EPA Report to Congress on Black Carbon

Presentation to the Black Carbon Review Panel of the Council on Clean Air Compliance Analysis

Omni Shoreham Hotel, Washington, D.C.

April 18, 2011

Black Carbon Report to Congress:

October 2009 Interior Appropriations Bill Requirement

- "Not later than 18 months after the date of enactment of this Act, the Administrator, in consultation with other Federal agencies, shall carry out and submit to Congress the results of a study on domestic and international black carbon emissions that shall include:
  - an inventory of the major sources of black carbon;
  - an assessment of the impacts of black carbon on global and regional climate;
  - an assessment of potential metrics and approaches for quantifying the climatic effects of black carbon emissions (including its radiative forcing and warming effects) and comparing those effects to the effects of carbon dioxide and other greenhouse gases;
  - an identification of the most cost-effective approaches to reduce black carbon emissions; and
  - an analysis of the climatic effects and other environmental and public health benefits of those approaches."

EPA's Approach

- Characterize BC impacts on climate through extensive review of available scientific literature (including regional as well as global impacts)
- Identify currently available mitigation programs and technologies, including information on cost and effectiveness
- Evaluate, based on existing studies, the effectiveness of BC mitigation approaches for protecting climate, public health, and the environment

- Note: due to time and resource constraints, EPA did not attempt to conduct an integrated analysis of impacts and benefits of specific mitigation strategies

BC Report to Congress: Outline

- **Executive Summary**
- **Chapter 1** Introduction
- **Chapter 2** Black Carbon Effects on Climate
- **Chapter 3** Black Carbon Effects on Public Health and the Environment
- **Chapter 4** Emissions of Black Carbon
- **Chapter 5** Observational Data for Black Carbon
- **Chapter 6** Mitigation Overview: Climate and Health Benefits of Reducing Black Carbon Emissions
- **Chapter 7** Mitigation Approaches for Mobile Sources
- **Chapter 8** Mitigation Approaches for Stationary Sources
- **Chapter 9** Mitigation Approaches for Residential Heating and Cooking
- **Chapter 10** Mitigation Approaches for Open Biomass Burning
- **Chapter 11** Metrics for Comparing Black Carbon Impacts to Impacts of Other Climate Forcers
- **Chapter 12** Conclusions and Research Recommendations

BC Report to Congress: Outline (cont.)

- **Appendices:**
  - **Appendix 1** Ambient and Emissions Measurement of Black Carbon
  - **Appendix 2** Black Carbon Emissions Inventory Methods and Comparisons
  - **Appendix 3** Studies Estimating Global/Regional Health Benefits of Reductions in Black Carbon
  - **Appendix 4** Efforts to Limit Diesel Fuel Sulfur Levels
  - **Appendix 5** U.S. Emission Standards for Mobile Sources
  - **Appendix 6** International Emission Standards for Heavy-Duty Vehicles
- **Bibliography**

Key Conclusions of the Draft Report

1. BC and other light-absorbing particles exert a powerful influence over the earth's climate, especially at the regional scale.
2. BC is different from long-lived GHGs like CO_2 both in the variety of mechanisms by which it affects climate and its short atmospheric lifetime.
3. Mitigating BC can make a difference in the short term for climate, at least in sensitive regions.
4. BC mitigation strategies are likely to provide substantial public health and (non-climate) environmental benefits.
5. Careful targeting of mitigation programs is essential for both public health and climate purposes.
6. The sequence of policies is important for ensuring maximum benefits.
7. There is a strong need for additional quantitative analysis examining the climate, public health, and environmental impacts of specific control strategies.

Black Carbon Effects on Climate

- Black carbon (BC) is the most strongly light-absorbing component of particulate matter (PM), and is formed by incomplete combustion of fossil fuels, biofuels, and biomass.
  - BC can be defined specifically as the carbonaceous component of PM that absorbs all wavelengths of solar radiation. It is commonly referred to as “soot”. Per unit of mass in the atmosphere, BC can absorb a million times more energy than carbon dioxide (CO_2).
  - Other carbon-based PM may also be light-absorbing, particularly brown carbon (BrC), which are organic carbon (OC) compounds that absorb light within the visible and ultraviolet range of solar radiation. The net contribution of BrC to climate is presently uncertain.

Chp 2: Climate Effects (cont.)

- The full effect of BC on climate must be assessed in the context of co-emitted pollutants.
- Atmospheric processes that occur after BC is emitted, such as mixing, aging, and coating, can also affect the net influence of BC on climate.
- The short atmospheric lifetime of BC and the mechanisms by which it affects climate distinguish it from long-lived GHGs like CO_2.
  - *BC has a short atmospheric residence time of days to weeks*. This short lifetime, combined with the strong warming potential of BC, means that the climate benefits of reductions in current emissions of BC will be nearly immediate.
  - *Emissions sources and ambient concentrations of BC vary geographically and temporally*, resulting in climate effects that are more regionally and seasonally dependent. Likewise, mitigation actions for BC will produce different climate results depending on the region, season, and emission category.

Chp 2: Climate Effects (cont.)

