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LCA of a Non-thermal Production of Pure Hydrogen from Biomass

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1 Introduction

The non-thermal decentralised small-scale production of hydrogen from biomass is currently under investigation within the EU FP6 project: HYVOLUTION. The HYVOLUTION process starts with the conversion of biomass to make a suitable feedstock for the following bioprocess, which consists of a thermophilic fermentation and a consecutive photo-heterotrophic fermentation. The selected biomasses are by-products from food industry, molasses and potato steam peels, and the specifically grown substrate Miscanthus. A dedicated gas upgrading is also developed [1].

The present paper aims an evaluation of the environmental impact of the non thermal hydrogen production of HYVOLUTION compared to the environmental impact of methane based hydrogen generation.

2 Methodology

The Life Cycle Assessment (LCA) methodology was chosen to evaluate the environmental impact of the biological hydrogen production. The environmental burdens and benefits of the entire production chain are discovered and quantified. The whole LCA was based on the ISO 14040 [2] and 14044 [3]. The analysis is conducted with the help of the SimaPro 7.1 software [4]. As an impact assessment methodology Eco-indicator 99 (H) V2.06/ Europe EI 99 H/A was used. The method uses an average weighting set to the three damage categories human health, ecosystem quality and resources. The functional unit set for the entire process is 1 kg H_2, due to its easy convertibility to other units and the fact that in the database data are available which are related to mass units.

2.1 Goal and scope

The final goal of HYVOLUTION is to establish a technology for decentralized production of hydrogen based on locally available biomass. The HYVOLUTION technology itself has the function to produce a manifold applicable energy carrier – H_2.

The LCA is deliberately carried out in parallel to the project development in order identify and foresee environmental high loaded in- and outputs. It can be regarded as a consulting tool for process development and optimization. As a consequence, the intended audience of this LCA is the partners of the project or generally scientists or engineers involved in the process development.

2.2 System boundary

The system boundaries (see Figure 1) include the entire process chain of the non thermal hydrogen production. It starts with the transport of the feedstock to the plant and ends with the upgraded hydrogen gas. The process steps in between are feedstock pre-treatment, thermophilic fermentation, photo fermentation and gas upgrading. The biological and chemical inputs (e.g. enzymes, phosphate and nutrients) as well as heat, electricity and water demand of the process steps are included in the system boundaries. The storage and transport of the produced hydrogen are out of the system boundaries and hence are not considered in the LCA.

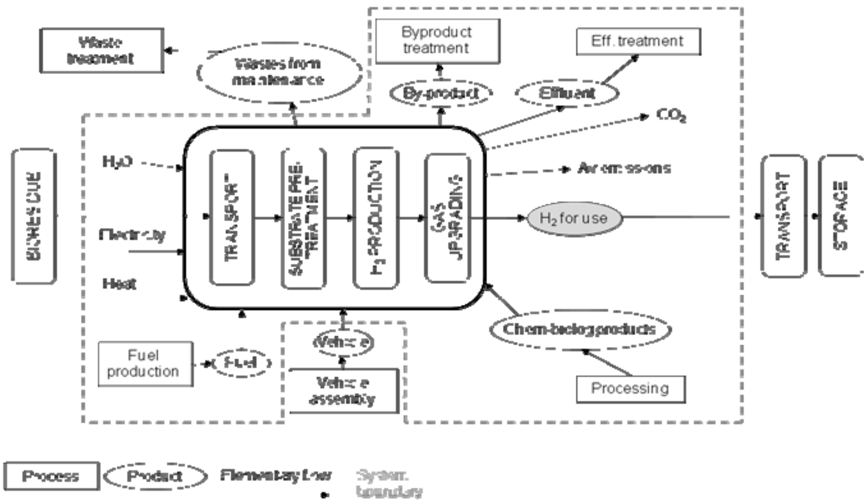

Figure 1: System boundaries of the HYVOLUTION process, including transport, pre-treatment, thermophilic and photo fermentation.

3 Life Cycle Inventory

The present analysis is based on potato steam peels (PSP) as a substrate for the HYVOLUTION process. According to the sensitivity analysis in the simulation activities in a work package of the project a number of data sets for the non-thermal hydrogen production using PSP as feedstock are available [5]. The base case data set only connects the different process steps without consideration of any process improvements due to process and heat integration. For this base case, the production of 1kg H_2 needs 249,3kg PSP and a total water amount of 2,390kg. The other data sets vary from the base case by the recirculation of sewage and the reduction of buffer concentration in the photo fermentation. Recirculation of sewage refers to the use of process effluents in the thermophilic and photo fermentation.

