Atmospheric Consequences of the Perspective Use of Hydrogen in the European Transport Sector in 2050

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1   Introduction

Hydrogen is the second most abundant oxidizable trace gas in the atmosphere. In the troposphere, the lowest part of the atmosphere reaching from the surface to about 10km height, hydrogen influences the concentration of the hydroxyl radical OH. This radical is the main oxidizing agent in the atmosphere and its concentration determines the lifetime (and thus the radiative forcing influence) of the greenhouse gas methane and it controls regional pollution levels downwind from emission sources. The concentration of OH is determined by a complex interplay of different chemical reactions of various air pollutants such as the mainly man made trace gases nitrogen oxides NO_x, carbon monoxide CO and the mainly biogenic volatile organic compounds VOCs.

Despite of this importance as an indirect greenhouse gas the tropospheric cycle of hydrogen is quite uncertain. Figure 1 shows the different source and sink terms and uncertainties following the review paper [1] for present day conditions. Future wide-spread use of hydrogen as energy carrier could lead to significant perturbations in the global atmospheric hydrogen budget and therefore influence the methane and air pollutant removal rate.

To assess the impact of a possibly emerging hydrogen economy on the atmospheric composition, not only the likely rise in hydrogen emissions has to be considered. Accompanying changes in NO_x and CO emissions due to enhanced needs for power generation on the one hand and reduced air pollution from the combustion of fossil fuels on the other hand must be treated as well. This is particularly important for the transition period where the economy of scale suggests that the required hydrogen will largely be produced by coal gasification and gas reforming.

The large-scale introduction of hydrogen as energy carrier necessitates the build-up of new infrastructures for production, transport, storage and distribution. Considering the costs of this build-up and the accompanying research and development expenses, in the beginning only highly developed countries can afford the introduction of H_2 into the energy sector. The largest potential for hydrogen use is generally seen in the sector of mobile applications, in particular as propellant in passenger cars, busses and light-duty freight vehicles [2]. In order to realistically assess the potential consequences of increased hydrogen use on the environment, plausible emission scenarios have to be developed based on realistic assumptions about the evolution of a hydrogen network and the technologies that will be applied in the hydrogen production and distribution chain (e.g. Hyways, 2006). In the paper at hand European traffic emission scenarios have been developed to assess the potential changes in atmospheric composition over the next decades. Simulations of the global atmospheric hydrogen budget were done with the global atmospheric chemistry and transport model ECHAM5-MOZ [3, 4].
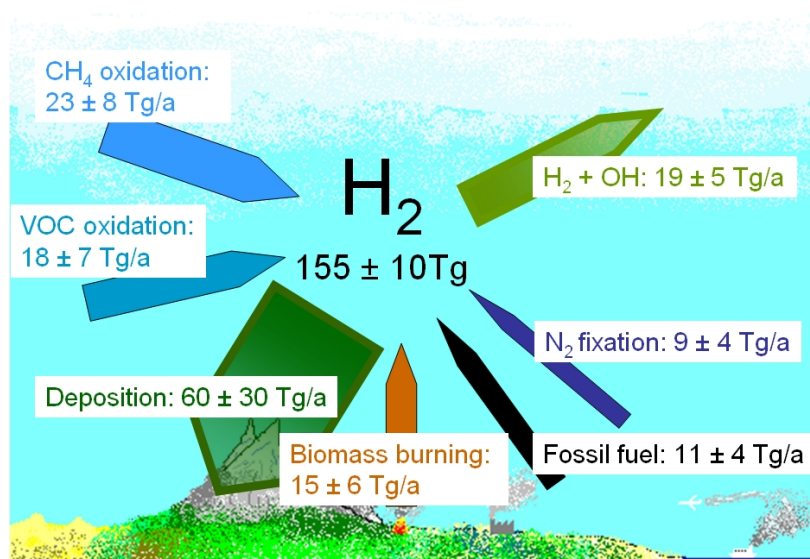
Figure 1:   Tropospheric mass, sources, and sinks of H$_2$ at present.

