The U.S. Environmental Protection Agency (EPA) recently funded research to expand black carbon knowledge through its Science to Achieve Results (STAR) grants program. This research will provide the scientific basis for policy solutions targeting black carbon sources such as biomass burning.
Where there's smoke, there's fire—and black carbon. Black carbon is the sooty material emitted from combustion processes, including diesel engines and other sources that burn fossil fuels, biofuels, or biomass. This soot contributes to fine particulate matter (PM2.5), which is small enough to be easily inhaled into the lungs and has been associated with cardiovascular and respiratory illnesses.

Additionally, black carbon absorbs light as heat, which can affect the climate. When black carbon is aloft, it can warm the air and instigate changes in rain and cloud patterns; black carbon on snow can speed up melting. Unlike greenhouse gases, which can remain in the atmosphere for decades or centuries, black carbon particles settle to earth in a few days or weeks. Consequently, reducing black carbon emissions could not only improve human health, but also quickly have a positive effect on our changing climate.

Since the role of black carbon in the atmosphere is broad and complex, the EPA funded research to expand black carbon knowledge through its STAR grants program. EPA STAR supports high-quality research by the nation’s leading scientists and engineers to improve the scientific basis for decisions on environmental issues.

In 2010, ten grants totaling $7.6 million were awarded by EPA STAR to universities and organizations. Grantees focused on various aspects of the black carbon issue, such as better accounting for its emissions and uncertainty, tracking its climate-relevant properties as it “ages” or reacts with other vapors and particles in the atmosphere, and better representing its ability to impact formation of cloud droplets.

This cutting-edge research will provide the scientific basis for policy solutions targeting black carbon sources such as biomass burning. A few highlights from the research findings are summarized below.

**Accounting for Impact, Emissions, and Uncertainty**

The most comprehensive attempt yet to evaluate black carbon behavior and its impact on climate came from Tami Bond at the University of Illinois at Urbana-Champaign and coauthors. Their thorough review suggested that many computer models underestimate the global atmospheric absorption of the pollutant. The group has subsequently worked to improve computer models of black carbon, with a focus on atmospheric warming and cloud impacts.

Fuel combustion in the developing world produces highly variable emissions, so Rufus Edwards at University of California, Irvine partnered with Kirk Smith at the University of California, Berkeley and Dr. Bond to take field measurements of home cookstoves and small-industrial fuel burning in the Himalayas and El Salvador (see Figure 1). They showed that fuel type can affect whether the resulting particles have a warming or cooling effect on climate, and that small industry stoves and pottery kilns have very different emissions profiles than household stoves. This information will be incorporated into regional and global emissions inventories. The team also observed low usage of new, more efficient cookstoves, and households “stove stacking” by continuing to use their old stove in addition to the new stove. These findings may help explain why emissions reductions from cookstove adoption are often lower than predicted from laboratory studies.

**Figure 1:** Cookstove study pictures reproduced with permission from Rufus Edwards and Ryan Thompson.
Clarifying the Impact of Black Carbon by Melissa Day, Sherri Hunt, and Bryan Bloomer

Black carbon may be removed from the atmosphere through deposition on surfaces such as vegetation or snow. The effect of black carbon on snow was investigated by Sarah Doherty’s team at the University of Washington (see Figure 2). Previous researchers focused on Arctic snow, but this team investigated lower latitude snow in China and North America, where the highest concentrations of black carbon on snow occur. Variability in the snow’s light absorption was found to be dominated by emissions produced between snowfall events, from sources like disturbed agricultural soil, increased winds, local wood stoves, industrial oil fields, and diesel trucks. Sources and light absorption varied across the locations studied. These results will be used to improve our understanding of the impact of black carbon pollution sources on climate in the Arctic and mid-latitudes.

Changing Chemistry over Time

In simple models, particles have often been represented as individual species floating around with no interactions, but real particles in the atmosphere have been observed to mix with other gas and particulate species. Through processes like physical layering or chemical reaction, one species can be partially or fully covered by one or more other species, and this mixture can change over time. Nicole Riemer and Matthew West at the University of Illinois at Urbana-Champaign used ecology theories of species diversity to better describe aerosol mixing behavior, in an effort to better understand how mixing state affects climate impacts. This new particle-resolved computer model was compared to field measurements to see how to improve simpler, more common models.

