Applied Energy 177 (2016) 852–862

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Expanding the biomass resource: sustainable oil production via fast pyrolysis of low input high diversity biomass and the potential integration of thermochemical and biological conversion routes

J. Corton [a,*], I.S. Donnison [a], M. Patel [b], L. Bühle [c], E. Hodgson [a], M. Wachendorf [c], A. Bridgwater [b], G. Allison [a], M.D. Fraser [a]

[a] Institute of Biological Environmental and Rural Sciences, Aberystwyth University, Gogerddan, Aberystwyth, Ceredigion SY23 3EB, UK
[b] European Bioenergy Research Institute, Aston University, Birmingham B4 7ET, UK
[c] Department of Grassland Science and Renewable Plant Resources, University of Kassel, Steinstr. 19, 37213 Witzenhausen, Germany

HIGHLIGHTS

- Biomass is generated during management of low input high diversity (LIHD) landscapes.
- Samples of LIHD biomass were subjected to fast pyrolysis.
- Demineralization through washing and pressing was associated with higher oil yields.
- Oil yields were within the range following fast pyrolysis of Miscanthus and Willow.
- Gross estimates of 4×10^5 tonne per year of oil could be displaced using Welsh LIHD biomass.

ARTICLE INFO

Article history:
Received 7 January 2016
Received in revised form 10 May 2016
Accepted 14 May 2016

Keywords:
Integrated processing
Conservation biomass
Fast pyrolysis
Biomass availability
Low input high diversity
Biocrude

ABSTRACT

Waste biomass is generated during the conservation management of semi-natural habitats, and represents an unused resource and potential bioenergy feedstock that does not compete with food production. Thermogravimetric analysis was used to characterise a representative range of biomass generated during conservation management in Wales. Of the biomass types assessed, those dominated by rush (*Juncus effuses*) and bracken (*Pteridium aquilinum*) exhibited the highest and lowest volatile compositions respectively and were selected for bench scale conversion via fast pyrolysis. Each biomass type was ensiled and a sub-sample of silage was washed and pressed. Demineralization of conservation biomass through washing and pressing was associated with higher oil yields following fast pyrolysis. The oil yields were within the published range established for the dedicated energy crops miscanthus and willow. In order to examine the potential a multiple output energy system was developed with gross power production estimates following valorisation of the press fluid, char and oil. If used in multi fuel industrial burners the char and oil alone would displace 3.9×10^5 tonnes per year of No. 2 light oil using Welsh biomass from conservation management. Bioenergy and product development using these feedstocks could simultaneously support biodiversity management and displace fossil fuels, thereby reducing GHG emissions. Gross power generation predictions show good potential.

1. Introduction

Declining fossil fuel reserves and the negative environmental impact associated with their use has driven research into alternative and sustainable alternatives. Renewable energy supplies in the form of liquid, gas and solid fuel are reliant on biomass as a feedstock [1]. Production of these products from biomass grown in areas that could be used to grow food has received criticism [2]. This has led to research into the use of low input high diversity (LIHD) biomass, that is generated during the management of semi-natural landscapes, for energy production [2–4], where there is no negative impact, either direct or indirect, on food production.

Across Europe semi-natural landscapes are in decline due to changes in agricultural practices [5]. For many semi-natural vegetation communities in the UK overstocking in the 1980s was

* Corresponding author.
E-mail address: jcc@aber.ac.uk (J. Corton).

http://dx.doi.org/10.1016/j.apenergy.2016.05.088
0306-2619/

followed by understocking in the late 1990's and beyond. Both situations are detrimental to biodiversity [6]. One way to preserve the biodiversity of these habitats and landscapes is to cut and remove the biomass. If they are not managed by cutting landscape degradation takes place and biodiversity decreases as dominant plant species spread [7,8]. Many conservation bodies and charities employ this management method and generate large amounts of biomass as a consequence [9]. Currently the biomass generated during conservation management is treated as waste and left for decomposition. However, this widespread and plentiful resource could be used as a feedstock for bioenergy, plus its use could have a positive impact upon national GHG targets, biodiversity and ecosystem services [3].

In 2006 Tilman et al. [2] highlighted the advantages of LIHD grasslands for biofuel production in the USA, and European perspectives have been provided [3,10–12]. Work by Tonn et al. [13] employed biomass from land in Germany hat was no longer utilised for livestock production to make bioenergy in the form of combustion fuel. Fischer Tropsch fuel production was modelled by Corton et al. [3]. The potential of the Estonian resource has been reported Heinsoo et al. [10]. More recently Meerbeek et al. [14] examined conservation biomass alongside roadside verge waste as feedstocks for biogas production via anaerobic digestion (AD). However, none of these works examined process routes that utilise fast pyrolysis.

