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Impact of H_2 Emissions of a Global Hydrogen Economy on the Stratosphere

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"Green" hydrogen is seen as a major element of the future energy supply to reduce greenhouse gas emissions substantially. However, due to the possible interactions of hydrogen (H_2) with other atmospheric constituents there is a need to analyse the implications of additional atmospheric H_2 that could result from hydrogen leakage of a global hydrogen infrastructure. Emissions of molecular H_2 can occur along the whole hydrogen process chain which increases the tropospheric H_2 burden. The impact of these emissions is inverstigated.

Figure 1 is a sketch that clarifies the path way and impact of hydrogen in the stratosphere. The air follows the Brewer-Dobson circulation in which air enters the stratosphere through the tropical tropopause, ascends then to the upper stratosphere and finally descends in polar latitudes within a typical transport time frame of 4 to 8 years.

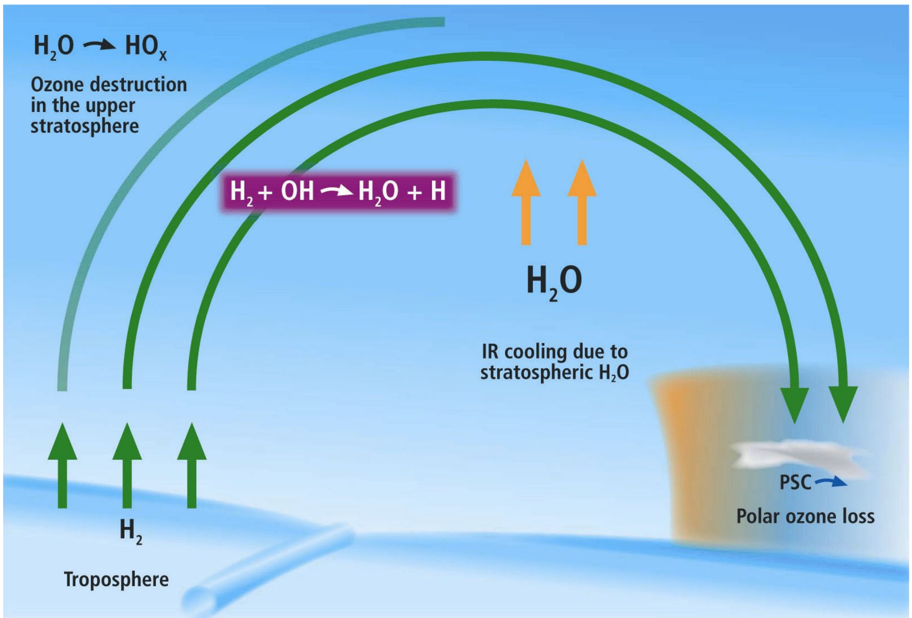

Figure 1: Impact of H_2 in the stratosphere.

Along this pathway, hydrogen is oxidised to form water vapour. As stratospheric air is typically very dry, any additional hydrogen release results in an increase of stratospheric water vapour. The impact on ozone is three-fold:

1. an increased production of HO_x radicals OH and HO_2 from H_2O that contribute to gas-phase ozone depletion

2. an increased heterogeneous reactivity of polar stratospheric particles (liquid sulfate aerosol and Polar Stratospheric Clouds, PSCs) responsible for chlorine activation and subsequent ozone loss
3. an increased infrared cooling of the stratosphere due to rising infrared emissions leading to an enhanced presence of PSCs

While (1) can be neglected, the effects (2) and (3) are important and may lead to additional polar ozone depletion. Hence a global hydrogen economy could potentially provoke polar ozone loss and could lead to a substantial delay of the current projected recovery of the stratospheric ozone layer.

In 2003, Tromp et al. published a simulation study indicating a significant reduction of stratospheric ozone due to emissions by leakages of a potential future H_2 economy, mainly by effect (2) and (3) mentioned above. This study was heavily criticised because of unrealistically high estimation of the overall hydrogen emission rate (20%) and because of inconsistencies of model parameters [1-3].

Investigations of the complete process chain and estimates of future trends in hydrogen technologies show that the expected loss rates of 2% and below are technically feasible [4, 5] For comparison, current emissions of natural gas are estimated to be between 0.5 and 1.8% throughout the production chain [6-8].