When black carbon is accompanied or covered by organic aerosol in a particle, the inclusion of other components changes the particle’s light absorption and its appearance shifts from black to brown; this mixture is called brown carbon. Brown carbon is mainly associated with biomass burning, and different types of fuel and burn conditions can alter its appearance and behavior. Researchers at the Carnegie Mellon University Center for Atmospheric Particulate Studies were the first to show that burning several types of wood produced different kinds of organic aerosol that can produce absorptive brown carbon after being subjected to photochemical aging. This is a new class of light-absorbing compounds not previously included in models.

The inclusion of better descriptions of black carbon (e.g., brown carbon) will improve model predictions of both concentration and absorption. Several researchers worked to improve black carbon representation at different geographical scales; a global chemical transport model was improved by Jesse Kroll and collaborators at the Massachusetts Institute of Technology and Boston College, an open-source community toolkit for regional- and city-scale models was developed by Gregory Carmichael at the University of Iowa and coauthors, and point-level evaluation of combustion sources was completed by James Schauer at the University of Wisconsin-Madison and Michael Bergin at the Georgia Institute of Technology. One surprising result came from the latter laboratory, which showed that although some diesel control methods effectively limited black carbon emissions, relatively large amounts of brown carbon were still released. Better models will help decision-makers understand where and how to most efficiently improve air quality in the future, and there is still work to be done.

Interactions with Water

Cloud formation is driven by how a particle attracts water over time. A particle’s water uptake—or hygroscopicity—can

More Information

For more information about EPA STAR research projects and to learn about upcoming awards and solicitations, visit EPA’s website at http://www.epa.gov/research-grants/air-research-grants.
also affect how effectively it can deposit itself in the lungs, making this both a climate and health issue. Akua Asa-Awuku at University of California, Riverside investigated how the shape of fresh and aged biomass burning aerosol changes over time, and how to account for it in the context of cloud formation (see Figure 3). Her team also found that aerosol systems can contain a type of compound called surfactants, which can significantly affect the system’s ability to attract and take up water from the surrounding environment.8

Atmospheric models often have a simplistic representation of the reaction between particles and water, so Annmarie Carlton and her team at Rutgers University examined the chemistry between water droplets and aerosol particles within a cloud.9,10 They plan to incorporate recently discovered pathways for in-cloud particle formation into the Community Multiscale Air Quality (CMAQ) chemical transport model, a tool used for investigating and managing air quality.

Summary
These EPA STAR-funded projects have enabled scientists to substantially improve our understanding of black and brown carbon. Researchers have improved global impact estimates, investigated cookstove emissions, examined how these particles absorb light and warm their surroundings, and clarified the behavior of particles over time as they interact with light, other pollutants, and water. Bolstered by these findings, new models will be able to simulate more realistic predictions for our future climate and health.

Future Work
Black carbon and other biomass burning emissions remain a priority area for policy-relevant research. Many publications are still forthcoming from the portfolio discussed here; to keep up to date, visit EPA’s online black carbon research database.11

Understanding the emissions from bigger fires like wildfires and controlled agricultural burns is critical, especially given that climate change is predicted to increase the severity and frequency of fires.12 Research has shown that particle properties can change after emission, particularly within a pollutant plume; this can alter the light-absorbing properties of black carbon.

The inclusion of better descriptions of black carbon (e.g., brown carbon) will improve model predictions of both concentration and absorption.
carbon and potentially even enhance its toxicity.\textsuperscript{13} Fires, therefore, constitute both a local and regional pollutant source, with global implications.

The STAR solicitation “Particulate Matter and Related Pollutants in a Changing World” will support several projects related to fires, with awards expected in 2016. Furthermore, multi-agency studies of fires in laboratory, field, and modeling settings will be conducted over the next several years during the Fire Influence on Regional and Global Environments Experiment (FIREX) and Fire and Smoke Model Evaluation Experiment (FASME). EPA STAR also awarded $9 million for the 2012 solicitation “Measurements and Modeling for Quantifying Air Quality and Climatic Impacts of Residential Biomass or Coal Combustion for Cooking, Heating, and Lighting”. The agency intends to continue investment in these critical research fields.\textsuperscript{em}