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# Bioethanol from waste: Life cycle estimation of the greenhouse gas saving potential

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ABSTRACT

This paper considers two alternative feedstocks for bioethanol production, both derived from household waste—Refuse Derived Fuel (RDF) and Biodegradable Municipal Waste (BMW). Life Cycle Assessment (LCA) has been carried out to estimate the GHG emissions from bioethanol using these two feedstocks. An integrated waste management system has been considered, taking into account recycling of materials and production of bioethanol in a combined gasification/bio-catalytic process. For the functional unit defined as the 'total amount of waste treated in the integrated waste management system', the best option is to produce bioethanol from RDF—this saves up to 196 kg $CO_2$ equiv. per tonne of MSW, compared to the current waste management practice in the UK.

However, if the functional unit is defined as 'MJ of fuel equiv.' and bioethanol is compared with petrol on an equivalent energy basis, the results show that bioethanol from RDF offers no saving of GHG emissions compared to petrol. For example, for a typical biogenic carbon content in RDF of around 60%, the life cycle GHG emissions from bioethanol are 87 g $CO_2$ equiv./MJ while for petrol they are 85 g $CO_2$ equiv./MJ. On the other hand, bioethanol from BMW offers a significant GHG saving potential over petrol. For a biogenic carbon content of 95%, the life cycle GHG emissions from bioethanol are 6.1 g $CO_2$ equiv./MJ which represents a saving of 92.5% compared to petrol. In comparison, bioethanol from UK wheat saves 28% of GHG while that from Brazilian sugar cane – the best performing bioethanol with respect to GHG emissions – saves 70%. If the biogenic carbon of the BMW feedstock exceeds 97%, the bioethanol system becomes a carbon sequester. For instance, if waste paper with the biogenic carbon content of almost 100% and a calorific value of 18 MJ/kg is converted into bioethanol, a saving of 107% compared to petrol could be achieved. Compared to paper recycling, converting waste paper into bioethanol saves 460 kg $CO_2$ equiv./t waste paper or eight times more than recycling.



## 1. Introduction

Transport is a significant contributor to greenhouse gas (GHG) emission, accounting for about 20% of global carbon dioxide emissions and 25% of emissions in the United Kingdom (UK); these figures are growing faster than for any other sector (The Royal Society, 2008). Therefore, reducing the emissions from this sector could contribute significantly to reaching the EU targets on climate change. Currently, the European Commission's non-binding target is to have 5.75% of biofuels used for transport by 2010 (Frondel and Peters, 2007). In the future, it is expected that these targets will be increased to 10% and will become mandatory.

It is thus important as well as timely to identify sustainable options for integration of biofuels into the transport sector. Currently, the majority of the biofuels are produced from food crops, including wheat, corn, sugar beet and soy. This has already led to undesirable socio-economic effects with respect to food production, including increases in food prices, shortage of fodder, and growing competition for land (Cramer, 2007; Mol, 2007; Thompson, 2008). Furthermore, the environmental advantages of biofuels derived from food crops are not clear and in some cases the impacts can be higher than that of petrol due to the cultivation of the feedstock (Crutzen et al., 2007; Zah, 2007).

In contrast, biofuels derived from waste do not pose similar risks; on the contrary, using non-recyclable waste as a resource would save the landfill disposal capacity, support the re-use of resources and lead to a reduction of GHG emissions from disposal sites, thus helping to fulfil the requirements of various legislation, including the European Waste Framework Directive (European Commission, 2006).

This paper considers the use of Municipal Solid Waste as a potentially sustainable source of bioethanol and discusses the potential for GHG savings on a life cycle basis compared to petrol and bioethanol derived from food crops.

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## 2. Bioethanol from MSW: system definition

The bioethanol production system is evaluated in this work as part of an integrated waste management system. Two feedstocks for bioethanol production are investigated: Refuse Derived Fuel (RDF) and Biodegradable Municipal Waste (BMW). As shown in Figs. 1 and 2 this leads to different integrated waste management systems, as follows:

(i) RDF (Fig. 1): Municipal Solid Waste (MSW) is pre-sorted into the recyclables and the remaining waste. The former is collected and sent to a materials recovery facility and subsequently to recycling. The remaining MSW is collected and routed via a transfer station to a Mechanical and Biological Treatment (MBT) plant. The recyclable and non-combustible fractions are separated in the MBT plant and the remainder is stabilised, shredded and processed into RDF, which is then treated in the bioethanol production plant to produce ethanol. The recyclable fraction is sent to recycling while the remaining waste from the MBT plant is landfilled.
(ii) BMW (Fig. 2): MSW is pre-sorted into recyclables, BMW (including garden and food waste and forest residue) and remaining waste. The recyclables are treated in the same manner as in the previous waste management option. BMW is transferred directly to the bioethanol production plant without any pre-treatment. The remaining waste is incinerated.

