ERA Project ID:	F0160077
Title of project:	Area Fugitive Emission Measurements of Methane and Carbon Dioxide
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Executive Summary

The project was conducted at the Horizon oil sands facility, particularly mine pits and tailings ponds. The aim of the project, as proposed to ERA, was to demonstrate, validate, and compare various technologies including inverse dispersion modelling, fixed sensors including smart poles, open path systems, drones, and satellites.

explicitly, the goals of the project were to:

- Develop a robust, accurate reliable sensor with low background interference and power requirements capable of the continuous measurement of CO_2 and CH_4 for an extended period of time in all four seasons.
- Develop/ improve existing air models to more accurately represent conditions in the field under various meteorological conditions.
- Conduct measurements during the colder months, October to April, to determine if there are any changes in fugitive Greenhouse Gas Emissions.
- Develop a guidance document for government and industry to conduct area fugitive emissions measurements, listing the equipment specifications and placement of sensors to conduct Inverse Dispersion Modelling (IDM) of area fugitive emissions.

The project team included Alberta Environment and Parks (AEP), the University of Alberta (UofA), the University of Guelph (UofG), Southern Alberta Institute of Technology (SAIT), RWDI, Boreal Laser, Luxmux and Spectral Sensor Solutions (S3).

Measurement approaches by RWDI, UofA and S3 were implemented at the Canadian Natural Horizon oil sands facility (the Facility) and were used to estimate annual greenhouse gas (GHG) emissions from the Canadian Natural Horizon Pond (the pond) and Open pit surface mine areas. The UofG participated in measurement campaigns largely providing auxiliary meteorological measurements and modelling support. SAIT participated in the measurement campaigns performing drone-based concentration measurements and trailer-based concentration and meteorological measurements. Luxmux worked to develop their SmartPole system but were ultimately unable to fully deploy a working field version of the SmartPole system during the scheduled monitoring period.

1. Project Description

Canadian Natural Resources Limited (Canadian Natural) was the lead applicant in a proposal to Emissions Reduction Alberta (ERA) to field validate and commercialize solutions surrounding the quantification of fugitive methane (CH_4) and carbon dioxide (CO_2) emissions, both greenhouse gases (GHGs) from large industrial area sources which are characterized by complex terrain and heterogeneous air emissions zones. The impetus for the work was that the techniques currently used to measure and model air emissions from these sites as required by Alberta Environment and Parks (AEP) are limited in their ability to provide spatial and temporal coverage.

The project was conducted at the Horizon oil sands facility, particularly mine pits and tailings ponds. The aim of the project, as proposed to ERA, was to demonstrate, validate, and compare various technologies including inverse dispersion modelling, fixed sensors including smart poles, open path systems, drones, and satellites.

More specifically, the goals of the project were to:

- Develop a robust, accurate reliable sensor with low background interference and power requirements capable of the continuous measurement of CO_2 and CH_4 for an extended period of time in all four seasons.
- Develop/ improve existing air models to more accurately represent conditions in the field under various meteorological conditions.
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2. Project Outcomes and Learnings (including, as appropriate)

Oil sands mining facilities are regulated in Alberta under the Specified Gas Reporting Regulation (SGRR) (Government of Alberta, 2020a) and are additionally subject to the newly implemented Technology Innovation and Emissions Reduction Regulation (TIER). The SGRR requires facilities that emit 10,000 tonnes or more of specified gases to submit annual reports on their emissions. These emissions must be quantified in accordance with the guidance outlined in the Specified Gas Reporting Standard (Government of Alberta, 2020b). Under this regulation fugitive emission estimation from the large

industrial area sources such as the Horizon Pond and Mine surfaces are addressed by the AEP Quantification of Area Fugitive Emissions at Oil Sands Mines documentation (Government of Alberta, 2019). Currently, AEP only approves of the use of Flux Chambers (FC) for emission estimation at oil sands facilities (Government of Alberta, 2019). Alternative methodology may be implemented by seeking approval on a case-by-case basis. In light of the regulation, it is therefore paramount that any assessment of emission estimation methodology to be made relative to the FC technique.

