



# Emissions of toxic pollutants from co-combustion of demolition and construction wood and household waste fuel blends

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## HIGHLIGHTS

- Food waste content between 1 and 4 wt% has no influence on PAH, PCBz and PCPh formation.
- Replacing MSW with RDF increases POPs emission.
- The use of DC increases the formation of toxic PCDDs, PCDFs and PCBs.
- Pre-treatment of DC is suggested as a way to reduce POPs emission.

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## ABSTRACT

Four different types of fuel blends containing demolition and construction wood and household waste were combusted in a small-scale experimental set-up to study the effect of fuel composition on the emissions of polychlorinated dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs), biphenyls (PCBs), chlorobenzenes (PCBzs), chlorophenols (PCPhs) and polycyclic aromatic hydrocarbons (PAHs). Two woody materials, commercial stemwood (ST) and demolition and construction wood (DC) were selected because of the differences in their persistent organic pollutants (POPs), ash and metals content. For household waste, we used a municipal solid waste (MSW) and a refuse-derived fuel (RDF) from MSW with 5–20 wt% and up to 5 wt% food waste content respectively. No clear effect on the formation of pollutants was observed with different food waste content in the fuel blends tested. Combustion of ST-based fuels was very inefficient which led to high PAH emissions ( $32 \pm 3.8$  mg/kg<sub>fuel</sub>). The use of DC clearly increased the total PCDD and PCDF emissions ( $71 \pm 26$  µg/kg<sub>fuel</sub>) and had a clear effect on the formation of toxic congeners ( $210 \pm 87$  ng WHO<sub>2005</sub>-TEQ/kg<sub>fuel</sub>). The high PCDD and PCDF emissions from DC-based fuels can be attributed to the presence of material contaminants such as small pieces of metals or plastics as well as timber treated with chromated copper arsenate preservatives and pentachlorophenol in the DC source.

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## 1. Introduction

Fuels that contain only high-quality biomass, such as stemwood, are generally considered to have low environmental impact but can be very expensive. Moreover, high-quality wood conversion into bio-based chemicals and advanced materials, such as fibre or

nanomaterial is considered by the forestry and bioenergy sector to be a better use of biomass than energy production. The use of waste materials, such as municipal solid waste (MSW) or waste wood, in a fuel blend has two main advantages: recovery of the energy contained in the materials; whilst being a method of waste disposal for those waste types that cannot be reused or recycled (European Commission, 2008). This is the reason why waste materials are becoming attractive resources for use in fuel production. However, modelling studies have suggested that the use of these materials may reduce the combustion efficiency (Moran et al., 2009) and lead to an increase in toxic air pollutants. Most of these pollutants are

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products of incomplete combustion: polychlorinated dibenzo-*p*-dioxins (PCDDs), dibenzofurans (PCDFs), biphenyls (PCBs), chlorobenzenes (PCBzs), chlorophenols (PCPhs) and polycyclic aromatic hydrocarbons (PAHs). The main concern with PCDDs, PCDFs (McKay, 2002; EPA, 2003), PCBs (EPA, 2003) and PAHs (Howsam et al., 1998) is their toxicity related to carcinogenic effects, and persistence in the environment. PCBzs and PCPhs are precursors of dioxin formation and PCBzs and PAHs are considered to be PCDD and PCDF indicators (Zhou et al., 2015). Here, it is crucial to be clear that even when the waste fuel composition is an important factor in the formation of these pollutants, it is not the only factor. The formation of POPs depends on many factors. In particular, PCDD and PCDF formation depend largely on combustion and post-combustion zone temperatures, residence time and turbulence in the combustion zone, presence of catalyst and precursors, and oxygen concentration (Olie et al., 1998). The use of mixed household waste, and in particular food waste, for the production of biofuels, such as biogas, using mechanical biological treatments has gained importance in the current energy and waste management sector (Department of Environmental Food & Rural Affairs (DEFRA), 2013a; Department of Environmental Food & Rural Affairs (DEFRA), 2013b). For almost any application, it is important to achieve an effective separation of food waste from the waste source. Separation can be carried out either in households or at waste management facilities using mechanical treatments such as shredding and screening. The outcome of this process is a residual fraction suitable for combustion (Myrin, 2011). The heterogeneity of this fraction makes recycling difficult and co-combustion in waste-to-energy plants (Nemerow et al., 2009) is, at present, the best alternative for handling it according to the waste hierarchy (European Commission, 2008), while the energy contained in the waste is recovered. However, some household waste components are a source of chlorine and metals (Ke et al., 2017) which, together with a carbonaceous matrix, are key elements for the formation of PCDDs and PCDFs under specific conditions (Stieglitz et al., 1989; Conesa et al., 2002).

