Final Report
Hydrogen Effects on Climate, Stratospheric Ozone, and Air Pollution

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Abstract

This project examined the effects on (1) air pollution of converting all U.S. fossil-fuel onroad vehicles (FFOV) to hybrid vehicles and hydrogen fuel cell vehicles (HFCV), where the hydrogen is produced by wind-electrolysis, steam-reforming of natural gas, and coal gasification, on air pollution and (2) climate/stratospheric ozone of converting the world's fossil-fuel onroad vehicles to HFCVs, where the hydrogen is produced by wind-electrolysis.

With respect to the first topic, it was concluded that converting all U.S. onroad vehicles to hydrogen fuel-cell vehicles (HFCV) may improve air quality, health, and climate significantly over FFOV (namely gasoline and diesel), regardless of whether the hydrogen is produced by steam-reforming of natural gas, wind-electrolysis, or coal gasification. Most benefits would result from eliminating current vehicle exhaust. Wind- and natural-gas-HFCV offer the greatest potential health benefits. Wind-HFCV should benefit climate most. An all-HFCV fleet would hardly affect tropospheric water vapor concentrations. Conversion to coal-HFCV may improve health but would damage climate more than fossil/electric hybrids. The real cost of hydrogen from wind-electrolysis may be below that of U.S. gasoline.

With respect to the second topic, converting the world's fossil-fuel onroad vehicles (FFOV) to hydrogen fuel cell vehicles (HFCV), where the hydrogen is produced by wind-powered electrolysis, should reverse observed trends in tropospheric global warming and stratospheric cooling and reduce anthropogenic aerosol particle emissions reaching the stratosphere. The resulting stratospheric aerosol and ice cloud reductions should decrease heterogeneous chemical loss of ozone, speeding recovery of the stratospheric ozone layer. These results differ from those of a previous analysis that considered the effects on stratospheric ozone of adding leaked hydrogen without reducing gas or particle emissions from FFOV. Wind-powered HFCV should also reduce tropospheric methane by reducing its emissions, reduce tropospheric ozone, and displace essentially equivalent emissions of water vapor and hydrogen currently emitted by FFOV. The climate and ozone-layer benefits of battery-electric vehicles, where the electricity is derived from noncombusting renewable energy, should be similar to those of wind-powered HFCV.

Introduction

This project examined the potential effects on air pollution, climate, and stratospheric ozone, of replacing fossil-fuel motor vehicles with hydrogen fuel cell vehicles, where the hydrogen is produced either from steam reforming of natural gas, coal gasification, or wind energy. The effects were estimated with a three-dimensional numerical model of the atmosphere and ocean that was driven by emissions and treated gases, aerosol particles, meteorology, clouds, radiation, oceans, soils, and other surfaces. During the first stage of the project, U.S. emission scenarios were developed and nested global-U.S. simulations were run to examine the short-term effects on air pollution and health of replacing gasoline and diesel in all onroad U.S. vehicles with hydrogen generated from wind, natural gas, or coal. In the second stage of the project, a global emission scenario was developed and global simulations were run examining the long-term effect of hydrogen from wind on global climate, stratospheric ozone, and tropospheric pollution. Final results for both stages of the project are discussed.

Background

During the past few years, several papers were published examining the effects of a hydrogen economy on the atmosphere. Tromp et al.[1] modeled the potential impact of increasing atmospheric hydrogen on stratospheric ozone. They suggested that the addition of hydrogen would increase stratospheric water vapor and cool the stratosphere, a process that would delay recovery of the ozone layer. The paper did not look at the effect of simultaneously reducing fossil-fuel emission nor calculate the climate response of hydrogen itself, which is examined here.

Schultz et al.[2] examined the effects of a hydrogen economy on tropospheric air chemistry and direct radiative forcing of gases. Their scenarios assumed that a reduction in anthropogenic emission would accompany an increase in hydrogen use. They calculated that NO_x, CO, and OH would decrease and methane would increase in the global troposphere upon switching to hydrogen. Warwick et al.[3] similarly examined the effect of hydrogen leakage plus reduction in NO_x, CO, CH_4, and NMHC on tropospheric chemistry. Neither study (1) treated the effects of hydrogen on climate response (e.g., feedbacks to meteorology); (2) examined the effects of switching to hydrogen on local or regional pollution (they looked at large-scale effects); (4) treated aerosols or effects of a hydrogen economy on them; (5) treated specific emission scenarios, or (5) treated emissions resolved to the county level. These processes were treated for this project.

Results

Six papers relating significantly or partially to this been were published and one has been submitted. Two of the papers examined the effects on air pollution and health of converting all U.S. onroad vehicles to hydrogen fuel cell vehicles. Three papers discussed model improvements, and one examined wind resources, which are relevant to one of the hydrogen scenarios. Abstracts of three of the papers (Publications 1, 2, and 7) are as follows:

Switching to a U.S. Hydrogen Fuel Cell Vehicle Fleet: The Resultant Change in Emissions, Energy Use, and Greenhouse Gases

W.G. Colella, M.Z. Jacobson, and D.M. Golden
Journal of Power Sources, 150, 150-181, 2005