- *BC influences climate through multiple mechanisms*:
  - *Direct effect*: BC absorbs both incoming and outgoing radiation of all wavelengths.
  - *Snow/ice albedo effect*: BC deposited on snow and ice darkens the surface and decreases reflectivity (albedo), thereby increasing absorption and accelerating melting.
  - *Indirect effect*: BC also alters the properties of clouds, affecting cloud reflectivity, precipitation, and surface dimming.
- The direct and snow/ice albedo effects of BC are widely understood to lead to climate warming. The indirect effects of BC on climate via interaction with clouds are much more uncertain, but may partially offset the warming effects.

Chp 2: Climate Effects (cont.)

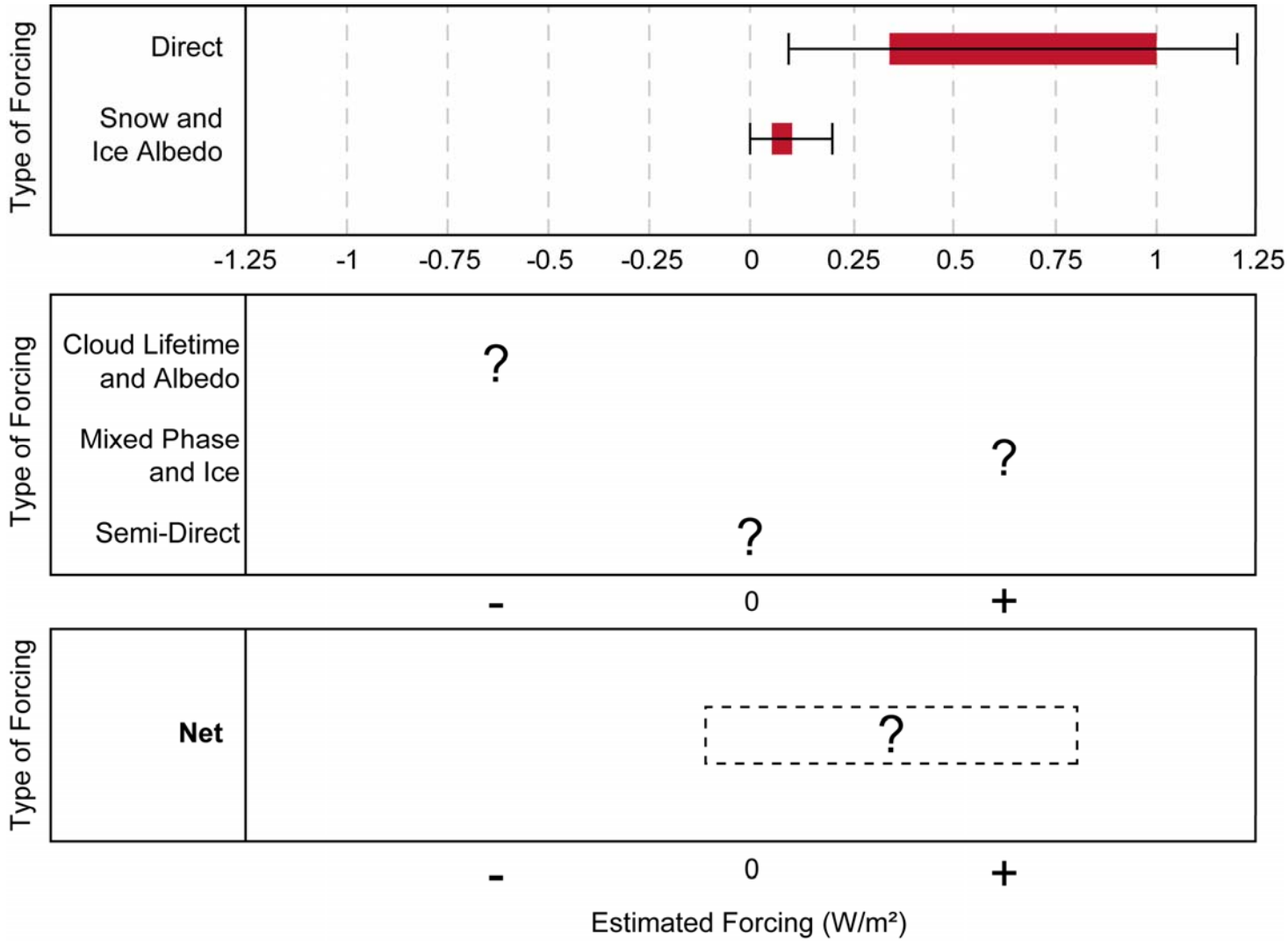


Figure 2-8. Estimates of Radiative Forcing from Black Carbon Emissions Only. The boxes indicate ranges of central estimates from the papers identified in this report. The error bars indicate the highest and lowest uncertainty estimates from those papers.

Chp 2: Climate Effects (cont.)

- Regional climate impacts of BC are highly variable
  - Effects of BC on atmospheric warming and melting are especially strong in sensitive regions such as the Arctic and the Himalayas. Estimates of snow and ice albedo forcing in key regions also exceed global averages.

- BC also contributes to surface dimming and the formation of Atmospheric Brown Clouds (ABCs)
  - These effects result in changes in the pattern and intensity of precipitation

Chp 2: Climate Effects (cont.)