There are many variables involved in the combustion process that influence its efficiency and emissions including combustion technology, air/oxygen supply, temperature, turbulence, and presence of catalysts. The chemical composition of the fuel influences the combustion and stack gas concentrations (Fiedler, 2004). In our previous study, the thermal behaviour of waste wood and MSW-based fuel blends was evaluated using techniques such as DSC and TG-FTIR (Edo et al., 2016a), with special emphasis on their food waste content. The materials tested were waste wood, MSW, refuse-derived fuel (RDF) and a combustible fraction obtained after MSW was extruded in a high-pressure press to separate the organic fraction from the combustible fraction of the MSW source (Edo et al., 2016a).

For this study, the main component of the fuel blend, lignocellulosic material (stemwood or demolition and construction wood, DC), was combined with MSW-based materials (MSW and RDF) with varying food waste content. This study has focused on exploring how the composition of these fuel blends is related to their combustion performance in terms of emissions of organic pollutants. The results can provide a decision support for use of DC wood or virgin wood in combination with MSW materials with varying food waste content, to produce a fuel blend that generates the lowest possible emissions, or at least within acceptable limits. This study is a first assessment of the viability of using DC and MSW fuels in co-combustion facilities.

As a continuation of our previous work (Edo et al., 2016a), the performance of the fuel blends in an actual co-combustion process were evaluated in an experimental campaign conducted using a domestic pellet stove. The intention was not to verify their future

use in such an appliance, but merely as an intermediate evaluation stage prior to proceeding to experiments in larger scale (pilot- and/or demo-scale). Since a domestic pellet stove is easy to operate and designed to manage relatively low fuel feeding rates, it was an appropriate way to carry out combustion experiments. There are several published studies on co-combustion of MSW and biomass in small-to medium-scale units (up to 50 MW). As an example, Moran et al. (2009) investigated the ratio between biomass and RDF in a fuel blend needed to balance efficiency, low emissions and reasonable price. Maasikmets et al. (2016) determined emission factors for different pollutants emitted from combustion of MSW and wood in domestic heaters Myrin et al. (Svensson Myrin et al., 2014) reported the PCDD/F emission from co-combustion of RDF with different food waste content and waste wood in a full-scale incinerator, concluding that the food waste content was a key factor for reducing the emissions of these pollutants. However, the use of waste wood and municipal solid waste fuel blends and their influence on the emissions of organic pollutants has not been evaluated, and we have not been able to identify any studies considering the differences in food waste content. Hence the relevance of this study, which increases the knowledge on combustion of such fuel blends.

## 2. Materials and methods

### 2.1. Fuel preparation

Four different materials were used to produce four different fuel blends: commercial stemwood (ST), demolition and construction waste wood (DC), municipal solid waste (MSW) and refuse-derived fuel (RDF) from MSW. ST was selected as a reference wood material because of its low content of persistent organic pollutants (POPs), ash and metals (Gao et al., 2017). As was described in a previous study (Edo et al., 2016b), DC is a material with elevated concentrations of chemical and material contaminants and, therefore, is very likely to produce pollutants when combusted. MSW is the household waste fraction remaining after the separate collection of household food waste. MSW comprises plastics, paper, cardboard, textiles but may also contain 5–20 wt% food waste. Different mechanical treatments can be applied to MSW in order to improve its quality as a fuel by changing its composition. Our previous study showed that screening and shredding are efficient methods for removing chlorine from the MSW (Edo et al., 2016a) by reducing the food waste content in the source; resulting in a combustible fraction, RDF. It mainly comprises plastics and papers and may contain up to 5 wt% food waste. DC, MSW and RDF are available in large quantities in Sweden.

The fuel blends were a mixture of 80% woody material (either ST or DC) and 20% household waste (either MSW or RDF) by weight, pelletized (5 mm diameter and 10–12 mm length) to improve homogeneity and feed properties. The final food waste content in the fuel blends was up to 4 wt% for those blends containing MSW and up to 1 wt% for those with RDF. Hereafter, fuel blends whose main component was ST or DC will be referred as ST fuel blends (ST:MSW and ST:RDF) and DC fuel blends (DC:MSW and DC:RDF). The term household waste refers to both MSW and RDF.

DC was collected at the Däva facility, the combined heat and power (CHP) plant owned by Umeå Energi AB in Umeå (Sweden). Further details about the origin of the materials, sampling procedure, and fuel preparation can be read in a previous study (Edo et al., 2016a). Characterisation of the fuels was carried out in accordance with the standard methods described in the Supporting information (SI). Chlorine and metals were analysed in the fuel blends, whilst all the other parameters were analysed in the individual fuels and calculated for the blends. Chemical properties of

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