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Impact of a future H_2 transportation on atmospheric pollution in Europe

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HIGHLIGHTS

- European air quality improves in the future due to emission regulations.
- When road traffic is converted to H_2, air quality improves further.
- H_2 leaked into the atmosphere does not have a large negative impact on air quality.

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ABSTRACT

Hydrogen (H_2) is being explored as a fuel for passenger vehicles; it can be used in fuel cells to power electric motors or burned in internal combustion engines. In order to evaluate the potential influence of a future H_2-based road transportation on the regional air quality in Europe, we implemented H_2 in the atmospheric transport and chemistry model LOTOS-EUROS. We simulated the present and future (2020) air quality, using emission scenarios with different proportions of H_2 vehicles and different H_2 leakage rates. The reference future scenario does not include H_2 vehicles, and assumes that all present and planned European regulations for emissions are fully implemented.

We find that, in general, the air quality in 2020 is significantly improved compared to the current situation in all scenarios, with and without H_2 cars. In the future scenario without H_2 cars, the pollution is reduced due to the strict European regulations: annually averaged CO, NO_x and PM2.5 over the model domain decrease by 15%, 30% and 20% respectively. The additional improvement brought by replacing 50% or 100% of traditionally-fueled vehicles by H_2 vehicles is smaller in absolute terms. If 50% of vehicles are using H_2, the CO, NO_x and PM2.5 decrease by 1%, 10% and 1% respectively, compared to the future scenario without H_2 cars. When all vehicles run on H_2, then additional decreases in CO, NO_x and PM2.5 are 5%, 40%, and 5% relative to the no-H_2 cars future scenario. Our study shows that H_2 vehicles may be an effective pathway to fulfill the strict future EU air quality regulations.

O_3 has a more complicated behavior – its annual average decreases in background areas, but increases in the high-NO_x area in western Europe, with the decrease in NO_x. A more detailed analysis shows that the population exposure to high O_3 levels decreases nevertheless.

In all future scenarios, traffic emissions account for only a small proportion of the total anthropogenic emissions, thus it becomes more important to better regulate emissions of non-traffic sectors.

Although atmospheric H_2 increases significantly in the high-leakage scenarios considered, the additional H_2 added into the atmosphere does not have a significant effect on the ground level air pollution in Europe.

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1. Introduction

Road traffic is a major source of greenhouse gases and pollutants. Greenhouse gases affect the earth system globally, leading to global warming and ocean acidification. Pollution affects human health and ecosystems in particular in densely populated areas. Fine particulate matter (PM2.5) enters the lungs and enhances allergies, asthma, lung infections and long term lung diseases. PM2.5 is recognized as one of the main pollutants reducing life expectancy in Europe (EEA, 2013); recent studies show that PM2.5 affects health already at levels much lower than present European air quality limits (Beelen et al., 2014). NO_x contributes to acid rain formation; it is a precursor for tropospheric ozone, aerosols and other toxic chemicals, and affects human health, especially the respiratory system (EEA, 2013; WHO, 2013). CO is a precursor for tropospheric ozone, participates in atmospheric chemistry, and is a toxic gas, affecting blood ability to transport oxygen. Tropospheric O_3 is not emitted directly but formed under influence of NO_x and volatile organic compound (VOC) emissions. It is one of the major components of photochemical smog; it affects human health, ecosystems and causes important crop losses (EEA, 2013; WHO, 2006, 2008).

In Europe (EU 28), emissions from road traffic were responsible for about 25% of the total CO emissions, 39% of NO_x and 15% of the primary PM2.5 in 2012 (EEA, 2014). Road transport was responsible for 26% of O_3 precursor emissions in Europe in 2007 (EEA, 2010).

Replacing fossil fuels by H_2 in a potential future "hydrogen economy" is attractive, in the context of reducing availability of fossil fuels and increased awareness on the problems of pollution and climate change. When using fuel cell technology, H_2 burning emits only water, thus using H_2 as a fuel would avoid direct emissions of both anthropogenic greenhouse gases and pollutants.

Regarding H_2 safety, it is often thought that H_2 would be a dangerous fuel quickly leading to explosions. However, with adequate handling, H_2 can be a safer fuel than e.g. gasoline or methanol: because of its high buoyancy it does not accumulate around leak points, reducing the risk of explosions; also, a H_2 fire causes fewer toxic emissions and less severe radiant heat damage (Adamson and Pearson, 2000; Veziroglu and Barbir, 1992).

