Addressing Global Warming, Air Pollution Health Damage, and Long-Term Energy Needs Simultaneously

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Summary

Proponents of ethanol suggest that it is a clean and renewable fuel that will reduce air pollution and address climate change. Data, computer model results, and new emission information suggest that ethanol is neither clean nor has it been shown that it can slow global warming. To the contrary, its promotion will continue the public health crisis that has resulted in thousands of premature air-pollution-related deaths and millions of cases of asthma and respiratory disease each year in the U.S. It will also divert resources from the primary practical solutions to global warming and air pollution simultaneously, namely wind- and solar energy for electric power, electric vehicles, and electricity-derived-hydrogen fuel-cell vehicles. The main findings of this report are as follows:

1) Laboratory data and the first three-dimensional computer model simulations on the subject suggest that E85 fuel (85% ethanol and 15% gasoline) will increase atmospheric levels of ozone and PAN, leading indicators of photochemical smog, in the Los Angeles basin, the most polluted airshed in the U.S.

2) E85 will increase two major carcinogens, acetaldehyde and formaldehyde while slightly reducing another, butadiene, and reducing a fourth, benzene.

3) E85 vehicles are at best an equal and at worst a greater risk to public health than equivalent gasoline vehicles. E85 will continue to contribute to the thousands of cases of premature mortality and millions of cases of asthma and respiratory disease in the U.S. that gasoline and diesel vehicles currently cause.

4) Studies to date suggest little reduction or an exacerbation of global warming due to corn-ethanol versus gasoline as a fuel. All the studies, though, have neglected at least seven sources of emission that enhance global warming, suggesting that corn ethanol must cause more warming than all studies have estimated.

5) Cellulosic ethanol is a technology that has been around for over 15 years at the laboratory scale but still does not exist at the field scale. All studies of cellulosic ethanol have missed the same emission sources as the corn-ethanol studies missed.

Thus, all estimates of the effects of cellulosic ethanol on global warming to date are premature and low.

6) Wind and solar energy can reduce both global warming and air pollution simultaneously. A recent world wind-mapping study suggests that sufficient wind power is available over land to satisfy all electric and vehicle power demand worldwide up to five times over. Solar power is more abundant than wind. Solar photovoltaics are more expensive than wind but easier to site. Solar thermal is both easy to site and inexpensive.

7) Fossil-fuel vehicles can be replaced, and their pollution eliminated, by electric vehicles, where the electricity is derived from wind or solar power, and by hydrogen fuel cell vehicles (HFCVs), where the hydrogen is derived from wind or solar power. In the latter case, hydrogen is obtained by using electricity from wind or solar to split water into hydrogen and oxygen. No pollution is emitted during this process or during the use of the HFCV, in which the chemical reaction is reversed (hydrogen plus oxygen producing water and energy). Although these technologies face hurdles (e.g., possible platinum shortages upon large penetration of HFCVs and setting up a fueling or charging infrastructure in both cases), the technologies work. Today, California has about 100 hydrogen vehicles and many electric vehicles on the road. Hydrogen electrolysis from wind is estimated conservatively to cost $1.12-$3.20 per equivalent gallon of gasoline.

8) Wind and solar together can eliminate millions of cases of asthma and respiratory disease and hundreds of thousands of deaths worldwide from air pollution each year and ultimately, can eliminate global warming. The health and climate cost of E85 from corn-ethanol is estimated to be near $0.30-$1.80/gallon. This cost will also be eliminated with wind- and solar-powered vehicles.

Introduction

Global warming and health effects of air pollution are two of the greatest problems affecting the world's population today. Indoor plus outdoor air pollution is the seventh leading cause of death worldwide, killing an estimated 2.7 million people prematurely each year[1]. Air pollution kills 50,000-100,000 each year in the U.S. [2-5] and about 300,000 in Europe[6] prematurely. The main causes of air-pollution-related death are asthma, bronchitis, emphysema, lung disease, heart disease, and respiratory allergies[5]. About 40% of fatalities are due to power plant emissions and 50%, to on- and offroad vehicle emissions. Pollution from onroad vehicles alone may result in 1-3.3 million cases of asthma and 17-30 million cases of respiratory illness each year in the U.S.[7].

