THE POSSIBLE ROLE OF HYDROGEN FROM WOODY BIOMASS IN A FUTURE SUSTAINABLE TRANSPORTATION SYSTEM

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ABSTRACT: Hydrogen made from renewable energy is supposed as one of the most promising transportation fuels of the future. As woody biomass might be used for liquid synthetic biofuels as well as for biohydrogen, in this paper a comparison is made, which possible benefits of hydrogen production from biomass could be achieved compared to the production of synthetic biofuels. Based on a life cycle approach the production of biohydrogen and FT-diesel from woody biomass, as the most interesting biomass resource, is analyzed for the European situation. The overall greenhouse gas emissions, energy and material consumption were calculated to compare bio-hydrogen and FT-Diesel applications for transportation purposes. There are different options to integrate biomass derived sustainable transportation fuels in a future transportation system. Biohydrogen might be one interesting option, which must be compared to other biomass based transportation fuels to identify the most promising biomass utilization routes in a mid-term perspective. Here an assessment is made for Europe to indicate, what might be the possible role of biohydrogen in a future sustainable transportation system compared to other current and future transportation fuels.
The comparison of the overall greenhouse gas emissions, energy and material consumption shows that biohydrogen from woody biomass might be an interesting fuel in combination with a high efficient and zero emission fuel cell system vehicle in a long term perspective (> 2020). The hydrogen infrastructure and future technological development mainly of fuel cell vehicles are preliminary conditions for the use of biohydrogen. For a midterm perspective synthetic biofuels from wood biomass (e.g. FT-diesel) are more promising, because they are easy to integrate in the existing infrastructure of fossil fuel (distribution, filling stations and ICE vehicles).
Keywords: hydrogen, Fischer Tropsch, transportation sector, life cycle assessment (LCA)

1 INTRODUCTION

The annual worldwide production of hydrogen is about 520 Bil. Nm³, mainly used as chemical raw material and in metallurgy. About 60% of the hydrogen is directly produced from fossil fuels and about 40% is a by-product of the petrochemical industry and the electrolyses for chlorine production. The energy content of the annual hydrogen production is about 5,700 PJ.

Hydrogen as energy carrier is produced in different thermochemical processes using fossil and renewable primary energy and raw materials. In principle it is also possible to produce hydrogen in biological processes with certain micro organisms. Hydrogen as energy carrier may be used in many different ways: hydrogen can be stored, transported and used to produce electricity, heat and power in stationary and mobile applications. The international research and discussion focuses on the questions, to which extent hydrogen as an energy carrier may play a role in future energy systems: Technical applications, costs, potentials and implementing strategies are analyzed. The background and the motivation of these international activities are the vision of a worldwide hydrogen economy, because hydrogen is considered as one of the cleanest and most innovative energy carriers to supply energy services. The main requirement for this vision is the production of hydrogen from renewable energy ("renewable hydrogen") carriers and raw materials. Therefore this paper focuses on renewable hydrogen made from woody biomass.

The European Commission has developed a future vision of a possible hydrogen energy future in 2050 (Figure 1), where hydrogen might play a major role as energy carrier for different energy services. To initiate current activities a skeleton proposal for a European hydrogen and fuel cell roadmap was developed [2]. This European roadmap is guidance for activities in Bioenergy Network of excellence (Bioenergy Noe; www.bioenergynoe.org) towards hydrogen from biomass ("biohydrogen") as energy carrier.

The introduction of biohydrogen must be seen in the context of current energy policies in Europe, which is lead by the following principles

- reduction of energy use
- increase of energy efficiency
- (further) increase of renewable energy
- reduction of greenhouse gas emissions
- reduction of air pollutants in cities

So far the long term perspectives for biohydrogen in the European energy system are seen in the transportation sector as main application. As biomass can easily be stored and used to produce combined heat and power at different capacity levels - small CHP with Organic Rankine Cycle or big CHP with Integrated gasification Combined Cycles (IGCC) - the stationary combined heat and power production from biohydrogen is not considered to play a significant role in a future sustainable energy system.

