ANAEROBIC BIODEGRADABILITY OF WOOD: A PRELIMINARY REVIEW

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ABSTRACT

The literature shows that wood is relatively non-biodegradable in anaerobic environments, though there is a wide variety of results ranging from <2% to 40% of stoichiometric conversion, or roughly <1% to 20% of wood carbon converted to methane carbon. This contrasts with IPCC assumptions that 50% of wood will degrade in landfill environments. The literature results vary with tree species, with wood density (hardwood or softwood), and with particle size. The most reliable and recent laboratory results found 1.5% conversion for softwoods and 6% conversion for hardwoods at <20 mm size, after 1.5 years under ideal laboratory conditions. The only field study of long-term biological decomposition had one site show 20% biological degradation after 46 years, and the other show no detectable (<4%) degradation after 25 years. This review shows relatively strongly that untreated wood degradation in anaerobic environments is best estimated to be 0-20%, or 10% as a good overall estimate, with roughly 5% of the carbon in wood converted to methane. The literature indicates lower anaerobic degradability for pine and eucalyptus wood. At these efficiencies, wood disposed in landfills should be roughly carbon-neutral with the negative of methane production balanced by the positive of carbon sequestration.

1 INTRODUCTION

Lignin is recalcitrant to anaerobic biodegradation (Young and Frazer, 1987). In addition, we know that lignin can interfere with the biodegradability of associated cellulose and hemi-cellulose by limiting microbial access (Barlaz, 1996). As a result, one would expect that more natural materials with higher lignin contents would be less biodegradable. Wood can have significant amounts of lignin, especially if unprocessed with bark, or when in small diameters, such as for smaller branches.

The more that wood is processed, the more lignin is removed and the more the close physical relationship is distributed, which can enhance biodegradation. Milling of wood to small pieces can be expected to increase anaerobic biodegradation. Addition of chemicals to remove lignin, as in the production of paper, would be expected to increase biodegradation. For these reasons, one expects commercial paper products and sawdust to be much more biodegradable anaerobically than raw wood. In addition, many wood products are chemically treated to reduce the rate of aerobic biological decay. It should be no surprise that chemically treated wood would also be less degradable anaerobically. The sensitivity of methane-producing micro-organisms to many trace organics and metals would support the assumption that chemically-treated wood is very difficult to degrade anaerobically.

On the other hand, the 2006 IPCC Guidelines state “The reported degradabilities, especially for wood, vary over a wide range and are yet quite inconclusive. They may also vary with tree species”. They conclude that a default value of 50% potential degradation is appropriate. This value of 50% degradation for wood in landfills has been widely cited and copied. Bogner and Spokas (1993) suggest less than 25% of the carbon in landfills is converted to landfill gas. Micales and Skog (1997) in a previous review conclude only 26% of the carbon from paper and 0-3% of the carbon from wood are released as landfill gas (CO2 + CH4).

The proper assessment of the issue of anaerobic biological degradation is important for assessments of greenhouse gas impacts of land disposal of wood and wood wastes, influencing the life-cycle assessment of greenhouse gas impacts of wood products. The assessment also impacts substantially on the sequestration benefits of anaerobic burial of wood and wood wastes. Finally, the issue is of relevance to those operating anaerobic digestion systems who might infer from IPCC documents that woody materials are suitable digester feedstock.

This research investigated the available literature on wood decomposition in anaerobic environments. A number of different methods are used to report anaerobic biodegradability. In this paper, all methods are converted to two:

1. The methane production as a % of the methane that could be produced in an anaerobic environment, assuming lignin could biodegrade. This can be useful when evaluating how much lignin and other factors can inhibit biodegradation, and also can be used to estimate the carbon remaining in the ground after anaerobic biodecomposition (100% minus this value). This is useful in estimates of carbon sequestration.
2. The carbon that is converted to methane as a percentage of the total biogenic carbon. This is useful for estimates of greenhouse gas impacts of methane.

Because the typical anaerobic gas production is 50% CH4 and 50% CO2, efficiency using Method 2 is roughly half of the efficiency using Method 1. However, we use the available carbon, hydrogen, and oxygen data, supplemented by values from literature, to estimate (stoichiometrically) the gas composition for each earlier study, and so the ratio between methods varies from study to study. The efficiencies are given as Method 1[Method 2]. Only some of our results can be reported at this time and so the focus is on particle size and wood type.

2 INFLUENCE OF PARTICLE SIZE AND WOOD TYPE

Table 1 provides a summary of the effects of particle size and wood type. Padgett (2009) used sample material size of less than 20mm by 50mm. Hardwood tested showed a methane yield of 29.93ml CH_4/g TS while softwood yielded 7.4ml CH_4/g TS. Conversion efficiencies were found to be 1.5[0.92]% for softwoods and 6.1[3.7]% for hardwoods.

Ximenes (2007) tested softwoods and hardwoods from two landfill sites and found an average methane conversion efficiency of roughly 6% for both softwoods and hardwoods. The sample size was between 10mm and 100mm. The Lucas Height Landfill woods (both softwoods and hardwoods) produced undetectable amount of methane. Sydney Park Landfill softwoods produced 904ml CH_4/g TS methane and hardwoods produced 86.14ml CH_4/g TS methane.

