CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	**Impact of Crude Inlet Temperature and Density on Pipeline Operation**
Alberta Innovates Project Number:	212201593
Submission Date:	November 2022
Total Project Cost:	$137,659
Alberta Innovates Funding:	$22,943.55
AI Project Advisor:	Murray Gray

2. APPLICANT INFORMATION:

Applicant (Organization):	**Canadian Natural Resources Ltd.**
Address:	2100 – 855 2nd St SW, Calgary AB T2P 4J8
Applicant Representative Name:	Sanjay Shah
Title:	Manager, Utilities Integration
Phone Number:	403-386-6025
Email:	sanjay.shah@cnrl.com

3. PROJECT PARTNERS

Please provide an acknowledgement statement for project partners, if appropriate.

RESPOND BELOW

The following organizations were also sponsors of the project and active participants in the project steering committee:

Enbridge	In Kind
Suncor	Cash and In Kind
Imperial Oil	Cash and In Kind
Cenovus	Cash and In Kind
APMC and Alberta Energy	Cash and In Kind

A. EXECUTIVE SUMMARY

Provide a high-level description of the project, including the objective, key results, learnings, outcomes and benefits.

RESPOND BELOW

The objective of the project was to examine two opportunities to improve pipeline access of bitumen-derived crude oils to Eastern Canada and the US. The work was sponsored and guided by members of the National Partial Upgrading Committee NPUC), including oilsands producers, Alberta Energy and Alberta Petroleum Marketing Commission, in partnership with Enbridge to provide in kind support and guidance. Pipeline transport has been a major issue for oilsands producers due to the need to dilute bitumen with natural gas condensate or naphtha to meet specifications on viscosity and density. A significant fraction of the diluent is recycled at US refineries and shipped back to Alberta for reuse. While this strategy makes effective use of the light diluent fractions, the diluent volume occupies space in the export pipelines, and separation and shipment of the diluent increases greenhouse gas emissions.

A) **Preheating of bitumen blends to allow use of less diluent**: The first opportunity examined in the study was preheating of the feed diluted bitumen (dilbit) at the source terminal in Alberta to temperatures up to 30°C. Once the crude oil is injected in to the large-diameter pipelines used for diluted bitumen, the friction of the crude oil against the pipe walls and the friction of pumping more than compensates for heat conduction to the soil along the pipeline, so the crude oil temperature gradually rises from Alberta through Saskatchewan and Manitoba. This study used a hydraulic model validated by Enbridge to examine these temperature profiles for a range of diluent blends preheated up to 30°C. In all cases the result for preheated crude oil was a higher winter temperature profile through the northern sections of the pipeline, enabling transport of bitumen with less diluent at lower pumping power. The diluent saving ranges up to 37% in winter depending on the degree of under-blend. Although the lower diluent-blends are pumped at a lower flow rate, the actual bitumen transporting rate is about 0.5~1.6% higher than transport of typical dilbit. The power consumption reduction is in the range from 0.3% to 4.5%. The volume transported was reduced, with a reduction in energy for pumping, but the net volume of bitumen transported was the same or slightly higher.

A major operating issue with pipelines is the ability to restart operation after a shutdown of pumping. Restarting the pipeline at winter conditions was simulated for the reduced-diluent blends. The window for restarting the flow with the existing facilities at winter conditions is about 21 days for the case with the largest reduction in diluent (diluent was reduced by 37% then the blend was preheated to 30°C to meet inlet viscosity). Higher diluent fractions gave longer windows of time for successful restart. These results suggest that restarting after a winter shutdown is not a significant risk.

The preliminary economics of preheating pipeline feed suggest that this new mode of pipeline operation may be very attractive to both pipeline operators and to shippers of bitumen. A heating unit to handle 1 million bbl/d would require 59 MW of natural gas, at a capital cost of approximately $36 million. A more detailed analysis of system-wide capital and operating expenses and commercial negotiation is required to fully assess the opportunity. Although the GHG emissions of transportation would be increased by installing a heater at the pipeline terminal, this increase would be more than offset by the reduction in pumping power and the reduction in indirect GHG emissions associated with the production, separation, and transportation of the diluents.

