Overview of Black Carbon

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Region 9 Black Carbon Symposium
November 14, 2012

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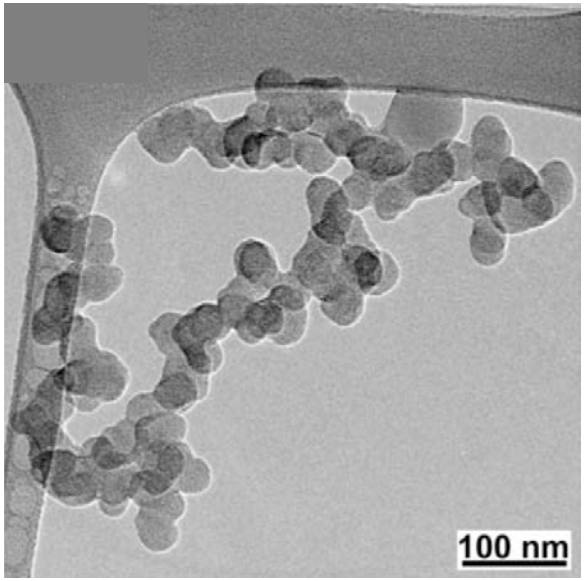
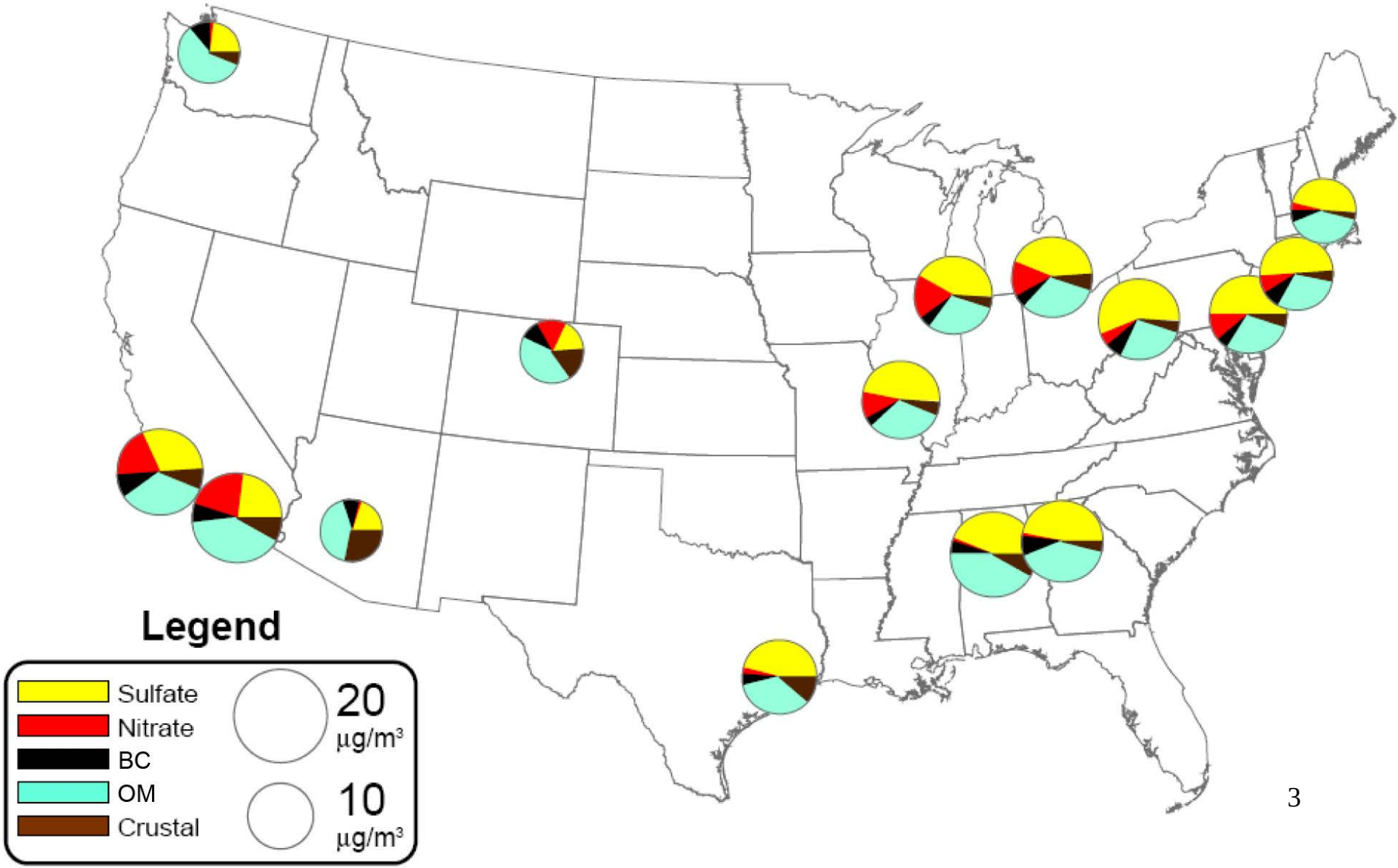
What is Black Carbon?



- Black carbon is the most strongly light-absorbing component of particulate matter (PM).
  - BC is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths.
- Other types of particles, including sulfates, nitrates and organic carbon (OC), generally reflect light.

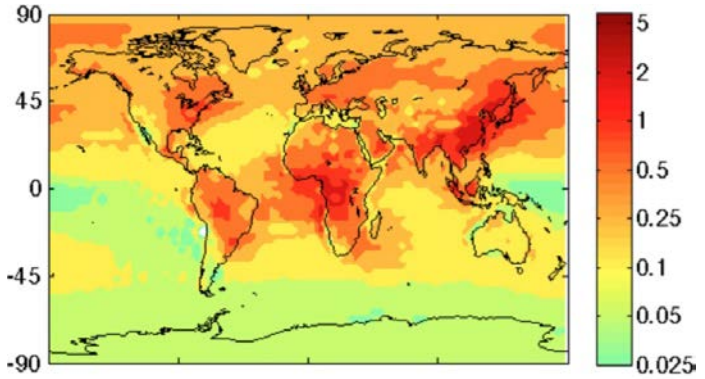
- BC is formed by incomplete combustion of fossil fuels, biofuels, and biomass.
- BC is emitted directly into the atmosphere in the form of fine particles (i.e., "direct $PM_{2.5}$").
- BC is a major component of "soot", a complex light-absorbing mixture that also contains organic carbon.

Composition of $PM_{2.5}$ for 15 Selected Urban Areas in the United States



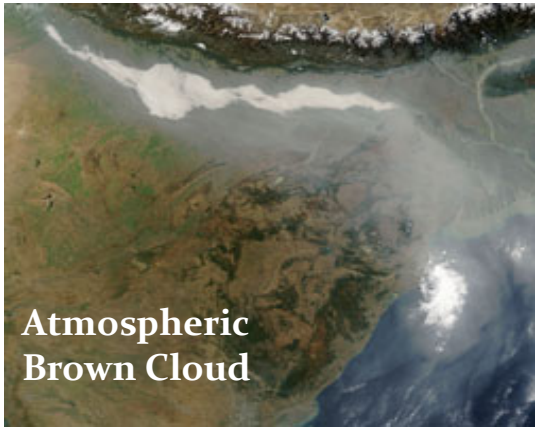
Climate Effects of Black Carbon

- BC influences climate by:
  - directly absorbing light (⇒ warming)
  - reducing the reflectivity ("albedo") of snow and ice through deposition (⇒ warming)
  - interacting with clouds (⇒ cooling and/or warming)
- BC's climate impacts likely include increased global average temperatures and accelerated ice/snow melt.
- Sensitive regions such as the Arctic and the Himalayas are particularly vulnerable to warming/melting effects of BC.
- BC also contributes to surface dimming, the formation of ABCs, and changes in the pattern and intensity of precipitation.



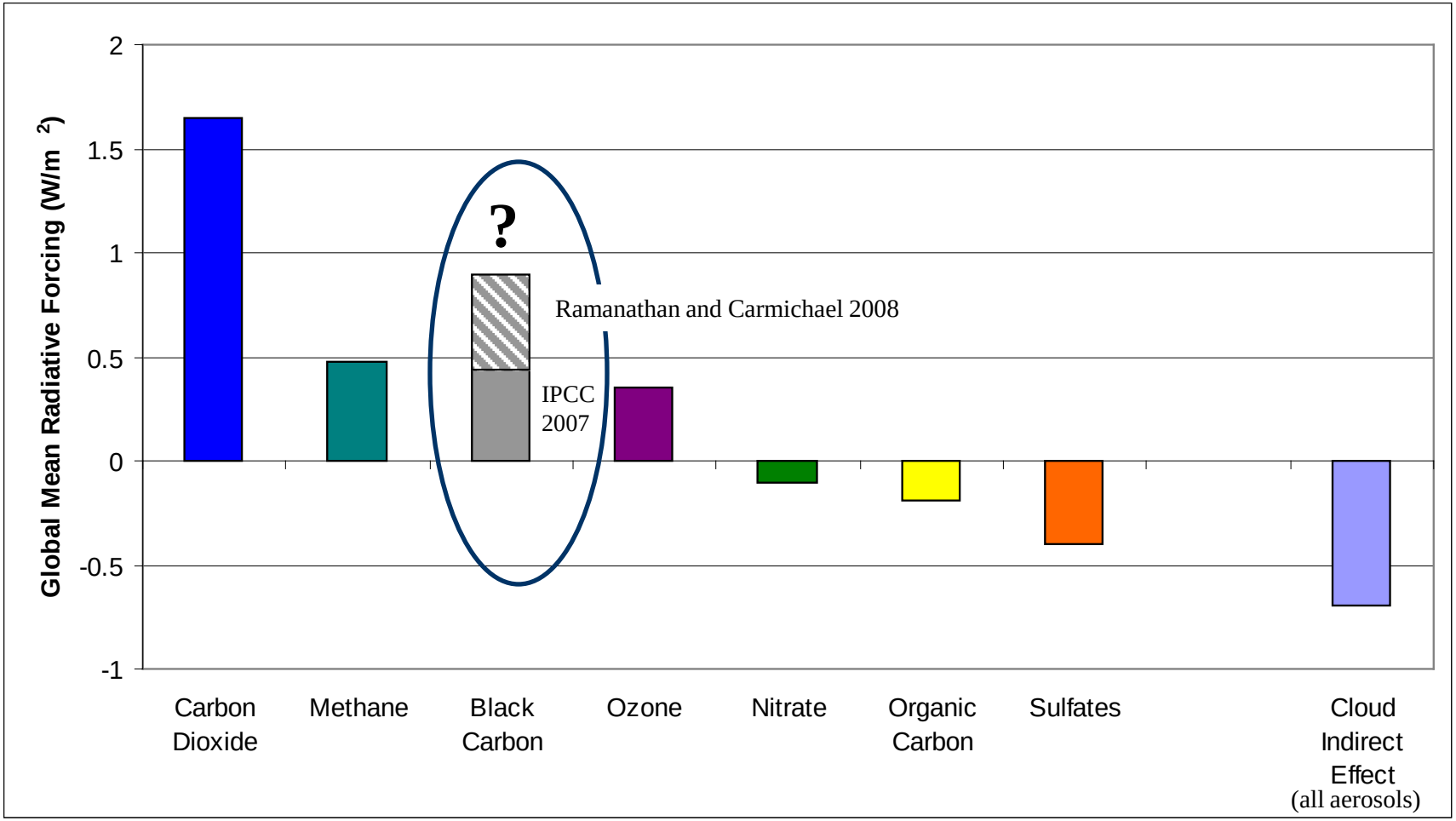
Global Direct Forcing due to Black Carbon
(Watts per square meter, from Bond. et al., 2007)

Deposition on Snow/Ice



NASA Goddard Space Flight Center/Jeff Schmaltz

Comparison of Global Average Radiative Forcing of Key Short-Lived Forcers vs. CO_2



(Adapted from IPCC Synthesis Report, 2007; as well as Ramanathan and Carmichael, 2008)

