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Life cycle assessment of hydrogen supply chain with special attention on hydrogen refuelling stations

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ABSTRACT

The controversial and highly emotional discussion about biofuels in recent years has shown that greenhouse gas[2] (GHG) emissions can only be evaluated in an acceptable way by carrying out a full life cycle assessment (LCA) taking the overall life cycle including all necessary pre-chains into consideration. Against this background, the goal of this paper is it to analyse the overall life cycle of a hydrogen production and provision. A state of the art hydrogen refuelling station in Hamburg/Germany opened in February 2012 is therefore taken into consideration. Here at least 50% hydrogen from renewable sources of energy is produced on-site by water electrolysis based on surplus electricity from wind (mainly offshore wind parks) and water. The remaining other 50% of hydrogen to be sold by this station mainly to hydrogen-fuelled buses is provided by trucks from a large-scale production plant where hydrogen is produced from methane or glycerol as a by-product of the biodiesel production. These two pathways are compared within the following explanations with hydrogen production from biomass and from coal. The results show that – with the goal of reducing GHG emissions on a life cycle perspective – hydrogen production based on a water electrolysis fed by electricity from the German electricity mix should be avoided. Steam methane reforming is more promising in terms of GHG reduction but it is still based on a finite fossil fuel. For a climatic sound provision of hydrogen as a fuel electricity from renewable sources of energy like wind or biomass should be used.

1. Introduction

To limit the global mean temperature increase to 2 °C by the mid of this century, roughly 80% of the global greenhouse gas (GHG) emissions must be reduced till 2050 referring to the 1990 baseline. This is true for all sectors of the economy and thus also especially for the transportation sector as one to the fastest growing sectors.

Within the mobility sector different ways of achieving this target are under development at the moment. For land transportation two alternative power trains are regarded as most promising, namely battery-electric and hydrogen driven

Abbreviations: GHG, Greenhouse gas; HRS, Hydrogen refuelling station; ISO, International Organisation for Standardization; IPCC, International panel on climate change; LCA, Life cycle assessment; LCI, Life cycle inventory; SMR, Steam methane reforming; SCOT, Shell Claus Offgas Treating; PSA, Pressure Swing Adsorption; NIP, National Innovation Programme for Hydrogen and Fuel Cell Technology; H_2, Hydrogen; CO_2, Carbon dioxide; H_2S, Hydrogen sulphide; CH_4, Methane; CO_2-eq, Carbon dioxide equivalent; N_2O, Nitrous oxide; Electro, Electrolysis from conventional electricity; Electro. ren, Electrolysis from green electricity; Pyror, Pyroreforming.

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vehicles [1]. As both options are based on secondary energy carriers, from a GHG reduction point of view it is important which source of energy is used for the production and provision of the electricity respectively the hydrogen. For both possibilities, a production from fossil fuel energy (e.g. coal, natural gas) is possible. Alternatively renewable sources of energy (e.g. wind power, biomass) can be utilised.

1.1. *Analysed options*

On the first glance, the advantages and disadvantages concerning the GHG emissions of the various options are not visible. Therefore already several studies, e.g. [2,3], have analysed the environmental impact, in particular GHG emissions, from hydrogen production as a fuel for transportation purpose. Nevertheless, this question has not been answered completely due to various assumptions, different frame conditions, various system boundaries, and a changing state of technology.

To overcome these problems and thus to provide to a much better understanding of the possibilities to reduce GHG emissions by using hydrogen within land transportation systems, the goal of this paper is it to study by means of a life cycle assessment (LCA) six different hydrogen provision pathways about their potential GHG emissions with reference to an exemplarily defined hydrogen production and dispensing facility:

1. On-site water electrolysis with electricity from renewables,
2. On-site water electrolysis with the German electricity mix,
3. Central steam methane reforming,
4. Central production from by-product glycerol, pyroreforming,
5. Central coal gasification,
6. On-site woody biomass gasification.

