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EPA BLACK CARBON AND GLOBAL WARMING

HEARING

BEFORE THE

COMMITTEE ON OVERSIGHT AND GOVERNMENT REFORM

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

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EPA BLACK CARBON AND GLOBAL WARMING

THURSDAY, OCTOBER 18, 2007

HOUSE OF REPRESENTATIVES,
COMMITTEE ON OVERSIGHT AND GOVERNMENT REFORM,
Washington, DC.

The committee met, pursuant to notice, at 10:06 a.m. in room 2154, Rayburn House Office Building, Hon. Henry A. Waxman (chairman of the committee) presiding.

Present: Representatives Waxman, Maloney, Cummings, Kucinich, Tierney, Norton, McCollum, Hodes, Davis of Virginia, Shays, Mica, Duncan, Issa, and Bilbray.

Staff present: Phil Schiliro, chief of staff; Phil Barnett, staff director and chief counsel; Greg Dotson, chief environmental counsel; Earley Green, chief clerk; Teresa Coufal, deputy clerk; Caren Auchman and Ella Hoffman, press assistants; Leneal Scott, information systems manager; David Marin, minority staff director; Kristina Husar, minority counsel; Larry Brady, minority senior investigator and policy advisor; Patrick Lyden, minority parliamentarian and member services coordinator; Brian McNicoll, minority communications director; Benjamin Chance, minority clerk; and Ali Ahmad, minority deputy press secretary.

Chairman WAXMAN. The meeting of the committee will please come to order.

Today's hearing will focus on the issue of black carbon and global warming. Black carbon is commonly known as soot. It is emitted from our diesel trucks, our trains, planes, ships, and even our fireplaces. Over the years, Congress and the Environmental Protection Agency have focused on tiny particles like black carbon because it cut short the lives of our seniors and sickened our children; however, black carbon is also important because of the ongoing role it plays in the warming of the Earth.

Today we will hear that black carbon may be responsible for almost 20 percent of the warming the planet is currently experiencing. Experts will tell us that black carbon may be the second most significant global warming pollutant after carbon dioxide; yet controlling black carbon has not been seriously examined at the Federal level as a way of possibly mitigating global warming.

At today's hearing we will explore what may seem to be an overwhelmingly complex issue involving atmospheric chemistry, global climate modeling, and literally millions of sources of air pollution.

It may seem complex, and indeed there are complexities and unanswered questions, but it is manageable. Here is what we know: Global warming is happening and carbon dioxide is the principal pollutant of concern. Other pollutants, like black carbon, also con-

tribute to the problem. Because black carbon doesn't stay in the Earth's atmosphere as long as carbon dioxide, controlling it may achieve major benefits in the short term.

We may need short-term benefits in order to prevent irreversible impacts from occurring. Reducing particulate air pollution, like black carbon, could also achieve major public health benefits.

This is not a theoretical issue. We can now see the impacts of global warming with our own eyes. To illustrate this last point, I have several slides of glaciers that I would like to put up on the screen.

This first is of Carroll Glacier in Alaska. As you can see, this glacier has basically disappeared in the 97 years between when these photographs were taken. As you can see it is a straight glacier untouched by any warming, complete ice, no deterioration. We will soon see a photograph that shows a very different picture.

We also have photographs which we will exhibit in the near term, and these photographs are of McCall Glacier, which has receded dramatically over the last 45 years, and then there is also Toboggan Glacier that has vanished over the course of 90 years.

The glaciers of the world are receding. These receding glaciers are one measure of the warming that we now know to be occurring, but it isn't the only one. What is happening in the Arctic is alarming.

We have a time-lapsed animation of Arctic sea ice. This animation shows the last 30 years of summer sea ice, based upon data compiled by the National Snow and Ice Data Center. It begins in 1978 and runs through 2007. While Arctic sea ice has been consistently declining over the years, this past summer was truly stunning.

If you look on the right, you can see the area that has now been lost, which has opened up perhaps sea lanes that we never expected, but problems that we should definitely be concerned about.

Global warming is happening, and the planet's natural systems are giving us every reason to pay attention to this problem.

Today we have a very distinguished panel and I thank you all for being here and for paying attention to this problem. I am very pleased that they have agreed to appear, and we look forward to your testimony.

We want to bring in part of the debate on global warming that has not been the focus of attention yet on the Hill, and we think this hearing will give us the opportunity to do that.

[The prepared statement of Chairman Henry A. Waxman follows:]

Opening Statement of Rep. Henry A. Waxman
Chairman, Oversight and Government Reform Committee
Hearing on Black Carbon and Global Warming
October 18, 2007

Today's hearing will focus on the issue of black carbon and global warming.

Black carbon is commonly known as soot. It's emitted from our diesel trucks, our trains, our planes, ships, and even our fireplaces. Over the years, Congress and the Environmental Protection Agency have focused on tiny particles like black carbon because they cut short the lives of our seniors and sicken our children.

However, black carbon is also important because of the ongoing role it plays in the warming of the Earth.

Today we will hear that black carbon may be responsible for almost 20% of the warming the planet is currently experiencing. Experts will tell us that black carbon may be the second most significant global warming pollutant after carbon dioxide.

Yet controlling black carbon has not been seriously examined at the federal level as a way of possibly mitigating global warming.

At today's hearing we will explore what may seem to be an overwhelmingly complex issue involving atmospheric chemistry, global climate modeling, and literally millions of sources of air pollution.

It may seem complex — and indeed there are complexities and unanswered questions — but it is manageable. Here's what we know:

- Global warming is happening and carbon dioxide is the principal pollutant of concern.

Other pollutants, like black carbon, also contribute to the problem.

- Because black carbon doesn't stay in the atmosphere as long as carbon dioxide, controlling it may achieve major benefits in the short-term.
- We may need short-term benefits in order to prevent irreversible impacts from occurring.
- Reducing particulate air pollution, like black carbon, could also achieve major public health benefits.

This is not a theoretical issue. We can now see the impacts of global warming with our own eyes. To illustrate this last point, I have several slides of glaciers that I'd like to put up on the screen.

The first is of Carroll glacier in Alaska. As you can see, this glacier has basically disappeared in the 97 years between when these photographs were taken .... The second set of photographs are of McCall glacier which has receded dramatically over the last 45 years.... Finally, Toboggan glacier has also vanished over the course of 90 years.

The glaciers of the world are receding. It is one measure of the warming that we now know is occurring. But it isn't the only one.

What's happening in the Arctic is alarming. We have a time lapsed animation of Arctic sea ice that I'd like to play for you. This animation shows the last 30 years of summer sea ice based upon data compiled by the National Snow and Ice Data Center. It begins in 1978 and runs through 2007. While Arctic sea ice has been consistently declining over the years, this past summer was truly stunning.

Let's play that animation now.

Global warming is happening and the planet's natural systems are giving us every reason to pay attention to this problem.

Today we have a very distinguished panel that has been paying attention to this problem. I'm very pleased that they've agreed to appear and I look forward to hearing their testimony.

Chairman WAXMAN. Mr. Davis.

Mr. DAVIS OF VIRGINIA. Thank you, Mr. Chairman, and thank you for holding today's hearing to consider the relationship between black carbon emissions and climate change.

Climate change is a critically important issue, and as policymakers it is our job to consider all sensible options to reduce the emission of climate-warming pollutants. My head is not in the sand on this issue. I am not one who denies the reality of climate change, and I am motivated to learn more about what we can do to advance the debate and come up with some potential solutions. Therefore, I think this hearing can serve as an example of how we as a committee can work together to rationally investigate the facts surrounding climate change, and at the same time seek agreement on the best way forward.

While the United States and the world have focused attention on reducing carbon dioxide emissions, it appears that not enough attention has been focused on controlling black carbon and its effects on the climate.

According to the witnesses scheduled to testify, there is significant scientific evidence that black carbon is the second leading cause of climate change after carbon dioxide. In layman's terms, black carbon is soot. It is emitted into the air during fossil fuel and biofuel combustion and biomass burning. Developing nations like China and India are the leading source of black carbon emissions, while the United States is only responsible for about 6.1 percent.

Unlike some ways of controlling CO_2 emissions, technology already is available to reduce emissions in black carbon. That technology has reduced by a factor of five the soot emissions in this country since the 1950's. We need to find ways to ensure the developing world has access to this technology.

One witness will tell us that reductions in black carbon emissions could buy us significant time to reduce CO_2 emissions. That would be a welcome respite to allow the world to develop consensus solutions that don't stall growth or give some nations competitive advantages over others.

Because the developing world is the major source of black carbon emissions, this hearing serves as a reminder that any future international treaties on climate change must include China and India. Failure to do so would forfeit a prime opportunity to bring about meaningful changes in behavior that both include quality of life and reduce the immediate impact of climate change on the planet.

Moreover, as we look for ways to mitigate harmful greenhouse gases, we must do so while acknowledging that energy is essential to the economic activity that sustains and improves our quality of life.

Renewable energy shows great promise, and biofuels have provided some relief from our dependence on traditional energy sources that contribute to climate change. However, the only fuels that have a realistic growth potential—solar, wind, biomass—only make up about 3.5 percent of the Nation's energy supply. Even with healthy growth, these energy sources will not cure our dependence on coal and oil. Accordingly, policymakers must look to technologies that decrease the externalities associated with the use

of energy so that we can limit emissions that contribute to climate change.

There is no question that we live in a challenging world and we only have real-world options available to us to address the twin challenges of climate change and energy independence.

This committee and this Congress should devote more time and attention to exploring these options so that we can craft effective, real-world solutions. Reducing black carbon emissions around the world may be an overlooked, cost-effective solution that will provide enormous benefits.

Finally, I want to thank our distinguished panel who will be testifying today for their dedication to the science of climate change and for taking the time to share their knowledge with us and their expertise.

Thank you.

[The prepared statement of Hon. Tom Davis follows:]

HENRY A. WAXMAN, CALIFORNIA
CHAIRMAN

TOM DAVIS, VIRGINIA
RANKING MINORITY MEMBER

ONE HUNDRED TENTH CONGRESS

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Statement of Rep. Tom Davis
Ranking Member
Committee on Oversight and Government Reform
"Black Carbon and Global Warming"
October 17, 2007

Thank you, Mr. Chairman, for holding today's hearing to consider the relationship between black carbon emissions and climate change. Climate change is a critically important issue and, as policy makers, it's our job to consider all sensible options to reduce the emission of climate warming pollutants.

My head is not in the sand on this issue. I'm not one who denies the reality of climate change, and I'm motivated to learn more about what we can do to advance the debate and potential solutions.

Therefore, I think this hearing can serve as an example of how we as a Committee can work together to rationally investigate the facts surrounding climate change and at the same time seek agreement on the best way forward.

While the United States and the world have focused attention on reducing carbon dioxide emissions, it appears that not enough attention has been focused on controlling black carbon and its effects on the climate. According to the witnesses scheduled to testify, there is significant scientific evidence that black carbon is the second leading cause of climate change after carbon dioxide. In laymen's terms, black carbon is soot that is emitted into the air during fossil-fuel and bio-fuel combustion and bio-mass burning.

Developing nations like China and India are the leading source of black carbon emissions, while the United States is responsible for only about 6.1 percent. Unlike some ways of controlling CO2 emissions, technology already is available to reduce emissions of black carbon. That technology has reduced by a factor of 5 the soot emissions in the United States since the 1950s. We need to find ways to ensure the developing world has access to this technology.

One witness will tell us that reductions in black carbon emissions can buy us significant time to reduce CO2 emissions. That would be a welcome respite to allow the world to develop consensus solutions that do not stall growth or give some nations competitive advantages over others.

Because the developing world is the major source of black carbon emissions, this hearing serves as a reminder that any future international treaties on climate change must include China and India. Failure to do so would forfeit a prime opportunity to bring about meaningful changes in behavior that both improve quality of life and reduce the immediate impact of climate change.

Moreover, as we look for ways to mitigate harmful greenhouse gases, we must do so while acknowledging that energy is essential to the economic activity that sustains and improves quality of life. Renewable energy shows great promise, and bio-fuels have provided some relief from our dependence on traditional energy sources that contribute to climate change.

However, the only fuels that have a realistic growth potential (solar, wind, and biomass) only make up about 3.5 percent of the nation's energy supply. Even with healthy growth, these energy sources will not cure our dependence on coal and oil. Accordingly, policy makers must look to technologies that decrease the externalities associated with the use of energy so that we can limit emissions that contribute to climate change.

There is no question that we live in a challenging world, and we only have "real world" options available to us to address the twin challenges of climate change and energy independence. This Committee and this Congress should devote more time and attention to exploring these options so that we can craft effective, "real world" solutions. Reducing black carbon emissions around the world may be an overlooked, cost-effective solution that will provide enormous benefits.

Finally, I want to thank the distinguished panel who will be testifying today for their dedication to the science of climate change and for taking the time share their knowledge and expertise with us.

Chairman WAXMAN. Thank you.

We have a very distinguished panel.

Mr. Issa, did you want to say anything? If not, we will proceed to the panel.

Mr. ISSA. That would be fine just to proceed.

Chairman WAXMAN. OK.

We have Dr. Mark Jacobson, who is the co-founder and director of the Atmospheric Energy Program at Stanford University's Department of Civil and Environmental Engineering, where he has been a faculty member since 2004. His research is dedicated to addressing atmospheric problems such as climate change and urban air pollution. Since 1994, he has published two textbooks and more than 70 peer-reviewed journal articles on related topics. We are pleased that you are here.

Dr. Tami Bond leads a research group at the University of Illinois at Urbana-Champaign focused on aerosols and the global environment. She is well known for her work identifying black carbon emission sources. We are pleased that you are here.

Dr. V. Ramanathan has been researching climate and atmospheric science for more than 30 years. Among other positions, he currently serves as a member of the World Clean Air Congress Advisory Board as co-chief scientist for the Atmospheric Brown Cloud Project and is Chair to the National Academy of Science's Committee on Strategic Advice on the U.S. Climate Change Science Program. He is a distinguished professor of atmospheric and climate sciences at the Scripps Institute of Oceanography at the University of California, San Diego.

Dr. Charles Zender is the director of the Earth System Modeling Facility and leads the Climate Health, Aerosols, Radiation, and Micro-Physics Group at the University of California, Irvine. His recent research focuses on the impact of aerosol deposits on snow and ice in the Arctic, and he holds a Ph.D. in astrophysics, planetary, and atmospheric science from the University of Colorado at Boulder. We are pleased you are here.

And Dr. Joel Schwartz is a professor of environmental epidemiology at the Harvard University School of Public Health. He has conducted research on the adverse health impacts of air pollution all over the world, including studies in the United States, the European Union, Canada, Israel, and Turkey, among others. Dr. Schwartz, it is good to see you, as well.

It is the practice of this committee to ask all witnesses that appear before us, because we are an investigative committee, to testify under oath. It seems a bit awkward with scientists, because you are going to give us theories and ideas that may change. In fact, you may change your minds as you look at some of these matters further. But we will keep with our practice and ask you to please stand and raise your right hands.

[Witnesses sworn.]

Chairman WAXMAN. The record will reflect that each of the witnesses answered in the affirmative.

Dr. Jacobson, let's hear from you first.

STATEMENTS OF MARK Z. JACOBSON, PROFESSOR OF CIVIL AND ENVIRONMENTAL ENGINEERING, ATMOSPHERE/ENERGY PROGRAM, STANFORD UNIVERSITY; TAMI C. BOND, ASSISTANT PROFESSOR OF CIVIL ENGINEERING, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN; V. RAMANATHAN, PROFESSOR OF CLIMATE AND ATMOSPHERIC SCIENCES, SCRIPPS INSTITUTE OF OCEANOGRAPHY, UNIVERSITY OF SAN DIEGO; CHARLES ZENDER, ASSOCIATE PROFESSOR OF EARTH SYSTEM SCIENCE, UNIVERSITY OF CALIFORNIA AT IRVINE; AND JOEL SCHWARTZ, PROFESSOR OF ENVIRONMENTAL EPIDEMIOLOGY, HARVARD UNIVERSITY

STATEMENT OF MARK Z. JACOBSON

Mr. JACOBSON. Thank you, Chairman Waxman, Ranking Member Davis, and the committee for inviting me to testify today. I will speak on the role of black carbon in global climate change and methods of reducing black carbon emissions.

Fossil fuel and biofuel burning soot particles containing black carbon have a strong probability of being the second leading cause of global warming after carbon dioxide and ahead of methane. Because of the short lifetime of soot relative to greenhouse gases, control of soot, particularly from fossil fuels, is very likely to be the fastest method of slowing global warming. Because soot particles are generally small, and small aerosol particles are the leading cause of air pollution mortality, controlling soot emissions will not only slow global warming but also improve human health.

The U.S. soot contributions to global warming may exceed each of its methane and its nitrous oxide contributions to global warming. Despite soot regulations to date based on health grounds, the United States has significant room to reduce soot emissions further, thereby reducing health and climate problems further.

Soot is an aerosol particle emitted during fossil fuel, biofuel, and biomass combustion. Soot particles contain black carbon, organic carbon, and smaller amounts of sulfur and other chemicals. Soot particles warm the air by converting sunlight into infrared or heat radiation and emitting the heat radiation to the air around them. This differs from greenhouse gases, which heat the air by absorbing the Earth's infrared radiation but not sunlight.

When soot particles age in the atmosphere, they become coated by other chemicals, increasing their size and their ability to heat the air, but also their ability to form clouds. Soot particles that end up on snow or sea ice surfaces also darken those surfaces, contributing to their warming and melting.

The figure now on the screen shows the relative contributions of greenhouse gases, soot, the urban heat island effect, and cooling particles to global warming, as determined by recent detailed computer model simulations. About half of actual global warming today is being marked by cooling particles which contain sulfate, nitrate, ammonia, certain organic carbon, and water primarily. Thus, as cooling particles are removed by the cleanup of air pollution, much global warming will be unmasked; nevertheless, the removal of such particles is still desirable for improving human health.

The figure also shows that fossil fuel plus biofuel soot may contribute to about 16 percent of gross global warming, which is the

warming before cooling is subtracted out, but its control and isolation could reduce 40 percent of net global warming.

Soot particles also differ from greenhouse gases in that soot particles have relatively short lifetimes of around 1 to 4 weeks. This compares with 30 to 43 years for carbon dioxide and 8 to 12 years for methane. The lifetime of a chemical is the time required for its concentration in the air to decay to about 37 percent its original value.

Because of soot's short lifetime and strong climate impacts, reduction in its emissions can result in rapid climate benefits. This is illustrated by the figure now on the screen, which shows that controlling soot could reduce temperatures faster than controlling carbon dioxide for up to 10 years, but controlling carbon dioxide has a larger overall climate benefit over 100 years.

Whereas the United States emits about 21 percent of global anthropogenic carbon dioxide, it emits about a little over 6 percent of global fossil fuel plus biofuel soot. Nevertheless, the warming due to U.S. soot appears to exceed the warming due to U.S. methane and nitrous oxide.

Proposed methods of controlling fossil fuel soot have included improving engines, changing fuels, adding particle traps, and changing vehicle types. Recent emission regulations in the United States have begun to address reducing particle emissions, but more needs to be done.

It is thought that because diesel vehicles contain better gas mileage than gasoline vehicles, using more diesel will slow global warming; however, this concept ignores the larger emissions of fossil fuel soot from diesel and the resulting climate effects. Further, the addition of a particle trap to diesel vehicles, while decreasing particles significantly, increases carbon dioxide, and the ratio of NO_2 to NO in exhaust, thereby increasing ozone in most of the United States.

Improvements in neither gasoline nor diesel vehicles can contribute significantly to reducing carbon dioxide emissions by 80 percent, the level needed to stabilize atmospheric carbon dioxide, while accounting for future economic growth. A more certain method is to convert from fossil fuel to electric, plug-in hybrid, or hydrogen fuel cell vehicles, where the electricity or hydrogen is produced by a renewable source such as wind, solar, geothermal, hydroelectric wave, or tidal power. Such a conversion would reduce global warming and improve human health simultaneously.

The figure on the screen shows results for the first wind mapping study of North America at 80 meters above the ground. This is all from data. The Great Plains has long been known as the Saudi Arabia of wind, but the figure identifies other ares, particularly coastal, of intense winds that were previously unknown. The data indicate that the United States has twice as much wind energy than total energy consumed from all sources, and ten times as much wind energy as electricity consumed in locations where wind is economical.

The United States could replace all its on-road vehicles with battery electric vehicles powered by 71,000 to 122,000 5-megawatt wind turbines, which is less than the 300,000 airplanes produced during World War II by the United States.

The land area needed for such wind turbines is 0.5 percent of the United States, much less than the 15 percent of the United States that has fast wind. The wind area required is also 1/30th of that required for corn ethanol and 1/20th of that required for cellulosic ethanol to replace the same vehicles. The land area required for solar energy is also very low.

In sum, an effective method of reducing the combined effects of carbon dioxide and soot on climate and health is to convert as many combustion devices as possible to those powered by renewable energy.

Thank you again for considering my testimony.

[The prepared statement of Mr. Jacobson follows:]

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Testimony for the Hearing on Black Carbon and Arctic
House Committee on Oversight and Government Reform
United States House of Representatives
The Honorable Henry A. Waxman, Chair
October 18, 2007

By Mark Z. Jacobson

I would like to thank the Honorable Chairman and committee for inviting me to testify today. I will speak on the role of black carbon in global climate change, the U.S. contribution to black carbon's global climate effect, and methods of reducing black carbon emissions.

Summary

Soot particles containing black carbon, from fossil-fuel and biofuel burning sources, have a strong probability of being the second-leading cause of global warming after carbon dioxide and ahead of methane[1,2]. Because of the short lifetime of soot relative to greenhouse gases, control of soot emissions, particularly from fossil-fuel sources, is very likely to be the fastest method of slowing global warming for a specific period[1]. Because soot particles are generally small, and small aerosol particles are the leading cause of air pollution mortality, controlling soot emissions will not only slow global warming but also improve human health. The United States' soot contribution to global warming may exceed each its methane and nitrous oxide contributions to global warming. Despite soot regulations to date based on health grounds, the United States has significant room to reduce soot emissions further, thereby improving the length and quality of life and reducing the impacts of global warming.

Definitions

Soot is an amorphous-shaped particle emitted into the air during fossil-fuel combustion, biofuel combustion, and biomass burning. Soot particles contain black carbon, organic carbon, and smaller amounts of sulfur and other chemicals. Soot from diesel combustion usually appear black because it contain a high fraction of black carbon, which absorbs all colors of visible light, preventing such light from reaching our eyes. Soot from biofuel burning is brownish because it contains a higher ratio of organic carbon to black carbon than diesel soot, and organic carbon absorbs short light wavelengths preferentially, appearing brown.

Soot particles heat the air by converting sunlight into infrared (heat) radiation and emitting that heat radiation to the air around them. This differs from greenhouse gases, which do not absorb much sunlight; instead, they absorb the Earth's heat radiation and reemit it to the air.

Soot particles that fall to snow and sea ice surfaces, either on their own or within ice crystals or snow flakes, darken those surfaces, contributing to the melting of snow and ice and the warming of air above both[3,2,4].

When soot particles age in the atmosphere, they become coated by relatively transparent or translucent chemicals, increasing their size and the probability that sunlight will hit and be absorbed by the particle. As such, aged, coated soot particles heat the air more than do new, uncoated soot particles. The enhanced heating by soot upon its coating has been demonstrated from physical principles and in the laboratory[5-10].

Whereas new soot particles from fossil fuel sources in particular are oily so do not allow clouds to grow on them easily, coated soot particles attract water and allow clouds to grow on them. The growth of a cloud drop on a coated soot particle eventually causes the soot particle to reflect light significantly, reducing sunlight significantly, cooling the ground and air. However, cloud drops containing soot still warm the air more than do cloud drops without soot[11-13]. Determining the overall effect of soot on climate requires accounting for these and other effects. Such calculations suggest a strong net global warming by fossil-fuel plus biofuel soot (Table 1, Figure 1).

Table 1 shows the direct radiative forcing of anthropogenic (fossil-fuel, biofuel, and biomass burning) greenhouse gases, as provided by the Intergovernmental Panel for Climate Change[14], and black carbon from all anthropogenic sources, as provided from several studies. Based on these results, black carbon may be the second-leading case of global warming after carbon dioxide and ahead of methane in terms of its direct radiative forcing.

Table 1. Top-of-the-atmosphere global direct radiative forcing by anthropogenic gases and particulate black carbon.

	Global direct radiative forcing (W/m^2)	Percent of total
Carbon dioxide	+1.66	48
Methane	+0.48	14
Nitrous oxide	+0.16	4.6
Halocarbons	+0.34	9.7
CFCs*	+0.268	
HCFCs*	+0.039	
HFCs+PFCs+SF_6	+0.017	
Ozone (tropospheric and stratospheric)*	+0.30	8.6
Total gases	+2.94	84
Anthropogenic black carbon*	+0.55	16
Total gases + black carbon	3.49	100

*Non-Kyoto chemicals. Greenhouse gas direct forcings are from IPCC[14]. The anthropogenic black carbon direct forcing is from Ref. 15 and compares with 0.54 W/m^2 from Ref. 8, 0.50 W/m^2 from Ref. 16, 0.53 W/m^2 from Ref. 17, and 0.5-0.8 W/m^2 from Ref. 18.

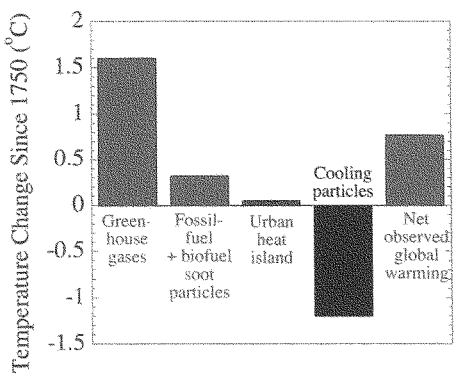
Because biomass-burning particles (which differ from biofuel particles), when emitted, are less oily and contain a much lower black carbon fraction than do fossil fuel soot particles, biomass-burning particles tend to cool climate on a global scale, but may cause regional warming[19]. Biomass-burning gas warming, though, from permanent deforestation, exceeds the global cooling due to biomass burning aerosol particles[19].

Because of the net cooling due to biomass-burning particles, the discussion that follows will be concerned with fossil-fuel and biofuel burning soot. Of the two, fossil-fuel soot warms

more per unit mass than does biofuel soot because of the greater fraction of black carbon and greater oiliness of fossil-fuel soot relative to biofuel soot.