BC Impacts: Arctic

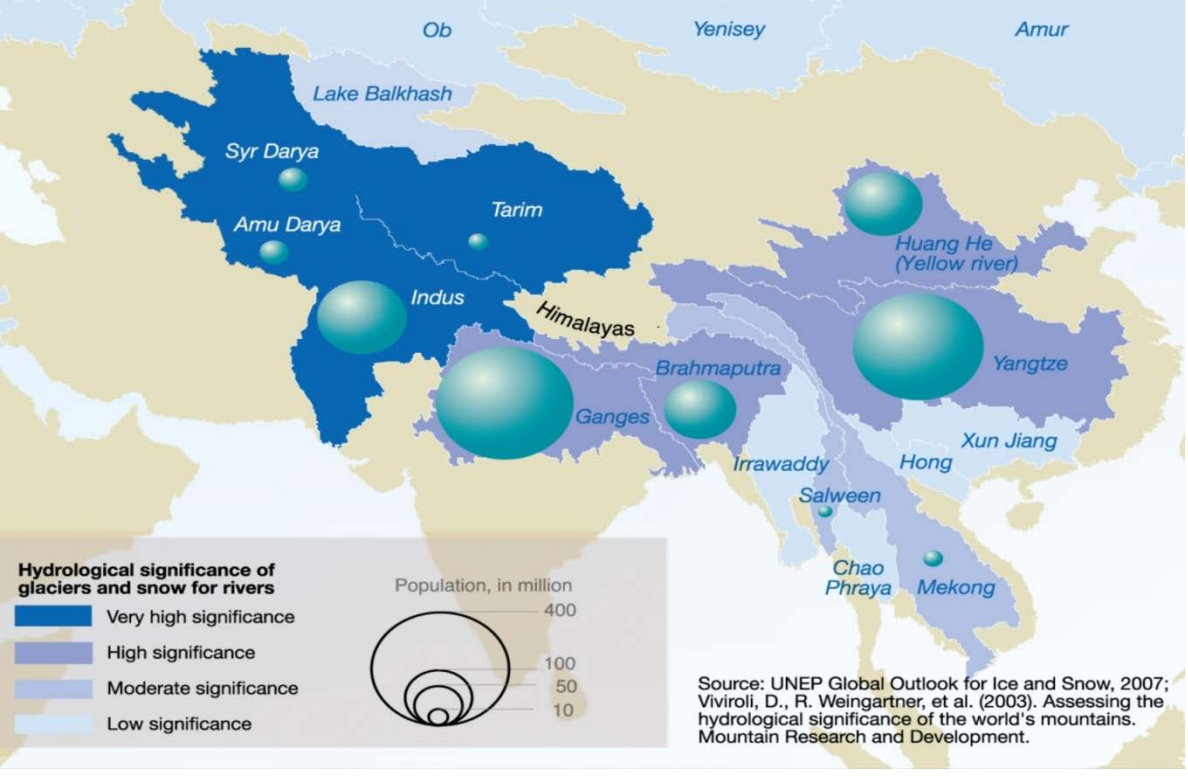
- Arctic temperatures increasing faster than global average (IPCC, 2007)
- BC may be significant contributor to Arctic warming and ice melt

Source: Reuters

BC Impacts: Glaciers

In the Himalayan region, solar heating from BLACK CARBON at high elevations may be just as important as carbon dioxide in the melting of snowpacks and glaciers (Ramanathan & Carmichael, 2008)

Himalayas: Source of 14 Major Rivers in Asia Under Threat



Western U.S.

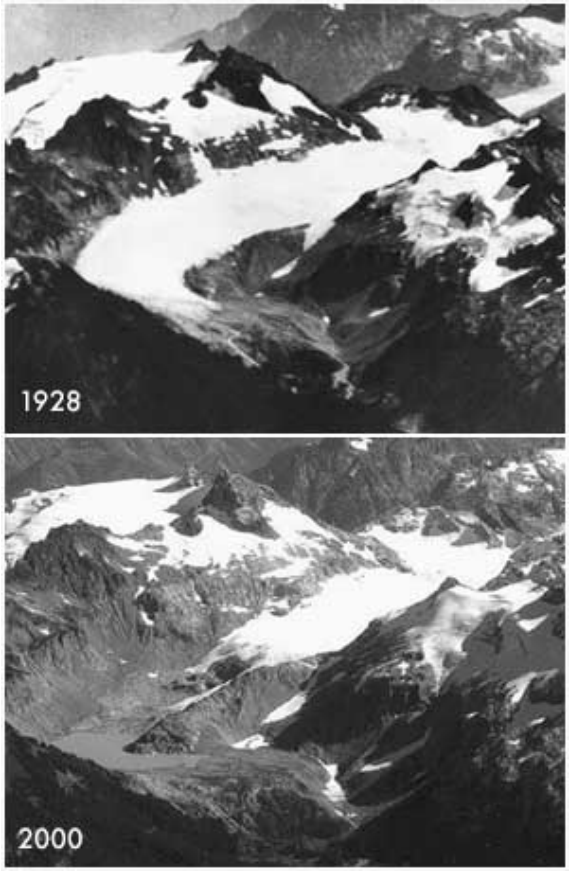
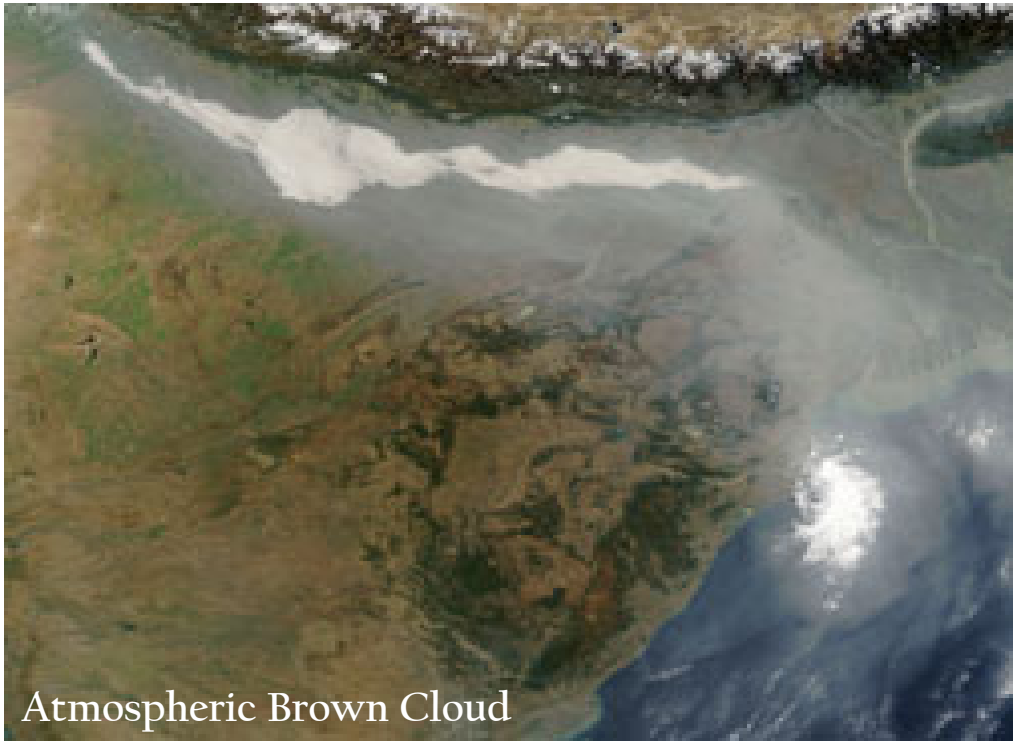


Photo: USGS

BC Impacts: Precipitation

- Pollution plumes known as Atmospheric Brown Clouds (ABCs) may also affect rainfall patterns
  - ABCs contain significant amounts of BC, as well as organic carbon, sulfates, nitrates, and dust
- Can persist up to 7 months per year



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Health Effects of Black Carbon

Brick Kiln in Kathmandu

- BC contributes to the adverse impacts on human health, ecosystems, and visibility associated with $PM_{2.5}$.
- Short-term and long-term exposures to $PM_{2.5}$ are associated with a broad range of human health impacts, including respiratory and cardiovascular effects and premature death.

- The World Health Organization (WHO) estimates that indoor smoke from solid fuels is among the top 10 major mortality risk factors globally, contributing to approximately 2 million deaths each year (mainly among women and children).
- Emissions and ambient concentrations of directly emitted $PM_{2.5}$ are often highest in urban areas, where large numbers of people live.

Traditional Cookstove in India

Black carbon (BC)

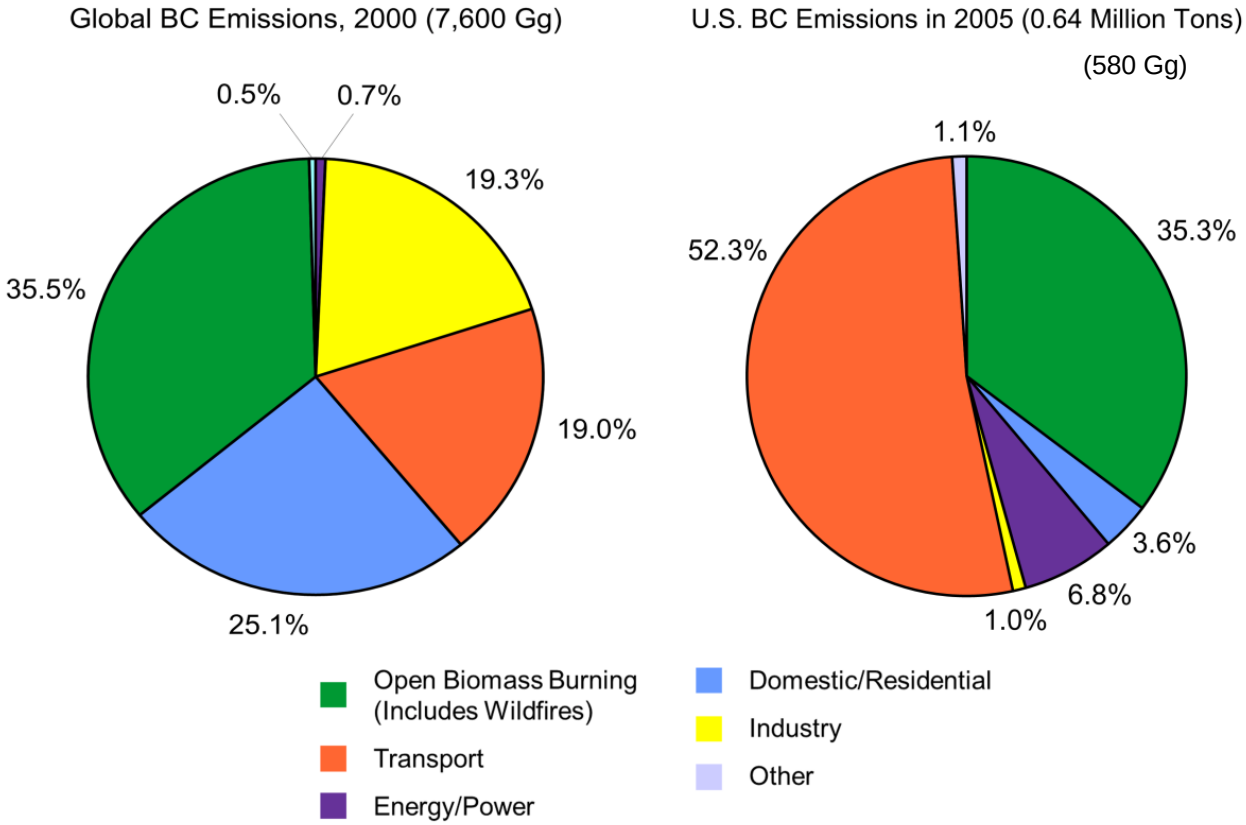
- As a part of $PM_{2.5}$, BC is associated with premature mortality
- BC is a climate warmer - absorbs sunlight in atmosphere and deposits on snow and ice, reducing reflected sunlight
- >90% of global anthropogenic BC emissions from three sectors

Industrial:
Brick kilns
Coke ovens

Residential:
Solid fuel burning cookstoves

Transportation:
On-road diesels
Off-road diesels

Black Carbon Emissions

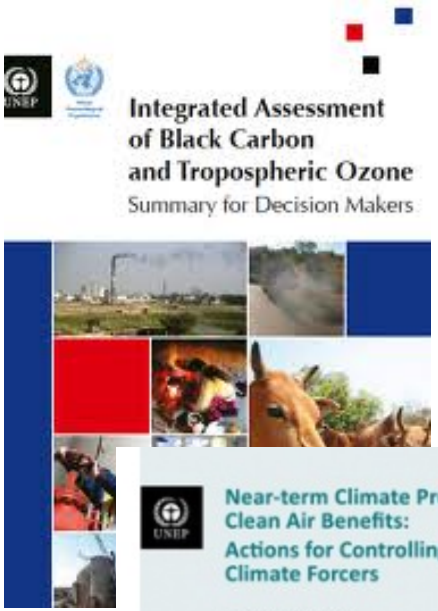


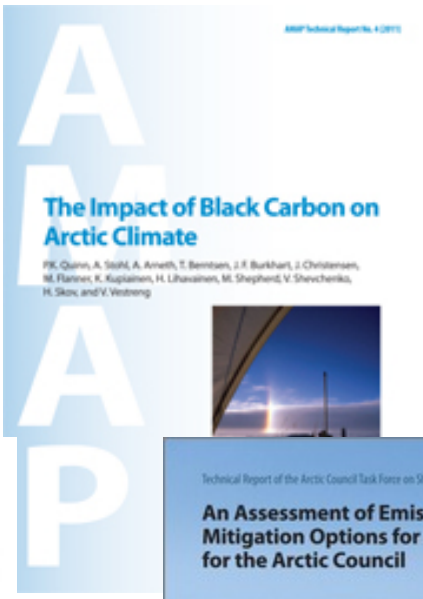
- 75% of global BC emissions come from Asia, Africa and Latin America.
- U.S. currently accounts for approximately 8% of the global total, and this fraction is declining.
- Emissions patterns and trends across regions, countries and sources vary significantly.
- In the U.S., BC emissions ~12% of all direct $PM_{2.5}$ emissions nationwide.
- Mobile sources are the largest U.S. BC emissions category (with 93% of mobile source BC coming from diesels).