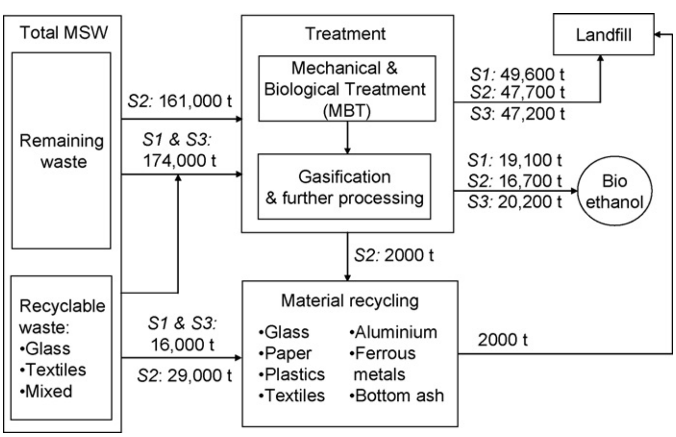


**Fig. 1.** A life cycle model of bioethanol production from RDF within an integrated MSW management system (Scenarios 1–3) (S1, S2 and S3: flows for Scenarios 1, 2 and 3, respectively).

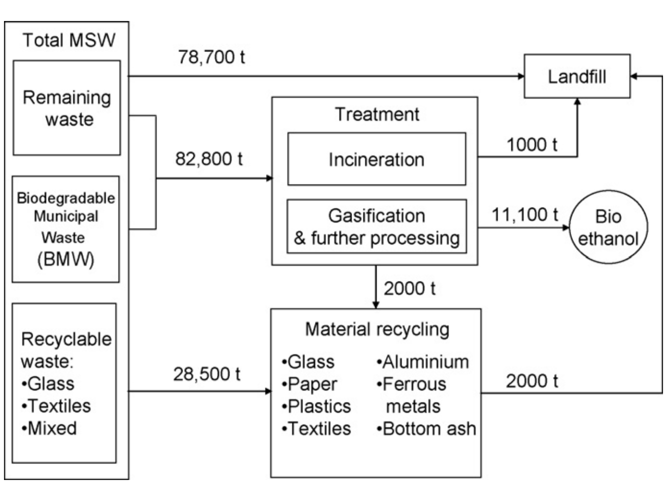


**Fig. 2.** A life cycle model of bioethanol production from BMW within an integrated MSW management system (Scenario 4).

In the bioethanol plant, the RDF or BMW are fed through a gasifier to produce synthesis gas (CO and $H_2$) and heat. Synthesis gas is then routed to a bio-catalytic fermenter to generate ethanol, which is then purified by distillation. Molecular sieves are used to remove the remaining water in ethanol and to obtain anhydrous ethanol that can be used as transport fuel. In addition to ethanol, butanol and other co-products are also produced. The heat from the gasifier is utilised to generate electricity and pre-heat the waste as well as for ethanol distillation.

## 3. Methodology for calculating the life cycle emissions of GHG

A life cycle approach has been used to calculate the GHG emissions from the bioethanol production systems outlined in Figs. 1 and 2. The ISO 14044 methodology for Life Cycle Assessment (LCA) has been used for these purposes (ISO, 2006). The aim of the study is twofold:

- to compare the GHG emissions for bioethanol derived from RDF and BMW in an integrated waste management system, considering different waste management scenarios; and
- to compare the GHG emissions from bioethanol produced from RDF and BMW with petrol and bioethanol derived from food crops.

Therefore, two functional units have been defined. For the comparison of different waste management scenarios, the functional unit is defined as the 'treatment of 190,000 t of MSW/year'. The comparison of bioethanol from waste with petrol and other bioethanols is based on the functional unit defined as 'MJ of fuel equivalent'.

The following five integrated waste management scenarios have been considered:

- Baseline scenario (Fig. 3): based on the waste management situation in the UK in 2004 (DEFRA, 2006);
- Scenario 1 (Fig. 1): As Baseline scenario, but with the addition of the MBT plant and the bioethanol production process; in this scenario, plastic and paper are converted into RDF in the MBT plant instead of being recycled; RDF is then used as feedstock in the bioethanol plant;

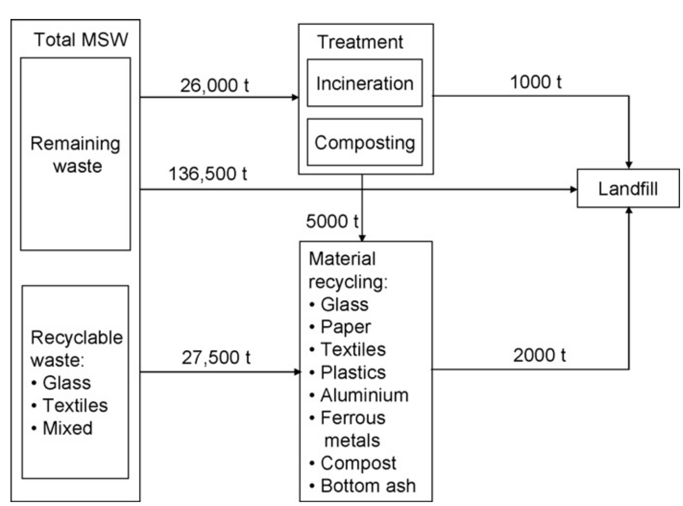


**Fig. 3.** Baseline scenario: based on the waste management situation in the UK in 2004 (DEFRA, 2006).