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Measurement of diesel combustion-related air pollution downwind of an experimental unconventional natural gas operations site

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GRAPHICAL ABSTRACT

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ABSTRACT

Background & aim: Unconventional natural gas (UNG) extraction activities have considerable potential to affect air quality. However, there are few published quantitative observations of the magnitude of such impacts. To provide context, we compared measured exposures to diesel engine exhaust close to industrial fracking equipment at an UNG training simulation site in Łowicz, Poland to pedestrian exposures to traffic-related air pollution in the city centre of Glasgow, UK.
Methods: We made mobile and static measurements at varying distances from sources in both of the above locations with a portable aethalometer (Aethlabs AE51) for black carbon (BC) and portable monitors (Aeroqual Series-500) for nitrogen dioxide (NO_2) and ozone (O_3). Duplicate BC measurements were compared with NO_2 observations, after correction of the NO_2 sensor response for O_3 interference effects.
Results: Duplicate BC instruments provided similar real-time measurements (r = 0.92), which in turn were relatively highly correlated with NO_2 observations at 5-min temporal resolution at the UNG experimental site (r = 0.75) and on the walking route in Glasgow city centre (r = 0.64) suggesting common diesel sources for NO_2 and BC in both locations. Average BC and NO_2 concentrations measured approximately 10 m downwind of diesel fracking pumps were 11 and 113 μg/m^3 respectively. These concentrations were approximately 37 times and 4 times higher than upwind background BC and NO_2 concentrations at the site; and approximately 3 times higher than average BC and NO_2 concentrations measured in traffic influenced areas in Glasgow.
Conclusions: Marked elevations of BC and NO_2 concentrations were observed in downwind proximity to industrial fracking equipment and traffic sources. This suggests that exposure to diesel engine exhaust emissions from fracking equipment may present a significant risk to people working on UNG sites over extended time

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periods. The short time resolution of the portable instruments used enabled identification of likely sources of occupational and environmental exposure to combustion-related air pollutants.

1. Introduction

Unconventional natural gas (UNG), e.g. tight gas and shale gas, has been defined as gas trapped within relatively impermeable rock formations (Wang et al., 2014). Extraction of UNG as a substitute for conventional hydrocarbon sources has transformed natural gas production worldwide, especially in the USA. However, the development of UNG in countries outside the USA, including the UK, has been constrained as a result of concerns over possible impacts on human health and ecosystems. Current evidence regarding possible public health risks associated with UNG development is limited in detail and quality, resulting in intense debate around potential public health issues (Adgate et al., 2014; Hays et al., 2015; Kovats et al.; Werner et al., 2015). Controversy of this nature is often a direct consequence of uncertainties in scientific assessment (NPL, 2015), which in turn hampers policy decisions, and can result in high levels of anxiety within local communities (Larock and Baxter, 2013); and may produce adverse health effects not directly related to the extent of exposure to environmental pollution (Chapman et al., 2013). For example, in Scotland limitations in scientific evidence about possible health effects culminated in a moratorium on shale gas and coal bed methane extraction to allow a health impact assessment to be completed (Scottish-Government, 2015). In 2017 the Scottish Government announced an indefinite continuation of this moratorium with particular concerns being noted about the insufficiency of epidemiological evidence on the health risks associated with UNG industrial activities (Scottish-Government, 2017; SEPA, 2017b).

Air quality is one of several health concerns related to UNG developments (Field et al., 2014). There are analogies between the challenges of assessing potential public health risks from air pollution from UNG development and existing areas of environmental health research including traffic-related (HEI, 2010) and waste management related environmental pollution (Mohan et al., 2009; UK-Committee-on-Toxicity, 2010; Vrijheid, 2009). UNG operations, including well construction/operation and transportation of gas/other materials from the site, release a range of air pollutants (including nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), carbon monoxide (CO), sulphur dioxide (SO_2) and benzo(a)pyrene (BaP) (Field et al., 2014)). These pollutants have guideline values specified by the World Health Organization (WHO) and Health, Safety and Executive (HSE) for ambient (Krzyzanowski and Cohen, 2008) and occupational (HSE, 2013; SCOEL, 2014) exposure respectively (Table 1). Another pollutant of concern associated with diesel combustion is black carbon (BC), which is mostly found within fine particle fractions (Viidanoja et al., 2002). Currently, there are no legislative air quality standards for BC (EEA, 2013) despite its increasingly clear association with negative health outcomes (Englert, 2004; Heal and Quincey, 2012; WHO, 2012) and its recognition as a 'marker' of local combustion emissions. Exposure to diesel exhaust particles is often characterised by exposure to elemental carbon, and in some cases black carbon has been used as a proxy exposure metric in environmental (Grahame et al., 2014; Janssen et al., 2011) and occupational (Forder, 2014) situations.

