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The decay of engineered wood products and paper excavated from landfills in Australia

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Large volumes of engineered wood products (EWPs) and paper are routinely placed in landfills in Australia, where they are assumed to decay. However, the extent of decay for EWPs is not well-known. This study reports carbon loss from EWPs and paper buried in landfills in Sydney, Brisbane and Cairns in Australia, located in temperate, subtropical and tropical climates, respectively. The influence of pulp type (mechanical and chemical) and landfill type (municipal solid waste – MSW and construction and demolition – C&D) on decay levels were investigated. Carbon loss for EWPs ranged from 0.6 to 9.0%; though there is some uncertainty in these values due to limitations associated with sourcing appropriate controls. Carbon loss for paper products ranged from 0 to 58.9%. Papers produced from predominantly mechanical pulps generally had lower levels of decay than those produced via chemical or partly chemical processes. Typically, decay levels for paper products were highest for the tropical Cairns landfill, suggesting that climate may be a significant factor to be considered when estimating emissions from paper in landfills. For EWPs, regardless of the landfill type and climate, carbon losses were low, confirming results from previous laboratory studies. Lower carbon losses were observed for EWP and paper excavated from the Sydney C&D landfill, compared with the Sydney MSW landfill, confirming the hypothesis that conditions in C&D landfills are less favourable for decay. These results have implications for greenhouse gas inventory estimations, as carbon losses for EWPs were lower than the commonly assumed values of 23% (US EPA) and 50% (Intergovernmental Panel on Climate Change). For paper types, we suggest that separate decay factors should be used for papers dominated by mechanical pulp and those produced from mostly chemical pulps, and also for papers buried in tropical or more temperate climates.

1. Introduction

Large volumes of engineered wood products (EWPs) and paper are consumed in Australia. For 2014–15, 2.0 million tonnes (Mt) of EWPs and 3.6 Mt of paper were consumed, with particleboard and medium-density fibreboard (MDF) accounting for approximately 80% of the total weight of EWPs and printing, writing and packaging papers accounting for approximately 80% of the total weight of paper consumed (ABARES, 2016). Although national estimates of disposal of EWPs in landfills in Australia are not available, an analysis for the State of Victoria suggested that it is substantial, with EWPs accounting for approximately 32% of the total volume of wood waste sent to landfill (Sustainability Victoria, 2014). Although a high proportion of paper is typically recycled in Australia, a significant volume of paper is nonetheless disposed of in landfills: the Federal Department of Environment in Australia estimates that approximately 1.5 Mt of paper is disposed of annually (Department of Environment, 2014). Whereas EWPs are primarily disposed of in construction and demolition (C&D) landfills, significant volumes of paper are found in commercial and industrial (C&I) and in municipal solid waste (MSW) (Department of the Environment, Water, Heritage and the Arts, 2010).

Despite the large quantities of EWPs and paper disposed of in landfills annually, relatively limited research has been conducted on the decomposition of these products under the anaerobic conditions that prevail in landfills. As anaerobic decay of organic materials in landfills results in the generation of carbon dioxide and methane (IPCC, 2006), improved knowledge on the decay of specific components that make up a significant proportion of the

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organic waste stream improves understanding of methane potential and greenhouse gas emissions from waste management.

EWPs are made up primarily of wood particles or fibres bound together with added resins into products that serve a variety of purposes, including structural applications and furniture. Resins typically account for 6–9% of the dry weight of particleboard and approximately 12% for MDF, with wax content ranging from 0.3 to 1% of the total weight (Stark et al., 2010; Xing et al., 2006).

The pulps used in the manufacture of papers can be grouped into two distinct main classes, based on the method of production: mechanical or chemical pulping. In mechanical pulping, the objective is to maintain the majority of the lignin to achieve high yield with acceptable strength and brightness, for use in applications such as newsprint, low-cost books (paperbacks) and telephone directories (Bajpai, 2012). In chemical pulping, which is used for most commercially-produced papers (FAO, 2011), the objective is to remove non-cellulose wood components. A large proportion of the hemicelluloses (30–70%) is degraded and dissolved during chemical pulping (Sjöström and Westermark, 1999). Chemically produced papers contain a considerable proportion of inorganic constituents (primarily calcium carbonate and clay) – up to 30% in copy papers (Kipphan, 2001). These inorganics are added to enhance printing quality and smoothness. Typically, high-quality magazines, catalogues and some types of cardboard contain a high proportion of chemical pulps. The differences in pulp type are likely to influence paper decay rates in landfills, as lignin is considered recalcitrant under anaerobic conditions in landfills (Colberg, 1988; Ham et al., 1993), with recent studies showing no depolymerisation of lignin from a number of substrates including wood and newsprint following anaerobic decay (De la Cruz et al., 2014).

