REPORT ON THE MAY 8, 2013 ADVISORY COUNCIL MEETING ON THE BLACK CARBON: MEASUREMENT AND MODELING, AND BLACK CARBON: EXPOSURE AND MITIGATION

Key Points

Black Carbon – Exposure and Mitigation

Presenter: Veerabhadran Ramanathan, Distinguished Professor, Scripps Institution of Oceanography, University of California, San Diego. In the 1970s Dr. Ramanathan discovered the greenhouse effect of chlorofluorocarbons (CFCs) and numerous other manmade trace gases, and he forecasted in 1980, along with R. Madden, that global warming would be detectable by 2000. Dr. Ramanathan, along with Paul Crutzen, led an international team that first discovered widespread Atmospheric Brown Clouds (ABCs). He showed that ABCs led to large scale dimming, decreased monsoon rainfall and rice harvest in India, and played a dominant role in melting Himalayan glaciers. His team developed unmanned aerial vehicles with miniaturized instruments to measure black carbon (BC) in soot over Asia and to track pollution from Beijing during the Olympics. Dr. Ramanathan has estimated that reduction of BC can reduce global warming significantly, and he is following this up with Project Surya, which will reduce soot emissions from bio-fuel cooking in rural India for purposes of climate mitigation. Dr. Ramanathan chaired a National Academy report that calls for a major restructuring of the Climate Change Science Program, and it was received favorably by the Obama administration. His numerous awards include the 2009 Tyler Prize, Volvo Prize, Zayed prize, Rossby Medal, and Buys-Ballot Medal for pioneering studies in climate and environment. He has been elected to the American Philosophical Society, US National Academy of Sciences, Pontifical Academy by Pope John Paul II, and Royal Swedish Academy of Sciences.

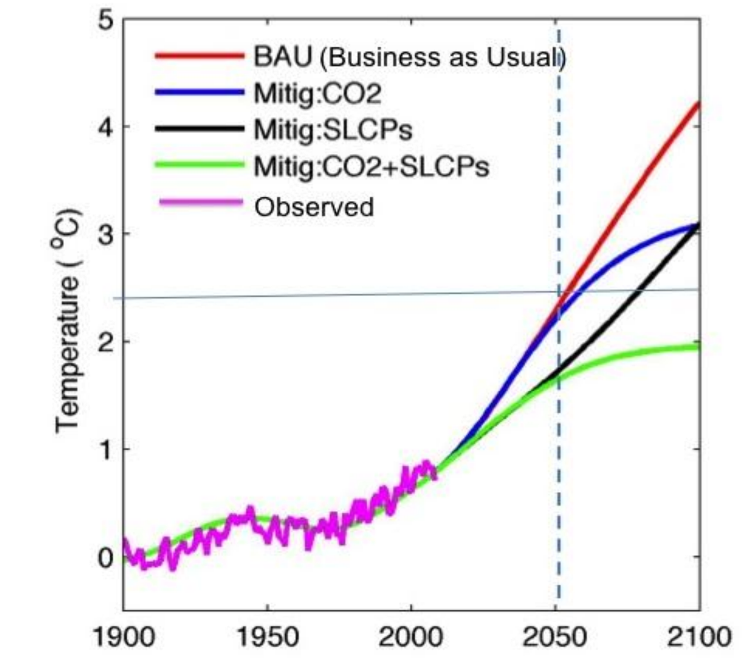
1. Black carbon (BC; all acronyms are defined in Glossary), along with methane, ozone, and some hydrofluorocarbons (HFCs), are termed short-lived climate pollutants (SLCPs) and are positive (i.e., warming) climate forcers,[1] with BC second only to CO_2 as a climate warming forcer. The Global Warming Potential (GWP; see Glossary) per ton of BC is estimated to be 2,500-4,000 times that of CO_2 (not accounting for the warming effects of BC through the reduction of snow and ice pack albedo after its deposition). Due to the short period of time that BC remains in the atmosphere (days to months), the range of BC's GWP values (2,500-4,000) depends upon the time frame examined (100 vs. 20 years, respectively).

