E&P – EAST COAST

TERRA NOVA Flare Reduction Study

NRCan Emissions Reduction Fund R&D Project

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Executive Summary

Suncor Energy has identified potential enhancements to the Terra Nova FPSO (Floating, Production, Storage and Offloading) that align with the corporate strategic objective to be a net-zero company by 2050. One of those enhancements is associated with the production flaring and the intent of this research and development project is to evaluate flare reduction initiatives with the goal of lowering Greenhouse Gas (GHG) emissions from Terra Nova. To support this project Suncor was awarded $495,985 from Natural Resources Canada's Emissions Reduction Fund, Offshore RD&D program, which is managed and administered by Energy Research & Innovation Newfoundland & Labrador. The project was initiated in September 2021 and was completed March 2022.

Production flaring is a common practice that refers to the controlled burning of natural gas that is a by product of oil production and processing. Flaring is a necessary safety measure and process in reservoir management, and during normal operations flare gas is released from various sources on the FPSO. This gas is sent to flare and burned off resulting in GHG emissions. The intent of this project is to conduct two (2) front-end engineering & design (FEED) studies focused on 1) retrofitting a closed flare system on Terra Nova and 2) improving the current gas injection barrier testing methodology. The closed flare FEED study was conducted by Suncor in collaboration with local subject matter experts (SME) from Wood Group, and the improved barrier testing study was completed internally by Suncor SMEs.

In a closed flare system, flare gas is redirected back into the gas processing system and re-injected into the reservoir as opposed to sending it up the flare. This has the potential benefit of reducing GHG emissions. Closed flare systems are now standard on new oil production facilities, however retrofitting an existing facility such as Terra Nova is more difficult and first requires a FEED study to identify implementation variables and constraints. Four concepts were identified and after a systematic evaluation upgrading the current Recovery Gas Blower was selected for further review. The FEED study did confirm that despite being technically acceptable and capable of reducing emissions by 19,000 tonnes of CO_2e annually, significant construction and implementation constraints were revealed. In developing the preliminary implementation plan the combination of high construction hours and POB limitations made it apparent this work could only be executed during an offshore maintenance shutdown anticipated for 2025. This will however limit the potential GHG reduction benefit because the current asset life extension project is only expected to extend Terra Nova's service life by approximately 10 years upon an anticipated return to service in late 2022. Considering the short remaining field life and the significant constraints identified in the FEED study it is not feasible to implement a closed flare system on an aging facility. From a GHG emissions perspective it is not a practical solution for reducing Terra Nova's carbon footprint when compared to other such initiatives in Suncor's portfolio.

The second study focused on improving the current protocol for routine testing of Terra Nova's well barrier elements. Barrier testing is a regulatory task performed in accordance with Suncor's well intervention and integrity management strategy and requires the gas compression train to be taken offline and to flare or burn all produced gas. Developing a method to keep the gas compression train online when testing will allow gas to be processed by the facility without flaring. Currently barrier testing is conducted twice a year on Terra Nova's two gas injection wells and contributes to its annual GHG emissions. By changing the barrier test procedure to utilize the annulus bleed system there is no need to shut down gas injection during the test. The study confirmed it is possible to modestly increase the flow through the annulus bleed with a larger restriction orifice, thus improving the chance for successful gas injection barrier testing. This option only requires a minor retrofit and is primarily a shift in the current logic and procedure. Annual GHG reductions up to 4,000 tonnes of CO_2e are possible and unlike a closed flare system this benefit could be realized for a longer period considering the relative ease of implementation. The results of the study will support subsequent detailed engineering and feasibility assessments to support the business decision to proceed with implementation to allow Suncor and Canada to achieve their net zero targets.

