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Atmospheric impacts of black carbon emission reductions through the strategic use of biodiesel in California

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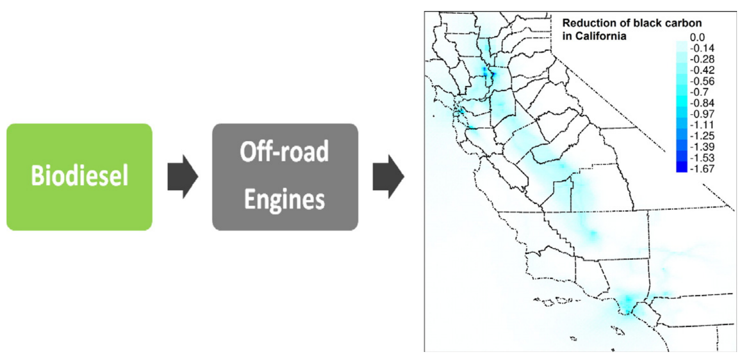
HIGHLIGHTS

- We measure BC emission reductions due to adoption of biodiesel fuel.
- We predict changes in PM due to adoption of biodiesel fuel in California.
- PM2.5 BC decreases 2× due to biodiesel use in off-road engines in California.
- Coating thickness increases on residual BC which enhances their absorption efficiency.
- Absorption of solar energy is not reduced due to the adoption of biodiesel.

GRAPHICAL ABSTRACT



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ABSTRACT

The use of biodiesel as a replacement for petroleum-based diesel fuel has gained interest as a strategy for greenhouse gas emission reductions, energy security, and economic advantage. Biodiesel adoption may also reduce particulate elemental carbon (EC) emissions from conventional diesel engines that are not equipped with after-treatment devices. This study examines the impact of biodiesel blends on EC emissions from a commercial off-road diesel engine and simulates the potential public health benefits and climate benefits.

EC emissions from the commercial off-road engine decreased by 76% when ultra-low sulfur commercial diesel (ULSD) fuel was replaced by biodiesel. Model calculations predict that reduced EC emissions translate directly into reduced EC concentrations in the atmosphere, but the concentration of secondary particulate matter was not directly affected by this fuel change. Redistribution of secondary particulate matter components to particles emitted from other sources did change the size distribution and therefore deposition rates of those components. Modification of meteorological variables such as water content and temperature influenced secondary particulate matter formation.

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Simulations with a source-oriented WRF/Chem model (SOWC) for a severe air pollution episode in California that adopted 75% biodiesel blended with ULSD in all non-road diesel engines reduced surface EC concentrations by up to 50% but changed nitrate and total PM2.5 mass concentrations by less than ±5%. These changes in concentrations will have public health benefits but did not significantly affect radiative forcing at the top of the atmosphere. The removal of EC due to the adoption of biodiesel produced larger coatings of secondary particulate matter on other atmospheric particles containing residual EC leading to enhanced absorption associated with those particles. The net effect was a minor change in atmospheric optical properties despite a large change in atmospheric EC concentrations. These results emphasize the importance of considering EC mixing state in climate research.

1. Introduction

Light-absorbing aerosols, mainly black carbon (BC) or elemental carbon (EC), have a significant influence on global climate, despite the fact that they have a short residence time in the atmosphere (Andreae and Gelencser, 2006). EC can be considered as the most efficient absorbing aerosol species for visible light, showing a positive radiative forcing effect similar to greenhouse gases such as CO_2 and methane (Bond et al., 2004; Samset et al., 2013, 2014; Wang et al., 2014). Considering the immediate warming impact of light absorbing aerosols, it has been suggested that controlling their emissions could slow down the rate of global warming (Anenberg et al., 2012; Ban-Weiss et al., 2012; Bond, 2007; Bond et al., 2013; Hansen et al., 2000). The main global sources of EC emissions include open biomass burning; residential burning of coal, wood, dung and agricultural residues; and fossil fuel combustion from vehicles and industrial activities (Bond et al., 2004; Jacobson, 2012; Wang et al., 2011). At the global level, mobile sources account for ~25% of EC emissions, from which ~70% correspond to diesel fuel combustion (Bond et al., 2004).