Global warming is the increase in near-surface air temperatures due to the emission, since the Industrial Revolution, of greenhouse gases and particulate black carbon. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other components. Black carbon is the main component of soot, the black material visible from the exhaust of farm equipment, construction machines, buses, passenger vehicles, generators and other machines that run on diesel or jet fuel and, to a lesser extent, other fuels. Of global warming to date, approximately 47% is due to carbon dioxide, 16% to black carbon, 14% to methane, and 4% to nitrous oxide[8]. Current and anticipated effects of global warming include increases in regional temperature extremes, heat-related illness and mortality, susceptibility to infection, severe-weather events, ocean acidification, sea-level rise and coastal flooding, and shifts in agriculture production.

The health costs due to vehicular air pollution are estimated to be equal or greater than the costs of global warming today although both are significant[7]. Because population is increasing and more people worldwide are consuming increasing levels of resources, both air quality and global climate will deteriorate further unless strategies to address both are implemented quickly. Due to the severity of both, any strategy that addresses air pollution and global warming simultaneously is superior to any strategy that reduces one but not the other. Similarly, any strategy that focuses on one problem but diverts financial resources away from a more efficient solution to both problems simultaneously is bound to leave a damaging legacy.

The problem of controlling carbon dioxide is so enormous, that it is necessary to reduce today's emission rate of fossil-fuel carbon dioxide by 70% just to stabilize atmospheric carbon dioxide at its current level of 375 ppmv while accounting for growth in future emission over just the next 15 years.[9] Such stabilization would reduce only 45% of the future growth in temperatures since carbon dioxide is responsible for only this percent of global warming. Thus, any strategy that diverts financial resources into a technology that reduces carbon emission by 50% or less at the expense of a technology that reduces such emission by 100% is a strategy that will punish future generations. The fatality of such a strategy becomes apparent when one realizes that merely doubling carbon dioxide emission (which happened over the last 38 years), would wipe out any benefit of the 50% technology; the 100% technology is truly sustainable since an increase in population has no impact on the emission.

It has been proposed that the use of ethanol as a fuel is the panacea for global warming and will reduce air pollution. More specifically, it has been suggested that blends with 85% ethanol and 15% gasoline (E85) will reduce air pollution and carbon emission significantly. Below, these issues are examined.

Effects of E85 on Air Pollution

Table 1 shows the measured changes in emissions from several laboratory and field studies when a E85 versus a gasoline was used in a vehicle or engine. The table shows that, in general, E85 increased emissions of nonmethane organic gases (NMOG), methane, formaldehyde (a carcinogen), acetaldehyde (a carcinogen), and nitrogen dioxide, and they increased the ratio of nitrogen dioxide to nitrogen oxide. In contrast, E85 reduced ethane, butadiene (a carcinogen), benzaldehyde (a carcinogen), carbon monoxide, and nitric oxide. Notably, the studies found that E85 increases acetaldehyde by 1400-3600% (a factor of 14-36) and formaldehyde by 40-240%. These gases are two of the five most important ozone precursors in photochemical smog. Acetaldehyde is also a major precursor to peroxyacetyl nitrate (PAN), a potent eye irritant in smog.

Table 1. Measured percentage changes in emissions of several gases or groups of gases from E85 (85% ethanol-15% gasoline blend) vehicles relative to gasoline vehicles (+ indicates higher E85 emission). The NO_2:NO_x ratio for E85 is also shown (last row). For comparison, the NO_2:NO_x ratio for gasoline vehicles is 0.1. Also shown (last column) are model values used here.

	D96	B98	W01	L02	M02	D06	N06	MODEL
Total organic gas (TOG)					+38%	+43%		
Nonmethane org gas (NMOG)		+15%	+63%			+31%	+0%	+15%
Methane (CH_4)				+43%				+43%
Formaldehyde (HCHO)		+60%	+240%		+41%			+60%
Acedaldehyde (CH_3CHO)	+1440%	+3660%	+1430%		+3100%			+1900%
Benzaldehyde (C_6H_5CHO)					-69%			-69%
Other aldehdyes					-60%			-60%
Ethene (C_2H_4)	-17%							-17%
Butadiene (C_4H_6)		+0%	-13%					-17%
Benzene (C_6H_6)	-85%	-62%	-78%					-85%
Toluene ($C_6H_5CH_3$)								-85%
Xylene ($C_6H_4CH_3CH_3$)								-85%
Carbon monoxide (CO)		+62%			-23%	-4%	+31%	-10%
Nitric oxide (NO)					-85%			
Nitrogen dioxide (NO_2)					+100%			
NO_x (as NO_2)		-34%			-59%	-59%	+33%	-29%
NO_2:NO_x					0.65			0.65