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ABBREVIATIONS

AIV	Acoustic Induced Vibration
C-NLOPB	Canada Newfoundland & Labrador Offshore Petroleum Board
DHSV	Downhole Safety Valve
ERF	Emissions Reduction Fund
FEED	Front End Engineering Design
FO	Flow Orifice
FPSO	Floating Production Storage & Offloading
GHG	Greenhouse Gas
HAZOP	Hazard & Operability Study
HP	High Pressure
LP	Low Pressure
NORSOK	Norwegian Offshore Sector Standards
NRCan	Natural Resources Canada
POB	Personnel On Board
RD&D	Research, Development and Demonstration
RGB	Recovery Gas Blower
RO	Restriction Orifice
S/D	Shutdown
SME	Subject Matter Expert
Sm^3	Standard Cubic Meters
CO_2e	Carbon Dioxide Equivalent
WBE	Well Barrier Element

1 PROJECT OVERVIEW

As Canada's largest integrated energy company Suncor's primary purpose is to provide trusted energy that enhances people's lives, while caring for each other and the Earth. By growing the business in low greenhouse gas (GHG) fuels and optimizing the existing hydrocarbon business the objective is to become Canada's leading energy company and net-zero by 2050. To meet this objective Suncor has taken the systematic approach of evaluating and comparing numerous emissions reduction initiatives across its entire portfolio to arrive at responsible and feasible solutions that maximize the benefit to Canada and the environment. This aligns perfectly with the aim of the Emissions Reduction Fund (ERF) sponsored by Natural Resources Canada (NRCan) and in collaboration with NRCan, Suncor can help Canada meet its environmental commitments and reduce GHG emissions and create a lower carbon economy.

To achieve this, enhancements to certain operations on the Terra Nova FPSO that contribute to annual GHG emissions have been identified for further evaluation to help reduce its carbon footprint. Production flaring is one of those operations, and the intent of this R&D project is to advance current understanding and knowledge related to flare reduction potential. To realize that potential Suncor was awarded $495,985 in funding from NRCan under the ERF Offshore RD&D program, which is managed and administered by Energy Research & Innovation Newfoundland & Labrador (ERINL) to study the available options. To that end, this project has the following objectives:

1. Identify and evaluate solutions applicable to Terra Nova
2. Establish the potential benefits and key constraints.
3. Support the development of the business case and assessment of feasibility

By implementing a closed flare system and/or modifying current operating procedures related to flaring, annual reductions in GHG emissions could be realized. To confirm this, an early-stage engineering review or FEED (front-end engineering design) study of flare reduction systems applicable to the Terra Nova FPSO is required.

Suncor SMEs selected two (2) flare reduction or recovery initiatives for further study as the most likely candidates for achieving a reduction in GHG emissions attributed to flaring on Terra Nova. The first is the implementation of a closed flare system whereby flare gas is redirected back into the gas processing system and re-injected into the reservoir as opposed to sending it up the flare. Retrofitting of current facilities and addition of new equipment on the FPSO would be required with this option. The second idea is primarily a procedural change with minimal physical modifications to the production facilities required. Currently, when completing regulatory required gas injection well barrier testing the gas compression train is taken offline, and all produced gas is flared. This required is outlined in Terra Nova's well intervention and integrity management strategy. By developing an improved method to keep the system online when barrier testing, additional gas flaring would be prevented.

The scope of both R&D projects is to perform a preliminary technical evaluation and identify potential benefits of both ideas, as well as develop a preliminary implementation plan for Terra Nova. To assist with the closed flare study, Suncor collaborated with Wood Group, a multinational engineering and consultancy firm with extensive experience in this area. The improved barrier testing study was conducted in-house by Suncor SMEs with direct expertise in Terra Nova operations and process engineering.

2 SCOPE 1 - CLOSED FLARE STUDY

Currently, facilities on the Terra Nova FPSO include low pressure (LP) and high pressure (HP) Flare systems. The LP Flare system includes some safety relief, but primarily has a steady state flow that is in continuous operation while the facility is producing or extracting hydrocarbons. This is normally referred to as background flare and is evident from the flame emanating from the tip of the flare boom. Suncor has recognized

a potential benefit from a reduction in background flare volume that could lessen GHG emissions. The HP Flare on the other hand is transient in nature and is designed primarily to accommodate safety relief and as such cannot be altered and is not covered in this project.

