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Review

Pulp and paper mill sludge management practices: What are the challenges to assess the impacts on greenhouse gas emissions?

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ABSTRACT

Pulp and paper mill sludge (PPMS) is an organic residual generated from the wastewater treatments. PPMS management involves economic, environmental and social costs that will likely increase in the future as landfilling tends to be reduced or banned in certain jurisdictions. The reduction or the banning of landfilling may be considered as a climate change mitigation measure since organic waste disposal is normally associated with greenhouse gas (GHG) emissions. This critical review aims to (1) describe the variety of the current and emerging PPMS management practices that are alternatives to landfilling and (2) underline the crucial need for GHG emission assessments. The management practices of the three main PPMS types (primary, secondary and de-inking) comprised in this review are land application (agriculture, silviculture, land reclamation and composting), energy recovery (combustion, anaerobic digestion, pyrolysis, bioethanol, hydrogen production and direct liquefaction) and integration in materials (biocomposite, cement, asphalt and adsorbent–absorbent). Future research should focus to increase the comprehension of known GHG determinants from the PPMS management practices and reveal unknown factors. Life cycle analyses, based on direct GHG emission measurements, are needed to determine GHG emissions from current and emerging practices and plan a responsible future reduction or banning of landfilling. Such analyses will contribute to assist decision makers in implementing the best PPMS management practices with the least impact on climate change.

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1. Introduction

Pulp and paper mill sludge (PPMS) is the main organic residual generated from the wastewater treatments of the pulp and paper industry. The annual world production of paper and paperboard is estimated to 400 million tons (FAOSTAT, 2015) and is predicted to reach up to 550 million tons by 2050, which could increase the PPMS production by 48–86% compared with the actual rates (Mabee and Roy, 2003). PPMS management and disposal involve economic, environmental and social costs that will likely increase in the future. Some jurisdictions actually tend to reduce or ban landfilling of organic residuals by improving the efficiency of resource use and recycling (Council of the European Communities, 1991; US EPA, 1994; Ljunggren Söderman, 2003; EC-BiPRO, 2007; Fytili and Zabaniotou, 2008; Monte et al., 2009; MfE, 2010; MDDEP, 2011; Gouvernement du Québec, 2012), which will likely induce a change in the actual management practices (Mabee and Roy, 2003; Pervaiz and Sain, 2015). The actual greenhouse gas (GHG) emissions from the variety of PPMS management practices are unknown and should be addressed especially in the light of upcoming changes, consequence of reducing or banning landfilling.

The actual and common PPMS management practices are landfilling, land application for agricultural, silvicultural and reclamation purposes, and energy recovery through combustion (CANMET, 2005; Camberato et al., 2006; Gavrilescu, 2008; Likon and Trebše, 2012; MDDELCC, 2015; Pervaiz and Sain, 2015). The proportions of PPMS directed to one of these practices vary with time and jurisdiction policies. For instance, in the U.S., up to 87% of PPMS was landfilled in 1979 (Amberg, 1984) whereas this proportion has now decreased to 52% (Pervaiz and Sain, 2015). Nowadays in the province of Quebec, Canada, the annual production of 1.4 million tons of PPMS are managed at 29% by landfilling, 31% by land application, 35% by energy recovery and 5% by other practices (MDDELCC, 2015). The Quebec's government policies aim to ban landfilling of PPMS by 2020 (MDDEP, 2011; Gouvernement du Québec, 2012) resulting in major challenges for the industry to change their PPMS management practices in order to meet the government objectives. The practice of landfilling will also tend to decrease in other jurisdictions following the application of such policies and pressure from the low public acceptance (Wang et al., 2008; Joo et al., 2015; Pervaiz and Sain, 2015). Depending on the local context for each paper mill, the tonnages actually directed to landfill sites may not be only manageable by current energy recovery installations and land availability. Energy recovery through combustion benefits to pulp and paper industry (e.g., heat and electricity production) but it can be costly due to the implantation of combustion facilities and the prior PPMS dewatering process (CANMET, 2005; Mahmood and Elliott, 2006; Xu and Lancaster, 2008). Land application is generally feasible (Camberato et al., 2006; Pervaiz and Sain, 2015) and well accepted but this option can be practically and economically difficult for certain paper mills. For instance, some paper mills are located at great distances from agricultural lands, leading to high management costs and GHG emissions related to transport. Moreover, the heavy metal contents of some types of PPMS and the odor, especially when the spreading is done in the vicinity of residential areas, can be environmental and public acceptance issues in rare exceptions (Rashid et al., 2006; Pervaiz and Sain, 2015).

There is a need to integrate novel PPMS management practices as land application and/or energy recovery through combustion may not be the common alternatives to dispose the PPMS tonnages actually directed to landfill sites. Several alternative management options, other than combustion for energy recovery, are emerging, such as anaerobic digestion for biogas production, pyrolysis and bioethanol production (Monte et al., 2009; Meyer and Edwards, 2014). PPMS can also be integrated as a component of biocomposites, bioplastics, cement and asphalt, as well as being used for adsorbent-absorbent productions (Beauchamp et al., 2002; Mari et al., 2009; Monte et al., 2009; Li et al., 2011; Yan et al., 2011; Likon and Trebše, 2012; Almquist and Qin, 2013; Soucy et al., 2014; Pervaiz and Sain, 2015). These emerging options also have the potential of being opportunities for industrial synergies, leading to mutual economic benefits. The residual of one industry becomes the primary matter for another industry, fitting with the concept of industrial ecology.

The reduction or the banning of PPMS landfilling could represent a potential abatement for GHG emissions, especially in North America (Fischedick et al., 2014). So far, the GHG emissions from PPMS landfilling have only been theoretically estimated (1 ton of landfilled low-ash PPMS could release 2.69 tons of CO_2 and 0.24 ton of CH_4 due to aerobic and anaerobic decomposition; Buswell and Mueller, 1952; Likon and Trebše, 2012) and robust data series from direct GHG measurements are non-existent for different landfill conditions and mill operations (NCASI, 2005; IPCC, 2006). The GHG emissions from wastewater treatment plants can be estimated with models and life cycle analyses (Ashrafi et al., 2013a, 2013b, 2015; O'Connor et al., 2014; Zang et al., 2015) but the emissions from PPMS management are unknown outside the mill operations. The impacts on climate change from the pulp and paper industry can also be estimated through its GHG emissions using calculation tools such as the one built by the National Council for Air and Stream Improvement (NCASI, 2005). However, data from direct GHG emission measurements that isolate the contribution of PPMS management practices on the GHG emission budgets are missing in the NCASI calculation tool and are not considered in the guidelines of the Intergovernmental Panel on Climate Change (IPCC) for national greenhouse gas inventories (IPCC, 2006). Therefore, direct measurements linked to various PPMS management practices could be used in databases such as the Ecoinvent database utilized by the SimaPro software for example (Ecoinvent, 2013; PRé Consultants, 2014), or to build models similar to the biosolids emissions assessment model (BEAM) that estimates GHG emissions from municipal biosolid management (SYLVIS, 2009; Brown et al., 2010).

This review aims to describe the variety of the actual and emerging PPMS management practices that are alternatives to landfilling. Moreover, the objective is to underline that GHG emission assessments from PPMS management practices are needed to: