BLACK CARBON
A REVIEW AND POLICY RECOMMENDATIONS

PRESENTATION TO THE US EPA
DECEMBER 12, 2008
**Policy Workshop Team:**

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OUTLINE:

- Challenges and Opportunities in Black Carbon Reduction
- Understanding the Importance of Black Carbon
- Addressing Domestic Black Carbon Emissions
- Addressing Black Carbon Abroad
- Policy Options to Coordinate Transnational Cooperation on Black Carbon
- Concluding Remarks
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CONTRIBUTION OF BC TO GLOBAL WARMING

Causes of Global Warming

- Greenhouse gases
- Fossil fuel + biofuel soot particles
- Urban heat island
- Cooling particles
- Net observed global warming

M.Z. Jacobson
BC CHALLENGES AND OPPORTUNITIES: A CONCEPTUAL OVERVIEW

- Global distribution of BC emissions
  - By type
  - By region
  - By sector

- Challenges of BC emissions reduction

- Opportunities for, and resulting from, BC emissions reductions
  - Policy
  - Politics
Types of Black Carbon emissions

- Contained BC emissions sources
  - Dominated by fossil fuel combustion
  - Organic carbon (OC) co-emitted in low concentrations
  - Strong warming effect

- Uncontained BC emissions sources
  - Dominated by agriculture, forests, and savannah burning
  - High OC co-emissions
  - Negligible or negative warming effect
GLOBAL ANNUAL EMISSIONS OF BC BY REGION AND SOURCE TYPE (GIGAGRAMS = KILOTONS)

Total share of global BC emissions in parentheses
GLOBAL BREAKDOWN OF BC EMISSIONS BY SOURCE

(Bond et al., 2004)
BREAKDOWN OF GLOBAL BC EMISSIONS BY SOURCE – WEIGHTED BY RADIATIVE FORCING CONTRIBUTION
Why is it hard to reduce Black Carbon emissions?

- Scientific uncertainty, complexity, and chemical variability of Black Carbon
- Large Proportion of Emissions from Developing Countries
- Dispersion of Emissions Sources
- High Cost of Replacement Technologies
- Administrative Challenges of Black Carbon Emissions Reduction
Oppportunities Presented by BC Mitigation

- Short Lifetime and High Radiative Forcing of BC means Reductions Yield Rapid Climate Benefits
- Immediate Availability of Solutions
- Health Benefits of Emission Reductions
- Energy Efficiency and Service Quality Gains
- Agricultural Yield and Sustainable Land Use
- Infrastructure Development
- Political Advantages and Funding Sources Chasing Co-Benefits
- Arctic Protection
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**Radiative Forcing**

- Measures the change in Earth’s energetic balance produced by a climate agent.
- An instantaneous measure, associated with atmospheric composition at a specific point in time.
- Does not imply anything about future radiative forcing.

![Graph showing effective radiative forcing for various greenhouse gases and other factors](image)

- **Effective Radiative Forcing (W/m²)**
  - CO₂, CH₄, other LLGHGs, BC + OC, Other aerosols, BC snow albedo, Other

**IPCC (2007)**
**Radiative Forcing**

- Measures the change in Earth’s energetic balance produced by a climate agent.
- An instantaneous measure, associated with atmospheric composition at a specific point in time.
- Does not imply anything about future radiative forcing.

![Effective Radiative Forcing](image)

Legend:
- IPCC (2007)
- Ramanathan and Carmichael (2008)
Approximate Contribution of Fossil Fuel and Biomass Carbonaceous Aerosols

Effective Radiative Forcing (W/m²)

-0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8

BC
Fossil Fuels (avg. OC:BC ~ 1)

OC

BC
Biomass (avg. OC:BC ~ 6)

OC

Snow Albedo

We commonly express total RF in terms of equivalent CO$_2$ (ppm CO$_2$e)

[CO$_2$e] = amount of CO$_2$ alone required to produce a given total radiative forcing

e.g., total LLGHG forcing of 2.66 W/m$^2$ = 454 ppm CO$_2$e
with BC & OC included: 2.9–3.2 W/m$^2$ = 480-510 ppm CO$_2$e

But note that these are aggregate metrics for atmospheric concentrations at a given point in time – it is much more difficult to compare emissions of aerosols to emissions of CO$_2$
That’s because the lifetimes are very different

Relative RF over time of one ton each of BC and CO₂ emitted over the course of one year

- Black Carbon
- CO₂
How does action or inaction on BC affect CO₂ emission reduction goals?