At the onset, a pre-FEED study was conducted where several available and proven technologies for flare gas recovery were assessed and ranked. The outcome of that pre-FEED study was the selection of one preferred concept, in particular a closed flare system that would allow recovery of the LP Flare Gas. The results and ranking are summarized below.

LP Flare Gas Recovery Options Summary

Options	1 Recovery Gas Blower Upgrade	2 Rotary Lobe Compressor	3 Reciprocating Compressor	4 Vapour Recovery Ejector
Meets Design Criteria / Operational Concerns	YES	YES	YES	YES
Cost Estimate	LOWEST	HIGH	MEDIIUM	MEDIUM
Execution Window	2025	2025	2025	2025
Construction Hours	LOWEST	HIGH	HIGH	HIGH
Operation / Maintenance Requirements	LOWEST	HIGH	HIGH	MEDIUM
Project Risks	NORMAL	HIGH	HIGH	HIGH

The preferred option was #1, upgrade the Recovery Gas Blower (RGB) which despite having similar risks and construction (implementation) constraints to the other concepts it is the most favourable in terms of cost, operational & maintenance requirements. From a project execution and operability perspective, option #1 has the lowest risk level, and each of the other 3 options will require creating or finding deck space for a new equipment skid with the associated offshore crane lift. The operations and maintenance requirements are significantly greater for options 2, 3 & 4. Options 2 and 3 will also have an inherent downtime expectation that renders these as having a lower overall availability for recovery of LP Flare Gas. It should be noted the above table is only a summary of the comparative study completed during pre-FEED and the viability of the preferred concept is the focus of the FEED study and not determined during pre-FEED.

All options did meet the evaluation criteria and were technically acceptable, however it was realized during pre-FEED that significant work would be required to implement such a system. The magnitude of work scope made it apparent this could only be done during an extended offshore maintenance shutdown planned for 2025 because of the significant number of offshore construction hours and limitations on POB.

Based on the comparative assessment, it was concluded that upgrading the RGB is the most favourable option and was recommended to progress to FEED. The following is a high-level overview of FEED activities and outcomes.

2.1 FEED Scope

The objective is to minimize continuous LP flaring on the Terra Nova FPSO. The following key items were addressed during FEED related to the evaluation of a closed flare system:

- Replacement of existing RGB with the available greater capacity spare unit.

- Addition of a high integrity, fast opening valve.
- New piping infrastructure to support the design.
- New structures to access new valving and instrumentation.
- Instrumentation, Control Valves, and Control Instrumentation.
- Heat trace for freeze protection and insulation for heat trace application.

Other scopes of work may present itself once detailed engineering is complete pending various project decisions and requirements.

2.1.1 Process Design Description

Currently the RGB is dedicated for capture of volatile gases from the crude storage tanks and is part of the hydrocarbon gas blanketing system installed under a previous initiative to reduce emissions. The existing cargo tank RGB would be replaced with the available larger capacity spare unit. The feed source is out of the new RGB isolation valve on the modified LP flare header to a tie point flange at the RGB previously installed for this purpose. A capacity check was conducted on the larger RGB, and the supplier was consulted to provide their input on the revised feed characteristics. The larger blower has excess capacity for the flare gas recovery cases and has a small impact on required horsepower.

When isolated from the flare tip for flare gas recovery purposes, the only source of pressure at the LP flare drum would be upstream vented and purge gases and condensed water. As the vent rates are somewhat variable and the water vapour pressure is low, pressure control via the RGB speed would dictate the normal operating pressure.

The recovered LP flare gas would be routed through a new purpose-built recovery line. An actuated high integrity fast opening shut-off valve would be installed in the recovery line to the LP Compressor. This valve would open when recovery mode is initiated and closed when flaring is initiated.