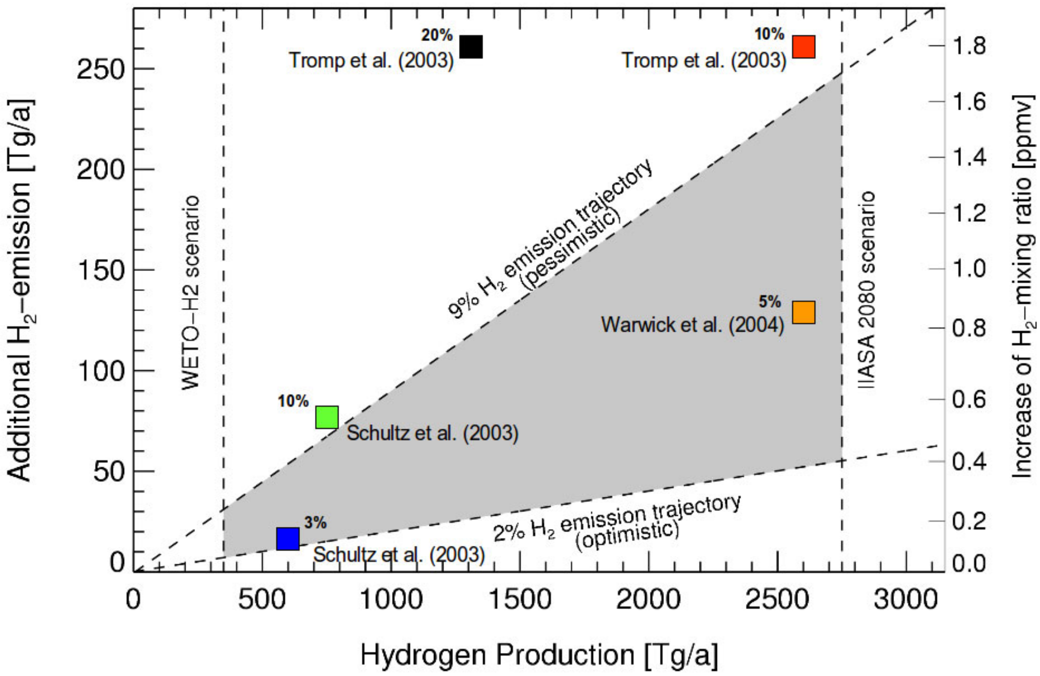

Figure 2: Projected hydrogen production and emissions.

Figure 2 shows the range of projected hydrogen production rates bracketed by the WETO-H_2 and the IIASA-2080 scenarios [9, 10]. Corresponding emissions by leakages are shown on the ordinate. The realistic range is indicated by the grey shaded area. Also shown are the assumptions made in the earlier studies by Tromp et al. [11], Warwick et al. [12], and Schultz et al. [13]. The second ordinate shows the corresponding estimated tropospheric hydrogen increase. For the atmosphere, only the hydrogen emissions and not the global production rates are relevant.

As the impact of additional hydrogen emissions is rather small, we used methods designed such that the resulting effect would not be hidden within the natural variability.

Simulations of the Chemical Lagrangian Model of the Stratosphere (CLaMS) [14] were used to investigate the impact of H_2 emissions on the stratosphere. First, the H_2 oxidation and the corresponding water vapour increase along the Brewer-Dobson circulation is simulated in a box model mode of CLaMS. The results of these simulations were used to analyse the impact of possible H_2 emissions on stratospheric polar ozone in two complementary methods.

The first method is an estimation utilizing the fact that a tight linear correlation between derived chemical ozone loss and temperature-threshold based proxies V_{psc} and V_{ACl} has been found [15-17]. We investigated how these two proxies would change with increasing water vapour and with decreasing temperatures. This change was then translated into additional ozone depletion. From this analysis it was found that the largest effect of additional hydrogen emissions would occur for the coldest stratospheric Arctic winters. The complementary second method was to run a set of simulations with the full 3-dimensional Chemical Transport Model (CTM) CLaMS [14, 18] on the identical meteorology with the exception that the water vapour was varied corresponding to the hydrogen emission assumptions [19].

Even under extreme assumptions, i.e. a replacement of 90% of the current global fossil primary energy input replaced by hydrogen, a leakage rate of approximately 10% of the product gas into the atmosphere, and no reductions of current stratospheric CFC levels (that should decrease due to the regulations of the Montreal Protocol), the results of both methods show only very moderate increase of polar stratospheric ozone depletion due to the additional hydrogen emissions. Hence the risk of a substantial damage to the stratospheric ozone layer due to hydrogen emissions of a hydrogen economy is very low compared to the positive climate implications that would evolve from the avoidance of greenhouse gas emissions.

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