B) Transportation of partially upgraded bitumens with higher density than current specifications: The second opportunity studied was pipeline transport of partially upgraded bitumen that exceeds current density limits for pipeline operation. The oilsands industry has identified partial upgrading as a method of reducing the need for diluent for pipelining, and to increase the value of the bitumen blends to downstream refineries. The current pipeline tariffs stipulate a maximum density of 940 kg/m^3, which is not a barrier for normal dilbits because they are blended to meet viscosity requirement. Processing of bitumen through partial upgrading can significantly decrease the viscosity, but the density is altered much less. Consequently, some partially upgraded bitumens would require addition of extra diluent to meet this density requirement. The same hydraulic model as in part A of the study was used to study pipeline transport of several partially upgraded bitumens that meet current viscosity requirements, but exceed the density.

The study showed that the pipeline transport of these high-density blends was not a significant issue, because the pipeline operation was dominated by viscosity. The viscosity of the example partially upgraded bitumens was less sensitive to temperature than unprocessed bitumen, so these crude oils gave equivalent behavior at low winter temperature but gave less viscosity reduction or “thinning” at higher temperatures. Some modification of pumping operation might be required, particularly in some southern pipeline segments that operate at temperatures over 35°C.

Learnings: The results of this initial feasibility study indicated that transport of bitumen, and partially upgraded bitumen, with less diluent could allow more efficient use of existing pipelines. The project was successful because of the active collaboration between industry and government members of the National Partial Upgrading Committee and Enbridge. The participation of Enbridge was critical in guiding the scope of the work to address operating concerns, in enabling accurate simulations of the operation of a representative pipeline network, and in validating the detailed methodologies for each portion of the study.

Outcomes: This study is the first stage in NPUC's initiative to enable more efficient transport of bitumen and partially upgraded bitumen. The encouraging results from this initial feasibility study set the stage to launch a longer-term project to enable adding less diluent to bitumen for pipeline transport. At this time, NPUC anticipates three stages of work:

Stage 1: Building a group of committed producers to define the opportunity and refine the project economics

Stage 2: Engage with pipeline companies to define a framework for collaboration and to conduct essential follow-up technical analysis

Stage 3: Project implementation – execute the required engineering and project work to design and build facilities and modify existing equipment

Benefits: Operation of pipelines with new blends of bitumen create an opportunity for all stakeholders to benefit in a win-win-win scenario. By reducing the amount of diluent required for transport of bitumen and partially upgraded bitumen, the producers significantly reduce their costs for shipping and separating diluent. Application of this approach to 1 million barrels per day of diluted bitumen could reduce net diluent costs significantly. Offsetting a portion of these savings, higher tariffs for shipment of the new blends would enable the pipeline operators to recoup the costs of adding and operating inlet heaters and reducing the volume of diluent shipped through their lines. Lower operating costs would enhance the financial sustainability of oilsands production, and make the industry more robust. On the environmental side, the GHG footprint of pipeline transport would be reduced because the emissions associated with heating the dilbit would be more than offset by reducing the indirect emissions associated with diluent management, through production from natural gas, transport, and separation at downstream by refineries for shipment back to Canada. Finally, downstream refineries would benefit from handling smaller volumes of diluent for separation and return by pipeline.

B. INTRODUCTION

Please provide a narrative introducing the project using the following sub-headings.

- **Sector introduction:** Include a high-level discussion of the sector or area that the project contributes to and provide any relevant background information or context for the project.
- **Knowledge or Technology Gaps:** Explain the knowledge or technology gap that is being addressed along with the context and scope of the technical problem.

RESPOND BELOW

The oilsands industry in Alberta make major economic contributions by extracting bitumen resources an preparing them for transport and refining, either within Alberta or in Eastern Canadian or US refineries. The majority of bitumen produced is shipped by pipeline from major terminals at Edmonton and Hardisty. The transportation of bitumen by pipeline is feasible only if a significant volume of diluent is added. The amount of diluent depends on the source of the bitumen, any processing to remove asphaltenes, and the reference ground temperature for pipeline operation. Up to 31% diluent is required for Athabasca bitumen at winter conditions. Even though the diluent is either returned to Canada or used in products by the downstream refineries, the net cost to producers is significant, adding up to $14 USD/barrel in purchasing and handling costs (Keesom, W. and J. Gieseman (2018). Bitumen Partial Upgrading 2018 Whitepaper AM0401A. Calgary, AB, Alberta Innovates: pp. 152.)