In the event the LP flare tip isolation valve opens when the flare gas recovery is shut down, the flare gas must be ignited with a reliable ignition system. Currently flare ignition is achieved using the existing ballistic ignition system on a manual start. This would be addressed during detailed design.

2.1.2 LP Flare Modifications

Required physical modifications would include:

a) LP Flare Header Tie Points, Piping, and Valves:

A section of existing LP Flare Drum discharge piping would be modified to accommodate pressure transmitters, actuated & manual isolation valves, purge piping and a condensate drain assembly.

b) Recovery Gas Blower Tie Points, Piping, and Valves:

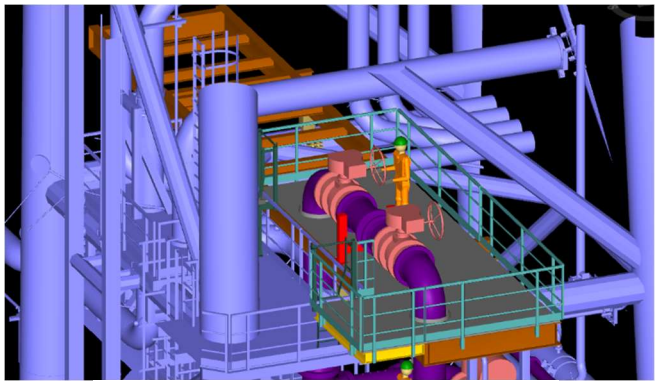
Approximately 160 metres of piping from the modified LP flare header to a previously installed RGB tie point flange and condensate drain assembly.

2.1.3 Instrumentation and Controls

Modifications would be required in the existing RGB controls configurations to accommodate speed control and shutdown from the newly installed pressure transmitters on the LP Flare header.

2.1.4 Structural

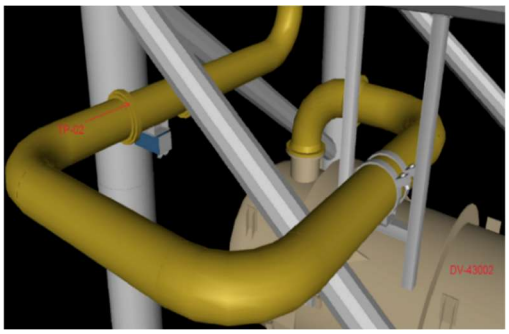
As part of the modification, platforms would be required in various locations to access, operate and service new equipment. The figure below is an example of a platform section (in green) that would be installed to access piping isolation valves (purple and pink)



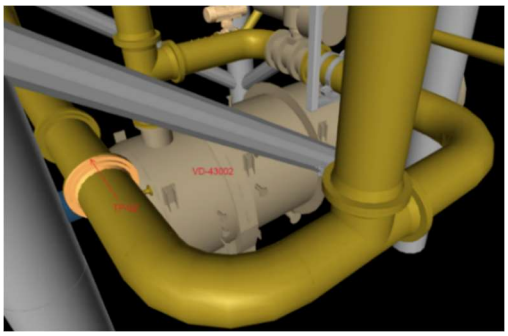
Required Access Platform

2.1.5 Piping

All required piping and tie-in points have been identified and design details developed including service details, insulation requirements, location, and construction requirements, as noted in the figures below. The piping exiting the top outlet flange at the LP Flare drum would be replaced with a revised design to allow for isolation from the LP Flare Tip and redirection of flow to the RGB.

