WOODROW WILSON SCHOOL of Public & International Affairs

Black Carbon
A Review and Policy Recommendations

Presentation to the US EPA
December 12, 2008

Policy Workshop Team:

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- **Frank Norcross**, is second-year masters student in the Woodrow Wilson School. His field of concentration is Economics and Public Policy with a certificate in Science, Technology, and Environmental Policy.
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- **Faculty Advisor: Denise Mauzerall**, (PhD, Harvard) is an Associate Professor of Public and International Affairs in the Science, Technology and Environmental Policy Program in the Woodrow Wilson School of Public and International Affairs at Princeton University. Her research is at the intersection of air quality and climate change.

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- **Rosa Shim**, National Clean Diesel Campaign, U.S. EPA
- **Clare Sierawski**, U.S. Department of State
- **Bill Snape**, Center of Biological Diversity, Washington College of Law, American University
- **Daniel Sperling**, University of California, Davis
- **Kimmo Teinila,** Finnish Meteorological Institute
- **Jan T. Thompson**, Royal Norwegian Embassy in Moscow
- **Tom Wenzel**, Lawrence Berkeley National Laboratory

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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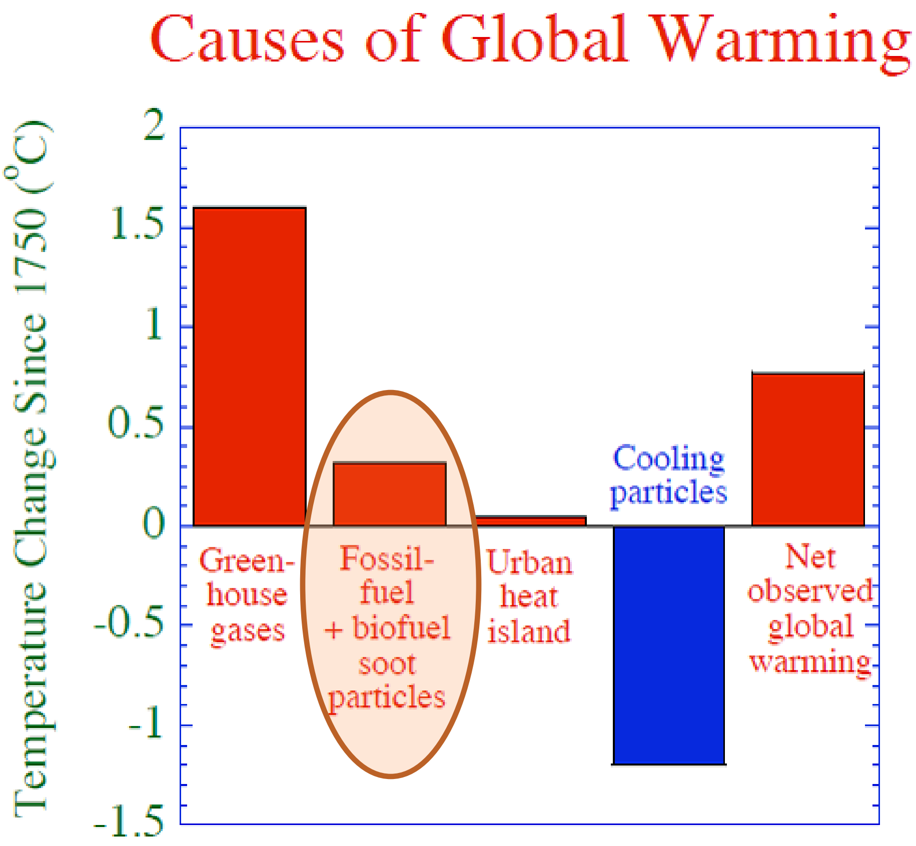
Contribution of BC to global warming



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

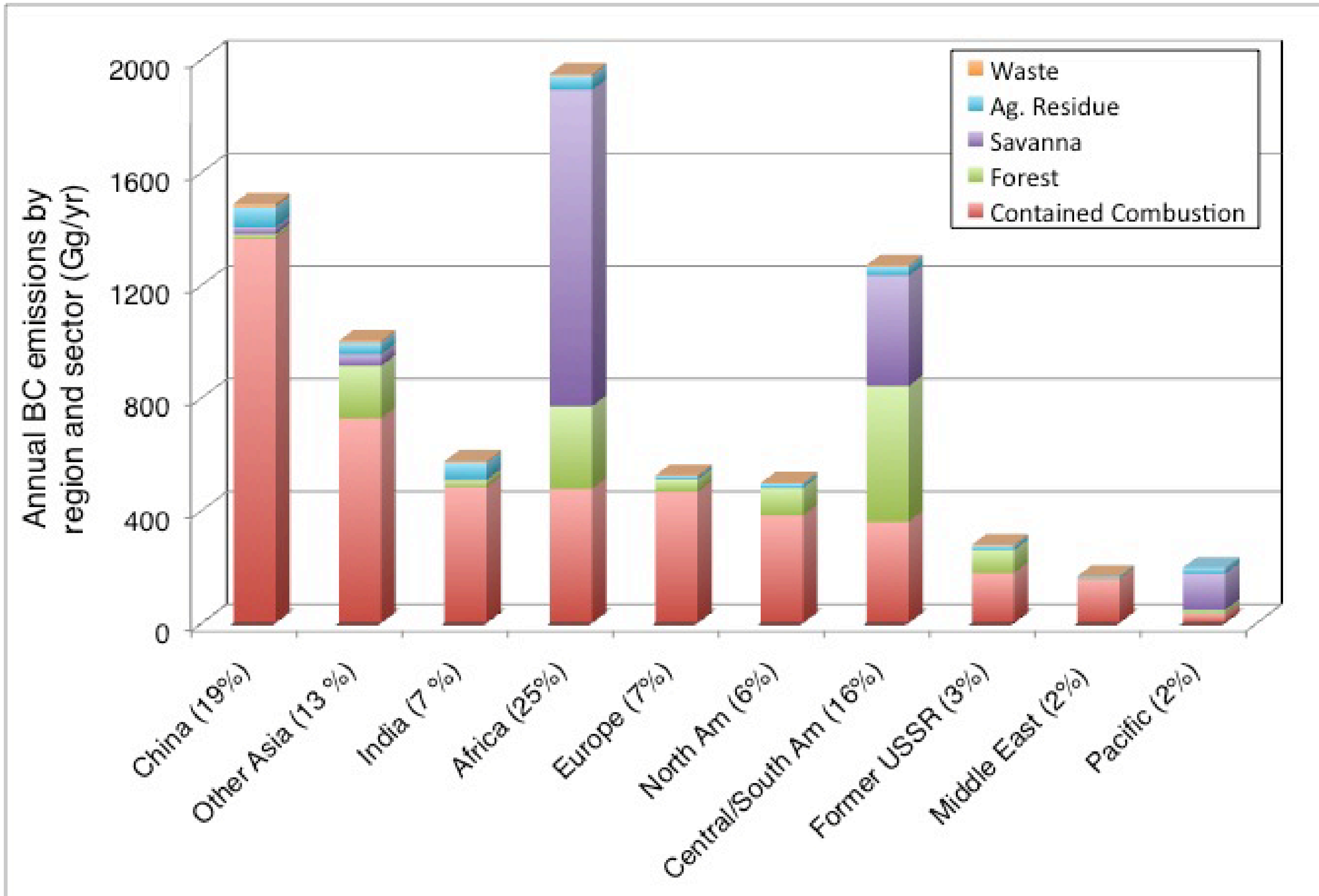
- Opportunities for, and resulting from, BC emissions reductions
  - Policy
  - Politics

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

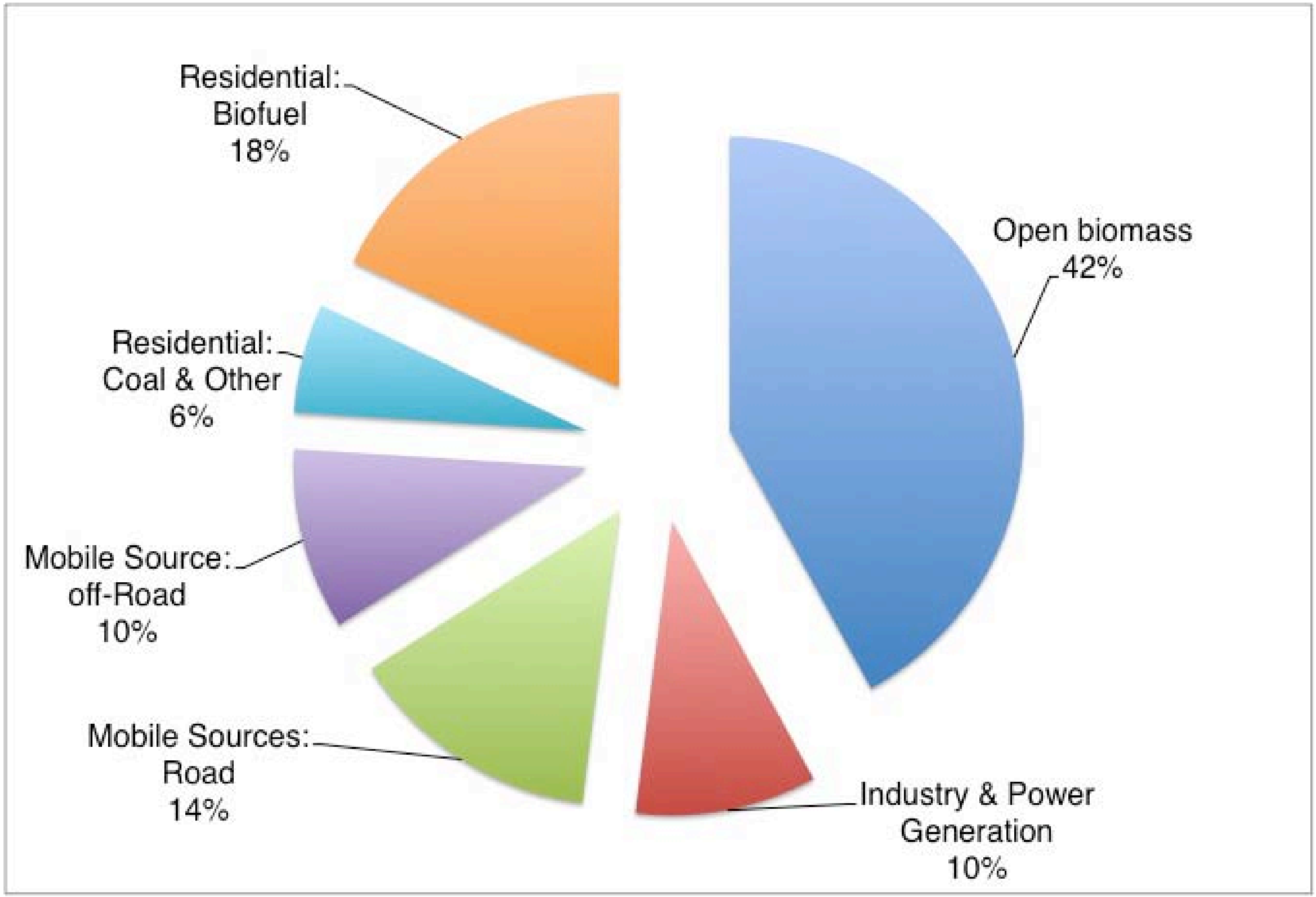
- Uncontained BC emissions sources
  - Dominated by agriculture, forests, and savannah burning
  - High OC co-emissions
  - Negligible or negative warming effect