FC is relatively simple to implement, repeatable, inexpensive, and accessible by non-experts. However, the method provides an emission measurement over a small footprint (US EPA FC chambers cover 0.13 m^2) requiring many measurements to fully characterize a large source, particularly when this source may not have spatially uniform emissions. To address this issue AEP outlines specific guidance on the number of sampling locations and emissions zones that are required for ponds and mine surfaces. The FC method as implemented according to AEP guidance is deployed to these zones to obtain 30 to 90-minute samples from the emitting surface. Collected data are then extrapolated, both spatially and temporally, to obtain annual area source emission rates.

Measurement approaches by RWDI, UofA and S3 were implemented at the Canadian Natural Horizon oil sands facility (the Facility) and were used to estimate annual greenhouse gas (GHG) emissions from the Canadian Natural Horizon Pond (the pond) and Open pit surface mine areas. The UofG participated in measurement campaigns largely providing auxiliary meteorological measurements and modelling support. SAIT participated in the measurement campaigns performing drone-based concentration measurements and trailer-based concentration and meteorological measurements. Luxmux worked to develop their SmartPole system but were ultimately unable to fully deploy a working field version of the SmartPole system during the scheduled monitoring period.

A total of 4 field campaign were completed starting in spring 2018 and the final campaign was completed in the fall of 2019. The field work was scheduled to cover winter, spring summer and fall time frames. Milestone reports were prepared by each of 5 project partners and final technical reports submitted in 2020. Spectral Sensor Solutions completed a monitoring campaign over the tailings pond in the summer of 2019.

A final synthesis report was prepared by AECOM which included an impartial assessment of the various data collection, analysis and modelling results. The complete report is included as Appendix I.

Although no clear winner emerged from the project, two clear techniques appeared to offer the most value. For simple terrain applications and over small areas the EC method provides the most value and utility. Commercially available, fully automated EC solutions are available capable of providing defensible emission estimates. The changing spatial extent of emitting sources however, coupled with the potential need for EC footprint modelling complicates EC implementation. An IDM based solution (i.e., WindTrax or similar modelling systems adequate for simple terrain) appears to be the most promising.

At the complex terrain at the mine, IDM solutions that employ valid modelling frameworks that can accommodate complex terrain (i.e., CALPUFF or SCICHEM) appear to be the most promising. Unlike EC though, IDM approaches are less mature, slowly undergoing iterative progress and refinement (as was the case for the models in this study) and have yet to be optimized nor automated. Where instrumentation costs are of concern, the placement of a limited number of point measurement

sources in upwind and downwind location appears to be the most cost-effective method of applying IDM.

3. Greenhouse Gas Benefits

The primary goal of the project was to develop new methods for collecting, analysing and reporting on fugitive emissions of methane and carbon dioxide from oils sands mining operations. The focus was on the mine pits and tailings pond rather than the bitumen processing and upgrading operations.

During the summer 2019 field campaign, we were able to identify elevated methane emissions related to basal dewatering operations in the east mine pit. Next steps proposed for mining operations is to capture and quantify accurate methane volumes. If volumes are significant, systems will be put in place to capture those emissions, which will reduce our overall methane volumes in the mining operations.

4. Economic and Environmental Impacts

The research and field trials completed under this ERA program have contributed to improving our scientific understanding of GHG emissions from diffuse sources and quantification methods. Accurate characterization of these sources will allow more focussed mitigation efforts and GHG reductions.

There are a number of new emerging technologies coming onto the market for fugitive emissions monitoring. These systems are competing against the flux chamber approach which is a well established method and relatively inexpensive. The new systems need to demonstrate that they are more accurate and efficient to compete with the flux chambers. In the Alberta oil sands, CNRL is so far the only operator using the inverse dispersion modelling as an alternative method. It has not been widely accepted by other operators or the regulator at this time.

The new monitoring systems under development by Luxmux did not have any successful field trials during the course of the project. Challenges related to the sensor design, power consumption and overall performance prevented them from demonstrating a commercially viable system. Accordingly, there was no need to complete the Technology Transfer and Commercialization Plan. All the other monitoring systems deployed for the project with our other project partners were using commercially available technologies.

5. Overall Conclusions

After completing the assessment of the alternative methods that were applied to conduct CO2 and CH4 emissions measurements at the Facility, AECOM concludes all approaches described were technically sound and an improvement over the currently widely used FC method for regulatory reporting. We further conclude each alternative method is superior to the FC method in generating a

more representative picture of the true emissions from the sources at the Facility (due to a larger measurement footprint and a larger number of data points collected), and each is more cost effective than FC when considering labour costs and the number of flux measurement generated per field campaign. The following subsections present our recommendations for conducting future regulatory emissions measurements at the Facility

6. Scientific Achievements

The research and field trials completed under this ERA program have contributed to improving our scientific understanding of GHG emissions from diffuse sources and quantification methods. Accurate characterization of these sources will allow more focussed mitigation efforts and GHG reductions.