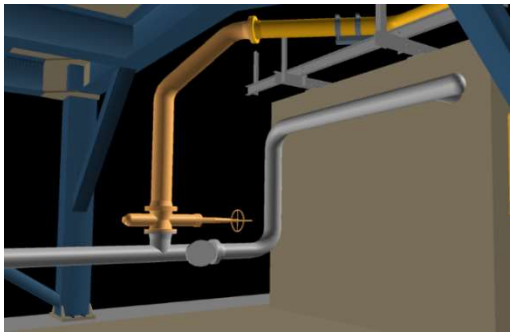


Existing LP Flare Drum Piping



Re-designed LP Flare Drum Piping

The RGB supply piping would tie into the modified LP Flare header and run approximately 160 meters to the existing flange at the inlet to the blower. The new line and condensate pot would be heat traced for freeze protection. New piping is coloured yellow in the figure below.



New RGB Inlet line to Existing Flanged Connection

2.1.6 Technical Safety

Loss prevention design for the project and this assessment would follow the requirements of existing Terra Nova philosophies and relevant CNLOPB regulations. In accordance with that a FEED/Coarse HAZOP was completed to identify hazard and operability scenarios associated with the proposed modifications. Scenarios were assessed at a high level, and recommendations were generated to be addressed in the detailed design and engineering phase. And as per normal practice, further risk assessments and loss prevention design reviews will be required at the detailed design stage.

2.1.7 Implementation Schedule

Based on the complexity of the project, final implementation of the closed flare system on Terra Nova would have to occur during an offshore maintenance turnaround anticipated for 2025. Leading up to that, detailed engineering and other key tasks noted in the following table will be conducted.

Project Milestone	Duration (Days)	Target Start	Target Completion
Detailed Engineering	695	03-Oct-22	16-Jun-24
Procurement	365	24-Oct-22	29-Mar-24
Construction	125	03-Mar-25	22-Aug-25
Commissioning and Start-up	48	25-Aug-25	29-Oct-25

2.2 GHG Emissions Reduction

A preliminary greenhouse gas emissions forecast was performed to estimate the environmental benefit of implementing a closed flare system on Terra Nova. Suncor expects to reduce GHG emissions by approximately 19,000 tonnes of CO_2e per year. This forecast factors in historical Terra Nova emissions data and future GHG reductions gained from facility and process enhancements that are underway during the 2022 asset life extension upgrade. It should be noted this potential reduction in emissions will take effect in 2026 following the 2025 implementation. Following an anticipated return to service in 2022, the asset life extension is expected to add approximately an additional decade to the life of the field, hence limiting the effective benefit timeline.