Figure 1 shows the relative contributions to global warming, as determined by recent computer model simulations, by greenhouse gases, fossil-fuel plus biofuel soot, the urban heat island effect, and cooling aerosol particles. Cooling aerosol particles include particles containing sulfate, nitrate, chloride, ammonium, potassium, certain organic carbon, and water, primarily. The sources of these particles differ, for the most part, than sources of fossil-fuel and biofuel soot. The figure shows that about half of actual global warming to date is being masked by cooling particles, suggesting that, as such particles are removed by the clean up of air pollution, a significant amount of global warming will be unmasked. Nevertheless, the removal of such particles is desirable to improve human health. The figure also shows that fossil-fuel plus biofuel soot may contribute to about 16% of gross global warming (warming due to all greenhouse gases plus soot plus the heat island effect), but its control in isolation could reduce 40% of net global warming.

Figure 1. Primary contributions to observed global warming 1750 to today from global model calculations. The fossil-fuel plus biofuel soot estimate is from Ref. 2. and accounts for the effect of soot on snow albedo.



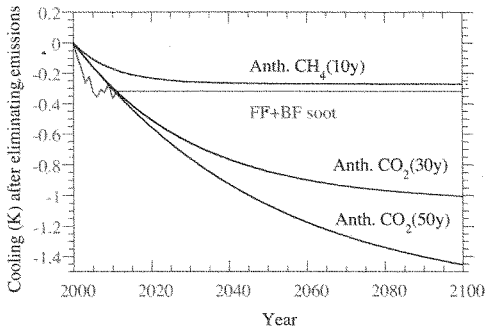
Soot particles also differ from greenhouse gases in that soot particles have relatively short lifetimes in the atmosphere of around one to four weeks. Greenhouse gases have long lifetimes (e.g., 30-43 years for carbon dioxide[20,21] and 8-12 years for methane). The lifetime of a chemical is the time required for the chemical's concentration to decay to about 37% its original value.

Because of their short lifetimes, soot particles containing black carbon have strong warming effects regionally, near where they are emitted[7,22-24], although many soot particles travel globally.

Because of soot's short lifetime and its strong climate impact, the reduction in its emissions can result in rapid climate benefits. This point is illustrated in Figure 2, which shows the modeled reduction in global near-surface air temperatures resulting from the elimination of all anthropogenic methane, carbon dioxide, and fossil-fuel plus biofuel soot emissions, separately. The figure shows that controlling all soot would reduce temperatures faster than

controlling all carbon dioxide for a period on the order of 10 years, but controlling carbon dioxide, has a larger overall climate benefit than controlling soot over a 100-year period. Controlling soot also slows warming faster than controlling methane.

Figure 2. Comparison of time-dependent change in globally-averaged near-surface temperature due to eliminating global anthropogenic emissions of each CO_2, CH_4, and fossil-fuel plus biofuel soot. From Ref. 2. For CO_2, two possible lifetimes are shown. The actual lifetime of CO_2 is closer to 30 years than 50 years[20,21].



As mentioned earlier, fossil-fuel soot is a stronger warmer than biofuel soot. Table 2 summarizes the 20- and 100-year global warming potentials of fossil-fuel soot and, separately, the black carbon in fossil-fuel soot. These numbers mimic the results in Figure 2, which apply to fossil-fuel plus biofuel soot, that controlling a unit emissions of soot continuously will have a greater impact over the short term than controlling a unit emissions of carbon dioxide.

Table 2. 20- and 100-year global warming potentials (GWPs) for fossil-fuel soot and black carbon within fossil-fuel soot.

X	20-year GWP	100-year GWP
FF soot	2530	840-1280
BC in FF soot	4470	1500-2240

The global warming potential is defined here as the change in temperature per unit emissions of X relative to the change in temperature per unit emissions of CO_2. Multiply the GWPs in the table by 12/44 to obtain the GWP relative to CO_2-C. BC= black carbon. FF soot=56% black carbon + 43% primary organic carbon + 1% sulfate.

U.S. and World Emissions of Soot

Whereas the U.S. emits about 21% of globally-emitted anthropogenic carbon dioxide, it emits about 6.1% of the globally-emitted fossil-fuel plus biofuel soot (Table 3).

Table 3. U.S. contributions to world non-aircraft, non-shipping fossil-fuel (FF) and biofuel (BF) black carbon (BC) and primary organic carbon (POC) emissions in particles ≤2.5 μm in diameter ($PM_{2.5}$) and particles ≤10 μm in diameter (PM_{10}).

	U.S. (Gg-C/yr)	World (Gg-C/yr)	U.S. Percent of World Total
$PM_{2.5}$			
FF BC+POC	347.2	5400	6.4
BF BC+POC	477.7	8124	5.9
Total	824.9	13,524	6.1
PM_{10}			

FF BC+POC	457.5	7165	6.4
BF BC+POC	4668	11,392	4.1
Total	1125	18,556	6.1
Carbon dioxide	1,660,000	7,900,000	21

$PM_{2.5}$ data are from Ref. 25. PM_{10}:$PM_{2.5}$ ratios are from the 2002 U.S. National Emission Inventory (Ref. 26). The U.S. $PM_{2.5}$ FF BC+POC emission rate from Ref. 25 of 347 Gg/yr compares with 526.8 Gg/yr from the U.S. National Emission Inventory (Table 5), thus is conservative. Most of the differences are due to higher organic carbon in the U.S National Emission Inventory.

Nevertheless, the warming due to the U.S. soot exceeds the warming due to either U.S. methane or nitrous oxide (Table 4). As such, fossil-fuel plus biofuel soot may be the second-leading source of U.S. global warming emissions.

Table 4. Percent warming of component relative to carbon dioxide

	Worldwide	U.S.
FF+BF soot	32	9.3
Methane	29	8.8
Nitrous oxide	9.6	7.7

Derived from Table 1 and Figure 2.

The main sources of U.S. fossil-fuel soot are nonroad vehicles, followed by onroad mobile vehicles, stack emissions, and fugitive sources, respectively (Table 5). Fossil fuels include diesel fuel, heavy fuel oil, aviation fuel, liquefied petroleum gas, gasoline, kerosene, coke briquettes, hard coal, brown coal, peat, coking coal, and fuel waste.

About half of U.S black carbon in particles smaller than 2.5 μm in diameter ($PM_{2.5}$) is from fossil-fuel sources (Table 5). The rest is from areas sources: agricultural fires, structural fires, slash/prescribed burning forest wildfires, unpaved road dust, paved road dust, and construction dust, according to the 2002 U.S. National Emission Inventory[26].

Table 5. United States black carbon (BC) and primary organic carbon (POC) emissions (Gg/yr) in particles ≤2.5 μm in diameter ($PM_{2.5}$) and particles ≤10 μm in diameter (PM_{10}), from the 2002 U.S. National Emission Inventory (Ref. 26). Total fossil-fuel is the sum from all sources except area sources.

	Stack	Fugitive	Area	Nonroad Mobile	Onroad Mobile	Total	Total Fossil-fuel
$PM_{2.5}$							
BC	28.1	3.6	221	123.3	74.1	449.9	229.2
POC	135.2	28.8	1637	87.2	46.4	1935	297.6
Total	163.3	32.4	1858	210.5	120.5	2384.9	526.8
PM_{10}							
BC	41.3	5.8	422.1	145.4	90.6	705.2	283.1
POC	173.3	40.1	3914	101.5	70.2	4299	385.1
Total	214.6	45.9	4336.1	246.9	160.8	5004.2	668.2

By 2030, global fossil-fuel black carbon emissions are expected to increase (Table 6), according to two future emission scenarios that follow the Special Report on Emission Scenarios (SRES) A1B and B1 emission trajectories[27]. These scenarios account region-specific, chemical-specific, and emission-sector-specific changes in future emissions. Although emissions in the United States and much of Europe are expected to decline, emissions in the rest of the world are expected to increase to a greater extent, causing a net increase in black carbon emissions.

Table 6. World fine-particle global emission rates (Tg-C/yr) of black carbon (BC) and primary organic carbon (POC) in soot today and in 2030 under the A1B and B1 IPCC emission scenarios,. Sulfate emissions are described in the footnote. From Ref. 27.

	(a) Aircraft	(b) Shipping	(c) All other Fossil Fuel	(d) Total Fossil Fuel (a+b+c)	(e) Biofuel	(f) Biomass burning	(g) Total (d+e+f)
Today							
BC	0.0062	0.147	3.029	3.182	1.634	1.728	6.544
POC	0.0062	0.047	2.371	2.424	6.490	14.89	23.80
A1B scenario							
BC 2030	0.0062	0.155	5.616	5.777	0.808	1.728	8.313
POC 2030	0.0062	0.050	3.911	3.967	3.290	14.89	22.15
B1 scenario							
BC 2030	0.0062	0.135	3.273	3.414	0.668	1.728	5.810
POC 2030	0.0062	0.044	2.268	2.318	2.725	14.89	19.93

Fine BC and POC emissions from aircraft were obtained by applying emission factors of 0.038 g-BC/kg-fuel (Ref. 28) to fuel-use data from Ref. 29 and Ref. 30 and assuming a POC:BC emission ratio of 1:1. Those from shipping were estimated by dividing the gridded, monthly sulfur shipping emission rate from Ref. 31, which totaled 4.24 Tg-S/yr, by 29.5 g-S/kg-fuel (Ref. 32, Table 1, for 1999 data) and multiplying the result by 1.02 g-BC-C/kg-fuel for shipping (Ref. 25). That for POC was obtained in the same manner, but by multiplying the result by 0.33 g-POC-C/kg-fuel (Ref. 25). Fine BC and POC for all other fossil-fuel sources globally were obtained from Ref 25 after subtracting out shipping emissions. The totals from Ref. 25 before subtracting out such emissions were 3.040 Tg-BC-C/yr and 2.408 Tg-POC-C/yr. Fine biofuel-burning BC and POC emissions were obtained from Ref. 25. The POM:POC emission ratio is about 1.6:1 for fossil fuels and 2:1 for biofuel and biomass burning, where POM is Primary Organic Matter and equals POC plus non-carbon functional groups. The emission rate of S(VI) from fossil fuels was 1% that of BC+POM+S(VI).

Proposals to Reduce Soot Emissions

Proposed methods of controlling fossil-fuel soot have included improving engines, changing fuels, adding particle traps, and changing vehicle technologies. Recent particulate matter emission regulations in the U.S. have begun to address reducing onroad and nonroad vehicle particulate matter emissions, but more can still be done.

A concern that is often raised with respect to controlling soot emissions, such as with a particle trap, is whether such controls will reduce emissions of particles that cool climate or only those that warm climate. First, the control of all particles is beneficial from a health perspective, regardless of whether the particles cause cooling or warming. Second, almost all particles emitted from diesel vehicles are types that warm climate rather than cool climate. Particles that cool climate generally originate from different sources than but have some overlap those that warm climate. For example, most sulfate particles, which cool climate, originate from sulfur dioxide from coal-fired power plants. In the U.S., such plants emit some, but not a lot of fossil-fuel soot (Table 5).

Although controlling soot emissions from existing diesel engines is beneficial for reducing particle emissions, the addition of a trap decreases the mileage, thus increases the carbon dioxide emissions from such vehicles by 3.5-8.5%[33-35].

Alternatively, the conversion of gasoline vehicles to diesel vehicles, even with a particle trap, may increase particle emissions and is unlikely to reduce global warming, as discussed in detail below

Comparison of diesel versus gasoline

It is generally thought that diesel vehicles obtain better gas mileage and emit less carbon dioxide than equivalent-class gasoline vehicles and, therefore, using more diesel vehicles will address the climate problem. However, this concept ignores the larger emissions of fossil-fuel soot from diesel than gasoline vehicles and the resulting climate effects. It also ignores the fact that the addition of control devices to diesel vehicles to reduce their soot and nitrogen oxide emissions, required to meet California and EPA Tier 2 Permanent Bin emission standards and to address the climate problem of soot, reduces the gas mileage of the diesel vehicles. Finally, it does not consider that, in the United States, the lowest-carbon-emitting vehicles in 2006 were gasoline and gasoline-electric hybrid vehicles, not diesel vehicles (Table 7). The addition of particle traps to the best diesels sold in 2006 in the U.S. would reduce the standing of the diesels further. Also, the addition of a particle trap to diesel increases the NO_2:NO ratio in diesel exhaust increases, exacerbating photochemical smog[36]. Finally, even with a particle trap, diesel vehicles still emit more particles than do gasoline vehicles.

Table 7. Highest-mileage passenger vehicles in the U.S. in 2006, ranked by their CO_2 emissions (with and without a particle trap in the case of diesel).

Vehicle	Energy source	Avg. mpg	CO_2 (g-C/km)	CO_2 (g-C/km) w/trap
Honda Insight (M)	Gas	53	28.0	
Honda Insight (A)	Gas	47	31.5	
Toyota Prius (A)	Gas/electric	46.5	31.9	
Honda Civic (A)	Gas/electric	42.5	34.9	
Honda Civic (A)	Gas	31	47.9	
Toyota Corolla (A)	Gas	30.5	48.6	
VW Golf, Jetta (M)	Diesel	35.5	48.5	50.9
VW N. Beetle, Jetta (A)	Diesel	34	50.6	53.1

(A) denotes automatic transmission; (M) denotes manual transmission. The table assumes a gasoline and diesel density of 737 g/L and 840 g/L, respectively, a gasoline and diesel carbon content of 85.5% and 87.0%, respectively, and an increase in fuel use with a trap+filter of 5% (see text). Source of fuel economy: Ref. 37.

Figure 3 illustrates the net effect of diesel versus gasoline vehicles on climate for a range of mileage differences between diesel and gasoline (up to 30% better mileage for diesel). The figure examines the time-dependent impacts on climate of diesel versus gasoline vehicles, accounting for carbon dioxide and fossil-fuel soot (primarily black carbon plus organic matter) emissions from both.

Figure 3a shows that, when diesel vehicles have 15% better mileage than gasoline vehicles, the diesel vehicles cause more global warming over 100 years, regardless of whether they are emitting fossil-fuel soot at a particulate matter emission standard of 10 milligrams per mile (mg/mi), 40 mg/mi, or 80 mg/mi and regardless of the atmospheric lifetime of carbon dioxide (30 or 50 years). This conclusion applies to diesel vehicles having 0-15% better mileage as well.

Figure 3. Comparison of the calculated ratio of the CO_2-C emission reduction required per unit of fossil-fuel (FF) soot (BC+OM) emitted for diesel vehicles to cool global climate with the actual ratio of CO_2-C emission reduction per unit mass fossil-fuel soot emission when diesel achieves (a) 15% and (b) 30% better mileage than gasoline and when diesel has different fossil-fuel soot emission rates. The three solid, straight lines in each figure represent the actual ratios of CO_2-C saved to FF soot emitted for a modern diesel vehicle emitting 0.08, 0.04, and 0.01 g/mi soot. The intersection of each straight line with each modeled curve indicates the period during which diesel vehicles enhance global warming in comparison with gasoline vehicles under the given emission standard. For example, in the case of the 0.08 g/mi standard, diesel warms climate in comparison with gasoline for >100 yr for both CO_2 lifetimes and for both differences in diesel versus gasoline mileage. Although gasoline soot emissions are low, the figure can be applied correctly only when the PM standard numbers in the figure represent the difference between diesel and gasoline soot emissions. From Ref. 21.

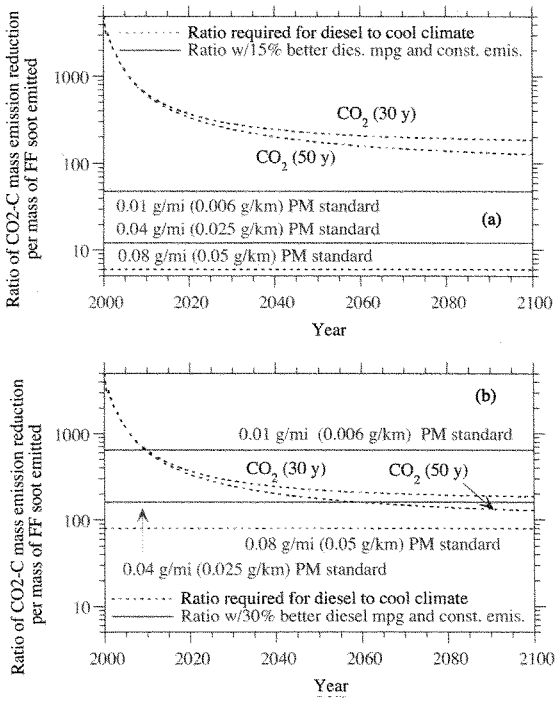


Figure 3b shows that, when diesel vehicles have 30% better mileage than gasoline vehicles, diesel vehicles emitting particles continuously at a particulate matter emission standard of 40 mg/mi or 80 mg/mi may warm climate more than gasoline vehicles for more than 100 yr for a CO_2 lifetime of 30 years, which is close to the actual data-constrained lifetime of CO_2 of 30-43 years[20,21]. However, diesel emitting at 10 mg/mi (Tier 2, bins 2-6 emission standard) may warm climate relative to gasoline for about 10 yr at 30% higher mileage.

However, because no diesel vehicle available in the U.S. in 2006, 2005, or 2004 emitted less CO_2 than did the best gasoline vehicle available (Table 7 for 2006), the 30% scenario in not applicable to the best available vehicles in the United States. As such, 2006 and earlier diesel vehicles sold in the U.S. all caused more global warming than did the best gasoline cars available, over a 100-year period.

Table 7 shows that the highest-mileage diesel vehicles (manual-transmission VW Golf and Jetta) obtained only 14.5% better mileage than did the automatic-transmission gasoline-powered Honda Civic. However, this translated into greater CO_2 emissions for the highest-mileage diesel vehicles since diesel fuel has a greater density and carbon content than does gasoline (Table 7, footnote). The addition of a particle trap to a diesel vehicle increases its fuel use by 3.5-8.5%[33-35]. Assuming a 5% increase, diesels with a trap emit even more CO_2 per unit distance than do the gasoline vehicles in Table 7. In all cases, gasoline-electric hybrid vehicles available in the U.S. in 2006 emitted less CO_2 than did diesel with or without a trap or gasoline vehicles, aside from the Honda Insight, which was a smaller gasoline vehicle than the others.

In 2007, subcompact diesel vehicles appear to have been removed from the United States market, most likely because none could meet the Tier-2, bin 2-6 emission standard of 10 mg/mi without adding a particle trap. This appears to have been beneficial from a climate perspective based on the results described above. However, lower-mileage diesel passenger cars as well as diesel trucks, buses, farm equipment, and contruction machines are still sold.

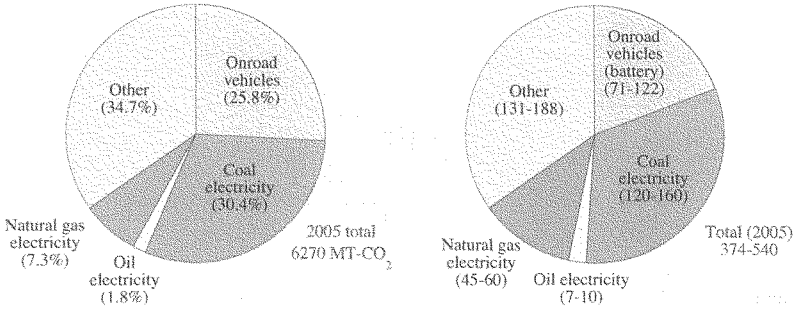
In sum, there is not an advantage and a potential disadvantage of diesel versus gasoline in terms of climate and air pollution impacts. However, neither type of vehicle is satisfactory or useful for solving climate and health problems as the emissions from both are very high. Even modest improvements in mileage standards for all vehicles are beneficial, but will only delay the eventual increase in emissions due to a larger population.

Conversion of the Vehicle Fleet

A more certain method of reducing global warming caused by both fossil-fuel soot and carbon dioxide is to convert vehicles from fossil fuel to electric, plug-in-hybrid, or hydrogen fuel cell vehicles, where the electricity or hydrogen is produced by a renewable energy sources, such as wind, solar, geothermal, hydroelectric, wave, or tidal power.

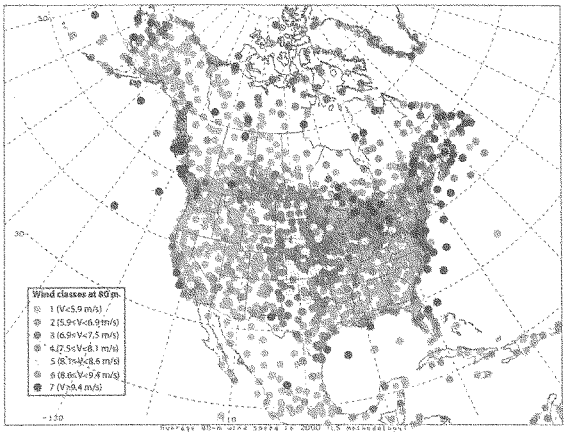
In the case of replacing all onroad vehicles with electric and/or hydrogen fuel cell vehicles powered by renewables, the vehicles would emit zero carbon dioxide, particles, nitrogen oxides, and hydrocarbons. Such a conversion would eliminate 160 Gg/yr (24%) of U.S. (or 1.5% of world) fossil-fuel soot (Table 5) and about 26% of U.S. (or 5.5% of world) carbon dioxide (Figure 4a). This sum of the two would eliminate about 0.06 K (about 7.7%) of global warming. However, the elimination of hydrocarbons and nitrogen oxides would also eliminate some cooling particles, reducing the net benefit by at most, half, but improving human health.

Figure 4. (a) Sources of U.S. CO_2 and (b) thousands of 5 MW wind turbines needed, placed in locations where the mean annual wind speed is 7.5 m/s (high number) to 8.5 m/s (low number), to displace 100% of CO_2 from each source (2005). Onroad vehicles include light and heavy-duty vehicles. Data from Ref. 38.



Is enough renewable energy available to power all U.S. onroad vehicles?. Recently, global wind speeds at 80 meters above the ground, the hub height of many modern wind turbines, were mapped for the first time from data[39]. The figure below shows the resulting map for North America. The Great Plains has long been known to be a region of strong winds, but the figure identifies some areas of intense winds that were previously unknown, including off the southern and southeastern coasts of the United States, along the coasts of Texas, California, Washington State, and Alaska, and over/around the Great Lakes.

Figure 5. Annually-averaged wind speeds 80 meters above the ground in North America. Wind speeds greater than 6.9 meters per second (m/s) are economically viable. From Ref. 38.



For wind energy to be economically viable, the annual-average wind speed at 80 meters must be at least 6.9 meters per second (15.4 miles per hour). Based on the mapping analysis just discussed, 15 percent of United States land area (and 17 percent of land plus coastal offshore area) may have wind speeds above this threshold (globally, 13 percent of land area is above the threshold).

From the numbers above, the total energy available from the wind in the United States (onshore plus coastal offshore) over economically-viable wind areas is about 55,000 TWh, or twice the total energy consumed by all energy sources in the United States (28,000 TWh[40] and more than ten times the electricity consumed (3700 TWh). In other words, if the United States could capture only a fraction of the available wind at 80 meters, wind could supply a significant portion of U.S. electric power, including that used to supply electricity for all onroad vehicles converted to battery-electric vehicles.

Figure 4 shows that the U.S. would need only about 71,000-122,000 5 MW turbines to power all onroad (light and heavy-duty) vehicles in the U.S. converted to battery-electric vehicles. The word "only" is used since this number is much less than the 300,000 airplanes the U.S. manufactured during World War II.

Figure 6 shows that the land area required for wind turbines to provide electricity for batteries to replace all U.S. onroad vehicles is only 0.35-0.6% of the U.S. (with the turbine area touching the ground only 1-2 square kilometers). The area required for wind is about 1/30th that required for corn-ethanol (E85) and 1/20th that required for cellulosic ethanol (E85), on average, to replace the same vehicles. The land area for wind to produce electricity for hydrogen for fuel cell vehicles is about three times greater than that for wind producing electricity for batteries, but the climate benefits of the exhaust gases from the vehicles are the same in both cases. The land area required for solar energy to provide electricity for batteries is about 1/5th that of wind turbines in terms of their spacing but much greater than that in terms of the wind turbine area touching the ground.

Figure 6. Percent of U.S. land required to replace all U.S. onroad vehicles with other vehicle types. Data from Ref. 38.

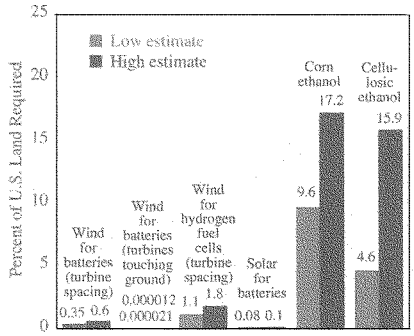


Figure 7 shows the percent decrease in total U.S. carbon dioxide emissions due to converting to different vehicle types or fuels. Conversion to battery-electrics or hydrogen fuel cell vehicles powered by renewable energy would provide better benefits than converting to corn or cellulosic ethanol fueled vehicles.

Figure 7. Percent decrease in total U.S. carbon dioxide emissions upon replacing 100% of onroad vehicles. Data from Ref. 38. Corn and cellulosic ethanol lifecycle carbon reductions relative to gasoline were calculated by multiplying reductions from Ref. 41 as 2% and 50%, respectively, by 26%, the percent of U.S. CO_2 from onroad vehicles. These numbers were multiplied by 30% to account for the landuse limits of corn and cellulosic crops in the U.S., estimated from Figure 6. Wind turbines were assumed to have 2% embedded carbon. Photovoltaics were assumed to have 10% embedded carbon.

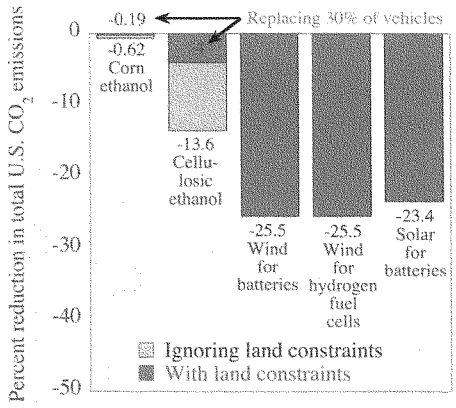
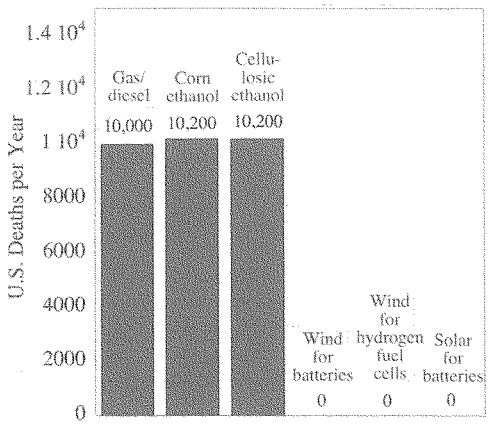


Figure 8 shows the estimated number of deaths per year in 2020 due to converting to different vehicle types or fuels. This death rate is conservative, particularly with respect to

particulate matter health effects. Conversion to battery-electrics or hydrogen fuel cell vehicles powered by renewable energy would eliminate all motor-vehicle tailpipe air pollution deaths[43].