However, it is important to consider all potential effects. In 2000s, several studies (Prather, 2003; Schultz et al., 2003; Tromp et al., 2003; Warwick et al., 2004) drew attention to the fact that a hydrogen economy would be associated with an increase in atmospheric H_2 due to leakage, and this additional atmospheric H_2 could have negative effects on the atmosphere. Additional H_2 in the atmosphere could enhance the stratospheric ozone hole (Tromp et al., 2003), and could indirectly increase the radiative forcing by influencing the greenhouse gases methane and tropospheric ozone (Prather, 2003). Later, more detailed studies showed that these negative effects are much smaller than feared initially, and small compared to the potential benefits (Derwent et al., 2006; Jacobson, 2008; Vogel et al., 2012; Wang et al., 2013b; Warwick et al., 2004).

The benefits of a hydrogen economy can be significant, especially regarding air quality. All studies to date reported considerable improvements in air quality, if (part of) the economy or transportation were switched to H_2 as an energy carrier. The first studies on this subject considered the present (~2000) situation and assumed an immediate transition to a H_2 economy.

In their modeling study, Schultz et al. (2003) considered a conversion to H_2 of 50% of the total economy (which is roughly equivalent to 100% conversion of the transportation sector). This resulted in decreases in simulated NO_x (30%), CO (3%) and O_3 (5%) mole fractions. They also found that in polluted areas in Western Europe, China and Eastern US the average surface O_3 would increase; however, even in these areas, the peak O_3 values were predicted to decrease, which would result in fewer violations of air quality limits. Another finding of this study was a decrease in oxidizing power of the troposphere, because the decrease in NO_x leads to less OH.

In a similar study, Warwick et al. (2004) assumed a complete replacement of the fossil fuel economy, and found reductions in tropospheric O_3 (2.2%) and OH (5%).

Jacobson et al. (2005) assumed a conversion of all US vehicles to H_2, and compared the effects on air quality, health and climate for several H_2 production options. Unlike the other studies, they also took into account the emissions associated to the production of H_2. The results showed that using H_2 produced from wind energy offers the largest benefits for health and climate. For all H_2 production methods, significant reductions were found for CO, O_3, NO_x, black carbon, and other tropospheric pollutants.

Jacobson (2008) estimated the effects of converting the global vehicle fleet to H_2 produced by wind-powered electrolysis, and found reductions over 10 years in tropospheric CO (5%), NO_x (5–13%), O_3 (6%) and OH (4%).

The recent study of Wang et al. (2013a), which estimated the effects of converting the global transportation to H_2, is the first one to place the simulations in the future (2050). The study is global, and includes higher resolution simulations with focus on the US territory. Their baseline (no H_2 cars) emission scenarios are based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) growth scenarios A1F1 and B1 (Nakicenovic et al., 2000), combined with present-day fossil fuel burning emission factors. A1F1 and B1 are the highest and lowest emission SRES scenarios. Both assume a large population increases and a world integrated economically; the A1F1 scenario assumes rapid economic growth and intensive use of fossil fuels, while in B1 the economy becomes more information oriented and less material intensive, and employs more clean and resource efficient technologies. The simulations using these baseline scenarios predict significantly increased air pollution in 2050 compared to present. The pollution decreases then significantly compared to the baseline when switching all the road traffic to H_2. The largest improvements are found in most polluted, highly populated areas. Wang et al. assume no emissions of air pollutants are associated with H_2 production.

In the present study we investigate the effects on air quality in Europe of a future (2020) H_2 -based road transportation sector, using the chemistry transport model LOTOS-EUROS. We compare future emission scenarios in which 50% or 100% vehicles are converted to H_2, with a future "baseline" scenario without H_2 vehicles. Our baseline emission scenario assumes that the current and planned European legislation concerning emissions of air pollutants is fully implemented. We account for NO_x emissions associated to the production of H_2 for vehicle use.

2. Methods

2.1. Model

LOTOS-EUROS is an Eulerian 3D chemistry transport model designed to simulate air pollution in the lower troposphere in Europe (Schaap et al., 2008). The model has been used to simulate for example ozone (Vautard et al., 2006; Schaap et al., 2008), particulate matter (Manders et al., 2009), secondary inorganic aerosol (Schaap et al., 2004a; Erisman and Schaap, 2004), black carbon