Table 2-1. Comparison of BC to CO_2 on the Basis of Key Properties that Influence Climate

	BC	CO_2
Atmospheric lifetime	Days to weeks	100+ years (some stays for millennia)
Distribution of atmospheric concentrations	Highly variable both geographically and temporally, correlating with emission sources	Generally uniform across globe
Direct radiative properties	Absorbs all wavelengths of solar radiation	Absorbs only thermal infrared radiation
Global mean radiative forcing (IPCC)	0.34±0.25 W m^{-2} direct forcing 0.1±0.1 W m^{-2} (snow/ice albedo forcing)	1.66±0.17 W m^{-2}
Cloud interactions	Multiple cloud interactions that can lead to warming or cooling, as well as effects on precipitation	No direct cloud interactions
Surface albedo effects	Contributes to accelerated melting of snow/ice and reduces reflectivity by darkening snow and ice, enhancing climate warming	No direct surface albedo effects
Contribution to current global warming	Likely 3rd largest contributor (after CO_2 and CH_4), but large uncertainty	Largest contributor

BC Effects on Health and the Environment

- Exposure to fine particles ($PM_{2.5}$) including BC is associated with a broad range of adverse respiratory and cardiovascular effects, as well as premature death.
  - Health effects associated with exposure to BC are generally consistent with those observed for $PM_{2.5}$, with the most consistent evidence for cardiovascular effects, and fewer studies supporting an association with respiratory effects or mortality.
  - At present, we have insufficient information to fully assess the health effects of BC relative to other constituents of $PM_{2.5}$.
- BC is a component of indoor air pollution associated with the burning of solid fuels (mostly biomass) for cooking and heating by approximately 3 billion people worldwide
  - Exposure to indoor air pollution from solid fuel use has been estimated to cause ~ 2 million deaths per year, mainly among women and children
- $PM_{2.5}$, including BC, is linked to adverse impacts on ecosystems, to visibility impairment, to reduced agricultural production in some parts of the world, and to materials soiling and damage.

Emissions of Black Carbon

- BC emissions vary significantly among regions in terms of both magnitude and principal source categories.
- The regions of the world responsible for the majority (nearly 75%) of BC emissions world-wide are Africa, Asia, and Latin America.
- In developing countries, biomass burning and residential sources are the dominant sources of BC, while in developed countries, emissions of BC are lower and are often dominated by transportation and industry.

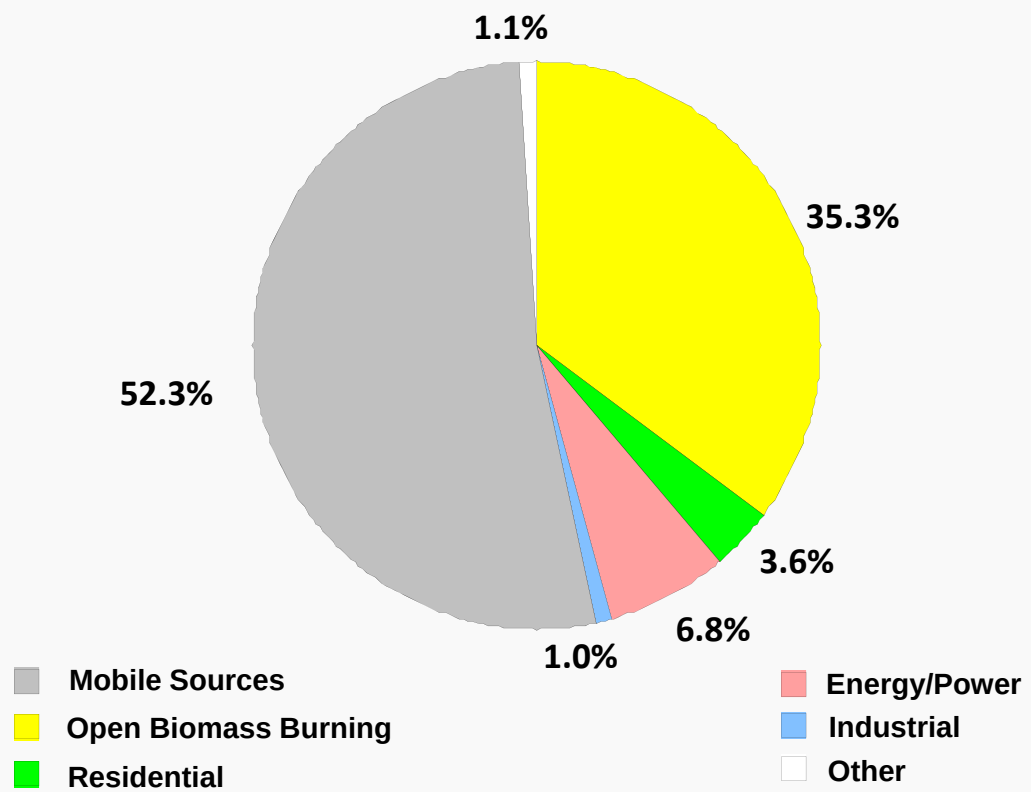
- Organic carbon (OC) is a significant co-emitted pollutant among the major BC emitting sources
  - Because OC generally scatters solar radiation and exerts a cooling influence on climate, the total amount of OC vs. BC in an emissions mixture is important. This ratio varies significantly among source categories.