Figure 8. Conservative estimate of future (c. 2020) U.S. deaths per year from onroad vehicles assuming full penetration of the vehicles. Data from Refs. 38, 42.



In sum, the best solution to the problem of health- and climate-relevant emissions from vehicles is the large scale conversion from liquid fuel to electric vehicles powered by renewable energy and hydrogen fuel cell vehicles, where the hydrogen is produced by renewable energy, as such vehicles emit no carbon dioxide, soot particles, nitrogen oxides, or hydrocarbons.

Summary

- Fossil-fuel soot plus biofuel-soot have a strong probability of being the second-leading cause of global warming after carbon dioxide and ahead of methane. Such soot may account for 16% of gross global warming (warming due to greenhouse gases, soot, and the urban heat island effect) and 40% of net warming (gross warming minus the cooling due to non-soot aerosol particles).

- Due to the short atmospheric lifetime of soot, its control appears to be the fastest method of slowing global warming for a specific period.

- The control of soot will not only slow global warming but also improve human health.

- The best method of reducing the combined effects of carbon dioxide and soot on climate and health problems is to convert as many onroad and nonroad vehicles to vehicles powered by renewable energy (e.g., battery-electrics, plug-in-hybrids, and hydrogen fuel cell vehicles) and to replace as much electric power as possible with renewable electric power sources.

- For example, the U.S. could theoretically replace all onroad vehicles with battery-electric vehicles powered by electricity from 71,000-122,000 5-MW wind turbines, less than the 300,000 airplanes the U.S. produced during World War II.

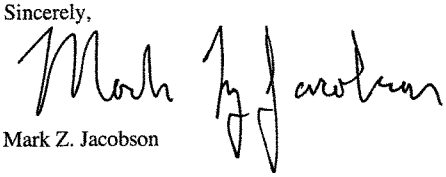
- Use of electric vehicles for short commutes and hydrogen-fuel-cell vehicles or plug-in-hybrid vehicles for long commutes would be one approach.

- The addition of particle traps to existing diesel vehicles is a secondary strategy that will reduce soot emissions but will slightly increase carbon dioxide emissions.

- The conversion of gasoline to diesel vehicles is a poor strategy for addressing global warming since such a conversion increases particle soot emissions and can decrease carbon dioxide emissions only under sufficiently large mileage differences between the two.

Thank you for considering this information,

Sincerely,



Mark Z. Jacobson

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Chairman WAXMAN. Thank you. We appreciate that testimony.

Dr. Bond, we would like to hear from you.

STATEMENT OF TAMI C. BOND

Ms. BOND. Chairman Waxman, Ranking Member Davis, and members of the committee, I have spent the last 12 years modeling and measuring sources of black carbon, and I am pleased to share my expertise about the role of black carbon in climate change.

I commend your committee for continuing this discussion at a national level, and I am honored to participate. Thank you very much for your invitation.

I will speak to you on sources of black carbon, its role in the climate system, and the potential for mitigation. These are the major points of my presentation, which are supported further in my written testimony: First, the major sources of black carbon are known.

Second, historically clean alternatives reduce black carbon emissions. This transition occurs naturally during economic development, but it can be accelerated.

Third, black carbon and other products of incomplete combustion should be considered together with greenhouse gases.

Fourth, mitigation options that address black carbon, particularly in developed countries, are not always cost effective compared to greenhouse gases when climate benefits alone are considered.

Fifth, some options can economically reduce warming. These offer major co-benefits in terms of human health and local environmental protection.

The first slide there is showing that black carbon emissions in 2000 came from four categories: diesel engines for transportation or industrial use; solid fuels, such as wood and coal, for cooking and heating; open forest and savannah burning, both natural and for land clearing; and solid fuel use in industrial combustion.

The comparative magnitude of each contribution will change as these estimates improve, but the major sources will neither vanish nor grow to dominate the whole picture.

Fuel use in the United States has grown phenomenally since World War II, but black carbon emissions have decreased due to cleaner technology and fuels. Estimates of the North American emission trend are broadly consistent with the Arctic record.

History suggests a consistent trajectory during a nation's economic development. Initially, emissions come from solid fuels for heating and cooking. These fade as incomes increase and clean household energy is introduced.

Next, emissions from the industrial sector increase and are reduced by regulation. In the meantime, internal combustion engines for transportation and other mobile power proliferate and eventually dominate.

It is rarely possible to reduce greenhouse gases alone, aerosols alone, or black carbon alone. Evaluating all emissions from a single source is more comprehensive and more accurate than looking at the effects of individual chemical species such as carbon dioxide only.

No current efforts on climate mitigation are evaluated in this way; however, rapid changes such as those occurring in the Arctic suggest that no opportunity should be missed.

Particles from diesel engines and cook stoves are strongly light absorbing and therefore warming, despite the presence of non-absorbing cooling particles from these sources. Particles from open biomass burning, however, are on the border between cooling and warming.

This figure shows a very preliminary evaluation of cost-effectiveness in terms of CO_2 equivalent reductions. Here I discuss only methods of eliminating existing black carbon emissions.

Mitigation options for solid fuel combustion include improving wood cook stoves and promoting cleaner fuels, including distillate fossil fuels. This would also reduce exposure to indoor smoke, a major health hazard.

Reducing vehicle emissions is possible through accelerated retirement, retrofits, and targeting of high emitters.

The figure I show supports some optimism, because some costs are close to worthwhile, even from a climate protection perspective. Some reductions appear affordable, while some appear costly; however, consideration of immediate benefits, health and environmental protection, and Arctic snow forcing will decrease the costs, as well. However, caution is also necessary.

First, many of the least-expensive mitigation actions can be found in developing countries. Industrialized countries have already enacted many of the least-expensive aerosol reductions, and the remaining black carbon is expensive to mitigate. Thus, acknowledging the role of black carbon in the climate system is unlikely to detract developed countries from reducing greenhouse gases.

Second, reductions may be challenging, despite strong justification for climate protection. The two measures that appear most promising—reducing diesel emissions and improving cooking fuels—involve millions of small sources and operators, whose ability to afford the relatively low-cost investments is limited.

In conclusion, black carbon reductions can contribute to climate protection, and exploration of this possibility should proceed rapidly, although cautiously. Reducing emissions can eliminate warming quickly, and in some cases economically. These measures also result in major health and environmental benefits; however, they are not always cost effective for climate purposes, alone, especially in industrialized countries, and they reduce warming only in the short term.

Thank you.

[The prepared statement of Ms. Bond follows:]

Testimony for the Hearing on Black Carbon and Climate Change

House Committee on Oversight and Government Reform

United States House of Representatives

The Honorable Henry A. Waxman, Chair

October 18, 2007

Tami C. Bond, Assistant Professor

University of Illinois at Urbana-Champaign

Chairman Waxman and Ranking Member Davis, and members of the Committee, I am pleased to have this opportunity to share my expertise about black carbon, its origins, and its role in climate change. I commend your committee for continuing this discussion at the national level, and I am honored to participate. Thank you for your invitation and your consideration.

I am Tami Bond, Assistant Professor of Civil and Environmental Engineering at the University of Illinois, Urbana-Champaign. I have spent the last twelve years modeling and measuring sources of black carbon and other aerosols.

1. Scope of testimony

I will be speaking today on the sources of black carbon, on its role in the climate system especially as it compares to greenhouse gases, and on the potential for mitigation based on my understanding of sources and intervention options. Following are the major points of my presentation:

- To the best of our knowledge, black carbon comes from four major source types.
- History shows that black carbon emissions can be reduced rapidly when cleaner alternatives are available.
- When considering mitigation options, black carbon and other products of incomplete combustion should be considered together with greenhouse gases, especially when they contribute a significant fraction of the atmospheric impact.
- Mitigation options that address black carbon, particularly in developed countries, are not always cost-effective compared to greenhouse gases.
- Some mitigation options can quickly and economically reduce warming by eliminating black carbon and other products of incomplete combustion. Some of these offer major co-benefits in terms of human health and local environmental protection. Implementing them will be challenging, but reduction technologies are available.

2. Sources and magnitudes of black carbon emissions

My colleague, Dr. Jacobson, has already reviewed the definitions of black carbon and its radiative forcing relative to that of greenhouse gases. He has also discussed its potential for reducing warming in the immediate future.

2.1. Black carbon comes from four major source types

Black carbon emissions in 2000 (Figure 1, ref 1) resulted mainly from four source categories: (1) diesel engines for transportation or industrial use; (2) residential solid fuels such as wood and coal, burned with traditional technologies; (3) open forest and savanna burning, both natural and initiated by humans for land clearing; and (4) industrial processes, usually from smaller boilers.

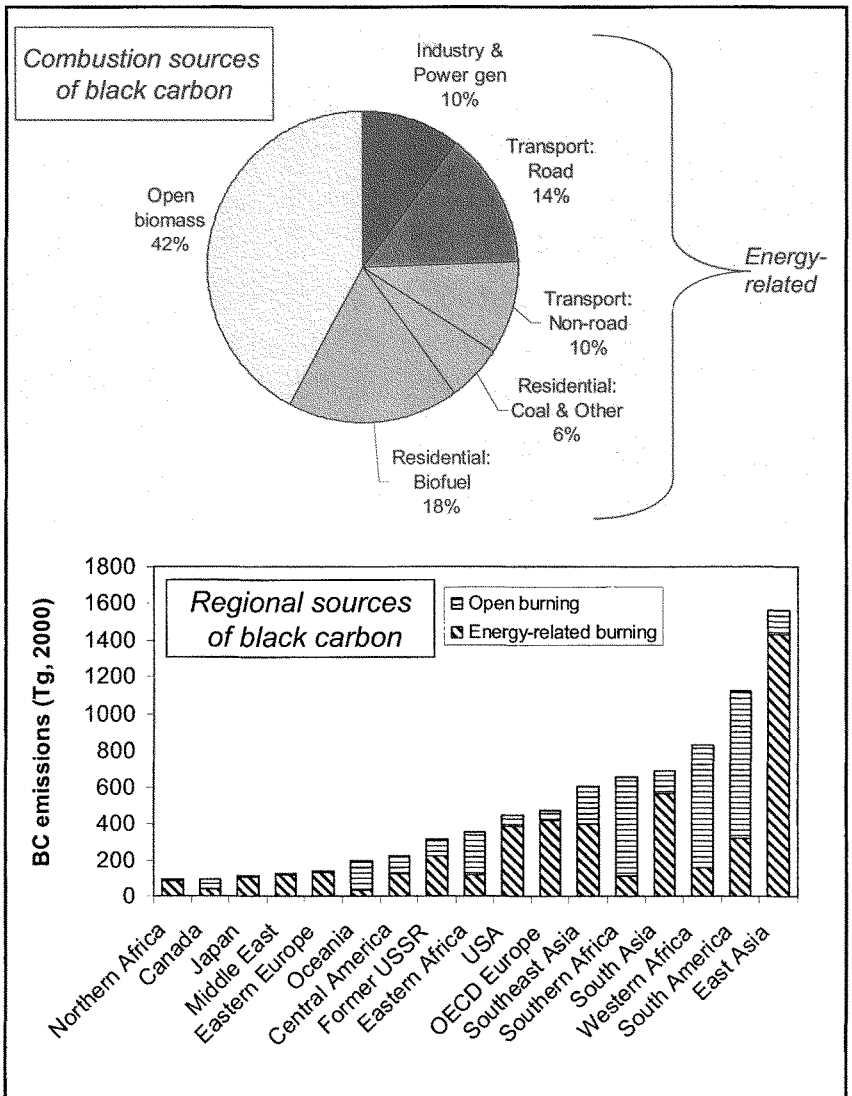

Figure 1. Sources of black carbon: combustion type and region.
From ref 1, updated to year 2000 data.

I have summarized only emissions of black carbon, although they are also emitted with organic carbon, cooling particles, and many gaseous chemicals. The values I present here are compatible with those in Dr. Jacobson's testimony, but they are tabulated differently. My approach is to ask first, "Where does the black carbon come from?" and then, when discussing each source, "If these sources are mitigated, how likely is it that warming will be reduced?"

These estimates are necessarily imprecise, especially when compared with carbon dioxide emissions. That is mainly because: (1) For black carbon, emissions from the same *fuel* can vary by orders of magnitude, depending on the quality of the burning. (2) Within a particular source *type*, black carbon can come from millions of individual combustion units, resulting in a wide range of emission levels. For example, 10-20% of a vehicle fleet can produce half the total emissions [2, 3]. (3) Finally, if the process or combustion fluctuates, emissions from the same *source* vary with time, and fluctuating conditions can result in large emission puffs [4].

In order to produce the emission estimates in Figure 1, we estimate the types of technology used in each world region, often based on sparse data. There are thousands or millions of sources of each type, none of which is continuously monitored. We have to assume that a few measurements can be used to characterize these emissions. Because pollution is undesirable, the worst emitters usually do not want to be detected, and do not offer themselves for emission testing. Emission estimates are biased low if this limitation is not considered. Representing these and other issues on a global basis is a real challenge.

Despite the uncertainties, these estimates identify the major contributors to black carbon emissions. As estimates improve, the magnitude of each sectoral contribution may change. However, these major contributors will neither vanish, nor grow to dominate the entire picture. This last statement is based on an uncertainty analysis included in the development of the global emission estimate [1].

2.2. Black carbon emissions can be reduced quickly by improving fuels or combustion

Engineers and regulatory agencies have long experience with reducing particulate matter [5], from metering shovelfuls of coal [6] to the Clean Air Acts. This means that tools are available for reducing black carbon, a component of that particulate matter.

In 1932, an engineer described a coal heater as "...simply a device for stewing off tars and vapors of inconceivable variety as to composition, odor and filth for the effective work of polluting the atmosphere." [7] Enter the pulverized coal boiler, whose emissions contain little black carbon [8]. Temperatures were high, and particles were suspended and better mixed. Due to vastly improved combustion, black carbon emissions in the United States decreased (Figure 2a, ref 9) despite phenomenal growth in coal use. Estimates of the North American emission trend [9, 10] are broadly consistent with the Arctic record [11]. Because of improvements in combustion, global black carbon emissions have

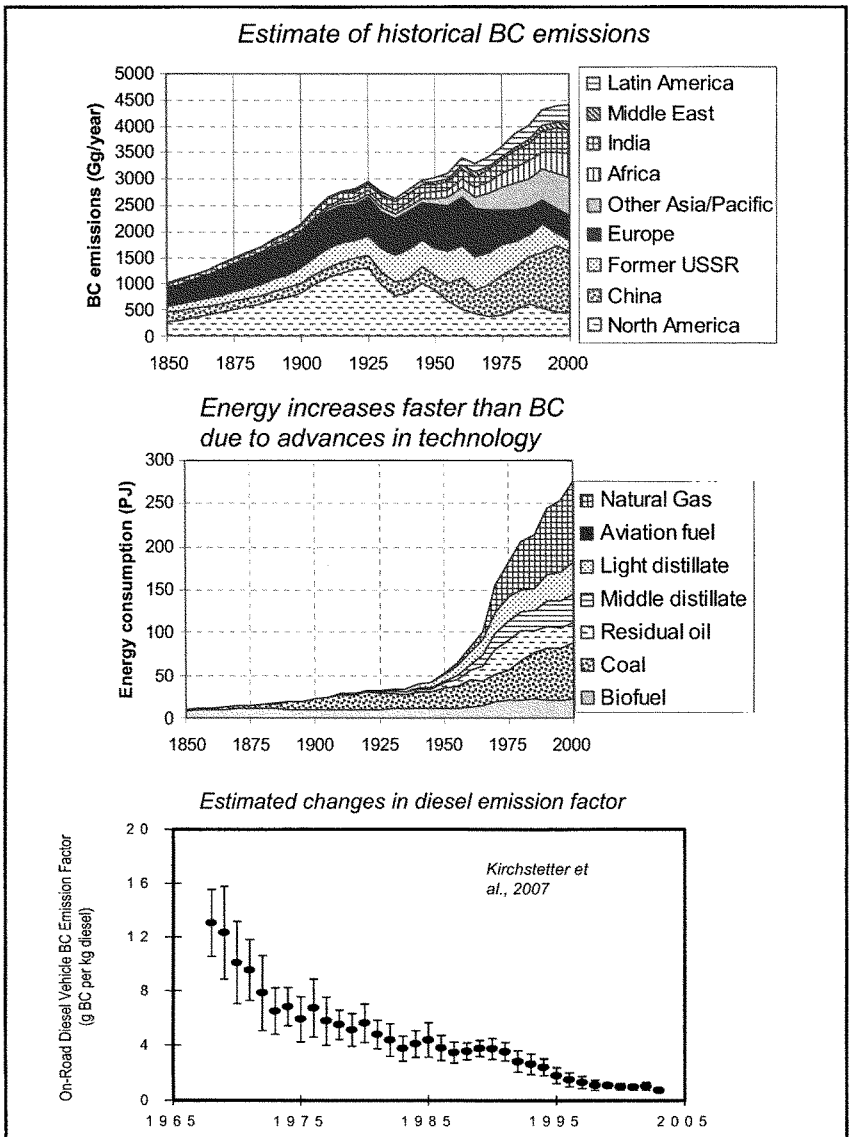

Figure 2. Historical changes in black carbon, energy, and emission intensity.
Top two figures from ref 9; bottom figure from ref 12.

increased at a much slower rate than global fuel consumption (Figure 2b). This is true even if one considers only the increase in the dirtiest fuels (coal and middle to heavy distillate oil). Diesel emission rates have decreased just as dramatically in response to regulation (Figure 2c, ref 12).

History also suggests an approximate development path, as shown in Figure 3. The large emissions from developing regions (Figure 1) are mostly from open biomass burning and from small-scale traditional combustion of solid fuels such as wood and coal. A plausible hypothesis is that in countries which have limited infrastructure and availability of clean fuels, black carbon emissions come mainly from solid fuels for heating and cooking. Over time, cleaner fuels and devices are adopted, and transportation becomes the main source. Some countries may also show increases in industry and transport, depending on the availability of local coal.

Given proper conditions and incentives, polluting technologies can be quickly phased out. In some small-scale applications (such as domestic cooking in developing countries), health and convenience will drive such a transition when affordable, reliable alternatives are available. For other sources, such as vehicles or coal boilers, regulatory approaches may be required to nudge either the transition to existing technology or the development of new technology.

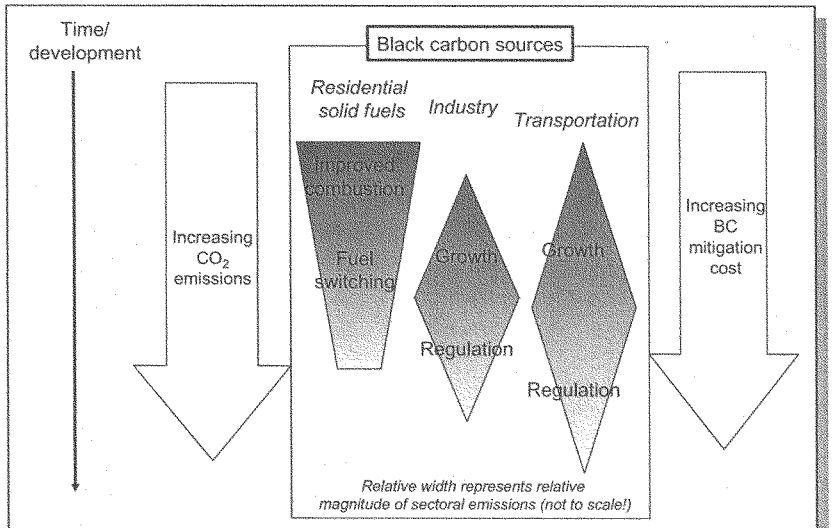

Figure 3. Development path of black carbon emissions.

Figure 1 shows large contributions from developing regions. The course of history in the United States and Europe suggests that these contributions will decrease. A key question is how quickly this transition will occur. Health concerns, air quality concerns, technology development, and potential greenhouse gas mitigation policies could all accelerate the transition.

3. Radiative forcing by sector or source

3.1. Each source affects many chemical species

In discussing black carbon mitigation options, two biases are inherent in conventional representations and accounting procedures: (1) assignment of forcing by species rather than by process, and (2) almost exclusive attention to longer-lived species, such as carbon dioxide or methane, and neglect of shorter-lived species, such as black or organic carbon, although their impacts are not limited to their environments. The practical implication of these biases is neglect of promising mitigation options that may increase carbon dioxide emissions but achieve over-compensating reductions in the emissions of other species, e.g., black carbon. If rapid changes become necessary, such as in response to Arctic warming, including short-lived species with very high short-term warming impacts may be warranted.

The Intergovernmental Panel on Climate Change, as well as much scientific research, quantifies how individual chemical species affect the climate system. A typical presentation identifies the contributions of greenhouse gases, sulfate particles, or carbon particles. (For example, see Figure SPM-2 in ref 13.) However, it is rarely possible to reduce greenhouse gases alone, aerosols alone, or black carbon alone. A more comprehensive way to assess climate impact is by combining all contributions from an individual source. For example, sectors such as power generation, industry, transportation, or households affect greenhouse gases, aerosols, and ozone precursors. A few studies have quantified net effects from sources such as open biomass burning, or total forcing by of aerosols from individual sectors [14].

3.2. Considering all emissions opens possibilities

The source-specific approach is particularly important when black carbon and other products of incomplete combustion are a significant part of radiative forcing. That is the case for each of the four major contributors to black carbon emissions. Forcing from all emissions must be counted in order to identify whether these actions have the intended effect. Limiting attention to traditional[1] greenhouse gases alone has two dangers:

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[1] I use the term *traditional* greenhouse gases to refer to the species listed in the Kyoto Protocol: carbon dioxide, methane, and nitrous oxide. Other greenhouse gases listed in the Kyoto Protocol (hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) are emitted from industrial processes and are not products of incomplete combustion. The Framework Convention on Climate Change (FCCC) lists many other greenhouse gases. Non-gaseous warming agents such as black carbon are not mentioned there, but the principle of comprehensiveness is enshrined in the text.

- **Missed opportunities** occur if radiative forcing could be reduced economically, but these sources were ignored because their primary contribution (products of incomplete combustion) is not included in the list of species for mitigation.

- **Misinformation about net benefits** of a choice may result when black carbon and other products of incomplete combustion are a significant part of radiative forcing. Table 1 summarizes two classic studies demonstrating this principle. The quote by Kirk Smith (box) is not intended to advocate for CO_2 emissions. Rather, it suggests that sources with incomplete combustion should clean up the combustion first, and then transition to a low-carbon pathway.

As this Committee has already acknowledged the potential importance of short-lived species by holding this hearing, emphasis on this point may be unnecessary. However, it should be clear that existing international agreements, and all current efforts on climate mitigation actions, are *not* evaluated with a comprehensive approach.

> *"If one is going to put carbon gases into the atmosphere, the least damaging from a global warming standpoint is CO_2; most [products of incomplete combustion] have a higher impact per carbon atom."*
>
> *-- Kirk R. Smith, Annual Reviews of Energy & the Environment [17]*

4. Black carbon reduction as a climate solution

4.1. There are preliminary measures to compare black carbon and CO_2

Because greenhouse gases and aerosols affect the climate system on different spatial and temporal scales, it is difficult to compare them in the same framework. However, we must invoke some basic measure of equivalence in order to evaluate whether addressing black carbon is cost-effective. One such measure is the amount of warming caused after

Table 1. Two studies demonstrate the need to consider total emissions in evaluating climate change

Source	*Conclusion from Greenhouse-gas forcing*	*Conclusion from total forcing*	*Citation*
Vehicles	Diesel vehicles produce less CO_2 than gasoline vehicles	Black carbon plus CO_2 emissions cause diesel vehicles to warm climate in the near term	Jacobson [15, 16]
Domestic cooking	Distilled fossil fuels (kerosene, LPG) release CO_2, while renewably harvested wood does not	Wood may cause more warming due to thermal inefficiency and products of incomplete combustion	Smith et al. [17]

one kilogram of the chemical species of interest is emitted. To compare chemical species with different lifetimes, the warming is integrated over a time frame of interest.[ii]

Estimates suggest that 1 kg of black carbon absorbs about **500-700 times** more energy in 100 years than 1 kg of CO_2 when only direct interaction with sunlight is considered [18, 19]. This range is lower than the global warming potential (GWP) in Dr. Jacobson's testimony. It includes *only* atmospheric forcing, for compatibility with the definition presented by the Intergovernmental Panel on Climate Change (IPCC, ref 20). Although our values differ because of the impacts considered, the major finding is not in question: **black carbon adds 2-3 orders of magnitude more energy to the climate system than an equivalent mass of CO_2.**

The time frame over which the warming impact is to be measured for the purpose of establishing 'equivalence' is of critical importance. Short-term impacts are naturally the highest for short-lived species such as black carbon: 1 kg of black carbon, emitted today, adds about **2000 times** as much energy to the Earth system over 20 years as 1 kg of carbon dioxide.

There are debates surrounding the validity of the comparison between long-lived gases like CO_2 and short-lived species like black carbon [21, 22, 23, 24, 25]. These will not be discussed here. Later, the comparison will be used only for a preliminary comparison of feasibility and cost-effectiveness. The recent synthesis by the IPCC [20] also presents integrated forcing for CO_2 and black carbon, providing some justification for this comparison.

Black carbon affects the climate system in many more ways than just direct interaction with sunlight. Changes in snow and ice albedo increase black carbon warming relative to CO_2 [26]. Changes such as cloud brightening (known as "the indirect effect") will decrease this relative warming [27]. The magnitudes of these changes are not well known. Efforts targeted toward estimating the incremental change in these both snow and clouds due to individual actions should be pursued.

4.2. Black carbon can be a short-term solution

Such a large warming may be hard to fathom. It occurs because black carbon is an extremely good absorber of visible light. Carbon dioxide stays in the atmosphere for decades, but it absorbs just a small amount of infrared radiation. One gram of black carbon in the atmosphere adds about 1800 watts to the Earth system as long as it is in the atmosphere [18]. That is about the amount of power consumed by eighteen bright light

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[ii] *Forcing* as commonly shown by IPCC is the rate of energy input. For an analogy, the rate at which a household uses electricity is similar to forcing. *Integrated forcing* is similar to an electric bill which totals all use over a specific period of time.

bulbs or a large barbecue grill. One gram of black carbon is emitted from about half a gallon of diesel fuel in a mid-1990s engine, or a lump of bituminous coal (if it is burned badly) that is the size of a large potato. Fortunately, black carbon is washed out of the atmosphere in a few days [28,29]. This large warming and rapid removal suggests the ability to make a difference quickly.