Based on a Delphi study on Europe's energy future to 2030 among 3000 European energy experts leads to following aspects [1]:

- short and medium perspective hydrogen can be produced from conventional sources - most probably natural gas – but on mid to long-term hydrogen from renewable energy should be main aim
- development of energy and cost efficient hydrogen production and storage needs intensified research
- hydrogen development path should be elaborated to specify hydrogen's role in the future energy system
- high market penetration of hydrogen production from diverse and renewable energy sources is due to happen in very long term, i.e. after 2030
- for high penetration of hydrogen into the energy market fiscal measures and regulations will be necessary
- main challenge associated with the use of hydrogen is the need to invest in the extensive, new infrastructure

for production, transportation, storage and usage systems

- serious doubts exist concerning the overall efficiency of the fuel cycle, so it is recommended to develop more efficient processes and avoid the risk of stranded assets
- there are strong recommendations to strive for the production of hydrogen from renewable energy, but the potential of renewable energy sources in the EU may be too limited for large-scale production and the resources may be more efficiently employed for other uses

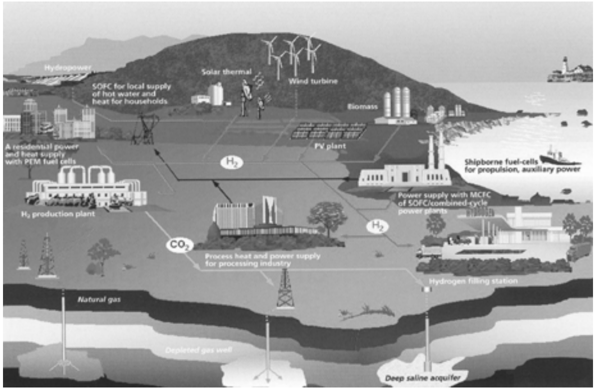

Figure 1: Hydrogen Energy and Fuel cells – a vision of our future [2]

2 GOAL AND SCOPE

The aim was to develop an assessment, if and under which conditions renewable hydrogen from biomass is a promising energy carrier of the future in the European energy system. Within this assessment the advantages and disadvantages of biohydrogen compared to the use of biomass for liquid transportation biofuels as Fischer-Tropsch (FT)-Diesel are analyzed. Technological, economic and ecological aspects are considered. These analyses shall provide an indication of the potential role of renewable biohydrogen to mobilize further potentials and applications for the additional use of biomass in Europe in transportation sector.

The following topics are considered:

- assessment of framework conditions for renewable hydrogen as energy carrier of the future
- biohydrogen compared to use of biomass for FT-diesel
- energy options and possible role of biohydrogen in the European roadmap for hydrogen.

The increase of biomass as renewable energy is an important driver for current and future energy policies. This analysis concentrated on transportation services, if biomass should be used directly as liquid biofuel or indirectly via biohydrogen and what the possible benefits compared to fossil fuels are (Figure 2).

The assessment is based on life cycle approach to analyze greenhouse gas emissions, primary energy consumption and material demand. In addition the transportation costs from other publications are used to cover also economic aspects. A comparison for the supply of transportation services with biohydrogen to the direct use of biomass for liquid biofuels (BTL) is made. The assessment focuses on possible hydrogen applications in European as transportation fuel around the year 2020, this means other biohydrogen applications are not considered, e.g. providing additional hydrogen for FT liquids and upgrading bio-oil from fast pyrolyses.

The three compared systems to provide transportation services are characterized as follows, a summary is shown in Figure 3:

1. "indirect use of wood biomass": biomass is used to produce biohydrogen by gasification of wood chips from forest residues, which are transported about 100 km to the plant, the gaseous biohydrogen is distributed with a pipeline (200 km) to the filling station, where it is compressed to 450 bar, after storage the biohydrogen is filled in a 300 bar tank of a fuel cell vehicle, which is used to provide the transportation service.
2. "direct use of wood biomass": biomass is used to produce FT-diesel by gasification of wood chips from forest residues, which are transported about 100 km to the plant, the FT-diesel is distributed (200 km) with a truck to the filling station, where existing infrastructure for diesel is used to storage and pump the FT-diesel in the tank of a vehicle with a diesel internal combustion engine, which is used to provide the transportation service.
3. "fossil energy": raw oil is extracted in Saudi Arabia and transported via ship and pipeline to a European refinery, where diesel is produced. The diesel is distributed with a truck to the filling station, where the diesel is used in a vehicle with a diesel internal combustion engine to provide transportation service.

The biomass wood chips derive from forest residues in Europe. For the biohydrogen production two different possible systems are considered.

- maximizing hydrogen production (1a) without electricity
- (economic) optimizing combined hydrogen and electricity production (1b).

