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# Source apportionment of ambient fine and coarse particulate matter at the Fort McKay community site, in the Athabasca Oil Sands Region, Alberta, Canada

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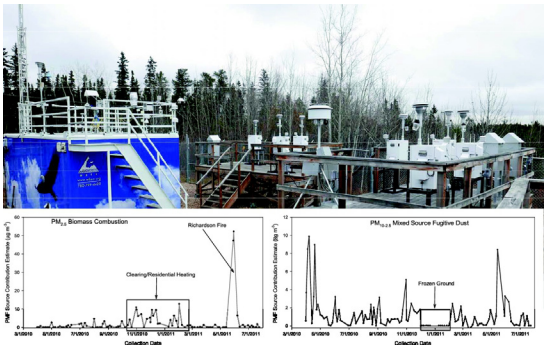
## HIGHLIGHTS

- Fine and coarse particulate matter was quantified in Fort McKay, Alberta.
- Receptor modeling elucidated and quantified significant contributing sources.
- 58% of $PM_{2.5}$ and 83% of $PM_{10-2.5}$ was attributable to oil sands production operations.
- 25% of the observed $PM_{2.5}$ was attributed to biomass combustion.

## GRAPHICAL ABSTRACT

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## ABSTRACT

An ambient air particulate matter sampling study was conducted at the Wood Buffalo Environmental Association (WBEA) AMS-1 Fort McKay monitoring station in the Athabasca Oil Sand Region (AOSR) in Alberta, Canada from February 2010 to July 2011. Daily 24 h integrated fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$) particulate matter was collected using a sequential dichotomous sampler. Over the duration of the study, 392 valid daily dichotomous $PM_{2.5}$ and $PM_{10-2.5}$ sample pairs were collected with concentrations of $6.8 \pm 12.9\ \mu g\ m^{-3}$ (mean ± standard deviation) and $6.9 \pm 5.9\ \mu g\ m^{-3}$, respectively. A subset of 100 filter pairs was selected for element analysis by energy dispersive X-ray fluorescence and dynamic reaction cell inductively coupled plasma mass spectrometry. Application of the U.S. EPA positive matrix factorization (PMF) receptor model to the study data matrix resolved five $PM_{2.5}$ sources explaining 96% of the mass including oil sands upgrading (32%), fugitive dust (26%), biomass combustion (25%), long-range Asian transport lead source (9%), and winter road salt (4%). An analysis of historical $PM_{2.5}$ data at this site shows that the impact of smoke from wildland fires was particularly high during the summer of 2011. PMF resolved six $PM_{10-2.5}$ sources explaining 99% of the mass including fugitive haul road dust (40%), fugitive oil sand (27%), a mixed source fugitive dust (16%), biomass combustion (12%), mobile source (3%), and a local

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copper factor (1%). Results support the conclusion of a previous epiphytic lichen biomonitor study that near-field atmospheric deposition in the AOSR is dominated by coarse fraction fugitive dust from bitumen mining and upgrading operations, and suggest that fugitive dust abatement strategies targeting the three major sources of $PM_{10-2.5}$ (e.g., oil sand mining, haul roads, bulk material stockpiles) would significantly reduce near-field atmospheric deposition gradients in the AOSR and reduce ambient PM concentrations in the Fort McKay community.


## 1. Introduction

The Athabasca Oil Sands Region (AOSR) in northern Alberta, Canada contains economically recoverable petroleum reserves estimated to be approximately 170 billion barrels (Attanasi and Meyer, 2010; Alberta Energy, 2017). These proven petroleum reserves rank the AOSR third in the world behind Saudi Arabia and Venezuela. Oil production in the AOSR has been steadily increasing over the last decade from 0.6 million barrels per day in 2000, to 2.3 million barrels per day in 2014 (Alberta Energy, 2017). Synthetic crude oil production from bitumen in the AOSR is accomplished using a combination of surface mining and drilling (in situ) production. Of the proven reserves, it is estimated that 20% of the bitumen will ultimately be recovered through surface mining and 80% from in-situ production techniques (Government of Alberta, 2008). The type and magnitude of inorganic air pollutants emitted from these two extraction techniques are unique compared to other air emission sources. Quantifying their relative contribution to observed ambient particulate matter (PM) concentrations and atmospheric deposition are critical to emission mitigation and local environmental impact management. A lichen biomonitoring study identified the fugitive emission of coarse mode PM ($PM_{10-2.5}$) from oil sand production activities as the primary driver of the observed atmospheric deposition and spatial patterns in the AOSR (Landis et al., 2012).