Both Hansen [30, 31] and Jacobson [32] suggested that black carbon emission reductions could form a viable component of reducing anthropogenic climate effects. This proposal has been taken up in other climate strategies [33], but always as part of a portfolio. It is generally recognized that black carbon cannot provide sufficient warming reduction to counteract CO_2 increases, and that greenhouse gases will dominate forcing by the end of the twenty-first century [34, 35]. However, addressing black carbon is a promising time-buying strategy to keep temperature increases below a critical value, or to take rapid action if sensitive systems are approaching a tipping point.

4.3. There is growing confidence that some sources warm climate

Despite the uncertainties, there is growing measurement evidence that some of the major sources (Figure 1) of black carbon contribute to warming. Carbon dioxide and ozone precursors cause warming. Thus, if the particles themselves contribute net warming, the total emissions from a source are most likely warming as well.

> *"Ramping up mitigation efforts quickly enough to avoid an increase of 2°C to 2.5°C... would require very rapid success in reducing emissions of CH_4 and black soot worldwide, and it would require that global CO_2 emissions level off by 2015 or 2020 at not much above their current amount..."*
>
> *-- Scientific Expert Group on Climate Change and Sustainable Development, 2007* [ref 33]

Measurements of absorption, scattering, and chemical composition from diesel engines [36, 37] and cookstoves [38, 39] show that these particles are strongly light-absorbing and therefore warming, despite the presence of non-absorbing aerosols. Organic carbon particles do not swell as much as sulfate in moist air [40], reducing their cooling potential. Organic carbon particles from solid-fuel burning also absorb a small amount of light [41, 42], making them less cooling or even warming.

Measurements also indicate that particles from open biomass burning [43] are either cooling or on the border between cooling and warming. There are no good "control technologies" for the prevention of open biomass burning; the interventions have to be adopted via changes in land use policies and the time to achieve the desired impacts can be quite long. Because of these uncertainty, this source—a large fraction of black carbon emissions— will not be considered in the analysis that follows.

5. Mitigation opportunities

Addressing black carbon appears to be a good idea. It results only from suboptimal combustion. It affects climate, visibility, and health negatively. It has the potential to reduce warming rapidly. However, as with greenhouse gases, cost is one of the main obstacles to action. This is no less true for black carbon than it is for carbon dioxide. Despite the fact that black carbon is unwanted, removing it is not free.

5.1. Only a few measures are cost-effective when climate alone is considered

The comparison between black carbon and carbon dioxide discussed above was necessary to discuss climate benefits on a CO_2-equivalent basis. Acceptable costs, if *only* climate benefits are considered, are typically a few dollars to a few tens of dollars per tonne of CO_2 equivalent.

Table 2 presents an estimate of climate benefit for several sources. Here, I will discuss only methods to eliminate *existing* black carbon emissions, since these actions will be required to reduce present-day climate impact. This cost assessment is quite preliminary. Because black carbon is fairly new on the climate stage, deep investigations of black carbon mitigation have not yet occurred, as they have for carbon dioxide. Thus, only the most readily available solutions are listed in the table.

Many of these sources appear inexpensive under a 20-year assessment, and only a few approach cost-effectiveness with 100-year values.[iii] Many of the least expensive mitigation actions are appropriate for developing countries. In accordance with Figure 3, countries undergo many of the least expensive aerosol reductions as they develop. As a country emits more CO_2, the remaining black carbon becomes harder to remove and more expensive. Thus, internal reductions of black carbon are unlikely to detract developed countries from reducing greenhouse gas emissions.

Table 2 supports both optimism and caution.

<u>*Optimism*</u> is fitting because the costs are close to worthwhile from a climate protection perspective. These costs are likely to decrease as solutions are explored. Furthermore, because each of these solutions will yield human health benefits by improving outdoor or indoor air quality, ancillary benefits may decrease the effective cost. There is a wealth of knowledge in both urban air quality management[iv] and in mitigation of indoor air pollution which should be tapped to suggest more robust solutions and more realistic cost estimates.

[iii] Note that these calculations assume no discounting of benefits. If any discounting is included, then the attractiveness of reducing short-lived species with high short-term warming impacts becomes much greater.
[iv] For example, the Clean Air Initiative for Asian Cities ("cai-asia"), http://www.cleanairnet.org/caiasia/

Table 2. Comparison of possible CO_2-equivalent reductions for eliminating all black carbon from several technologies, from ref 18.

emitting technology	abatement technology	EF-BC (g/kg)	fuel (kg/yr)	lifetime (yr)	lifetime BC (kg)	equiv CO2 (t) 100-yr	equiv CO2 (t) 20-yr	cost ($/t CO2 eq) 100-yr	cost ($/t CO2 eq) 20-yr
diesel engines									
Current light vehicle	particle trap ($250-500)	0.9	1500	10	14	10	31	25-50	8-16
Superemitting light vehicle	repair ($500-1000+); vehicle turnover (several $k)	3	1500	5	23	15	50	30-130	10-40
Pre-regulation truck	particle trap ($5k-10k)	2	10000	10	200	140	440	36-71	11-23
residential solid fuel									
Wood cookstove	cleaner stoves, fuel switching ($3-100)	0.7	2000	3	4.2	2.9	9.2	1-34	0.3-11
Coal cookstove	same as wood stove	8	1000	3	24	16	53	0.2-6	0.1-2
other transport									
gasoline: 2-stroke engine	education, engine switching	1	300	5	1.5	1.1	3.3	not estimated	
industry & power									
coal: low-tech brick kiln	switch kiln type *	5	500000	1	2500	1750	5500	18-35	5.5-11

<u>Caution</u> is necessary because black carbon reductions may be much more difficult to achieve despite strong economic justification.[v] The two measures that appear most promising, reducing diesel emissions and improving cooking fuels, each deserve some additional caveats which I will discuss below. Both involve thousands or millions of small sources and operators whose ability to afford the relatively small, low-cost investments is limited.

5.2. Changing household energy use patterns is limited by access and financial resources

Cooking and heating with wood, coal and waste is often done in small stoves with no or limited pollution control. Users who are exposed to the smoke from indoor burning of solid fuels are at risk for acute and life-threatening respiratory infections [44, 45]. The apparent simplicity of the solutions to this challenge is deceptive.

Improved stoves. Improving wood cookstoves is one method of reducing radiative forcing. The lowest costs in Table 2 are associated with small, inexpensive improved stoves. However, the least expensive stoves presently do the least to reduce emissions. Quality cookstoves may cost $50 or more, instead of the $3 used for the lowest cost estimates in the table. Dissemination, uptake and persistence of the improved stoves have also proven difficult. Viable technology is only a prelude to clean combustion; programs must consider the wishes of the affected populations [46].Technical and marketing aspects of improved wood stoves are active areas of exploration. For example, improved cookstove programs in China have been successful [47], and both pilot and full-scale projects have been conducted by the Partnership for Clean Indoor Air and the Shell Foundation.

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[v] Furthermore, the trading community has no experience with 20-year time horizons; it is not clear that accepted prices for short-term reductions would remain identical to the long-term reductions contemplated today.

Cleaner fuels. Transition to cleaner fuels is a second method of reducing radiative forcing, even if these fuels are derived from fossil fuels [see 17]. Distillate fuels such as kerosene and LPG, or compacted solid fuels such as charcoal and densified briquettes often burn cleanly. To the users, they may represent convenience and a modern lifestyle, in addition to cleanliness. However, unprocessed wood is often perceived as "free", and marketed fuels such as LPG, kerosene or charcoal or even electricity are still affordable to only a small fraction of consumers in developing countries. Reducing adoption costs, and supporting the development of supply and service infrastructure may make these sources affordable.

5.3. There is a built-in lag in vehicle fleets

There are two major impediments to altering diesel emissions immediately: the heterogeneity and the longevity of the vehicle fleet. The costs in Table 2 reflect studies in industrialized countries, and simple, inexpensive maintenance procedures or training programs may reduce emissions when vehicle quality or maintenance is lower on average.

Heterogeneity. In the United States and Europe, regulations have a long history, and regulations for off-road vehicles will be implemented in the near future. When emissions are not uniformly high, a few vehicles may contribute a large fraction of the pollution. These high emitting vehicles or "superemitters," which may be difficult to locate, are also the place to target either clean up or replacement. Emission reductions and costs vary widely between vehicles, so that black carbon reductions range from economical to rather costly [48].

Longevity. While black carbon remains in the atmosphere for just a few days, a vehicle in use remains so for several years. Thus, there is a long-lived reservoir in the black carbon system, but it exists in the vehicle fleet, not in the atmosphere. Based on modeling done for ref [49], fleet-average emissions for normal vehicles lag the standard by about five years. Because stringent standards must be eased in, it is critical to implement regulations in developing countries as soon as possible, so that the cleanest possible vehicles are put into action during periods of rapid growth when the fleet is being developed.

6. Conclusions

- History indicates that black carbon emissions can and will be reduced as development occurs. However, this transition can be accelerated.
- Black carbon can make rapid contributions to reducing warming, and some of its major sources exert net warming despite the co-emission of cooling aerosols.
- In developed countries, mitigation options for black carbon are not always cost-effective compared to greenhouse gases. Black carbon is unlikely to detract from the need for greenhouse gas reductions.
- Some black carbon mitigation options can economically reduce warming. These actions also have significant health or air-quality benefits. However, implementing each has challenges.

Thank you for your consideration.

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Chairman WAXMAN. Thank you very much, Dr. Bond.

Dr. Ramanathan.

STATEMENT OF V. RAMANATHAN

Mr. RAMANATHAN. Honorable chairman and members of the committee, I am really honored to be here. I am going to talk about more the global and regional effects of these black carbon particles.

They basically start off as soot as an urban or rural haze, and then fast atmospheric transport spreads this haze far and wide in a matter of a week over an entire subcontinent or an ocean basin. My basic work is to use satellite measurements to track these plumes and then launch aircraft to make detailed measurements of their effects on climate.

In atmosphere, black carbon is mixed with other particles such as sulfates, nitrates, and together the mix of manmade particles are sometimes referred to as atmospheric brown clouds, or ABCs.

First, touching on the global warming issue, BC is one of the strongest absorbers as far as particles are concerned of solar radiation in the atmosphere. My own estimates of BC heating from observations is that the current solar warming effect of BC is maybe as much as 60 percent of that current CO_2 greenhouse warming effect.

I want to point out that the estimates of the BC warming effect are uncertain by a factor of three or more, as well as our understanding of the emissions.

Now, digressing to the whole mix of particles, I want to comment on the global water budget. These brown clouds lead to large reductions in the amount of sunlight in the surface, and we call it dimming, and the corresponding increase in the solar heating. They both are two sides of the same coin. Together, the ABC dimming leads to a weaker hydrological cycle and drying of the planet, which connects ABCs, or atmospheric brown clouds, directly to availability of fresh water.

Moving on to the regional climate impacts, the regional effects of brown clouds are estimated to be particularly large over Asia, Africa, and the Arctic. Since the dimming and atmospheric heating are non-uniform in space and time, modern studies have linked the black carbon effects on climate to the Saharan drought, the decrease in monsoon rainfall over India, and drying of modern China. These are all recent model studies.

A more recent study by my group employing unmanned aerial vehicles [UAVs], shows from direct observations that black carbon enhances atmospheric solar heating by about 50 percent. This heating may have contributed as much as greenhouse warming to the glacier retreat, which is a major, major issue for the Asian region.

I want to comment next to last on the black carbon reductions and its effect on global warming. I basically consider this not as a mitigation in complete, more as buying time, because the BC warming effect may offer an opportunity to reduce the projected warming trends in the short term.

The lifetime of BC is about a few weeks, so its effect would manifest almost immediately. The reduction of BC emissions is also important to public health, and I defer to my colleague, Dr. Schwartz, for that.

Let me proceed to understand, because of the uncertainty, by a careful and well-documented, scientific study of the impact of black carbon reduction. Toward this goal we have teamed up with a team of NGO's and public health experts and proposed a project in the Periyar PURA region in India where we are going to adopt a large rural area with 20,000 population and provide alternate cooking and biogas plans and measure the impact of this on the atmosphere.

Last, I want to comment that the black carbon reduction is not proposed as an alternative to CO_2 reduction; at best, it is a short-term measure to probably buy a decade or two, time for implementing CO_2 emission reduction strategies.

The problem is highly uncertain, so I wanted to summarize with what is it we have reasonable consensus on. First, the lifetime of black carbon is about a few days to a few weeks is generally agreed upon, and globally black carbon has a net warming effect on the climate system, that is also generally agreed. However, the magnitude of the current warming effect is subject to a large uncertainty ranging from 15 percent to as much as 60 percent of the warming effect of CO_2.

Next also there is a consensus BC adds solar heating to the atmosphere but causes dimming of the surface.

The fifth point—again, reasonable consensus—is atmospheric brown clouds'—this is ABCs—own particles lead to dimming of the surface, and the global average effect of this is to decrease rainfall.

And the last point, which will be addressed by my colleague—we have reasonable consensus on that—deposition of BC on sea ice and snow darken the surface and leads to more solar absorption and melting of sea ice and snow.

Prior confirmation is the regional effects of BC on shifts in the rainfall patterns and the retreat of the Himalayan glaciers. These need additional studies.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Ramanathan follows:]

Role of Black Carbon on Global and Regional Climate Change

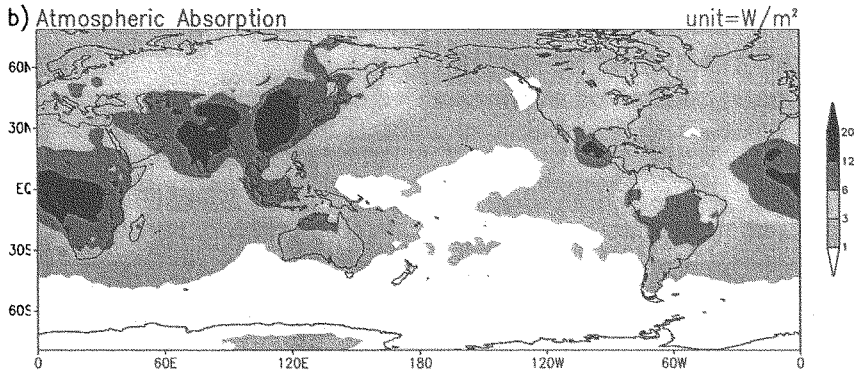
V. Ramanathan
Scripps Institution of Oceanography
University of California at San Diego

Testimonial to the House Committee on Oversight and Government Reform
Chair: The Honorable Henry A Waxman

Hearing on the role of black carbon as a factor in climate change

Thursday, October 18, 2007 Rayburn House Office Building, Washington DC

Some of the material in this paper is extracted from lectures given at the Pontifical Academy of Sciences, Vatican, (2006), the Bjerknes lecture given at the AGU fall symposium in San Francisco (2006) and the keynote talk at the *17th International Conference on Nucleation and Atmospheric Aerosols, Galway, Ireland (2007)*



Atmospheric Solar Heating (Wm^{-2}) by Black Carbon for the period 2000-2003.

Synopsis

Our understanding of the impact of black carbon (BC) aerosols has undergone major revisions, due to new experimental findings from field observations such as the Indian Ocean Experiment (Ramanathan *et al.* 2001b) and ACE-Asia (Huebert *et al.* 2003), new satellite observations (MODIS, MISR and CALIPSO), surface observatories such as AERONET (Holben *et al.* 2005) and Atmospheric Brown Cloud (ABC) Observatories (Ramanathan *et al.* 2007a), and aerosol chemical-transport models (Carmichael et al, 2003 and Chin et al, 2002 and Collins et al, 2001; Jacobson, 2002). Black carbon is a form of aerosol (suspended particle in the air) emitted as soot, both indoors (from cooking with wood, cow dung and crop residues) and outdoors through bio mass burning, coal and diesel combustion. The indoor smoke ultimately escapes outdoors and becomes part of air pollution. The outdoor pollution starts off as urban or rural haze. Fast atmospheric transport spreads the haze far and wide, in about 2 to 7 days, over an entire sub-continent or an ocean basin (see images in text).

Basically, black carbon solar absorption, gives rise to the blackish color in the vicinity of the smoke (e.g, tailpipe of a diesel truck) and contributes to the brownish color in the sky. In the atmosphere, BC is mixed with other aerosols such as sulfates, nitrates, numerous organic acids and dust (Guazotti et al, 2001), and together, the mix of manmade particles are sometimes referred to as Atmospheric Brown Clouds (ABCs). Globally, biomass and biofuel burning contributes about 65% and fossil fuel about 35% (Bond et al, 2004). There is a significant uncertainty (factors ranging from 2 to 5) in estimates of emission strengths. Until 1960s extra-tropical regions were the major sources of BC emissions, while now the major source regions have shifted to tropical regions (Bond et al 2007).

The greenhouse effect of CO_2 and gases arise from the trapping of heat radiation (also known as infrared radiation) given off by the earth's surface. On the other hand, the warming effect of BC arises because it absorbs (retains or traps) the solar radiation reflected by the earth's surface and clouds, which would have otherwise escaped to space. The CO_2 warming effect is known within $\pm$15%, whereas the estimated BC effect is subject to a threefold or larger uncertainty. Black carbon plays a major role in the dimming of the surface and a correspondingly large solar heating of the atmosphere. When globally averaged, BC is estimated to exert a net positive radiative forcing at the top-of-the atmosphere (i.e, a global warming effect). The estimates of BC heating by this author's group (Chung et al, 2005 and Ramanathan et , 2007a), using observationally constrained data from satellites, ground stations and field observations is that the current BC radiative forcing at the top-of-the atmosphere (the so-called radiative forcing as per IPCC) effect is as much as 60% of the current radiative forcing due to CO_2 greenhouse effect. Thus, next to Carbon Dioxide (CO_2), black carbon (BC) in soot particles is potentially the second major contributor to the observed twentieth century global warming (also see Jacobson 2002).

Reverting to the general effects of all aerosols (and not just BCs), ABCs enhance scattering and absorption of solar radiation and also produce brighter clouds (IPCC, 2007) that are less efficient at releasing precipitation (Rosenfeld et al, 2001). These in turn lead to large reductions in the amount of solar radiation reaching Earth's surface (also known as dimming), a corresponding increase in atmospheric solar heating, changes in atmospheric thermal structure, surface

cooling, atmospheric warming, alterations of north-south and land-ocean contrast in surface temperatures, disruption of regional circulation systems such as the monsoons, suppression of rainfall, and less efficient removal of pollutants (Ramanathan et al, 2001b, 2005, 2007b; Menon et al, 2001). Together the aerosol radiation and microphysical effects can lead to a weaker hydrological cycle and drying of the planet which connects aerosols directly to availability of fresh water, a major environmental issue of the 21st century (Ramanathan et al, 2001b). For example, the Sahelian drought during the last century is attributed by some models to aerosols (Rotstayn and Lohman, 2002). In addition, new coupled-ocean atmosphere model studies suggest that aerosols may be the major source for some of the observed drying of the land regions of the planet (e.g India and northern China) during the last 50 years (Ramanathan et al, 2005 and Meehl et al, 2007). Regionally aerosol induced radiative changes (forcing) are an order of magnitude larger than that of the greenhouse gases, but because of the global nature of the greenhouse forcing, its global climate effects are still more important. However there is one important distinction to be made. While the warming due to the greenhouse gases is projected to increase global average rainfall, the large reduction in surface solar radiation due to absorbing aerosols would decrease it.

The regional effects of BC are estimated to be particularly large over Asia, Africa and the Arctic. In these regions its effects, during the last century, may have been just as important as CO_2 in altering surface and atmospheric temperatures, monsoon circulation and rainfall patterns, and retreat of sea ice in the arctic and the retreat of glaciers in the Himalayas. However, this situation will change in a few decades, when CO_2 will become the dominant contributor to climate changes, both on global and regional scales. The interaction of the regional climate effects of greenhouse gases and ABCs deserve more attention. For example, a recent study (Ramanathan *et al.* 2007b) employing unmanned aerial vehicles suggest that BC enhances atmospheric solar heating by as much as 50%. When this data are combined with CALIPSO and other satellite data over S, SE Asia and the Indian Ocean and employed in a climate model, the simulations suggest the lower atmospheric warming over the S and SE Asian region, (including the elevated Himalayan regions) by ABCs is as much as that due to the greenhouse warming. Thus the atmospheric solar heating by BC may be intensifying the greenhouse gas effects on the Himalayan glacier retreat.

BC warming effect offers an opportunity to mitigate the projected warming trends in the <u>*short term*</u> (as also suggested by others, e.g, Jacobson, 2002; Bond and Sun, 2005). My thesis is that, BC reductions have the potential to delay the time of onset of the so-called dangerous climate change. For example, a reduction of BC emissions by a factor of 5, may reduce the radiative forcing (i.e. change in the net energy added to the planet) by about 0.3 Wm^{-2} to 0.8 Wm^{-2}. In comparison, if CO_2 continues to increase at the current rate of increase, it will add about 0.3 Wm^{-2} per decade. Thus a drastic reduction in BC has the potential of offsetting the CO_2 induced warming for a decade or two. Effectively, BC reduction may provide a possible mechanism for buying time to develop and implement effective steps for reducing CO_2 emissions. There are three issues that need to be factored in further consideration of this proposal:

i) The life time of BC is of the order of days to several weeks, depending on the location. Thus the BC concentration and its global heating will decrease almost immediately after reduction of its emission;

ii) Inhalation of soot is a major public health issue. For example, in India, alone it is estimated inhalation of indoor smoke is responsible for over 400,000 deaths annually (mostly among women and children; Pachauri and Sridharan, 1998). Air pollution related fatalities for Asia is estimated to be as high as 2 million (indoor smoke inhalation and outdoor brown clouds). Thus reduction of BC emissions may be warranted from public health considerations too.

iii) The developed nations have reduced their BC emissions from fossil fuel sources by a factor of 5 or more since the 1950s. Thus the technology exists for a drastic reduction of fossil fuel related BC. With respect to biofuel cooking, it can be reduced of not eliminated, by providing alternate cooking methods to rural areas in Asia and Africa. But we need to conduct a careful and well documented scientific study of the impact of BC reduction on radiative forcing and its cost effectiveness. Towards this goal, this author along with a team of NGOs, public health experts and alternate energy experts, has proposed Project Surya, that will adopt a large rural area of about 20,000 population, in India, and provide alternate cooking with biogas plants, smoke free cookers and solar cookers. The objective of the pilot phase of this experiment is to estimate from observations, the warming potential of BCs and the impact of BC reduction on human health (http://www-ramanathan.ucsd.edu/ProjectSurya.html) and the cost of reducing BC emissions from biofuels. Results from this pilot experiment will be used to scale up for the entire sub continent.

iv) The notion that we may reach the state of dangerous climate change during this century is increasingly perceived as a possibility. Given this development, options for mitigating such dangerous climate changes. The present BC reduction proposal should also be considered in this context, and by no means, BC reduction is being proposed by this author as an alternative to CO_2 reduction. At best, it is a short term measure, to buy a decade or two time for implementing CO_2 emission reduction.

I. Global Effects of Anthropogenic Aerosols

The global build up of greenhouse gases (GHGs), is the most vexing global environmental issue facing the planet. GHGs warm the surface and the atmosphere with significant implications for, rainfall, retreat of glaciers and sea ice, sea level, among other factors. What is less recognized, however, is a comparably major global problem dealing with air pollution. Until about ten years ago, air pollution was thought to be just an urban or a local problem. But new data (Ramanathan et al 2001a and 2007a) have revealed that, due to fast long range transport, air pollution is transported across continents and ocean basins, resulting in trans_oceanic and trans-continental plumes of atmospheric brown clouds (ABCs) containing sub micron size particles, i.e, aerosols, consisting of sulfates, nitrates, black carbon(a mix of elemental carbon and organic carbon compounds) among numerous other compounds. ABCs intercept sunlight by absorbing as well as reflecting it, both of which, lead to a large reduction of solar radiation at the surface (sometimes referred to as dimming). The dimming effect is enhanced further because aerosols nucleate more cloud drops which makes the clouds reflect more solar radiation. The other side of this dimming issue, is the absorption of solar radiation by ABCs (mainly by black carbon), which adds solar heating to the lower atmosphere. The sum of the surface dimming and atmospheric solar heating is the so-called top-of-atmosphere (TOA) radiative forcing (as per IPCC), which is estimated by us to be about -1.5 Wm^{-2} ($\pm$0.75 Wm^{-2}). When this is compared with the 3 Wm^{-2} (TOA) forcing due to greenhouse gases, it leads us to the conclusion that, globally, ABCs may have masked as much as 50% ($\pm$25%) of the warming due to greenhouse gases. Note that the uncertainty estimates given inside the parentheses should be interpreted as follows: The masking effect has a three-fold range of 25% to 75%. The logical deduction from this estimate is that, if and when air pollution regulation succeeds in eliminating the emission of these particles, the surface warming can intensify by about 0.7 to 1.5 K, where the range is due to a range in assumed climate sensitivity of 2 to 4 K due to doubling of CO_2. When this range is factored in with the threefold uncertainty in the aerosol masking effect, stopping the emission of anthropogenic aerosols, could result in a global mean warming of about 0.4 °C to 2.4 °C. Similar conclusions of the role of ABCs have been inferred by others (e.g, see Andreae *et al.* 2003). There are two key issues: First the life time of ABCs in the atmosphere are of the order of weeks and thus atmospheric concentrations of ABCs as well as their radiative forcing will respond (i.e. decrease) within several weeks after the emission reductions. However, the climate system may take a decade or more to respond completely to the reduction in aerosol forcing due to the inertia of the ocean-atmosphere system.

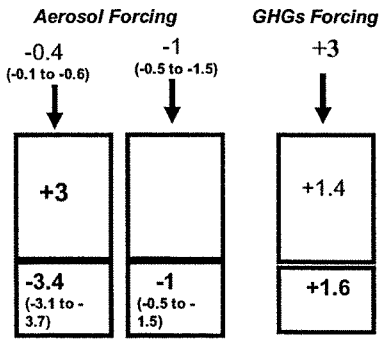


Figure 1. Global Mean anthropogenic forcing due to aerosols (the two panels on the right) and due to greenhouse gases. The blue boxes show the atmospheric forcing; the brown box at the bottom show the surface forcing; the sum of the two is the forcing at top-of-atmosphere (TOA). The aerosol values are estimayed for 2000 to 2003 and are taken from Ramanathan *et al.* (2001) and Chung *et al.* (2005) and Ramanathan (2007), while the GHGs at TOA is from IPCC (2007) for 2006. Also see Crutzen *and Ramanathan* (2003) on the *parasol* effect of aerosols.