2. Effective approaches to mitigate global climate change must include a two-part strategy that reduces both SLCPs and long-lived pollutants (such as CO_2). As shown in Figure 1 (below), while mitigating CO_2 or SLCPs alone will produce measurable decreases in global temperatures, when compared to proceeding with business as usual, mitigating both simultaneously could avoid approximately half the warming expected by 2050. Of

[1] Positive (i.e., warming) climate forcers (see Glossary) cause more solar energy to be retained by the planet, thus producing a warming effect . Negative (i.e., cooling) forcers have the opposite effect, i.e., they act as "mirrors" to scatter solar energy, thus producing a cooling effect.

the total warming avoided by 2050 through the mitigation of SLCPs and CO_2 in concert, 90% is attributable to SLCP mitigation. While effects from the mitigation of long-lived pollutants like CO_2 might not be felt until well into the future, reduction of SLCPs can result in mitigation of some near-term climatic impacts, e.g., immediate SLCP control could reduce expected 2050 increases in sea level by an estimated 30%.

Figure 1: Observed and simulated global mean surface temperature under different mitigation strategies



Source: Hu A, Xu Y, Tebaldi C, Washington WM, Ramanathan V. Mitigation of short-lived climate pollutants slows seal-level rise. *Nature Climate Change*, advance online publication, 14 Apr 2013.

3. Exposure to BC results in significant health impacts. A recent WHO study estimated that ambient particulate matter (PM), of which BC is a major component, accounts for approximately 3.1 million deaths annually worldwide. Additionally, it is estimated that indoor air pollution from solid-fuel combustion, during which BC is produced, accounts for 3.5 million deaths annually worldwide. Local reductions in BC emissions thus can result in immediate improvements in local health.

4. California actions since the 1980s to reduce PM, especially from diesel sources, have resulted in an approximately 50% reduction in BC concentrations, and this reduction has occurred in spite of increased diesel fuel consumption. At the same time, only a negligible reduction has been achieved for many co-emitted pollutants that act as cooling climate forcers. These results justify diesel emission reduction programs as a continued component of climate change mitigation.

5. BC emissions are increased from vehicles in congestion situations, due to idling, stopping, and restarting.

6. BC emissions are a significant problem in Asia, Africa, and other developing regions with weak diesel regulations and with high use of traditional solid-fuel cookstoves. California has been successful in reducing its BC emissions, primarily through regulations mandating adoption of improved diesel technologies in recent decades. California can thus assist developing countries in reducing their BC emissions by sharing expertise on policy implementation and on technical innovations (e.g., diesel control technologies and development of cleaner, low-emitting cookstoves).

7. BC can be measured in real time using cellphones augmented with relatively inexpensive thermal-optic technologies. These technologies could be deployed to community members to provide better estimates of local BC concentrations.

8. Brown carbon (BrC), a subcomponent of organic carbon (OC), defined by its optical absorption properties, is commonly co-emitted with BC during biomass burning. It appears to have a warming effect on climate, with a GWP of 20-25% of that of BC.

9. Some components of biomass burning (e.g., ash and nitrate precursors) are cooling climate forcers, while others (BC and BrC) are warming climate forcers. It is now thought that the net effect of biomass burning on climate is either zero or slightly warming.

Black Carbon in the San Francisco Bay Area: Trends in Ambient Concentrations and Emissions

Presenter: Robert Harley, Professor, Department of Civil and Environmental Engineering, University of California, Berkeley, where he has been on the faculty since 1993. Prof. Harley holds a bachelor's degree in Engineering Science (Chemical Engineering option) from the University of Toronto, and both an M.S. and Ph.D. in Environmental Engineering Science from the California Institute of Technology (Caltech). Prof. Harley's research focuses on air quality and sustainable transportation; he is an author of over 75 papers published in peer-reviewed scientific journals. He now serves as an associate editor of *Atmospheric Chemistry and Physics*. Prof. Harley received the National Science Foundation's young investigator (CAREER) award in 1996, as well as a visiting scientist fellowship (1999-2000) at the University of Colorado / NOAA Aeronomy Lab in Boulder. He served for three years as Vice Chair of the Civil and Environmental Engineering Department at Berkeley (2001-04), chairing committees responsible for undergraduate curriculum and graduate student admissions. He also served as Environmental Engineering faculty group leader (2007-10). During the first half of 2011, he was a visiting scientist at the Max Planck Institute for Chemistry in Mainz, Germany. Prof. Harley is also appointed as a Faculty Scientist/Researcher in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory, a U.S. Department of Energy science lab located adjacent to campus.