Addressed using a simple model of emissions, atmospheric lifetimes, and costs. Assume a baseline business-as-usual like IPCC SRES scenario A1B. Ignore SOx and NOx – assume they will be phased out for air quality reasons.

Assume costs of reductions ~ (fractional emission reduction)². Then what CO₂ emissions minimize cost while reaching a 450 ppm CO₂e target in 2100 (which provides 50% chance of warming <3.6º F [2ºC])?
How does action or inaction on BC affect CO$_2$ emission reduction goals?

Emission Scenarios leading to 450 ppm CO$_2$e (2.6 W/m$^2$) in 2100

**Scenario Set 1:**
With phaseout of carbonaceous aerosols from fossil fuel emissions

- Target CO$_2$e: 450 ppm
- Target CO$_2$: 375–388 ppm

**Scenario Set 2:**
Carbonaceous aerosol emissions constant at 1996 levels

- Target CO$_2$e: 450 ppm
- Target CO$_2$: 347–372 ppm

For each scenario, we calculate CO$_2$ emission trajectories using the IPCC (2007) forcing estimates for fossil fuel and biomass BC + OC aerosols, the Ramanathan and Carmichael (2008) estimates, and their average. In all scenarios, we assume constant biomass BC + OC emissions.
Scenario 1:
With phaseout of carbonaceous aerosols from fossil fuel emissions

Target CO₂e: 450 ppm
Target CO₂: 375–388 ppm
**Scenario 1: Phaseout**
Target CO$_2$: 375–388 ppm

**Scenario 2:**
Carbonaceous aerosol emissions constant at 1996 levels

Target CO$_2$: 450 ppm
Target CO$_2$: 347–372 ppm
**CO₂ EMISSIONS**

- **ACTION ON BC** is worth about 2 decades of action on carbon dioxide.

- **Unfortunately**, this action is implicit in most CO₂ emissions scenarios.

- **So NOT acting on BC** costs us about two decades, and may make a 450 ppm CO₂e target unreachable by 2100.
The BC forcing is strongly regionally.

Atmospheric solar heating due to BC (Ramanathan & Carmichael, 2008)

Special regions of concern in the Himalayas in the Arctic.

Modeled radiative forcing from the snow albedo effect (Hansen & Nazarenko, 2004)
NO SAFE THRESHOLD FOR PM EXPOSURE

Cost of health impact of vehicular PM emissions in urban areas:
$\sim$16,000 - $207,000/ton

(McCubbin & Delucchi, 1999)

**Figure 2.** The estimated concentration–response relation between PM$_{2.5}$ and the risk of death in the Six Cities Study, based on averaging the 32 possible models that were fit. Also shown are the point-wise 95% CIs around that curve, based on jackknife estimates.

(Schwartz et al., 2008)
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US SOURCES OF BC EMISSIONS

Transport, forest burning, and biofuel burning are the largest sources of BC emissions in the US.

Source: Bond et al. (2004) and Streets et al. (2004)
In terms of climate impacts, diesel emissions dominate.

Sources: Bond et al. (2004) and Streets et al. (2004)
Diesel engines emit far more BC per ton than gasoline engines and have little co-emitted OC.

**PM Emissions Factors (g/kg)**

- Diesel non-farm off-road
- Diesel farm engines
- Diesel, on-road general
- Gasoline

Sources: Bond et al. (2004)
Diesel Engine Retrofits

- Retrofit technology can reduce BC emissions by up to 90%.

- Retrofitting is cost effective for the health benefits of reduced BC emissions alone.

- Decreased efficiency (3.5-8.5%) from retrofitting could result in greater GHG and BC emissions than a regular gasoline engine (Jacobson 2005).
SHORT-TERM POLICY OPTIONS

- Improve vehicle fuel efficiency for on-road vehicles

- Locate and replace super-emitters
  - Emissions factors 10 times those of other diesel vehicles
  - Inspection and enforcement are key
  - Market-based approaches

- Continue to enforce Bush administration’s stringent off-road diesel standards
  - Expected to cut “harmful” diesel emissions by 2010
  - Inspection and enforcement are key

- Improve funding for retrofit programs for both on- and off-road vehicles
  - Dirty vehicle tax to fund retrofits
  - Guarantee “retrofit loans” for small fleet owners
  - Tax breaks and subsidies to construction firms, large farms
LONG-TERM POLICY OPTIONS

- Make BC emissions mitigation a priority in the Obama fiscal stimulus package, citing both health and climate concerns

- Create avenues for intermodal freight transport
  - Case study: DOT’s Red Hook Container Barge Project
    - Removed 54,000 trucks from NY/NJ highways