The global mean estimates shown in Fig 1 underscores the relative contributions of aerosols and GHGs at the surface, the atmosphere and the surface. While at the surface, the aerosol dimming (negative forcing of -4.4 Wm^{-2}) is much larger than the GHGs forcing of 1.6, the positive atmospheric forcing of 3 Wm^{-2} within the atmosphere by aerosols (ABCs) enhances the GHGs forcing of +1.4 Wm^{-2}, such that the sum of the surface and the atmospheric forcing, i.e, forcing at TOA, is -1.4 Wm^{-2} for ABCs and +3 Wm^{-2} for GHGs. Thus the net anthropogenic forcing by anthropogenic modification of the radiative forcing is positive.

Because of the large reduction of solar radiation at the surface (see Fig 1, the bottom box in the left and middle panels) ABCs can lead to a weaker hydrological cycle and drying of the planet which connects aerosols directly to availability of fresh water, a major environmental issue of the 21st century. Thus, there is one important distinction to be made: *While the warming due to the greenhouse gases will make the planet wetter, i.e. more rainfall, the large reduction in surface solar radiation due to absorbing aerosols will make the planet drier (Ramanathan et al, 2001a).*

The Particular Role of Black Carbon

Some aerosols, like sulfates and nitrates, have a negative forcing (surface cooling effect) while black carbon has a net positive forcing (surface warming). Black carbon is a mix of elemental and organic carbon emitted by fossil fuel combustion, bio mass burning and bio-fuel cooking (wood fires and cow dung) as soot. In the atmosphere, black carbon aerosols are mixed with sulfates and organics and it is not straight forward to untangle the effect of black carbon from that of the mixed (black carbon and others) aerosol. Thus most if not all of the published estimates of black carbon are derived from models. Black

carbon affects the radiative forcing of the planet in many different ways (taken from Ramanathan *et al,* 2001):

i) Interception of direct sunlight: BC absorbs the direct solar radiation and this is the largest contributor to the surface dimming and atmospheric solar heating by ABCs. This effect, however, does not contribute too much to the top-of-the atmosphere forcing, and its main contribution is to reduce the surface solar heating and thus perturb the hydrological cycle. Globally, its effect is to reduce evaporation and rainfall.

ii) Interception of reflected sunlight: BC also absorbs the solar radiation reflected by the surface and clouds and thus reduces the solar radiation reflected to space by the earth-atmosphere system. It is this effect that is the main contributor to the positive radiative forcing by BC.

iii) Deposition in Sea Ice and snow: Deposition of BC over sea ice and snow, increases the absorption of solar radiation by ea ice and snow which is another source of positive radiative forcing.

iv) In addition to the above direct effects, BC solar heating is linked with evaporation of low clouds which is another source of positive radiative forcing.

Based on the observationally constrained regional effects of ABCs shown later (from Chung *et al.* 2005 and Ramanathan *et al.* 2007b), we estimate the net effect of BC (from items i and ii above) for the 2000 to 2003 period to be about **+0.9 Wm^{-2}**. This should be compared with the 1.6 due to CO_2 and 1.4 Wm^{-2} due to all other greenhouse gases (CH_4, N_2O, Tropospheric Ozone and Halons, IPCC, 2007). The published estimates for item iii varies from + 0.1 to 0.3 Wm^{-2}. Thus, with a combined forcing (from items i, ii, and iii) of **1 to 1.2 Wm^{-2}** ($\pm$ 0.4 Wm^{-2}) BC is likely to be the second most important contributor (next to CO_2) to global warming.

II. Regional Hotspots of ABCs

It is important to recognize that ABCs are a hemispherical to global scale problem. However, because of the short life times (days to weeks) ABCs are concentrated in regional and mega-city hot spots. Long range transport from these hot spots gives rise to wide spread plumes over the adjacent oceans (see Fig 2). Using satellite data such as those shown in Fig 2, Ramanathan *et al.* (2007b) recently identified *5 regional hot spots* around the world: *1) East Asia* (eastern China, Thailand, Vietnam and Cambodia); *2) Indo-Gangetic Plains in S Asia* (the north west to north east region extending from eastern Pakistan, across India to Bangladesh and Myanmar*);* 3) Indonesia; 4) Southern Africa extending southwards from sub-Saharan Africa into Angola and Zambia and Zimbabwe; 5) The Amazon basin in S America. In addition, the following 13 *mega city hot spots* have been identified: *Bangkok, Beijing, Cairo, Dhaka, Karachi, Kolkata, Lagos, Mumbai (Bombay), New Delhi, Seoul, Shanghai, Shenzen and Tehran.* Over these hotspots, the annual mega AODs exceed 0.3 and the absorption optical depth is about 10% of the AOD, indicative of the presence of strongly absorbing soot accounting for about 10% of the anthropogenic aerosol amount.

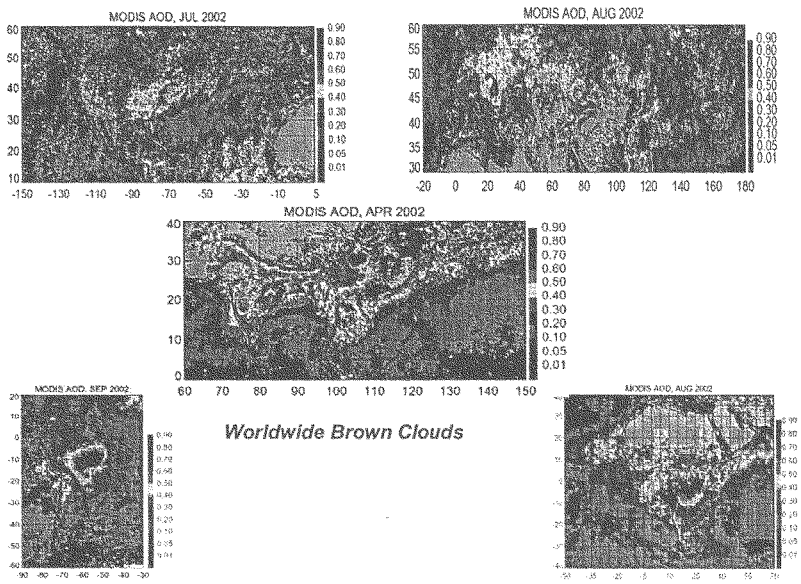


Figure 2. Monthly mean aerosol optical depths derived from MODIS aerosol instrument on NASA's TERRA satellite. The optical depth is a good index for the product of the aerosol number concentration and their surface area from the surface through the depth of the atmosphere. The color shading is dark blue for AODs smaller than 0.05 (clean marine background); green for 0.2 (visible brown clouds) , yellow for 0.4 to 0.5 (very hazy)and red for AODs>0.6 (heavily polluted). Source: Ramanathan et al (2007).

III. Surface Dimming by ABCs

Is the Planet dimmer now than it was during the early twentieth Century? Solar radiometers around the world are indicating that surface solar radiation in the extra tropics was less by as much as 5% to 10% during the mid twentieth century (e.g, see Stanhill, and Wild et al), while in the tropics such dimming trends have been reported to extend into the twenty first century. But many of these radiometers are close to urban areas and it is unclear if the published trends are representative of true regional averages. The Indian Ocean Experiment (Ramanathan et al 2001b) used a variety of chemical, physical and optical measurements to convincingly demonstrate (Satheesh and Ramanathan, 2000) that ABCs can lead to dimming as large as 5% to 10% (i.e, decrease in annual mean absorbed solar radiation of about 15 $W.m^{-2}$), over widespread regions in the N Indian Ocean and S Asia. In order to get a handle on the global average dimming,

recently we integrated such field observations with satellite data and aerosol transport models to retrieve an observationally constrained estimate.

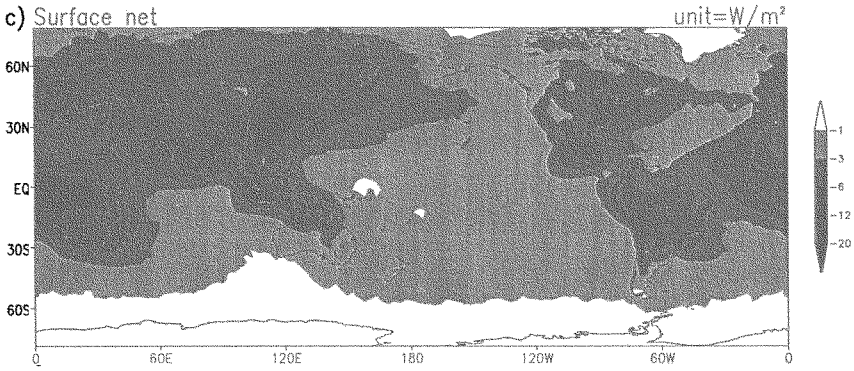


Figure 3. Integrated and Observationally constrained estimate of Annual mean Global Dimming by ABCs around the world for 2001-2003. Ref: Chung, Ramanathan, Podgorny and Kim, 2005.

As seen from Fig.3, over large regions the reduction of solar absorption at the surface exceeds 12 Wm^{-2} (>5%), which is consistent with the dimming reported from surface observations. The global-annual average dimming (for 2002), however, is -3.5 $W.m^{-2}$, as opposed to 10 to 20 Wm-2 global averaged dimming estimated by studies that used surface radiometers over land areas. *Thus great care should be exercised to extrapolate surface measurements over land areas to global averages.* The global dimming of -3.5 Wm^{-2} has been compared with the GHGs forcing of 3 Wm^{-2} from 1850 to present, i.e, 2005, (IPCC, 2007). Such comparisons, without a proper context could be misleading, since the dimming at the surface is not the complete forcing. It does not account for the atmospheric solar heating by ABCs, discussed next.

IV *Global Solar Heating of Atmosphere by BCs*

There is an important distinction in the forcing by scattering aerosols, like sulfates, and that due to absorbing aerosols like soot (see Ramanathan et al 2001 for a detailed elaboration of the points noted below). For sulfates, the dimming at the surface, is nearly the same as the net radiative forcing due to aerosol since there is no compensatory heating of atmosphere, and hence a direct comparison of the surface dimming with GHGs forcing is appropriate. For soot, however, the dimming at the surface is mostly by the increase in atmospheric solar absorption, and hence the dimming does not necessarily reflect a cooling effect. It should also be noted that the dimming at the surface due to soot solar absorption can be factor of 3 larger than the dimming due to reflection of solar (a

cooling effect). Figure 3 below shows our recent estimates of the global distribution of the atmospheric solar heating by manmade aerosols for the period 2001-2003.

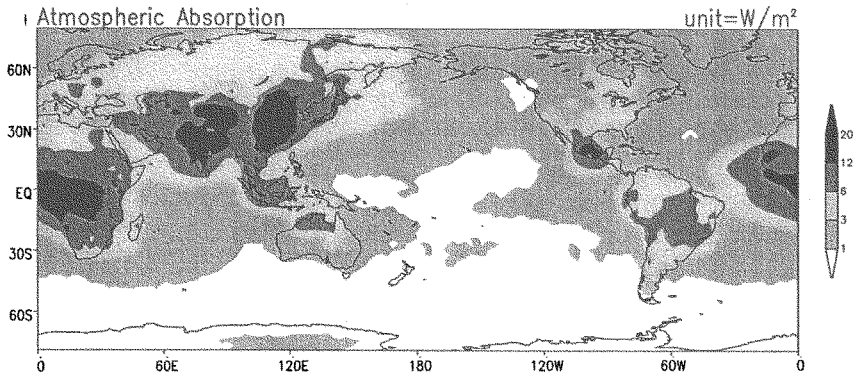


Figure 4. **Integrated and observationally constrained estimate of annual mean atmospheric Solar heating by ABCs for 2001-2003. Ref: Chung, Ramanathan, Podgorny and Kim (2005).**

V. Interactions between GHGS and ABCs on Regional Scales

The Asian Monsoon

The fundamental driver of evaporation of water vapor is absorbed solar radiation at the surface, particularly, over the sea surface. The precipitation over land is driven by two major source terms: evaporation from the land surface and long range transport of moisture from the oceans and its subsequent convergence over the land regions. It is then logical to posit that the large reduction of absorbed solar radiation by the land and sea surface due to interception of sunlight by ABCs (Fig 2) should lead to an overall reduction of rainfall. The observed precipitation trends over the last 50 years reveal major regions which experienced an overall reduction of rainfall (Sahel and the Indian monsoon) as well as a shift in the rainfall patterns (Fig 4). Numerous climate model studies have been published which suggest that inclusion of the aerosol dimming can help explain the Sahelian drought (Rotstayn and Lohmann, 2002); the decrease in Indian monsoon rainfall (Chung and Ramanathan, 2002; Ramanathan *et al*, 2005; Meehl *et al.* 2007; Lau *et al.* 2007); and the north-south shift in east Asian rainfall (Menon *et al.* 2002). Ramanathan *et al.* (2005) conducted a coupled ocean atmosphere model study with

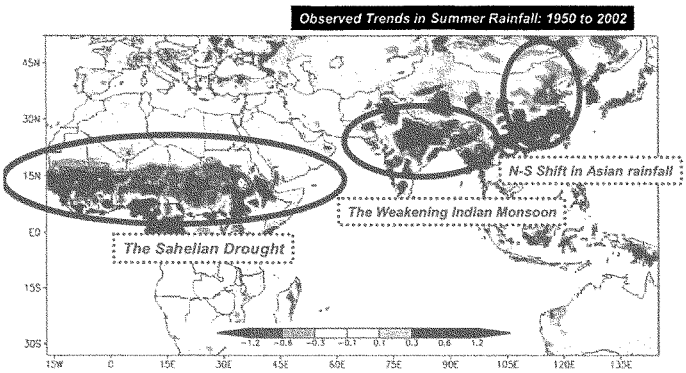


Figure 5. Trend in observed rainfall from 1950 to 2002. The figure shows the change in rainfall between 1950 and 2002; It was obtained by multiplying the year linear trend in mm/day/year by 52 years. The precipitation data is the Hadley center CRU data (Ref: Mitchell and Jones, 2005)

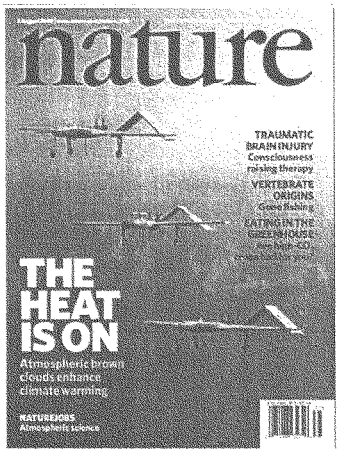
prescribed greenhouse forcing and ABC forcing (Figs 2 and 3) over S. Asia from 1930 to 2002. For the time dependent ABC forcing, they scaled the observationally constrained forcing (2001-2003) with history of SO_2 and soot emission for S. Asia from 1930 to 2002. Their model simulations, along with those reported in Meehl *et al.* (2007) and Lau *et al.* (2007), suggest the following effects of ABCs on the regional rainfall:

1. Dimming Trends: the simulated trend in dimming of about 7% over India was consistent with the observed trends obtained from radiometer stations (12 stations) in India, thus providing evidence for large dimming due to ABCs.
2. Atmosphere: heated by absorption and scattering of solar radiation
   - Warmer atmosphere is more stable: less precipitation
3. Surface: less solar radiation ('dimming'), thus more cooling (offset GHG warming)
   - Reduced solar radiation over Northern Indian Ocean (NIO): less evaporation, ***less precipitation***
   - Pollution is greater over NIO than SIO, which weakens the summertime sea surface temperature gradient: less circulation, weaker monsoon, ***less precipitation***
4. Monsoon Impact: the resulting deceleration of summer monsoonal circulation, the decrease in evaporation, and the increase in stability are the primary mechanisms for the reduction in the summer monsoon rainfall in the model simulations of Ramanathan *et al.* (2005) and Meehl *et al.* (2007).

These recent findings have catalyzed the creation of an international program for a better understanding of aerosol effects on the Asian monsoon (Lau *et al.* 2007).

Retreat of Himalayan Glaciers

UAVs document solar heating by BC (Stacked UAV montage from the Cover of Nature, Aug 2, 2007).



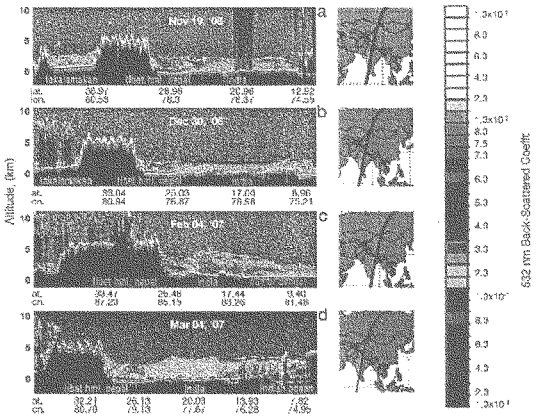


Figure 5. Color-coded profiles of 532nm backscatter return signal from the CALIPSO satellite lidar showing the vertical distribution of ABCs. The image shows ABCS surrounding the Himalyas from both the S and the SE Asian side (Source: Ramanathan et al, 2007b).

The retreat of the Himalayan-Hindu Kush (HHK) glaciers is one of the major environmental problems facing the Asian region. These glaciers feed several major Asian river systems including the Indus, Ganges, Brahmaputra, Mekong, Yangtze and Huang He. The livelihood of over 2 billion Asians are influenced by these rivers. The glacier retreat began in the mid nineteenth century in response to the termination of the mini ice age. The retreat has accelerated since the 1970s and includes major HHK glaciers such as Gangotri and over 90% of the Tibetan glaciers. Glaciologists (e.g. Thompson et al, 200x) link this acceleration to the large warming trend of about 0.25 C per decade that has been observed over the elevated HHK regions. The prevailing understanding is that the warming trend is part of the global warming due to greenhouse gases. But several American and European scientists have speculated that solar heating by soot in Atmospheric Brown Clouds and deposition of dark soot over bright snow surfaces may also be important contributing factors.

New research published in the Aug 2 issue of the journal Nature (Ramanathan et al, 2007a) offers direct observational evidence for the magnitude of the solar heating of the lower atmosphere by tiny soot particles resulting from fossil fuel combustion, bio mass burning and cooking with wood and other bio fuels. We launched light weight (30kg) unmanned aerial vehicles with miniaturized instruments to sample the brown clouds. Since the UAVs were flown simultaneously at different altitudes from surface to 3000 m, we were able to capture the ABCs between our aircraft and measure the sunlight absorbed at different altitudes as well as the dimming at the surface. We found that ABCs enhanced atmospheric solar heating by as much as 50% between 1 and 3 km. NASA's CALIPSO satellite carrying a laser instrument, tracked the thick Indian Ocean plume all the way across S Asia into the HHK region. It also showed ABCs stretching from the western Pacific Ocean across E Asia up to the Tibetan Plateau. Thus the HKK was surrounded by ABCs up to about 3 to 4 km.

The next obvious question was the impact of the large soot solar absorption on the atmospheric warming trends. For this we had to rely on an American climate model developed by over 20 scientists from around the US over a period of two decades. I was one of the early developers of this model in the 1980s. We adopted satellite and ground base observations for over 5 years and simulated the impact of the ABCs on the climate. In addition, we integrated into the model, the emission history of soot for the last 70 years and simulated the Asian climate from 1930 to 2005 with and without ABCs. These simulations showed that ABCs contributed as much as greenhouse gases to the warming trend of the atmosphere between 1 to 5 km, i.e, the elevations where the HKK glaciers are located. It is important to note that our simulations do not contradict the surface cooling effect of ABCs. In fact, in our simulations, ABCs cooled the surface over most of the plains in Asia, while warming the overlying free atmosphere. The surface cooling and the atmospheric warming are two sides of the same energy-balance coin: absorption by ABCs causes solar radiation that otherwise would have warmed the surface to instead warm the free atmosphere from1 to 5 km above the surface. In addition, the ABC induced warming was due to air pollution originating from all of Asia and not just S Asia, as can be seen most every day from satellite particle sensors. The latter two points were missed by the media covering the finding.

While our finding about the magnitude of the solar heating and its spatial extent are robust, the model simulations of the atmospheric warming require confirmation by independent studies. This process may take decade or two, for it took over a century to reach consensus on the global warming effects of greenhouse gases such as CO_2.

VI. Major Source of Uncertainty: Emission Sources for BC

Our ability to model the effects of BCs in climate models is severely limited. One of the main reason is the large uncertainty (factor of 2 or more) in the current estimates of the emission of the organic (OC) and elemental carbon (EC) (See Bond *et al.* 2004 and 2007).. Furthermore, biomass burning contribute significantly to the emissions of OC and EC and the historical trends (during the last 100 years) in these emissions are unknown and models currently resort to ad-hoc methods such as scaling the current day emissions with past trends in population.

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Chairman WAXMAN. Thank you very much for your testimony.
Dr. Zender.

STATEMENT OF CHARLES ZENDER

Mr. ZENDER. Thank you Chairman Waxman, Mr. Davis, and members and staff of the committee for hearing my testimony regarding the effects of black carbon on Arctic climate.

The Arctic is warming about twice as rapidly as the rest of Earth. Although long-lived, manmade greenhouse gases are the dominant cause of Earth's recent warming, short-lived black carbon particles explain a significant fraction of the observed Arctic warming.

My colleagues have described what BC is, where it comes from, and how effectively BC reductions could slow near-term global warming. The four points most relevant to black carbon in the Arctic are: First, that most Arctic black carbon comes from fossil fuel combustion, not from open fires; second, black carbon appears to warm the Arctic more than any other agent except CO_2; third, Arctic climate is very sensitive to the surface warming of the type that black carbon causes; fourth, reducing Arctic black carbon now will cool the planet more than will a delayed reduction.

We know that economic and technological factors affect Arctic black carbon concentrations. From 1880 to 1950, industrial emissions increased black carbon concentrations in Greenland's snow sevenfold relative to pre-industrial levels. Black carbon concentrations in Greenland have been lower since about 1950, likely due to North American shifts in combustion fuels and technology, combined with wildfire suppression.

Black carbon decreased in some Arctic regions from the late 1980's and early 1990's during the decline of industrial activity in the former Soviet Union. Late 20th century increases in Greenland black carbon may be linked to increased coal combustion in the rapidly expanding Asian economies.

There are three reasons why black carbon warms the Arctic more than any agent except CO_2. First, black carbon absorbs sunlight and warms the Arctic atmosphere by approximately the same amount as human injected CO_2. This happens in spring and summer when snow and ice are most vulnerable to melting.

Second, black carbon also warms the Arctic, including in winter, by thickening low-level clouds that then trap more of Earth's emitted heat.

Finally, black carbon warms the Arctic after it lands on the surface. Uniquely, surface black carbon is an impurity that darkens the otherwise bright Arctic snow and ice, causing them to absorb more sunlight. This dirty snow, seen in the picture, warms and melts the Arctic's surface very efficiently, because the heat is trapped at the surface by the strong Arctic temperature inversions and by the insulating properties of the snow, itself.

Over the course of the Arctic spring, black-carbon-contaminated snow absorbs enough extra sunlight to melt earlier, weeks earlier in some places, than clean snow.

Melting Arctic surfaces uncover the darker, underlying surfaces such as tundra and ocean. These dark surfaces then absorb even

more sunlight, triggering a powerful climate warming mechanism known as the ice-albedo feedback.

In the pre-industrial climate, black carbon was less effective than wind-blown dust at triggering ice-albedo warming, but, as shown in this slide, manmade greenhouse gases have not only warmed the Arctic; they have exacerbated its vulnerability to warming by other pollutants such as black carbon.

The diagram shows that darkening of snow and ice by human-injected black carbon has warmed the Arctic by about half a degree centigrade since the pre-industrial era. Warm snow is darker than cold snow, so the ability of a cleaner Arctic surface to cool the planet will diminish as the Arctic warms. Snow and ice retreat also weaken black carbon's leverage over Arctic climate; hence, the diagram shows that reducing the concentration of black carbon now will cool the Arctic significantly more than a delayed reduction.

Nothing in climate is more aptly described as a tipping point than the zero-degree centigrade boundary that separates frozen from liquid water—the bright, reflective snow and ice from the dark, heat-absorbing ocean. Arctic snow, glaciers, and sea ice are, on average, about 1.5 degrees centigrade warmer than in the pre-industrial era. This may not sound like a lot, but each above-freezing day causes more melt, which amplifies the strong Arctic warming effects.

Greenhouse gas and black-carbon-induced warming are inexorably pushing more of the Arctic, earlier in the year, toward its zero-degree centigrade tipping point.

In summary, because of its short life time and strong effects, reducing Arctic black carbon concentrations sooner rather than later is the most efficient way that we know of to retard Arctic warming.

Thank you for your attention.

[The prepared statement of Mr. Zender follows:]

Written testimony to the Oversight and Government Reform Committee
United States House of Representatives
October 18, 2007

Arctic Climate Effects of Black Carbon

Charles S. Zender
Department of Earth System Science
University of California, Irvine

Abstract

The Arctic is warming about twice as rapidly as the rest of Earth. Black carbon (BC) particles are an important short-lived pollutant that explain a significant fraction of the observed Arctic warming. Most Arctic BC comes from fuel-combustion not from open fires. Arctic climate is very sensitive to the surface warming that BC causes. BC appears to warm the Arctic more than any other agent except CO_2. Reducing the concentration of Arctic BC now will cool the planet more than a delayed reduction.

Written Testimony

My name is Charlie Zender and I am an Associate Professor of Earth System Science at the University of California, Irvine. In that capacity I perform government-funded research on the roles of Black Carbon (BC) and other aerosols on global climate and, in particular, on the Arctic region. I am currently on sabbatical leave at the Laboratoire de Glaciologie et Géophysique in France conducting laboratory experiments on snow as part of International Polar Year activities. This committee requested that I testify regarding the effects of black carbon on Arctic climate. I thank Chairman Waxman, Mr. Davis, and the members and staff of the committee for this opportunity.

The Arctic is warming about twice as rapidly as the rest of Earth (*ACIA*, 2005). Although long-lived man-made greenhouse gases (GHGs) are the dominant cause of Earth's recent warming (*IPCC*, 2007), black carbon (BC) particles and other short-lived pollutants explain a significant fraction of the observed Arctic warming (*Flanner et al.*, 2007; *Quinn et al.*, 2007). Man-made BC has many attributes that make it a logical target for mitigation strategies that aim to decelerate near-term global warming (*Jacobson*, 2002, 2004), and Arctic warming in particular. Such policies can only complement, not replace, the longer term, GHG-oriented mitigation policies that are required to stabilize planetary temperatures.

