Biomass and Bioenergy 108 (2018) 207–216

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

'Woods-to-Wake' Life Cycle Assessment of residual woody biomass based jet-fuel using mild bisulfite pretreatment

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ARTICLE INFO

Keywords:
LCA
Lignocellulosic feedstock
Biofuel
Iso-paraffinic kerosene
Harvest slash
Avoided impacts

ABSTRACT

The residual woody biomass (a.k.a. harvest slash) produced during forest harvest operations in the Pacific Northwest is generally collected into piles and burned and/or left on the forest floor to decompose. Producing drop-in biofuels from this residual cellulosic feedstock can provide an alternative use for this unused resource while simultaneously displacing petroleum based fuels. Utilizing a 'Woods-to-Wake' (WoTW) Life Cycle Assessment (LCA) approach, which is comparable to a Well-to-Wake (WTW) LCA for petroleum based aviation fuel, this paper assesses the environmental implications of feedstock recovery, production, and utilization of residual woody biomass based biojet fuel. This paper also presents a comparative assessment of the environmental implications of substituting petroleum based jet fuel with that of residual woody biomass based biojet fuel.

The bioconversion process presented in this paper uses a mild bisulfite pre-treatment of the feedstock to liberate the C5 and C6 sugars which then go through enzymatic hydrolysis and saccharification to produce fermentable sugars. The sugars are then converted to bio-jet fuel (iso-paraffinic kerosene, IPK) using a proprietary biocatalytic fermentation and oligomerization process. The WoTW environmental implications of producing woody biomass based jet-fuel are then compared to the WTW environmental impacts of producing petroleum based jet-fuel. The results reveal that the WoTW global warming impact of residual wood based bio-jet fuel represents a 78% improvement over the WTW global warming impact of petroleum-based jet fuel.

1. Introduction

Interest in the biochemical conversion of non-merchantable woody biomass (especially harvest slash) into biofuels and other usable energy products is continually growing [1–3]. One of the reasons for this increased interest is that, as countries seek ways to reduce GHG emissions, renewable forest based bioenergy is seen as an appealing alternative to fossil fuels [4]. In the US, the significance of converting residual forest biomass into biofuels goes beyond fossil fuel displacement. Typical forest harvest operations in the US, especially along the western part of the country, leave a considerable volume of unused woody biomass in the forest in the form of treetops and branches [5]. Given the limited economic feasibility of extracting these harvest residues, the residual woody biomass is typically piled and burned in the forest as prescribed burns [6–8]. Moreover, the lack of a reliable market for woody biomass has reduced the economic incentives to conduct forest thinning activities, resulting in the steady accumulation of woody biomass in forests which have reached hazardous levels [9,10]. This increasing volume of woody biomass has contributed to the increase in the number of catastrophic wildfires that have occurred in the western US over the past decade. The burning of woody biomass in forests (both prescribed burns and wildfires) is a major source of greenhouse gas emissions in the western US [11,12]. Woody biomass burning results in emissions of various compounds, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), volatile and semivolatile organic compounds (VOC and SVOC), particulate matter (PM_{10} and $PM_{2.5}$), ammonia (NH_3), sulfur dioxide (SO_2) and methane (CH_4) [13]. While some of the emitted chemicals, such as CO_2 and CH_4, are potent agents of global climate change [14], biomass burning also adversely affects local and regional air quality, with acute negative impacts on human health at the local and regional levels [15].

One strategy for the increased utilization of thinning and post-

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https://doi.org/10.1016/j.biombioe.2017.10.041
Received 15 September 2016; Received in revised form 5 April 2017; Accepted 28 October 2017

Abbreviations

ASTM	American Society for Testing and Materials
CO	Carbon monoxide
CO_2	Carbon dioxide
FRS	Fermentation residual solids
GHG	Greenhouse gas
GREET	Greenhouse gases, regulated emissions, and energy use in transportation
GW	Global warming
GWP	Global warming potential
iBuOH	Isobutanol
IPK	Iso-paraffinic kerosene
ISO	International Standards Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
MBS	Mild bisulfite
NH_3	Ammonia
NO_x	Nitrogen oxide
PM	Particulate matter
SO_2	Sulfur dioxide
SSL	Spent sulfite liquor
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile organic compounds
WoTW	Woods-to-Wake
WTW	Well-to-wake

harvest residual woody biomass is its conversion to advanced second generation drop-in fuels. Conversion of the residual biomass into bio-fuel will not only remove slash piles from forests which mitigates the negative environment impacts of decaying or burning [16,17], but it will displace fossil fuels, thereby reducing our reliance on petroleum-based fuels. Renewable second generation (from non-food sources) jet fuel is a practical solution for the aviation industry looking for an alternative carbon-reduction strategy that requires no aircraft or engine modifications [18,19]. Despite the potential environmental benefits of using forest residuals, the economic feasibility of extracting residuals from the forest is limited due to a combination of low market demand and high collection and transportation costs [20,21]. Recently, the use of clean renewable fuels has been encouraged since the Energy Independence and Security Act was signed into law in 2007, providing meaningful economic opportunity for the reduction of foreign oil dependence and greenhouse gas emissions [22]. The US Energy Information Administration (EIA) requires that the overall greenhouse gas emissions of cellulosic bio-fuel must be 60% lower than the carbon emissions generated during the production of petroleum-based jet fuel in order to meet public procurement guidelines [23]. It has been suggested that the replacement of fossil fuels with biofuels produced from forest residues and forest thinning could substantially reduce greenhouse gas emissions [24].

