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Evaluating Hydrogen Emissions from Incomplete Combustion: Historical Trends and the Role of Policy

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Context: Expanding the use of hydrogen (H_2) throughout the economy is widely regarded as a key approach to fossil fuel dependent decarbonizing sectors. However, recent studies have been showing that emissions of hydrogen to the atmosphere are indirectly associated with climate impacts, such as the prolonged lifetime of methane (CH_4) as well as the formation of ozone (O_3) and stratospheric water vapor (H_2O). Despite hydrogen's short atmospheric lifetime (4-7 years), the studies estimate that hydrogen atmospheric interactions could lead to a Global Warming Potential over 100 years (GWP-100) ranging from 6 to 18. Hydrogen emissions have two main sources: a) direct leakages from related appliances and infrastructure (eg.: electrolyzers, distribution networks, fuel cells); or b) incomplete combustion of fossil fuels or biomass due to poor oxygen supply, where carbon monoxide (CO) and H_2 are formed.

Objective: This study aims to quantify historical hydrogen emissions from incomplete combustion from 1990 to 2020 and compare their CO_2-equivalent contribution. In addition, we evaluate the influence of policy measures on reducing these emissions.

Methodology and Data: The current work adopts the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model framework, which takes into account activity level (fuel consumption) by sector, emission factors and the application of control strategies for emissions abatement. We adopt historical fuel consumption from statistical data along with GAINS model's assumptions. Hydrogen emission factors are derived from carbon monoxide (CO) emission factors by a conversion ratio estimated from the literature. Control strategies represent the countries' regulations adopted over the period of 1990-2020.

Expected Results: As an indirect greenhouse gas, hydrogen emissions may not be as prominent as CO_2, CH_4, or N_2O, which are commonly monitored. Nevertheless, hydrogen leakage does occur and should be included in emissions inventories. Historical data and future projections could indicate consistent yearly reductions, largely driven by stricter control measures and policies—particularly vehicle standards aimed at reducing a variety of pollutants, including CO. The primary sources of hydrogen emissions from incomplete combustion are gasoline-fueled light-duty vehicles and biomass burning in the domestic sector, although sector-specific contributions may differ across countries.

Discussion: While the expansion of a hydrogen economy may lead to higher emissions from direct leaks, hydrogen has also been released into the atmosphere through past and ongoing fuel combustion. Both sources must be taken into account to ensure these emissions do not undermine the expected benefits of a decarbonized, hydrogen-based economy. This underscores the importance of existing pollution-reduction policies and their co-benefits. Although control strategies have been effective in certain sector, such as transportation, emissions from domestic biomass burning remain difficult to manage and continue to pose challenges in developing countries. Finally, the overall effect of any strategy depends not only on its effectiveness but also on how future activities are distributed across different sectors.