**STANFORD UNIVERSITY**
**Atmosphere/Energy Program**

Department of Civil & Environmental Engineering
Terman Engineering Center, M-31
Stanford, California 94305-4020

**MARK Z. JACOBSON**
Professor of Civil & Environmental Engineering
and, by courtesy, Energy Resources Engineering

Telephone: 650-723-6836
Fax: 650-725-9720
Email: jacobson@stanford.edu
www.stanford.edu/group/efmh/jacobson

Testimony for the Hearing on Black Carbon and Global Warming
House Committee on Oversight and Government Reform
United States House of Representatives
The Honorable Henry A. Waxman, Chair
The Honorable Tom Davis, Ranking Minority Member
October 18, 2007

By Mark Z. Jacobson

I would like to thank Chairman Waxman, Congressman 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.

## Summary

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 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 United States' soot contribution to global warming may exceed each its methane and nitrous oxide contributions. 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.

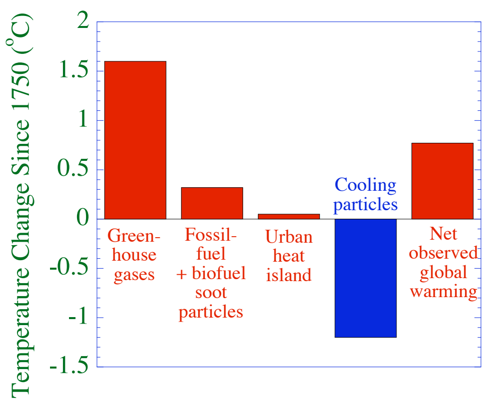
## Definitions

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 (heat) radiation and emitting the heat 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 also darken those surfaces, contributing to their warming and melting.

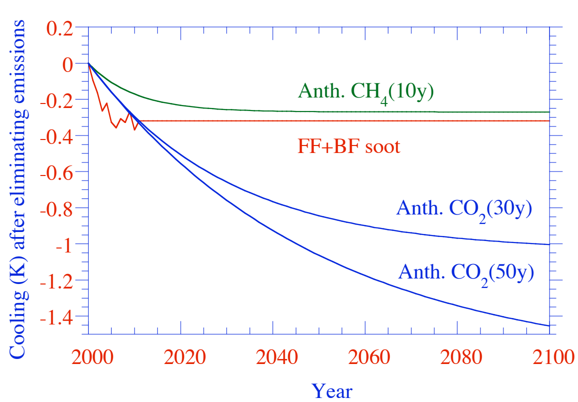
The figure on the screen shows the relative contributions of greenhouse gases, soot, the urban heat island effect, and cooling particles to global warming, as determined by recent detailed computer simulations. About half of actual global warming to date is being masked by cooling particles, which contain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

The figure also shows that fossil-fuel plus biofuel soot may contribute to about 16% of gross global warming (warming before cooling is subtracted out), but its control in isolation could reduce 40% of net warming.




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

Because of soot's short lifetime and strong climate impact, the reduction in its emissions can result in rapid climate benefits. This is illustrated by the figure 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.



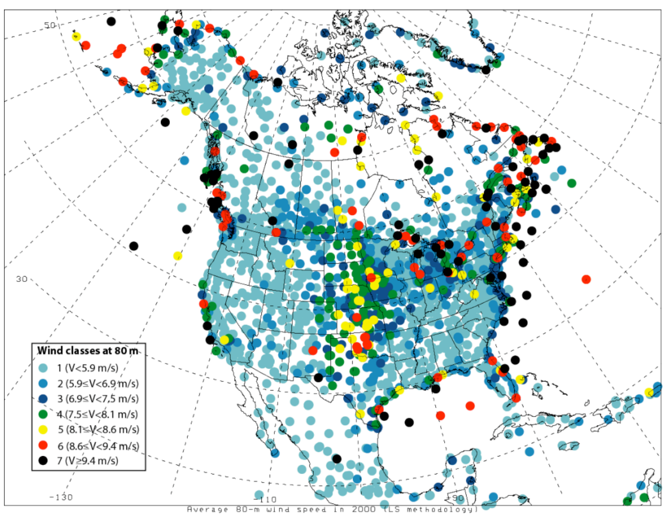

Whereas the U.S. emits about 21% of global anthropogenic carbon dioxide, it emits about 6.1% of the global fossil-fuel plus biofuel soot. Nevertheless, the warming due to U.S. soot appears to exceed the warming due to U.S. methane or nitrous oxide.

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 U.S. have begun to address reducing particle emissions, but more needs to be done.

It is thought that because diesel vehicles obtain 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, increases carbon dioxide and the ratio of $NO_2$:NO in exhaust, increasing ozone in most of the U.S.

Improvements in neither gasoline nor diesel vehicle can contribute significantly to reducing carbon dioxide emissions by 80%, 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 renewable energy, such as wind, solar, geothermal, hydroelectric, wave, or tidal power. Such a conversion would reduce global warming and improve human health.

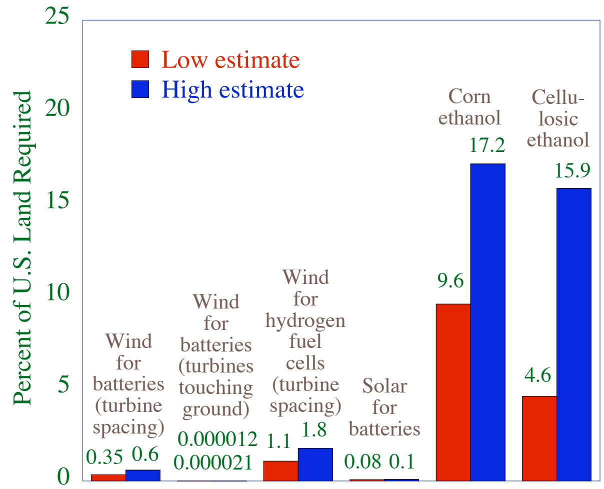
The figure on the screen shows results from the first wind mapping study of North America at 80 meters above the ground. The Great Plains has long been known as the "Saudi Arabia of wind", but the figure identifies other areas, particularly coastal, of intense winds that were previously unknown. The data indicate that the U.S. has twice as much wind energy than total energy consumed and ten times as much wind energy as electricity consumed.




The U.S. could replace all its onroad vehicles with battery-electric vehicles powered by 71,000-122,000 5 MW turbines, less than the 300,000 airplanes the U.S. manufactured during World War II. The land area needed for such wind turbines is 0.5% of the U.S., much less than the 15 percent of U.S. that has fast winds. The wind area required is also 1/30$^{th}$ that required for corn-ethanol (E85) and 1/20$^{th}$ that required for cellulosic ethanol (E85) to replace the same vehicles (Figure on the screen). The land area required for solar energy is also 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.


Percent of U.S. Land Required
25
20
15
10
5
0
Low estimate
High estimate
Wind for batteries (turbine spacing)
0.35
0.6
Wind for batteries (turbines touching ground)
0.000012
0.000021
Wind for hydrogen fuel cells (turbine spacing)
1.1
1.8
Solar for batteries
0.08
0.1
Corn ethanol
9.6
17.2
Cellu-losic ethanol
4.6
15.9