Currently the only method of reducing this shipping cost is upgrading or partial upgrading of the bitumen, to significantly reduce its viscosity. For the past decade, the industry has investigated technologies for partial upgrading, and several technologies are now at TRL 7 or 8 with potential for commercialization. Partial upgrading is effective, but the capital costs are significant at over $10,000 per barrel per day of production. The cheapest partial upgrading processes are not able to significantly reduce the density of the bitumen product, so that even after the viscosity is reduced to meet pipeline specifications, addition of incremental diluent is required to reduce the density to below the current maximum level of 940 kg/m^3.

The oilsands industry faces two technology gaps in pipeline transport; first, how to cheaply reduce the amount of diluent without expensive processing, and second, how to minimize diluent for partially upgraded bitumen by enabling the shipment of blends with density over 940 kg/m^3.

C. PROJECT DESCRIPTION

Please provide a narrative describing the project using the following sub-headings.

- **Knowledge or Technology Description:** Include a discussion of the project objectives.
- **Updates to Project Objectives:** Describe any changes that have occurred compared to the original objectives of the project.
- **Performance Metrics:** Discuss the project specific metrics that will be used to measure the success of the project.

RESPOND BELOW

The project is an engineering analysis of two technologies that would significantly enhance the utilization of pipelines for bitumen transport.

a) Preheat bitumen blends at pipeline terminals so that even with lower diluent content, the viscosity of the bitumen in the pipeline would be pumpable by existing equipment. This innovation relies on the balance between heat losses to the ground surrounding buried pipelines, and the frictional heating due to pumping energy and flow along the pipe wall. The hypothesis is that pre-heating the blend can raise the crude oil temperatures through the northern sections of pipeline where the low temperatures require the largest volume of diluent.

b) Ship partially upgraded bitumens (PUBs) that meet the existing dynamic viscosities of diluted bitumens, but have higher densities than the current limit of 940 kg/m^3. PUBs up to 960 kg/m3 were examined, with viscosities at or below the limit of 350 cSt at a ground reference temperature of 18°C (summer condition).

The objective of the study was to define the potential barriers to shipping new bitumen blends by examining the following aspects of pipeline operability:

A) Increasing Dilbit inlet temperature at the hub (Hardisty)
   - Define equipment suitability (increased temp, density/viscosity spec implications)
   - Shutdown impact– restart after 3-5+ day shutdown
   - Dilbit heating up options (conceptual basis)

B) For the PUB case with increases in density relative to current dilbits, consider similar issues to Part (A).

C) Define capital cost, operating cost, and heat duty

The scope of the work included suggestions for mitigating any barriers for shipping the new blends.

The final overarching objective of the project was to provide a study report as a public document to facilitate conversations with different stakeholders in the pipeline system operation and regulation.

No changes in the objectives occurred in the course of the project.

The project metrics are to work towards expanding pipeline access for bitumen by defining the technical barriers and costs for new bitumen blends. If successful, this initial feasibility study would contribute to the longer term goal of modifying pipeline infrastructure to begin shipment of reduced-diluent blends

D. METHODOLOGY

Please provide a narrative describing the methodology and facilities that were used to execute and complete the project. Use subheadings as appropriate.

RESPOND BELOW

The study used standard methods for simulating pipeline operation. These were:

1) A hydraulic model for the pipeline network, provided by Enbridge, indicating pipe diameters, distances, and pumping power available at each station.
2) Diluted bitumen properties as a function of temperature were developed from standard assays and correlations.
3) A heat transfer model for exchange between the warm pipeline and the surrounding soil. Representative temperature conditions for winter and summer conditions along the length of the pipeline were used.

The properties of the diluted bitumens and the partially upgraded bitumens were based on lab assays of Athabasca bitumen, diluent, and three PUB products. Estimates for density and viscosity as a function of temperature were from standard methods.

The study examined the following cases:

a) Steady state winter operation (multiple diluent concentrations)
b) Steady state summer operation (multiple diluent concentrations and PUBs)
c) Restart under winter conditions (multiple diluent concentrations)
d) Options for heating diluent blends, heat duty and capital cost (Class 5).