Surface mining in the AOSR results in large-scale land disturbance similar to coal, copper, gold, and other traditional mining operations. Currently, the soil and glacial till overlaying the oil sand deposits (over burden) is removed and the exposed oil sands are excavated and transported for processing using large scale shovel and truck hauling operations. Atmospheric pollution from shovel and truck fleet operations mainly consists of fugitive PM emissions (wind-blown dust) and diesel engine combustion exhaust (Landis et al., 2012; Wang et al., 2015; Wang et al., 2016). Bitumen is separated from the sand and clay matrix components of the oil sands using a warm water frothing technique (Masliyah et al., 2004; Osacky et al., 2013), and in four of the current commercial operations is upgraded to sweet light synthetic crude on site. Upgrading by-products, such as elemental sulfur and petroleum coke, are in many cases consolidated in large on-site storage piles (Zhang et al., 2016). The water, sand, and clay waste streams are pumped to large tailings ponds where much of the water is recycled; the sand and clay are consolidated and used for mine reclamation activities. Limestone in the AOSR is quarried, crushed, and used for development of haul roads and other construction activities. Overburden stored for future mine reclamation, haul roads, petroleum coke storage piles, tailings ponds, and limestone quarrying and crushing operations are all potential sources of fugitive wind-blown dust (Landis et al., 2012; Zhang et al., 2016).

This paper presents results from a study designed to quantify the ambient $PM_{2.5}$ (fine) and $PM_{10-2.5}$ (coarse) concentrations, and identify the contributions from emission sources to Fort McKay, a centrally located First Nation and Metis community, in the AOSR previously identified as being impacted by emissions from nearby oil sand bitumen production operations (Landis et al., 2012). $PM_{2.5}$ concentration trends measured at the site from 1999 to 2015 are presented to place the current measurements into historic context, and a seasonal analysis of source apportionment results highlights the importance of temporal monitoring representativeness.

## 2. Methods

### 2.1. Sampling site

The Wood Buffalo Environmental Association (WBEA) AMS-1 Bertha Ganter-Fort McKay ambient air monitoring station (57°11′21.70″ N; −111°38′26.06″ W) is located in the Fort McKay First Nation and Metis community. This monitoring site was originally established in 1983 as an Alberta Environment Station, and was subsequently incorporated into the WBEA network, moved to its current location, and upgraded in 1997. AMS-1 currently provides real-time ambient air quality information including the Air Quality Health Index (AQHI) to the community. The AMS-1 site is located in an area that is in close proximity to ongoing oil sand production operations such as mining, separating, and upgrading of bitumen (Fig. 1). Routine WBEA ambient monitoring data including continuous (i) $PM_{2.5}$ mass measured using ThermoScientific (Franklin, MA) Model 1400B Tapered Element Oscillating Microbalance (TEOM) from 1998 to June 2011 and a ThermoScientific Model 5030 Synchronized Hybrid Ambient Real-time Particulate Monitor (SHARP) from June 2011 to present, (ii) total oxides of nitrogen ($NO_x$) measured using a ThermoScientific Model 42i chemiluminescence analyzer, (iii) sulfur dioxide ($SO_2$) measured using a ThermoScientific Model 43i pulsed fluorescence analyzer, and (iv) ammonia ($NH_3$) measured using a ThermoScientific Model 17i chemiluminescence analyzer (WBEA, 2011) were incorporated into this study.

### 2.2. Collection and weighing of filter-based ambient particulate matter samples

Twenty-four hour ambient PM samples for mass, sulfur, and element determination were collected on a daily basis onto Teflon filters using a ThermoScientific Model 2025D Sequential Dichotomous air sampler (a U.S. EPA designated Federal Equivalent Method for $PM_{2.5}$) from February 22, 2010 through July 27, 2011. The dichotomous sampler utilized a $PM_{10}$ impactor inlet operating at 16.7 LPM to make the initial particle size cutoff at 10 μm mass median aerodynamic diameter (MMAD). The virtual impactor or "dichotomous splitter," followed the $PM_{10}$ impactor inlet and dynamically segregated the particles into fine (≤2.5 μm) and coarse (10–2.5 μm) size fractions that were collected onto two separate filters (Loo and Cork, 1988). The virtual impactor accelerated incoming $PM_{10}$ aerosols using a jet to impart sufficient momentum that they resisted the lateral sheer of the major flow and traversed into the receiving jet and were captured onto the coarse filter. Calibrated mass flow controllers maintained the fine particle filter flow at 15.0 LPM and the coarse particle filter flow at 1.67 LPM to ensure the correct MMAD size cut.

The virtual impactor resulted in the collection of all coarse mode particles from the total flow (16.7 L $min^{-1}$) plus the fine mode particles in the minor flow (1.67 L $min^{-1}$) on the coarse filter. As a result, the fine mode and corrected coarse mode concentrations (mass, sulfur, and elements) are adjusted for this artifact using Eqs. (1) and (2), respectively.

$$C_{Fine} = \left(\frac{M_{Fine}}{V_{Fine}}\right) \quad (1)$$