For the following three cases LCAs were conducted:

- HYVOLUTION – PSP 1(Base case): Simple balance, no recirculation, 20mM buffer
- HYVOLUTION – PSP 2: Simple balance, replacement of 90% of tap water by process effluents, 20mM buffer
- HYVOLUTION – PSP 3: Simple balance, no recirculation, 4mM buffer

Reference systems

The purpose of having a reference system is to compare the burden and benefit of the new developed process to a state-of-the-art technology of producing hydrogen. The hydrogen production by the HYVOLUTION process is compared to a fossil fuel based hydrogen generation and furthermore to a hydrogen production from biogas. Both reference systems are based on the steam methane reforming (SMR) which is a widely used, well discovered and is a documented process for centralized industrial plants.

4 Impact Assessment

4.1 Base case – HYVOLUTION – PSP 1

The total environmental impact of the case HYVOLUTION – PSP 1 (Base case) is 4.3 pts. The impact can be allocated to the four process steps: 0.5 pts from the pre-treatment, 0.8 pts from dark fermentation, 2.6 pts from the photo fermentation and 0.4 pts from the gas upgrading. The highest impact categories to the overall process are carcinogens (1.38 pts), fossil fuels (1.07 pts), respiratory inorganics (1.04 pts) and climate change (0.21 pts). Figure 2 shows further details to the described facts. The biggest impact on carcinogens and respiratory inorganics, is obviously caused by the use of phosphate in the photo fermentation. In the dark fermentation the highest impact is on fossil fuels, as well as in the pre-treatment, due to steam consumption. In case of gas upgrading it is not verified what impacts are caused, since detailed balance data for this process steps are not available yet from process simulation. The assumed loss of 10% of hydrogen would lead to environmental impact increase of 0.4 pts.

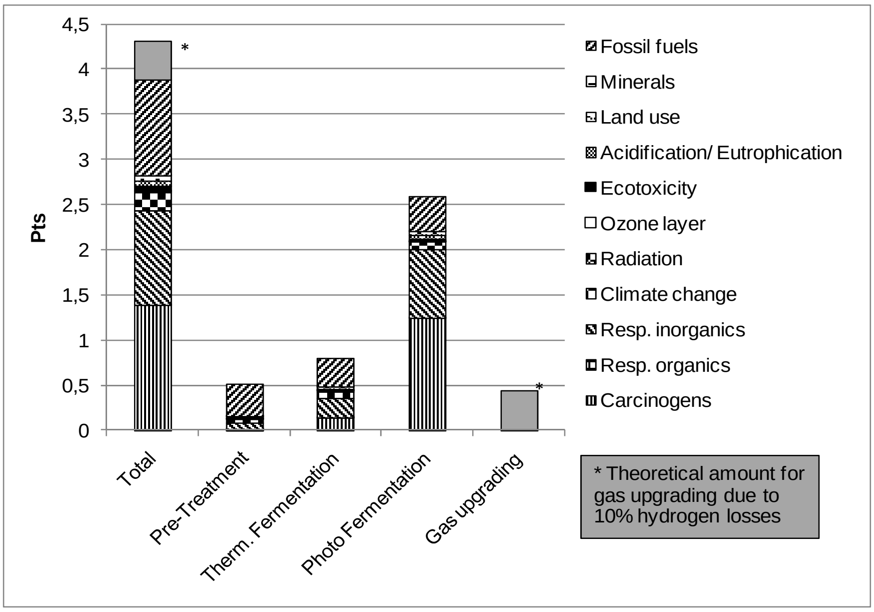

Figure 2: Environmental impact of HYVOLUTION - PSP 1 (Base case), displaying the total environmental impact allocated to the impact categories and the single process steps.

Allocating the impact to the inputs and outputs, three process ingredients are identified causing a high environmental load (see Figure 3). The highest environmental impact is caused by phosphate with 2.3 pts. It corresponds to 53.5% of the total environmental impact of the HYVOLUTION process. The phosphate is used in the photo fermentation as a buffer. It is furthermore used in the dark fermentation in a lower concentration, but also causes a nameable impact of 0.23 pts. The second highest impact of 0.47 pts is created by the use of a base in the dark fermentation. The use of steam for pre-treating the substrate causes the third highest impact of the total HYVOLUTION process. It can be seen that the inputs to the HYVOLUTION process are mainly responsible for its high environmental load. The outputs directly caused by the HYVOLUTION process are CO_2 and sewage. Its cumulative environmental load is only 0.07 pts, which corresponds to 1.7% of the total impact.