7. Peer Reviewed Journal Articles

- Nambiar, M. K., & Aliabadi, A. A. (2020), `Diurnal and Seasonal Variation of Simulated Area-fugitive Methane Emission Flux from an Open-pit Mining Facility', Nature Scientific Reports.
- Ahmadi-Baloutaki, M., & Aliabadi, A. A. (2021), `A Very Large-Eddy Simulation Model Using a Reductionist Inlet Turbulence Generator and Wall Modelling for Thermally Stable Atmospheric Boundary Layers', Fluid Dynamics.
- Nambiar, M. K., Byerlay, R. A., Nazem, A., Nahian, M. R., Moradi, M. & Aliabadi, A. A. (2019), `A Tethered Air Blimp (TAB) for Observing the Microclimate over a Complex Terrain', Geoscientific Instrumentation, Methods and Data Systems, 9, 193-211.doi:10.5194/gi-9-193-2020
- Nahian, M. R., Nazem, A., Nambiar, M. K., Byerlay, R., Mahmud, S., Seguin, A. M. Robe, F. R., Ravenhill, J., & Aliabadi, A. A. (2020), `Complex Meteorology over a Complex Mining Facility: Assessment of Topography, Land Use, and Grid Spacing Modifications in WRF', Journal of Applied Meteorology and Climatology, 59(4), 769-789, doi:10.1175/JAMC-D-19-0213.1.
- Byerlay, R. A. E., Nambiar, M. K., Nazem, A., Nahian, M. R., Biglarbegian, M. & Aliabadi, A. A. (2020), `Measurement of Land Surface Temperature from Oblique Angle Airborne Thermal Camera Observations', International Journal of Remote Sensing, 41(8), 3119-3146, doi:10.1080/01431161.2019.1699672.
- Aliabadi, A. A., Veriotes_, N., & Pedro, G. (2018), `A Very Large-Eddy Simulation (VLES) Model for the Investigation of the Neutral Atmospheric Boundary Layer', Wind Engineering & Industrial Aerodynamics, 183, 152-171, doi: 10.1016/j.jweia.2018.10.014.

Conference Proceedings

- F.R. Robe, C. Reuten, A.M. Seguin, D. Chadder, N. Veriotes, T. Flesch, 2017: Quantification of Area Fugitive GHG Emission at Oil Sands Mines by a Novel Inverse Dispersion Modeling Approach, *Proceedings s COSIA Innovation Summit 2017*, Calgary, March 2017.
- F.R. Robe, C. Reuten, A.M. Seguin, D. Chadder, N. Veriotes, T. Flesch, 2017: Quantification of Area Fugitive GHG Emission at Oil Sands Mines by a Novel Inverse Dispersion Modeling Approach, *Proceedings s AWMA CPANS Annual Conference 2017*, Edmonton, May 2017.

- F.R. Robe, C. Reuten, A.M. Seguin, D. Chadder, N. Veriotes, T. Flesch, 2017: Quantification of Area Fugitive GHG Emission at Oil Sands Mines by a Novel Inverse Dispersion Modeling Approach, Paper # 263568, *Proceedings of the AWMA 110th Conference and Exhibition*, Pittsburgh, June 2017.
- A.M. Seguin, C. Reuten, F.R. Robe, D. Chadder, N. Veriotes, 2018: Is it worth measuring CO2 fugitive emissions at Tailings Pond and Mine Faces, , *Proceedings COSIA Innovation Summit 2018*, Calgary, May 2018
- C. Reuten, F.R. Robe, A. M. Seguin, D. Chadder: Quantification of Area Fugitive Greenhouse Gas Emissions at Oil Sands Mines: Bayesian Solution to Inverse Dispersion Modelling Challenges. *Proceedings 58th Annual PNWIS Conference*, Nanaimo, November 2018
- F.R. Robe, A.M. Seguin, C. Reuten, D. Chadder, M. Endsin, 2019: Quantification of GHG Emission from Tailings Pond and Mine Faces with Inverse Dispersion Modelling (IDM) Approach, Paper # 699991, *Proceedings of the AWMA 112th Conference and Exhibition*, Quebec City, June 2019.
- A.M. Seguin, C. Reuten, F.R. Robe, D. Chadder, M. Endsin, 2019: Quantification of GHG Emission from Tailings Pond and Mine Faces with IDM-CALPUFF, Proceedings of COSIA Innovation Summit 2019, Calgary, June 2019.

