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GHG emission balances and prospects of hydrogen enhanced synthetic biofuels from solid biomass in the European context

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HIGHLIGHTS

- We study GHG emissions of hydrogen enhanced synthetic biofuels from solid biomass.
- We provide a review for the newly proposed EU sustainability criteria.
- The carbon intensity of electricity used to produce hydrogen is a defining factor.
- To pass future GHG criteria electricity with under 110 $gCO_2/kW\,h$ emission is needed.
- We also study the effect of adding an emission factor for the wood feedstock.

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ABSTRACT

The European Commission has proposed a minimum share of 3.6% for advanced biofuels in transport in 2030. Satisfying this target using synthetic biofuels would require 48–62 Mt/a of forest residue feedstock. If all biofuel plants were maximally enhanced with additional hydrogen input, the biomass demand would be reduced by 35 Mt to 16–24 Mt/a. As sustainable biomass is a limited resource, such drastic improvements in the efficiency of biomass use have a favourable impact on biomass availability. In this work we assume electrolysis of water as the source of hydrogen and investigate the GHG emission balances of hydrogen enhanced biofuels using the calculation method provided in the European Union's sustainability criteria for biofuels. The required 70% emission saving compared to fossil fuels is achieved when the carbon intensity of electricity remains under 84–110 gCO_2/kWh, depending on the process configuration. In addition, we study the possibility that an emission factor could be allocated to the wood biomass, referring to recent discussions on climate impacts of forest bioenergy. Without hydrogen enhancement, the emission factor needs to remain below 13 gCO_2/MJ_{wood} to meet the 70% requirement, while for hydrogen-enhanced configurations it could increase to 36 gCO_2/MJ_{wood}, under the assumption of zero emission electricity.

1. Introduction

The global transportation infrastructure is built around petroleum-derived fuels, which are currently responsible for almost a quarter of energy-related carbon dioxide (CO_2) emissions [1]. Significant reduction to these emissions requires both efficiency improvements and a large-scale shift to low-GHG (greenhouse gas) energy carriers. Accordingly, the European Union has set a mandatory 10% target for renewable energy in transport by 2020, which is complemented by a binding sustainability criteria for liquid and gaseous biofuels in the Renewable Energy Directive, also known as RED [2]. The EU Commission has recently published a new proposal of the directive (referred to as RED2) for the period of 2021–2030 [3]. In RED2, no general target for renewable energy in transport is set, but a minimum share of renewable fuels that suppliers need to include in their fuel supply is proposed. This minimum share for 'advanced biofuels', 'renewable liquid and gaseous transport fuels of non-biological origin', 'waste based fossil fuels' and 'renewable electricity' shall be at least 1.5% in 2021 and increase to 6.8% in 2030.[1] Of this minimum share, 'advanced biofuels' shall cover at least 0.5% in 2021 and 3.6% by 2030. In this paper,

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[1] In RED2 'advanced biofuels' refers to biofuels and biogas produced from feedstocks listed in part A of Annex IX of the directive including, i.e. cellulosic feedstocks, wastes and residues. The 'renewable liquid and gaseous transport fuels of non-biological origin' and 'waste based fossil fuels' listed under the minimum share target refer to, e.g. different power-to-gas solutions, renewable hydrogen, etc.

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we study the production of advanced biofuels from forest residues (via gasification) and hydrogen (via electrolysis of water), which can be considered a combination of 'advanced biofuels' as defined in RED2 and hydrogen based fuel.

The production of advanced biofuels for transportation can be based on a broad range of feedstocks and technological approaches. However, biofuels from non-edible lignocellulosic feedstocks (e.g. forestry and agro-residues) produced by a thermal conversion process based on gasification and catalytic fuel synthesis are often proposed [4]. The efficiency of such biorefineries has been a topic for a considerable number of studies, with estimates usually ranging between 50 and 60% (LHV), depending on the process configuration and the choice of end-product [5–9]. If by-product heat from the process can also be utilised, either as process steam or district heat, an additional 20–30% point improvement can be attained, leading to around 80% overall efficiency [9]. Thus, in terms of energy use, the production of synthetic biofuels makes for an efficient use of biomass, provided close attention is paid to heat integration issues.

However, in terms of material use the situation is quite different, as less than half of the feedstock carbon can be converted to biofuels using the aforementioned technique. Such modest carbon conversion is not a result of process-related imperfections, but rather due to biomass being a hydrogen-poor feedstock, i.e. after all the inherently available hydrogen is used up, the remaining "surplus" carbon needs to be vented from the process as CO_2. Hannula (2016) [10] studied the possibility of lifting this inherent constraint by feeding additional hydrogen into the process from an external source (see Fig. 1). The results indicated a possibility to increase the biofuel output by 2.6–3.1-fold in comparison to a similar process without hydrogen addition. This observation, also corroborated in Refs. [11–18], has potentially important consequences for the discussion of biomass availability and the ensuing biofuel supply potential. In this study *hydrogen enhancement* is used to describe a process where additional hydrogen (from an external source) is added to the biorefinery process, with the specific intention of increasing the carbon efficiency of the process. This concept differs substantially from the commonly applied hydrotreatment process, where the intention is either to remove unwanted substances or to improve the quality of the product (cf. hydrotreatment of HVOs, pyrolysis oil or Fischer-Tropsch waxes), but not to substantially increase the overall carbon efficiency of the process.