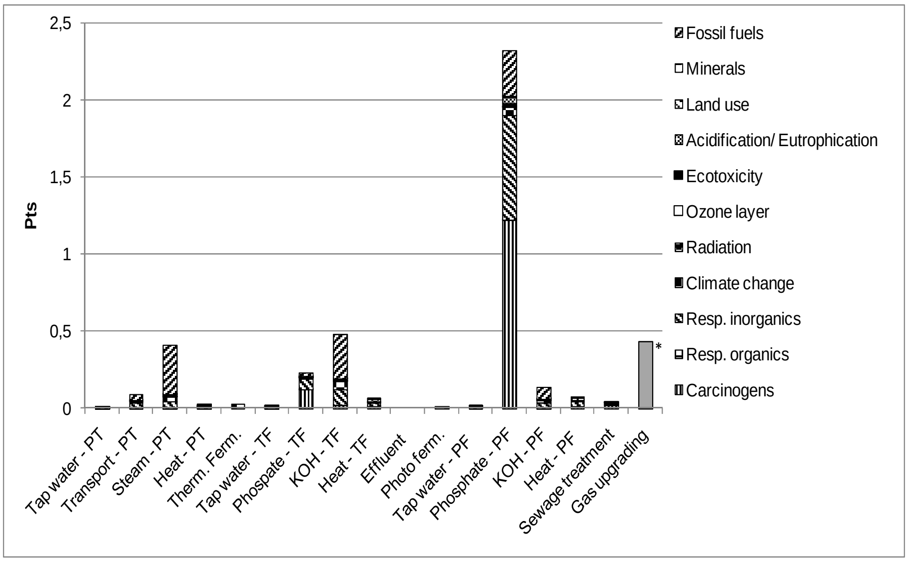

Figure 3: Allocation of the environmental impact to the inputs and outputs of the single process steps in HYVOLUTION – PSP 1 (Base case).

4.2 HYVOLUTION – PSP 2

In HYVOLUTION – PSP 2 it is foreseen to recirculate the major part (90%) of the sewage from the whole process to the dark and photo fermentation. As a positive consequence the fresh water and buffer demand would be reduced, leading to an environmental impact reduction of 65.8% to 1.47 pts. The process step giving the highest impact remains the photo fermentation, but its amount is reduced by 78.5% to 0.56 pts. The pre-treatment creates the second highest impact with 0.5 pts. The dark fermentation decreases its environmental impact by 67.5% to 0.26 pts. The highest impact categories in this process step are still fossil fuel (0.58 pts), respiratory inorganics (0.35 pts) and carcinogens (0.31 pts) with a change in order.

The impact allocation to the inputs and outputs of the HYVOLUTION process shows that the use of phosphate in the photo fermentation still has the highest environmental impact of 0.48 pts. In comparison to the total HYVOLUTION process it is 32.2%. The input with the second highest impact is steam from the pre-treatment with 0.41 pts. The base used in the dark fermentation has the third highest impact with 0.19 pts. Further inputs getting more significant are transport of the substrate and the heat input necessary to run the bioprocesses and the pre-treatment. The impacts of the bioprocesses are also more visible in this evaluation. But in total the output of the HYVOLUTION process steps itself has an impact of only 0.07 pts which corresponds to 4.8% of the overall process including the input of feedstock, water heat and other chemicals.

4.3 HYVOLUTION – PSP 3

In HYVOLUTION – PSP 3 the buffer concentration used in the photo fermentation is reduced from 20mM to 4mM without any recirculation of sewage applied. The photo fermentation and the gas upgrading are the only process steps changing their environmental impact in comparison to HYVOLUTION – PSP 1. The total impact is reduced by 52.1% to 2.06 pts. The impact is allocated to the process steps as follows: 0.79 pts from dark fermentation, 0.5 pts from pre-treatment, 0.49 pts from photo fermentation and 0.26 pts from gas upgrading. The highest impact categories generally stay the same as in HYVOLUTION – PSP 1, but their order change: Fossil fuel (0.88 pts), Respiratory inorganics (0.49 pts) and Carcinogens (0.37 pts).