One process that was developed around the specific requirements (low sugar and high mineral content) of LIHD biomass was the Integrated Generation of Solid Fuel and Biogas from Biomass (IFBB) procedure [4,15]. The IFBB process is a green biorefinery model [16] whereby hydrothermal pre-treatment and mechanical dehydration (HPMD) by pressing, using a screw press, produces a fibrous product (press cake) with a significantly lower mineral composition than that of the original feed-stock. The intention was to make a better combustion fuel through partial demineralisation [17]. Lower alkali metal composition is correlated with a higher ash softening temperature and this is desirable in a combustion fuel. Demineralisation also has positive implications for emissions and combustion chamber preservation by lowering sulphur (SO_X) and chlorine concentrations [18]. In the IFBB process the fluid generated during pressing was used as a feedstock for anaerobic digestion and the biogas generated used as an energy source for the system, ensuring a favourable energy balance [15]. The volume of fluid generated is dependent upon the moisture content, water wash pre-treatment employed and species composition of the feedstock. An approximation for guidance would be ~0.3 tonnes of fluid (wet weight) per tonne of dry feedstock [3].

One process route that could potentially be integrated into a green refinery system (such as IFBB) is fast pyrolysis. Fast pyrolysis is a process whereby organic vapours, gas, water and char are produced by heating biomass to 450–600 °C. The process is characterised by high heating rates and low residence times for the organic vapours that are generated [19]. The organic vapours and water are rapidly condensed to form a homogenous bio-oil, and this oil is the primary and major product of fast pyrolysis. The oil can be used as a fuel for burning in boilers following burner modification, steam reformed to make hydrogen fuel or processed to produce chemicals [20]. Fast pyrolysis is also ideal for decentralised systems as the liquid product has a very high energy density and can be readily transported to the point of use. In the current work we subjected biomass in the form of silage that had been hydrothermally pre-treated and screw-pressed (as in the IFBB process), plus control ensiled biomass that had not been pressed, to fast pyrolysis.

An analysis of the impact of semi-demineralisation upon the yields from fast pyrolysis was one aspect of the current study. Another aspect was to examine the broad potential of a system that exploits AD of the press fluid with fast pyrolysis of the press cake to create multiple energy carriers. Work by Lou et al. [21] demonstrated that de-ashing and mineral removal was important for successful bio-oil production using bamboo as a feedstock. The presence of minerals had an influence upon the bio-oil composition and encouraged undesirable CO_2 production during fast pyrolysis. Following HPMD however, only partial demineralisation was achieved and we have yet to establish the effect of the process on product yields following fast pyrolysis. Mineral composition is known to be dependent on species and habitat origin as well as pre-treatment [22]. In this work we examined the impact of vegetation community type on the product yields and the characteristics of those products as obtained from fast pyrolysis of LIHD biomass.

Biomass harvested from conservation of semi natural habitats is heterogeneous being made up of a diverse range of plant species. In this paper we seek to determine the suitability of LIHD biomass as a feedstock for oil production via fast pyrolysis following conservation through ensiling and after a washing and pressing pre-treatment. The results of this conversion are compared to those generated from fast pyrolysis of the purpose grown bioenergy crops miscanthus and willow.

Combining thermochemical and biological conversion routes (fast pyrolysis and AD respectively in the current study) into a unified system has been examined previously but not in the manner proposed in this work. One processing system that combines thermochemical and biological conversion routes has been reported previously by Monlau et al. [23] and is a good example of how conversion routes can be cascaded to encourage positive energy balances. Monlau et al. [23] used the digestate waste produced during anaerobic digestion as a feedstock for pyrolysis, once dried by the excess energy from the anaerobic digestor. Therefore the system exploits a feedback between the two conversion routes (through drying) and this differs from the approach taken by Inyang et al. [24] for example, who pyrolysed digestate without integrating a feedback loop between the conversion routes.

In the final section a potential system is illustrated that combines anaerobic digestion of the press fluid alongside oil and char production via fast pyrolysis. Estimations of gross energy output are presented. This provides some perspective as to the scope and potential scale of the resource and system. It is envisaged that the gap between research and commercial realization of the fast pyrolysis conversion route may benefit from the energy generated from anaerobic digestion of press fluids, in combination with the valorisation of the char bi-product. Novel experimental data was generated by subjecting representative UK LIHD feedstocks to fast pyrolysis. Gross theoretical outputs of the whole system are calculated using published resources. Therefore this work implements a cascading processes promoted by the notion of industrial symbiosis [25] in order to increase the feasibility of biomass conversion.

2. Materials and methods

2.1. Experimental design

During research associated with the IFBB system six distinct UK semi-natural vegetation communities that were dominated by different plant species were harvested and prepared by (a) ensiling only, or (b) ensiling followed by hydrothermal pre-treatment with mechanical dehydration (HPMD; generating a press cake and a fluid). Each community type had three fenced established plots measuring 10 m by 10 m. Resource constraints meant that we prioritised our analyses on four fast pyrolysis runs which tested the impact of demineralisation by HPMD on the products of fast pyrolysis.