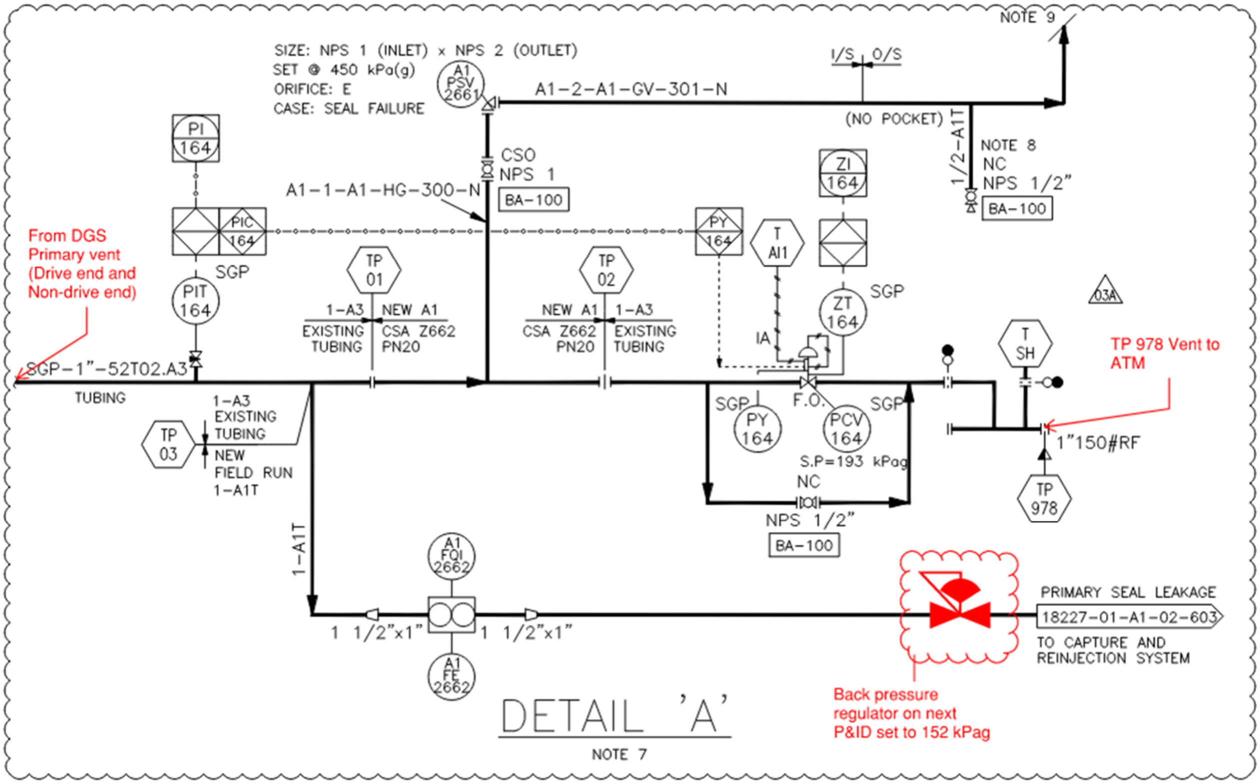

Figure 4: Dry Gas Seal System Tie-In

Therefore, the desired outcome of proving that the Dry Gas Seal system reliability will be unaffected has been met.

Specifications and Standards Compliance

A competitive Request for Quotation (RFQ) event was held with multiple Booster Compressor skid equipment package vendors. All applicable industry and TC Energy specifications and standards were included in the RFQ scope of work package.

After a detailed technical and commercial evaluation, Flowserve was awarded the contract for the Booster Compressor skid equipment package. Flowserve's proposal was fully compliant with all the applicable specifications and standards. Therefore, the desired outcome of ensuring the Booster Compressor skid equipment package vendor offering is compliant with TC Energy and industry standards and specifications has been met.

