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Pyrolysis biochar systems for recovering biodegradable materials: A life cycle carbon assessment

Rodrigo Ibarrola *, Simon Shackley, James Hammond

UK Biochar Research Centre, University of Edinburgh, Crew Building, King's Buildings, Edinburgh EH9 3JN, United Kingdom

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ABSTRACT

A life cycle assessment (LCA) focused on biochar and bioenergy generation was performed for three thermal treatment configurations (slow pyrolysis, fast pyrolysis and gasification). Ten UK biodegradable wastes or residues were considered as feedstocks in this study. Carbon (equivalent) abatement (CA) and electricity production indicators were calculated. Slow pyrolysis systems offer the best performance in terms of CA, with net results varying from 0.07 to 1.25 tonnes of CO_2 eq. t^{-1} of feedstock treated. On the other hand, gasification achieves the best electricity generation outputs, with results varying around 0.9 MWhe t^{-1} of feedstock. Moreover, selection of a common waste treatment practice as the reference scenario in an LCA has to be undertaken carefully as this will have a key influence upon the CA performance of pyrolysis or gasification biochar systems (P/GBS). Results suggest that P/GBS could produce important environmental benefits in terms of CA, but several potential pollution issues arising from contaminants in the biochar have to be addressed before biochar and bioenergy production from biodegradable waste can become common practice.

1. Introduction

To address the indisputable issue of global warming, the European Union's aim is to advocate a limit of 2 °C increase of the global average temperature by 2050, compared to pre-industrial levels, for which atmospheric concentrations of greenhouse gases (GHGs) will need to remain below 550 ppm of CO_2 equivalent (where 'equivalent' refers to the six greenhouse gases referred to in the Kyoto Protocol) (EC, 2007). However, it has been suggested that this stabilization concentration implies an 82% probability of exceeding 2 °C (Anderson and Bows, 2008). Their analysis suggests that, in order to have a 93% probability of not exceeding this temperature increase, the concentration would need to be stabilized at, or below, 350 ppm of CO_2 eq. (lower than the current 430 ppm concentration).

To achieve this stabilization in concentrations, it will be imperative for local and national governments to design and implement strategies to mitigate the release of GHG emissions generated by anthropogenic activities and also to begin to remove CO_2 from atmosphere. The main objective of these strategies should be the identification of actions to deliver an integrated management of natural resources and the resulting waste generated from consumption activities.

Although post-consumer waste is a small contributor to global GHG emissions (around 5%) with a total of approximately 1300 Mt CO_2 eq. in 2005 (Bogner et al., 2007) a more sustainable and less carbon-intensive waste management sector could encourage emission reductions in other sectors that contribute to higher emission rates (e.g. agriculture, energy generation, etc.).

For example, carbon abatement (i.e. emission reductions) could be achieved if thermal treatment technologies such as pyrolysis or gasification are considered as part of sustainable land use practices. This abatement could come from the avoided methane emissions of biodegradable waste disposal in landfills, from the fossil fuel emissions displaced by renewable energy generation, by the fixation of carbon in the char (biochar) produced during the treatment process, and by the enhanced soil and crop effects which may arise if the biochar is used as a soil amendment.

This type of waste-bioenergy-soil management system is called a pyrolysis or gasification biochar system (P/GBS). P/GBS are starting to be considered as an important mechanism for the sustainable treatment of other types of biomass since they have the potential to provide significant CA (Hammond et al., 2011) as well as economic benefits for some feedstocks (Shackley et al., 2011). However, pyrolysis technologies, and to a lesser extent gasification, have not been widely deployed at large scale, although a handful of large working facilities do exist. This paper seeks to estimate the potential carbon benefits (or detriments) of widespread pyrolysis or gasification use, assuming that technological problems associated with scale up can be overcome.

* Corresponding author. Tel.: +44 0 131 6507252; fax: +44 0 131 6620478.
E-mail address: rodrigo.ibarrola@ed.ac.uk (R. Ibarrola).

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Depending on the energy value and carbon content of the waste, the materials typically obtained by, and used within P/GBS systems are syngas, bio-liquid (including bio-oil) and a char usually denominated as biochar if the intention is to use it for safe and beneficial applications to soil, or charcoal if the intention is to use it for other purposes such as energy generation, land restoration, etc. (Shackley and Sohi, 2010). The solid, gas and liquid yields vary depending on the production conditions and technology design. The highest char yields are obtained by slow pyrolysis (up to 35% of the total treated biomass), while the highest bio-oil (up to 75% of the total treated biomass) or syngas (up to 85% of the total treated biomass) yields can be produced by fast pyrolysis or gasification, respectively (Lehmann and Joseph, 2009).

The main feedstock sources that are considered for P/GBS research and deployment purposes are usually virgin biomass (organic material that has not been subject to chemical or biological transformation, amendment or treatment – such as agroforestry residues or bioenergy crops) and, to a lesser extent, non-virgin feedstocks (materials that are chemically and/or biologically transformed, such as biodegradable municipal or industrial waste).

