

Hydrogen Effects on Climate, Stratospheric Ozone, and Air Pollution

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Objective: This project studies the potential effects on climate, stratospheric ozone, and air pollution of converting vehicle fuel and electric power sources, in the U.S. and worldwide, from fossil fuels to hydrogen fuel cells.

Changes in technology have environmental implications that must be studied and examined prior to wide-scale adoption. Previous studies and models have not examined the climate response of a transition to hydrogen, the effect of hydrogen on atmospheric aerosols, nor the effect of using wind, coal, and/or natural gas to generate hydrogen. As such, a significant gap in our understanding of the effects of switching to hydrogen still exists. The purpose of this project is to try to fill some of this void with a numerical model that replaces current and future fossil fuels emissions with hydrogen-related emissions in a high-resolution emission inventory. The model then treats gases, aerosols, meteorology, and radiation simultaneously over a three-dimensional global grid that nests down to the urban scale.

Background: About 90% of current H₂ emissions originate from oxidation of methane, oxidation of nonmethane hydrocarbons, photolysis of formaldehyde (which originates from methane and isoprene), fossil-fuel combustion (particularly automobiles), and biomass burning. The remaining 10% originates from natural sources. The major losses of hydrogen are dry deposition to soils and oceans, and the chemical reaction, $\text{H}_2 + \text{OH} \rightarrow \text{H}_2\text{O} + \text{H}$ (*e.g.*, Schmidt, 1974).

One effect of hydrogen in the stratosphere is that it increases water vapor in the ozone. H₂O emitted near the surface does not readily penetrate to the stratosphere, but H₂ can penetrate readily into the stratosphere, where it can form H₂O by the reaction $\text{H}_2 + \text{OH}$. This is one of the few sources of water in the stratosphere (*e.g.*, Khalil and Rasmussen, 1990; Dessler *et al.*, 1994; Hurst *et al.*, 1999). Increased water in the stratosphere may increase the occurrence and size of Polar Stratospheric Clouds and stratospheric aerosols, both of which enhance stratospheric ozone reduction in the presence of chlorinated and brominated compounds. This issue will be examined as part of this project.

One mechanism by which increases in H₂ may enhance global warming is through a series of reactions that would produce O₃. In the troposphere, the loss of OH from $\text{H}_2 + \text{OH}$ would appear beneficial at first since OH is the chemical primarily responsible for breaking down organic gases, which generate ozone in photochemical smog. However, the H created from the same reaction instantaneously converts to HO₂ by $\text{H} + \text{O}_2 + \text{M} \rightarrow \text{HO}_2 + \text{M}$. HO₂ forms ozone in the troposphere by $\text{NO} + \text{HO}_2 \rightarrow \text{NO}_2 + \text{OH}$, followed by $\text{NO}_2 + h\nu \rightarrow \text{NO} + \text{O}$, followed by $\text{O} + \text{O}_2 + \text{M} \rightarrow \text{O}_3 + \text{M}$. Since O₃ is a greenhouse gas, the increase in H₂ may slightly increase near-

surface global warming. This mechanism of O₃ formation is less important in the stratosphere due to the lesser quantity of NO in the stratosphere than in the troposphere.

Another chemical effect of H₂ is that its reaction, $H_2 + OH \rightarrow H_2O + H$, reduces the rate of the reaction $CH_4 + OH \rightarrow CH_3 + H_2O$ because both reactions compete for a limited amount of OH. As a result, the lifetime of methane, CH₄, a greenhouse gas, increases.

Activities:

- (A) Identify the scenarios to consider and all possible changes in emissions associated with each.
- (B) To simulate the scenarios defined under Task A, design computer model experiments, run test simulations, and compare results against a large measurement database. Some model improvement will be undertaken.
- (C) Run pairs of simulations for each scenario described under Task A. For each pair, run both a baseline simulation representing current fuel use and a sensitivity simulation representing hydrogen fuel use, where hydrogen is generated from difference sources.

Approach: For the study, data from emission inventories of vehicles and electric power plants will be replaced with those resulting from hydrogen generation and hydrogen fuel cell use. Base case model predictions will be evaluated against an array of gas, aerosol, and meteorological measurements. Sensitivity studies, in which vehicles and electric power plants are switched to hydrogen, will be analyzed in terms of their resulting effects on climate, stratospheric ozone, and air pollution. The outcome of this study will be a comprehensive assessment of the potential effects on the atmosphere of converting vehicle and electric power sources in the U.S. and worldwide to hydrogen.

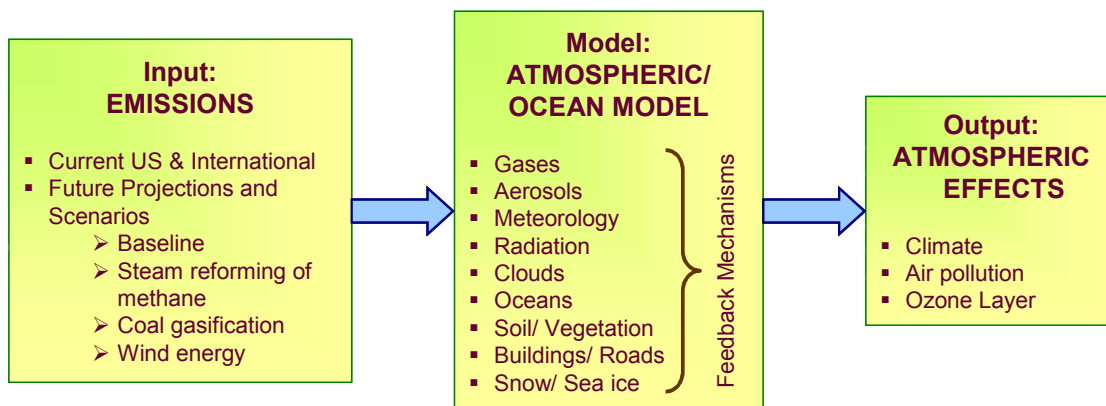


Figure 1: Schematic of Model Approach

References

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