The impact allocation to the inputs and outputs of HYVOLUTION - PSP 3 shows a different result as the previous allocations. The input with the highest environmental load is the base used in the dark fermentation. Its impact is assessed with 0.47 pts follow by the steam production with 0.41 pts. The previously highly charged use of phosphate has now an environmental impact of only 0.28 pts which means a reduction by 87.8% compared to the base case. Further significant inputs are the phosphate to the dark fermentation (0.23 pts) and the transport of the substrate (0.09 pts). The outputs of the process have an impact of 0.07 pts which corresponds to 3.4% of the whole HYVOLUTION process.

4.4 Comparison

The reference systems generally show a lower environmental impact than the three HYVOLUTION – PSP cases (see Figure 4). The steam methane reforming of purified methane from biogas has the lowest impact of all the processes with 0.17 pts. The steam methane reforming has an environmental impact of 0.75 pts. Its main impact is caused by the extraction and use of natural gas.

A comparison of HYVOLUTION – PSP 1 (Base case) to the centralized steam methane reforming shows that the HYVOLUTION process in the current development stage has a 5.7 times higher impact. The recirculation of sewage, as done in HYVOLUTION – PSP 2, leads to a HYVOLUTION process with twice of the impact of the steam methane reforming. A comparison of the HYOLUTION processes to the steam methane reforming of a CO2 cleaned biogas shows a 252 time higher impact as HYVOLUTION – PSP 1 and a 86 times higher impact as HYVOLUITION – PSP 2.

5 Discussion and Conclusion

At the current state of development the non-thermal small-scale decentralized hydrogen production shows a 5.7 times higher environmental impact than the large scale centralized

SMR. A possible process improvement (recirculation of sewage) would lead to an environmental impact that is only twice high than the one of the SMR. In HYVOLUTION – PSP 1 (base case) 98.3% of the environmental impact is caused by the inputs; mainly phosphate, base and steam. The process emissions or solid outputs only cause 1.7% of the impact. This corresponds to 0.07pts of the LCA evaluation. The backpack the process ingredients are wearing is extremely high in the non-thermal hydrogen production and therefore their consumption needs to be degreased.

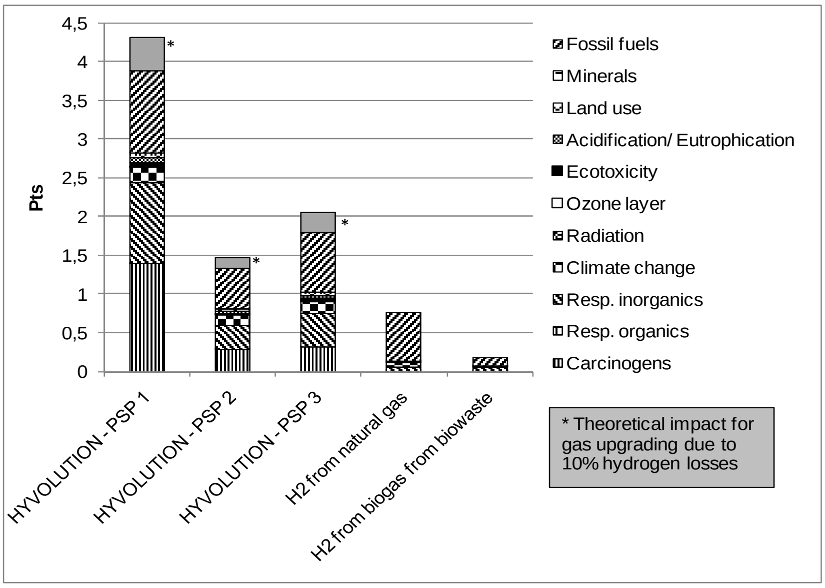

Figure 4: Comparison of HYVOLUTION - PSP 1, 2 and 3 to the reference systems, showing a generally higher environmental impact of the new developed HYVOLUTION technology in contrast to the state of the art technologies.

Compared to the SMR or the biogas technology the non thermal hydrogen production is a new development, which needs to be improved in future. During the HYVOLUTION project a lot of basic research was realized which established the process as a whole and needs to be adapted by engineering activities (heat integration). Furthermore a replacement of high loaded inputs (phosphate or potassium) with ecologically produced inputs needs to be realized, in order to lower the environmental impact.

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