Additional details on the methodology of the study are provided in the appended report from the engineering consultant, Worley.

E. PROJECT RESULTS

Please provide a narrative describing the key results using the project's milestones as sub-headings.

- Describe the importance of the key results.
- Include a discussion of the project specific metrics and variances between expected and actual performance.

RESPOND BELOW

Based on the results of the hydraulic analysis of pipeline operation with diluted bitumens that are preheated and partially upgraded bitumens, the study concluded the following:

- Preheating of the crude oil enables transport of bitumen with less addition of diluent. The diluent saving ranges from 11% to 37.2% depending on the degree of under-blend. Although the diluent usage saving reduces the pumpable flow rate, the actual bitumen transporting rate is about 0.5~1.6% higher than transport typical dilbit. The power consumption reduction is in the range from 0.3% to 4.5%.
- Pipeline flow rate decreases about 2.2%~11.2% below the design flow rate of 5890 m^3/h (bitumen + diluent) when transporting the under-blend fluids (Fluid_18°C[1], Fluid_24°C, and Fluid_30°C) due to bottlenecks in the existing pipeline system. Further hydraulic analysis may be required to examine the system and to mitigate the flow reduction using e.g. DRA or allowing all VFD to overdrive.
- Transporting under-blend fluid (Fluid_24°C) at a higher inlet temperature (30°C) is beneficial but with only marginal flow increase (1.9%) and small power consumption reduction (7068 hp or 5.3 MW).
- Pipeline shutdown and restart analysis shows that the pipeline can be restarted with the heavier blends under winter conditions. The restart window time with the existing facilities is about 21 days for the heaviest under-blend (Fluid_30°C) in winter condition, 39 days for Fluid_24°C, and >100 days for Fluid_18°C by extrapolation. The restart fluid viscosity limit is evaluated to be about 1200 cP. If pump station controls can be modified, the restart window time may be extended longer, subjected to further hydraulic analysis.
- The impact of transporting partially upgraded bitumen with densities over the current limit of 930 kg/m^3 on pipeline operation is limited. The example higher density partially upgraded fluids in this study had altered the fluid properties, resulting in a different viscosity profile with temperature as compared to unprocessed bitumen blends. The viscosity is still the dominant factor in transporting bitumen in the pipeline system.
- A gas-fired heating unit for 1 million barrels per day of diluent to deliver at 30°C at a Hardisty terminal would have a heat duty of 59 MW under winter conditions and a capital cost of $36 million

Detailed results and figures are provided in the attached report from Worley.

[1] In this report, Fliud_T°C e.g. Fluid_18°C stands for a diluted bitumen which its diluent content is adjusted to meet 350cSt (pipeline spec) at that particular temperature.

The addition of a heater will result in GHG emissions if natural gas is used, however, this project will reduce overall GHG on a complete LCA basis. The dilbit heater will emit approximately 0.37 kg CO_2/bbl of bitumen (winter case, Fuild_30°C of this study), significantly offset by a reduction of over 0.18 Kg GHG/bbl of bitumen CO_2 emissions due to less electric power consumption for pumping. The net emissions would be 0.19 kg CO_2/bbl of bitumen. The use of less diluent reduces the indirect emissions associated with its production and transport. For diluted bitumen with 30% diluent, these indirect emissions are 8.38 kg CO_2/bbl dilbit (Sleep et al., Journal of Cleaner Production, 281, 2021, 125277). A 37% reduction in diluent, therefore, will reduce these emissions by 3.1 kg CO_2/bbl, much larger than the net change in pipelining emissions. Typical emissions footprint SAGD dilbit production and transportation is approximately 65.7 kg CO_2/bbl.

The net cost of adding diluent to Athabasca bitumen is up to $14 USD/barrel in purchasing and handling costs to meet winter viscosity specifications (Keesom, W. and J. Gieseman (2018). Bitumen Partial Upgrading 2018 Whitepaper AM0401A. Calgary, AB, Alberta Innovates: pp. 152.). Delivery of heated bitumen to the pipeline inlet at 30°C would allow a reduction in diluent volume to 22% in winter. On an annual basis, averaging winter and summer conditions, use of a 22% diluent would reduce diluent use by 18.4 million barrels per year, relative to a current pipeline operating at 1 million bbl/d of dilbit at 29% diluent (average of 31% in winter, 27% in summer). Allowing for higher pipeline tariffs to cover the increased cost of operation and required capital costs, making the new mode of operation financially attractive to pipeline companies, this type of operation would still result in substantial savings to producers.