A reference simulation was made for the years 2001-2008 to test the capability of the model to simulate global hydrogen concentrations and their observed seasonal cycle. The results were compared with available measurements of hydrogen and other trace gases as shown in Figure 2. At the left hand side time series of monthly means at Mace Head in Ireland are shown, at the right hand side the latitudinal gradient of annual means of the year 2003 is shown. The model (red squares) agrees with the observations within the measurement uncertainty, which is dominated by uncertainties in the instrument calibration [5]. The modeled hydrogen budget terms lie within the error margins given in [1]. ECHAM5-MOZ therefore can be said to be suitable for modelling the global hydrogen cycle.
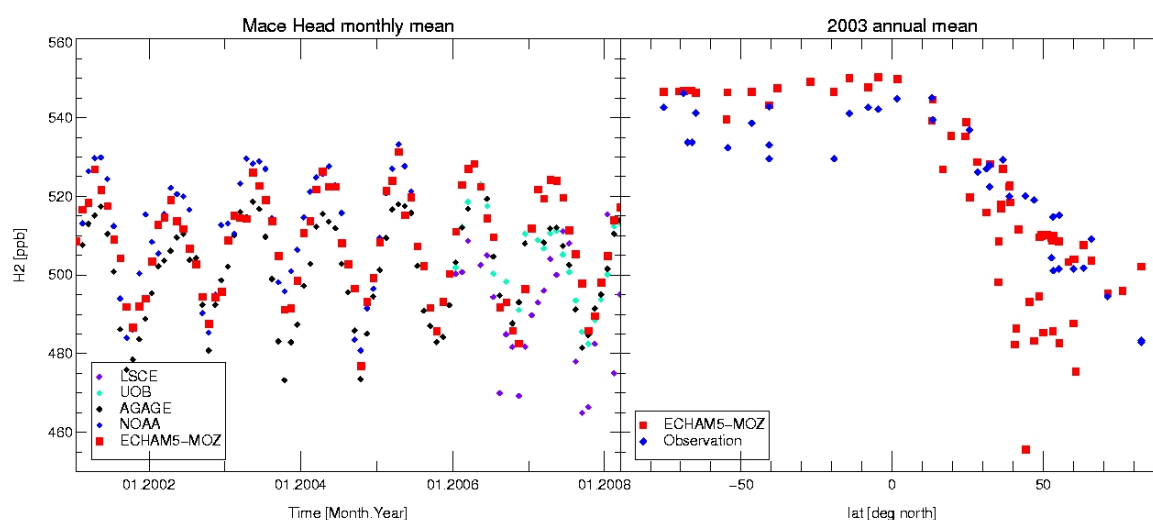

Figure 2:   Observation vs. model hydrogen concentrations.

Two emission scenarios were developed based on the European HyWays project [1] and using extrapolated projections from the European Commission report "European Energy and

Transport -Trends to 2030" [6, 7]. The first is a business as usual (BAU) scenario, with fossil fuels remaining the main energy carrier till 2050. For simplicity we assume that no technological development takes place to reduce the average NO_x, CO and VOC emissions of the vehicle fleet. This scenario is compared to a hydrogen scenario (HY) where 50% of the traffic sector fossil fuel use in 2050 is replaced with hydrogen fuel cell cars which are free of air pollutant emissions. As a consequence, traffic emissions of trace gases other than hydrogen are half that of the BAU scenario. Conversely, country specific power plant emissions are scaled up to accommodate for the increased energy needs to produce the hydrogen. This scaling assumes that the primary energy mix will remain similar for each country. The potential fraction of "carbon-free" (i.e. wind, solar or nuclear) energy use for hydrogen production is taken into account. A high estimate of a 10% loss rate of hydrogen in the production, distribution and storage chain is used. This quite pessimistic (worst case) assumption was chosen to see a clear effect in the global hydrogen distribution. It should be noted however, that optimistic assumptions predict loss rates as low as 2% to be achievable [8] and leakage rates of about 3% can probably be assumed as realistic [9].

The European and global emissions of CO, H_2 and NO_x in the year 2000 are summarized in table 1 together with the emissions derived from the BAU and HY scenarios. The baseline emissions were taken from the RETRO inventory [10-13]. Transport (tra) and power generation (pow) are stated separately.