The methodology that is most often used in order to clearly identify the potential economic and environmental benefits associated with each stage of a value-chain is life cycle analysis (LCA). In this research we will use this methodology to focus solely on non-virgin feedstocks for two reasons.

Firstly, the utilization of these feedstocks in P/GBS would not usually incur impacts usually associated with bioenergy crops or virgin feedstock production (e.g. land use competition for food production (Tenenbaum, 2009) or carbon debt incurrence from land clearing and preparation (Fargione et al., 2008) since the generation of the waste in urban or rural areas would occur with or without P/GBS as a result of the production and consumption of goods and services in all sectors of the economy. Note that in cases where the non-virgin feedstock is diverted from another purpose, for example animal feed or wood board manufacture, indirect land use change could occur as a result.

Secondly, there is less evidence to support the CA and economic benefits from using non-virgin feedstocks in P/GBS systems. Only a handful of studies or reviews have analysed the CA implications of P/GBS systems based on non-virgin feedstocks treatment (Lehmann and Joseph, 2009; Shackley and Sohi, 2010).

Applying this LCA methodology, the objectives of the present study will be to address the CA and energy benefits of P/GBS based non-virgin material treatment (biochar and energy generation). Three different configurations for thermal treatment (slow pyrolysis, fast pyrolysis, and gasification) will be tested.

2. Methodology

2.1. Feedstock selection and LCA design

The feedstocks analysed are materials that fall into the category of urban biodegradable waste (e.g. sewage sludge, green waste, food waste, wood waste, used cardboard) and materials derived from their treatment (e.g. digestates from anaerobic digestion (AD) or dense refuse derived fuel, DRDF). Urban wastes must be thoroughly separated before being used for processes such as pyrolysis or gasification, or contaminants could be formed. Other biodegradable materials or residues derived from industrial processes such as paper manufacturing or recycling, poultry processing or whisky production (e.g. paper sludge, poultry litter, whisky remains/draff) are considered. These were selected following criteria such as local availability and their current waste treatment or disposal context in the UK, this being the reference scenario or system (RS).

Considering the aforementioned, we established incineration as the RS for poultry litter and DRDF, cattle feed as the RS for whisky draff, recycling as the RS for cardboard, landfills as the RS of

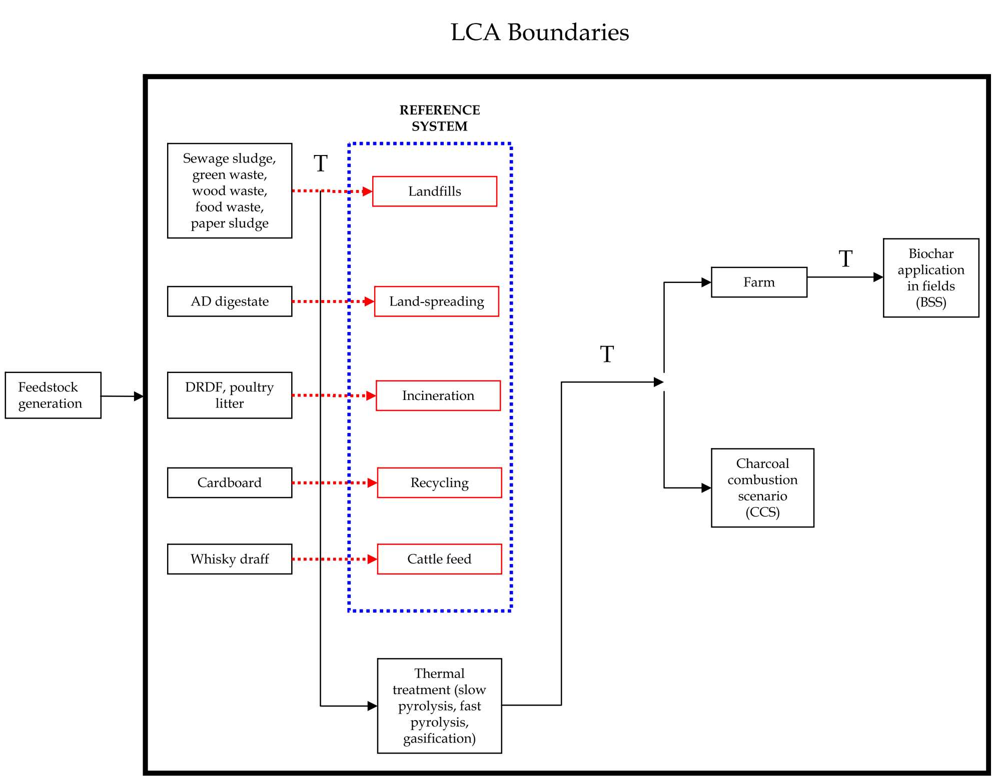

Fig. 1. P/GBS system boundaries and life cycle stages. Arrows denote flows where *T* refers to transportation stage.