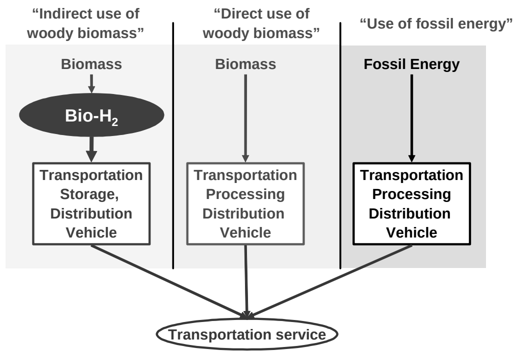

Figure 2: Comparison of energy systems – indirect use of biomass via biohydrogen, direct use of biomass (BTL) and use of fossil energy for transportation services

No	Resources	Fuel	Conversion	Propulsion system passenger vehicle[4)]
1a	Forest residues	Bio-hydrogen (Bio-H_2)	Gasification maximizing hydrogen production [1)]	Fuel cell (FC) [5)]
1b	Forest residues	Bio-hydrogen (Bio-H_2)	Gasification optimized with electricity as by-product [2)]	Fuel cell (FC) [5)]
2	Forest residues	FT-Diesel	Gasification with FT-synthesis with electricity as by-product [3)]	Internal combustion engine (ICE) [6)]
3	Crude oil	Diesel	Oil refinery	Internal combustion engine (ICE) [6)]

1) efficiency: 60% biomass to bio-H_2
2) efficiency: 32% biomass to bio-H_2 and 12% electricity
3) efficiency: 45% biomass to FT-diesel and 10% electricity
4) 10.000 km/a, lifetime 10 years
5) efficiency: 0.3 kWh/km
6) efficiency: 0.4 kWh/km

Figure 3: Systems considered to produce and use renewable hydrogen „Bio-H_2", FT-Diesel and fossil diesel, [3], [4], [5]

3 METHODOLOGY

The comparison of the three different systems for transportation services systems is made on a life cycle basis for environmental and economic aspects. For details see [3], [4] and [5]. This means starting with renewable biomass production in nature until ending up with a transportation service, where also all facilities that are necessary to provide the transportation service e.g. machineries to collect forest residues, truck to transport the wood, conversion facilities to biohydrogen and vehicle are included (Figure 4).

The following environmental effects are considered:
- greenhouse gas emissions
- (fossil) primary energy consumption
- material demand

The greenhouse gas emission are calculated in carbon dioxide equivalents including carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O). The primary energy consumption describes the necessary amount of energy input to provide the transportation service, where a distinction between fossil and renewable energy (mainly biomass) carriers is made. The material demand describes, how much material e.g. steel, concrete is necessary to provide the transportation service.

The comparison is done for the supply of a transportation service "1 km drive in a passenger car" where the environmental effect are given in the following units:
- greenhouse gas emissions in g CO_2-eq/km
- primary energy consumption in $kWh_{primary\ energy}$/km
- material demand in g/km.

It is assumed, that the by-product electricity substitutes renewable electricity from hydropower and biomass CHP plants.

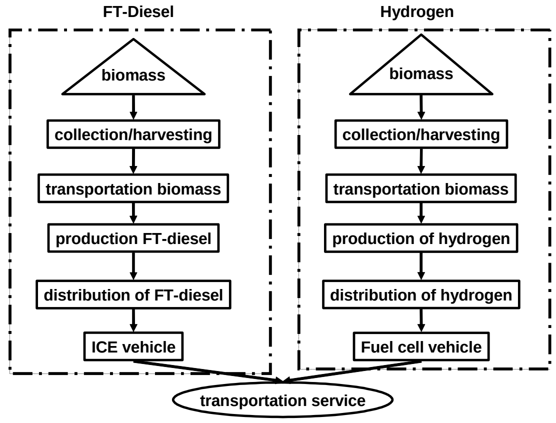

Figure 4: Scheme of considered transportation systems with woody biomass

4 RESULT

The results for the three considered environmental effects are shown. Afterwards a summary of all considered aspects is given.

4.1 Environmental effects

In Figure 5 the greenhouse gas emissions of the transportation service based on the life cycle consideration of the different transportation systems are shown. The "FT-diesel/ICE (2)" has with 23 g CO_2-eq/km the lowest and the "fossil diesel/ICE (3)" with 138 g CO_2-eq/km the highest greenhouse gas emissions. The two systems with "Bio-H_2/FC(1a, 1b)" have 35 and 37 g CO_2-eq/km. This shows that the direct use of biomass for transportation system has about 40% lower greenhouse gas emissions than the indirect use of biomass via biohydrogen. One main reason is that the production of a fuel cell vehicle is associated with about 30 g CO_2-eq/km compared to 13 g CO_2-eq/km of an ICE vehicle. The difference between 1a and 1b is low, as the substitution of renewable electricity has low influence on total greenhouse gas emissions. Undoubted all transportation systems using biomass contribute to a significant reduction of 73% (biohydrogen) to 83% (FT-diesel) while substituting fossil diesel.