The Daily Star 2/24/09

U.S. Emissions

- BC emissions from U.S. sources represent ~ 8% of the global total
  - Nearly 90% of mobile emissions are from diesel sources
  - Open biomass burning is dominated by wildfires (68%)
  - BC emissions often concentrated in urban areas

Figure 4-3. U.S. BC Emissions in 2005 (0.65 Million Tons, 580 Gg)



Global Emissions

- More than two-thirds of the almost 8 million tons (7300 Gg) in global BC emissions come from open biomass burning and residential sources.

Figure 4-9
Global BC Emissions, 2000
(7,764 Gg)

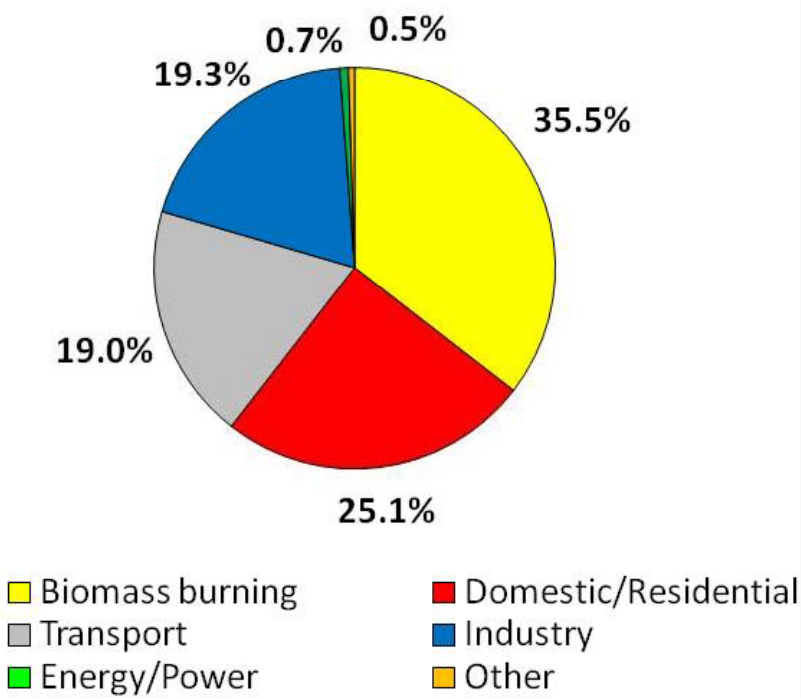
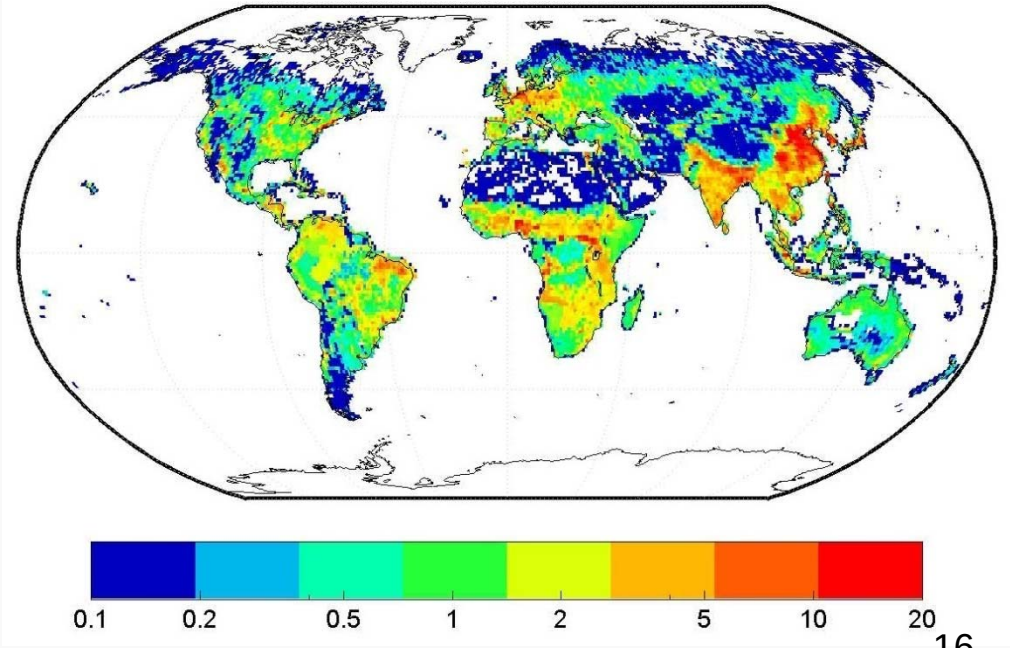


Figure 4-7
Global BC Emissions by Region (Gg) in 2000 (Bond, 2007)



Global Emissions Trends

- Developing countries (e.g., China and India) have shown a sharp rise in BC emissions over the past 50 years.
- In contrast, BC emissions from developed countries have been declining since mid-20th century.