1. Results from a recent Denver-based speciated $PM_{2.5}$ study indicate that the BC fraction of traffic-related $PM_{2.5}$ is highly correlated with adverse cardiovascular and respiratory hospital admissions. It is still unclear, however, whether BC is directly toxic, or whether BC particles carry toxic chemicals on their surface.

2. Coefficient of Haze (COH) is an excellent surrogate for BC concentrations. Long-term COH measurements in the Bay Area were available until 2003, when their samplers were discontinued due to lack of available parts. These measurements showed that Bay Area BC concentrations steadily decreased over the decades.

3. Real-time BC monitoring in the Bay Area can be accurately accomplished by use of relatively low cost real-time light absorption methods. Within the Air District monitoring network, BC is explicitly observed by fine-particulate speciation at four sites and by real-time absorption at three others.

4. In the Bay Area, BC accounts for approximately 10% of winter $PM_{2.5}$ emissions, almost exclusively from mobile sources and wood smoke. Combining the Air District's winter $PM_{2.5}$ emissions inventory with source apportionment results from Dr. Lynn Hildemann shows that heavy-duty trucks and off-road mobile sources together account for 73% of emissions, while another 21% are from wood smoke.[2] Some local concentrations may result from emissions originating from areas outside the Bay Area.

5. Bay Area studies of BC show:
    a. BC concentrations (like $PM_{2.5}$ in general) are highest in the winter due to stable meteorological conditions (i.e., poor mixing) and increased seasonal residential wood-burning.
    b. BC emission rates per gallon for diesel-fueled vehicles are currently 50 times greater per vehicle on average than those of gasoline-fueled vehicles.
    c. As the diesel fleet gets cleaner, the majority of Bay Area BC traffic emissions will come from an increasingly small number of vehicles. This remaining group of uncontrolled vehicles thus represents an important target for reducing overall BC concentrations.
    d. Emission controls on port drayage have decreased localized peak BC concentrations in West Oakland, but area-wide annual average BC concentrations have not decreased. This is likely due to the local dominance of other sources, such as adjacent railroads and traffic on nearby highways.

6. BrC emissions from lubricating-oil burning are higher in diesel (as compared to gasoline) vehicles, as diesel engines consume more lubricating oil (except in the case of gasoline gross polluters).

---

[2] Recent analysis by Air District staff attributes Bay Area BC emissions as follows: 50% from diesel engines, 15% from other fossil fuel combustion, 25% from residential wood-burning, and 10% from other wood smoke sources. These data can be viewed on page 51 of the 2012 report: *Understanding Particulate Matter: Protecting Public Health in the San Francisco Bay Area.*
baaqmd.gov/~/media/Files/Planning%20and%20Research/Plans/PM%20Planning/ParticulatesMatter_Nov%207.ashx

7. Major decreases in BC are expected to continue as California regulations pertaining to heavy-duty diesel engines take effect. Additional California regulatory efforts that will control BC emissions from goods movement, light-duty vehicles, and wood-burning are also underway.

Emerging Issues

Many issues raised by the speakers are well covered in pages 47-58 of *Understanding Particulate Matter: Protecting Public Health in the San Francisco Bay Area* (cited in footnote #2 above).

1. Efforts aimed at BC reduction are essential components in the mitigation of the adverse effects of climate change and thus must be implemented in concert with efforts to reduce CO_2 and other climate warming forcers.

2. While climate change is generally considered on a global level, widespread local control of BC emissions can result in significant immediate local health benefits and in important near-term climate benefits at the global and local levels (e.g., in California, through increased surface snow-pack albedo and consequent lower risk of reduced water supply).

3. BrC appears to be a contributor to climate change, but further quantification of its influence is necessary.

4. Co-emitted species produced during biomass burning in California (such as nitrate precursors and ash) are cooling climate forcers and must be considered when developing BC and BrC mitigation strategies.

5. The underlying mechanisms behind, and the relative magnitude of, the direct health effects of BC and BrC, as well as of the toxic chemicals carried on their surfaces, are not fully understood. Further research in these areas will help refine and clarify priorities for emission reduction targets.

6. A detrimental positive feedback loop (see Glossary) exists, in which BC- and BrC-induced climate change results in increased drought, leading to increased wildfire risk, and in turn to greater BC and BrC emissions.