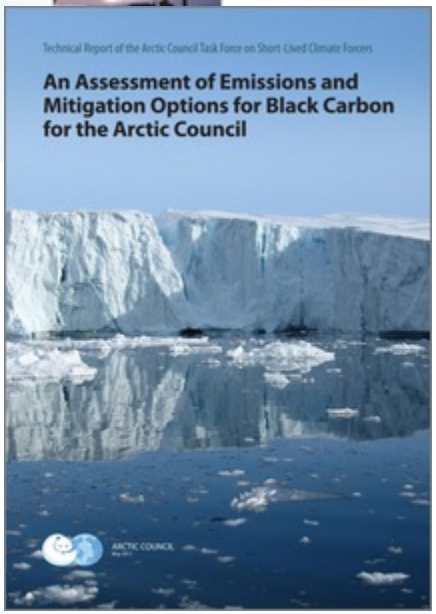
Potential Benefits of BC Mitigation

- Targeted strategies to reduce BC emissions can be expected to provide climate benefits within the next several decades, and may be particularly important for sensitive regions such as the Arctic.
- Reductions in BC and GHGs are complementary strategies for mitigating climate change.
- The health and environmental benefits of BC reductions are also substantial.
  - Average public health benefits of reducing directly emitted $PM_{2.5}$ in the U.S. are estimated to range from $290,000 to $1.2 million per ton $PM_{2.5}$ in 2030.
  - Globally, $PM_{2.5}$ reductions due to BC mitigation measures could potentially lead to hundreds of thousands of avoided premature deaths each year.

Science-policy reports on short-lived climate forcers

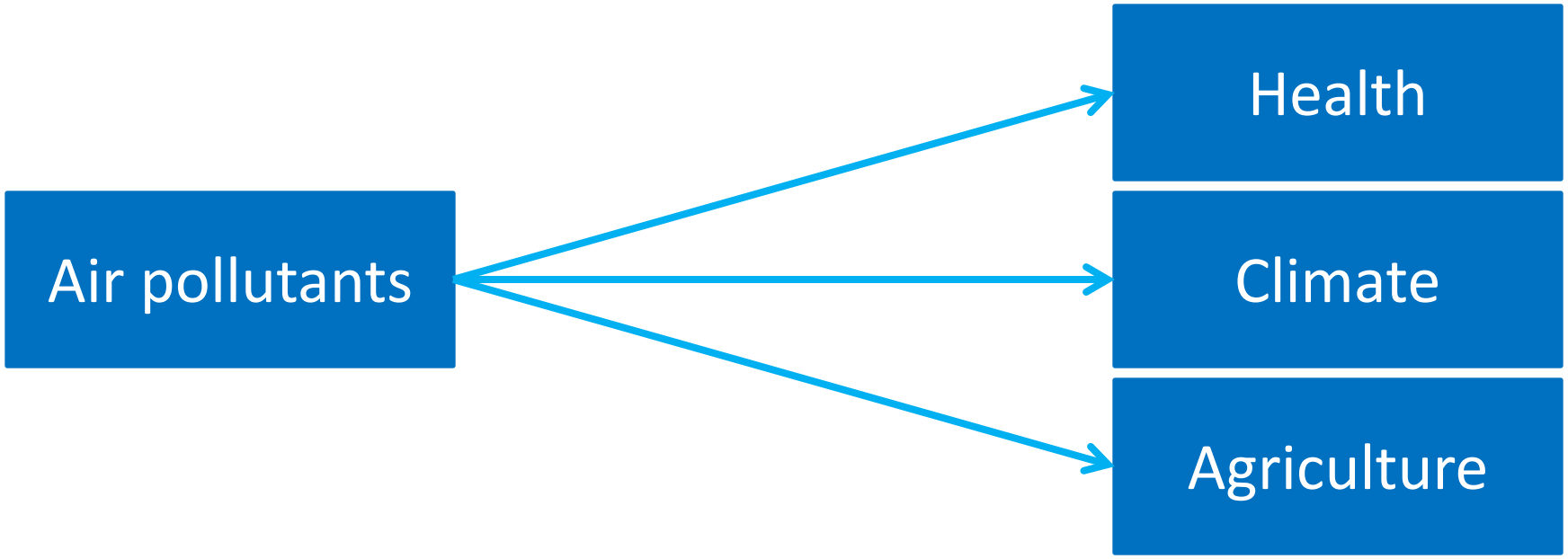






Simultaneously mitigating air pollution and near-term climate change

- Mitigation measures targeting $PM_{2.5}$ and ozone are employed around the world
- Those that target black carbon (BC) and methane may have climate co-benefits

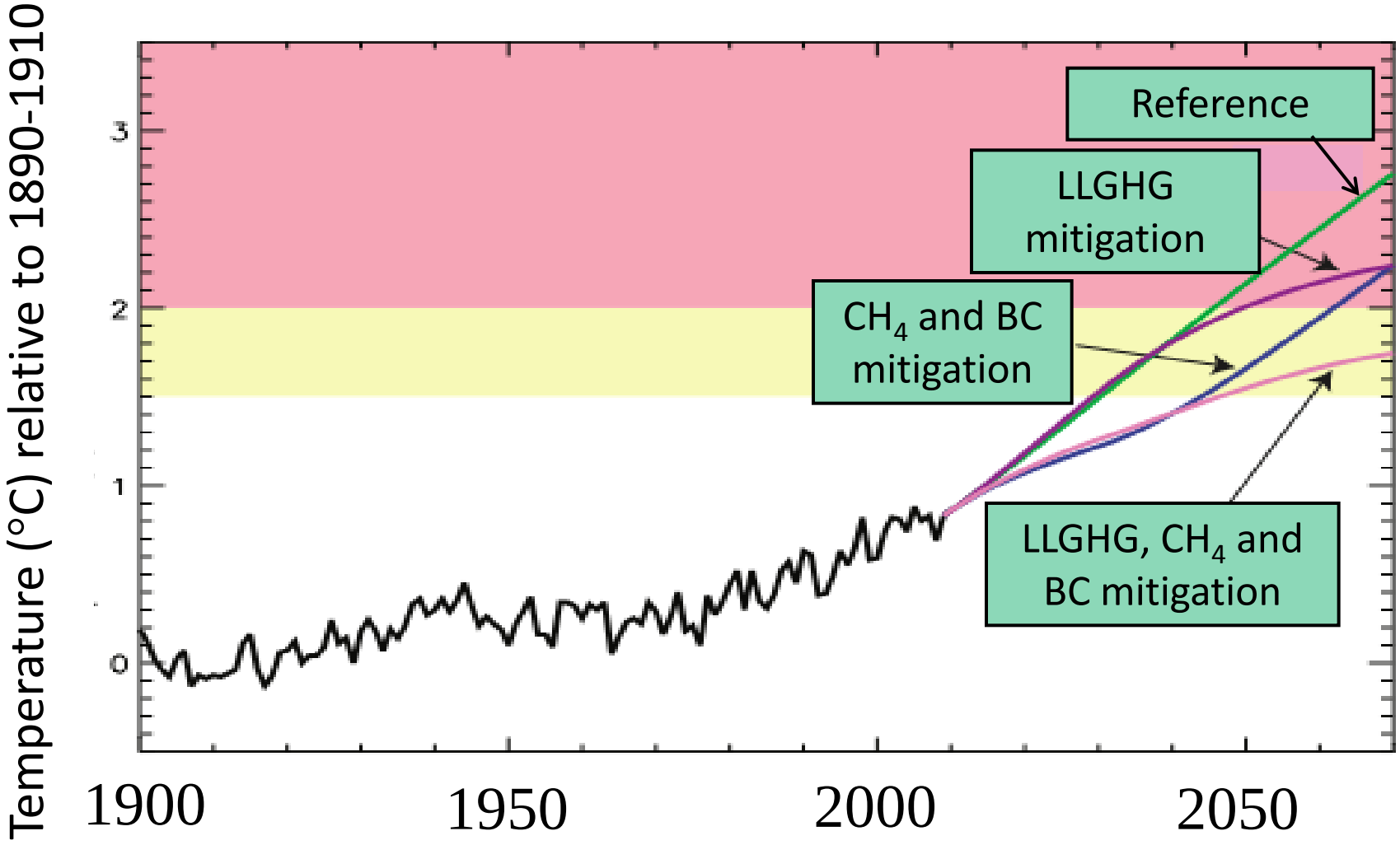


What are the climate, health, and agricultural benefits of further implementing climate-friendly air pollution mitigation measures that have already been employed around the world?

UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone

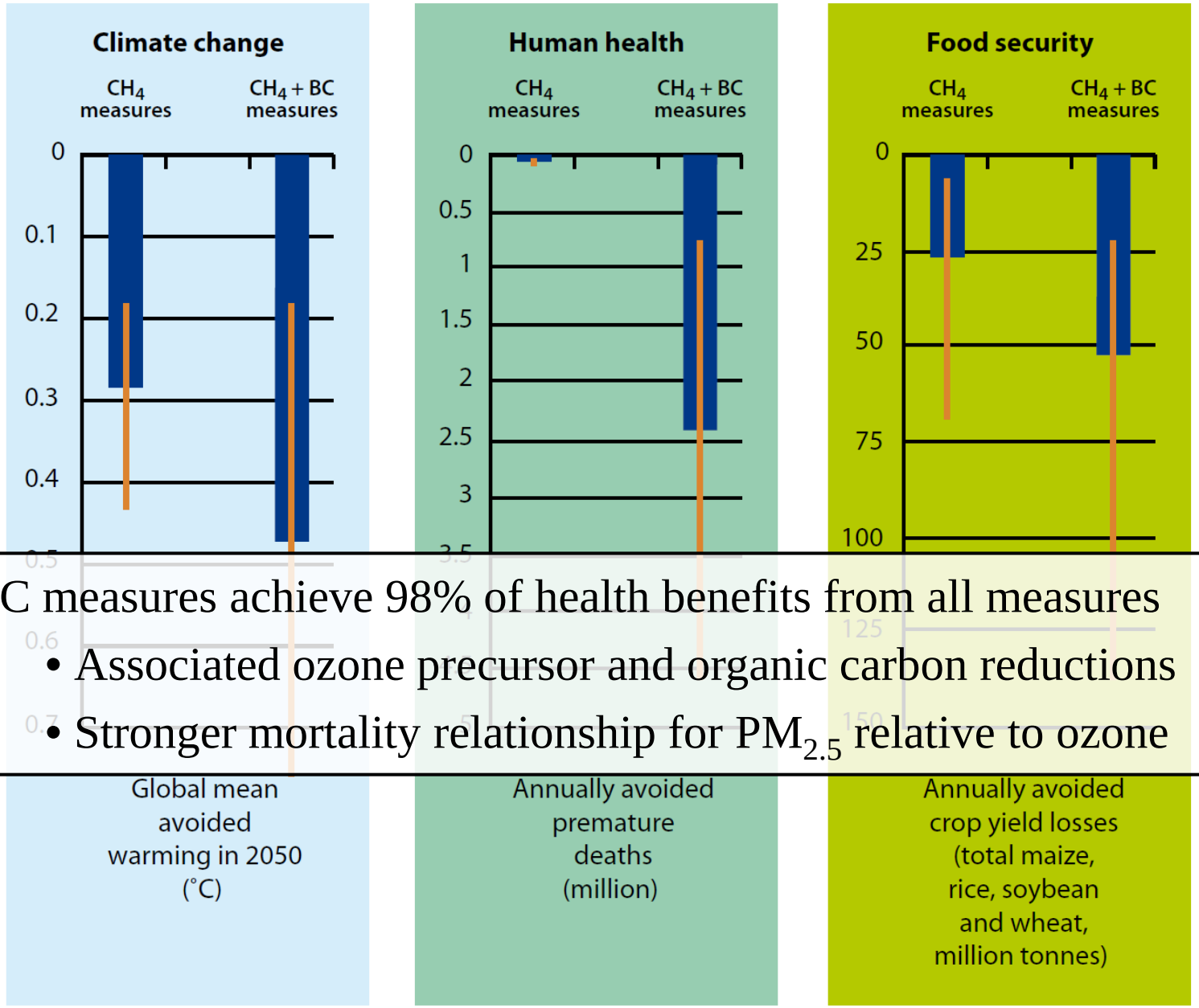
- Screened ~2000 emission control measures in GAINS database
- Identified 14 specific BC and methane emission control measures based on potential benefits for near-term climate
- Examined 5 emission scenarios:
  - Present-day (2005)
  - 2030 reference (World Energy Outlook, IEA 2009)
  - **Methane** measures
  - Methane + **BC Group 1** measures (technological – i.e. diesel particulate filters, improving biomass cook stoves)
  - Methane + BC Group 1 + **BC Group 2** measures (policy – i.e. elimination of high-emitting vehicles and biomass cook stoves)
- Calculated climate, health, agricultural, and economic benefits of the 3 groups of measures

Near-term climate benefits



UNEP/WMO Integrated Assessment of BC and Ozone, 2011; Shindell et al. *Science*, 2012