Global annual emissions of BC by region and source type (gigagrams = kilotons)



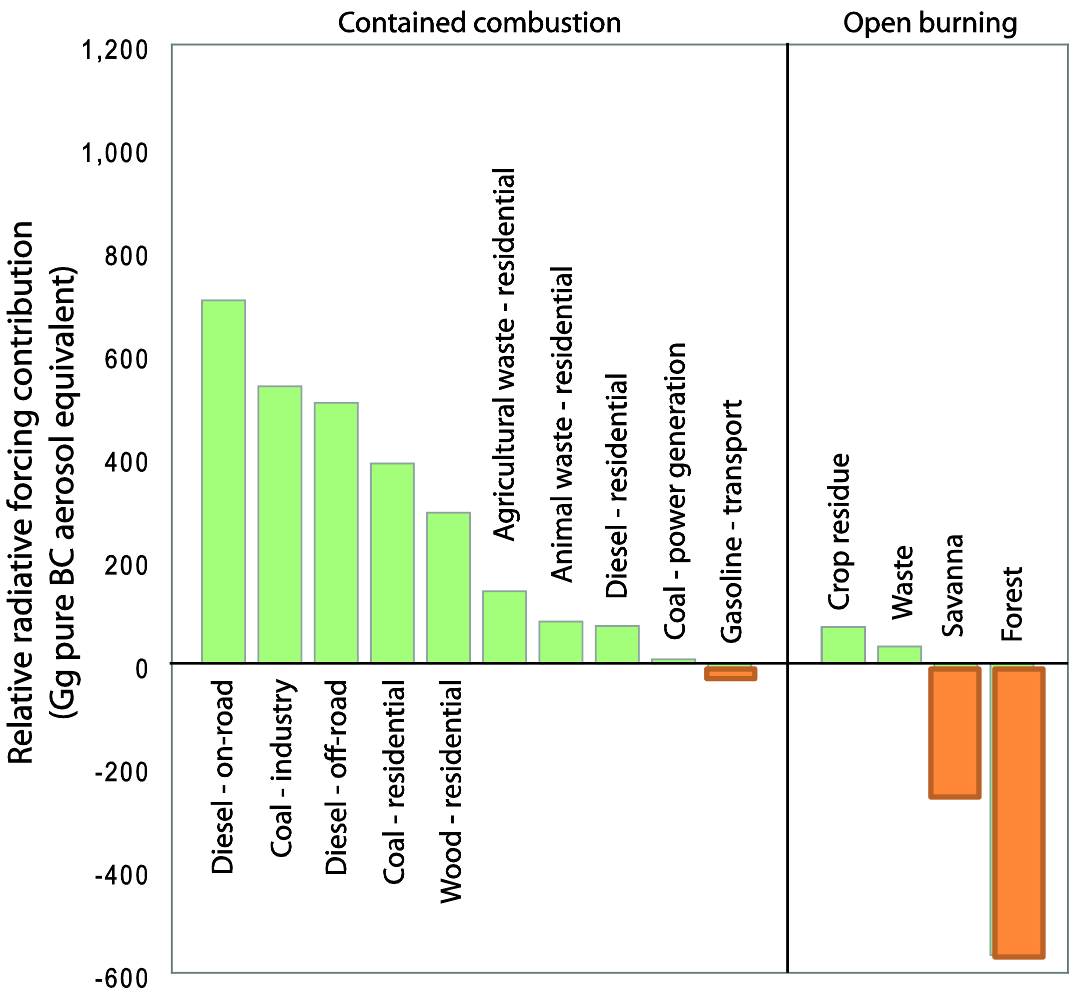
Total share of global BC emissions in parentheses

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

Opportunities 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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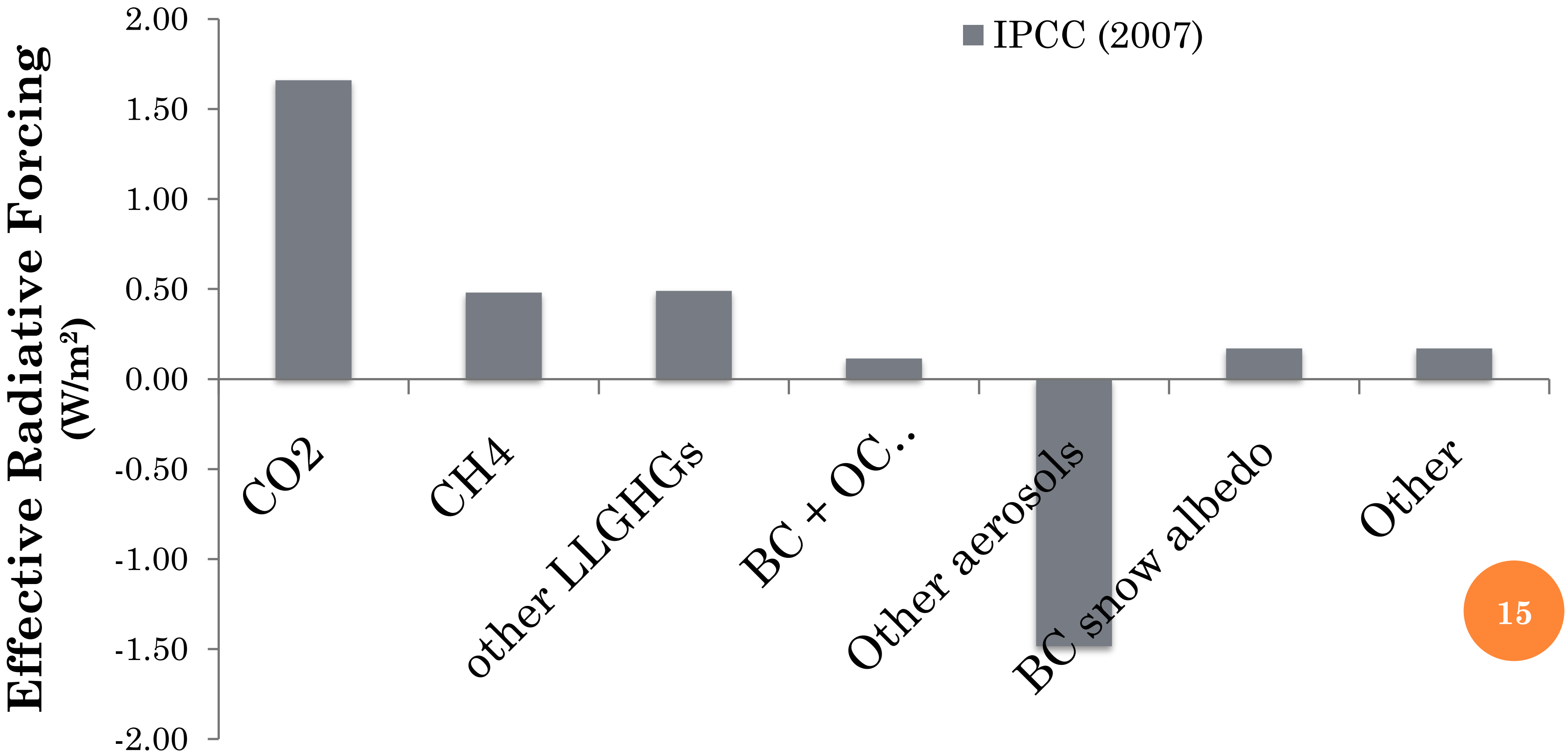
Radiative Forcing