3 SCOPE 2 - IMPROVED BARRIER TESTING

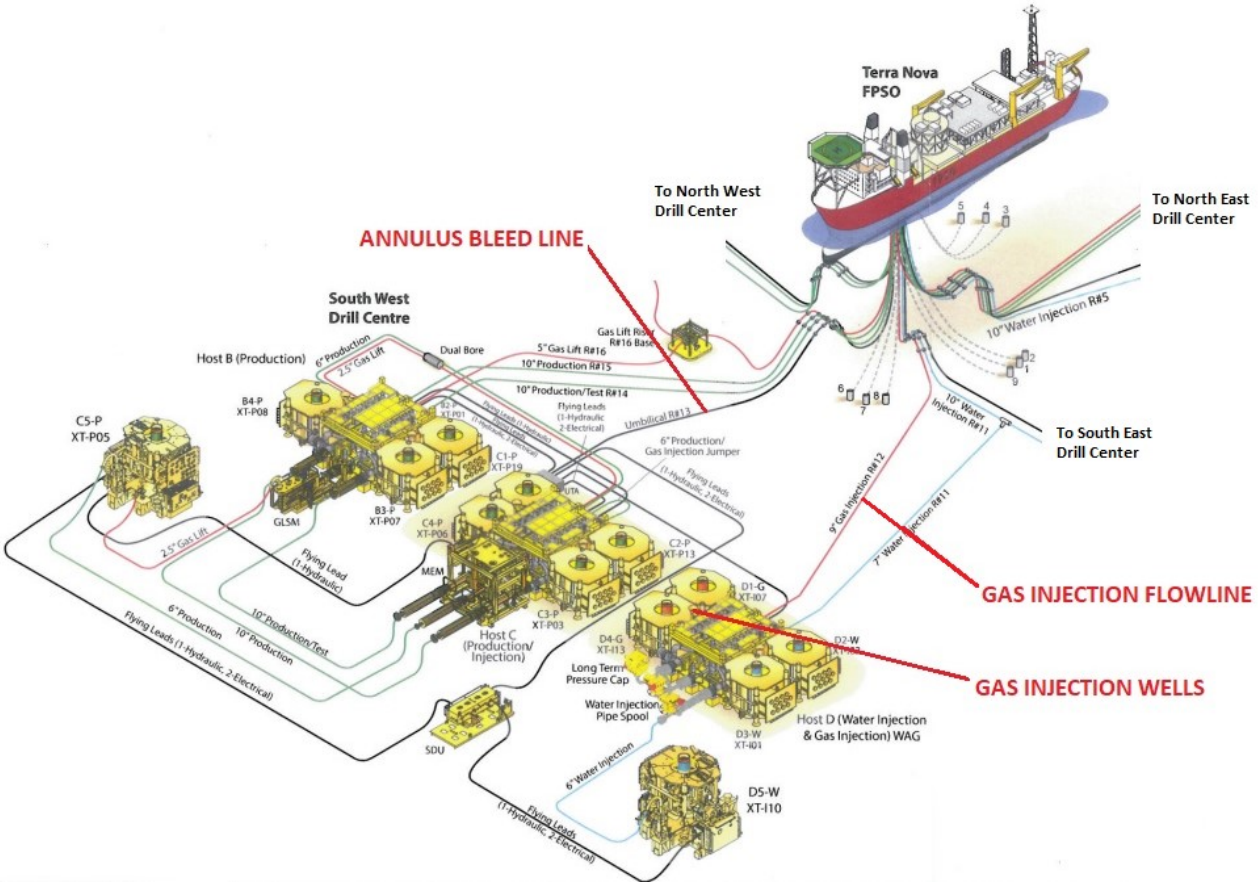
Suncor's Well Integrity and Intervention Strategy requires the Well Barrier Elements of Terra Nova's two gas injection wells be tested twice annually, resulting in four tests required each year. This is done to both confirm and maintain well integrity and control pressures to prevent the uncontrolled release of hazardous substances from a well.

Typically, to test the downhole safety valves (DHSV) in the gas injection well the gas injection system is taken offline and shutdown to depressurize the tubing and flowline to flare. This creates the required pressure differential to test and seat the DHSV which is a component of the primary barrier envelope. This test method requires depressuring the gas flowline and tubing of each well to flare, as well as any additional flaring due to ongoing production and/or upset conditions during testing. This portion of the project scope covers analysis to support changing the barrier testing procedure with the aim of reducing flaring, resulting in a reduction of GHGs on Terra Nova.

3.1 FEED Study

The proposal is to utilize the annulus bleed system to complete the barrier testing, and in doing so, gas injection can remain online and flowing to the alternate gas injection well while one is offline for barrier testing. This would reduce the total flare volume and allow a more stable plant operation to be maintained. Only a small volume of gas is required to be depressurized (and flared) through the annulus bleed line to complete the test.

The annulus bleed system has been used to complete barrier testing in the past. However, the biggest restriction during this procedure is a 3mm (internal diameter) flow orifice in the turret upstream of the closed drain header. This orifice is in place to protect against over pressure of the header and slows down the depressurization and reduces the chances of seating the DHSV. The system includes approximately 3000m of tubing/piping of various diameters with the restriction orifice located in the turret. The figure below shows the extent of this system.



Terra Nova Field Layout

This study was conducted to confirm if the flow orifice could be safety upsized, from the current 3mm, to allow increased flow during barrier testing. This would reduce the time for each barrier test and provide a better chance of seating the DHSV by depressuring the tubing faster.