This study examined the potential change in emissions and energy use from replacing the current U.S. fleet of fossil-fuel on-road vehicles (FFOV) with hybrid electric fossil fuel vehicles or hydrogen fuel cell vehicles (HFCV). Emissions and energy usage were analyzed for three different HFCV scenarios, with hydrogen produced from 1) steam reforming of natural gas, 2) electrolysis powered by wind energy, and 3) coal gasification. With the US EPA's National Emission Inventory as the baseline, other emission inventories were created using a life cycle assessment (LCA) of alternative fuel supply chains. For a range of reasonable HFCV efficiencies and methods of producing hydrogen, it was found that the replacement of FFOV with HFCV significantly reduced air-pollution-related emissions compared even with a switch to hybrids. All HFCV scenarios decreased net air pollution emissions, including nitrogen oxides, volatile organic compounds, particulate matter, ammonia, and carbon monoxide. These reductions were achieved with hydrogen production from either a fossil fuel source such as natural gas or a renewable source such as wind. Furthermore, replacing FFOV with hybrids or HFCV with their fuel derived from natural gas, wind, or coal was hypothesized to reduce the global warming impact of greenhouse gases and particles (measured in carbon dioxide equivalent emission) by 6%, 14%, 23%, and 1%, respectively. Finally, even if HFCV are fueled by a fossil fuel such as natural gas, if no carbon is sequestered during hydrogen production, and 1% of methane in the feedstock gas is leaked to the environment, natural gas HFCV were still estimated to achieve a significant reduction in greenhouse gas and air pollution emission over FFOV.

Cleaning the Air and Improving Health With Hydrogen Fuel Cell Vehicles
M.Z.Jacobson, W.G. Colella, and D.M. Golden
Science, 308, 1901-1905, 2005

This study found that converting all U.S. onroad vehicles to hydrogen fuel-cell vehicles (HFCV) may improve air quality, health, and climate significantly, whether the hydrogen is produced by steam-reforming of natural gas, wind-electrolysis, or coal gasification. Most benefits would result from eliminating current vehicle exhaust. Wind- and natural-gas-HFCV offer the greatest potential health benefits and could save 3700-6400 U.S. lives annually. Wind-HFCV should benefit climate most. An all-HFCV fleet would hardly affect tropospheric water vapor concentrations. Conversion to coal-HFCV may improve health but would damage climate more than fossil/electric hybrids. The real cost of hydrogen from wind-electrolysis may be below that of U.S. gasoline.

Effects of wind-powered hydrogen fuel cell vehicles on global climate and stratospheric ozone
M.Z. Jacobson

Converting the world's fossil-fuel onroad vehicles (FFOV) to hydrogen fuel cell vehicles (HFCV), where the hydrogen is produced by wind-powered electrolysis, should reverse observed trends in tropospheric global warming and stratospheric cooling and reduce anthropogenic aerosol particle emissions reaching the stratosphere. The resulting stratospheric aerosol and ice cloud reductions should decrease heterogeneous chemical loss of ozone, speeding recovery of the stratospheric ozone layer. These results differ from those of a previous analysis that considered the effects on stratospheric ozone of adding leaked hydrogen without reducing gas or particle emissions from FFOV. Wind-powered HFCV should also reduce tropospheric methane by reducing its emissions, reduce tropospheric ozone, and displace essentially equivalent emissions of water vapor and hydrogen currently emitted by FFOV. The climate and ozone-layer benefits of battery-electric vehicles, where the electricity is derived from noncombusting renewable energy, should be similar to those of wind-powered HFCV.

Publications 3-5 describe GATOR-GCMOM model improvements during the project period. The improvements were (a) a new method of solving nonequilibrium gas-aerosol transfer of acids and bases, (b) a new method of calculating absorption coefficients among multiple gases simultaneously, and (c) a new method of solving ocean-atmosphere exchange and ocean chemistry. Paper 6 discusses quantification of global wind resources from data.

Conclusions

The main conclusions of this project are described in Publications 1, 2, and 7. The first two publications laid out scenarios examining the effects on air pollution, health, and climate of converting all U.S. vehicles to hydrogen fuel cell vehicles when the hydrogen is generated in one of three ways. The papers also examined the effects of converting to gasoline-electric hybrid vehicles. Primary conclusions from the first two papers (Publications 1 and 2) are as follows:

1) Switching from the 1999 fossil-fuel onroad vehicle (FFOV) fleet to a hydrogen fuel cell vehicle (HFCV) or hybrid fleet may reduce air pollution, health, and climate problems and costs.
2) Although all three HFCV cases studied (wind, natural gas, coal) reduced health costs (since most air quality improvements resulted from eliminating FFOV exhaust), wind- and natural gas-HFCV reduced such costs the most and reduced ozone by up to 20 ppbv.
3) Wind-HFCV reduced climate costs the most, making it the most environmentally beneficial energy technology scenario.
4) Natural gas-HFCV increased CH_4 but reduced CO_2, making it the second-most-beneficial technology after wind-HFCV.
5) Hybrids reduced climate costs but increased health costs relative to coal-HFCV, suggesting a rough tie for third.
6) Hybrids and coal-HFCV reduced health and climate costs relative to FFOV.
7) HFCV had little impact on water vapor emission, either in terms of magnitude or location of the emission.

The main conclusions of the third paper (Publication 7) are as follows:

1) A wind-hydrogen economy is estimated to cool near-surface global temperatures and warm stratospheric temperatures, thereby slowing the effects of global warming.
2) A wind-hydrogen economy is estimated to reduce stratospheric and tropospheric mixing ratios of oxides of nitrogen and oxides of hydrogen.
3) Warmer stratospheric temperatures combined with lower NO_x and HO_x is estimated to increase stratospheric ozone, speeding recovery of the stratospheric ozone layer.
4) Reduced NO_x and organic gases in the troposphere is estimated to reduce tropospheric ozone.
5) Converting to hydrogen is expected to reduce tropospheric methane by reducing its emissions.
6) A hydrogen economy is expected to reduce particulate concentrations overall although some local increases may occur due to changes in precipitation patterns.

Publications

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2. Jacobson, M.Z., W.C. Colella, and D.M. Golden, Cleaning the air and improving health with hydrogen fuel cell vehicles, *Science*, 308, 1901-1905, 2005.
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References

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