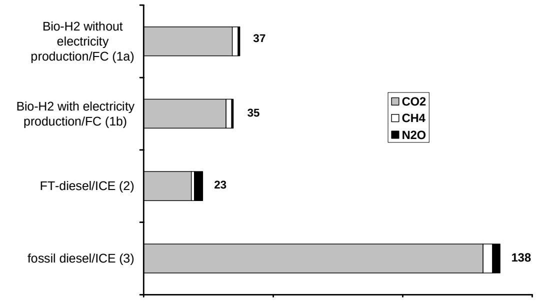

Figure 5: Greenhouse gas emissions of transportation service provided by biohydrogen, FT-diesel and fossil diesel

In Figure 6 the primary energy consumption of the transportation service based on the life cycle consideration of the different transportation systems are shown. The "fossil diesel/ICE (3)" has with

0.49 kWh/km the lowest total energy consumption, but with nearly 100% the highest share of fossil energy. The "Bio-H_2 without electricity production/FC (1a)" has with 0.93 kWh/km the highest primary energy consumption with a share of about 10% of auxiliary fossil energy. The "Bio-H_2 with electricity production/FC (1b)" has with 0.63 kWh/km less energy consumption than the "ICE FT diesel (3)" with 0.76 kWh/km. Comparing biohydrogen production with and without electricity shows, that the substitution of electricity might contribute to the reduction of the total energy consumption. The combined biohydrogen and electricity production has a 18% lower primary energy consumption compared to direct use of biomass for FT-diesel. Undoubted all transportation systems using biomass contribute to a significant reduction of use of fossil fuels while substituting fossil diesel, whereas the overall primary energy consumption is still higher than those of fossil fuels.

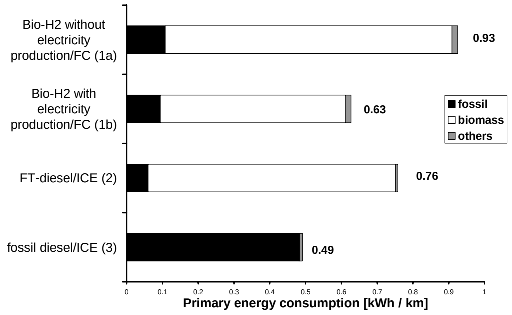

Figure 6: Primary energy demand of transportation service provided by biohydrogen, FT-diesel and fossil diesel

In Figure 7 the material demand of the transportation service based on the life cycle consideration of the different transportation systems are shown. The "Bio-H_2 with electricity production/FC (1b)" has with 25.2 g/km the highest and the "FT-diesel/ICE (2)" has with 6.6 g/km the lowest material consumption. Both biohydrogen transportation systems have significantly higher material demand compared to FT-diesel and fossil diesel, because of the high material demand to establish hydrogen infrastructure in relation to the comparatively low heating value of gaseous hydrogen compared to solid or liquid biomass.

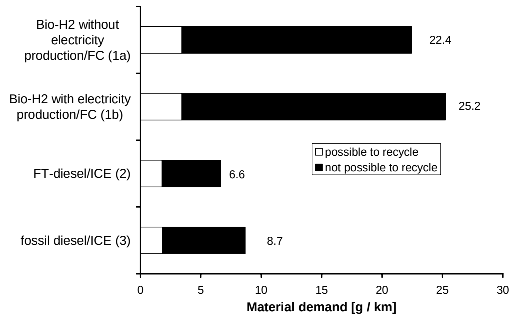

Figure 7: Material demand of transportation service provided by biohydrogen, FT-diesel and fossil diesel

4.2 Summary

The overall environmental and economic comparison of the considered transportation systems of direct and indirect use of biomass shows (Figure 8), that in nearly all aspects the direct use of biomass for FT-diesel is more attractive. Because biohydrogen needs beside biohydrogen production plants a totally new infrastructure for distribution and use of hydrogen, as FT-diesel is easy to integrate in existing infrastructure for diesel distribution and vehicles, therefore only FT-production plants must be built.

	Bio-H_2 versus fossil diesel	Bio-H_2 versus FT-diesel
Greenhouse gas emissions	+	-
(fossil) Primary energy demand	+ [2)]	+ / - [2)]
Material demand	+	-
Economy [1)]	-	-

+.....advantage (decrease), -.....disadvantage (increase)

1) taken from [4] and [6];

2) depending of electricity as by-product and its substituted electricity mix

Figure 8: Summary of life cycle based comparison

5 CONCLUSIONS

The comparison of the overall greenhouse gas emissions, energy and material consumption shows that biohydrogen from woody biomass might be an interesting fuel in combination with a high efficient fuel cell system vehicle in a long term perspective (> 2020) The hydrogen infrastructure and future technological development mainly of fuel cell vehicles are preliminary conditions for the use of biohydrogen. For a midterm perspective synthetic biofuels from wood biomass (e.g. FT-diesel) are more promising, because they are easy to integrate in the existing infrastructure of fossil fuels (distribution, filling stations and ICE vehicles).

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