7. California and Air District regulations to limit diesel emissions and PM have been successful in reducing BC concentrations, but more reduction is needed. Targets for local and regional BC emission reduction in the Bay Area include:

    a. Diesel sources, e.g., rail, ship, airport ground equipment, back-up generators, and gross polluting mobile sources
    b. Traffic management, including congestion mitigation and traffic calming

c. Residential (indoor and outdoor) wood-burning devices, recreational burning (e.g., campfires or bonfires), agricultural burning, and open biomass burning, including forest management.
d. Residential and commercial cooking, especially char broiling and barbecuing

8. BC is not currently part of the cap-and-trade system and it is not clear if it will be, but if it were, using the 2,500-4,000 GWP range of BC and a currently accepted California carbon market value of $10-15 per ton of CO_2 equivalent, BC could potentially be worth $25,000-60,000 per ton. The relative costs of reducing CO_2 and BC emissions will influence the feasibility of future reductions.

9. Burning of vehicle engine lubricating oil is linked to BrC emissions.

10. Wintertime BC and BrC emissions are of greatest concern for California climate due to more stable winter meteorological conditions and to the presence of the Sierra snow and ice, onto which BC is deposited, leading to accelerated melting.

11. Continued measurements of Bay Area BC and BrC can help verify the success of regulatory and incentive programs. Empirical evidence of successful mitigation efforts can support similar models for BC and BrC reduction programs that can provide health and climate benefits to communities worldwide.

Recommendations

The Advisory Council thus recommends that the Air District:

1. Improve Bay Area BC and BrC monitoring networks to better understand sources contributing to $PM_{2.5}$ health effects and to track the impacts of emissions control progress over the next decade. Increased monitoring is needed, both in locations with existing long-term measurements (for trend analysis) and in areas where more information is needed. To that end:

   a. Continue and expand Bay Area BC monitoring, concentrating on locations where historical COH measurements were once collected. Consider redeployment of COH monitors, if possible.
   b. Track progress on the development of BrC monitoring technologies.
   c. Further investigate BC in high peak concentration areas, such as in much-studied West Oakland, and expand ambient monitoring and source apportionment studies.
   d. Explore supplementation of the BC monitoring network through widespread deployment of low-cost monitoring technologies. These monitors could be useful during air pollution episodes, such as the recent Richmond refinery fire.
   e. Continue to refine and develop BC, BrC, and OC emissions inventories.
   f. Research the magnitude of the inter-basin transport of BC and BrC, e.g., to and from the Central Valley.

2. Continue and accelerate Air District efforts to target emission control of BC and BrC within the Bay Area. Additional control measures to consider or enhance include:

    a. Incentives and regulatory mechanisms that target:
        - Diesel sources, including gross polluting vehicles, off-road mobile equipment, rail, ship, airport ground equipment, and back-up generators
        - Residential indoor and outdoor burning [including fireplaces, wood stoves, chimineas (see Glossary), and fire pits], recreational burning (e.g., bonfires and campfires), agricultural burning, and open biomass burning and forest management
        - Residential and commercial cooking, including char broilers, barbecues, and wood-burning pizza ovens
    b. Emphasis on seasonal regulations and incentives that reduce winter BC and BrC emissions. For example, increasing the effectiveness of the Winter Spare the Air program.
    c. Continued incentive funding for programs to scrap vehicles with high-emitting diesel and gasoline engines.
    d. Working with the business community and others to develop more sustainable transport of freight and goods.
    e. Assisting planning agencies to implement strategies that minimize traffic and optimize flow on Bay Area roads.
    f. Supporting federal, state, and local policies and programs that reduce emissions, especially as they relate to ongoing CARB diesel reduction regulations.

3. Assess the relative health and climate effects of a range of contaminants (especially, CO_2, $PM_{2.5}$, BC, BrC, OC, nitrate precursors, ash, and methane) from a variety of source categories (e.g., fossil and renewable fuels burned in various engines, in heating and cooking appliances, and during wildfires). When developing climate and/or health improvement strategies, examine how the mitigation of one contaminant may have an unintended adverse consequence on the climate and/or health impacts of another contaminant.

4. Assess current and potential buyback-type programs (for old cars, old diesels, and wood burning devices) and consider modifying buyback formulas to incorporate information on BC's climate forcing potential. For example, use of the per-ton BC carbon credit value of $25,000-60,000 (as described above), vehicle buyback and fireplace removal/retrofit programs could be amended to reflect the value of reduced BC (and other climate forcing co-emitted pollutants, as applicable) emissions. Such programs could be subsidized by money collected from the purchase of carbon credits.