Benefits of mitigating BC and methane

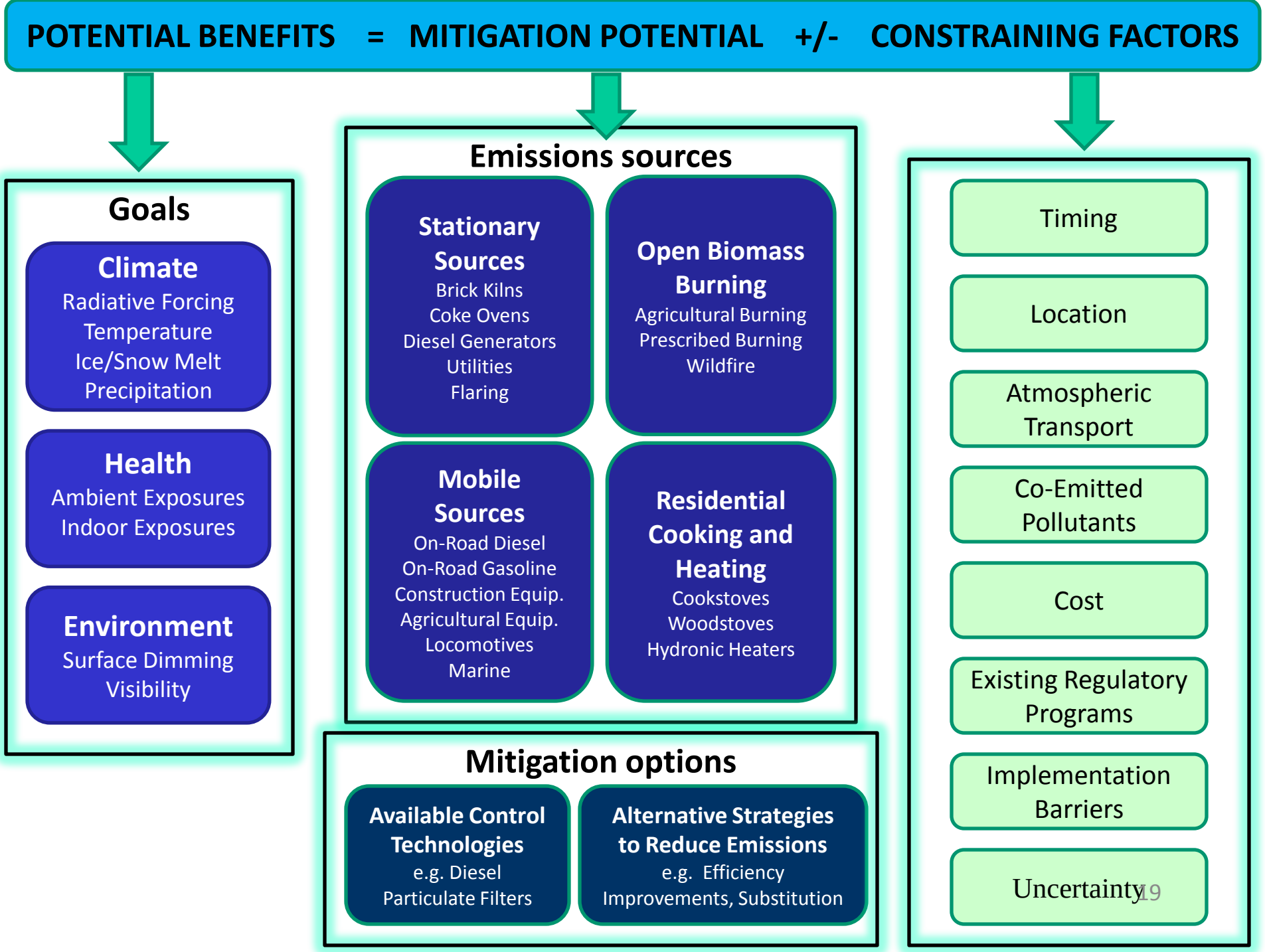


BC measures achieve 98% of health benefits from all measures

- Associated ozone precursor and organic carbon reductions
- Stronger mortality relationship for $PM_{2.5}$ relative to ozone

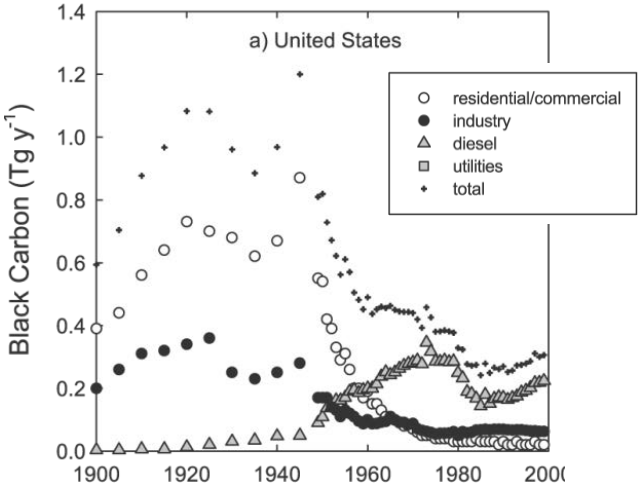
Mitigating BC: Key Considerations

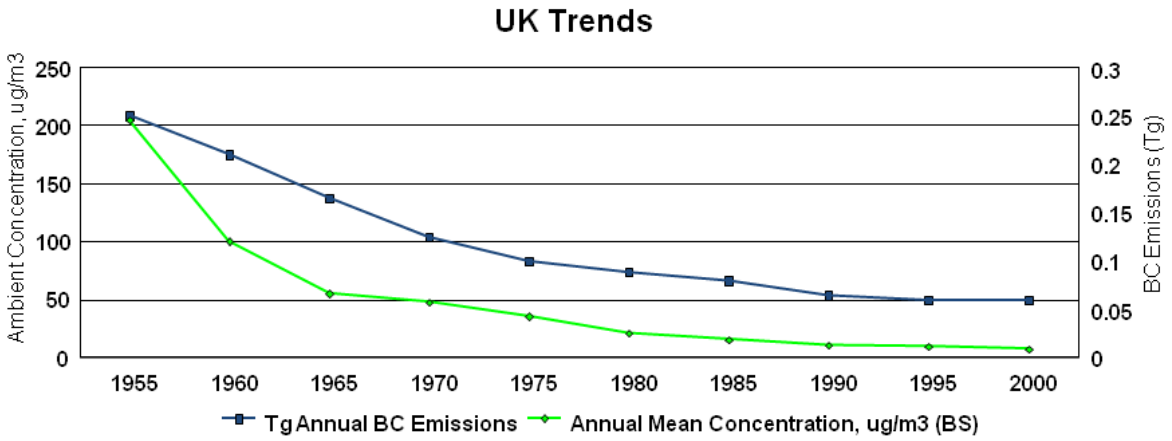
- For both climate and health, it is important to consider the location and timing of emissions and to account for co-emissions.
- Available control technologies can reduce BC, generally by improving combustion and/or controlling direct $PM_{2.5}$ emissions from sources.
- Some state and local areas in the U.S. have already identified control measures aimed at direct $PM_{2.5}$ as particularly effective strategies for meeting air quality goals.
- Though the costs vary, many reductions can be achieved at reasonable costs. Controls applied to reduce BC will help reduce total $PM_{2.5}$ and other co-pollutants.


POTENTIAL BENEFITS = MITIGATION POTENTIAL +/- CONSTRAINING FACTORS
Goals
Climate
Radiative Forcing
Temperature
Ice/Snow Melt
Precipitation
Health
Ambient Exposures
Indoor Exposures
Environment
Surface Dimming
Visibility
Emissions sources
Stationary Sources
Brick Kilns
Coke Ovens
Diesel Generators
Utilities
Flaring
Open Biomass Burning
Agricultural Burning
Prescribed Burning
Wildfire
Mobile Sources
On-Road Diesel
On-Road Gasoline
Construction Equip.
Agricultural Equip.
Locomotives
Marine
Residential Cooking and Heating
Cookstoves
Woodstoves
Hydronic Heaters
Mitigation options
Available Control Technologies
e.g. Diesel Particulate Filters
Alternative Strategies to Reduce Emissions
e.g. Efficiency Improvements, Substitution
Timing
Location
Atmospheric Transport
Co-Emitted Pollutants
Cost
Existing Regulatory Programs
Implementation Barriers
Uncertainty

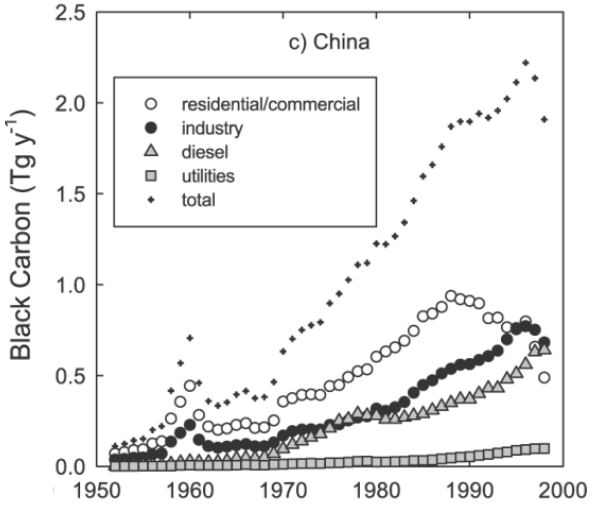
Black Carbon Emissions: Trends

- Long-term historic trends of BC emissions in the United States and other developed countries reveal a steep decline in emissions over the last several decades.
- Ambient BC concentrations have declined as emissions have been reduced.





- Developing countries (e.g., China and India) have shown a very sharp rise in BC emissions over the past 50 years.
- Total global BC emissions are likely to decrease in the future, but developing countries may experience emissions growth in key sectors (transportation, residential).



BC Mitigation Opportunities

United States

- The U.S. will achieve substantial BC emissions reductions by 2030, largely due to controls on new mobile diesel engines.
  - Diesel retrofit programs for in-use mobile sources are a valuable complement to new engine standards for reducing emissions.
- Other U.S. source categories have more limited mitigation potential due to smaller remaining emissions in these categories, or limits on the availability of effective BC control strategies:
  - Stationary sources
  - Residential wood combustion
  - Open biomass burning

Global

- The most important BC emissions reduction opportunities globally include:
  - residential cookstoves in all regions
  - brick kilns and coke ovens in Asia
  - mobile diesels in all regions
- A variety of other opportunities may exist in individual countries or regions.

Sensitive Regions

- Arctic: transportation sector (land-based diesel engines and Arctic shipping); residential heating (wood); and biomass burning.
- Himalayas: residential cooking; industrial sources (especially coal-fired brick kilns); and transportation (diesel engines).

Appendix

Technical measures for methane emissions

- Extended pre-mine degasification and recovery and oxidation of methane from ventilation air from coal mines
- Extended recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from the production of oil and natural gas
- Reduced gas leakage from long-distance transmission pipelines
- Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization
- Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control
- Control of methane emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs
- Intermittent aeration of continuously flooded rice paddies

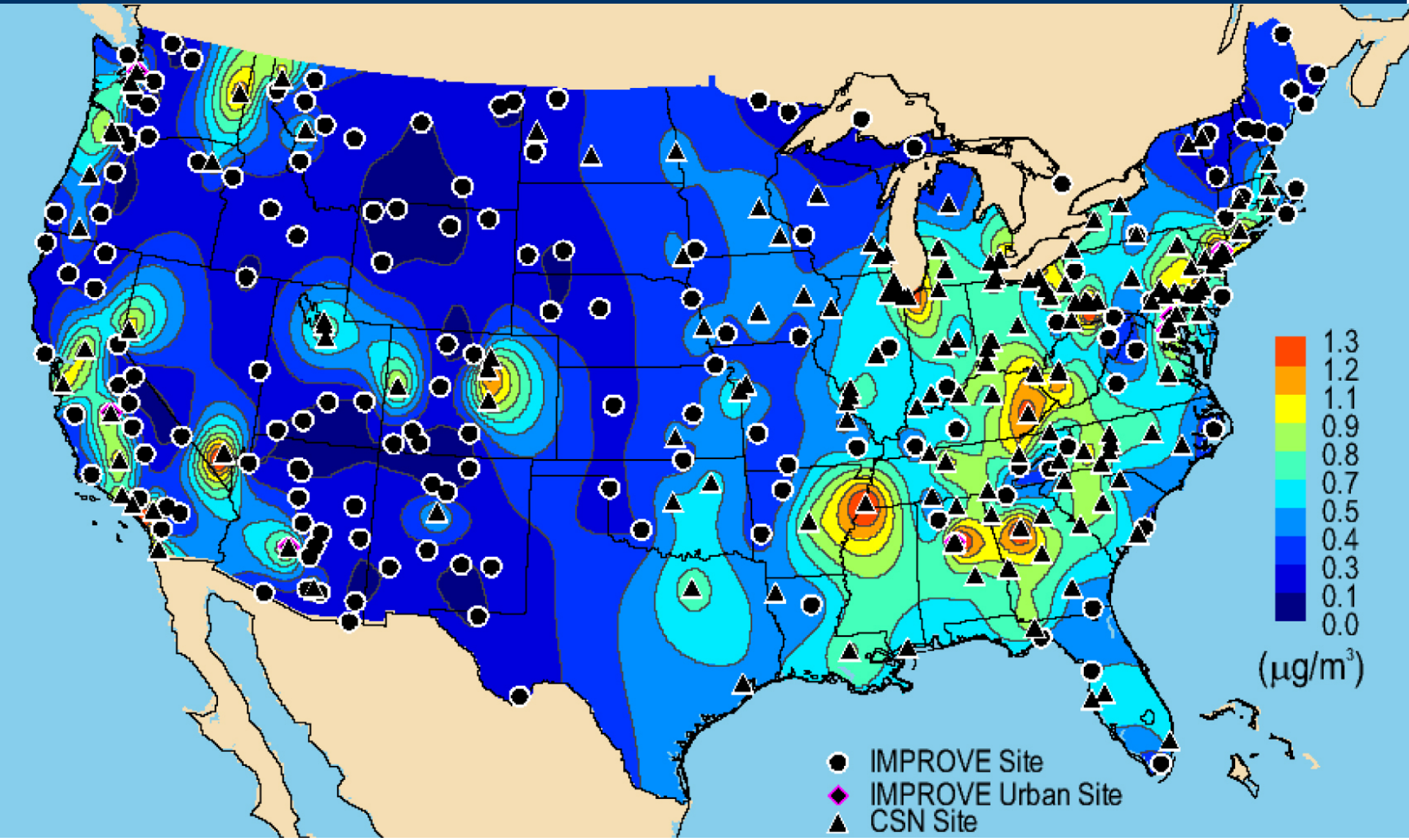
BC Group 1: Technical measures for reducing emissions of incomplete combustion

