Energy 104 (2016) 199–212

Contents lists available at ScienceDirect

Energy

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

Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment

Ilkka Hannula*

VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Finland

A R T I C L E I N F O

Article history:
Received 15 December 2015
Received in revised form
2 March 2016
Accepted 25 March 2016

Keywords:
Biomass residues
Gasification
Electrolysis
Carbon dioxide
Synthetic fuels
European Union

A B S T R A C T

Potential to increase biofuels output from a gasification-based biorefinery using external hydrogen supply (enhancement) was investigated. Up to 2.6 or 3.1-fold increase in biofuel output could be attained for gasoline or methane production over reference plant configurations, respectively. Such enhanced process designs become economically attractive over non-enhanced designs when the average cost of low-carbon hydrogen falls below 2.2–2.8 €/kg, depending on the process configuration. If all sustainably available wastes and residues in the European Union (197 Mt/a) were collected and converted only to biofuels, using maximal hydrogen enhancement, the daily production would amount to 1.8–2.8 million oil equivalent barrels. This total supply of hydrogen enhanced biofuels could displace up to 41–63 per cent of the EU (European Union)'s road transport fuel demand in 2030, again depending on the choice of process design.

1. Background

The amount of atmospheric carbon is currently increasing at a rate of 4.3 ± 0.1 gigatonnes (C) per year, mainly as a result of human activity [1]. Multiple lines of scientific evidence show that this increasing amount of carbon in the atmosphere is warming the global climate system [2–4]. To limit warming under 2 °C, the European Council in 2011 reconfirmed the EU (European Union) objective of reducing GHG (greenhouse gas) emissions by 80–95% by 2050 compared to 1990. The European Council also endorsed a binding EU target of at least 40% domestic reduction in GHG emissions by 2030 compared to 1990. The target will be achieved collectively by the EU in the most cost-effective manner possible, with the reductions in the ETS (Emissions Trading System) and non-ETS sectors amounting to 43% and 30% by 2030 compared to 2005, respectively.

Although carbon emissions are generally falling in the European Union, transportation still counts among the few sectors that resist this overall trend (see Fig. 1), as the progress made in improving vehicle efficiency has been largely off-set by the increased amount of personal and freight transport. Therefore, a wide-ranging switch to renewable fuels is required for driving down transportation emissions in the long term. According to a IEA (International Energy Agency) roadmap study [5], biofuels (i.e. fuels produced from renewable plant matter) could provide 27% of total transport fuel consumption by 2050 while avoiding around 2.1 gigatonnes of CO_2 emissions per year if sustainably produced. However, meeting this demand would require 65 EJ of biofuel feedstock, occupying around 100 million hectares of land, which was considered challenging by the study given the growing competition for land for food and fibre.

Searle and Malins [6] examined the availability of wastes and residues in the European Union that might be realistically mobilised in an economically viable manner for the production of advanced biofuels. Their estimates on the present and future (2030) feedstock availabilities in different categories is shown in Table 1. According to their findings, almost 1 million oil equivalent barrels per day could be supplied based on these feedstocks, displacing 16 per cent of road transport fuel demand in 2030 [6]. However, it is likely that competition over feedstocks will restrict the total potential, so the estimate should be understood as upper limit for the biofuels supply.

2. Introduction

This paper examines the potential to increase fuels production from a given amount of biomass, by feeding additional hydrogen to a gasification-based biorefinery. The process is not sensitive to the

* Tel.: +358 20 722 6370.
E-mail address: ilkka.hannula@vtt.fi.

http://dx.doi.org/10.1016/j.energy.2016.03.119
0360-5442/

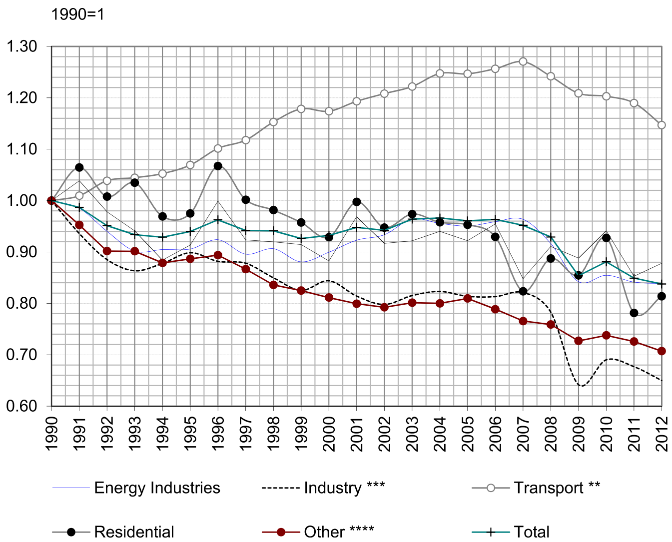

Fig. 1. GHG emissions* by sector in EU-28. Million tonnes CO_2 equivalent. (*) Excluding LULUCF (Land Use, Land-Use Change and Forestry) emissions and International Bunkers; (**) Excluding International Bunkers (international traffic departing from the EU); (***) Emissions from Manufacturing and Construction and Industrial Processes; (****) Emissions from Fuel Combustion in Agriculture/Forestry/Fisheries, Other (not specified elsewhere), Fugitive Emissions from Fuels, Solvent and Other Product Use, Agriculture, Waste, Other [35].