Jerger (1982) examined various species of softwoods and hardwoods of size 0.8mm. The only softwood, loblolly pine, had methane yield of 63ml CH_4/g VS with a conversion efficiency of 12[6.5]%. The average methane yield of the five hardwood tested was 222.8ml CH_4/g VS with an average methane conversion efficiency of 43.8[23.5]%. One of the hardwoods was eucalyptus with a conversion efficiency of only 2.9[1.5]%. Without eucalyptus, the other four hardwoods had averages of 54[29]%.

Turick (1991) tested 32 samples from 15 woody species with a sample size of 0.8mm. The samples can be grouped into willow, poplar, sycamore, locust and liquidambar which are all hardwoods. The softwood generally showed a high level of methane yield (208 ml CH_4/g VS for willow and 113 ml CH_4/g VS for poplar). Methane yields of 60ml CH_4/g VS, 60ml CH_4/g VS and 50ml CH_4/g VS resulted for the hardwoods sycamore, locust and liquidamber, respectively. Average methane yield for all these hardwoods was 57 ml CH_4/g VS. Average conversion efficiency for hardwoods is calculated to be 11.2[5.9]%.

Tong (1990) tested white fir (softwood) with size less than 0.5mm and found the methane yield to be 42 ml CH_4/g VS with a conversion efficiency of 8.6[4.4]%.

From the above results, it can be seen that as particle size decreases, wood degrades more. Both Padgett and Ximenes used larger pieces of samples, and the resulting methane yield for hardwoods and softwoods were lower compared with Jerger, Tong and Turick, which had considerably higher methane yields.

	Hardwood		Softwood	
Size (mm)	Methane Yield (ml CH_4/g VS)	Conversion Efficiencies (%)	Methane Yield (ml CH_4/g VS)	Conversion Efficiency (%)
0.5			42	8.6[4.4]
0.8	222.8	43.8[23.5]	63	12[6.5]
	57	11.2[5.9]	161	31[16]
10-100	43	11[6]	45	11[6]
20 by 50	29.93	6.1[3.7]	7.4	1.5[0.9]

Table 1: Influence of particle size and wood type on anaerobic biodegradability of wood. Conversion efficiencies are reported as the fraction of carbon converted to gas followed by the fraction of carbon converted to methane.

3 DISCUSSION

The difference between hardwoods and softwoods is not clear and is difficult to separate from the effect of particle size and also the effect of laboratory-to-laboratory variability. Perhaps of greater interest is that certain wood types, independent of being hard or soft, have inhibited degradation. These studies indicate that pine and eucalyptus wood biodegrade anaerobically less than other woods (poplar, willow, fir, sycamore, alder, cottonwood, oak). In addition to these studies, Kim (2007) in a study focused on biodegradation of treated wood products (beyond the scope of this short paper), tested Southern Yellow Pine as a control and found very little (<5[2.5]%) degradation anaerobically. The data are consistent with a hypothesis that woods with strongly resinous or aromatic natures are more resistant to anaerobic biodegradation. Because of the sensitivity of methane-producing microbial communities to toxins, it seems very possible that one of any number of trace organic compounds could inhibit anaerobic biodegradation of these woods.

The higher conversion efficiencies occur in laboratory studies with very small particle sizes, while very low conversion efficiencies are found for the one field study reported here and for one laboratory study with larger particle sizes. Excluding sawdust and wood shavings, it appears that wood conversion efficiencies in anaerobic environments are best estimated as 10[5]%. Even for small wood waste particles, the inability to achieve laboratory conditions in a disposal situation would indicate that one might expect conversion efficiencies of roughly 20[10]% for small particles of wood. For typical wood waste, and assuming a 5% conversion to methane, the greenhouse gas impact of wood waste to landfills would be a nett of zero, assuming that methane is 21 times more effective as a greenhouse gas compared to CO_2 from fossil fuels, and neglecting any greenhouse gas benefits from combustion of landfill gas or its displacement of fossil fuel use.

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REFERENCES

Barlaz M.A. (1996) Microbiology of solid waste landfills. In Microbiology of Solid Waste, ed. by A.C. Palmisano and M.A. Barlaz, CRC Press.

Bogner J. and Spokas K. (1993) ‘Landfill methane—rates, fates, and role in global carbon cycle’. Chemosphere, v. 26: 369-86.

Jerger D.J., Dolenc D.A., and Chynoweth D.P. (1982) ‘Bioconversion of woody biomass as a renewable source of energy’. Biotechnology Bioengineering Symposium, v. 12: 233-48.

Micales J.A. and Skog K.E. (1997) ‘The decomposition of forest products in landfills’. Int. Biodeterioration and Biodegradation, v. 39: 145-58.

Padgett J.M. (2009) ‘Biodegradability of wood products under simulated landfill conditions’. Masters Thesis, North Carolina State University.

Tong X., Smith L.H., and McCarty P.L. (1990) ‘Methane fermentation of selected lignocellulosic materials.’ Biomass, v. 21: 239-55.

Turick C.E. et al. (1991) ‘Methane fermentation of woody biomass’. Bioresource Technology, v. 37: 141-7.

Ximenes F.A., Gardner W.D., and Cowie A.L. (2008) ‘The decomposition of wood products in landfills in Sydney, Australia’. Waste Management, v. 28: 2344-54.

Young L.Y. and Frazer A.C. (1987) ‘The fate of lignin and lignin-derived compounds in anaerobic environments’. Geomicrobiol. J. v. 5: 261-93.