



Air quality in the Industrial Heartland of Alberta, Canada and potential impacts on human health



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HIGHLIGHTS

- Alberta's Industrial Heartland is Canada's largest hydrocarbon processing center.
- We characterize 77 volatile organic compounds (VOCs) emitted in this region.
- Dozens of VOCs, including carcinogens, were enhanced in the industrial plumes.
- Sources include propene fractionation, diluent separation and bitumen processing.
- Male hematopoietic cancer rates are higher in this region than elsewhere in Alberta.

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ABSTRACT

The “Industrial Heartland” of Alberta is Canada's largest hydrocarbon processing center, with more than 40 major chemical, petrochemical, and oil and gas facilities. Emissions from these industries affect local air quality and human health. This paper characterizes ambient levels of 77 volatile organic compounds (VOCs) in the region using high-precision measurements collected in summer 2010. Remarkably strong enhancements of 43 VOCs were detected, and concentrations in the industrial plumes were often similar to or even higher than levels measured in some of the world's largest cities and industrial regions. For example maximum levels of propene and *i*-pentane exceeded 100 ppbv, and 1,3-butadiene, a known carcinogen, reached 27 ppbv. Major VOC sources included propene fractionation, diluent separation and bitumen processing. Emissions of the measured VOCs increased the hydroxyl radical reactivity (k_{OH}), a measure of the potential to form downwind ozone, from 3.4 s^{-1} in background air to 62 s^{-1} in the most concentrated plumes. The plume value was comparable to polluted megacity values, and acetaldehyde, propene and 1,3-butadiene contributed over half of the plume k_{OH} . Based on a 13-year record (1994–2006) at the county level, the incidence of male hematopoietic cancers (leukemia and non-Hodgkin lymphoma) was higher in communities closest to the Industrial Heartland compared to neighboring counties. While a causal association between these cancers and exposure to industrial emissions cannot be confirmed, this pattern and the elevated VOC levels warrant actions to reduce emissions of known carcinogens, including benzene and 1,3-butadiene.

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1. Introduction

Volatile organic compounds (VOCs) are emitted from natural biogenic sources such as vegetation and biomass burning, and from anthropogenic sources such as the production, distribution and consumption of fossil fuels, including vehicular emissions (Guenther et al., 2000; Buzcu and Fraser, 2006). VOCs play key roles

in the radiative forcing and chemistry and of the atmosphere, for example producing tropospheric ozone (O_3) and secondary organic aerosol (SOA) (Sillman, 1999; Robinson et al., 2007). VOCs also control concentrations of the hydroxyl radical (OH) (Guenther et al., 1995), the principal oxidizing agent in the troposphere. Several halogenated VOCs are potent greenhouse gases and cause stratospheric ozone depletion, and are regulated under the Montreal Protocol and its Amendments (MPA) (UNEP, 2012).

In addition to their influence on air quality and climate, VOCs are of concern because of their potential health effects. As examples, benzene and 1,3-butadiene are known carcinogens (IARC, 2010).

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Biological evidence supports the causal linkage between certain pollutants and certain cancers, for example, between leukemia incidence/mortality and exposure to benzene (Snyder, 2002; Forrest et al., 2005) and 1,3-butadiene (Cheng et al., 2007; Kirman et al., 2010). Increased rates of leukemia, melanoma and genotoxic risk have been shown in petroleum workers and populations living downwind of petrochemical facilities such as oil refineries (Wong and Raabe, 2000; Whitworth et al., 2008; Barregard et al., 2009; Basso et al., 2011), although elevated rates and cancer mortality are not consistently observed (Tsai et al., 2004; Axelsson et al., 2010).

Established in the 1950s, the Industrial Heartland of Alberta is currently a large (582 km²) industrial area with more than 40 companies, including chemical, petrochemical, and oil and gas facilities (<http://www.industrialheartland.com>). It is situated about 30 km northeast of Edmonton (53°32'N, 113°30'W; population 812,000) and a few km northeast of Fort Saskatchewan (53°43'N, 113°13'W; population 19,000) in an otherwise rural farming area of Alberta (Fig. 1 and Fig. S1). The Industrial Heartland is the largest hydrocarbon processing region in Canada, and major land holdings include Shell Canada, Dow Chemical Canada, and Provident Energy & Williams Energy Canada (now Pembina Pipeline & Williams Energy Canada) (<http://www.industrialheartland.com>). Their products include ethane, propane, propene, butane, styrene, hexane, benzene, heavy aromatics, synthetic crude oil and condensate (AIHA, 2012). For example, Shell Scotford is the largest land holding in the Heartland and includes a chemical plant, a refinery, and an upgrader that separates diluent and processes bitumen from oil sands mined approximately 450 km to the north, with a current processing capacity of 255,000 barrels/day (AIHA, 2012).