5. Educate the public about: a) the roles BC and BrC play as SLCPs and b) the fact that technologies and tools to reduce BC and BrC emissions are presently available.

6. Given the rapid growth in research on numerous climate pollutants and on appropriate mitigation strategies, consider enhancing or expanding Air District staffing to designate a climate change point-person.

Glossary

ABAG: Association of Bay Area Governments in the San Francisco Bay Area

Albedo: Fraction of solar energy (shortwave radiation) reflected from the earth back into space by atmospheric aerosols and land surfaces. Measure of reflectivity of earth's atmosphere and surface. Pure ice, especially with snow atop it, has a high albedo. Ice or snow contaminated with BC has a reduced albedo, is less reflective, and therefore absorbs more solar energy.

Ash: Inert, non-combustible chemical compounds (generally similar to earth crustal elements) present in fuel or wood that can be co-emitted with other combustion emissions (e.g., CO_2, water vapor, BC, NO_x, etc.). Refined fuels (diesel, gasoline, and jet fuel) produce low ash amounts. Ash can scatter solar radiation in multiple directions, including back into space, thereby having a cooling effect on the climate. In the atmosphere, ash contributes to ambient $PM_{2.5}$ and PM_{10} concentrations.

BC: Black Carbon. Solid form of mostly pure carbon, produced by incomplete combustion of diesel and other fuels. Most effective form of PM (by mass) for absorbing all wavelengths of solar radiation.

Biomass: Organic materials, such as wood and agricultural wastes, which can be burned to produce energy or converted into a gas for use as fuel.

BrC: Brown Carbon. Component of OC related to the burning of biomass and of lubricating oil in vehicle engines. BrC absorbs ultraviolet and visible solar radiation, though not as efficiently as BC.

CARB: California Air Resources Board

Chiminea: Freestanding, front-loading, wood-burning fireplace or oven with a bulbous body, used in decorative backyard settings.

Climate forcers (negative and positive): Pollutants causing cooling or heating of the atmosphere, respectively.

CO_2: Carbon dioxide. Climate-warming product of combustion of organic materials (fuels and biomass).

COH: Coefficient of Haze. Measure of ambient air particulates highly correlated with BC measurements. Manufacture of COH analyzers has been discontinued.

Co-Emitted Pollutants: Gases and particles emitted concurrently with BC emissions (e.g., OC, sulfur dioxide, and nitrate and sulfate precursors).

GWP: Global Warming Potential. A measure of a chemical's relative contribution (per ton) to global warming in comparison to CO_2. A GWP is calculated over a specific time interval, commonly 20, 100, or 500 years.

HFC: Hydrofluorocarbon. Fluorocarbons used as refrigerants and in other industrial processes.

Mirrors: Used to describe air pollutants (e.g. nitrates, sulfates, and ash) that scatter solar radiation in many directions, including back into space, and thus have a cooling effect on climate.

MTC: Metropolitan Transportation Commission in the San Francisco Bay Area.

OC: Organic carbon. Compounds containing carbon (bound with hydrogen and other elements, e.g., oxygen). May be a product of incomplete combustion or formed through the oxidation of atmospheric Volatile Organic Compounds (VOCs).

PM: Particulate matter. A complex mixture of small particles and liquid droplets suspended in the atmosphere in various size ranges (i.e., PM_{10}, $PM_{2.5}$, ultrafine).

PM2.5: Ambient particulate matter less than 2.5 microns in diameter.

Positive Feedback Loop: Series of events that reinforce the original action. In context of this report, for example, BC and BrC emissions lead to increased global warming, which results in increased frequency of forest fires, which in turn emit BC and BrC, thus perpetuating and enhancing the BC and BrC cycles.

SLCP: Short-lived climate pollutants (e.g., BC, BrC, methane, ozone, and some HFCs) that have relatively short lifetimes (i.e., half lives of days to months) in the atmosphere compared to CO_2 and nitrous oxide (N_2O), which stay in the atmosphere for decades.

WHO: World Health Organization. United Nations health authority responsible for providing information, health-based standards, and guidelines on a broad spectrum of health issues, including the effects of air pollutants.