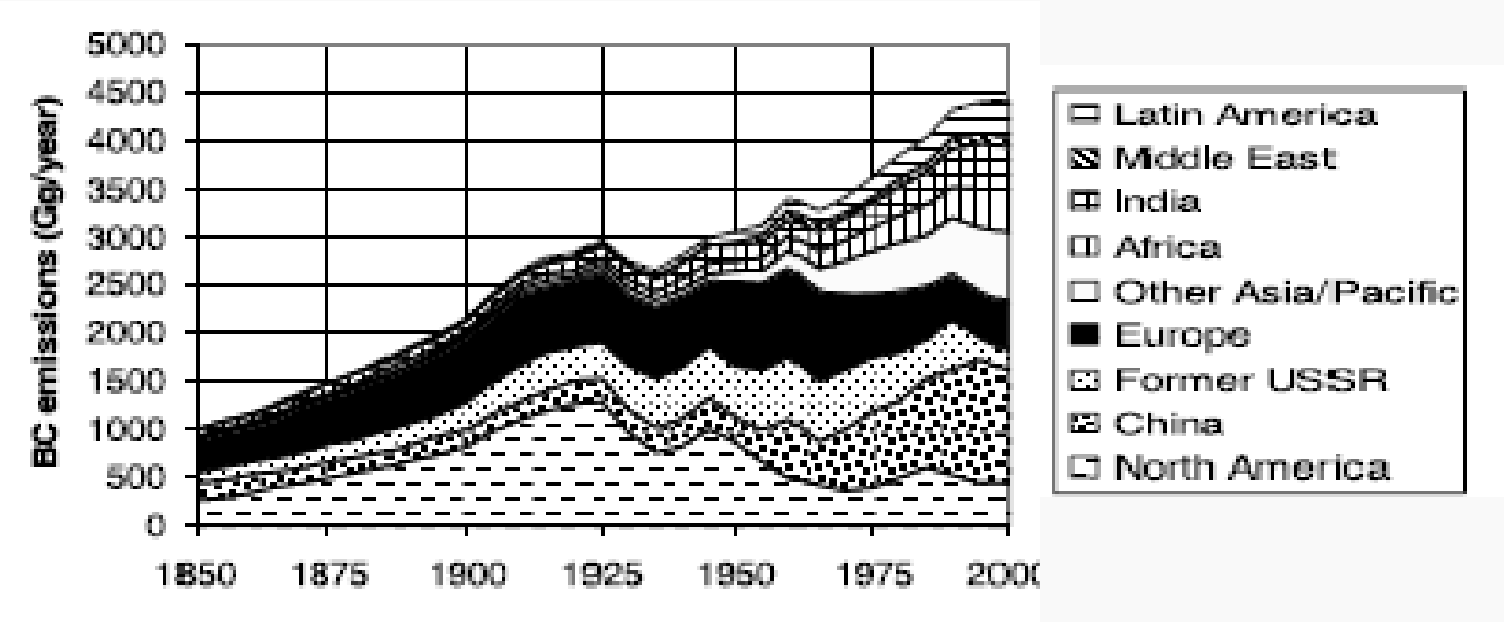


Figure 4-16 (from Bond et al., 2007)

Observational Data for Black Carbon

- Global ground-level BC measurements indicate estimated concentrations ranging from < 0.1 µg/m^3 in remote locations to ~15 µg/m^3 in urban centers.
  - Ambient levels in China ~10 times higher (in both urban and rural areas) than those in the North America or Europe.
- Remote sensing observations also show global variability in concentrations of absorbing aerosols in the total atmospheric column.
- Recent surface snow measurements indicate BC concentrations vary significantly over the Northern Hemisphere, with particularly high values reported in the Tibetan Plateau and throughout western China.
  - Dust and brown carbon may also significantly reduce snowpack reflectivity.
- Sediments and ice-cores provide long-term records of BC concentrations.
  - Globally, Northern Hemispheric ice core BC trends vary with location; some ice cores have BC values increasing to present-day, while other areas show maximum levels reached earlier in the 1900s.

Mitigation Overview: Climate and Health Benefits of Reducing Black Carbon Emissions

- Growth/decline in future BC emissions likely to vary by region and sector
  - Overall BC emissions are likely to decrease globally, but trend will be dominated by emissions reductions in developed countries and may be overshadowed by emissions growth in key sectors (transportation, residential) in developing countries, depending on growth patterns.