8. Next Steps

After completing the assessment of the alternative methods that were applied to conduct CO2 and CH4 emissions measurements at the Facility, AECOM concludes all approaches described were technically sound and an improvement over the currently widely used FC method for regulatory reporting. We further conclude each alternative method is superior to the FC method in generating a more representative picture of the true emissions from the sources at the Facility due to a larger measurement footprint and a larger number of data points collected. Each is more cost effective than FC when considering labor costs and the number of flux measurement generated per field campaign.

There were a number of challenges related to the measurement of CO2 in both the tailings pond and mine areas. The most significant challenge was determining reliable and consistent background contributions including emissions from large vehicles, shovels and plant related infrastructure. These issues were less significant at the pond but the influence of large areas of forest and wetlands west of the site confounded reliable measurements. These issues sometimes resulted in negative CO2 emission results. This was addressed by the S3 analysis by only using emission values calculated between 1 PM and 9 PM and averaging them to provide a "daytime" emissions value. The three average CO2 emission values provided a reasonable range of the true CO2 emissions from the pond.

We consider the most favorable approach for conducting emissions measurements from the mine areas and tailings pond is the IDM Method with the LGR Greenhouse Gas Analyzers. As discussed in the previous section, the instrumentation is robust and capable of collecting continuous data unattended. The only issue we had with the method related to the anomalously high results from the spring 2018 campaign. The other methods all showed promise but were more complicated in terms of deployment.

Recommendations going forward for adopting new methods for compliance monitoring will be based on discussions with our project partners, COSIA members and AEP. Cost considerations were not

considered in the third party review but will be a significant consideration for compliance monitoring in the coming years.

9. Communications plan

The ERA program sponsored by ERA was completed under the umbrella of the COSIA initiative. The project updates have been shared with CNRL's partners throughout the program and final reports, conclusions and recommendations will be shared likewise. CNRL has prepared and submitted recommendations to AEP on an annual basis since 2015 and that will continue.

Abstract and Keywords

The ERA funded project was a collaborative undertaking with CNRL coordinating efforts of the various project partners. Project proponents RWDI, UofA and UofG implemented their emission estimation methodologies at the Horizon Pond and Mines to estimate emission fluxes. RWDI measured emission fluxes using FCs as well as their AEP approved alternative CALPUFF Inverse Dispersion Modelling (IDM) based approach. The UofA employed Eddy Covariance (EC) and a WindTrax backward Lagrangian Stochastic (bLS) model to estimate emissions. S3 implemented their GreenLITE IDM approach along with their advanced REVEAL 2-D wind vector mapping instrumentation. The three IDM approaches differ in their choice of model as well as their measurement approach.

Key words: GHG monitoring, oilsands monitoring, emissions modelling, remote sensing, CO2 monitoring, methane measurement.

Appendix I

Area Fugitive Emission Measurements of Methane Carbon Dioxide

Synthesis and Assessment Report

Prepared by AECOM Canada Ltd.

EMISSIONS REDUCTION ALBERTA	Project Emissions Reductions	ID: F0160077
Recipient Organization	Canadian Natural Resources Limited	
Title	Area fugitive emission measurements of methane & carbon dioxide	

GHG Emission Reductions (ERs): 2011–2050	
2011	0
2012	0
2013	0
2014	0
2015	0
2016	0
2017	0
2018	0
2019	0
2020	0
2021	0
2022	0
2023	0
2024	0
2025	0
2026	0
2027	0
2028	0
2029	0
2030	0
2031	0
2032	0
2033	0
2034	0
2035	0
2036	0
2037	0
2038	0
2039	0
2040	0
2041	0
2042	0
2043	0
2044	0
2045	0
2046	0
2047	0
2048	0
2049	0
2050	0

Please Refer to ERA's Website For the Quantification Methodologies
https://www.eralberta.ca/calculating-ghg-emissions-reduction/