3.1.1 Process Analysis

A process and piping analysis was performed to determine if it is possible to safely increase gas flow through the annulus bleed and determine the maximum flow that can be achieved, as well as how this flow would improve gas injection barrier testing via this method. Using historical data (flowrate through annulus bleed) a system simulation model was created in Aspen Flare System Analyzer™. The model was validated with the actual flows

and pressures recorded in 2019 during a depressurization event. The pressure profile created within the model based on this event reasonably matches the pressure profile required for the same flow across a 3mm ID restriction orifice. Therefore, this model is suitable to evaluate increasing the restriction orifice in this system.

3.1.2 Increased Gas Flow

The system model indicates that the maximum achievable gas flow through this system is 265 kg/hr. This is approximately 60% more flow than what is currently being achieved during a barrier test with the existing 3 mm restriction orifice.

3.1.3 Pipe Stress Analysis

Acoustic fatigue is a consideration for piping in flare systems. The proposed flow condition was reviewed for acoustic induced fatigue (AIV) potential as per NORSOK Standard L-002 - 2016 - Piping System Layout, Design, and Structural. Results indicate no AIV potential at the current or proposed flow conditions.

3.1.4 Temperature Considerations

The temperature decrease across the restriction orifice is directly related to its pressure drop. During the 2019 event, the lowest temperature calculated across the restriction orifice was -31°C as recorded in the Turret closed drain vessel. This confirms no appreciable change to the temperature profile during depressurization activities is anticipated with the proposed increase in flow. If necessary, a complete temperature profile will verify this in the detailed design stage.

3.2 GHG Emissions Reduction

Utilizing the annulus bleed system to complete gas injection barrier testing would reduce the gas flared by up to 1.8 million Sm^3/year, which is the equivalent of 4400 tonnes of CO_2e a year. This is based on eliminating the need to depressurize the gas flowline to flare and any additional flaring due to ongoing production &/or upset conditions during the two barrier testing campaigns each year.

4 REVIEW OF PROJECT OBJECTIVES

The intent of each study is to expand Suncor's understanding of how flaring operations could be reduced on Terra Nova. This knowledge is then used to support the assessment of commercial feasibility and business decision to proceed with implementation. The following is a review of project objectives and how effective each study was at achieving them.

4.1 Solutions Applicable to Terra Nova

Regarding the Closed Flare system, the pre-FEED study did identify four (4) options that could effectively redirect flare gas and reduce GHG emissions associated with background flaring operations. By conducting a systematic comparative analysis of these options, a preferred concept applicable to Terra Nova was identified. A detailed FEED study was then conducted to further develop a preliminary implementation plan of that concept.

With relation to an improved method to conduct barrier testing, this study did demonstrate current methodology could be modified and a reduction in flaring is possible. Historical test data was used to validate the new proposed method that included minor equipment upgrades and a procedural change to the current testing protocol on Terra Nova. As with the closed flare system study, this study outlined the preliminary implementation framework and applicability for Terra Nova.

In both cases, this project objective was successfully achieved.

4.2 Benefits and Constraints.

A reduction in GHG emissions from Terra Nova is the primary benefit and driver for both studies. The implementation of a closed flare system could potentially reduce emissions by approximately 19,000 tonnes of CO_2e each year, from 2026 to 2033 the anticipated end of field date. The study did also establish an implementation plan, but in doing so did reveal significant construction constraints related to retrofitting the system on an aging facility. Considering this work must be completed offshore and the magnitude of offshore construction time the logistics to execute with limited POB capacity has also been identified as a constraint. As well, the complex nature of fitting new equipment and making allowances for support structure creates additional technical challenges for implementation.

Improvements to the current gas injection barrier testing protocol would benefit Terra Nova by reducing GHG emissions by approximately 4400 tonnes of CO_2e per year. Unlike the closed flare system, the implementation of the proposed new method does not present any significant constraints as only minor infrastructure upgrades are required. The primary consideration is adoption of the new method and a step change in the current logic around the testing protocol.