Project Costs

The forecasted project costs for this pilot project are currently on track to be ~$500k less per compressor than the project costs for the high-pressure reinjection pilot project previously completed by TC Energy outside of the CanERIC program. Because of the lower injection pressure, this pilot project has seen cost reductions in the following areas:

- Lower compressor package costs (~$400k cost reduction)
- Lower construction costs due to the use of tubing instead of hard piping (~$100k cost reduction)

Therefore, the pilot project is on track to validating that installing a low pressure, booster reinjection skid costs $500k less per compressor than installing a high-pressure reinjection skid. This will make it more economic for TC Energy to install a Dry Gas Seal Vent gas conservation solution at sites with lower vent emission volumes.

Broader Impact to Industry Learnings and Beyond

While economic Dry Gas Seal vent destruction technologies are known, economic solutions for DGS gas conservation still needs to be developed. The *DGS Vent to Utility Gas Booster Compressor Skid* provides industry with a more cost-effective solution to conserve Dry Gas Seal primary vents. This solution is at least $500k cheaper per compressor than the next most cost-effective known DGS Primary seal vent gas conservation solution for natural gas transmission compressor stations, being high pressure reinjection. The learnings described in the sections above can be used by other oil and gas companies to help design their own low pressure Dry Gas Seal primary vent reinjection system. Please note that this solution is not directly applicable to reciprocating compressor packing vents.

D. PROJECT AND TECHNOLOGY KEY PERFORMANCE INDICATORS

Organization:	Current Project	Commercial Deployment Projection
Project cash and in-kind cost ($):	$1,233,212*	$1,100,000 per DGS Vent source**
Technology Readiness Level (Start/End):	8	9
GHG Emissions Reduction (tCO2e/year abated):	510 tCO2e/year	~500 tCO2e/year per DGS Vent Source; Total reduction after potential abatement program is complete would equate to 10k to 15k tCO2e/year**
Estimated GHG abatement cost ($/tCO2e):	$2,418***	~$2,200***
Jobs created or maintained:	N/A	TBD**

*Please note that this is the project's Forecast at Completion at the time of writing this report. Since the project is not complete, this is an estimate only.
**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.
***GHG abatement cost ($/tCO2e) is more representative of midstream economics and costs.

E. RECOMMENDATIONS AND NEXT STEPS

Project Next Steps

At the time of writing this report, the pilot project is not complete. The remaining activities in the pilot project are as follows:

- Completion of Detailed Engineering and Design
- Delivery of Booster Skid equipment package to site
- Fabrication and Field Construction
- Commissioning and Post Installation Monitoring

The expected milestone dates for these activities can be found in Section B: Methodology - Project Schedule.

The following desired project outcomes have already been met:

- Backpressure Control and Dry Gas Seal Reliability, and
- Specifications and Standards Compliance.

The rest of the desired project outcomes are currently on track to be met. The remaining project activities which will confirm the desired project outcomes are shown in Table 5 below:

Table 5: Desired Outcomes and Evaluation Activities Remaining

Desired Outcome	Evaluation Activities Remaining
Gas Consumption and Utility Gas Reliability: Prove that the Utility Gas system can consume 100% of the DGS Primary Vent Emissions without operational upset.	1. Evaluation activities are all complete
Gas Consumption and Utility Gas Reliability: Prove that the Utility Gas system can consume 100% of the DGS Primary Vent Emissions without operational upset.	1. Monitor the Utility Gas System operation during commissioning and post installation to ensure that it is unaffected by the installation of the Booster Compressor Skid.
Specifications and Standards Compliance: Evaluate the Booster Compressor skid equipment package vendor offerings and ensure that they are compliant with TC Energy and industry standards and specifications.	1. Evaluation activities are all complete
Project Costs: Validate the project costs and confirm that this project type is less expensive than reinjecting into high pressure piping.	1. Confirm the project actuals at the end of the project and compare against past project actuals for the high-pressure reinjection solution.

DGS Program Next Steps

If the pilot project is completed successfully, TC Energy will use the project learnings to scope out and plan a potential Dry Gas Seal Vent conservation program at multiple sites with existing, on-site primary power generators. This program could have the potential to abate between 10k-15k tCO2e/year of methane emissions. 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.

F. References

Optimization and selection of the multi-objective conceptual design scheme for considering product assembly, manufacturing and cost. (n.d.). Retrieved May 24, 2023, from ResearchGate: https://www.researchgate.net/figure/The-main-components-of-the-centrifugal-compressor_fig3_359023402

G. Appendices

N/A