Regulations forcing the use of modern diesel emissions control technologies for on-road diesel vehicles are currently in place in the US and Europe, but controls applied to non-road diesel engines are typically less stringent [US EPA diesel emission regulations are categorized by light-duty, on-road heavy duty, and non-road heavy duty applications] (Johnson, 2006). As one example, Diesel Particle Filters (DPFs) greatly reduce EC emissions from on-road engines but are not expected to achieve high market penetration for the in-use fleet of off-road engines in the US or other regions of the world in the near future. As the contribution from on-road diesel engines shrinks, emissions from non-road heavy duty diesel engines will account for a larger fraction of the EC in the atmosphere. Fig. 1 illustrates that non-road diesel engines contributed approximately 34% of the total EC emissions in the US in 1996 (EIA, 2010) (Bond et al., 2004). The contribution in California was 58%. Strategies that reduce EC emissions from non-road diesel engines therefore have potential benefits for both local air quality and climate change.

Adoption of biodiesel presents one possible method to reduce emissions from non-road diesel engines without expensive retrofits. Biodiesel has been shown to decrease emissions of coarse particulate matter,

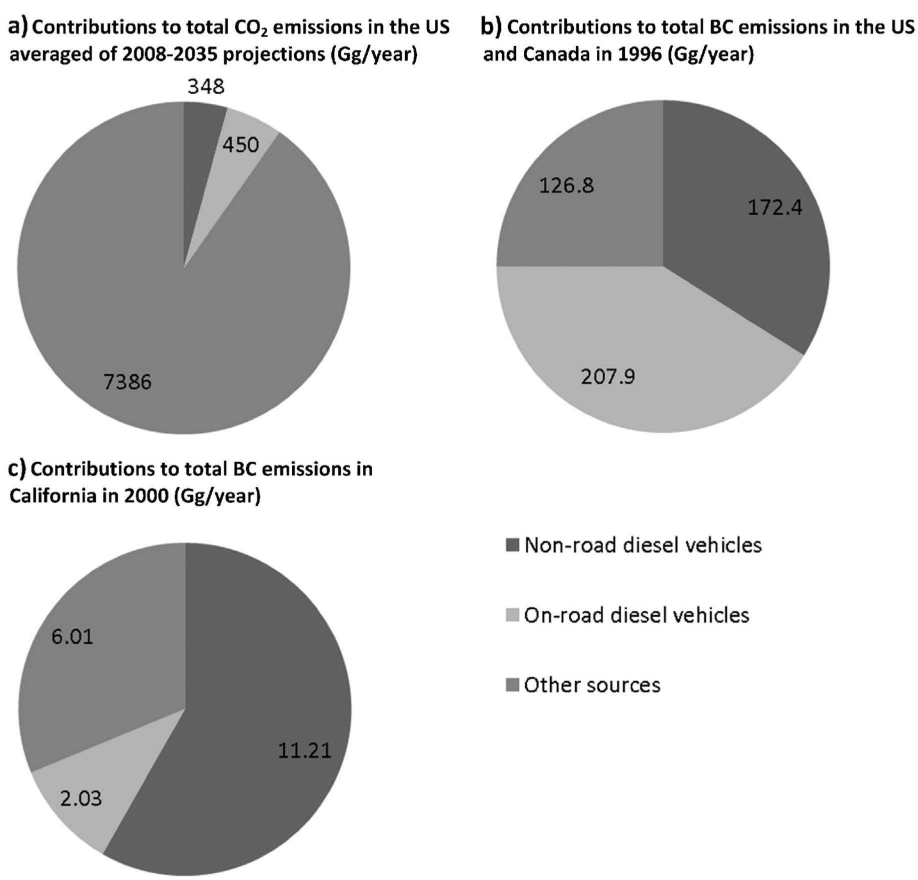

Fig. 1. Contributions of exhaust emissions of non-road diesel vehicles to a) total CO_2 emissions in the US, to b) total EC emissions in the US and Canada, and to c) total EC emissions in California. Contributions to total CO_2 emissions in the US were calculated from projected values to year 2035 (EIA, 2010). Contributions to total EC emissions in the US and Canada were obtained from a 1996 global EC emissions inventory (Bond et al., 2004). Contributions to total EC emissions in California were from California Air Resource Board (CARB).