Industrial emissions in the Heartland affect the local air quality, for example causing intermittent odor episodes in the nearby community of Fort Saskatchewan. However, there have been very few independent, peer-reviewed analyses of air quality in the region. Thirty VOCs were measured in the Heartland from 2004 to

2006, and elevated VOC levels were attributed primarily to industry followed by vehicles (Mintz and McWhinney, 2008). Air quality is monitored locally by the Fort Air Partnership (FAP), a multi-stakeholder group with members from industry, government and the public (<http://www.fortair.org>). Though the FAP data have not been published in the peer-reviewed literature, they show several exceedances of Alberta Ambient Air Quality Objectives (AAAQO) in 2010 for PM_{2.5}, SO₂, NH₃ and NO₂ (FAP, 2010). There were no reported O₃ exceedances in 2010 both for AAAQO standards (82 ppb in 1 h) and for Canada-Wide Standards (65 ppb in 8 h). The annual O₃ average for 2010 was 22 ppb, and a maximum 1-h O₃ value of 72 ppb was recorded in June (FAP, 2010).

Here we present concentrations of VOCs and carbon monoxide (CO) measured in the Industrial Heartland in August 2010, and we discuss potential impacts of industrial VOC emissions on air quality and on human health in the local population.

2. Methods

2.1. Ground-based air sampling

Previously our group identified VOC emission hot-spots within a 12 × 12 km region of the Industrial Heartland, during a grid study on April 10, 2008 (*n* = 58) as part of an Environmental Impact Assessment in the Heartland (unpublished data). For example, maximum levels of benzene, ethylbenzene and styrene downwind of the Shell Scotford complex were 1.6, 2.0 and 4.0 parts per billion by volume (ppbv, 10⁻⁹), respectively, or 19, 435 and 6070 times higher than local background concentrations measured on the same day. During the 2010 study the sampling strategy focused on these emission hotspots. Speciated VOC measurements were obtained by collecting whole air samples (WAS) into evacuated 2 L stainless steel canisters, followed by analysis at our University of California, Irvine (UC Irvine) laboratory using multi-column gas chromatography (see Supplementary material). Individual air

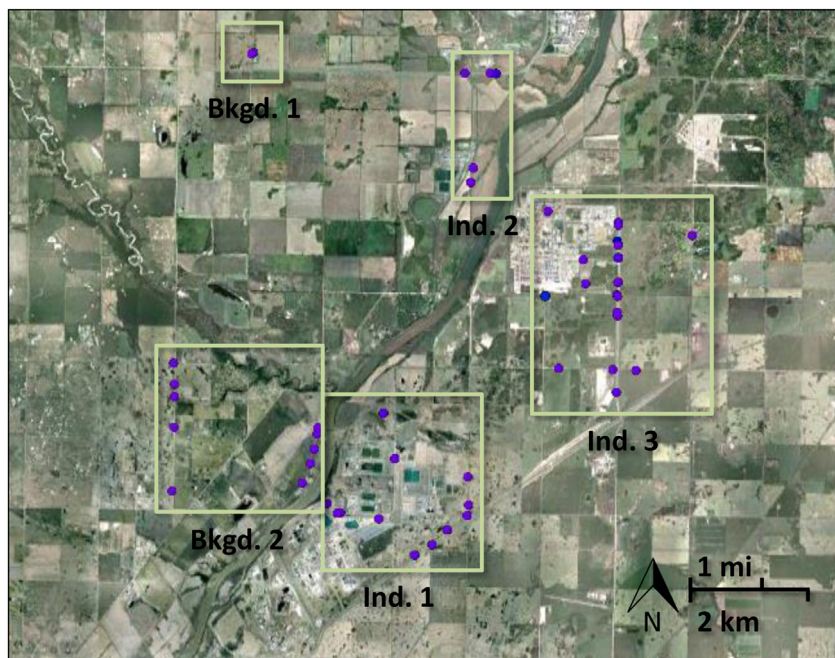


Fig. 1. Air sampling locations in the Industrial Heartland of Alberta (August 12–13, 2010; purple circles). 'Bkgd.1': farm background (*n* = 8); 'Bkgd.2': rural background closer to the industrial activity (*n* = 9); 'Ind.1': Fort Saskatchewan county (downwind of BP Canada, Dow Chemical or Keyera Energy; *n* = 21); 'Ind.2': Sturgeon county (downwind of Access Pipeline, Evonik Degussa or Provident/Williams; *n* = 9); 'Ind.3': Strathcona County (downwind of Shell Canada; *n* = 33). Fort Saskatchewan lies to the southwest of 'Ind.1'. Edmonton is another 30 km southwest (Fig. S1). Industrial land holdings in the Heartland are shown at <http://www.strathcona.ca/files/New-Files/AT-EDT-MA-HEARTLAND2010-1.pdf>. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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