- 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



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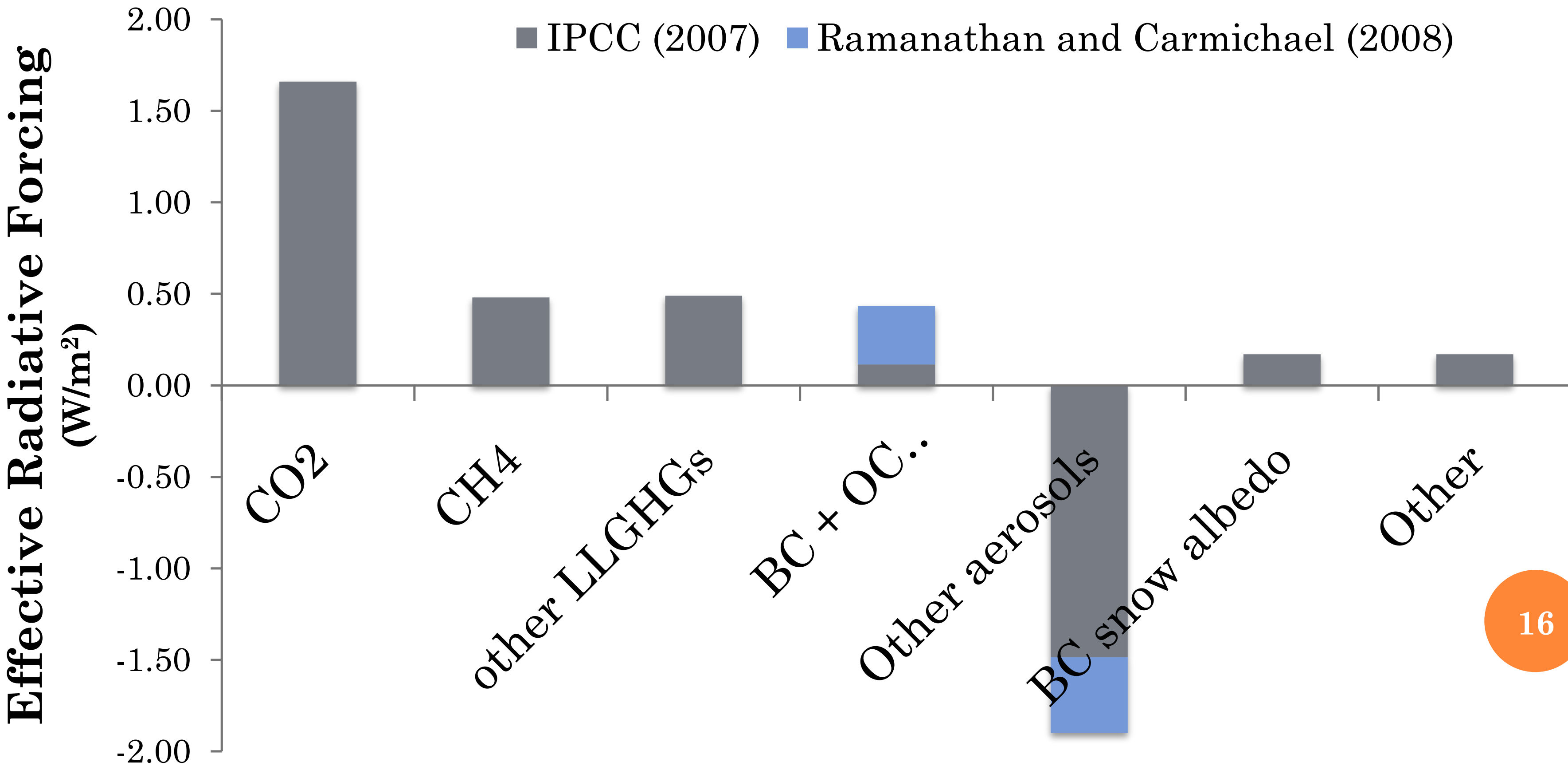
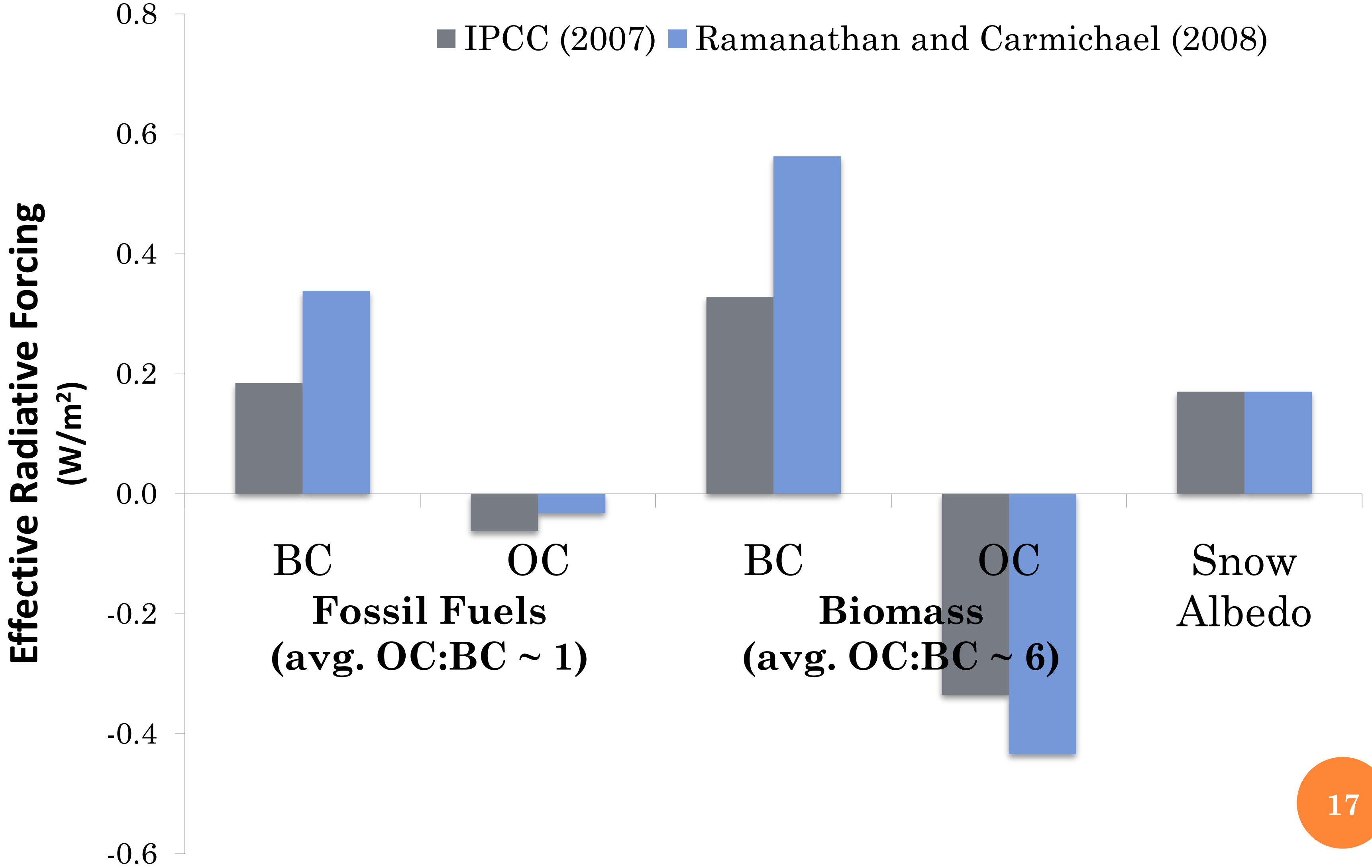


Approximate Contribution of Fossil Fuel and Biomass carbonaceous Aerosols



We commonly express total RF in terms of equivalent CO_2 (ppm CO_2e)

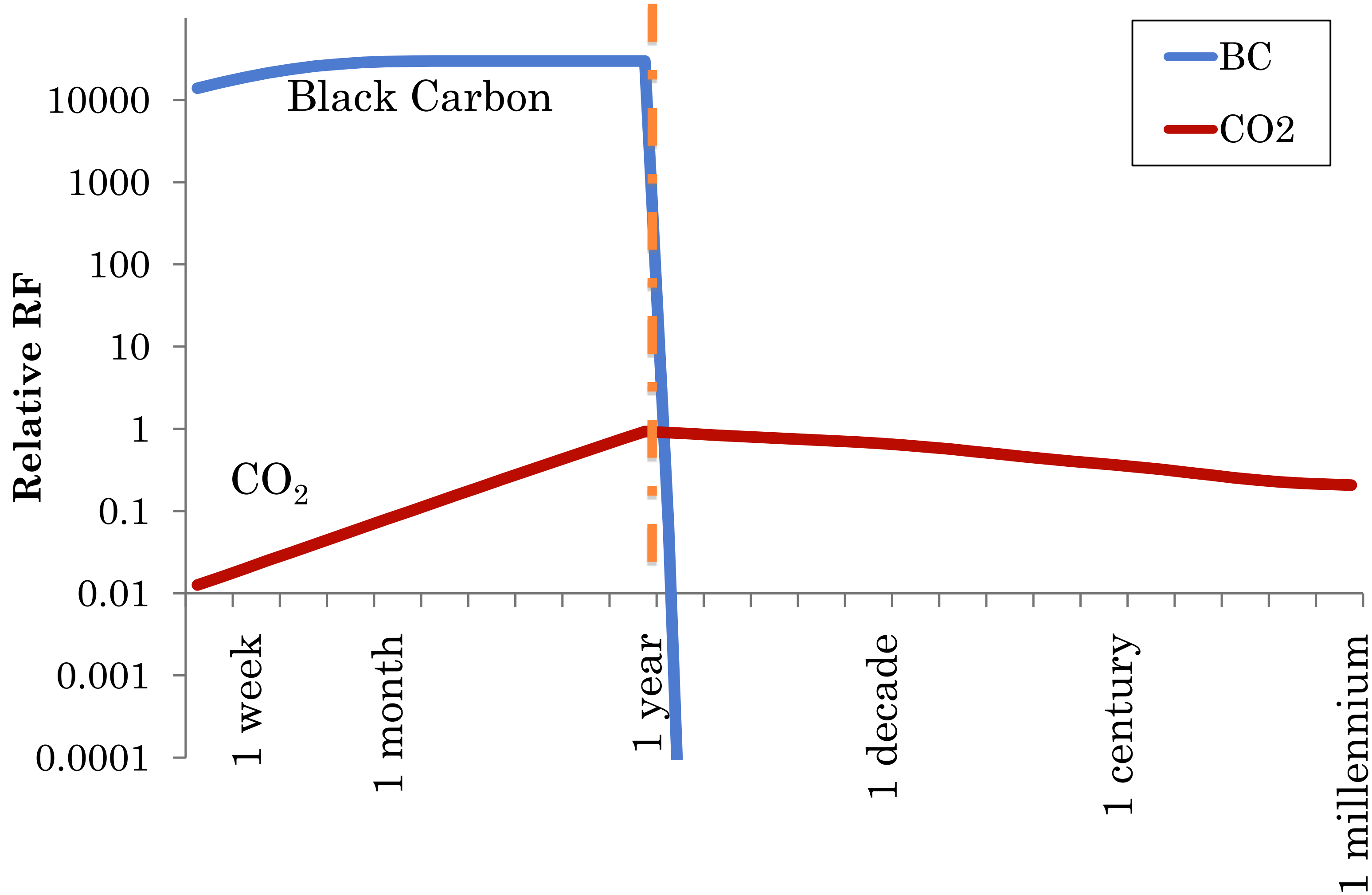
[CO_2e] = amount of CO_2 alone required to produce a given total radiative forcing

e.g., total LLGHG forcing of 2.66 W/m^2 = 454 ppm CO_2e
with BC & OC included: 2.9–3.2 W/m^2 = 480-510 ppm CO_2e

