Hydrogen and it's applications : Review of Life Cycle Assessment studies and Well-to-Wheel studies.

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This paper describes a review conducted in the context of a 5th Framework project called Hysociety of all recent and publicly available Life Cycle Assessments (LCA's) and Well-to-Wheel (WTW) studies of the production and use of hydrogen in various applications. The review focuses more on LCAs and on mobile hydrogen applications and covers over 100 articles.In general, the WTW and LCA methodology are similar, the main differences are that LCA covers a wider range of environmental impacts and usually also covers a wider system, including at least the production of the vehicle and the fuel cell. Very few LCA studies claim to be ISO compliant (a well accepted international standard for LCA studies).

The final results from different studies with different assumptions are often not easy to compare, because of differences in scope (chosen impacts), reference year of technology (2000, 2012, 2020), geographical differences, system boundaries, etc. Nonetheless the following main conclusions (about mobile hydrogen applications) can be drawn from this review:

LCA studies draw attention to important contributors such as: fuel tank (weight), precious metals (e.g. Pt and Pd), life time of membranes. Especially the production of the precious metals contributes significantly to impacts such as acidification and particulate matter and there is quite a wide range in the estimates between several studies.

The results of LCA studies that have compared a petrol car with a hydrogen fuel cell car and included at least the fuel life cycle, the use of the vehicle and the vehicle production gave the following range of outcomes:

- **Global warming (mainly caused by CO_2, CH_4 and N_2O)**

For centrally produced hydrogen through steam methane reforming (SMR) the reduction in GHG emissions during the full life cycle is in the range of 3 till 60 %.

For locally produced hydrogen the reduction in GHG is usually a bit less but the range is similar: 8 till 52 %.

For hydrogen produced from renewables sources (solar energy, hydropower, biomass, wind power) the reduction is in the range of 53 till 85 %.

- **Acidification (mainly caused by SOx and NOx)**

- For centrally produced hydrogen through SMR the change in acidifying emissions during the full life cycle is in the range of 25 % reduction till 600 % increase. The main contribution comes from the amount of Pt (platinum) needed for the production of the fuel cell.

- **Smog (mainly caused by VOC's)**

For centrally produced hydrogen through SMR the reduction in smog forming emissions during the full life cycle is in the range of 47-75 %.

For hydrogen produced by renewables (solar energy, hydropower, biomass, wind power) the reduction is in the range of 70 till 85 %.

- **Dust and Eutrophication**

Very few studies have addressed these issues; therefore we were not able to make a comparison.

Hybridisation offers more benefits for ICE cars than for the more efficient FC cars.

Recommendations for future LCA studies are to pay more attention to high uncertainty area's like the fuel tank, the amount of precious metals in fuel cells and the life time of membranes. Another recommendation is to include the option of hydrogen as a fuel in ICE cars in LCA.