The RED2 proposal of a 3.6% minimum share of advanced biofuels of the total fuel use in the EU corresponds to approximately 11 Mtoe of biofuels by 2030 [19], compared to 3.5 Mtoe of advanced biofuels used in 2014 in the EU (1% of total consumption), and 21 Mtoe of total renewables used in transportation in 2014 (5.9% of total EU consumption) [20]. Based on the work of Hannula (2016) we analyse how to achieve this target with different advanced biofuels concepts, and calculate the resulting need for sustainable biomass resources. Increasing the carbon efficiency of biomass conversion can greatly contribute to the improved sustainability of biofuels, as biomass and available land are both limited resources. However, other sustainability aspects, such as climate impacts also need to be ensured.

Both RED and RED2 include binding sustainability criteria for biofuels. These criteria provide a method for calculating the GHG emission savings gained by displacing fossil fuels with biofuels (the so called RED method). Only biofuels that are in compliance with the EU's criteria can be counted to the renewable energy targets, and can profit from national support systems. For biofuels produced in plants that come into operation during 2018, a minimum of 60% emission saving is required. In RED2 the emission saving limit has been raised to 70% for advanced biofuels.

The GHG emissions of hydrotreated biofuels have recently been studied in several publications [21–24], and the GHG emissions of

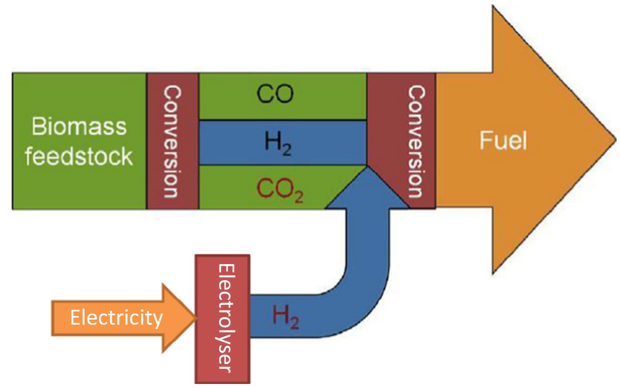

Fig. 1. Schematic representation of a hydrogen-enhanced synthetic biorefinery concept.

'advanced biofuels', according to the RED GHG calculation method, have been studied for example in [25–27]. However, only one previous study was found concerning the GHG emissions of the *hydrogen enhanced* biofuel concept by Bernical et al. 2013 [17]. No studies were found where a hydrogen enhanced concept was studied according to the RED criteria. Bernical et al. 2013 [17] concluded that in the hydrogen enhanced concepts the emissions caused by electricity consumption in hydrogen production have a major impact on the GHG emissions. The same challenge is encountered with power-to-gas, also know as CCU (carbon capture and utilisation) concepts, where hydrogen is needed to convert CO_2 from flue gas, process gases or air to methane or liquid fuels [28,29]. The GHG emissions related to power-to-gas concepts have started to gain attention in several publications [29–36]. These studies show that while an assumption of using only highly decarbonised electricity results in very positive climate impacts [33,34], the assumption of 100% grid electricity may result in even higher emissions compared to traditional (fossil) products [32], depending on the generation mix. Thus, our analysis puts a high emphasis on the emission profile of the electricity used to produce the hydrogen that is again used to enhance the biofuel process.

In this work we examine the GHG emissions that pertain to the production of advanced biofuels from the combination of forest residues (via gasification) and hydrogen (via electrolysis of water), for a number of process configurations, using the methods provided in the current EU RED and the updated RED2 sustainability criteria for biofuels. Our study shows how the use of biomass resources could be optimised with novel technologies. We also show how the development of future concepts relates to the implementation of the EU sustainability criteria, and provide a timely review of the newly proposed RED2 criteria, which concern the biofuels to be produced and sold in the EU in 2021–2030. The study is relevant for power-to-gas and other concepts reliant on hydrogen production via electrolysis. As the EU sustainability criteria for the power-to-gas concepts are yet to be defined, this study provides insights on critical aspects concerning the GHG calculation of these technologies.

In addition to the RED GHG criteria we study the possibility that an emission factor would be allocated to the wood biomass, referring to the recent discussion on climate impacts of forest bioenergy [e.g., 37–42]. This issue has been covered by some GHG studies on forest based biofuels [e.g., 25,26], but not in relation to the hydrogen enhancement, which will significantly affect the result due to the more efficient use of biomass. Our goal is to identify those emission factor thresholds (for biomass and electricity) that lead to 60% and 70% emission savings.