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

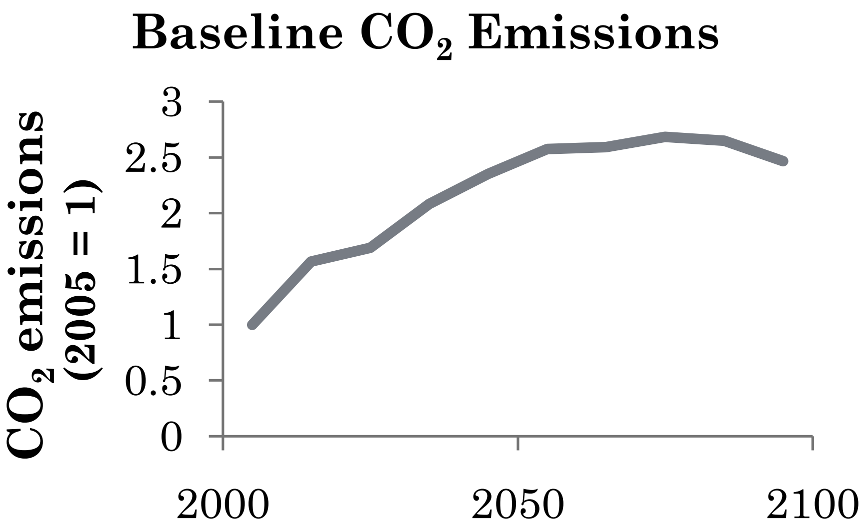
That's because the lifetimes are very different

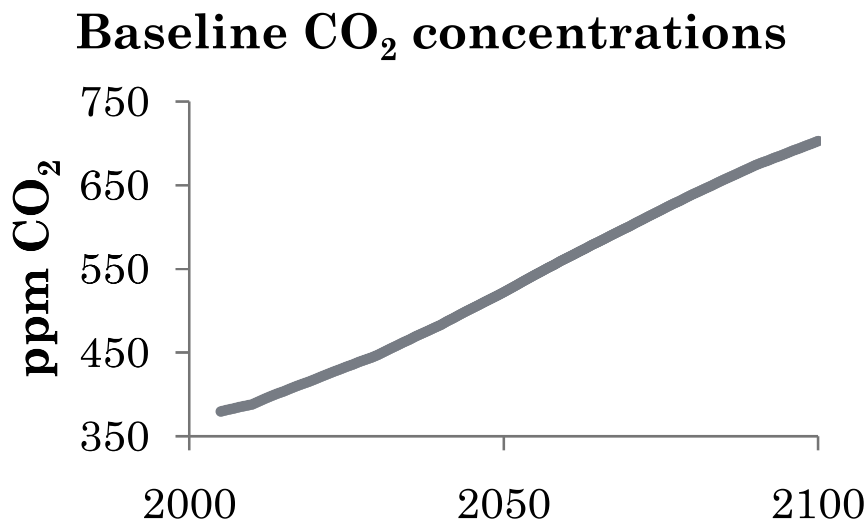
Relative RF over time of one ton each of BC and CO_2 emitted over the course of one year



How does action or inaction on BC affect CO_2 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 CO_2 emissions minimize cost while reaching a 450 ppm CO_2e 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_2e (2.6 W/m^2) in 2100

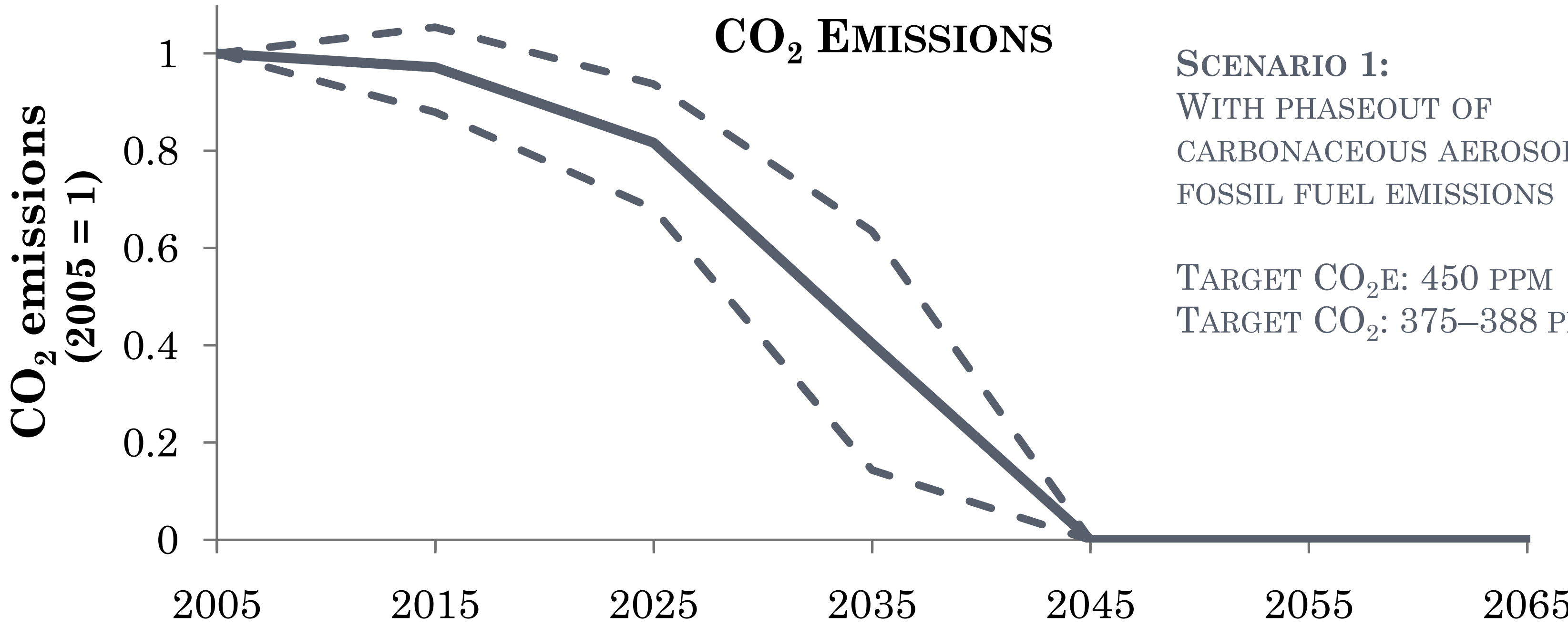
Scenario Set 1:
With phaseout of carbonaceous aerosols from fossil fuel emissions

Target CO_2e: 450 ppm
Target CO_2: 375–388 ppm

Scenario Set 2:
Carbonaceous aerosol emissions constant at 1996 levels

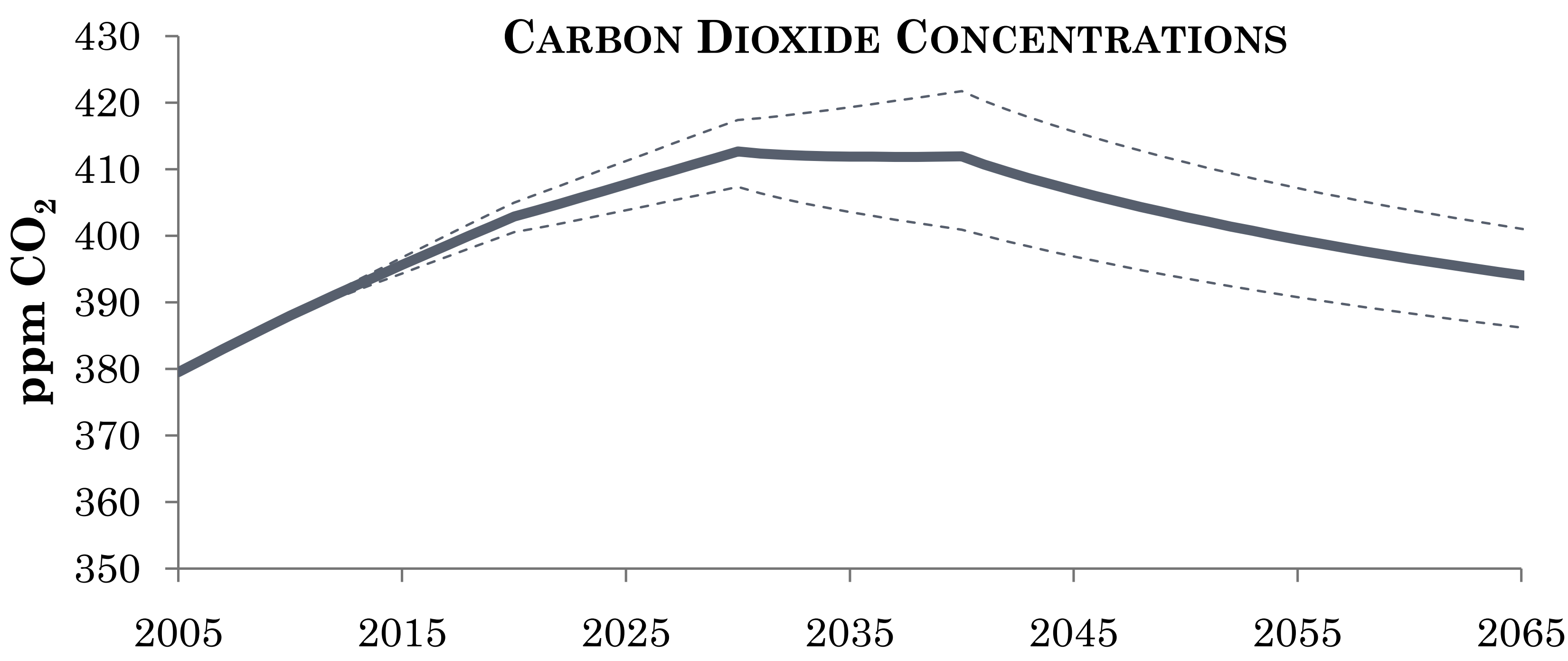
Target CO_2e: 450 ppm
Target CO_2: 347–372 ppm