To estimate the overall environmental impact associated with recovering residual woody biomass to produce bio-jet fuel, as well as any net reduction in emissions to the atmosphere achieved by displacing fossil fuels, the Life Cycle Assessment (LCA) method is used. Life Cycle Assessment (LCA) is an internationally recognized methodology to assess the environmental impacts of a product or activity (a system of products) over its entire life cycle. LCA has evolved into an internationally accepted method for analyzing the complex environmental impacts of a product [25].

This paper presents a comprehensive Life Cycle Assessment (LCA) of forest residue based aviation fuel using a ‘Woods-to-Wake’ (WoTW)

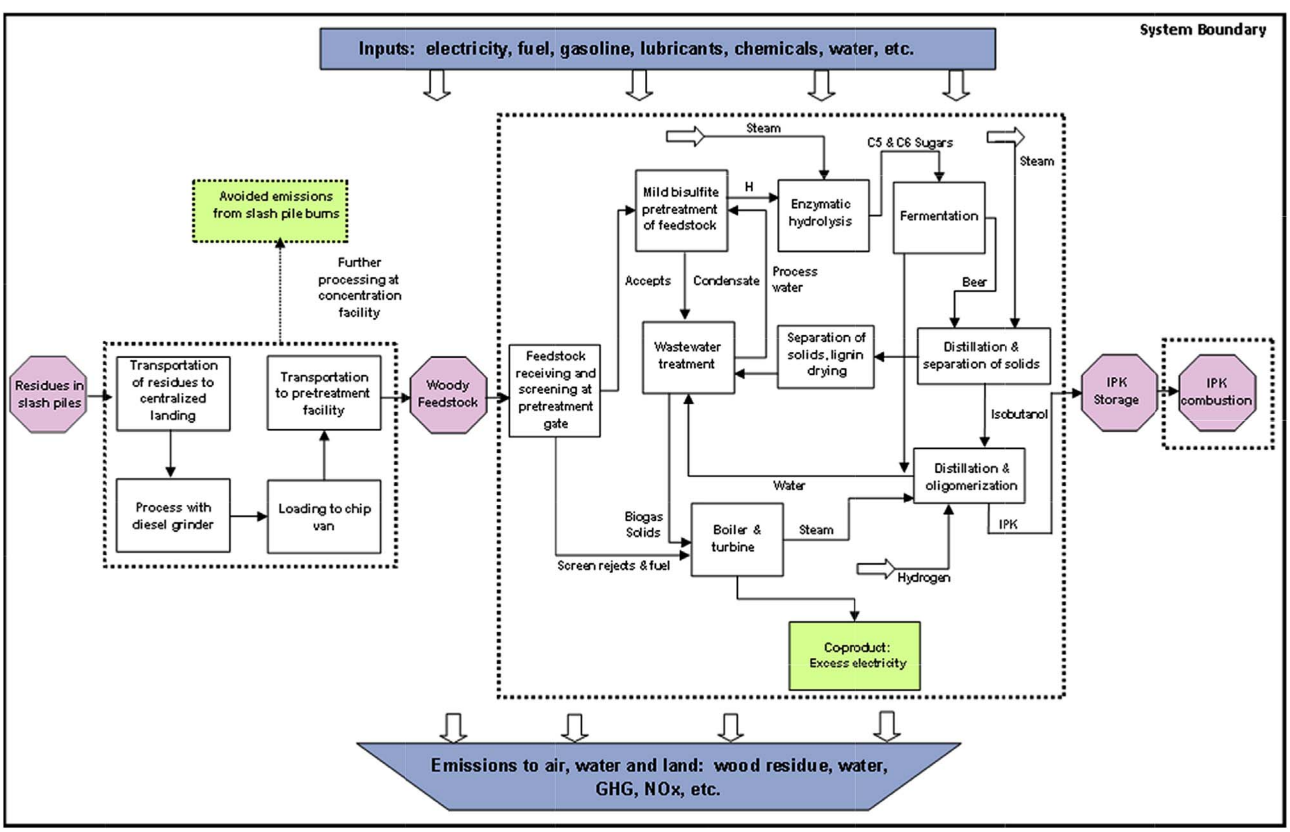

Fig. 1. System boundary of the residual woody biomass based jet-fuel LCA.