- Diesel particle filters as part of a Euro VI package for road and off-road diesel vehicles
- Introduction of clean-burning cook stoves for cooking and heating in developing countries
- Replacing traditional brick kilns with vertical shaft kilns and Hoffman kilns
- Replacing traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures in developing countries

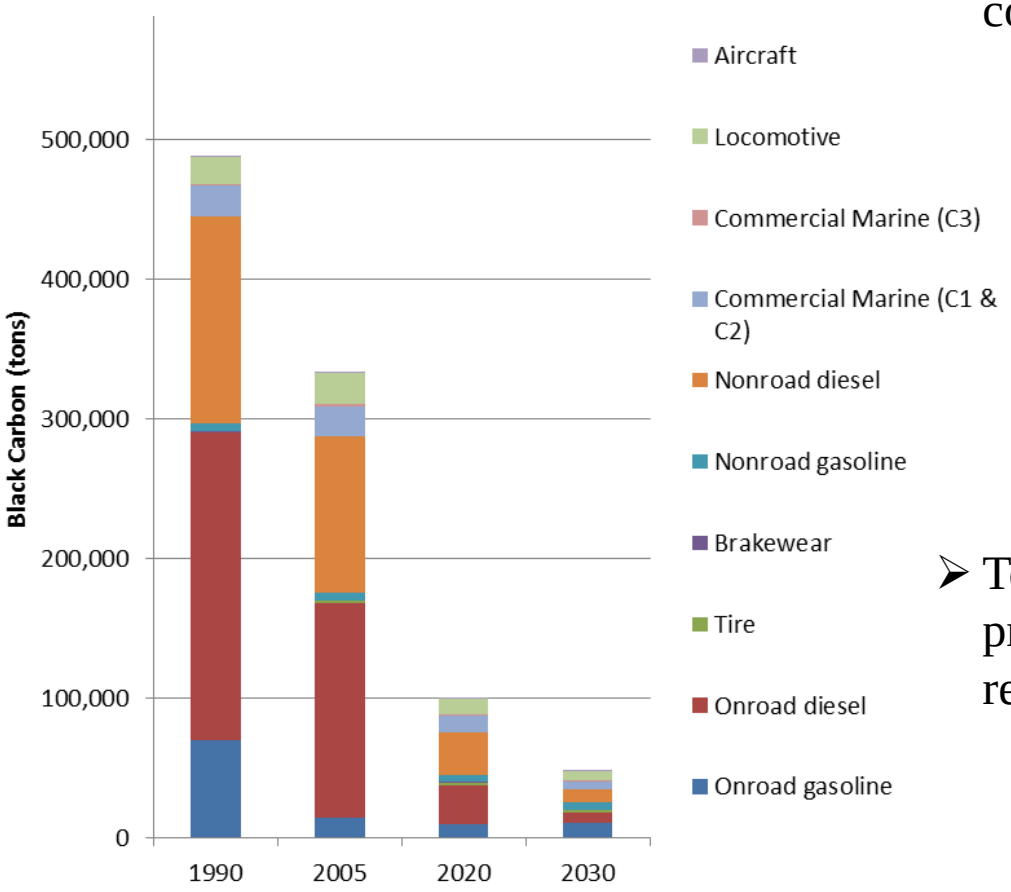
BC Group 2: Non-technical measures to eliminate the most polluting activities

- Elimination of high-emitting vehicles in road and off-road transport (excluding shipping)
- Ban of open field burning of agricultural waste
- Substitution of clean-burning cook stoves using modern fuels for traditional biomass cook stoves in developing countries

Annual Mean BC Concentrations (µg/m3) for 2005-2008



U.S. Mobile Sources



Emissions from U.S. Mobile Sources

- BC emissions from U.S. mobile diesel engines controlled via:
  - Emissions standards for new engines, including requirements resulting in use of diesel particulate filters (DPFs) in conjunction with ultra low sulfur diesel fuel.
  - Retrofit programs for in-use mobile diesel engines, such as EPA's National Clean Diesel Campaign and the SmartWay Transport Partnership Program.
- Total U.S. mobile source BC emissions are projected to decline by 86% by 2030 due to regulations already promulgated.
  - EPA has estimated the cost of controlling $PM_{2.5}$ from new diesel engines at ~ $14,000/ton (2010$).

U.S. Stationary Sources

- Controls on industrial sources, combined with improvements in technology and broader deployment of cleaner fuels such as natural gas, have helped reduce U.S. BC emissions more than 70% since the early 1900s.
- Regulations limiting direct PM emissions (including BC) affect more than 40 categories of industrial sources, including coke ovens, cement plants, industrial boilers, and stationary diesel engines.
- Available control technologies and strategies include:
  - Use of cleaner fuels.
  - Direct $PM_{2.5}$ reduction technologies (e.g. fabric filters (baghouses), electrostatic precipitators (ESPs), and diesel particulate filters (DPFs)).
  - The control technologies range in cost-effectiveness from \$48/ton $PM_{2.5}$ to \$685/ton $PM_{2.5}$ (2010\$) or more, depending on the source category. However, they also may involve tens of millions in initial capital costs.

U.S. Residential Heating and Cooking

- Emissions from residential wood combustion are currently being evaluated as part of EPA's ongoing review of emissions standards for residential wood heaters, including hydronic heaters, woodstoves, and furnaces.
- Mitigation options include replacing or retrofitting existing units, or switching to alternative fuels such as natural gas.
  - New EPA-certified wood stoves have a cost-effectiveness of about \$3,600/ton $PM_{2.5}$ reduced, while gas fireplace inserts average \$1,800/ton $PM_{2.5}$ reduced (2010\$).

Open Biomass Burning

- Open biomass burning is the largest source of BC emissions globally, and these emissions have been tied to reduced snow and ice albedo in the Arctic.
  - A large percentage of these emissions are due to wildfire (e.g., U.S. Alaskan fires).
  - Total organic carbon (OC) emissions (which may be cooling) are seven times higher than total BC emissions from this sector.
- $PM_{2.5}$ emissions reductions techniques (e.g., smoke management programs) may help reduce BC emissions.
- Appropriate mitigation measures depend on the timing and location of burning, resource management objectives, vegetation type, and available resources.
- Expanded wildfire prevention efforts may help to reduce BC emissions worldwide.

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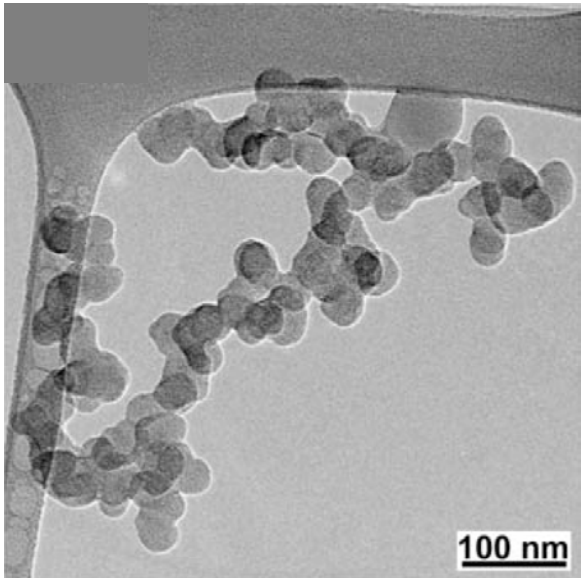

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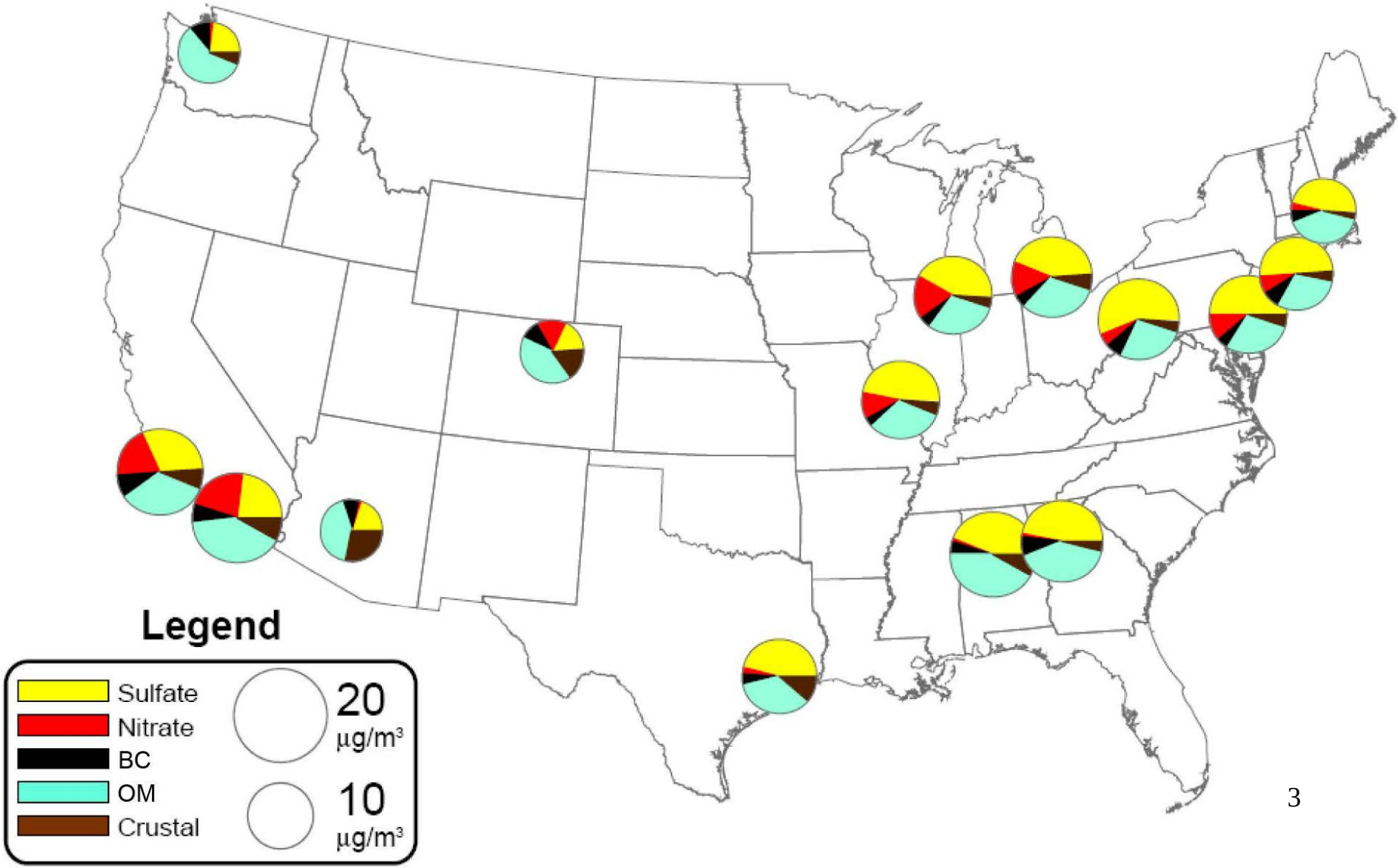