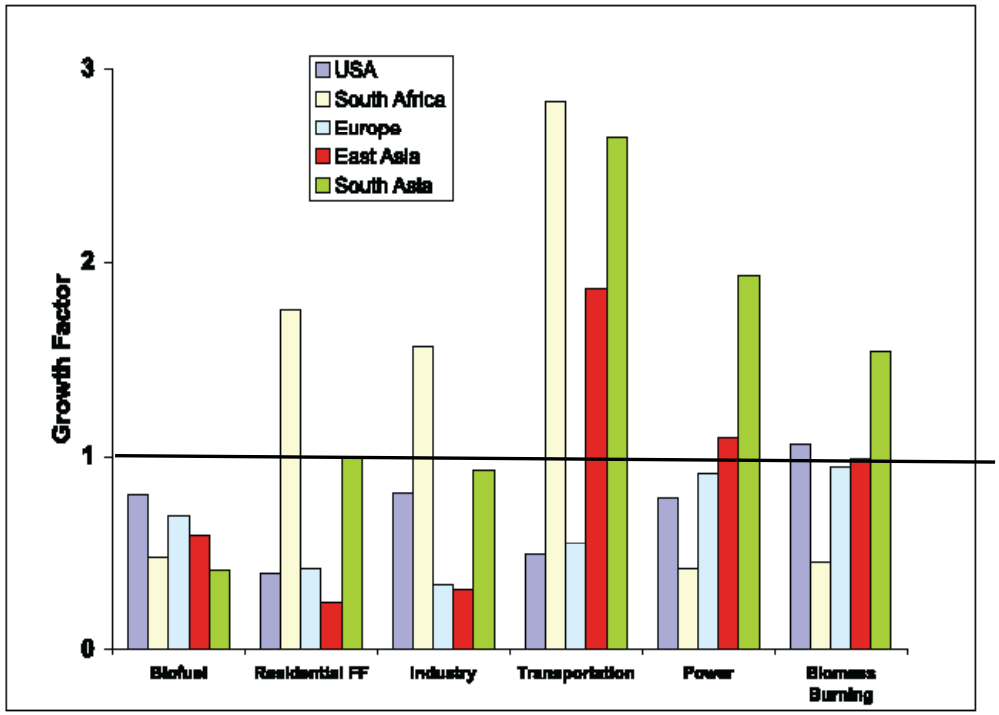


Figure 6-1. Black Carbon Emissions Growth, 2000-2030 under IPCC A1B Scenario. Black Carbon Emissions Growth Factors by Sector for Selected World Regions (from IPCC A1B scenario). (Source: Jacobson and Streets, 2009)

Chp 6: Mitigation Overview (cont.)

- Available control technologies can provide cost-effective reductions in BC emissions from many key source categories, resulting in some near-term climate benefits, especially at the regional level.
  - BC emissions reductions are generally achieved by applying technologies and strategies to improve combustion and/or control $PM_{2.5}$ (including BC) that is directly emitted from sources.
  - Benefits in sensitive regions like the Arctic, or in regions of high emissions such as India and Asia, may include reductions in warming and melting (ice, snow, glaciers), and reversal of precipitation changes.
  - BC reductions could help reduce the rate of warming soon after they are implemented.

Chp 6: Mitigation Overview (cont.)

- These cost-effective mitigation strategies will also provide substantial public health co-benefits.
  - Reductions in directly emitted $PM_{2.5}$ can substantially reduce human exposure, providing large public health benefits. In the United States, the average public health benefits associated with reducing directly emitted $PM_{2.5}$ are estimated to range from $270,000 to $1.1 million per ton $PM_{2.5}$ in 2030.
  - The cost of the controls necessary to achieve these reductions is generally far lower. For example, the costs of PM controls for new diesel engines are estimated to be less than $13,000 per ton $PM_{2.5}$.
  - Globally, the health benefits of mitigation strategies aimed at BC would be even larger, potentially involving hundreds of thousands of avoided premature deaths each year.

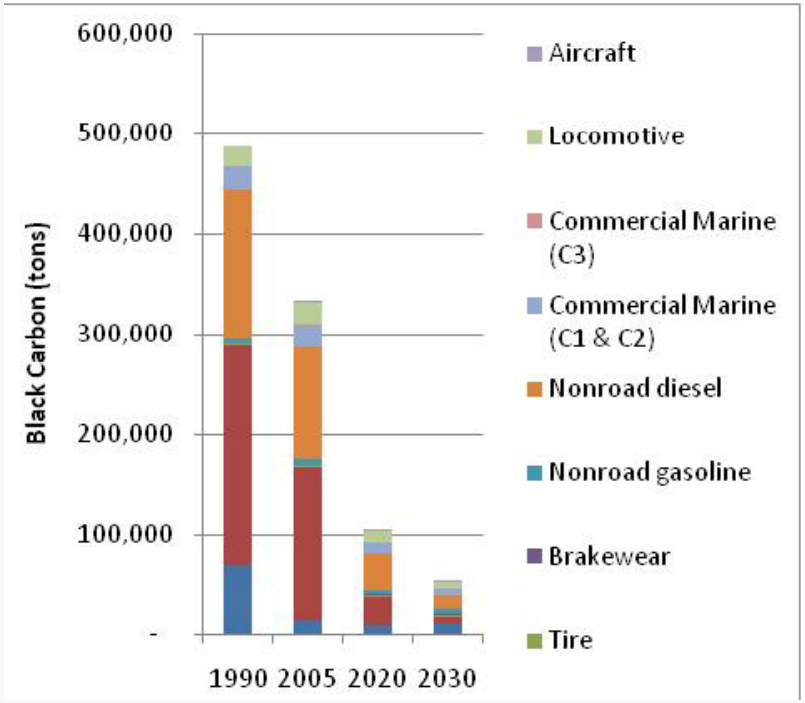
Chp 6: Mitigation Overview (cont.)

- Considering the location and timing of emissions and accounting for co-emissions will improve the likelihood that mitigation strategies will be beneficial for both climate and public health.
  - Strategies that focus on sources known to emit large amounts of BC—especially those with a high ratio of BC to OC, like diesel emissions—will maximize climate co-benefits.
  - The largest climate benefits of BC-focused control strategies may come from reducing emissions affecting the Arctic, Himalayas and other ice and snow-covered regions.
  - The largest health benefits from BC-focused control strategies will occur locally near the emissions source and where exposure affects a large population.