D96=Delucchi (1996)[12] – Table 13, comparing gasoline and E85; B98=Black et al. (1998)[13] – comparing Limina RFG and Lumina E85; W01= Winebrake et a. (2001)[14] – comparing conventional gasoline and E85; L02=Lipman and Delucchi (2002)[15] – Section 3.4, summarizing E85 studies; M02= Magnusson et al. (2002)[16] – comparing regular gasoline and E85 ethanol-regular blended gasoline under lean conditions – Tables 2 and 4; D06 = DOE (2006)[17], comparing gasoline and E85; N06=NREL (2006)[18] – comparing 1998 Tauraus with E85 and industry-averaged gasoline RF-A; MODEL=assumptions for model simulation.

The GATOR-GCMOM air pollution/climate/weather forecast computer model[19,7,11,21,34,35] was used together with the Environmental Protection Agency's U.S. National Emission Inventory and changes in emission due to E85 (last column of Table 1) estimated from the data in Table 1. The changes were applied to over 700 categories of gasoline vehicle in the emission inventory, to calculate the relative effects of E85 versus gasoline emissions on smog in the Los Angeles basin, the most polluted city in the United States.

Figure 1. Modeled differences during two days in August in near-surface ozone and peroxyacetyl nitrate (PAN) in the Los Angeles basin when all gasoline vehicles in the basin (in 2002) were converted to E85 vehicles under the assumption is the last column of Table 1.

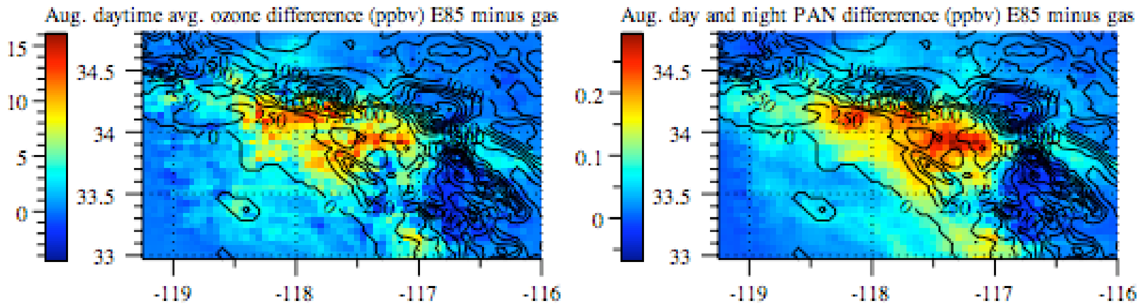

Figure 1 shows that both ozone and PAN mixing ratios increased significantly in Los Angeles upon the replacement of gasoline with E85. Both increases are significant enough to cause additional health effects in Los Angeles. Sensitivity tests suggest that, even at the same non-methane organic emission rate as gasoline (NMOG = +0% in Table 2), E85 vehicles enhance ozone and PAN due to the strong effects of acetaldehyde and formaldehyde on air pollution.

In summary, E85 data from laboratory studies and high-resolution computer simulations applying the data suggest that E85 is likely to exacerbate ozone and PAN, leading indicators of photochemical smog, in Los Angeles, the most polluted U.S. city. E85 will also increase two major carcinogens, acetaldehyde and formaldehyde while slightly reducing another, butadiene, and reducing a fourth, benzene, to a greater extent. Due to the carcinogenic products it produces and the enhanced ozone and PAN formation resulting from its use, E85 is an equal or greater risk to public health than gasoline. As such, both are expected to continue to contribute to the thousands of cases of premature mortality and millions of cases of asthma and respiratory diseases in the U.S.

Effects of E85 on Global Warming

Ethanol is referred to as a “renewable” energy carrier because, although carbon dioxide is emitted during its combustion, carbon dioxide is also removed from the atmosphere to grow the crop used to produce ethanol. However, crops require energy for fertilization, cultivation, irrigation, conversion to ethanol, and transport, among other processes, and much of the energy for these processes is currently derived from fossil fuels. A handful of studies have either examined the energy and carbon balances of ethanol or reviewed other studies[22-33]. In the U.S., the most widely-used crop for ethanol today is corn; in Brazil, it is sugarcane. While some studies have suggested that corn-ethanol results in a slight reduction in equivalent CO_2 emissions, others suggest a slight increase. (Equivalent CO_2 emissions are emissions of CO_2 plus emissions of other greenhouse gases and particles multiplied by their potential for global warming relative to CO_2. For example, methane has 23 times the global warming potential of CO_2.)