Micales and Skog (1997) postulated that a maximum of 30% of carbon may be lost from paper in landfills, based on published estimates of methane yields. There have been numerous anecdotal reports of paper excavated from landfills after a period of burial (e.g. Kinman et al., 1990; Bogner, 1990; Rathje and Murphy, 1992, Walsh and LaFleur, 1995, Ximenes et al., 2008, Wang et al., 2013). One study (Ximenes et al., 2008) reported retrieving large volumes of a range of paper types after 19–29 years of burial at one landfill in Australia. Decay has only been quantified in a few studies. For example Baldwin et al. (1998) quantified decay from newspapers that had been buried in landfills for up to six years, finding maximum decay of 17.4%. Wang et al. (2013) buried newsprint, copy paper, corrugated containers and a range of EWPs for between 1.5 and 2.5 years in landfills with leachate recirculation, and quantified carbon loss by chemical analysis of the retrieved samples. The carbon losses for EWPs such as particleboard and MDF were minimal, whereas high carbon losses were reported for paper types such as newsprint and corrugated cardboard (47–75%). Other studies have quantified decay of shredded EWPs (Wang et al., 2011) and shredded paper (e.g. Eleazer et al., 1997, Wang et al., 2015) that were exposed to anaerobic conditions in controlled bioreactor experiments. Such quantitative field and laboratory studies have not been carried out for EWPs and paper disposed of in Australian landfills. Furthermore, previous field studies have typically targeted MSW landfills, where conditions are considered more suitable for decay than in C&D landfills, due to a lack of easily decomposed substrates in C&D landfills.

The objective of this study was to determine carbon loss from EWPs and paper buried for varying periods of time in landfills located in contrasting environments in Australia, to better understand the greenhouse gas implications of burying a variety of wood and paper products in landfills. Two hypotheses were tested: (1) papers composed primarily of mechanically produced pulps decay to a lesser extent under anaerobic conditions in landfills than papers derived primarily from chemical pulps, and (2) decay levels for the various products is lower in C&D landfills compared to MSW landfills under similar climatic conditions.

This study focussed on chemical and physical analyses of EWPs and paper excavated from one MSW landfill and one C&D landfill in Sydney, New South Wales, and from two MSW landfills, located in Brisbane and Cairns, Queensland, Australia.

2. Materials and methods

2.1. Sites description

Two of the landfills were located in Sydney, New South Wales, and two in Queensland, (Brisbane and Cairns), where the temperature and rainfall are higher (Table 1).

In Table 2 we describe key characteristics of each of the landfills excavated. Although the exact composition of the waste in the landfills excavated was not measured, they received waste typical of MSW and C&D landfills in their regions. Time since closure was determined in consultation with landfill operators and also by the dates in excavated newspapers, magazines and telephone books.

The pH and temperature of the waste at different depths was recorded at the Sydney and Brisbane sites but not in Cairns due to instrument failure.

2.2. Physical and chemical analyses

2.2.1. Sample identification and moisture content

A total of 295 samples of EWPs and 354 paper samples were excavated from the four landfills (Tables 3 and 4). The EWPs and paper samples excavated represented a wide range of sizes, for example from small EWP offcuts to large particleboard panels. All samples were labelled, identified to type and sealed in plastic bags prior to storage at 4 °C.

Moisture content was determined on samples from a random subset of the excavated EWP and paper samples by oven-drying at 103 ± 2 °C until constant weight (AS/NZS 1080.1, 1997). The moisture content of the samples was expressed as mass water/mass wet weight (percentage).

2.2.2. Chemical analysis

A total of 130 EWPs and 175 paper samples were randomly selected for chemical analyses, by using the "random" function in Microsoft Excel, applied to each category of EWP and paper products. Where the number of samples recovered allowed, the minimum number of samples randomly selected for each product category was three. Sourcing of matching controls for chemical analyses of EWPs was challenging. A sample of plywood (provided by the Engineered Wood Products Association of Australia) produced around the same time the plywood samples excavated from the landfills would have been discarded (16–20 years prior to the excavation date) was used as a control. Samples of particleboard manufactured approximately 11 and 17 years prior to the excavation dates were obtained and used as controls. As it was not possible to source a MDF control sample that matched the burial times, a MDF sample produced at the time of the excavation was used as a control. For paper, the publication details in the samples made it possible to source closely-matched controls for many samples. This provided a unique opportunity to quantify potential carbon loss from the landfill samples by comparing the chemical composition of the excavated samples to that of controls. The same level of rigor could not be applied to samples that were difficult to match with pre-existing controls, such as more obscure publications and paper types such as cardboard.

Prior to chemical analysis, the landfill and control samples were oven-dried at 40 °C for four days (as samples with excessive