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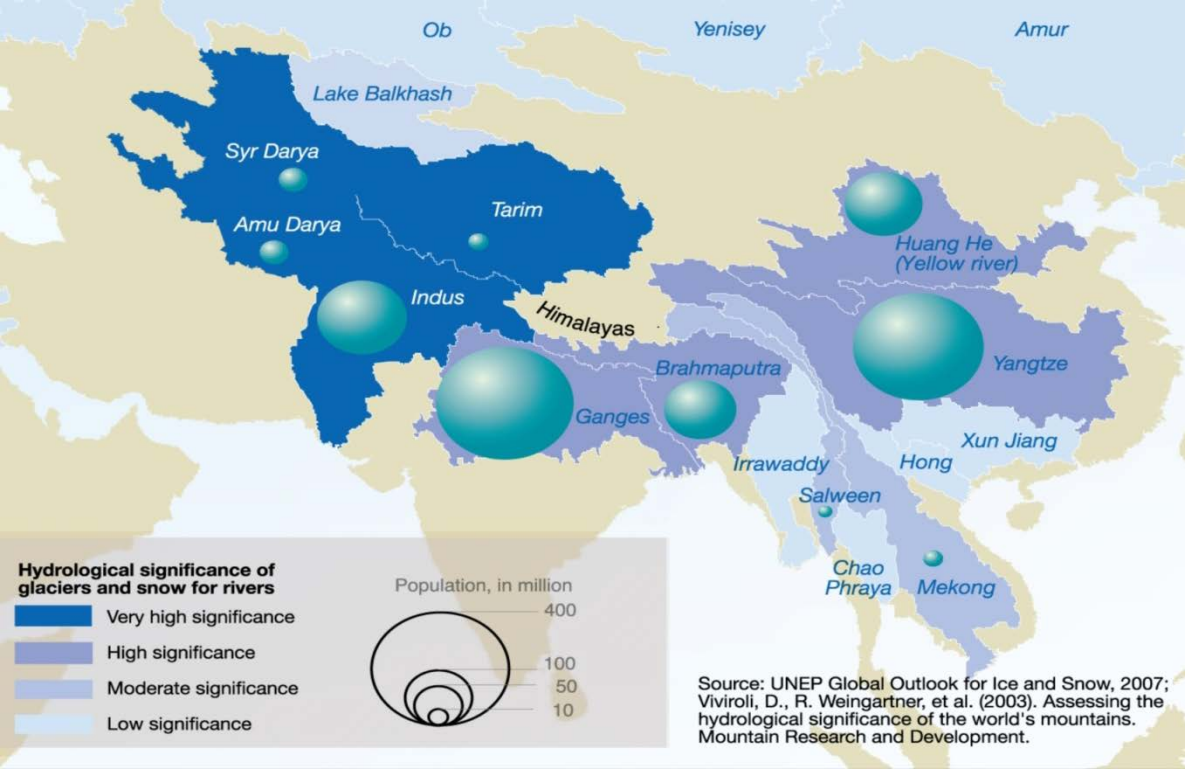

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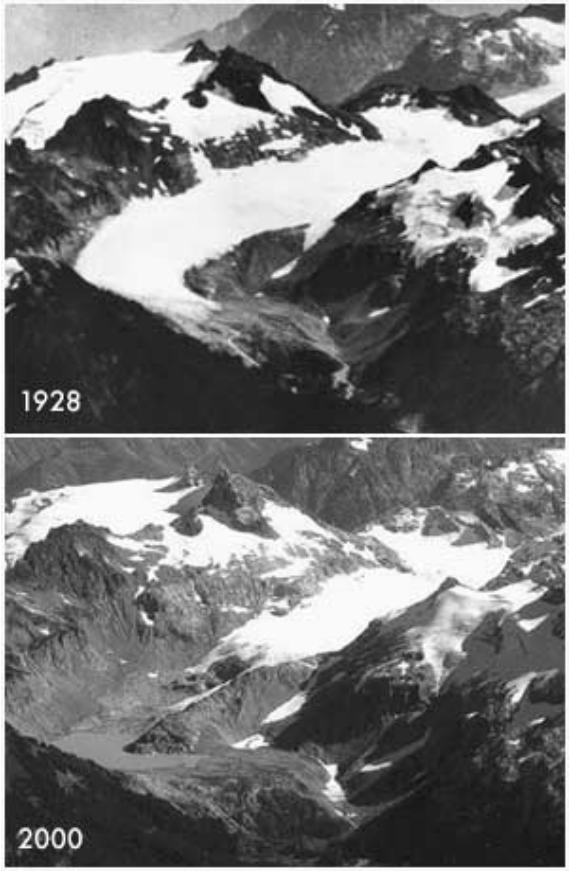

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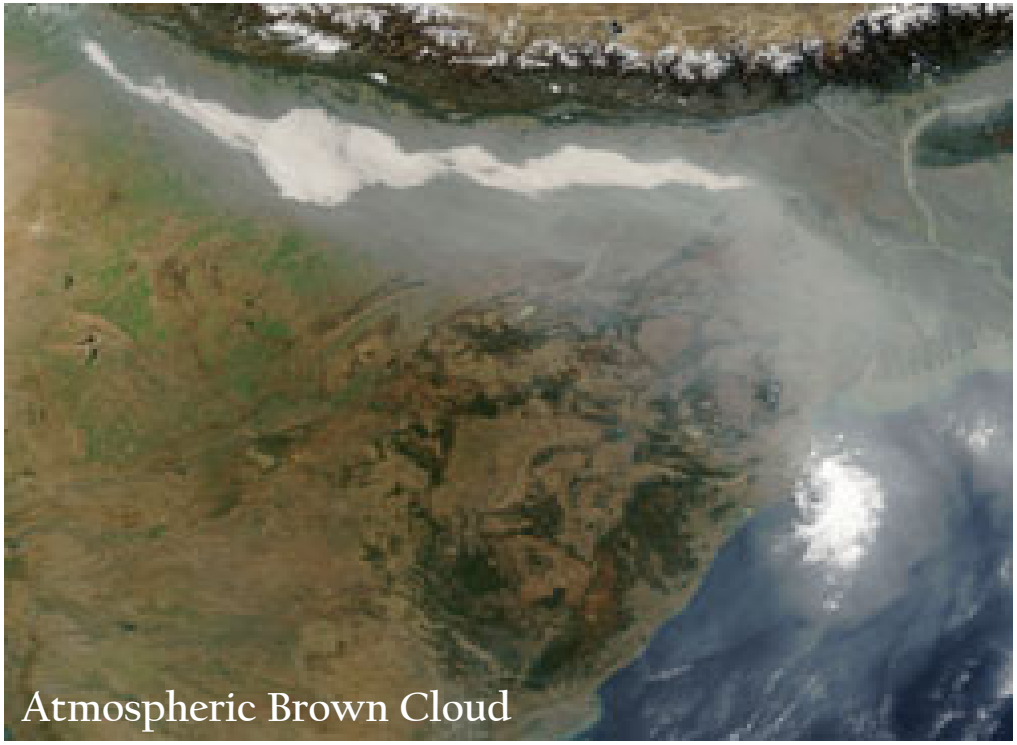

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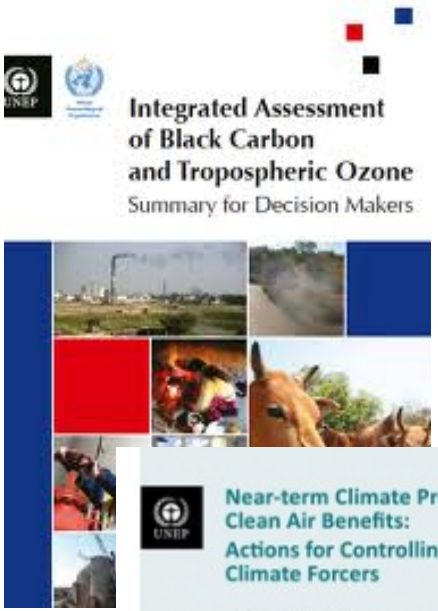
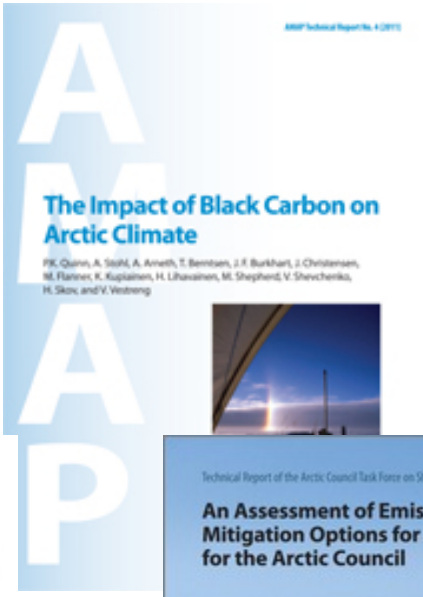
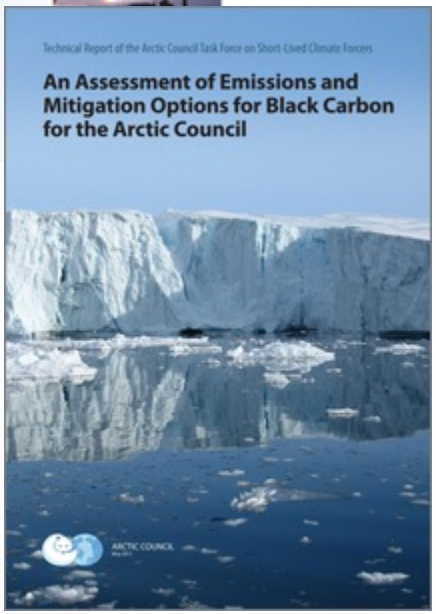
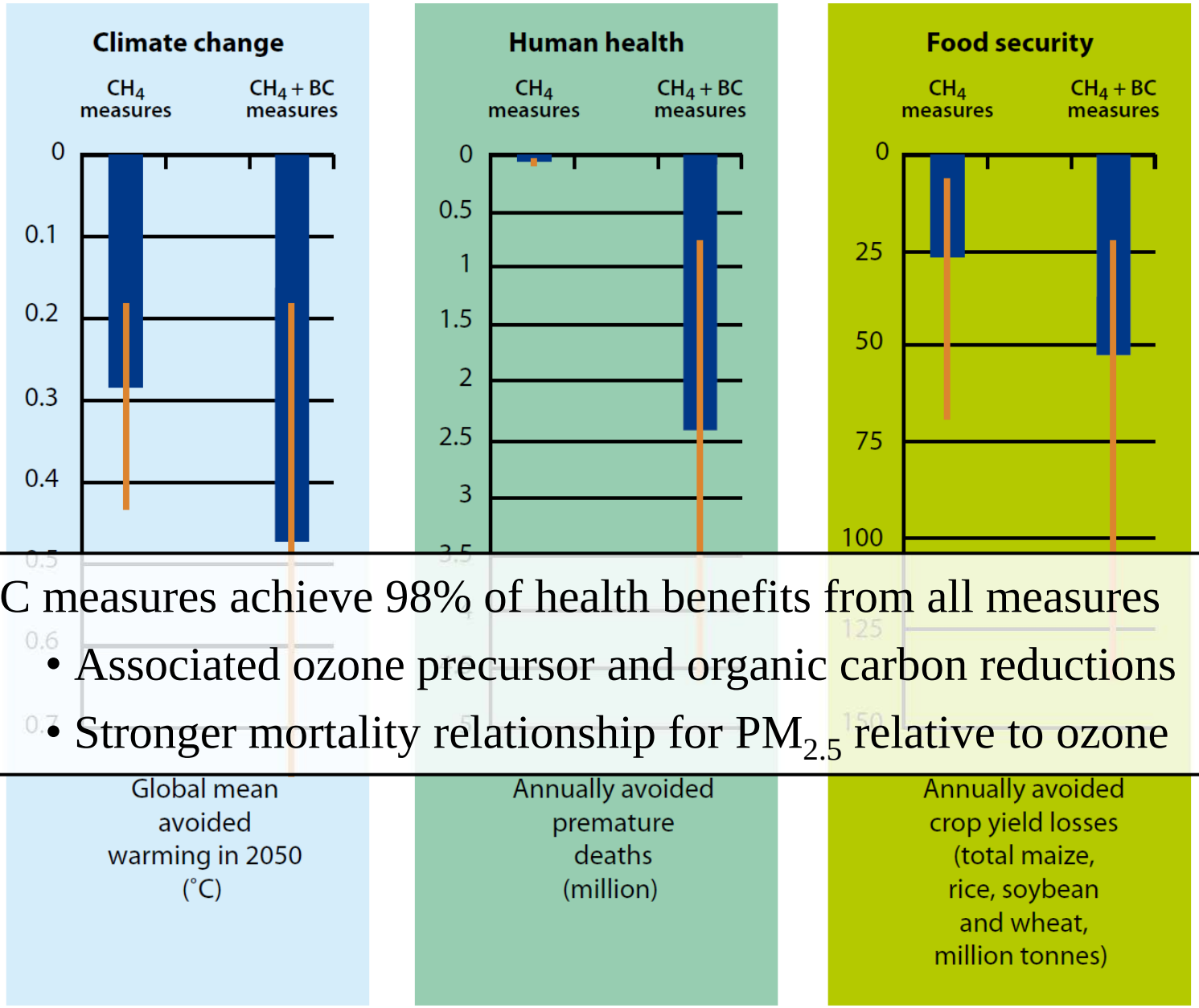