A small number of studies highlight risks of adverse health effects in communities exposed to atmospheric emissions from nearby UNG facilities (Elliott et al., 2017; Elsner and Hoelzer, 2016; Islam et al., 2016; Paulik et al., 2016). For example, McKenzie et al. (2012) collected air samples of volatile organic compounds (VOCs) and conducted health risk assessments in two groups living near UNG developments in Colorado; and observed that residents living within 0.8 km of UNG sites had a higher risk of developing cancer and non-cancer diseases. McKenzie et al. (2014) observed that maternal residence within 16 km from a gas well was associated with a raised prevalence of congenital heart defects and neural tube defects in offspring. McKenzie et al. (2016); Rabinowitz et al. (2015); Rasmussen et al. (2016) observed that frequent respiratory symptoms were experienced by people living less than 1 km close to the natural gas wells. However, in common with other areas of environmental health, in these studies of UNG sites there are crucial limitations in characterisation of exposure to potential hazards (Lioy, 2015), which prevent reliable confirmation or refutation of causal linkage between potential environmental influences on human health through misclassification bias (Armstrong, 1998).

In addition to uncertainties about environmental exposures affecting local communities, there is relatively limited published information on assessment of occupational exposures of people working in UNG operations. The most common sources of occupational exposure are likely to include: (1) direct and fugitive emissions of hydrocarbons from the well and associated infrastructure; (2) deliberate venting and flaring of gas and related petroleum products; (3) diesel exhaust emissions from hydraulic fracturing equipment, trucks and generators (Adgate et al., 2014; Bogacki and Macuda, 2014).

The implementation of adequate air pollution monitoring is vital for effective management of risks to human health from UNG operations. This includes the collection of information on spatial and temporal patterns of air pollution from measurements and/or modelling to estimate human exposure at specific locations (Adgate et al., 2014; McKenzie et al., 2014; Werner et al., 2015). For example, Zielinska et al. (2014) observed variations in benzene, NO_2 and VOCs concentrations from preliminary surveys and continuous measurements at several distances from the operation of UNG and within residential areas.

Knowledge about the potential health implications of air pollution from UNG operations can be substantially improved through the deployment autonomy of portable measurement systems. In this pilot study, we deployed miniature low power [hence portable and readily deployable (Lewis and Edwards, 2016; Snyder et al., 2013)] sensor-based systems to measure exposures upwind, within and downwind of operation of hydraulic fracturing equipment. Our study investigated short-term simultaneous exposure to BC, NO_2 and O_3 in different locations at a simulated UNG site in Poland. To the best of our knowledge few if any simultaneous measurements of these pollutants close to UNG sites have been published in primary scientific literature providing a challenge for comparison of our measurements with existing knowledge. Therefore we also made measurements of BC, NO_2 and O_3 within road-traffic influenced locations in Glasgow city-centre to provide context to the concentrations we measured at the UNG site. The results of our study have implications for best practice in protecting workers in close proximity to hydraulic fracturing equipment; and illustrate and

Table 1
Guidelines for environmental (Krzyzanowski and Cohen, 2008) and occupational exposure (HSE, 2013; SCOEL, 2014) to air pollutants measured in this study.

Air pollutant:	Guideline values (Environmental exposure)		Guideline values (Occupational exposure)	
	Averaging time:	Limit value:	Averaging time:	Limit value:
NO_2	1 h	200 μg/m^3	8 h	0.955 mg/m^3
	1 year	40 μg/m^3	15 min	1.91 mg/m^3
O_3	1 h	120 μg/m^3	15 min	0.4 mg/m^3