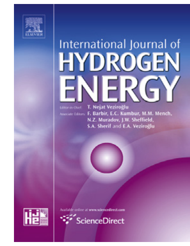
Available online at www.sciencedirect.com

ScienceDirect

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



Technical, economic and environmental assessment of technologies for the production of biohydrogen and its distribution Results of the Hy-NOW study

Konstantin Zech [a,*], Katja Oehmichen [b], Elias Grasemann [a], Julia Michaelis [c], Simon Funke [c], Michael Seiffert [a]

[a] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Department Biorefineries, Torgauer Straße 116, 04347 Leipzig, Germany

[b] DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Department Bioenergy Systems, Torgauer Straße 116, 04347 Leipzig, Germany

[c] Fraunhofer Institute for Systems and Innovation Research ISI, Breslauer Straße 48, 76139 Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 14 July 2014
Received in revised form
21 January 2015
Accepted 30 January 2015
Available online 12 March 2015

Keywords:
Biohydrogen
Production
Distribution
Economics
Emissions

ABSTRACT

This article summarises the results from the study "Hy-NOW". It covers the technical, economic and environmental performance of 3 selected concepts for the production and distribution of hydrogen from biomass. Firstly, the 3 concepts are selected based on the prerequisite, that they are suitable to be implemented in a demonstration plant within the short to medium term. 2 of the concepts are based on the allothermal gasification of biomass while the third is based on the steam reforming of biomethane. The results of the technical assessment show advantages for the gasification-based concepts in terms of their net biomass conversion efficiency. The economic assessment then shows the specific provision costs for the 3 concepts. The large-scaled gasification-based concept and the fermentation-based concept boast specific biohydrogen production costs of around 4 EUR/kg H_2. The small-scaled gasification-based concept leads to higher costs of around 6.3 EUR/kg H_2. With 30–40 % of the total provision costs, the distribution presents a substantial cost item. The gasification-based concepts both have greenhouse gas emissions of around 4 kg CO_2-Equivalents/kg H_2, while the fermentation-based concept has emissions of around 5 kg CO_2-Equivalents/kg H_2. The distribution of the biohydrogen produces more emissions than the provision of biomass and its conversion to biohydrogen combined.

Introduction

Biohydrogen is considered as a key option for providing sustainable and low-carbon transportation fuels in the future. The production and distribution of biohydrogen was examined within the study "Hy-NOW", which was funded through the German National Innovation Programme Hydrogen and Fuel Cell Technology (NIP). The study is structured into two

* *Corresponding author*. Tel.: +49 (0) 341 2434 478.
E-mail address: konstantin.zech@dbfz.de (K. Zech).

http://dx.doi.org/10.1016/j.ijhydene.2015.01.177

main parts. First, a pre-screening is conducted to deliver an oversight of the possible ways of biohydrogen production. The result is the identification of the 3 most promising production technologies. In doing so, the emphasis is laid on technologies that allow the realisation of a demonstration plant within the short to medium term. In the second part of the study, these 3 technologies are analysed in detail with regard to their technical, economic and environmental performance. The required distribution concepts are also included within the detailed analysis.

Hereafter, a summary of the results from the study "Hy-NOW" is presented. The pre-screening is outlined briefly, followed by the definition of the biohydrogen production and distribution concepts. The methodological approaches for the technical, economic and environmental assessments as well as the respective results are described afterwards. Finally, some concluding remarks are given. All assumptions and results are based on [7] if not indicated otherwise.

Materials and methods

As a background to the technical, economic and environmental assessments, the process leading to the selection of the 3 assessed technologies is outlined in the following. Then, the production and distribution concepts are defined and the methods of the assessments briefly explained.