My colleagues on this panel will describe what BC is, where it comes from, and how effectively BC reductions could slow down near-term global warming. My testimony describes four important aspects of BC effects on Arctic climate:

1. Most Arctic BC comes from fuel-combustion not from open fires.
2. Arctic climate is very sensitive to the surface warming that BC causes.
3. BC appears to warm the Arctic more than any other agent except CO_2.
4. Reducing Arctic BC now will cool the planet more than a delayed reduction.

Sources

Many of us grew up thinking of black carbon, also called soot, as the harmless smudges Santa Claus acquired sliding down our chimneys, and not as an environmentally harmful pollutant. So it can be disconcerting to learn that BC describes an agglomeration of carbonaceous particulates that form and are emitted (along with carbon dioxide) as combustion by-products from smokestacks, tail-pipes, forest fires, and humble cooking stoves.

Black carbon is generated by combustion of fossil-fuel (e.g., coal, oil, gasoline), bio-fuel (e.g., wood for stoves and heating), and open biomass burning (e.g., forest fires). Humans are responsible for fossil- and bio-fuel emissions. Biomass burning includes natural (e.g., lightning-sparked fires) and anthropogenic (e.g., agricultural, land-clearing fires) components in uncertain proportions. In most years, 70–90% of Arctic BC appears to stem from fuel combustion (*Koch and Hansen*, 2005; *Flanner et al.*, 2007). Year-to-year variability in fire conditions and transport paths lead to a considerable range in the biomass burning contribution, which may reach 50% in very strong boreal fire years (e.g., 1998).

Other combustion by-products include organic matter (sometimes called organic carbon) and inorganic aerosols (e.g., sulfate) that are highly reflective and so can have climate effects that differ from, and sometimes compete with, BC. Strategies to reduce BC must consider the effects on other combustion-derived aerosols since their sources are inextricably linked. The reflective aerosols produced by combustion have a smaller contrast with bright Arctic surfaces than does BC. To first order, this contrast causes BC to dominate the net effect of combustion-derived aerosols on the Arctic. It also explains why BC will become a less efficient warming agent in the Arctic as snow and ice surfaces there continue to warm, melt, darken, and thus to lose contrast with BC.

Unlike CO_2, an inert gas that remains in the atmosphere for many decades, BC is a particulate and deposits to the surface within about a week of its emission. During this week, a BC particle has good chance of circulating to the roughly 20% of the northern hemisphere that is seasonally or "permanently" snow and ice-covered, including Alaska, Greenland, and the Arctic Ocean. Twenty years of light absorption measurement from Barrow, Alaska, show the seasonality of Arctic BC superimposed on longer term trends (Figure 1).

Presently the vast majority of Arctic BC originates outside the Arctic. Emissions inventories, climate models, meteorological back-trajectories, and *in situ* samples confirm that most Arctic BC originates as fuel combustion by-products, primarily from the northern hemisphere mid-latitudes, followed by South Asia in importance (*Bond et al.*, 2004; *Koch and Hansen*, 2005; *McConnell et al.*, 2007; *Quinn et al.*, 2007). Biomass burning emissions and transport paths vary from year-to-year. Forest fires in North America and Siberia may contribute up to 30% of Arctic BC in years of exceptionally strong burning (e.g., 1998) (*Flanner et al.*, 2007).

Economic and technological factors clearly affect Arctic BC concentrations. The long term trends of BC in some Arctic locations can be obtained from ice cores. From 1880–1950, industrial emissions increased BC concentrations in Greenland snow seven-fold relative to pre-industrial levels (*McConnell et al.*, 2007) (Figure 2). BC concentrations in Greenland have been lower since about 1950, likely due to the shift to oil, gas, and cleaner coal burning in North America and to wildfire suppression. BC decreased in some Arctic regions in the late 1980s and early 1990s during the decline of industrial activity in the former Soviet Union. Late 20th century increases in Greenland BC may be linked to coal combustion in the rapidly expanding economies of Asia.

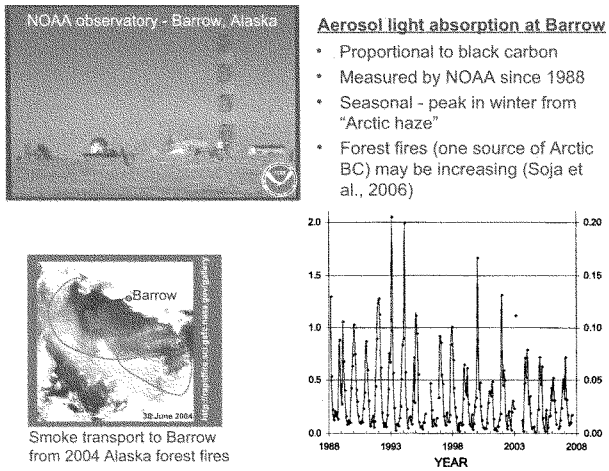

Figure 1: Light absorption, a proxy for BC, in Barrow, Alaska, 1988–2007. (J. Ogren, NOAA)

Climate Effects

In snow and ice-covered regions, BC plays an important climatic role both in the atmosphere and at the surface, i.e., before and after it is deposited. The contrast between the color of an aerosol and the planetary surface beneath it determine the net energetic effect, heating or cooling, that the aerosol has on the climate system. Black carbon is the darkest aerosol and snow and ice are, by far, the brightest surfaces of the planet. This high contrast combination causes BC to absorb sunlight and to warm the Arctic atmosphere. The direct absorption of sunlight by BC heats the Arctic atmosphere by approximately the same amount as human-injected CO_2 in spring and summer, when snow and ice are most vulnerable to melting (*Quinn et al.*, 2007). The bright aerosols (sulfate, organic matter) that are emitted from combustion along with BC have relatively little, if any, cooling effect on the Arctic because of their low contrast with the bright Arctic surface.

Black carbon also warms the Arctic, including in winter, by thickening low-level clouds that then trap more of Earth's emitted heat. BC is an important component of the Arctic Haze that peaks every winter (Figure 1). This haze increases the average cloud droplet concentration and inhibits the formation of large ice crystals which normally dessicate the cloud. The pollution-thickened clouds are more effective at trapping heat in the lower Arctic atmosphere (*Garrett and Zhao*, 2006).

Finally, BC warms the Arctic after it lands on the surface. Surface BC is an impurity that darkens the otherwise bright Arctic snow and ice, causing them to absorb more sunlight. I refer to this as "dirty snow". Dirty snow warms the Arctic surface very efficiently because the heat is trapped by the strong Arctic temperature inversions and by the insulating properties of the snow itself. Over the course of the Arctic spring, BC-contaminated snow absorbs enough extra sunlight to melt earlier—weeks earlier in some places—than clean snow.

The Intergovernmental Panel on Climate Change (IPCC) traditionally decomposes the complex

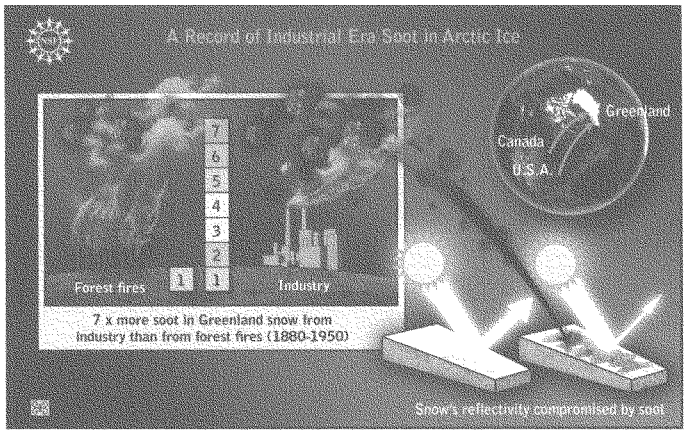

Figure 2: Industrial sources contributed seven times more BC to the Arctic than open fires from 1880–1950. (*McConnell et al.*, 2007)

effects of man-made activities on climate as a series of "radiative forcings" (Figure 3). The level of scientific understanding of aerosol-climate forcings (including Arctic BC effects) is low though steadily improving. The 2007 IPCC report explicitly recognizes for the first time the role of dirty snow and ice (i.e., surface deposition of BC) in climate change. The IPCC estimates that human-injected CO_2 traps about seventeen times more heat on Earth than dirty snow (*IPCC*, 2007).

Although highly useful for scientists and policymakers alike, such radiative forcing comparisons mis-lead when they are interpreted as the fraction of climate change caused by a given agent. One reason is that forcings applied to particularly sensitive pressure points, such as the Arctic, cause the Earth to warm more than equal forcings applied to less sensitive regions. For our purposes it is more logical to compare the *effects* of BC and CO_2 (as an established "yardstick") on temperature rather than to compare their radiative forcings (*Hansen et al.*, 2005b).

When snow, glacier, and sea-ice surfaces melt and retreat, they reveal the darker underlying surfaces such as tundra and ocean. These dark surfaces absorb even more sunlight, triggering a powerful climate-warming mechanism known as "ice-albedo feedback". BC on snow warms the planet about three times more than an equal forcing of CO_2 (*Flanner et al.*, 2007). Moreover, the BC-induced warming is concentrated in the Arctic whereas CO_2-induced warming is dispersed globally. BC appears to warm the Arctic more than any other agent except CO_2 because of its combined heating of the Arctic atmosphere and of the surface (*Jacobson*, 2004; *Flanner et al.*, 2007; *Quinn et al.*, 2007).

Until the 20th century BC was little more effective than other climate forcing agents at triggering ice-albedo warming But man-made GHGs have not only warmed the Arctic, they have exacerbated its vulnerability to warming by other pollutants such as black carbon. In the pre-industrial climate, dirty snow warmed the Arctic only by about 0.25 °C (Figure 4, *Zender and Flanner, Manuscript in Preparation*, hereafter ZF08). Natural soil dust (wind-blown dirt from arid regions) was then much more important at darkening the Arctic than black carbon.

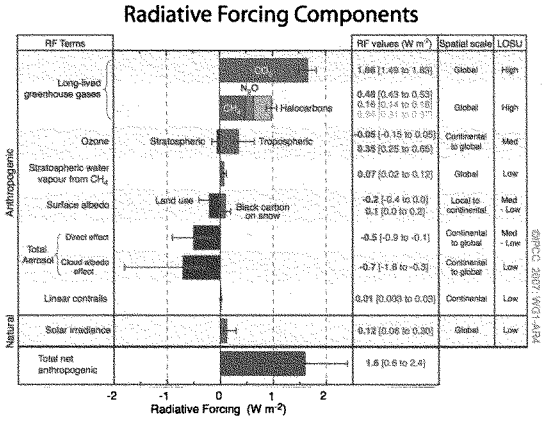

Figure 3: Global-mean radiative forcing estimates, scale, and certainty in 2005 (*IPCC*, 2007). Intercomparing forcings can be mis-leading: BC on snow warms the planet about three times more than an equal forcing of CO_2. Moreover, the BC-induced warming is concentrated in the Arctic whereas CO_2-induced warming is dispersed globally.

Black carbon deposition from fuel combustion has warmed the Arctic by about 0.5 °C since the pre-industrial era (*Flanner et al.*, 2007) (Figure 4). Warming by dirty snow and ice occurs primarily in the frozen regions of the northern hemisphere (including the Arctic) rather than the Antarctic, which is colder and less contaminated by black carbon. In today's warmer snows, very small concentrations of BC impurities ($\sim$10 ppb) are triggering astonishingly large ice-albedo warming.

Opportunities

The cooling power of a cleaner Arctic surface diminishes as the Arctic warms since warm snow is darker than cold snow. Snow and ice retreat also weaken black carbon's leverage over Arctic climate. Even with dramatic near-term intervention, future Arctic snow and ice cover will differ significantly from today's because of the current warming "commitment" of about 0.6 °C (*Hansen et al.*, 2005a). The spring and summer Arctic snow and sea-ice crucial for regulating Earth's temperature will be less extensive, warmer, darker, and, if current BC emission trends continue, dirtier (*Hall and Qu*, 2006). This reduced contrast between black carbon aerosol and the Arctic surface will reduce BC forcing and warming of the Arctic by mid-century (Figure 4, ZF08). Hence reducing the concentration of Arctic BC now will cool the planet more than a delayed reduction.

Nothing in climate is more aptly described as a "tipping point" than the 0 °C boundary that separates frozen from liquid water—the bright, reflective snow and ice from the dark, heat-absorbing ocean. Arctic snow, glaciers, and sea-ice are on average about 1.5 °C warmer than in the pre-industrial era. This may not sound like much, but each above-freezing day causes more melt which amplifies the strong Arctic warming effects. GHG and BC-induced warming inexorably push more of the Arctic, earlier in the year, towards its 0 °C tipping point.

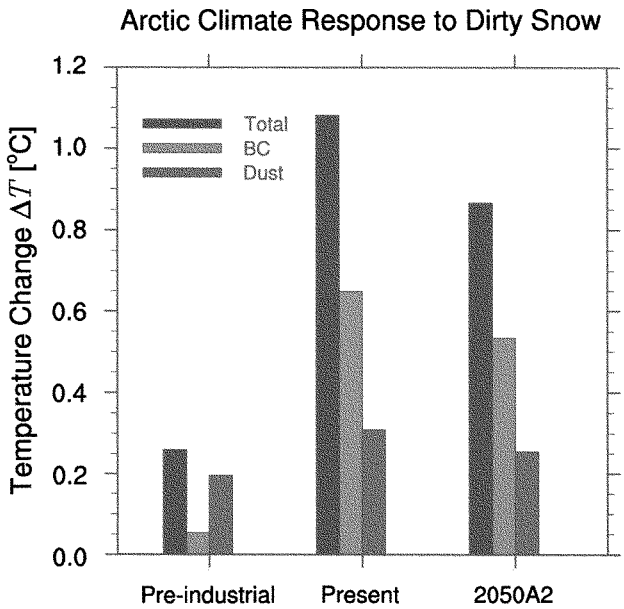

Figure 4: Predicted Arctic-mean temperature response [°C] to snowpack heating by black carbon and dust during Pre-Industrial, Present Day, and 2050 IPCC A2 climates. (*Zender and Flanner*, Manuscript in Preparation)

Man-made BC appears to have warmed the Arctic more than any other single agent besides CO_2. The most effective Arctic climate mitigation strategy would therefore target Northern Hemisphere sources of high absorptivity and low reflectance BC (e.g., diesel combustion and residential stoves) (*Quinn et al.*, 2007). Snow and ice are most vulnerable to BC emissions and deposition in spring so shifting prescribed agricultural and forest-management burns to other seasons may help to clean and brighten the Arctic. Reducing intra-Arctic BC emissions from generators and marine vessels will become increasingly important as industry and transport seek new opportunities in the thawing Arctic.

Summary

Arctic snow and ice now exist under a blanket of man-made GHGs that keeps them warmer and more vulnerable to pollution-induced melting. Arctic climate is very sensitive to the surface warming that BC causes. Aerosol heating, cloud thickening, and dirty snow explain why black carbon warms the Arctic more than any agent except CO_2. Reducing Arctic BC concentrations sooner rather than later is the most efficient way to mitigate Arctic warming that we know of.

Acknowledgments

I am grateful to M. Flanner, J. McConnell, J. Ogren, J. Randerson, P. Rasch, and S. Warren for helpful discussions and suggestions, and to F. Dominé for hosting my sabbatical at LGGE. Members of the Short-lived Pollutants and Arctic Climate (SPAC) working group synthesized many of the concepts presented here. Supported by NSF ARC-0714088 and NASA NNX07AR23G.

Download this manuscript from http://dust.ess.uci.edu/ppr/ppr_hogrc_wrt.pdf.

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Chairman WAXMAN. Thank you very much, Dr. Zender.

Dr. Schwartz.

STATEMENT OF JOEL SCHWARTZ

Mr. SCHWARTZ. Thank you very much, Chairman Waxman, Mr. Davis, members of the committee. I am pleased to be here to talk to you about the health effects of black carbon, if I can get my slides up.

Chairman WAXMAN. I want to congratulate all of you on the successful slides that you have had available to you in your presentation. It is very helpful to be able to follow the slides and actually see them.

Mr. SCHWARTZ. I want to start off by showing you what we are talking about. Particulate air pollution is, in fact, the only man-made object that is visible from space, and you can see it here over Bangladesh and the Himalayas up in the north.

You have heard a lot about what those particles do when they are up in the atmosphere in terms of absorbing heat, but I want to point out that the highest concentration of those particles is about at that altitude here where people breathe, and so I want to talk about what we know about the health effects of breathing those particles.

One of the things we know comes from the Harvard Six Cities Study, and this has now been replicated in a bunch of other cohort studies, and that is that breathing particles shortens people's life expectancy, and by non-trivial amounts. This is after controlling for hypertension, smoking, individual risk factors. The life expectancy in six U.S. cities versus the PM2.5 concentration—which is the total concentration of all combustion particles, not just the black ones—you can see more than a 2-year difference in life expectancy between the most-polluted and the least-polluted of these U.S. cities.

Again, this has been seen in multiple studies.

What is most interesting is what we saw when we went back to those cities and looked at another 10 years of followup in this cohort of individuals we had been studying. That was that, as air pollution levels declined in U.S. cities, the mortality rates—not life expectancy, but mortality rates on the Y axis—went down. And in the cities such as Stubenville with the "S" where there was a large drop in particle concentrations, there was a large change in mortality rates, whereas in Topeka with the "T" you can see a small drop in particle concentrations and a small drop in mortality rates.

So not only do we see that particles shorten life; we see that controlling particles results in a reduction in the mortality rate relatively quickly. So just as we get the global warming effects quickly, we get the mortality benefits quickly.

Now, again, this is talking about all combustion particles. What do we know about black carbon in particular? Not nearly as much, because we have only recently started to look at different kinds of combustion particles. But there was a study in the Netherlands where they estimated black carbon concentrations outside the homes of people based on models they fit using their monitoring data, and they also found that long-term exposure to black carbon was associated with a shortened life expectancy.

But what was interesting is the effect of the size that they saw. The amount of shortening was bigger per unit reduction in black carbon than what we saw per unit reduction of all combustion particles, suggesting that these particles, which in Europe and North America are predominately from diesel, are more toxic than average. Getting rid of them has more health benefits than average.

We did a study in eastern Massachusetts where we also put out 83 monitoring stations around the Boston metropolitan area measuring black carbon and developed a model to estimate the variation in black carbon concentrations over space and time, and then we got data on all the deaths in eastern Massachusetts, and we geocoded everybody's addresses. Looking at the people who died out-of-hospital, we found that, at the 75th percentile of black carbon concentration, 2.3 percent more deaths per day occurred than at the 25th percentile of black carbon concentrations.

Again, this is larger than what we see for all combustion particles when we look at these short-term effects. And in this study everyone was their own control. We looked at the black carbon outside the address of the subject the day before they died versus a week earlier when they didn't die. On average, it was higher the day before they died. That is what drove those results.

Since black carbon is expensive to measure but since it predominately comes from traffic, there have also been studies that have looked at traffic as a surrogate marker for this exposure. So we looked at all of the confirmed cases of heart attack in Worcester County over a period of a couple of years based on a heart attack registry they have, and we did a case control study with 5,000 cases and 10,000 controls. We found that, again, going from the 25th to the 75th percentile, traffic density within 100 meters of your house, increased your risk of having a heart attack by 4 percent, and at the same time controlling for that, every kilometer closer you lived to a major highway increased your risk of a heart attack by another 5 percent.

We followed people who had been admitted to the hospital for heart failure, which is a growing disease in the United States, and looked at their survival rate. We again found that doubling the traffic within 100 meters of the home increased their risk of dying in the next 5 years by 5 percent, and doubling the distance to a bus route cut the risk by 3 percent, so a significant contributor to mortality risks.

Now, that is in the United States, but, as you heard, most of the black carbon emissions are actually coming from developing countries, and what can we say about them?

First of all, heart disease is an increasing cause of death in China and in India, and so increasing risks for those matter to them, too.

Second, we did a randomized trial of people in Guatemala in the highlands retrofitting a chimney stove into their homes where they cooked without a chimney before and reducing their exposure to all of this biomass soot. What we saw in adult women in those homes was that doing that reduced their blood pressure by about 3.5 millimeters of mercury. That is half as much as you can get from giving people drugs to treat hypertension.

So, as heart disease is a growing cause of death in the developing world, there are opportunities there for them to improve the health of their subjects and reduce mortality substantially by doing things to control black carbon.

I would like to end by saying that the conundrum with carbon dioxide control is that everyone gets to benefit, even if you are the only one who pays. So we all want the other guy to pay. But you only get the benefit of the health effects of reduced exposure to black carbon if you are the one who reduces the exposure, because these things occur locally.

So China and India are the ones that are going to reap the health benefits of controlling black carbon in the future, and I think that has great prospects for helping us to convince them that it is time to act now.

Thank you.

[The prepared statement of Mr. Schwartz follows:]

Testimony for the Hearing on Black Carbon and Climate Change

House Committee on Oversight and Government Reform

United States House of Representatives

The Honorable Henry A. Waxman, Chair

October 18, 2007

Joel Schwartz

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It is my pleasure to provide this testimony on Black Carbon to the Committee on Oversight and Government Reform. As you have heard from the previous speakers, Black Carbon is modifying our climate. I want to make the related points that Black Carbon is a serious threat to health, that reductions in black carbon will produce immediate health improvements that make such interventions a double win, and that, unlike the case for CO2 emissions, most of those health benefits stay in the country that makes the reductions in emissions. This avoids the blame game, and incentive to get others to shoulder the burden of emissions reductions. Moreover, the estimated health benefits in developing countries are larger than in the developed world, although they too are substantial.

What is the evidence on health effects? I will begin with the developed world, where resources for scientific studies are greater. We have long known that particles in the air were not merely unaesthetic; they were associated with early death. Figure 1 below, taken from the London Smog episode of 1952 illustrates the association, and in this case the particles were almost entirely black smoke, from coal combustion and diesel buses[1]. A similar episode occurred in Donora, PA in 1948[2].

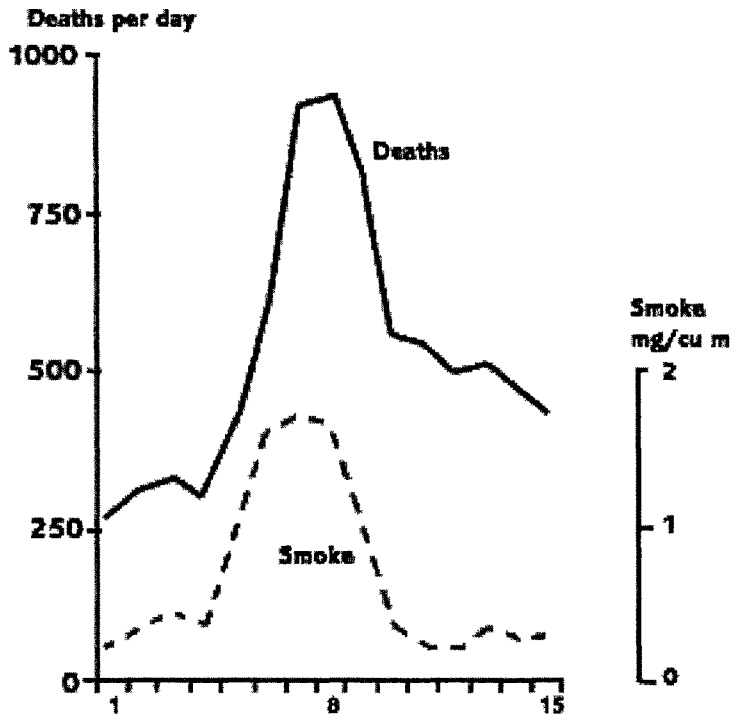


Figure 1. Daily Deaths and Black Smoke in London, Dec 1952.

In more recent times we have discovered that it is not just that daily death rates increase on days with high particle concentrations—life expectancy is lower in more polluted areas. Figure 2 shows the life expectancy in six US cities, from the Harvard Six City Study, after controlling for individual risks such as smoking, hypertension, etc, Vs the long-term average level of PM2.5

concentration in the air[3]. PM2.5—particles less than 2.5 micrometers in diameter, encompasses all combustion particles, including black carbon.

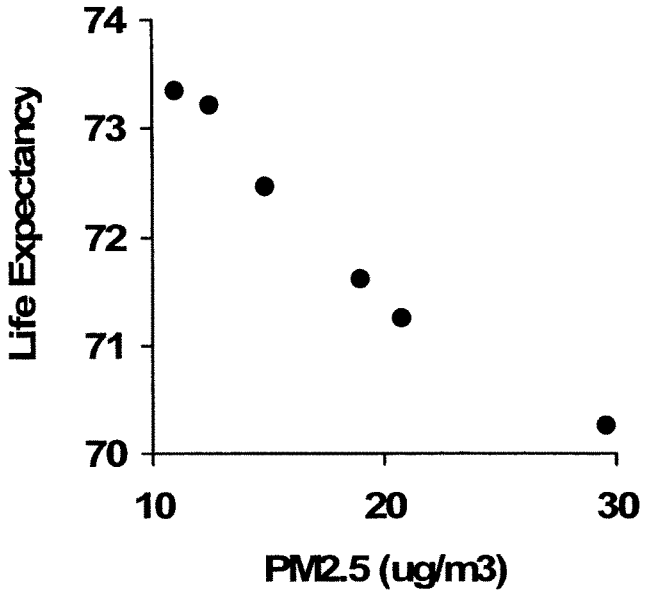


Figure 2. Survival Vs Particle Concentration in the Six City Study.

Since this result was published in 1993, it has been confirmed numerous times. Most recently, we conducted a further ten-year follow-up on the participants, a time after air pollution controls had led to reductions in particle concentrations. Figure 3, shows the results from this most recent analysis[4]. In cities where particle concentrations fell substantially, mortality

rates fell substantially, whereas in cities where there was little change in particle concentrations, the mortality rate changed little.