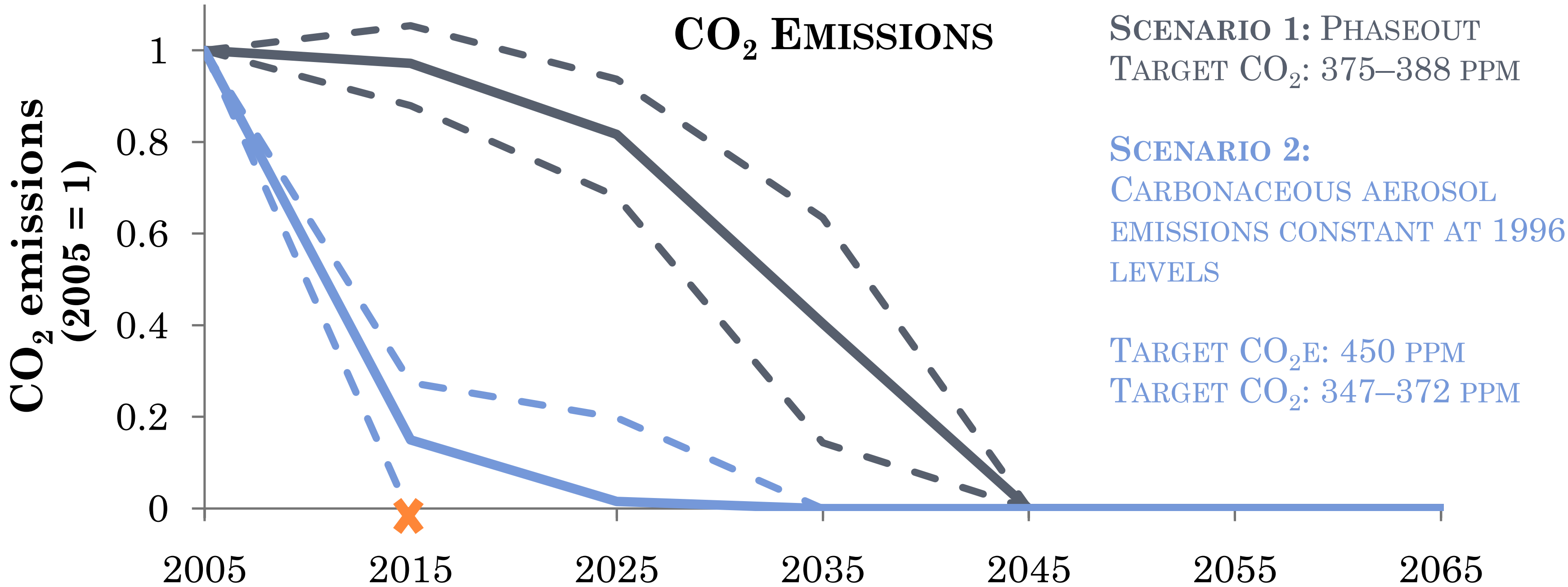
For each scenario, we calculate CO_2 emission trajectories using the IPCC (2007) forcing estimates for fossil fuel and biomass BC + OC aerosols, the Ramanathan and Carmichael (2008) estimates, and their average. In all scenarios, we assume constant biomass BC + OC emissions.



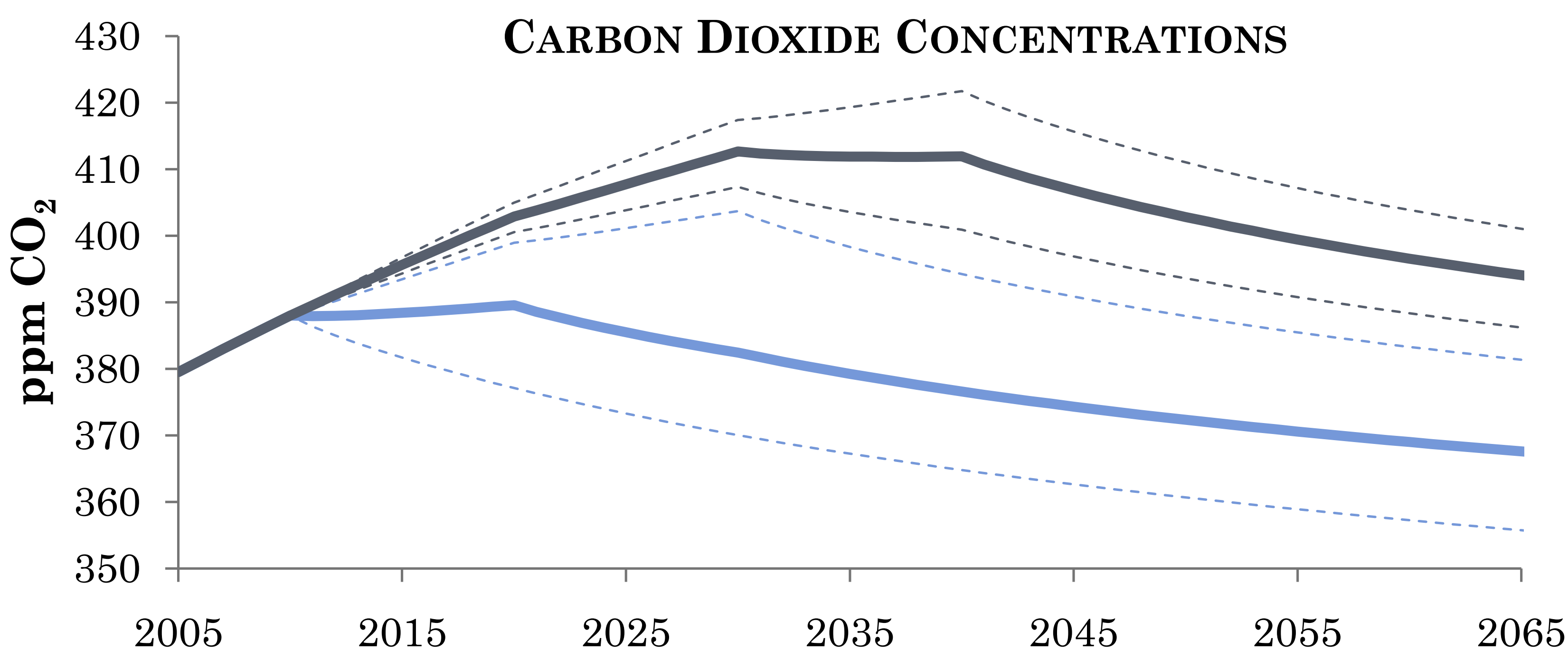
Scenario 1:
With phaseout of carbonaceous aerosols from fossil fuel emissions

Target CO_2e: 450 ppm
Target CO_2: 375–388 ppm

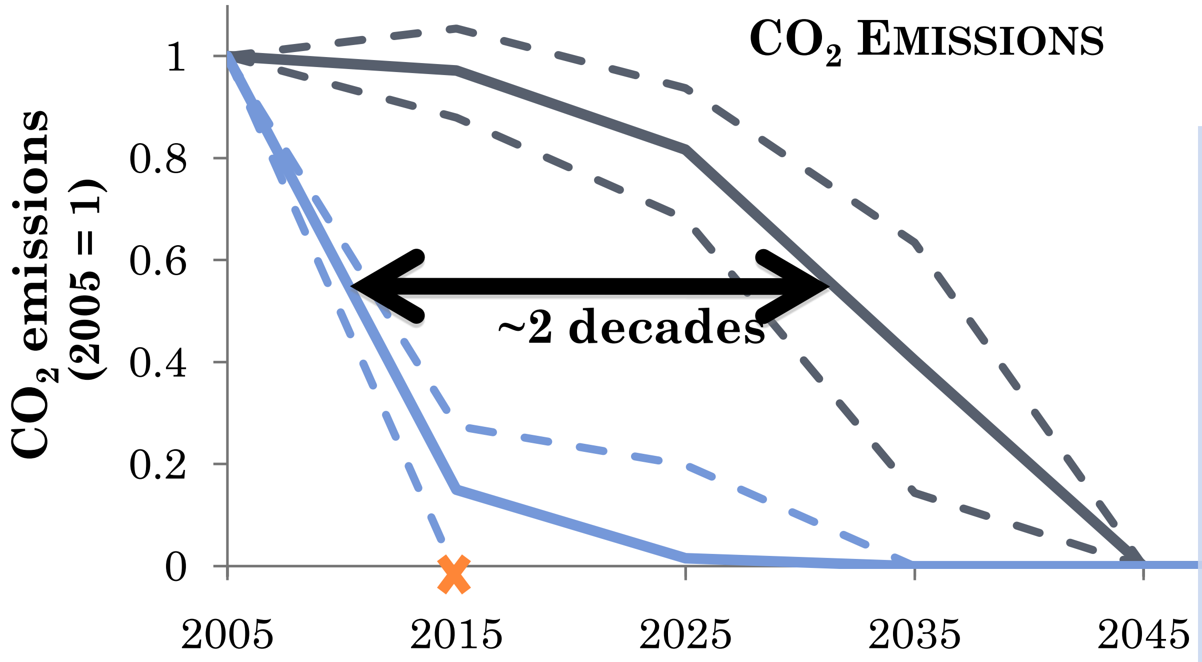




CO_2 EMISSIONS
CO_2 emissions (2005 = 1)
1
0.8
0.6
0.4
0.2
0
2005
2015
2025
2035
2045
2055
2065
SCENARIO 1: PHASEOUT
TARGET CO_2: 375–388 PPM
SCENARIO 2:
CARBONACEOUS AEROSOL EMISSIONS CONSTANT AT 1996 LEVELS
TARGET CO_2E: 450 PPM
TARGET CO_2: 347–372 PPM



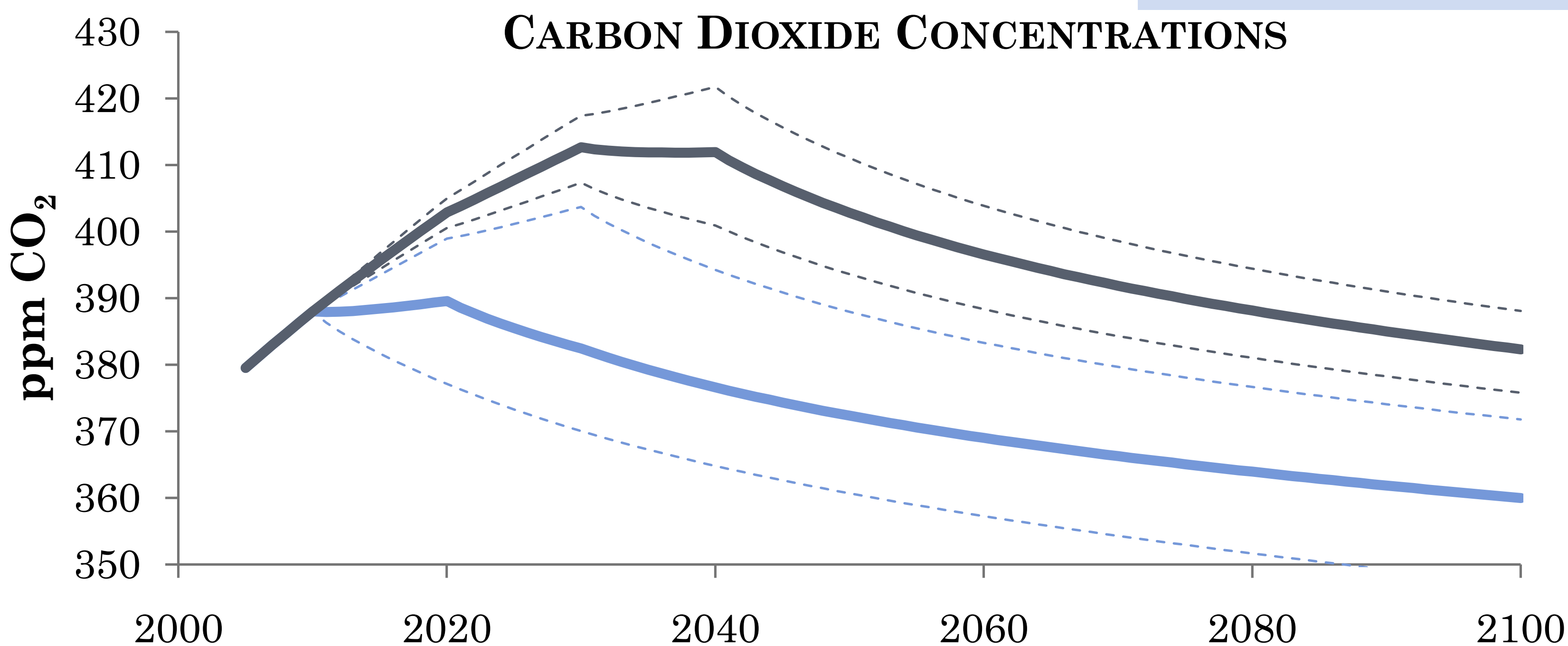
CARBON DIOXIDE CONCENTRATIONS
ppm CO_2
430
420
410
400
390
380
370
360
350
2005
2015
2025
2035
2045
2055
2065