origin of the hydrogen, but production via electrolysis of water, driven by electricity from low-carbon sources like wind, solar, hydropower or nuclear[1] is examined as a possible option. The investigation is based on a systematic analysis and comparison of eight selected plant configurations capable of producing synthetic biofuels from biomass feedstocks via thermochemical gasification. Mass and energy flows are calculated for each plant configuration with ASPEN® Plus (Aspen) process simulation software. The overall economics are also evaluated in terms of euros (€) per gigajoule (GJ), from the perspective of a synthetic fuel producer, based on an underlying component-level capital cost estimates.

The production of synthetic fuels (synfuels) from carbonaceous feedstocks is a well-established technology, although all commercial scale plants to date have been operated with fossil feedstocks (such as coal and natural gas) and redesign of some key parts of the process is required to switch using renewable feedstocks. A considerable amount of work has been done to accelerate the progress of synthetic biofuels technologies [7], which are currently moving through research, development and demonstration to commercialisation [8–11].

The possibility to enhance synthetic biofuels production with additional (electrolytic) hydrogen has been occasionally discussed in the scientific literature. Mignard and Pritchard [12] noted, using methanol production as an example, that the integration can contribute to more effective utilisation of biomass by increasing the methanol output by 130%. They also noted that co-utilisation of biomass and electricity could rise to prominence in the future if competition over land availability with food and feed production starts to limit the contribution of biofuels to a low-carbon economy. Hansen et al. [13] studied the consequences of using SOEC (solid oxide electrolysis) to assist methanol production from biomass gasification and concluded that methanol production can be more than doubled at the expense of using significant amount of

[1] Biomass is also an important source of low-carbon electricity, but this option is excluded here as it would compete for the same resource.

Table 1
Present and future (2030) availability of sustainable wastes and residues in the EU [6].

Category	Subcategory	Current availability, Mt/a	2030 availability, Mt/a
Waste	Paper	17.5	12.3
	Wood	8	5.6
	Food and garden	37.6	26.3
Crop residues		122	139
Forestry residues		40	40
Sum		225	223

electricity to drive the electrolysis. Pozzo et al. [14] analysed an advanced concept where DME (dimethyl ether) was produced with biomass gasification and high-temperature co-electrolysis (SOEC). They noted that the specific productivity of DME from biomass could be greatly increased (nearly doubled) by electrolyser enhancement. Hannula [15] examined the impact of a slight hydrogen addition on the performance and costs of synfuels production and found hydrogen supplemented biofuels more cost-effective than non-biomass synfuels (electrofuels) under a wide range of economic assumptions.

3. Methods

3.1. Plant configurations

All plant configurations analysed in this work are based on a thermochemical conversion of biomass residues to synthesis gas via gasification, followed by subsequent catalytic conversion of synthesis gas to fuels. These *base case* process configurations are compared with *enhanced* process configurations where biomass-derived synthesis gas is supplemented with external hydrogen to maximise the conversion of synthesis gas carbon to fuel. The considered plant configurations illustrate two basic gasification alternatives:

- autothermal (direct) gasification with a mixture of steam and oxygen, or
- allothermal (indirect) gasification with steam;

and two different end-product alternatives:

- synthetic gasoline via methanol, or
- synthetic natural gas (methane).

In addition, following alternatives for the treatment of syngas CO_2 are examined:

- removal by a physical scrubbing system,
- conversion to fuel with additional hydrogen from external source.

The combination of these alternatives gives eight basic configurations, each characterised by distinctive plant designs. The plants are identified by a sequence of two letters, where first letter indicates the gasifier type (O = oxygen, S = steam) and second letter the main product (G = gasoline, M = methane). In addition, for plant configurations that feature external hydrogen supply (to maximise overall carbon conversion), the acronyms are amended with a plus (+) sign. For a summary of the examined alternatives, see Table 2. A schematic illustration of the enhanced plant designs is given in Fig. 2, while process layouts (excluding syntheses) are given in Figs. A.10, A.11, A.12 and A.13.