Mitigation Approaches for Mobile Sources

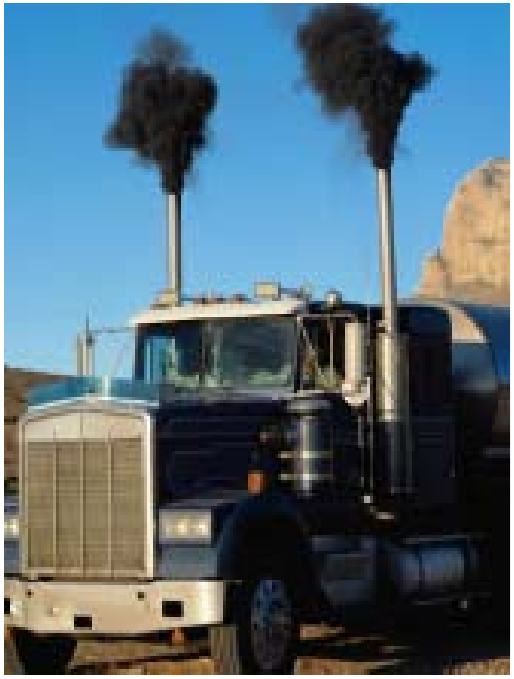
- Regulations in the U.S. and Europe affect BC emissions from on-road and nonroad diesel engines, locomotives, and commercial marine vessels.
  - In the U.S., new engine requirements are projected to reduce BC emissions from mobile sources (mainly diesels) by 86% from 2005 to 2030.
    - Main technology: diesel particulate filters (DPFs) combined with ultra low sulfur diesel fuel (ULSD). DPFs typically eliminate more than 90% of diesel PM and can reduce BC by as much as 99%, at a cost of ~ $11,000-$12,000/ton $PM_{2.5}$.
  - Internationally, other countries are adopting emission standards similar to EPA standards. However, standards for new engines lag behind in some regions, as does introduction of ULSD.

Figure 7-1. Estimated Changes in U.S. Mobile Source BC Emissions, 1990-2030.



Chp 7: Mobile Sources (cont.)

- Emissions from in-use engines can be reduced via diesel retrofits.
  - In the U.S., studies have shown DPFs can reduce PM emissions from in-use engines by up to 99%, at a cost of $5,000 to $15,000 for passive DPFs, and $20,000 to $50,000 for active DPF systems. However, not all engines are good candidates for DPFs because of old age or poor maintenance.
  - Other retrofit strategies include improved fleet maintenance practices; engine repower, upgrades, or reflash; cleaner fuels; fuel economy improvements; idle reduction programs; and shifts in mode of transportation.
  - Internationally, retrofit programs present significant financial and logistical challenges, especially in developing countries, where infrastructure is lacking to assist with vehicle registration, inspection and maintenance programs, technology certification/ verification programs, and application of readily available technologies.



Mitigation Approaches for Stationary Sources

- Dramatic decline in BC emissions from stationary sources in developed countries in 20th century
- Major source categories:
  - U.S.: coal combustion (industrial/commercial boilers, utilities) , industrial processes, and stationary diesel engines
  - Global: brick kilns, coke ovens (iron/steel production), industrial boilers
- Available controls/strategies:
  - Domestic: Fabric filters (baghouses), Electrostatic precipitators (ESPs), and DPFs (costs $35 - $500+/ton $PM_{2.5}$ + capital costs)
  - Global: replacement for smaller inefficient facilities, and/or application of existing control technologies

Photo: Clean Air Task Force

Mitigation Approaches for Residential Cooking and Heating

- 3 billion people depend on rudimentary stoves or open fires fueled by solid fuels (e.g., wood, dung, coal, charcoal, crop residues) for cooking and heating.
  - Current cookstove replacement programs hard to quantify: likely ~ 5-10 million improved stoves/year, but full stove market is 500-800 million homes
  - Reductions in emissions from this sector likely represent the largest public health opportunity among all the sectors considered in this report
- Available controls/strategies and costs
  - Solutions include: electric stoves; clean fuels (e.g., LPG, ethanol); processed solid fuels (e.g., charcoal, pellets); advanced biomass stoves; intermediate biomass stoves (e.g., rocket)
  - Not all solutions are available/affordable to all
  - Significant variability in performance among technologies– for both health and BC emissions

- Developed countries: residential wood combustion (RWC) may be significant source, especially in Arctic region
  - Replacing wood stoves/hydronic heaters and retrofitting fireplaces are most cost-effective strategies

Mitigation Approaches for Open Biomass Burning

- Largest source of BC emissions globally (however, total emissions of OC from this source category are 5-7 times higher).
  - Dominated by wildfire: in the U.S., wildfires account for 68% of BC emissions from open biomass burning.
  - Regions with highest emissions: Africa, Asia, and South America, followed by Russia/Central Asia and North America (but high interannual and regional variability).

- $PM_{2.5}$ emissions reduction techniques may reduce BC emissions from open biomass burning, but substantial uncertainty remains, especially given diverse, site-specific burning conditions.
- Appropriate mitigation measures depend on timing /location of burn, resource management objectives, vegetation type, and available resources.
- In world regions where biomass burning is widespread, mitigation will require training in proper burning techniques and tools to ensure effective use of prescribed fire.