Pre-screening of biohydrogen production technologies

Biohydrogen can be provided through various routes, which can be structured into (i) supply of raw material, (ii) conversion to biohydrogen, (iii) infrastructure for biohydrogen supply and (iv) energetic application of biohydrogen. Within the conversion step of biomass to biohydrogen, there is a large variety of possible technologies available, which can be divided into groups, with regard to the main conversion principle. These are primarily thermo-chemical conversion (e. g. reforming, gasification, pyrolysis etc.) and biochemical conversion technologies (e. g. fermentation, photolysis etc.). Physical-chemical (e. g. extraction) or biochemical conversion technologies can be used to produce secondary energy carriers (e. g. biogas) out of which biohydrogen can then be produced in a subsequent process step. Fig. 1 gives an overview of the possible routes to provide biohydrogen:

Within the "Hy-NOW"-study, the emphasis lies on direct conversion of biomass to biohydrogen, so the route via a biomass-based electricity generation with an ensuing electrolysis to produce hydrogen is omitted within the pre-screening. The direct conversion of biomass to biohydrogen via biochemical conversion is still subject to basic research and is therefore not able to be applied at a medium or large scale in the near future. The fermentation of biomass to hydrogen (similar to the biogas process) or the division of water through photolysis using microorganisms are therefore ruled out for the detailed analysis.

The thermo-chemical conversion based routes are however relatively advanced and a variety of processes are available that can produce biohydrogen or that can be adapted to do so. Table 1 shows examples of possible thermo-chemical processes for a biohydrogen production and their stage of development:

The selection of the 3 most promising technologies for the detailed analysis is based on a number of criteria, all targeted on the main objective to evaluate technologies that are able to be implemented in a demonstration plant within the short to medium term. The 3 major criteria are therefore the level of technology readiness, the system complexity and the required efforts to adapt the technology for a production of biohydrogen. A further criterion is the availability of data.

Based upon these deliberations, the 3 processes selected for the detailed analysis are (i) the steam reforming of biomethane, (ii) the fast internally circulating fluidized bed (FICFB) and the (iii) Heatpipe-reformer as two allothermal gasification technologies.

Biohydrogen production concepts

Based on the 3 selected technologies, biohydrogen production concepts are defined and later analysed. The biohydrogen outputs of the 3 concepts are chosen based on the typical outputs of the underlying technologies. The concepts are named as follows:

- Concept 1: *AFBG 1* with a biohydrogen output of 9 MW
- Concept 2: *AFBG 2* with a biohydrogen output of 3 MW
- Concept 3: *SRB* with a biohydrogen output of 6 MW

With the allothermal fluidized bed gasification (AFBG), concepts 1 and 2 both work according to a similar principle and are hence given their names accordingly. The reference technology for AFBG 1 is the FICFB process that has been realised in Europe with a thermal fuel power between 8 and 32 MW (here: 17.5 MW, cf. Table 4) [6]. The reference technology for AFBG 2 is the Heatpipe-reformer, which was offered with a thermal fuel power between 0.8 and 7 MW (here: 6.59 MW, cf. Table 4) [3]. Since the two concepts are based on a similar principle, the main difference between them is their biohydrogen output. Differences in the results of the detailed assessment can hence be mostly attributed to that circumstance. Similar results could be expected if both technologies were assessed assuming the same scale of capacity.

Fig. 2 depicts the layout of concept 1 (AFBG 1). Except for the gasification part of the concept, the layout is equal to that of concept 2 (AFBG 2). In both cases, the biomass (chopped forestry residues) is first dried and then gasified with steam in the absence of air to achieve a high caloric raw gas containing mostly CO_2, CO, H_2O, CH_4 and biohydrogen. After filtering, the CO in the raw gas is converted to biohydrogen and CO_2 in a water gas shift reactor utilizing further H_2O. The gas is cleaned and then the biohydrogen is extracted with a pressure swing adsorption. The separated CH_4 is circulated back to deliver the required process heat.

The layout of concept 3 is different from that of concepts 1 and 2 and is depicted in Fig. 3. It starts with a biogas process utilizing a typical raw material mix of maize silage, organic waste and liquid manure. The raw biogas is cleaned and then converted to biohydrogen and CO_2 utilizing steam reforming and a water gas shift reactor. For the separation of the biohydrogen, a pressure swing adsorption is