Deliverables: This project had a single milestone with the following project deliverables:

Activity	Deliverables
Complete engineering study	Draft report, including all calculation/simulation input and output files, sensitivity analysis, Joint Operational /Technical review, Joint risk review, Impact on selected example Refinery in comparison to current feed
Acceptance of report by NPUC steering committee	Revised final report for public releaser

With the acceptance of this public report, all deliverables for the project will be complete.

F. KEY LEARNINGS

Please provide a narrative that discusses the key learnings from the project.

- Describe the project learnings and importance of those learnings within the project scope. Use milestones as headings, if appropriate.
- Discuss the broader impacts of the learnings to the industry and beyond; this may include changes to regulations, policies, and approval and permitting processes

RESPOND BELOW

The main project learnings are the findings of the analysis conducted by the engineering contractor, Worley. The success of the project was due to excellent technical work and significant support and encouragement from Enbridge, who provided the based model for pipeline hydraulic operation and helped to validate the results of the Worley analysis.

The analysis by Worley is the first feasibility study on the pipeline transport of new blends. Additional technical analysis will be required before a project can proceed, and the NPUC steering committee is already working with Enbridge to define the gaps that need to be considered.

This study is extremely promising in indicating a low-cost, low GHG impact approach to making more efficient use of existing pipeline infrastructure. In order to move a project of this type to execution, the following steps are required:

1. The oilsands shippers need to agree on the desirability of this mode of operation, and agree on the economic benefits and risks.
2. The shippers need to work with pipeline companies, such as Enbridge, to reach agreement on sharing the benefits of this type of operation.
3. Follow-up detailed engineering studies on equipment, terminal operations, operation of different batches of crude oil with the new low-diluent blends, and refinery connections need to be completed.
4. Engagement with the Canadian Energy Regulator and other shippers is required to examine the benefits and risks of the new mode of operation, and to modify regulations and set tariffs for the new blends with reduced diluent content at higher delivery temperature.

G. OUTCOMES AND IMPACTS

Please provide a narrative outlining the project's outcomes. Please use sub-headings as appropriate.

- **Project Outcomes and Impacts:** Describe how the outcomes of the project have impacted the technology or knowledge gap identified.
- **Clean Energy Metrics:** Describe how the project outcomes impact the Clean Energy Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Program Specific Metrics:** Describe how the project outcomes impact the Program Metrics as described in the *Work Plan, Budget and Metrics* workbook. Discuss any changes or updates to these metrics and the driving forces behind the change. Include any mitigation strategies that might be needed if the changes result in negative impacts.
- **Project Outputs:** List of all obtained patents, published books, journal articles, conference presentations, student theses, etc., based on work conducted during the project. As appropriate, include attachments.

RESPOND BELOW

The project was successful indicating the feasibility of operation with lower diluent content if the blends are heated at the pipeline inlet. The project also indicated that shipment of partially upgraded bitumens with densities over 940 kg/m^3 is feasible, and long as the dynamic viscosity is similar to current dilbits. The study results set the stage for additional work to investigate project economics and development engagement between the shippers and pipeline operators to enable further analysis and develop a feasible project.

Metrics:

The project identified the following targets:

Clean Resources Metrics (Select the appropriate metrics from the drop down list)

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)
Collaborators	6	6	Funding partners are 4 oilsands companies and APMC. Enbridge is providing data and advice for the engineering study.
Practices informed/influenced	2	2	Enable changes to two properties of crude oil for pipeline transport to enable cheaper access markets.

The project targets were met, with 6 organizations collaborating on the study and two operating practices evaluated: preheating heavy blend of dilbit with reduced diluent and shipment of high-density partially upgraded bitumens.