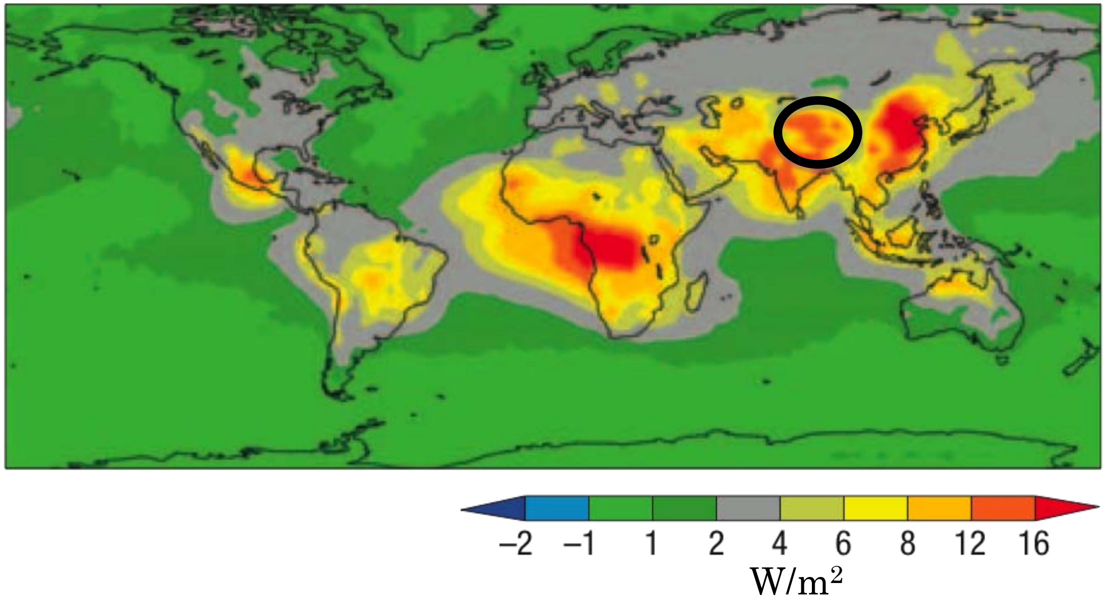
Action on BC is worth about 2 decades of action on carbon dioxide.

Unfortunately, this action is implicit in most CO_2 emissions scenarios.

So NOT acting on BC costs us about two decades, and may make a 450 ppm CO_2e target unreachable by 2100.

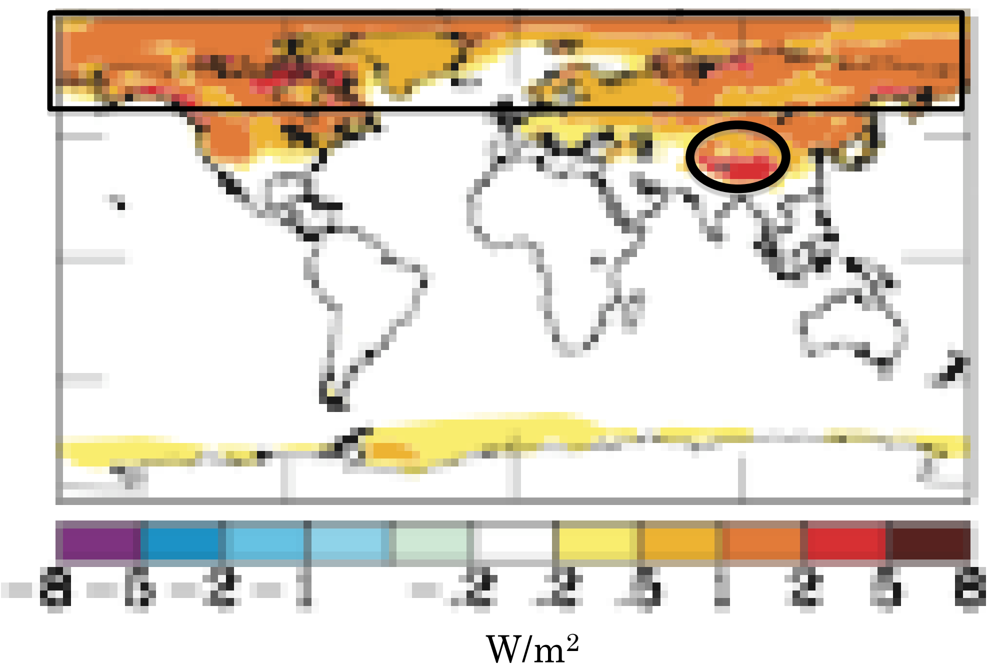


THE BC FORCING IS STRONGLY REGIONAL



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

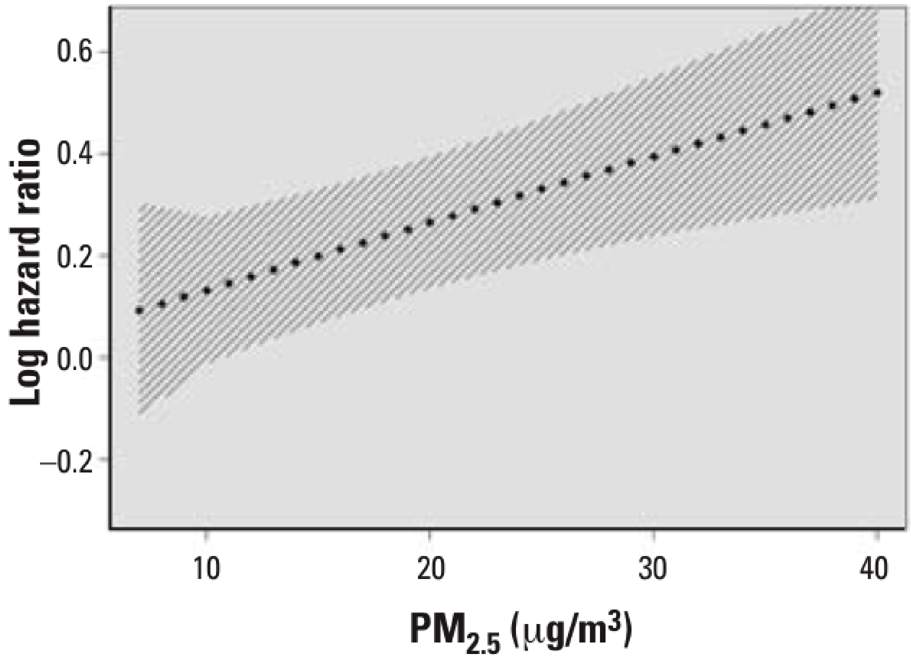


Figure 2. The estimated concentration–response relation between $PM_{2.5}$ and the risk of death in the Six Cities Study, based on averaging the 32 possible models that were fit. Also shown are the pointwise 95% CIs around that curve, based on jacknife estimates.

(Schwartz et al., 2008)

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

(McCubbin & Delucchi, 1999)

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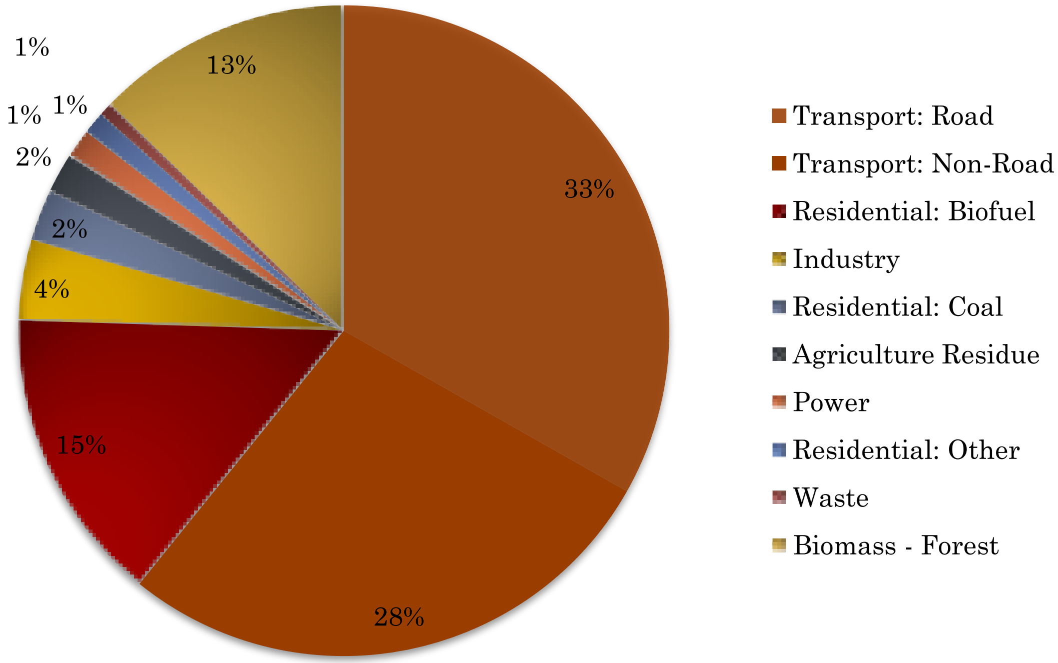
US Sources of BC Emissions