Benefits of mitigating BC and methane



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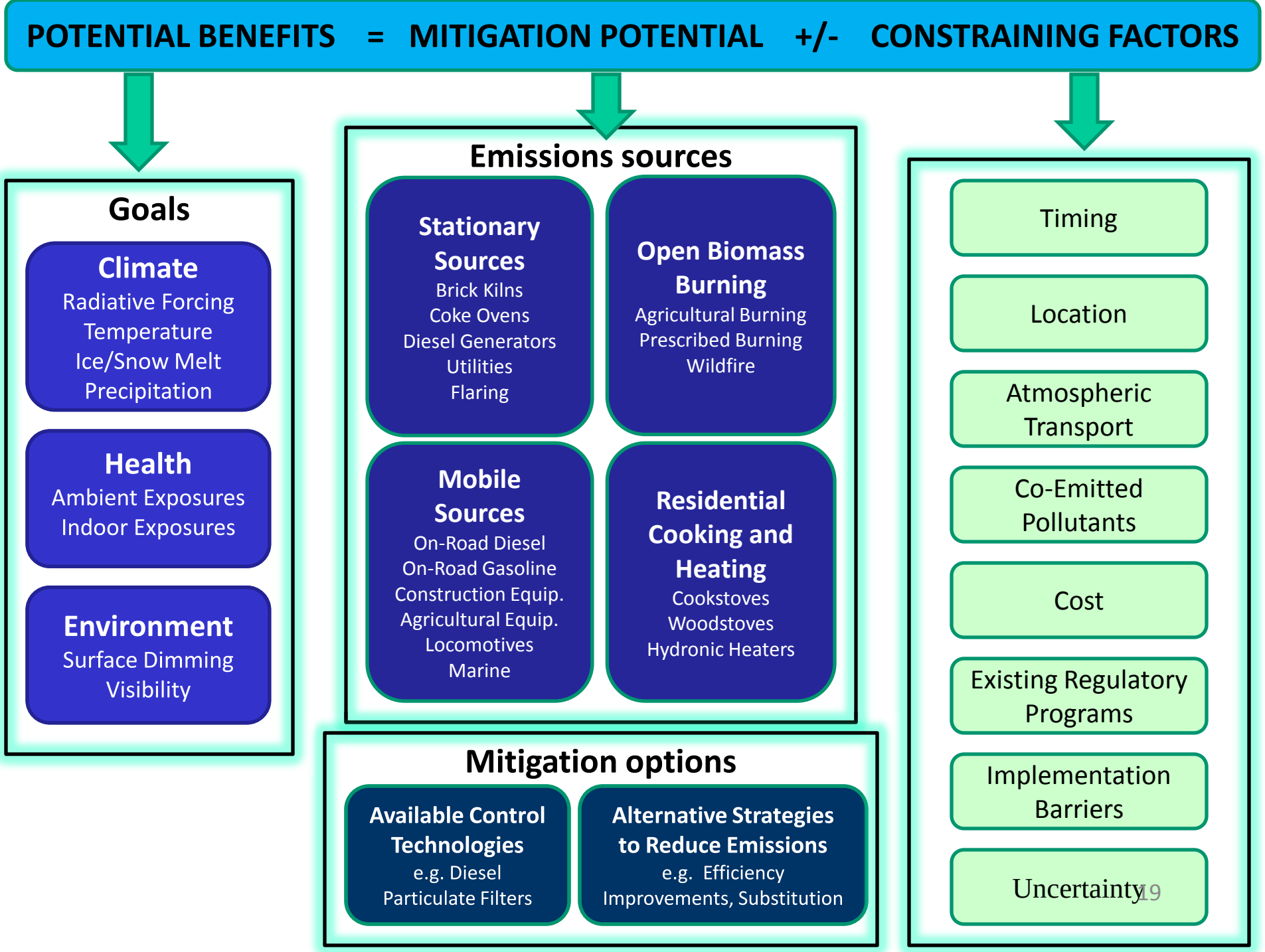
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Environment
Surface Dimming
Visibility
Emissions sources
Stationary Sources
Brick Kilns
Coke Ovens
Diesel Generators
Utilities
Flaring
Open Biomass Burning
Agricultural Burning
Prescribed Burning
Wildfire
Mobile Sources
On-Road Diesel
On-Road Gasoline
Construction Equip.
Agricultural Equip.
Locomotives
Marine
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Cookstoves
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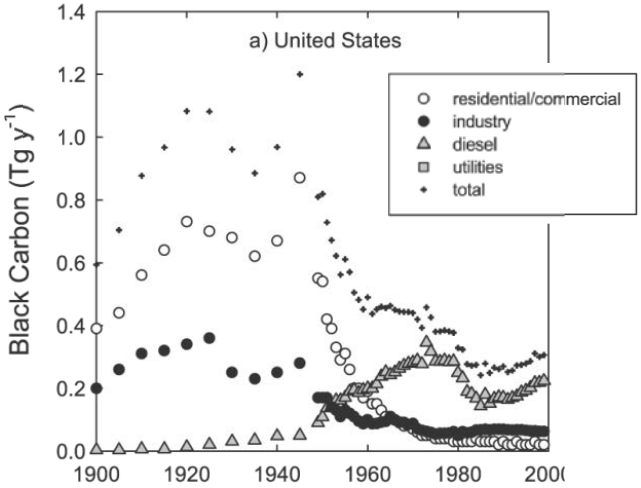

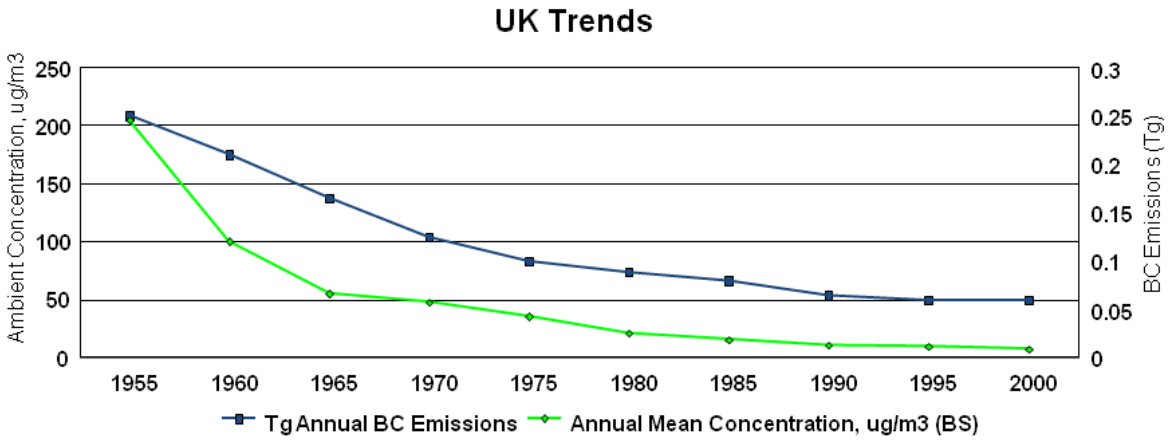

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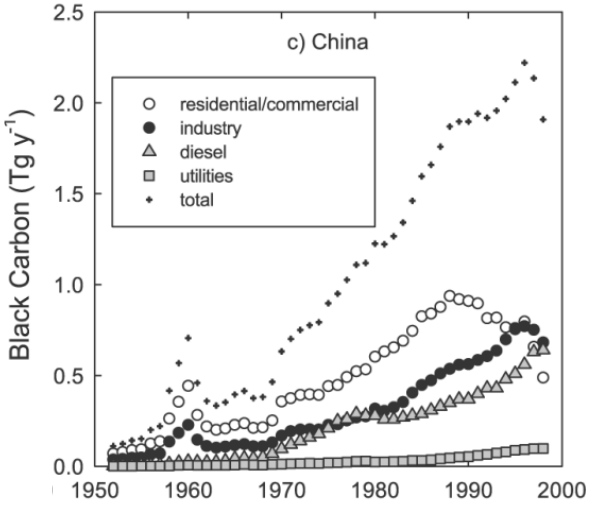
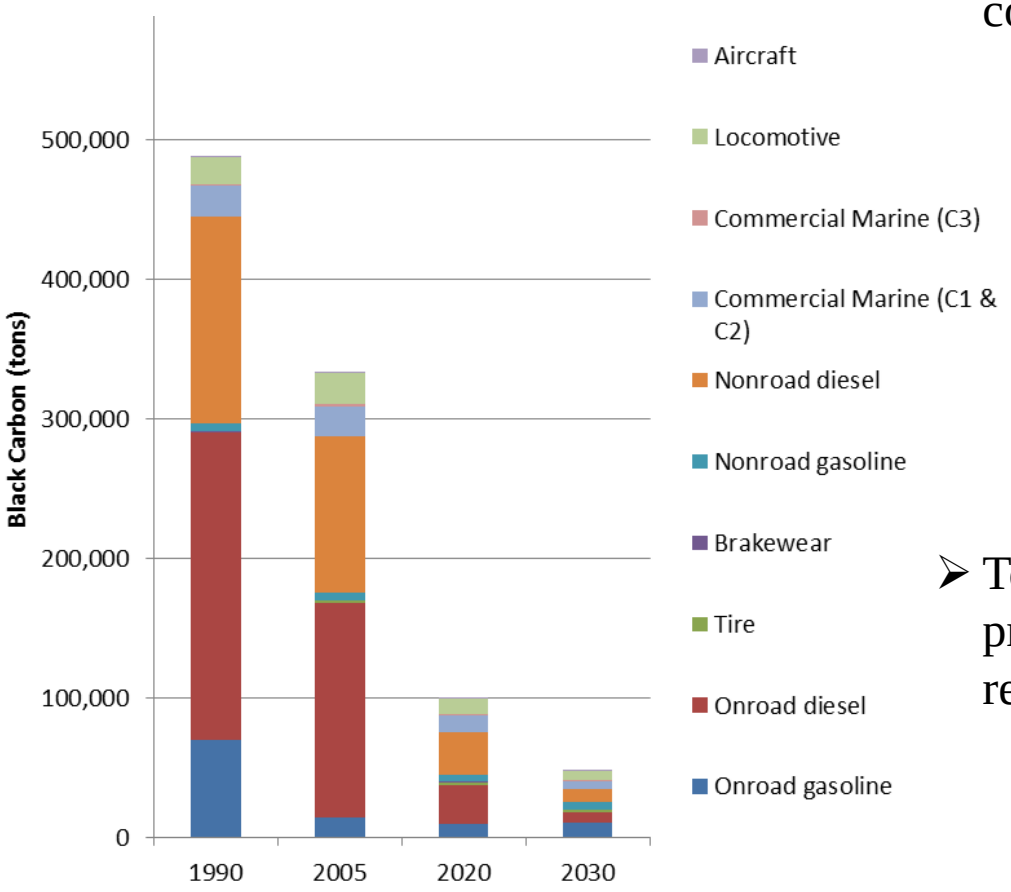


Appendix

U.S. Mobile Sources



Emissions from U.S. Mobile Sources

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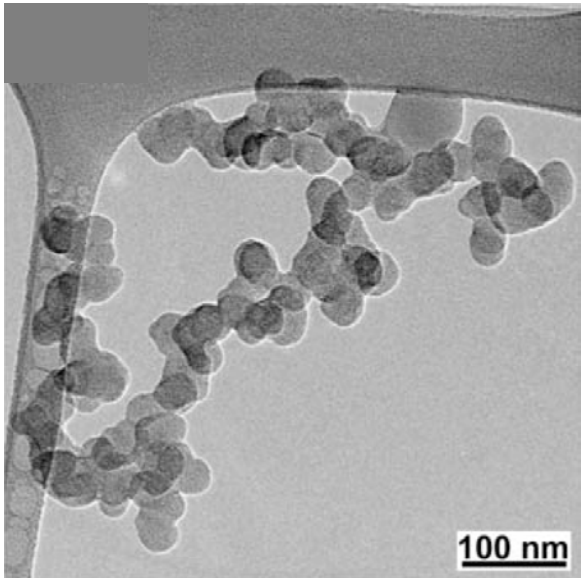
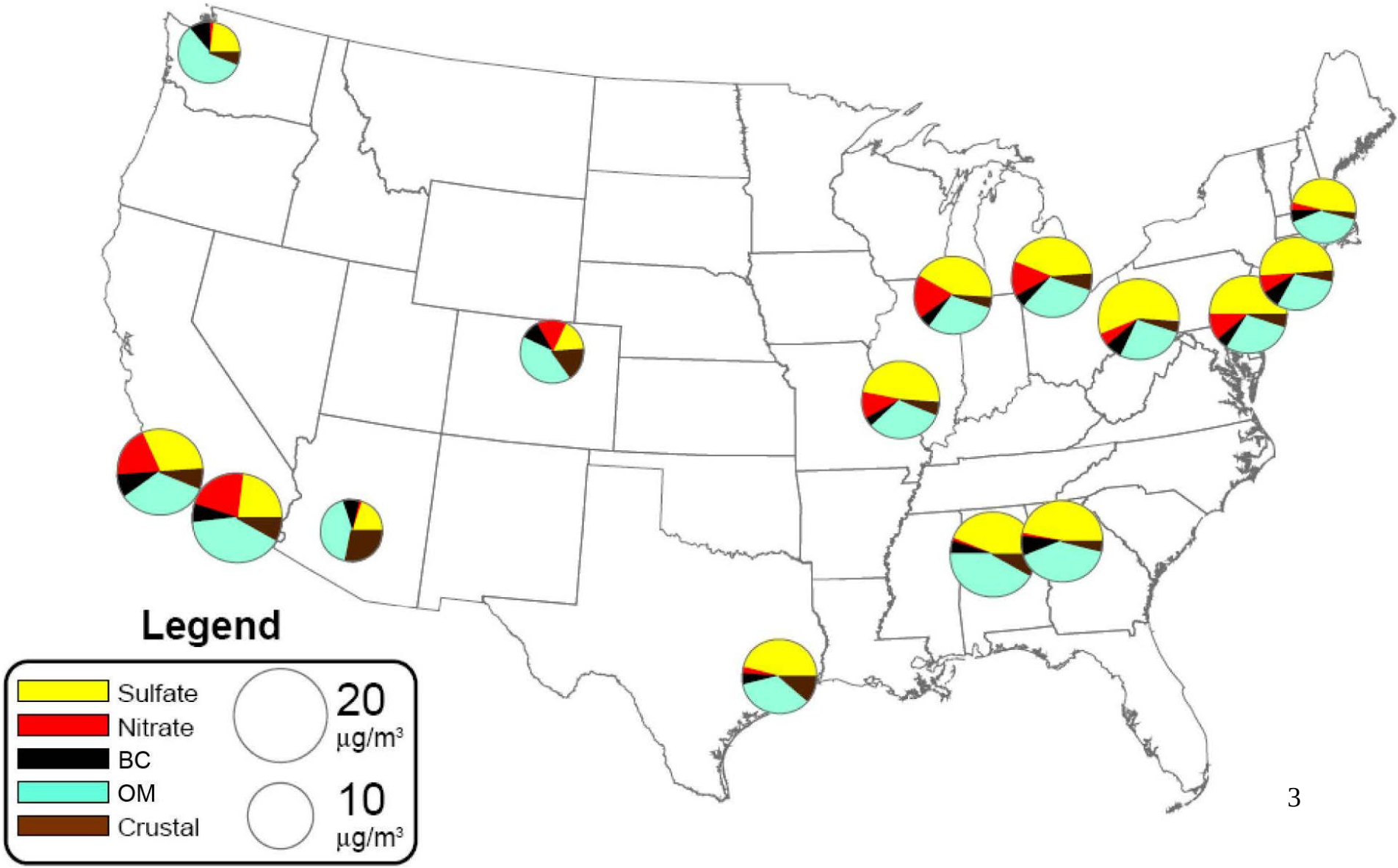
What is Black Carbon?