All studies, though, are missing the following equivalent CO_2 emissions associated with production of ethanol:

1) Equivalent CO_2 emissions associated with the time lag between ethanol combustion in a vehicle and ethanol-crop regrowth[11]. Crops do not regrow

instantaneously. Between combustion and regrowth, carbon dioxide is present in the atmosphere enhancing global warming. Example calculations of the average increase in atmospheric CO_2 due to this effect are given in the web site associated with Ref. (11).

2) Increases or decreases in sequestered carbon associated with replacing natural vegetation with a crop. For example, replacing rainforest, tropical forest, woodland with agriculture usually results in a permanent loss of stored carbon. Replacing prairie grass, which naturally stores significantly more carbon below ground than above with an agriculture crop that does not store so much combined carbon for the full year will also result in a net loss of carbon. Ref. 11 and the web site associated it give some examples of this effect.

3) Equivalent CO_2 emissions of particulate black carbon (BC), the second-leading cause of global warming. BC has a global-warming potential of 90-190 times that of carbon dioxide[10,34,35]. The largest sources of BC in the U.S. are agricultural equipment, construction machines, diesel trucks, and ships all of which are used in the corn-ethanol process.

4) CO_2, BC, CH_4, and N_2O emissions associated with transporting ethanol by rail, truck, or barge from the midwest to coastal areas for use since pipelines in the U.S. do not transport ethanol.

5) Enhanced methane emissions due to ethanol combustion (Table 1).

6) Enhanced tractor- and wind-driven emission of soil dust particles containing humic material (decayed organic plant matter) to the atmosphere and the resulting conversion of a portion of this material to carbon dioxide[33]. Agriculture enhances the erosion of soil by a minimum of 1 mm per year[33]. This eroded soil, which contains humic material, is readily lifted into the air by tractors and the wind. In the absence of agriculture, the humic material stays embedded in the soil, slowing its conversion rate to carbon dioxide.

7) Emissions associated with an 8%-by-energy gasoline additive to ethanol, counted as ethanol by the industry[33].

Accounting for these additional emissions would increase the global warming impact estimates in all the corn-ethanol studies to date, suggesting corn ethanol likely causes either no reduction in or exacerbates global warming. Since corn ethanol cannot come close to reducing carbon emissions by 70%, the reduction needed to stabilize carbon dioxide at 375 ppmv, its promotion at the expense of 100%-reduction solutions will exacerbate global warming and air pollution.

Several studies, have suggested that cellulosic ethanol, derived for example from switchgrass, will provide a significant carbon benefit over corn ethanol. However, research has been going on for at least 15 years to produce cellulosic ethanol[20,22,31], yet such technology has not been developed to date at the industrial scale, so all calculations of carbon cycling during production and consumption of cellulosic ethanol are hypothetical and premature[31]. All such calculations also omit the seven factors discussed above.

In summary, studies of the corn-ethanol and cellulosic-ethanol carbon balances have all neglected several sources of emission. Corn-ethanol studies show either little benefit or a disbenefit without accounting for such emission; so the addition of the emissions will reduce the benefit or increase the disbenefit further. Cellulosic ethanol is a nonexistent technology at the industrial scale, so the uncertainty in the emission associated with it is large, particularly considering the omission of several emission sources in these studies.

The health plus climate cost of a gallon of gasoline has been estimated as $0.30-$1.80 per gallon[7]. This cost would also apply to E85. Production of ethanol from crops has an additional impact on water supply, soil erosion, water contamination, and landuse modification that are discussed thoroughly elsewhere[33].

How to Address Climate and Air Quality Simultaneously

Due to the enormous scope of the problems, climate and air pollution can be addressed effectively together only with zero-emission energy sources, since total emissions from non-zero-emitting energy sources increase with increases in population or wealth. Table 2 shows that, of non-emitting energy sources, only solar and wind energy have sufficient availability to satisfy all energy demand worldwide (e.g., for vehicles, electric power, etc.). Nuclear energy is not included in Table 2 as a feasible renewable energy source to address air pollution and climate on a large scale because, although its air pollution and greenhouse-gas emissions are low, it has high risks associated with it, problems associated with disposal of radioactive waste, 5-10-year lead times before a new plant can come online, significant public opposition to it, uses a limited resource (uranium), and has requires fossil-energy for uranium enrichment.