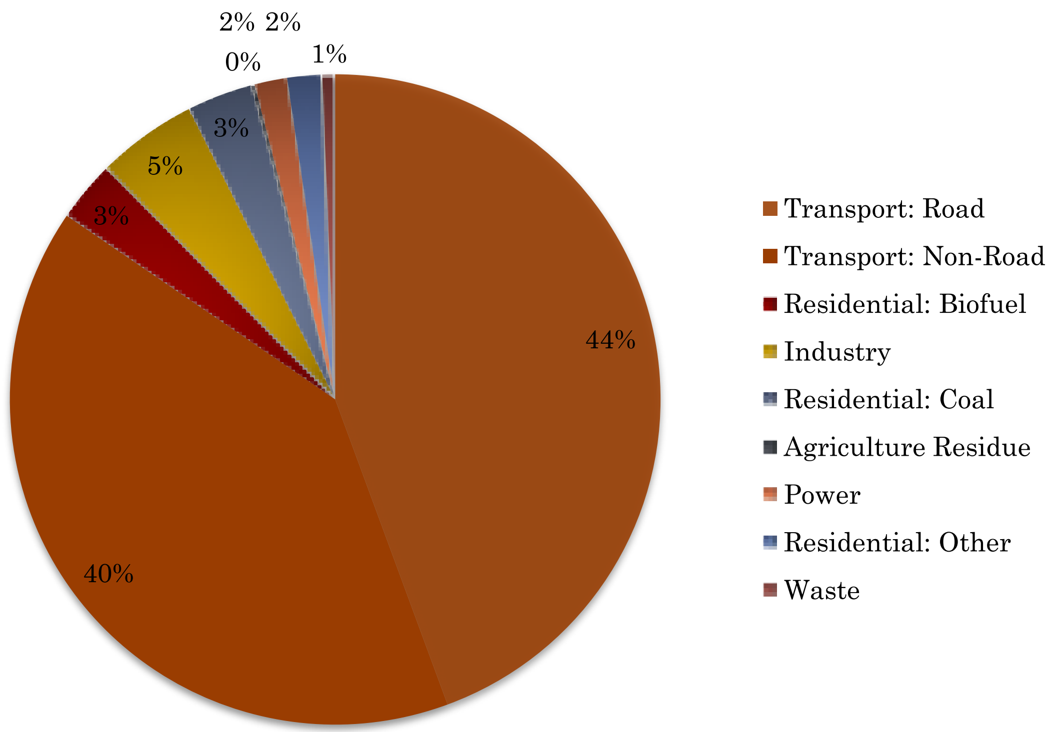
- Transport, forest burning, and biofuel burning are the largest sources of BC emissions in the US.



Source: Bond et al. (2004) and Streets et al. (2004)

Radiative forcing of BC from US Sources

- In terms of climate impacts, diesel emissions dominate.



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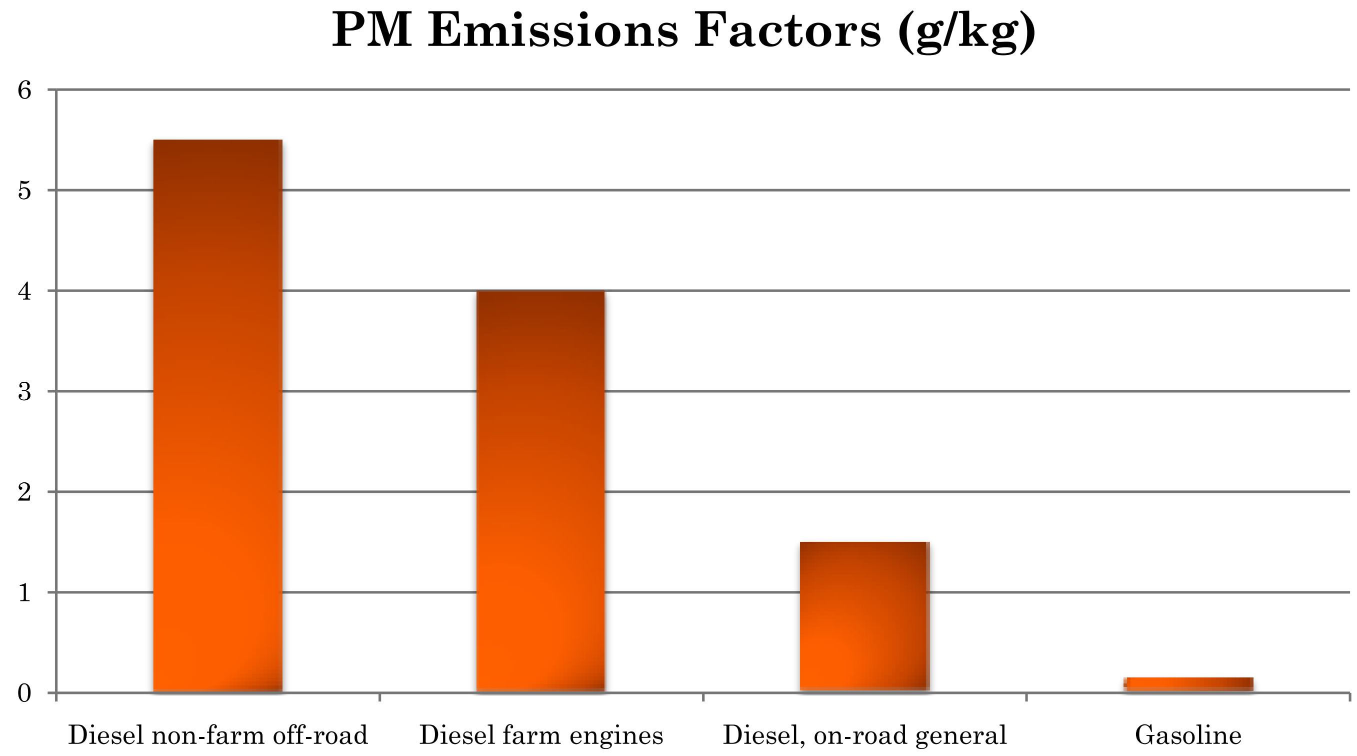
Diesel Engines

- Diesel engines emit far more BC per ton than gasoline engines and have little co-emitted OC.



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]*
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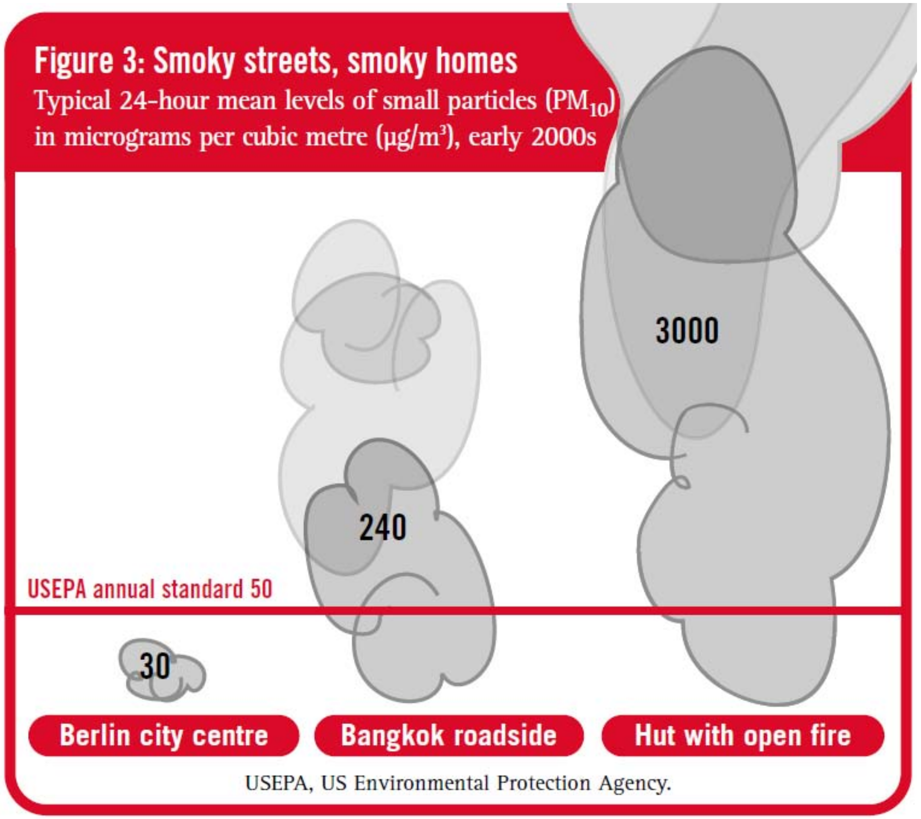