Metrics for Comparing BC to other GHGs

- Due to differences between BC and CO_2, no single metric is widely accepted for comparison purposes.
- Metrics developed for well-mixed GHGs such as Global Warming Potential (GWP) and Global Temperature Potential (GTP) are difficult to apply to BC.
- New metrics designed specifically for short-lived climate forcers like BC have been developed, including the SFP (Specific Forcing Pulse) and STRE (Surface Temperature Response per unit continuous Emission).
- Simplified metrics such as carbon mass ratios (e.g., OC/BC ratios) can also be used to help prioritize among mitigation options.
- Explicit tradeoffs between BC and CO_2 may not be appropriate, depending on policy goals. Factors to consider:
  - Time scale (20 years, 100 years, or more)
  - Nature of the impact (radiative forcing, temperature, or more holistic damages)
  - Aspects included (indirect effects, snow albedo changes, co-emissions)
  - Whether sources and impacts should be calculated regionally or globally

Research Recommendations

1. Additional quantitative analysis examining the climate, public health, and environmental impacts of specific control strategies.
2. Continued investigation of basic microphysical and atmospheric processes affecting BC and other aerosol species to facilitate improvements in modeling and monitoring of BC.
3. Improving global, regional, and domestic emissions inventories with more laboratory and field data on activity levels, operating conditions, and technological configurations, coupled with better estimation techniques for current and future emissions.
4. Focused investigations of the role of brown carbon (BrC).
5. More detailed analysis of the climate and health benefits of controlling BC from sources of specific types or in specific locations.
6. Refinement of climate metrics specific to BC and other short-lived climate forcers.
7. Systematic analysis of key remaining uncertainties and technical gaps including: (a) model intercomparison of BC radiative forcing and climate impacts, and comparisons to ambient measurements; and (b) sensitivity analysis of the factors influencing model results.

Charge Questions

General Questions for All Chapters

- In the Panel's view, does the draft Report accurately interpret and clearly communicate the findings of the current scientific and technical literature, including important uncertainties, pertaining to black carbon (BC)? Based on this literature, what are the Panel's views on the preliminary conclusions as summarized in the Executive Summary and in the key messages for each chapter?
- Is the Panel aware of any additional, policy-relevant studies that should be included in the draft Report to inform the preliminary conclusions? Are there specific studies that should be given more or less emphasis?

Chapter 2: Black Carbon Effects on Climate

- Does the draft Report accurately identify and characterize light-absorbing carbonaceous particles, including BC and brown carbon?
- Does the draft Report adequately explain and appropriately characterize the differences between BC and long-lived greenhouse gases such as CO_2?
- Does the draft Report appropriately characterize the mechanisms by which BC affects climate and the full range of climate effects of BC (including best available estimates of the magnitude of those effects)?

Charge Questions (cont.)

Chapter 3: Black Carbon Effects on Public Health and the Environment

- Does the draft Report accurately summarize and interpret the body of scientific evidence relating to the potential public health effects of BC?
- Does the draft Report accurately summarize and interpret the body of scientific evidence with regard to potential non-climate environmental (welfare) effects of BC?

Chapter 4: Emissions of Black Carbon

- Does the draft Report appropriately characterize available information on historical, current and future emissions of BC and related compounds in the United States and globally, and present this information clearly?
- Does the draft Report accurately summarize and interpret currently available information regarding the transport of BC emissions downwind of sources and the relationship between the location of emissions sources and the geographic region of climate and non-climate impacts?

Chapter 5: Observational Data for Black Carbon

- Does the draft Report appropriately characterize and interpret the information on BC that is available from the observational record?

Charge Questions (cont.)

Chapters 6-10: Mitigation Approaches to Reduce Black Carbon Emissions

- Does the draft Report accurately reflect and clearly communicate information on the available technologies, control strategies, and costs of reducing BC emissions in various sectors? Are there additional control technologies or mitigation strategies for specific sources or sectors that have significant potential to reduce U.S. or global BC emissions that should be included in the Report?
- Can the Panel suggest other reliable sources of information on the costs of reducing BC emissions, particularly for international sources, that should be considered in the Report?
- Does the draft Report appropriately characterize the range and magnitude of potential benefits for both climate and public health that could result from reductions in BC emissions?

Chapter 11: Metrics for Comparing Black Carbon Impacts to Impacts of Other Climate Forcers

- Does the draft Report accurately describe the range and limitations of metrics available to quantify and/or communicate the climate effects of BC, to compare BC with long-lived greenhouse gases such as CO_2, and to compare among BC mitigation alternatives?

Charge Questions (cont.)

Chapter 12: Conclusions and Research Recommendations

- Does the draft Report appropriately identify the highest priority research needs regarding BC?

Technical Appendices

- Do the technical appendices to the draft Report contain any information that should be included in the main body of the Report?

BC Report to Congress: Schedule

Task or Milestone	Completion Date
External Review Draft (for Peer Review)	March 23, 2011
Black Carbon Review Panel meeting	April 18-19, 2011
Final Peer Review Comments	June/July 2011
Federal Interagency Review Process	August 2011
Submit Final Report to Congress	Fall 2011

- Draft report available at EPA's Science Advisory Board Website: http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommittees/COUNCIL

BC Report to Congress: Authors

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