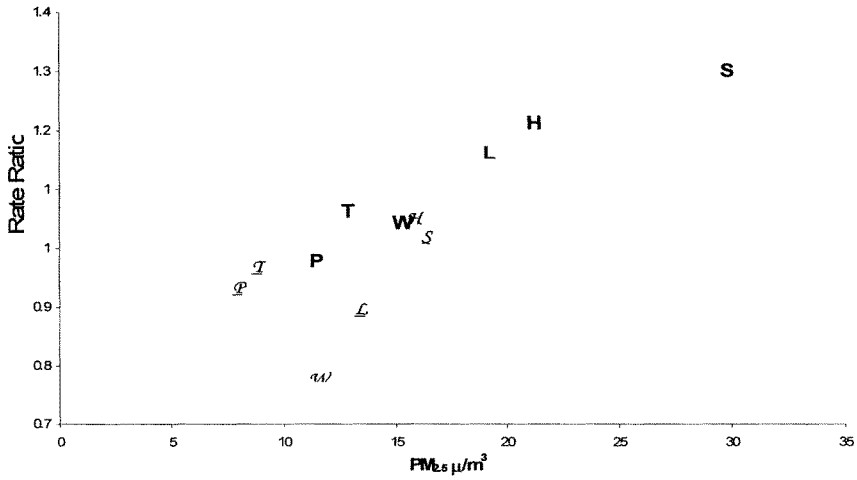


Figure 3. Change in Pollution Correlates with Change in Mortality Rate

Similarly, changes in prevalence of bronchitis, wheezing, etc have been reported following changes in particle concentrations in Germany[5] and Switzerland[6].

But these are studies of all combustion particles. What, specifically, can we say about black carbon? A recent study from the Netherlands estimated exposure to black particles at the home addresses of 5000 participants in a study similar to the Six City Study[7]. The magnitude of the mortality change

associated with these traffic particles, or with direct measures of traffic, was considerably larger than seen for PM2.5 in the Six City Study, suggesting that the effect of these diesel particles on health is greater.

We have recently published a similar study looking at the acute effects of black carbon. We used data from 84 black carbon monitors throughout the Boston Metropolitan Area to develop a model predicting concentrations at any address on any day. We geo-coded all of the deaths in Eastern Massachusetts for seven years, and estimated exposure at the home address for each person (who died outside of hospital) on the day before their death, and on a nearby day when they did not die. Thus we had a case-control study where each person stood as his or her own control. This controlled almost perfectly for smoking, hypertension, etc. We found that exposures were higher on the day of death, and that on days at the 75th percentile of BC concentrations, 2.3% more people died than on days at the 25th percentile. This was considerably larger that the acute effect of PM2.5[8].

In Worcester MA, we obtained addresses on all persons with validated heart attacks over a five year period, and on age and sex matched controls. We found that the risk of having a heart attach increased by 5% as traffic density within 100 meters of the home went from the 25th percentile to the 75th

percentile, and simultaneously increased by 5% for each kilometer closer to a major highway[9]. Traffic is the source of black particles in these urban areas. Others have reported similar results. For example, Peters and coworkers interviewed heart attack victims in the Intensive Care Unit to discover what they were doing immediately preceding the onset of symptoms, and what they were doing at the same time of day on the previous few days. They found that subjects were 2.9 times more likely to be in traffic the hour preceding their heart attack than the same hour of the day before[10]. This held true for people in public transportation, so it is not likely explained by the stress of driving.

Progress has also been made recently on understanding how these particles affect heart disease. For example, we have reported that a measure of arterial stiffness is increased following BC exposure[11], that inflammatory proteins in the blood, which are risk factors for heart attacks, are increased following BC exposure[12], and that depression of the ST segment of the electrocardiogram, and indicator of either inflammation in the heart, or its failure to obtain enough oxygen, was increased following BC exposure[13].

All of this makes it clear that decreasing black carbon concentrations in the developed world will save lives, as well as providing climate impacts. And while the US EPA's recent standards for new diesel engines, as well as the EU

upcoming standards, require over 90% reductions in emissions, there is no requirement for retrofit, despite diesel engine lifetimes that are typically 30 years. Hence there is scope for interventions. Retrofit kits are on the commercial market today. Indeed, London required all 6000 existing buses to be retrofit with particle filters in a two-year period, and their entire fleet is now low emitting vehicles.

The situation in the developing world involves even greater health risks, and hence larger potential for interventions that are too good for each country to pass up. Levels of particles in Chinese and Indian cities are much larger than in the US or Europe, as can be seen in Figure 4, and much of this is black carbon from coal or biomass burning.

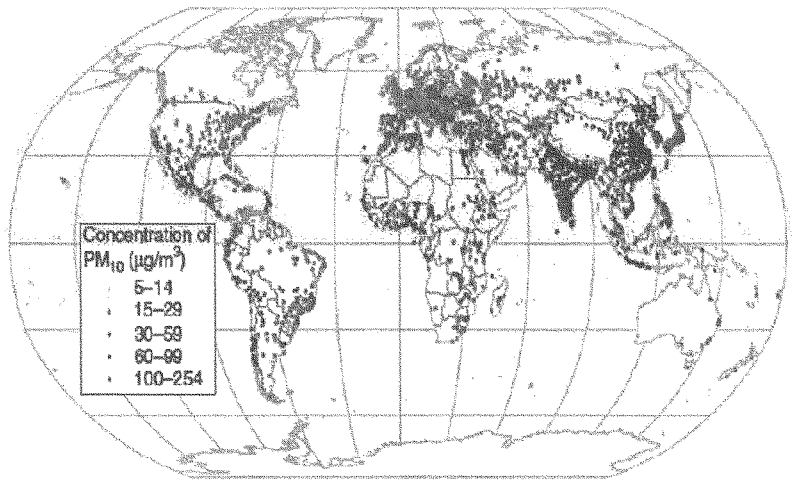
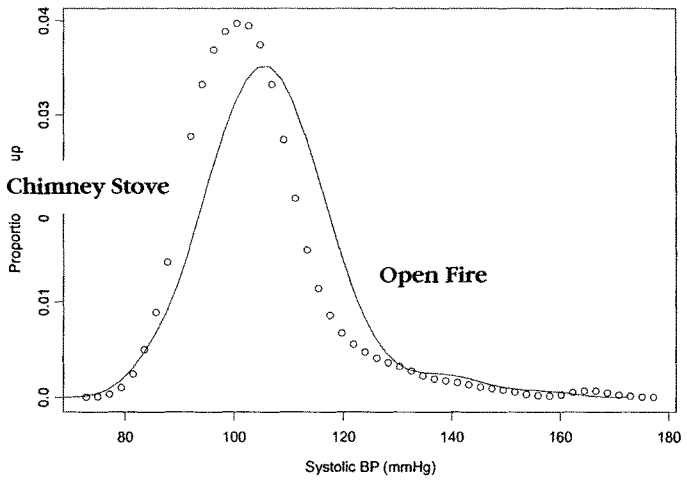


Figure 1. Estimated annual average concentrations of PM_{10} in cities with populations over 100,000 and in national capital cities. Source: (Cohen et al. 2005)

One key difference in developing countries is the level of exposure that occurs at home, due to the use of coal or biomass for cooking, often over open fires. Studies have shown that such exposure is associated with pneumonia in young children, which is the leading cause of infant mortality in most of these countries, and with chronic bronchitis in women who do the cooking. To date, little work has been done looking at the effect of this indoor exposure on heart disease. We recently collaborated with investigators at UC Berkeley on a randomized trial of an intervention giving people in the Guatemalan highlands an enclosed stove with a chimney. This significantly reduced indoor exposure, and resulted in more efficient combustion, and hence lower emissions. Figure 5, below, shows the distribution of blood pressure in the women randomized to get the stove, versus in the women who continued cooking on open fires.



The reduction in blood pressure is about half of what one obtains from the use of blood pressure medication, and suggests substantial heart disease benefits from cleaning up domestic fuel use[14].

In summary, controlling black carbon exposure, now, has immediate, substantial health benefits that more than justify the program. These benefits accrue to the countries that institute the controls, and simultaneously provide climate-related benefits. Moreover, in both developed and undeveloped countries, the technologies already exist and are available commercially, to accomplish these reductions.

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Chairman WAXMAN. Thank you very much.

I am going to start off the questions.

In 2002 the National Snow and Ice Data Center in Boulder, CO, reported that summertime melting in the Arctic was at a record level. If the Arctic sea ice continued to shrink at the same rate, they predicted that the Arctic could be ice-free in the summer of 2050.

In February of this year the Inter-Governmental Panel on Climate Change confirmed this view, projecting that it was possible that the Arctic could be ice free in summertime by the latter part of this century. Many around the world were shocked to think that we could see such a turn of events as soon as 2050, but then the summer of 2007 brought unexpected melting. Arctic sea ice plummeted to the lowest level ever recorded, shattering the previous record by nearly 25 percent. According to the National Snow and Ice Data Center, sea ice may have fallen by as much as 50 percent from the 1950's.

On October 1st the Center reported that the sea ice is in a downward spiral and may have passed the point of no return. As a years go by, we are losing more and more ice in summer and growing back less and less in winter.

The Center went on to say that the Arctic Ocean could be ice-free in summer as soon as 2030. According to some scientists, we may lose the Arctic sea ice even sooner than that.

Dr. Zender, you testified that the Arctic is warming about twice as rapidly as the rest of the Earth. Can you tell us if we need to be concerned about what is happening in the Arctic? And also how important is black carbon in what is happening in the Arctic?

Mr. ZENDER. Well, certainly the recent trends in Arctic sea ice extent are quite troubling. As you mentioned, the long-term trend until the last 1 or 2 years was about 8 percent per decade. With this year's record retreat, there is 23 percent less sea ice in the arctic than there was in 2005, the year of the previous record low.

What is troubling about these trends is that they are in agreement with model predictions that predict a steady decline followed by an abrupt tipping point, or complete disappearance of summertime Arctic sea ice.

The disappearance of summertime Arctic sea ice would be hard to imagine. It would be difficult to imagine a plausible mechanism to restore that sea ice in the future. Melting of Arctic ice surfaces is what you might call a wet process. It can occur very quickly. Ice can slide into the ocean very quickly, whereas restoration of such ice, sea ice, and glaciers is a slow, dry process that takes an order of magnitude longer to occur.

Conservative estimates which placed summertime ice-free Arctic in about the year 2040 a few years ago have reevaluated their findings. Many scientists think that an ice-free Arctic could occur much sooner, perhaps as quickly as 20 years.

I think the overall concern that is unique to the Arctic about warming is that when ice on land—not sea ice, but ice on land—melts, it contributes directly and immediately to sea level rise. Sea level rise is, of course, something that affects everyone worldwide who lives near the coast.

Chairman WAXMAN. The ice, if it melts in the water, would not contribute to the increasing ocean levels?

Mr. ZENDER. That is true; however, the ice that melts in the water does have an effect on the ocean circulation. By melting the sea ice, we then uncover the underlying ocean, which warms up. One of the critical areas in the Arctic that we are worried about is the temperature of the ocean near the Northern Hemisphere's greatest ice sheet, Greenland. Warming ice near Greenland could reduce the buttressing that the sea ice shelves have, which maintain the land glaciers that drain Greenland ice. If those buttresses disappear, then Greenland's ice balance will quickly turn more negative.

Chairman WAXMAN. Let me ask Dr. Jacobson, you testified that because of black carbon's short lifetime in the atmosphere, a reduction in its emissions can result in rapid climate benefits. If we want to forestall the warming we are seeing happen in the Arctic, is reducing black carbon part of the solution? And would we be able to achieve results as quickly by focusing solely on carbon dioxide?

Mr. JACOBSON. Yes, it is part of the solution. I think, as I mentioned in my testimony, the global contribution to global warming by black carbon from fossil fuel and biofuel sources is about 16 percent or so, and on a global scale. So theoretically, if you reduce all the black carbon worldwide from those sources, you could have a fast impact on reducing maybe proportionately not quite that number in the Arctic.

In the United States's case, U.S.'s contribution is about 6 percent, so there is less of an impact on average.

Of course, it depends on the effect of the Arctic countries that are responsible for the warming from black carbon, and it is not easy to tell, but the United States is a portion, and then there is Europe, and then there is Russia, and there is Southeast Asia and other parts of Asia that are contributing.

But we have definitely got a beneficial impact by controlling in the U.S. black carbon. It is not going to be a huge impact. You have to control the CO_2 simultaneously to ensure long-term stability of the Arctic, but you can get an immediate feedback, so there is a benefit.

Chairman WAXMAN. CO_2 control is not going to be sufficient alone?

Mr. JACOBSON. Definitely not in the short term, because, because of the long lifetime of CO_2, the warming that is occurring in the atmosphere due to CO_2, even if we eliminated all emissions today of CO_2, anthropogenic emissions, you are not going to see the feedback on the global climate system for many years to decades to come. We will see a little bit incrementally, but if you control all the CO_2 emissions today compared to all the black carbon emissions—and there is a lot more CO_2 emitted—it would take at least 10 years before CO_2 effects outpace the black carbon effects on this climate impact. So it is faster cooling if you control the black carbon compared to the CO_2; however, you want to do both simultaneously.

Chairman WAXMAN. Yes. Dr. Bond, you worked to understand the sources of black carbon. Can you tell us if we know which

sources we need to control if we want to reduce the presence of black carbon in the Arctic?

Ms. BOND. There have been studies done that suggest that about a third of the black carbon is from the United States and Europe, and about a third is from the developing world, especially in south and east Asia, and about a third is from arboreal forests. Now, these are still uncertain, but those give you the biggest contributors.

I believe that we know the sources in each of those regions. In the developed countries, as I mentioned during my testimony, a lot of it is from transportation, including both on-road and off-road mobile sources. Both the United States and Europe have taken action to reduce emissions from these sources, which means that they will be coming down in the near future, but it also means that there is experience in regulating those kinds of sources and in being successful at bringing the emissions down.

There are also measures to reduce emissions from solid fuel combustion in developing countries and, as well, from industrial combustion.

Those are the two major industrial type of sources that can be reduced. I don't think that we have a clear understanding of how to reduce black carbon from open biomass burning, especially remote forest burning. Some of those options have been looked at in terms of cost and they turn out to be extremely expensive, so I would say that the transportation and residential solid fuels would be the place to look first.

Chairman WAXMAN. Thank you.

Mr. Davis.

Mr. DAVIS OF VIRGINIA. Thank you very much, Mr. Chairman. I want to thank the panel.

Now, Europeans have really moved to diesel, haven't they, which is worse for black carbon; is that correct? And so they may be ahead of us in some ways and kind of behind. Is there any thought there of scrubbing this and moving to something else?

Mr. JACOBSON. The Europeans, about 40 to 50 percent of all the passenger vehicles sold are diesel. They emit a lot more NO_x. A diesel vehicle emits a lot more oxides of nitrogen, maybe ten times more than a gasoline vehicle. Also, without a control device, a huge amount more, a factor of 5 to 10 more particulate matter——

Mr. DAVIS OF VIRGINIA. You can see it in a diesel.

Mr. JACOBSON. Yes. And so a lot of the new cars now, they put particle traps on a lot of the new cars, but even with the particle trap, the particle trap decreases the mileage of the diesel by about 3 to 8 percent, so that means more CO_2 emissions, so there is a tradeoff. By reducing the particles, you increase the CO_2 emissions from the vehicles, but also you also change this ratio in the exhaust of the NO_2 to NO.

In the United States, what that does is NO_2 is a precursor to ozone in smog. In the United States that really produces smog right out of tailpipe. In Europe, where it is a little higher latitude, it is not so much. But in the United States we did a study looking what the effect would be, and you increase on average ozone over the United States by adding a trap to new diesel vehicles.

Mr. DAVIS OF VIRGINIA. Let me ask, I don't know who is best able to answer this, but what happens to black carbon once it has reached its life span? Does it just disappear? Does it settle on ice and continue to trap heat? Does it settle but stop conducting heat? What happens? What is the life span?

Mr. JACOBSON. Most of it is removed by precipitation and most of it will go over the ocean. Now, the stuff that settles onto snow, that will have a longer impact if it settles onto snow or sea ice because it sits there for a while until it gets buried or it sinks or is covered up by more snow, but even that more snow will have some black carbon. So most of it is removed to the oceans eventually, and a lot of it will deposit to the surface, too, in rain or in just some deposition to the surface. That stuff, because the surface is soil or blacktop or whatever it is, it is not going to have much of an impact there except maybe if it goes over sand in the desert.

Mr. DAVIS OF VIRGINIA. Dr. Ramanathan, let me ask you what percentage of the melting ice sheets in the arctic can you attribute to the black carbon? Is it hard to put a percentage on it?

Mr. RAMANATHAN. I have not by myself estimated the Arctic part. I think that is what Dr. Zender was talking about. But the key thing is in the Arctic, as I think was the point, the transport comes from all directions. Some comes from east Asia. We track these. Some comes from North America and eastern Europe, so all these sources are contributing to that.

The one issue I want to point out which has not come up is that with the sea ice retreating, there are no talks about new ships traveling through the open water, and ships are a major source for black carbon. I am concerned that now there is going to be an additional source of black carbon directly depositing and facilitating more ship traffic. That is an issue that has not come up yet and we need to worry about that, too.

Mr. DAVIS OF VIRGINIA. Let me ask Dr. Bond what respective roles should the developing and the under-developed nations play in mitigating the emissions of black carbon? What I am trying to say is, Was it a mistake not to include that in the Kyoto Protocol?

Ms. BOND. Was it a mistake? No. The Kyoto Protocol was a first step. It was never meant to be the ultimate solution.

Mr. DAVIS OF VIRGINIA. The end all. Yes.

Ms. BOND. So I am not going to comment on what we should have done in the Kyoto Protocol. What matters is what we can do now and next. I don't believe that we can reduce black carbon impacts on the global atmosphere without the cooperation of developing countries, but I think that all of this is consistent with the Framework Convention on Climate Change, which refers to differentiated responsibilities between developed and developing countries.

Mr. DAVIS OF VIRGINIA. Sure.

Mr. RAMANATHAN. I think we have to remember that close to 80 percent of the black carbon emission comes from developing nations.

Mr. DAVIS OF VIRGINIA. Right.

Mr. RAMANATHAN. Asia, Africa, Latin America. Because of the impact of the black carbon on the local and regional climate and

the glacier retreat, my own experience with India and China is there is tremendous interest in focusing on the air pollution issues.

Mr. DAVIS OF VIRGINIA. Yes. I have been to Shihon in China where people have to wear masks over their faces. That is the health issues that you addressed earlier, in addition to the global warming. But the polar caps, how much of this stuff finds its way up there? Obviously, you are talking about the steamships and planes, but is there that much other stuff up there that is generating the black carbon at the polar caps?

Mr. RAMANATHAN. I will defer to others.

Mr. ZENDER. The concentrations of black carbon in the Arctic are relatively low relative to the developing world where the sources are. The problem in the Arctic is that this black carbon has essentially a double or even triple lifetime. Because the Arctic is so very bright, as you know, the sunlight that it can absorb has two chances to be absorbed by it: on its way down, and on its way back up being reflected from the ice sheets. But then that third lifetime that I mentioned is once it lands on the surface a very, very small concentration of black carbon—we are talking parts per billion——

Mr. DAVIS OF VIRGINIA. It is just more potent there, basically? Is that what you are saying?

Mr. ZENDER. It is just more potent. It is the most potent warming agent we know of in the Arctic.

Mr. DAVIS OF VIRGINIA. OK. So it may not be significant in terms of its volume compared to other places, but it just has a more potent effect there?

Mr. ZENDER. That is right. The exposure to inhaled black carbon is very low in the Arctic; it is the atmospheric and surface effects and their consequences on climate that are of the most immediate concern, I think.

Mr. DAVIS OF VIRGINIA. Now, the sources for black carbon for the developed world are basically different from the developing world? For example, in Africa you have wood-burning stoves, we are cutting down and burning trees, and it may be diesel in Europe. Is that fair to say?

Ms. BOND. It is fair. It is a different mix. We still have fireplaces here.

Mr. DAVIS OF VIRGINIA. Right.

Ms. BOND. So it is not completely different, but for the most part this country and Europe has the benefit of access to clean household energy, but we have a lot of transport. We have a lot more transport because we have more goods. So there is a different mix, and if you——

Mr. DAVIS OF VIRGINIA. So if you fly a private plane somewhere, you are creating more black carbon, basically?

Ms. BOND. That is true.

Mr. DAVIS OF VIRGINIA. As opposed to flying coach or first class or something somewhere else, I mean, just to get into it. Yes.

If we make these technologies available to the developing world, are they available now and just not economic? I mean, what is the issue? I know in China we talked about Shihon. In Beijing we were there and didn't see the sky for 3 days, the smog was so bad. I mean, you would think over there if you make these technologies

available somebody would do something about it. What is the problem?

Mr. RAMANATHAN. I can comment on rural regions of India.

Mr. DAVIS OF VIRGINIA. OK. India is fine.

Mr. RAMANATHAN. Major source of biofuel. The government has connections to gas, natural gas, for cooking, but they can't afford it, so it is in some parts technology and others just sheer affordability of it.

Mr. DAVIS OF VIRGINIA. When you said that you meant natural gas or propane. Propane in the Third World is the preferable choice if available.

Mr. RAMANATHAN. This is methane, not propane.

Mr. DAVIS OF VIRGINIA. Thank you, Mr. Chairman.

Chairman WAXMAN. Thank you, Mr. Davis.

Mr. Cummings.

Mr. CUMMINGS. Thank you very much, Mr. Chairman.

Each of the witnesses today have emphasized that there are opportunities for mitigating emissions of black carbon. It seems that if we could reduce emissions of black carbon we could potentially realize significant climate benefits.

Dr. Jacobson, what is your advice to us as we begin to explore controls of black carbon emissions?

Mr. JACOBSON. Sir, there is the direct way of reducing emissions, which is adding particle traps to vehicles. In the United States, it is the off-road vehicles that are creating the most emissions, the construction machines.

Mr. CUMMINGS. The adding particle traps, is that a very expensive venture?

Mr. JACOBSON. I don't know the exact cost. The number I heard per tractor was $3,000, maybe to $5,000 or $6,000 if it is a big tractor, but that was a few years ago. I don't know. Tami might now.

Mr. SCHWARTZ. You know, for a bus or for a typical sized piece of construction equipment it is a couple of thousand dollars to add these things, but then they last for a long time. That is a capital cost.

Mr. CUMMINGS. When you say cost, you mean perhaps the life of the bus or the tractor?

Mr. SCHWARTZ. Yes. Or at least a good fraction of the life. The thing is that the new rules the U.S. EPA put out and the new Euro Five standards for diesel engines are only for new diesel engines. There is no retrofit requirement. That is where the opportunity is. There is an opportunity to retrofit it on existing engines, because diesel engines often last for 30 years.

Mr. CUMMINGS. Yes.

Mr. SCHWARTZ. That has been done. In London they retrofitted all 6,000 London buses with particle traps in 2 years. In Massachusetts they are going to retrofit all the municipal and school buses in a 3-year period. There are retrofit kits commercially for sale, and it is definitely a doable thing.

Mr. JACOBSON. But let me caution. That is an immediate step, but there are these unintended consequences, like the lower mileage, and therefore the higher CO_2 emissions resulting from those traps, and also the change in the NO_2 to NO ratio, which affects the ozone. This is particularly important for these big vehicles, the

trucks especially that are replaced with traps. There you get the highest ratio of NO_2 to NO, which would exacerbate the smog the most.

But I think even a better maybe—I don't know if it is a short- or long-term—solution is really if you want to control both the soot and the CO_2 simultaneously and the other air pollutants coming from these vehicles, it is really to switch your vehicle types to electric, plug-in hybrids, hydrogen fuel cell vehicles, because these all can eliminate simultaneously your CO_2, your black carbon, your ozone precursors, and the ozone and the particulates are the ones that cause most of the health problems, particulates even more.

So you can really solve the whole problem by really focusing on these different types of vehicles rather than trying to incrementally improve just the emissions of the black carbon or reduce the black carbon.

Mr. CUMMINGS. Dr. Schwartz, you look like you are trying to jump out your seat. Did you want to say something?

Mr. SCHWARTZ. Well, I agree that in the long term that is the way to go, but I need to point out that there are retrofit kits, particle traps and particle filters, that can be put on vehicles tomorrow, and that hydrogen fuel cell-powered or all-electric garbage trucks aren't going to be here for quite a while, and so there is an opportunity to have a staged strategy where we do something for the existing fleet with the commercially available technology that can be implemented in a couple of years, while developing the new vehicles that replace those vehicles when they come to the end of their lifetime.

Mr. CUMMINGS. OK.

Dr. Ramanathan, you have studied emissions in Asia. What can you tell us about the mitigation opportunities there?

Mr. RAMANATHAN. It is my personal view there are huge opportunities in terms of trying to mitigate the global warming potential. When you talk about Arctic, all these discussions are germane, but when you want to reduce the global warming, potential black carbon——

Mr. CUMMINGS. Can you keep your voice up?

Mr. RAMANATHAN. When you want to reduce the global warming potential of black carbon, your focus has to be on Asia and Africa and Latin America, because that is where the main sources are.

Although not an economist, I would venture to speculate it would be a lot cheaper to try to mitigate black carbon emission in Asia, particularly India and China in the major focus. For example, the biofuel emissions, cooking with wood and cow dung is at least 50 percent of the total emission of black carbon from south Asia. Replacing those cookers with solar cookers or biogas plans, the relative cost we have to estimate. That is what we are trying to do. But I think that is where the huge potential is there, the emission of black carbon, coal-fired appliance in China and biofuels in India and Africa.

This is a major vulnerable region. I wish I brought substance abuse. You will see huge plumes covering most of central Africa from the savannah burning. That is where I see major opportunities.

Mr. CUMMINGS. Thank you.

Chairman WAXMAN. Thank you, Mr. Cummings.

Mr. Bilbray.

Mr. BILBRAY. Thank you, Mr. Chairman.

Dr. Schwartz, I have been sort of out of the business, the air resources business, for a while, so if you can give me a crash refresher course, when you were talking about the morbidity related to diesel emissions, referring specifically to the particulates, I didn't hear you discuss what we ran into at the Air Resources Board in California, which was that the true toxic component was the benzene, and that the particulate was tending to be the carrying agent. Is the benzene still considered the most toxic component in the diesel emission?

Mr. SCHWARTZ. Well, there is actually more benzene in the exhaust from gasoline vehicles than from diesel vehicles, because aromatics tend to have too much octane, and you don't want octane in a diesel engine, unlike in a gasoline engine, and so you tend in a refinery to segregate the aromatics more to the gasoline. But there is certainly benzene in diesel exhaust, and if you are talking about cancer, then that is where the action is for sure.

But these deaths that we are looking at are deaths from heart disease, and that doesn't seem to be related to the benzene. It seems to be related to something about——

Mr. BILBRAY. So yours was specifically to cardiovascular?

Mr. SCHWARTZ. To cardiovascular mortality, and that really seems to be the particles.

Now, that said, it may well be that it is something that is carried by these particles other than benzene, like metals or some other things.