In both cases, this project objective was successfully achieved.

4.3 Feasibility and Business Case

To allow Suncor to determine what initiatives are environmentally sustainable and commercially feasible, various studies and assessments must be conducted. This project and the studies conducted provide the basis for the decision support package to determine if there is a business case for implementing the flare reduction options identified. Each study provided a technical assessment of each option and confirmed it is possible to reduce flaring operations on Terra Nova.

The closed flare study did confirm an environmental benefit could be realized by implementing such a system, however it requires a complex retrofit of an aging facility and the study did effectively identify several constraints in that regard. These benefits and constraints were used to evaluate the business case to arrive at the conclusion that implementing a closed flare system on Terra Nova is not feasible and that there are more effective, and practical solutions to allow Suncor to achieve it net zero targets.

Conversely, the improved well barrier testing study did provide a more favourable result that supports the new testing protocol. The potential environmental benefits have been established along with and a preliminary implementation assessment, including recommendations for subsequent detailed engineering. In keeping with Suncor procedures, the results of this preliminary study will be used to develop the decision support package to advance this initiative to the next stage and further define the business case and environmental benefits.

In both cases, this project object was successfully achieved.

5 CONCLUSIONS & NEXT STEPS

To become a net zero company by 2050, Suncor's strategy is to identify and support GHG reduction initiatives that are both sustainable and technically and economically feasible. By reducing background flaring on Terra Nova, Suncor has the potential to reduce GHG emissions and help achieve its net zero targets. To determine if this is feasible the first step is to perform a FEED study of possible solutions to support the business case. The objective of this R&D project is to perform two preliminary engineering studies of flare reduction options applicable to Terra Nova.

Along with identifying flare reduction options applicable to Terra Nova, this project evaluated how to implement these proposed systems from a technical and logistics point of view. In keeping with the nature of a FEED study, high-level considerations for deployment on Terra Nova were addressed.

The first study focused on flare reduction by retrofitting Terra Nova to implement a closed flare system that would re-direct and re-inject LP flare gas back into the reservoir as opposed to sending it up the flare. Key design and engineering tasks were established, along with the necessary equipment and facility modifications, such as structural and piping. Likewise, execution resources were identified, and a deployment schedule was developed as part of a preliminary closed flare implementation plan. This study did confirm the closed flare concept is technically possible using currently available technology; however, significant deployment constraints were also identified. A reduction in GHG emissions of 19,000 tonnes of CO_2e can be realized with this option however this benefit is limited because of the age of Terra Nova and the short service life remaining after the closed flare system was installed. A decision support package was prepared and presented to arrive at the decision to not proceed with implementation because it is not feasible when compared to other more effective GHG emission reduction initiatives in Suncor's portfolio of projects.

The second FEED study focused on improving the current barrier testing methodology. By changing the barrier test procedure to utilize the annulus bleed system to eliminate the need to shut down gas injection on both wells twice a year for barrier testing. The result of the study did indicate it is possible to modestly increase the flow through the annulus bleed with a larger restriction orifice, thus improving the chance for successful gas injection barrier testing using the annulus bleed line. The preliminary framework to implement an improved testing protocol was established and the required procedural changes and facility upgrades were also identified and evaluated. This option only requires minor retrofit of infrastructure and is primarily a step change in the current logic and procedure. A reduction in GHG emissions of 4,000 tonnes of CO_2e can be realized with this option and unlike the closed flare system this benefit could be realized for a longer period considering the relative ease of implementation pending final design and approval.

The outcome of both studies did meet the objective of this R&D project by demonstrating it is technically possible to reduce flaring operations on Terra Nova. The potential benefits and constraints were identified as well as the preliminary framework to implement both options. In terms of next steps, since the decision to not proceed with a closed flare system has been made, there is no further action regarding that initiative. However, the favourable results of the improved well barrier testing study will now be used to build the business case to support the advancement of Suncor's commitment to be a net zero carbon emissions company by 2050.