- Encourage switching away from fossil fuels
  - Use stimulus funding to improve the efficiency, range, and performance of non fossil-fuel technologies
  - Provide economic incentives for manufacturers and consumers of these technologies
SWITCHING AWAY FROM FOSSIL FUELS

- Filtered diesel engines and CNG are relatively “clean” in terms of PM emissions
  - Should be used for larger govt. vehicles (e.g. buses)

- However, both have significant GHG emissions and are non-renewable

- Develop and promote technologies that are renewable, sustainable, clean, and have low radiative forcing
  - E.g. Plug-in hybrid electric vehicles (PHEVs) and battery operated electric vehicles (BEVs)
  - Switch govt. vehicles to these technologies
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FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

- Developing nation BC emission are large and growing
  - China, India, Africa, Central/South America:
    - 67% of global BC emissions
    - 55% of net global RF from BC + OC
    - GDP Growth 2003-2007: China (10.8%), India (8.9%)

- More vulnerable to the impacts of climate change

- Health impacts of BC emission are greater

- Nascent infrastructure development

- Co-benefits of air pollution control provide opportunity for future engagement on climate change.
FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

- Developing nation BC emission are large and growing
- More vulnerable to the impacts of climate change
  - Countries in the weakest economic condition are the most vulnerable to climate change impacts [IPCC, 2007]
- Health impacts of BC emission are greater
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FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

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FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

Figure 3: Smoky streets, smoky homes
Typical 24-hour mean levels of small particles (PM_{10}) in micrograms per cubic metre (µg/m³), early 2000s

USEPA annual standard 50

Berlin city centre  Bangkok roadside  Hut with open fire

USEPA, US Environmental Protection Agency.

ENGINEERS WITHOUT BORDERS-PRINCETON PROJECT IN HUAMANZANA, PERU
FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

- Developing nation BC emission are large and growing
- More vulnerable to the impacts of climate change
- Health impacts of BC emission are greater
- Nascent infrastructure development
  - Vehicle fleets are projected to grow exponentially
- Co-benefits of air pollution control provide opportunity for future engagement on climate change
FOCUSING BC REDUCTIONS IN THE DEVELOPING WORLD

- Developing nation BC emission are large and growing
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- Co-benefits of air pollution control provide opportunity for future engagement on climate change.
IDENTIFYING AREAS OF OPPORTUNITY: GROSS ANNUAL BC INVENTORY BY REGION AND SECTOR

Adapted from Bond et al. (2004)
IDENTIFYING AREAS OF OPPORTUNITY: GLOBAL NET BC EMISSIONS (BC - 1/6 OC) BY REGION AND SECTOR

Adapted from Bond et al. (2004)
Areas of opportunity: Sector & Region

- Diesel in Asia
  - Status
    - Asian diesel 5% of global BC emissions in 1996.
    - Diesel consumption in Asia increased 90% between 1990 and 2008
  - Projections for India
    - Indian middle class projected to grow from 53 to 583 million between 2007 and 2025
    - Indian per capita VMT projected to increase 3X between 2001 and 2030
- Mitigation Avenues
  - Accelerate deployment of Ultra Low Sulfur Diesel Fuel combined with stronger vehicle emission standards.
  - Improved fuel efficiency / fuel switching
  - Transportation infrastructure planning
Areas of opportunity: Sector & Region

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Residential Biofuel in China & India

Status
- Residential biofuel emissions were 875 of 7950 Gg of global emissions in 1996
- 39% from China, 35% from India in 1996

Mitigation Avenues
- Gather information
  - Regional Wood Energy Development Programme (RWEDP)
  - Aethalometer deployment to monitor indoor emissions
- Disseminate information
- Promulgate standards
  - ISO standards
  - Performance testing and emission verification
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Areas of Opportunity: Sector & Region

Industrial Sources in China & Russia

Status
- Industrial sources account for 25% of China BC, 10% of Russia BC (potential Arctic deposition)
- Combined are 6.5% of global BC emissions

Mitigation Avenues
- Source characterization (especially small industry)
- Clean technology transfer
Areas of Opportunity: Sector & Region

- Industrial Sources in China & Russia

  - Status
    - 25% of China BC, 10% of Russia BC (potential Arctic deposition)
    - Combined 6.5% of emission globally

  - Mitigation Avenues
    - Source characterization (especially small industry)
    - Clean technology transfer
Open Biomass Burning in Africa & Latin America

Status

- 31% of global BC emission (10% forest, 19% savannah, 2% ag res)
- Higher OC:BC ratios than in contained burning mean reduction may result in net short-term warming from reduction of aerosols