Mr. BILBRAY. We found that. I mean, all the talking back in the 1970's was about dioxins. We found that the benzene in the diesel trucks was like a magnitude of 10 to 20 over the toxicity of certain dioxins and whatever, and so all at once we were realizing that to reduce health exposure we weren't doing waste incineration. We were sending around three trucks to recycle materials, and the health impacts were a net negative rather than a net positive.

When you did your modeling for morbidity, did you consider socio-economic numbers?

Mr. SCHWARTZ. Yes, we controlled for socio-economics.

Mr. BILBRAY. I mean, let's face it, the whole difference in places like Pittsburgh in 20 years going from a coal/steel industry to a high-tech industry, you do have a major jump between socio-economic, and that——

Mr. SCHWARTZ. And when you are talking about exposure to traffic, you have to remember the people who live on heavily trafficked streets tend to be poorer than the people who live in the nice houses.

Mr. BILBRAY. And people who are poor tend to have certain exposures.

Mr. SCHWARTZ. Absolutely. So, for example, in our study we had individual education for each of the people who died, and then we had census block group measures of socio-economic status we also controlled for.

Mr. BILBRAY. Yes. The scrubber issue when I was working with Mexico on Mexico City and we worked with Athens reducing their

emissions, they went through the scrubber originally, but the natural gas conversion seemed to be the much cleaner quantum leap sort of between where Mr. Jacobson is and where you are with the scrubber of being able to use natural gas as the major source but only using diesel as the igniter. Is there an environmental problem with shifting off actually from being your major source of fuel for these mobile sources from diesel over to natural gas?

Mr. SCHWARTZ. To my knowledge there isn't an environmental problem. Running buses on natural gas produces considerably less particles than running buses on diesel with a particle trap, so the natural gas conversion certainly would make sense. It makes more economic sense on fleets of vehicles that operate around the city and then come back to a terminal every day, either buses or trucks and things where they can fill up with the natural gas, than on the long-haul trucks where it is not always easy to find a source of fuel.

Mr. BILBRAY. Where infrastructure is there.

Mr. SCHWARTZ. Where the infrastructure is easy to put in. Exactly.

Mr. BILBRAY. I appreciate that.

Dr. Jacobson, the discussion of the transition in California, we were looking at the zero emission generators. California, we went to natural gas with our stationary sources because it was the only way to pencil out a lot of this generation within our air basins. The question is: the low-lying fruit is going to be—correct me if I am wrong—has always been stationary sources are always the place we can get the most bang for the buck. I mean, if there was any place historically we have been able to reduce substantially emissions with much more cost-effectiveness, stationary sources have been that, hasn't it?

Mr. JACOBSON. Well, yes. Historically in California most of the electricity is natural gas. We don't have much coal. We have a lot of hydroelectric.

Mr. BILBRAY. Let me correct you, sir. You burn coal in California air basins, you go to prison.

Mr. JACOBSON. Right. Yes. There is very little coal.

Mr. BILBRAY. Our concept is clean coal is about as logical as safe cigarettes.

Mr. JACOBSON. Right. But there is emissions from natural gas, but in California there is room for more renewable energy, of course. That may not be in the question, but we did mapping of winds offshore locations where you get really strong winds, and you can combine wind with hydroelectric, geothermal, and solar and you can power the entire State just about with the available resources.

Mr. BILBRAY. I just want to warn you, we got that issue, and transmission becomes a hot issue.

Mr. JACOBSON. That is the limiting factor, and that is actually why you kind of need maybe a national grid.

Mr. BILBRAY. But I agree with you. I think the big thing that California is going to have to confront is stop using natural gas as your stationary source because it will probably be our transition fuel between what you are talking about and what you are talking about, and we are burning it at power plants rather than using it

for our off-road, which is now the big challenge, as Mr. Waxman knows, in California, cracking down on those off-road emissions.

Thank you very much, Mr. Chairman.

Chairman WAXMAN. Thank you, Mr. Bilbray.

Ms. McCollum.

Ms. MCCOLLUM. Thank you, Mr. Chair.

This is a very interesting discussion, and I want to thank Mr. Waxman for having it.

Dr. Schwartz, I was feeling pretty good about turning off the air conditioner, leaving the windows open on a main street in D.C. where I hear a lot of trucks, and I know I have a lot of soot because I have to clean here more than I have to clean in the city of St. Paul, MN, so my trying to save burning fossil fuels running an air conditioner might lead to my increased risk of a heart attack, so thank you very much for not making me feel much better about my decision.

Mr. SCHWARTZ. Unfortunately, turning on the air conditioner and closing your windows cuts the particle concentrations coming into your house from outside in half.

Ms. MCCOLLUM. And I point that out because this isn't a one-fix solution; this is going to take a lot of different scientists such as yourself sitting around the table and a lot of different people willing to look at different ways and to change their lifestyle, and businesses in the way that they operate in order to really tackle this. This is, like I said, a very interesting discussion, and I thank the Chair for having it.

In Minnesota we decided to retrofit our school buses—we are calling it Project Green Fleet—to do what we could to reduce the amount of carbon. Has there been any studies done, for example, if all the school districts were to retrofit, what kind of impact it could have? Would that be a model that we could look at to maybe figure out some targeted ways where we could start doing things and also get the word out?

Mr. SCHWARTZ. I don't know of any studies that have looked at what the impact of just targeting school bus fleets are. I think that it is such a small fraction of the diesel fuel use in a given city that you are not going to see very much if you just go after the school buses as opposed to the construction equipment and the heavy duty trucks and all the other things, as well.

Ms. MCCOLLUM. But sometimes the way to address the problem is to get people to realize that there is a problem and to start talking about it.

Mr. SCHWARTZ. That is absolutely true, and there have been retrofit programs, and EPA funds some retrofit programs to go after school buses. One thing that we can do that is a double winner is all the buses you see lined up on Independence Avenue idling for 3 hours while the people that they drove to the museum are inside, if you just turn off the engines of buses when you are not actually driving some place then you save the CO_2 and the carbon and all sorts of other stuff. So awareness would be useful.

Ms. MCCOLLUM. We have done that, as well, in Minnesota, to turn the buses off.

Mr. SCHWARTZ. That is good.

Ms. MCCOLLUM. The developing world discussion is very interesting. I have had a fortune of traveling both in Asia and in Africa. It seems to me that we need to look at doing something similar to what we did with ozone with the Montreal Protocol on this.

Dr. Ramanathan, you have done a fabulous amount of work on this. Can you share with this committee—I also serve on State and Foreign Operations Appropriations—what we can do in working with partner countries to help them reduce their health effects and carbon?

Mr. RAMANATHAN. Thank you very much for that question.

I first of all would preface it, there is one thing we have to be aware of. This outdoor haze or this pollution contains partially black carbon, other particles, sulfates, nitrates, etc. These are all cooling particles. The black carbon is heating. When you add all of them together, they have massed as much as 50 of the global warming from greenhouse gases. What that means is that we have to be careful when we reduce those particulates.

See, the EPA, not only in the United States, but the EPAs of the world, they are focusing on air pollution. Traditionally when there is air pollution, it is sulfates. For example, I see in American media we complain about sulfate emissions from China. The problem is if you cut the sulfates and leave the black carbon behind, we can have at least a factor of two amplification in the warming what we will see just from air pollution regulations, because you are taking off the cooling particles.

So we have to make sure. I am not saying we should leave the sulfates behind. They have other ecosystem destruction. But we should make sure when we remove the sulfates we also remove the black carbon. That is No. 1 point.

In fact, Dr. Schwartz and I were in a big intercontinental air pollution meeting in Australia. We tried to bring it up. We tried to educate the air pollution community. Be careful. What you do has implications for climate change.

The second point I want to make is that again I don't want to be misunderstood. We have to cut down sulfate emissions because of acid rain and others, but please let's take out the black carbon at the same time because the sulfates, if any, is shielding the planet from the global warming.

The second is the black carbon emission. I was in a meeting last week where the Prime Minister was there, the finance minister, as well as Mr. Jeb Bush, former Governor of Florida. I was surprised how receptive they were when I talked about what the black carbon, haze, is doing to the regional climate and glaciers. As you know, China is now trying to reduce the emissions in Beijing just before the Olympic, and some of us are thinking this is a fantastic natural experiment to see downwind what happens.

For example, we published a study last year: 75 percent of the black carbon over the west coast of the United States during springtime comes from long-range transport from east Asia. So we are trying to see do we see an impact on air pollution just for this 1-month period.

Although I have not moved in government circles, my assumption is that they would be very receptive to United States and European governments trying to approach India and China on this

issue and see how collaborations and resource sharing would help them bring down the black carbon emission.

Chairman WAXMAN. Dr. Bond, did you want to comment?

Ms. BOND. I did, if you would allow me to.

Chairman WAXMAN. Sure.

Ms. BOND. I would like to point out that there is already collaboration between governments. At the Sustainable Development Meeting in Johannesburg, the United States and other countries initiated the Partnership for Clean Indoor Air. Now, this was not a climate or outdoor air protection committee; it was a group of organizations that now numbers about 150 NGO's and government organizations internationally, and they are working on the problem of household energy and solid fuels. That is something that has already been started.

Now, the climate benefits have not really been brought into that picture, but they are very receptive.

Chairman WAXMAN. Thank you, Ms. McCollum.

Mr. Shays.

Mr. SHAYS. Thank you. Mr. Chairman, really thank you so much for holding this hearing. It is rare when we have all doctors coming before us, so when I say "doctor" I will now have to use a name.

I would first like to ask Dr. Bond if you would turn to page 4. I am trying to understand where liquified LNG plants—there is a real effort to bring LNG into the United States, and it is somewhat controversial, particularly on Long Island Sound, and I have taken a position against it and others have, but I begin to wonder. We are at the end of the pipeline. Am I just making a bad decision here or not?

Liquified natural gas, just explain this middle chart to me, page 4. "Energy increases faster than BC due to advances in technology."

First you describe different types—biofuel, coal, oil, Middle East, light, distilled, aviation fuel, natural gas.

Ms. BOND. OK. Let me understand what you are trying to——

Mr. SHAYS. First explain this chart to me.

Ms. BOND. That chart is the global consumption of energy by fuel.

Mr. SHAYS. OK.

Ms. BOND. In history.

Mr. SHAYS. Now explain to me, in terms of black carbon, is liquified natural gas a less sooty, more sooty, indifferent?

Ms. BOND. Much less.

Mr. SHAYS. Much less.

Ms. BOND. Certainly. And the point of that figure was that it is both improved technology and cleaner fuels that have contributed to black carbon. This slower increase in black carbon emissions, if black carbon emissions went up as quickly as energy did over the last 50 years, we would not be able to breathe.

Mr. SHAYS. OK. Let me ask you this. In my house I have gas coming in. I now have a heating system that they don't want it to exhaust up through the chimney; they put it through the side of the house. Could they do that with oil as well, or is it more likely they can do it with gas?

Ms. BOND. Gas burns a lot cleaner than oil.

Mr. SHAYS. Right.

Ms. BOND. Especially during the transient periods where the furnace is turning on and off.

Mr. SHAYS. Thank you very much.

Dr. Ramanathan, would you explain to me the charges on eight? It looks like the United States is not that bad a player compared to others in the charts, these charts up top here. I am on page 8.

Mr. RAMANATHAN. Yes.

Mr. SHAYS. Explain those charts to me, if you would.

Mr. RAMANATHAN. Right. This is basically using most recent satellite measurements which give information about particulates, and look at the total loading of particulates in the atmosphere.

Mr. SHAYS. And red would be the worst case?

Mr. RAMANATHAN. Red is worse. By the time you have seen those charts green to yellow, you would already see the haze in the sky as brown clouds.

Mr. SHAYS. So is that the soot blowing off our coast?

Mr. RAMANATHAN. Thank you. What you see of the east coast, this is just not only soot, it is all particulates—sulfates, nitrates. That is why we call them brown cloud.

Mr. SHAYS. All particulates. But basically it is in the air blowing from the United States?

Mr. RAMANATHAN. Right. And you see that stream is all the coal plants in the east coast just going across the Atlantic.

Mr. SHAYS. OK. And then in China and in India we just see a mass of red.

Mr. RAMANATHAN. Exactly.

Mr. SHAYS. And it is all coal?

Mr. RAMANATHAN. And also I direct your attention to Africa, the savannah burning.

Mr. SHAYS. Yes. Now, this is not in defense of the administration, but it is wanting to understand something. They are doing a lot of bilateral agreements with various countries. The United States was told be part of Kyoto, in spite of the fact that China and India were not. They were told, you know, just be part of the family. If you can't meet it, at least you are part of the team.

But my understanding is the United States has done, in comparison to Europe, not as bad as people would think. That is kind of a negative way to say it, but actually we keep making some improvement. Is Europe making a lot more improvement versus the United States in global warming issues and particulates? Any of you can answer that, if that is all right.

Mr. RAMANATHAN. I think as far as the particulates are concerned, Europe versus the United States, I have the expert here. I would rather let Dr. Tami Bond respond to that.

Ms. BOND. Are you talking about all global warming emissions?

Mr. SHAYS. Yes. Let's do that first.

Ms. BOND. I am not sure I have the background to answer that, because I haven't really looked at energy intensity in Europe or the United States.

Mr. SHAYS. Dr. Jacobson.

Mr. JACOBSON. I will try. I think, in terms of air pollution, the United States has really been in the forefront, especially California. I mean, California is really the leader in the world.

Mr. SHAYS. Mr. Waxman's State?

Mr. JACOBSON. Yes.

Mr. SHAYS. OK.

Mr. JACOBSON. Yes, in terms of air pollution control.

Chairman WAXMAN. As opposed to any other California.

Mr. JACOBSON. I am not biased.

Mr. SCHWARTZ. If I could add to that, if you look at the particle concentrations in urban areas, they are lower in the United States than they are in Europe. Part of that is because of their emphasis on diesel engines, in fact, but not entirely. We have stricter standards on particle emissions in the United States than Europe.

Mr. SHAYS. Can I ask one last question, Mr. Chairman?

Chairman WAXMAN. Sure.

Mr. SHAYS. I live in an urban area. We have Indonesian ships that come out way off coast. They transport the coal on the barge and bring it in to a facility three-quarters of a mile from my house, maybe a mile from my house. Should I prefer that they burn—I think I know the answer—the so-called less-sulfur coal, or liquified natural gas?

Mr. SCHWARTZ. You are going to get less CO_2 emission per unit of electricity generated and less particulate and sulfate emissions per unit of electricity generated burning liquified natural gas than burning coal, even low-sulfur coal.

Mr. SHAYS. Thank you.

Mr. JACOBSON. Can I comment on that? In Long Island there was a proposed wind farm offshore, and that would obviously be better than the other two.

Mr. SHAYS. Absolutely. Absolutely, but are they mutually exclusive? That is the question we have to ask.

Mr. JACOBSON. Yes.

Mr. SHAYS. Yes. Thank you very much. Thank you again, Mr. Chairman.

Chairman WAXMAN. Thank you, Mr. Shays.

Mr. Hodes.

Mr. HODES. Thank you, Mr. Chairman. Thank you for having this very important panel. I want to thank the panel for being here today.

I want to focus first on black carbon international agreements. There has been some mention here, but as I understand it black carbon is not explicitly covered by international environmental agreements. Now, black carbon doesn't deplete the ozone layer, so it isn't covered by the Montreal Protocol. And black carbon isn't technically a greenhouse gas, so it is not covered by the United Nations Framework Convention on Climate Change. And the Kyoto Protocol requires the developed world to reduce its emissions of certain greenhouse gases, but the protocol doesn't include black carbon.

Given the depth of the problem which you have now graphically outlined for us, as we engage in new negotiations aiming toward the possibility of future international agreements that will succeed the Kyoto Protocol, should we be seeking to include black carbon in the agreement or agreements that hopefully we will participate in? I can start with Dr. Jacobson, and then anybody else on the panel. I would be interested in hearing your thoughts.

Mr. JACOBSON. I definitely think we should. Even though the United States' portion of the black carbon emissions is on the order of 6 percent—not the largest—it is a good example to set for the rest of the world. I strongly feel we should include it, because we know it is a warming agent, and, as you mentioned, it is not being controlled internationally, so it will have dual benefits of health and climate, and I think it should be controlled.

Mr. HODES. Dr. Bond.

Ms. BOND. First of all, I agree with Dr. Jacobson, not just because we want to control all the warming agents, but I think we really want to look at what we are doing when we undertake specific actions. And, as Dr. Jacobson has shown, you can decrease carbon dioxide and increase warming if you don't consider the black carbon. So I think we should at least be comprehensive.

Second, I don't agree that black carbon is not in the Framework Convention. I would say it is not part of the objective, which refers to stabilization of greenhouse gases. We don't really want to stabilize black carbon anyway. However, the Framework Convention does say that we should be comprehensive and that we should consider all sources, and sources include aerosols in their definition. So I don't think that what we are talking about is inconsistent, and I do think that future agreements could be conducted under that convention.

Mr. HODES. Could I just clarify for one moment? I appreciate the clarification, but it sounds like we need to be more specific about including black carbon as one of those sources which is of concern and not leave it perhaps to the generalized framework that you referred to. Do you agree?

Ms. BOND. I would agree with that. At the time the Framework Convention was written, this issue was not anywhere on the radar screen.

Mr. HODES. Great. Thank you.

Mr. RAMANATHAN. I participated in the Intergovernmental Panel on Climate Change. In addition, I run a United Nations environmental program called Atmospheric Brown Clouds focused on Asia. We have all the nations participating in this research, and I can give you a flavor of what Asians think about. We have Chinese. We have Indians. We have Koreans. We have Japanese.

I think my feeling is pushing the black carbon issue at the same level as the carbon dioxide in the international agreements may be premature for this one small reason: the first definitive study of the CO_2 effects on climate was published 40 years ago. It took us hundreds if not thousands of studies before we came to the state where there was some general consensus. I don't have to remind you scientists rarely agree on anything. When you get five of us together in a room, you get conflicting opinions.

Compared to that, the black carbon issue is in its infancy. For example, the study you heard by Professor Zender, my own study, and Jacobson's study, they are all less than 10 years old, and science is confirmed by repeatability, many trying to repeat our results.

There is still a wide uncertainty, so when we take the black carbon issue to the table the ones who are opposed to that could take the lowest estimate, which say it is not that important.

It has not been properly vetted through the IPCC process. My feeling is there could be more success than this by bilateral working within United States, Europe, India, and China, and try to make progress on that because Dr. Schwartz' research shows us there are health problems and my research shows it has regional problems, things like glacier melting and rainfall. So I think it may be easier to push it on the regional impacts issue than on the global issue.

Mr. HODES. I appreciate the difficulty of reaching agreement on those issues. It sounds a lot like working in Congress. We often disagree.

It sounds like you are addressing really the strategic implications of how we deal with the issue, but is it fair to say that, at least in your mind and that of the other panelists, there is no disagreement about the importance of dealing with black carbon?

Mr. RAMANATHAN. Yes, I agree with you. I agree with the opinions which were raised here. I am more thinking about the scientific uncertainty being larger so it poses strategic difficulties.

Mr. HODES. Thank you. I appreciate that.

Mr. Chairman, may I just give the other panelists a brief opportunity to finish the question?

Dr. Zender.

Mr. ZENDER. Thank you for the opportunity.

I agree with the panelists who summarized some of the conditions that led to the Framework Convention being oriented toward the mitigation of greenhouse gases, which, after all, were at the time known to be the primary cause of global warming. Since that period perhaps we have gained enough wisdom and knowledge through the scientific process to understand that not all the agents forcing the climate system cause an equal response in terms of climate, precipitation, and temperature per unit forcing.

If there were one thing that I could recommend be done differently in the next round of treaties, it would be to consider the response of the climate system, to look at the temperature effects of each forcing agent by sector and by time scale.

To reiterate, one of the conclusions I think that the panel has shared is that black carbon presents a unique opportunity because it can offset or mitigate warming on a very quick time scale, giving us an additional decade or perhaps two to struggle with the more complex emissions such as carbon dioxide that our infrastructure depends on to such a critical degree.

Mr. HODES. Thank you.

Dr. Schwartz.

Mr. SCHWARTZ. Thank you very much for the opportunity.

I agree with basically what has been said. I think that we are relatively much more uncertain about black carbon than about CO_2 in terms of climate change and stuff, but I think the existence of very substantial health benefits means we can afford to make that investment. It is justified on the health, alone, and so we can live with that uncertainty and incorporate it into one of the strategies going forward.

Mr. HODES. I thank you all very much.

Mr. Chairman, thank you for the additional time.

Chairman WAXMAN. Thank you, Mr. Hodes, for your questions.

Let me ask a few more questions, if I might.

Dr. Zender, if we look at the Arctic where we can see the dramatic level of destruction that is taking place in a timeframe that no one imagined, and we try to attribute how much of that warming is due to the black carbon, can you give us any estimate? Is that possible?

Mr. ZENDER. I think it is possible based on the results of our best understanding, which come from these general circulation or climate models which incorporate, as closely as they can, all processes known to contribute to the problem in the Arctic. My best guess is that up to 30 percent of the warming in the Arctic since pre-industrial can be attributed to manmade black carbon injections into the Arctic. This is an uncertain number and certainly greenhouse gases are playing the dominant role, especially CO_2.

What is interesting at the Arctic and why it is changing so rapidly is that it is more susceptible, more vulnerable to a tipping point situation because you have the ice that, once it melts, uncovers these dark surfaces.

So the current data showing record sea ice retreat, showing acceleration of glacial outpouring into the oceans around southern Greenland and around the west Antarctic ice sheet, are all indicators that you would expect to see from these same models that give us these estimates; that the models are doing something right there. They have a degree of skill there.

So my best estimate would be that sitting on top of a dominant greenhouse gas contribution is the role of short-lived pollutants, not only including black carbon in the Arctic, but also ozone and methane. Some of those are clearly causing quit a bit of warming in the Arctic.

Chairman WAXMAN. We hear a lot about tipping points with regard to global warming. You are talking about the tipping point in the Arctic, which is quite sobering, but we have heard from some researchers that tell us that if we don't deal with carbon emissions overall we are going to have a tipping point so that when we start dealing with it seriously the time lag before we see the benefits may be too late to stop irreversible damage.

Do any of you want to comment on that? Dr. Jacobson.

Mr. JACOBSON. Sir, I guess the three major tipping points are one, with regard to the coral reefs, like if we raise the temperatures another one degree celsius you might bleach the corals, and that would cause a lot of irreversible damage to fisheries, for example.

And then the second is the sea level rise due to, just as we are talking, if you melt all this Arctic ice, and in particular if you go down to the Antarctic and the west Antarctic ice sheet goes, then you are going to raise the sea level significantly. But in the case of the Arctic, because of the positive feedback, once you melt that ice you are warming the surface more, and make it harder to cool down.

This is a serious problem with the Arctic. Once you have melted that ice, you have all your sunlight warming the surface, so I am really concerned about that.

But I also want to point out that black carbon has a bigger effect on the Arctic than it does kind of on the rest of the world per unit

meter or some kind of unit like that, but so does CO_2. CO_2 actually also has a larger effect on the Arctic and over snow and sea ice compared to over land surfaces. You can see that just in numerical simulations over Russia and over the Arctic and over even in other places where there is snow. So I am concerned about the tipping point, but also I think you really need to control the CO_2 and the black carbon simultaneously, because both of them have super linear effects over snowy or highly reflective surfaces.

Chairman WAXMAN. So as we look at this global warming problem, if we deal with the black carbon we will get a more immediate benefit, maybe delay the tipping point that we are fearful about, and give us some additional time to avoid some of the irreversible damage to the planet that has been predicted?

Mr. JACOBSON. Yes. It would give additional time, but I guess I wouldn't want that to be translated into, OK, then we don't have to control the CO_2.

Chairman WAXMAN. Right.

Mr. JACOBSON. Which is the concern. It really needs to be done simultaneously I think with CO_2 controls. It is not really an either/or.

Chairman WAXMAN. OK. Thank you.

Mr. Davis, did you have any other questions?

Mr. DAVIS OF VIRGINIA. No. I just want to thank the panel for helping to illuminate us on this situation, and I hope that we can respond accordingly.

Thank you, Mr. Chairman.

Chairman WAXMAN. Thank you.

Ms. Norton, did you want to ask some questions?

Ms. NORTON. No questions.

Chairman WAXMAN. No questions. OK.

This has been a terrific education for us and we hope to share this hearing record with the rest of our colleagues in the Congress and others who are looking at the whole question of how do we come to terms with the global warming problems. I think you make a compelling case that we need to look at controlling black carbon as part of that solution.

I want to do some housekeeping.

I want to ask unanimous consent that all members of this committee will have an opportunity to enter an opening statement in the record if they wish to.

Second, I would like to be able to give the opportunity to Members to submit questions in writing to the panel and have you respond in writing to them if you would.

I thank you so much. I think you have done an excellent job, and I think this is an important hearing for the debate that we are continuing to have in the Congress of the United States. Thank you.

That concludes our business and the committee stands adjourned.

[Whereupon, at 11:50 a.m., the committee was adjourned.]

[The prepared statement of Hon. Diane E. Watson follows:]

Opening Statement
Congresswoman Diane E. Watson
Oversight & Government Reform
Hearing: "Black Carbon & Global Warming"
Thursday, October 18, 2007

Thank you Mr. Chairman for holding today's very important hearing that will explain the relationship between black carbon and global warming. According to the Intergovernmental Panel on Climate Change (IPCC), black carbon is one the most important climate warming pollutants after carbon dioxide. Although black carbon can be traced to rising global temperatures, it may also pose a serious health risk to children in Los Angeles.

Black carbon can be emitted by poorly constructed coal power plants. There are over one thousand coal plants that can be found in China. This is a concern to

me because in an Associated Press article titled, "China pollution Reaches American Skies," it states that the U.S. Environmental Protection Agency estimates that on certain days nearly 25 percent of the particulate matter in the skies above Los Angeles can be traced to China. Some experts believe that one day China could account for nearly a third of all California's air pollution. This is very troubling to me considering that black carbon is well known to pose public health concerns.

In Los Angeles, the National Institute for Environmental Health Service sponsors the Children's Health Centers that study the affects of the environment on children's respiratory systems. The Center's research has determined that ambient air pollutants are

more detrimental to children's health than previously thought.

As this committee looks for solutions to reducing emissions that cause global warming, we cannot overlook the fact that there is a global health risk associated with the problem. It is in the interest of our nation that we act before global warming becomes an irreversible crisis and causes catastrophe around the world.

I look forward to hearing the panel's testimony, especially regarding Asian pollution and the regional impacts of black carbon. Mr. Chairman, thank you and yield back the remainder of my time.

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