Table 1: Emissions of CO, H_2 and NO_x in the traffic and power generation section and in total given for the year 2000 RETRO inventory and the two year 2050 scenarios.

	CO [Tg/yr]			H2 [Tg/yr]			NOx [Tg/yr]		
	tra	pow	total	tra	pow	total	tra	pow	total
RETRO World	192	2,2	1026	5,8	0,1	29	31,8	26,7	132,0
RETRO 'EU'	22	0,3	39	0,66	0,01	1,13	6,7	3,6	15,9
BAU 'EU'	46	0,3	63	1,38	0,01	1,85	13,3	3,6	22,5
HY 'EU'	23	0,6	40	15,2	0,02	15,7	6,7	6,9	19,2

Compared to the year 2000 the transport emissions of all species in Europe will roughly double in the BAU scenario. The power generation emissions stay the same. In the HY scenario the traffic emissions of CO and NO_x nearly stay the same, but the power generation emissions of these species will rise by a factor of about two. The hydrogen transport emissions (all emissions of the hydrogen production, distribution and storage chain are attributed to this sector) will rise by a factor of 23 and will make up more than half of the today total global hydrogen emissions. Thus the European transport emissions will play an important role in the global hydrogen budget. This is also demonstrated in figure 3, where exemplarily the August monthly mean global hydrogen surface concentrations of the BAU (left side) and the HY scenario (right side) are shown. Although the additional H_2 emissions only take place in Europe, the surface concentration is elevated on the whole globe. As the amounts of NO_x and CO emissions do not change drastically the changes in the concentration patterns of this species remain locally in Europe. The highest changes (up to +20% and -15%) of the OH concentration also take place locally in Europe, accompanying

the NO_x and CO changes. In the "remote" regions away from Europe the elevated hydrogen lowers the OH concentration by about 1-3%.
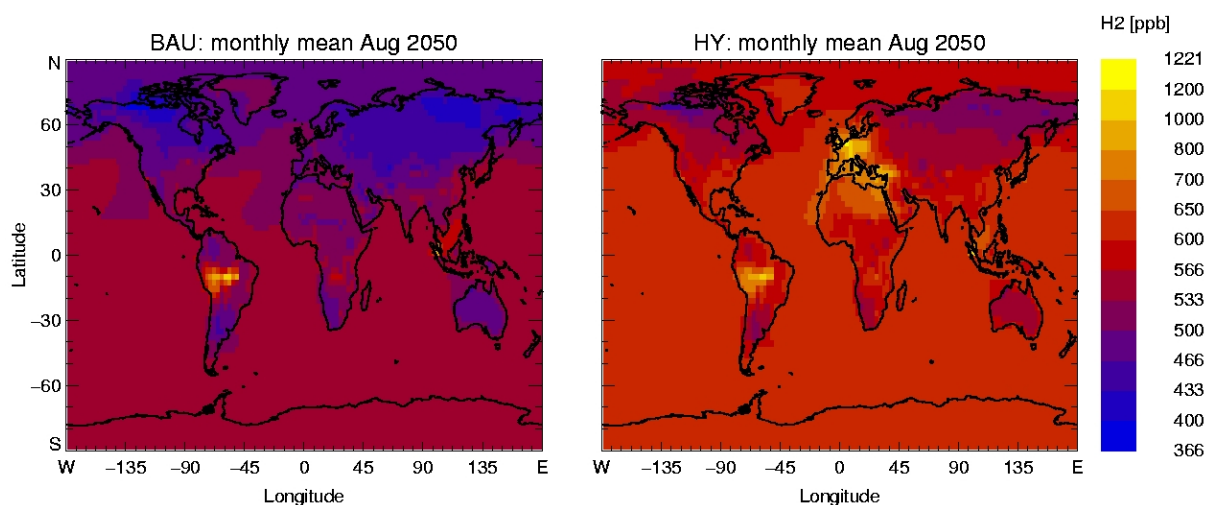

Figure 3:   **August monthly mean hydrogen surface concentration of the BAU and the HY scenario.**

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