Engineers without Borders-Princeton Project in Huamanzana, Peru

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

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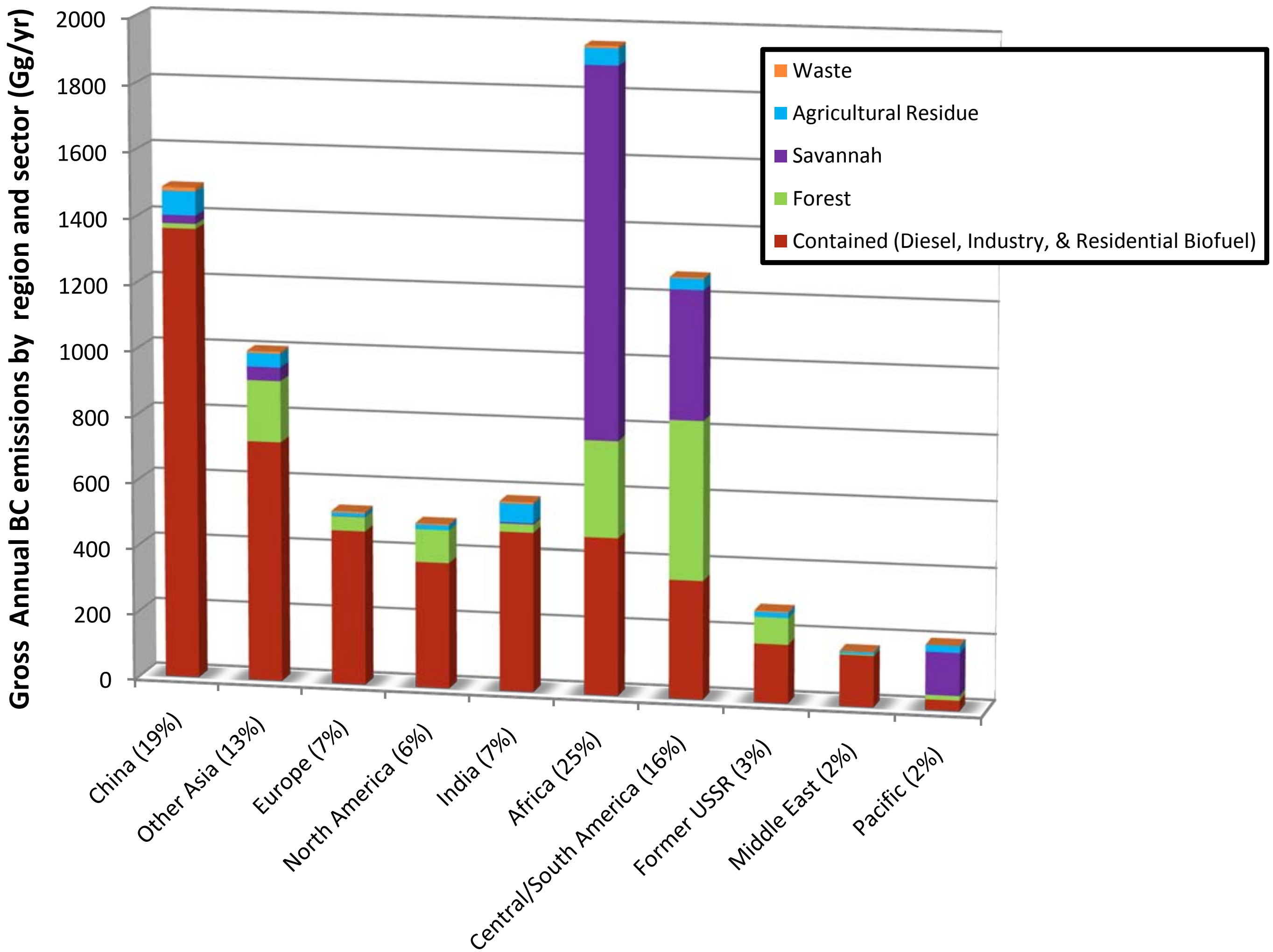
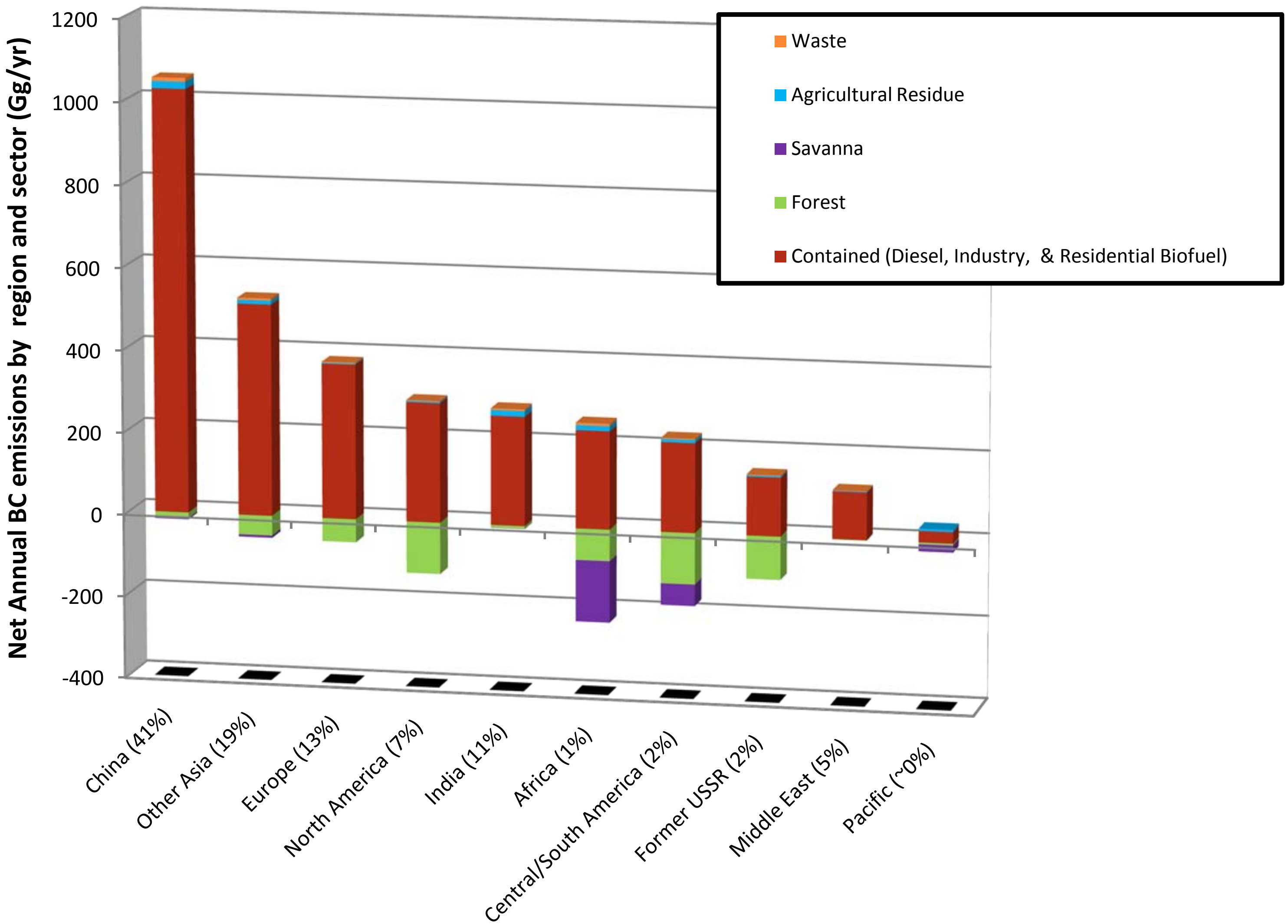
IDENTIFYING AREAS OF OPPORTUNITY:
GROSS ANNUAL BC INVENTORY BY REGION AND SECTOR



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

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Areas of opportunity: Sector & Region

- 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

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    - 25% of China BC, 10% of Russia BC (potential Arctic deposition)
    - Combined 6.5% of emission globally
  - Mitigation Avenues
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    - Clean technology transfer

Areas of opportunity: Sector & Region

- 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

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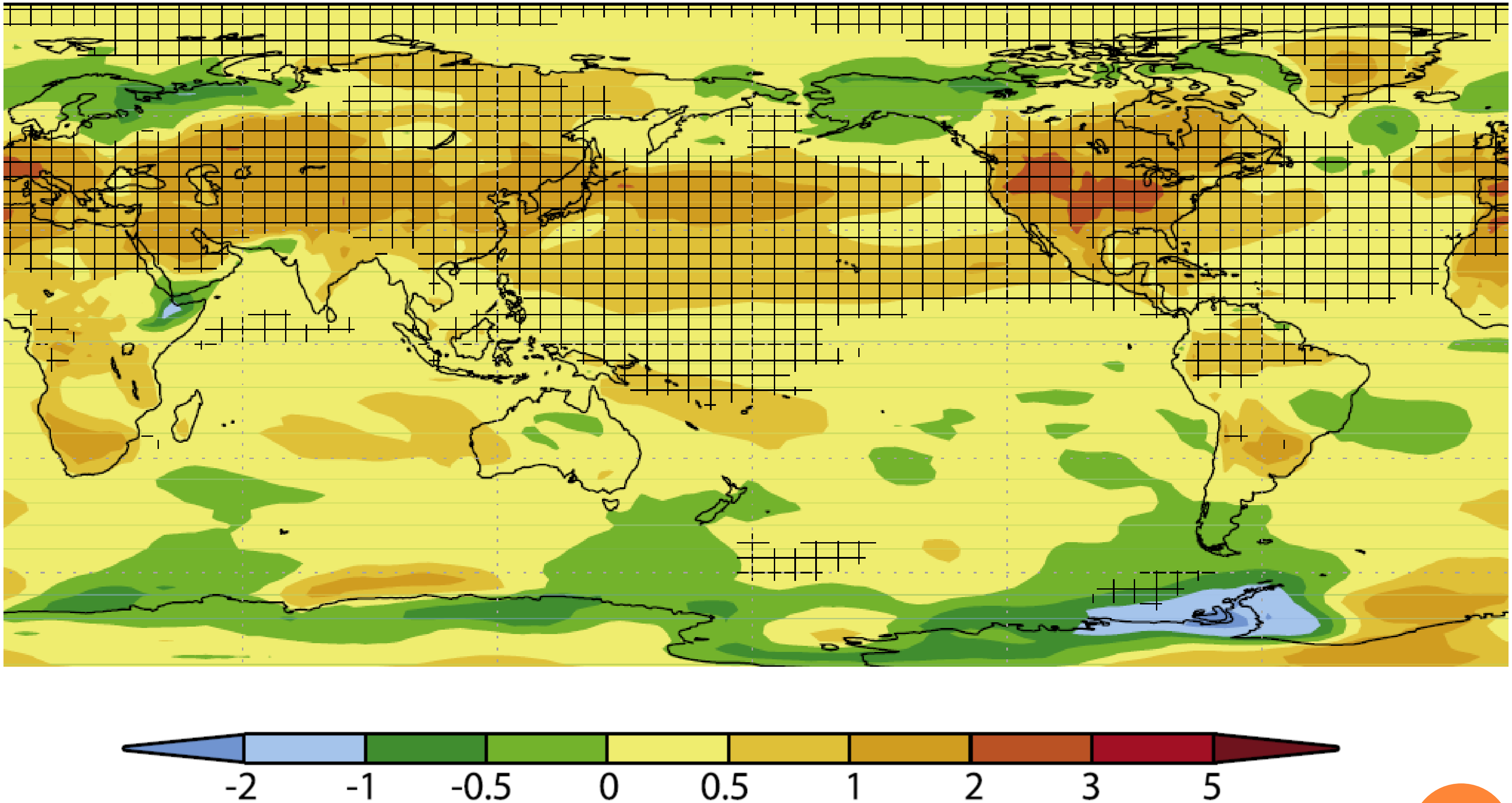
- Policy Options to Coordinate Transnational Cooperation on Black Carbon
- Concluding Remarks

Effect of changes in Short-Lived Aerosols on US Summer Temperature in 2100 relative to 2000



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 (eg. Arctic and Himalayas)
- Global Technical Standard
- Multi-lateral funds and technical assistance for developing countries

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

Concluding Remarks

BC Science

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

BC in the U.S.

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

BC Abroad

- 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

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