Table 2. Global power demand and availability from renewable energy sources.

	TW
Global overall power demand[36]	9.4-13.6
Global renewable power available	
Solar over land	31,000
Wind at 80 m and at > 6.9 m/s[36]	72
Hydroelectric[37]	6.5
Wave[37]	5
Tidal[37]	3.7

Table 2 shows that only solar and wind have the capability of addressing the world's energy demands on their own. Today, wind power is 3-5 times less expensive than is solar photovoltaic (PV) power, but siting PVs is often easier (e.g., on rooftops) than is siting wind power. Together, these two energy sources could supply the world's electric power plus vehicle fuel energy. For example, the world's electric power demand (1.6-1.8 TW) could be addressed with about 860,000 5-MW wind turbines placed offshore in mean annual winds > 8.5 m/s (the offshore average). The world's total energy demand (Table 2) could be addressed with 5 million such turbines.

In 2003, 54.09% of California's electric power originated from carbon- and smog-producing fuels (coal: 1.21%; natural gas: 47.43%, petroleum: 1.24%, other gas: 0.912%; wood: 2.0%; other biomass: 0.4%; MSW/LFG: 0.9%). The rest originated from hydroelectric power (18.8%), geothermal (6.7%), wind (2.0%), solar (0.3%), and nuclear power (18.46%).

All carbon- and smog-producing electric power in California could be replaced by 6280 5-MW turbines in wind speeds > 8.5 m/s. This number of turbines represents only a factor of 3.3 increase in the number of wind turbines currently installed in California (and an increase in their size from 1 MW to 5 MW). These turbines could be placed in 5 offshore wind farms and 5 onshore wind farms (e.g., by upgrading 3 existing onshore farms). All electric power and energy demand in California could be addressed with about 37,000 such turbines. By linking the wind farms together through the transmission grid, one-third or more of intermittent wind power would turn into reliable power[38]; thus with >20,000 turbines, all electric power supplied in California from wind would be reliable power (at the same reliability as a coal-fired power plant); the rest could be used to generate electricity for battery-operated vehicles or hydrogen for hydrogen fuel cell vehicles (HFCVs).

Although using wind- or solar-electricity for HFCVs is less efficient than using it for electric vehicles, HFCVs are still more efficient than the internal combustion engine. The cost of wind-generated electricity for hydrogen in HFCVs has been calculated to be $1.12-$3.20 per equivalent gallon of gasoline[7]. A HFCV economy would not require pipelines for hydrogen. Instead, hydrogen would be produced at a local filling station from water and electricity sent by transmission line. At large penetration of hydrogen vehicles, shortages of platinum (used in the fuel cell) could become an issue. However, such shortages may not materialize, particularly if platinum use in fuel cells decreases upon technology improvements as it did in the case of catalytic converters.

The expansion of solar energy in California would reduce the requirements for wind energy. One million solar roofs, each with 20 160-watt panels (3.2 kW) would displace about 5.2% of electricity produced from carbon- and smog-producing fuels in California. A ten-million solar roof plan would displace 52% of such electric power. The addition of 10 million solar thermal hot water systems in California would reduce natural gas requirements significantly as well. Solar-thermal systems are much less expensive than solar PV systems for a household.

Opponents of wind energy site loss of birds. According to the Bird Conservancy[39], the 15,000 operational wind turbines in the U.S. kill 10,000-40,000 birds/year. This number, however, compares with 50 million birds lost to transmission towers[39] and 50 million lost to cats and 200 million lost to the Avian Flu in 2005[40]. Even with 5 million turbines worldwide (satisfying all energy sources worldwide), the number of bird deaths would be small compared with those of transmission lines alone and it would not approach the human mortality and health costs of the fossil fuels wind would be displacing.

In sum, wind and solar power could satisfy all electric power and non-electric power requirements worldwide and simultaneously address climate change and air quality, eliminating the millions of cases of asthma and respiratory disease and hundreds of thousands of deaths worldwide each year due to fossil fuels. Biofuels will not address human health problems associated with fossil-fuel combustion nor has it been shown that biofuels can reduce global warming.

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