Program Specific Metrics (Select the appropriate program metrics from the drop down list)

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)
# of End Users participating	5	5	Four oilsands producers and Enbridge
$/bbl product uplift	$5/BBL	$5/bbl	Reduction in cost due to reduced diluent blending requirements

The project engaged the following end users: Cenovus, CNRL, Imperial, Suncor, and Enbridge as pipeline operator. The potential savings in costs are significant, subject to more detailed study of the pipeline operating costs.

Project Success Metrics (Metrics to be identified by Applicant Representative)

Metric	Project Target	Commercialization / Mobilization Target	Comments (as needed)
Expand pipeline access for bitumen	Define technical barriers and costs for new bitumen blends	Begin shipment of reduced-diluent blends	

The project was successful in defining the technical barriers to shipping the lowest-diluent blends, which may require some de-bottlenecking of pumping stations and changes to operation. The capital and operating cost of preheating pipeline feed blends was determined.

H. BENEFITS

Please provide a narrative outline the project's benefits. Please use the subheadings of Economic, Environmental, Social and Building Innovation Capacity.

- **Economic:** Describe the project's economic benefits such as job creation, sales, improved efficiencies, development of new commercial opportunities or economic sectors, attraction of new investment, and increased exports.
- **Environmental:** Describe the project's contribution to reducing GHG emissions (direct or indirect) and improving environmental systems (atmospheric, terrestrial, aquatic, biotic, etc.) compared to the industry benchmark. Discuss benefits, impacts and/or trade-offs.
- **Social:** Describe the project's social benefits such as augmentation of recreational value, safeguarded investments, strengthened stakeholder involvement, and entrepreneurship opportunities of value for the province.
- **Building Innovation Capacity:** Describe the project's contribution to the training of highly qualified and skilled personnel (HQSP) in Alberta, their retention, and the attraction of HQSP from outside the province. Discuss the research infrastructure used or developed to complete the project.

RESPOND BELOW

As an engineering feasibility study, the project had very limited direct benefit beyond employment of an engineering consultant. Major benefits are possible if the project goes ahead to preheat bitumen to enable operation with reduced diluent content. These benefits include:

1. Economic benefits from capital projects by pipeline operators, such as Enbridge, to install heating systems and modify pipeline systems. The minimum benefit would be a $36 million investment in a heater system. Additional projects to debottleneck pipeline infrastructure may be defined by further study of details of operation. These capital projects will create direct employment for engineering, fabrication, and construction. Indirect economic benefits would include reduced operating costs to oilsands companies which would increase the net benefits to the Province of

Alberta through higher royalties and potential investment of increased profits. The reduction in diluent would make bitumen blends more attractive to a majority of refineries who discount the value of dilbit due to the low relative value of the diluent and the cost for recovery and shipment.

2. Environmental – The project would increase direct GHG emissions from use of natural gas to heat the feed bitumen. The dilbit heater will emit approximately 0.37 kg CO_2/bbl of bitumen (winter case, Fuild_30°C of this study), significantly offset by a reduction of over 0.18 Kg GHG/bbl of bitumen CO_2 emissions due to less electric power consumption for pumping. The net emissions would be 0.19 kg CO_2/bbl of bitumen. The use of less diluent reduces the indirect emissions associated with its production and transport. For diluted bitumen with 30% diluent, these indirect emissions are 8.38 kg CO_2/bbl dilbit (Sleep et al., Journal of Cleaner Production, 281, 2021, 125277). A 37% reduction in diluent, therefore, will reduce these emissions by 3.1 kg CO_2/bbl, much larger than the net change in pipelining emissions. Typical emissions footprint SAGD dilbit production and transportation is approximately 65.7 kg CO_2/bbl. In comparison to this base level, both the net increase in direct emissions and the reduction LCA emissions are modest.
3. Social – A pipeline feed project would have limited impact on broader society. The oil and gas sector would benefit from enhanced collaboration between shippers and pipeline operators to achieve shared business and operating benefits.
4. Building Innovation Capacity – Benefits in this area would be insignificant.

I. RECOMMENDATIONS AND NEXT STEPS

Please provide a narrative outlining the next steps and recommendations for further development of the technology developed or knowledge generated from this project. If appropriate, include a description of potential follow-up projects. Please consider the following in the narrative:

- Describe the long-term plan for commercialization of the technology developed or implementation of the knowledge generated.
- Based on the project learnings, describe the related actions to be undertaken over the next two years to continue advancing the innovation.
- Describe the potential partnerships being developed to advance the development and learnings from this project.