Mitigation Avenues

- Biochar as soil amendment and for carbon sequestration
  - Predicated on re-allocation of biomass otherwise open burned
  - Collection of biomass required (rather than burning in place)
- Private agricultural sector engagement
  - EPA as advisor on corporate environmental strategy
Open Biomass Burning: Africa & Latin America

Status
- 31% of global BC emission (10% forest, 19% savannah, 2% ag res)
- Higher OC: BC ratios mean reduction is net cooling

Mitigation Avenues
- Biochar as soil amendment and for carbon sequestration
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  - Collection of biomass required (rather than burning in place)
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Effect of changes in short-lived aerosols on US summer temperature in 2100 relative to 2000 (Levy et al, 2008)

Temperature Difference Compared to 2000 in Degrees Celsius

(Levy et al, 2008)
HOW DO GLOBAL ENVIRONMENTAL PROBLEMS GET SOLVED?

- Example: Protecting the Stratospheric Ozone Layer -- the Montreal Protocol
  - Scientific discovery and continued research
  - Creation of global conferences and institutions as a forum for international debate
  - Focal point for public awareness: e.g. ozone hole
  - Some unilateral actions
  - Strong economic reasons (cost-benefit)
  - Industry involvement
  - Technology Assessment Panels
  - Funding for developing countries

Black Carbon has a long way to go by these measures...
POSSIBLE VENUES FOR INTERNATIONAL RESEARCH AND DISCUSSION FOR BLACK CARBON

- UNFCCC – “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference”

- LRTAP – Hasn’t regulated PM or BC before, but a 2007 taskforce found that:
  “inter-continental transport of particulates has significant implications for climate change” and recommended that air quality and climate change policies of member countries should be considered together

  (‘Review of the Gothenburg Protocol’ by CIAM)

- The Arctic Council – for Arctic BC deposition
Venues to Include Developing Countries

- International institutions responding to growing concern of particulates around the world could be a path to engagement:
  - Acid Deposition Network in East Asia (EANet)
  - Regional Air Pollution in Developing Countries (RAPIDC)
  - Air Pollution Information Network for Africa (APINA)
  - Emissions Database for Global Atmospheric Research (EDGAR)
POLICY SUGGESTIONS FOR DEVELOPING TRANSNATIONAL COOPERATION

- UNFCCC IPCC Special Report on Black Carbon as a Climate Forcing Agent

- Create an annual international conference on BC organized by UNFCCC, LRTAP, WHO, AGU, EPA, etc. to link climate and health impacts and mitigation strategies.

- Funding for BC research and emissions inventories

- Form an international technology assessment panel to explore BC mitigation strategies
Should Emissions Reductions of BC and GHG Be Traded?

- Many small sources make monitoring and enforcement a serious issue, present emissions inventories (4-22Gg) have large uncertainties – baseline?

- BC has a short lifetime, effects on climate vary depending on source and location AND it has spatially dependent health impacts, which confounds tradability of emissions with GHGs for a market price

- Adding BC to a delicate global climate negotiation would add complexity to the process, could create resistance from developing countries, and likely delay progress on both BC and GHG emission reductions
Policy Options for BC Reductions

- Reduce BC in Developed Countries
- Regional Hot-spot treaties (e.g., Arctic and Himalayas)
- Global Technical Standard
- Multi-lateral funds and technical assistance for developing countries
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CONCLUDING REMARKS

- BC is not like GHGs
- 2°C target is very difficult without tackling BC
- BC has strong regional effects
- BC has costly impacts on human health

- Developing nations: Major growing contributors
- Developing nations are more vulnerable to climate and health effects
- Focus on transport fleet (new vehicles and retrofits) and stoves

BC Science

- Target transportation sector
- Diesel retrofits cost effective for health reasons
- Improve fuel efficiency
- Locate super-emitters
- Reduce off-road vehicle emissions
- Fuel switching

BC in the U.S.

BC Abroad

International Policy

- Promote Awareness - Need IPCC Special Report on BC
- Hot-Spot treaties
- Global Technical Standards
- Multilateral funds
- No trading of BC with GHG
- Emissions Trading
- BC to BC?
DIRECTIONS FOR FUTURE RESEARCH

- Resolution of uncertainties in optical properties and atmospheric mixing state
- Resolution of uncertainties in vertical distribution and transport
- Development of impact metrics based on source and receptor region, with particular attention to Himalayas and Arctic as receptors
- Integrated Assessment Modeling of emissions strategies that address both BC and carbon dioxide