The first four options are defined according to the new built hydrogen refuelling station in Hamburg/Germany [4]. They are compared with often discussed alternatives for hydrogen production (i.e. coal and biomass gasification) that are at the moment not used for such purposes [5,6]. Through this project in Hamburg and other projects dealing with hydrogen production and distribution more and more experience can be gathered and the gained information used for life cycle assessments. That is why in this paper takes a more detailed look at the hydrogen refuelling facility in the following section. The analysed methods of hydrogen production are described in a more general way in Section 3 after a detailed description of the used methodology, Section 2. In that way the whole hydrogen provision pathway is modelled.

1.2. *Hydrogen refuelling station*

The hydrogen refuelling station modelled within this analysis is based on the new station opened in February 2012 in the HafenCity in Hamburg/Germany. Unlike other hydrogen stations this one only refuels hydrogen and is not designed as an add-on to an existing fossil fuel filling station.

This HRS offers two different pressure levels for vehicles (i.e. 35 MP for busses and 70 MP for passenger cars). This the new standard pressure for passenger cars because it enables the driver to carry more hydrogen in the car and to cover a bigger distance with one tankful. As this HRS is mainly constructed to refuel fuel cell busses, which will demonstrate new technology for them within the normal public transport operation in Hamburg in the years to come, most of the hydrogen to be sold is provided at 35 MP. Additionally, fuel cell passenger cars can be served according to the fuelling protocol SAE J2601 with 70 MP. An appropriate car park able to run with hydrogen of this pressure level is currently under development within several demonstration projects not only in Hamburg but also in other German cities [4]. For this, advanced framework conditions apply to the dispenser. Those include a specific fuel temperature at the dispenser nozzle, maximum fuel flow rate, maximum rate of pressure increase and other performance criteria to be fulfilled only with a highly sophisticated technology.

This station can refuel 750 kg hydrogen every day. Roughly 50% of it is produced on-site with three electrolysers each of them producing 60 m^3(STP)/h. To operate them either “green” electricity (i.e. electrical energy from renewable sources) to produce environmental friendly hydrogen or “conventional” electricity from the German electricity mix can be used. The amount of hydrogen that cannot be produced on-site will be trucked-in at night in a gaseous form by hydrogen trailers.

Each electrolyser consists of four stacks to be maintained individually. In a rack around the stacks the necessary auxiliary equipment is located. This offers a place-saving arrangement on the one hand (due to limited space at the location of the fuelling station) and easy maintenance on the other. The electrolysers can run either in full or in part load (range of 40–100%). This high flexibility as well as the big sized middle pressure storage tank enables the refuelling station to serve also as an electricity storage facility; i.e. hydrogen can be produced when there is excess electricity within the grid and stored until it is needed.

Besides these electrolysers and dispensers mentioned above, additionally the storage system, the dry coolers and compressors are very important parts of a hydrogen refuelling station. As the electrolyser is producing waste heat air cooling is needed to keep the whole system at the right temperature.

As two different pressure levels are served and hydrogen is trucked in as well as produced on-site a highly sophisticated storage and compression system, shown in Fig. 1, is implemented within the HRS investigated here. In the figure the size of the tank is indicated by the size of the coloured boxes and the colour itself illustrates the pressure level. First, the hydrogen produced by the electrolyser is pumped into the low pressure storage tank (LP-storage). It has a very small size of 1 m^3 and is operated at 1.6 MP. Afterwards – if no vehicles receive hydrogen resp. no direct demand is given – it is compressed to 4.5 MP and stored in one of the two middle pressure tanks (MP-storage). These storage facilities have an installed capacity of 95 m^3. In a last compression step the hydrogen is compressed to 40 respectively 85 MP. The respective high pressure storage (HP-storage) comprises four tanks from 1.2 to 0.6 m^3. Three of them are able to store hydrogen at 40 MP. Additionally one of those three tanks as well as the fourth one can store hydrogen at 83 MP to allow a direct servicing of the vehicles at the 70 MP level. As an