RESPOND BELOW

The NPUC Steering committee has the following plan to move the bitumen preheating project to commercial execution:

Stage 1: Building a group of committed producers to define the opportunity and refine the project economics – The idea of operating with new blends needs to be socialized and examined within the producer companies, to set the stage for a significant collaborative effort. The economic value of the project needs be examined and refined to encourage producers to devote time to the effort.

Stage 2: Engage with pipeline companies to define a framework for collaboration and to conduct essential follow-up technical analysis. The NPUC Steering Committee has already defined follow-up engineering analysis that is required before a go/no go decision can be made on a capital project. A prerequisite for this work to proceed is an agreed partnership framework between the oilsands producers and the pipeline operators.

Stage 3: Project implementation – execute the required engineering and project work to design and build facilities and modify existing equipment. Detailed engineering studies of all modes of pipeline operation, delivery, and connection to upstream and downstream customers needs to be examined as part of the scope of work. If the results continue to be encouraging, then engagement with the Canadian Energy Regulator and other stakeholders would be required to begin changing regulations and tariffs governing pipeline operation.

J. KNOWLEDGE DISSEMINATION

Please provide a narrative outlining how the knowledge gained from the project was or will be disseminated and the impact it may have on the industry.

RESPOND BELOW

During Stage 1 and Stage 2 work to follow-up on this initial feasibility study, the NPUC partners will present the results of the work to stakeholder groups to build interest in joining the collaborative effort. Audiences may include:

Canadian Crude Quality Technical Association

Canadian Heavy Oil Association

Alberta's Industrial Heartland Association

K. CONCLUSIONS

Please provide a narrative outlining the project conclusions.

- Ensure this summarizes the project objective, key components, results, learnings, outcomes, benefits and next steps.

RESPOND BELOW

This study investigated two hypotheses: first that preheating of diluted bitumen at the pipeline inlet would boost the temperature over the northern leg of operation, giving sustained reduction in viscosity over hundreds of kilometers of operation. The second hypothesis was that shipment of high density partially upgraded bitumens was feasible as long as their dynamic viscosity was comparable to existing dilbit blends.

Analysis of steady state pipeline operation, using a model of the Enbridge system, confirmed both hypotheses. Raising the temperature profile of the pipeline using an inlet heater is a feasible opportunity to enhance bitumen transportation with lower diluent use and lower pumping power than current unheated operation. Similarly, the transport of partially upgraded bitumen was entirely governed by the dynamic viscosity of the blends (in centipoise or mPa-s), The impact of fluid density was insignificant.

The restart of a pipeline under winter conditions was simulated, and the study showed a window of at least 21 days to restart a pipeline after shutting down, using existing equipment.

The study identified which sections of the pipeline network would be most constrained in handling the new bitumen blends and partially upgraded bitumens.

The potential economic benefits of preheating bitumen blends at the pipeline inlet are large, given the significant costs of diluent handling and the large volumes of diluted bitumen that are transported. Further work is required to define the detailed economics and to fully define the capital and operating costs, but a high-level analysis indicates that producers could reduce their cost of diluent by hundreds of millions of dollars per year. These savings would more than offset the capital and operating costs incurred by the pipeline operators, which would be recouped by higher pipeline tariffs for low-diluent bitumen blends.

The life cycle GHG emissions would be reduced by the new mode of operation. The emissions from heaters for inlet bitumen would be more than offset by reductions in pumping costs and the indirect GHG emissions associated with diluent addition.

Commercialization of this new mode of pipeline operation will require several stages of forming collaborative partnerships, conducting additional analysis of details of operation, and working with regulators and other stakeholders to revise operating regulations and tariffs. The final phase of work would be capital projects to install heaters and make other pipeline modifications. NPUC members have embarked on the first stage of building a partnership amongst oilsands producers to undertake these steps.

L. APPENDIX

The final engineering report from Worley is attached. The main report gives details on scope of analysis, methodology, and detailed results of simulations of pipeline operation. The attachments to the report summarize the fluid property data, the selection of heater system, and the capital cost of bitumen preheaters.