- Black carbon is the most strongly light-absorbing component of particulate matter (PM).
  - BC is a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths.
- Other types of particles, including sulfates, nitrates and organic carbon (OC), generally reflect light.

- BC is formed by incomplete combustion of fossil fuels, biofuels, and biomass.
- BC is emitted directly into the atmosphere in the form of fine particles (i.e., "direct $PM_{2.5}$").
- BC is a major component of "soot", a complex light-absorbing mixture that also contains organic carbon.

Composition of $PM_{2.5}$ for 15 Selected Urban Areas in the United States



BC Impacts: Arctic

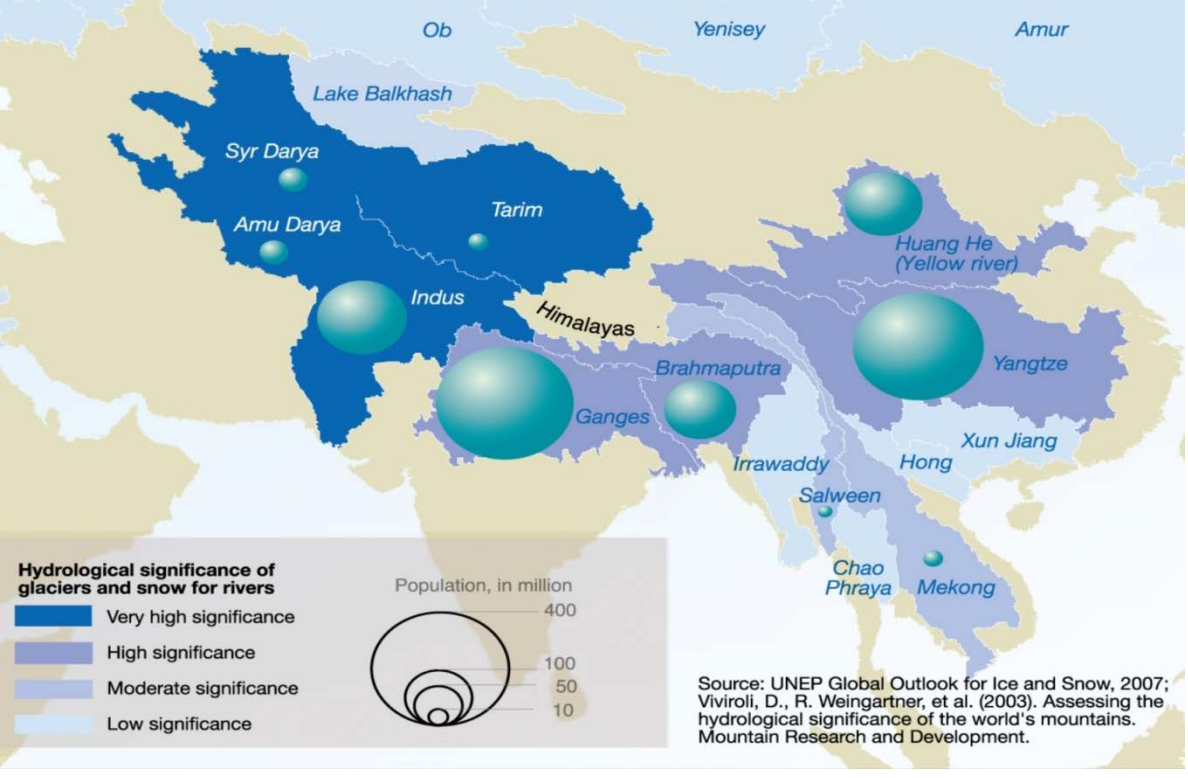
- Arctic temperatures increasing faster than global average (IPCC, 2007)
- BC may be significant contributor to Arctic warming and ice melt

Source: Reuters

BC Impacts: Glaciers

In the Himalayan region, solar heating from BLACK CARBON at high elevations may be just as important as carbon dioxide in the melting of snowpacks and glaciers (Ramanathan & Carmichael, 2008)

Himalayas: Source of 14 Major Rivers in Asia Under Threat



Western U.S.

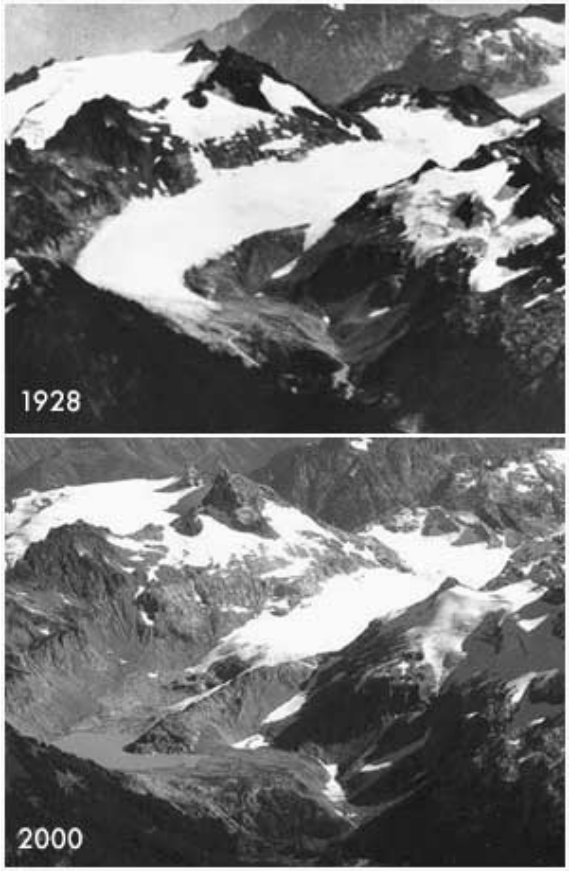
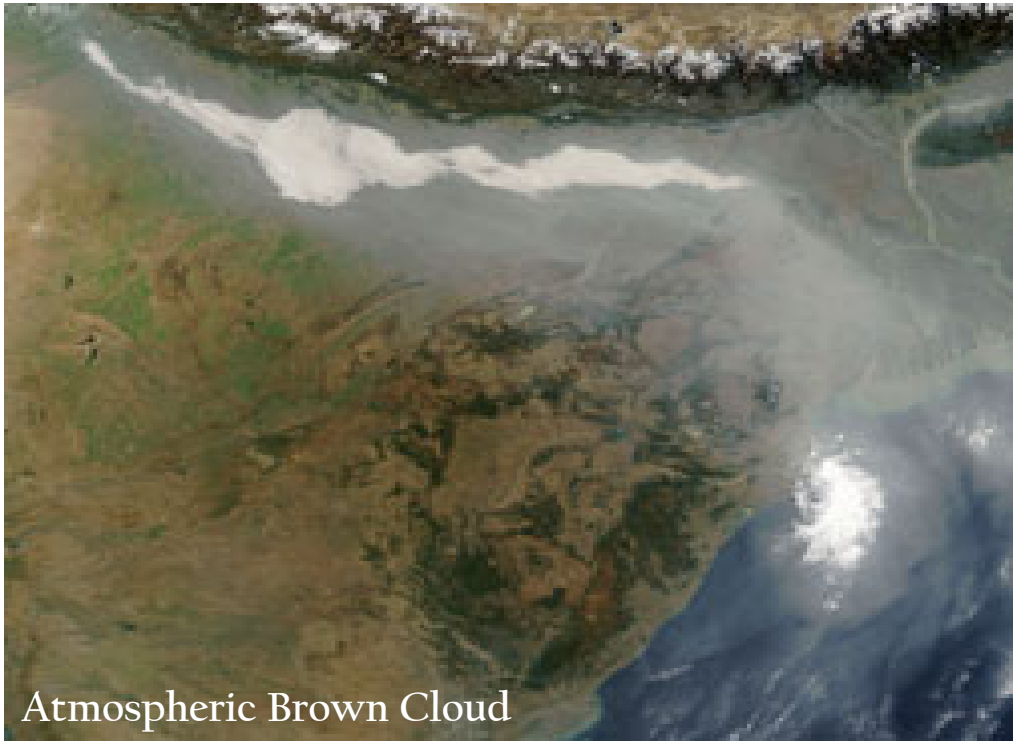


Photo: USGS

BC Impacts: Precipitation

- Pollution plumes known as Atmospheric Brown Clouds (ABCs) may also affect rainfall patterns
  - ABCs contain significant amounts of BC, as well as organic carbon, sulfates, nitrates, and dust
- Can persist up to 7 months per year



NASA Goddard Space Flight Center/Jeff Schmaltz

Health Effects of Black Carbon

Brick Kiln in Kathmandu

- BC contributes to the adverse impacts on human health, ecosystems, and visibility associated with $PM_{2.5}$.
- Short-term and long-term exposures to $PM_{2.5}$ are associated with a broad range of human health impacts, including respiratory and cardiovascular effects and premature death.

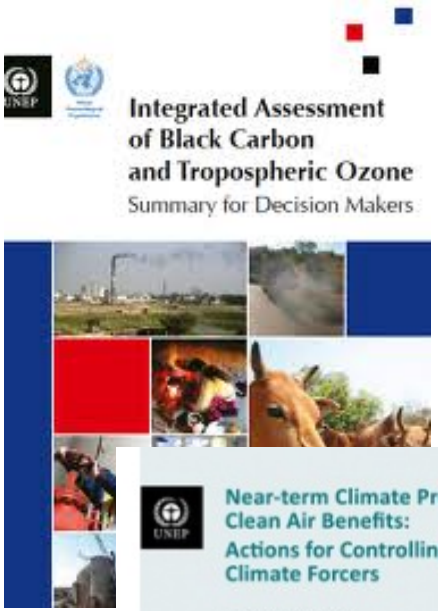
- The World Health Organization (WHO) estimates that indoor smoke from solid fuels is among the top 10 major mortality risk factors globally, contributing to approximately 2 million deaths each year (mainly among women and children).
- Emissions and ambient concentrations of directly emitted $PM_{2.5}$ are often highest in urban areas, where large numbers of people live.

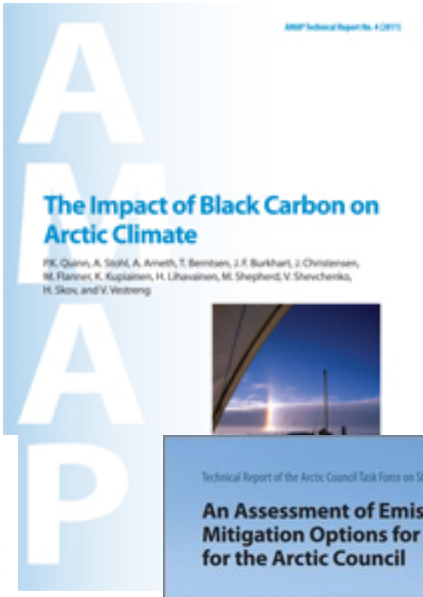
Traditional Cookstove in India

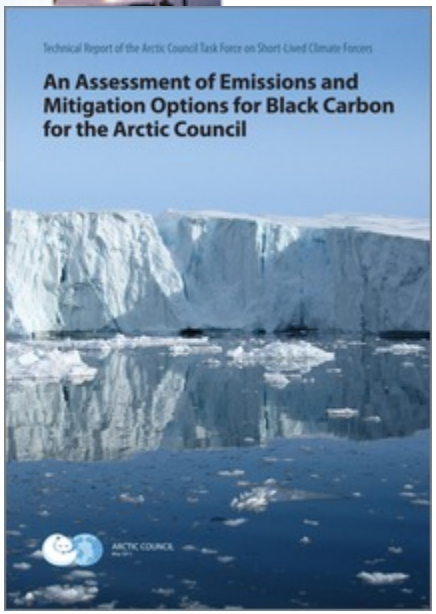
Potential Benefits of BC Mitigation

- Targeted strategies to reduce BC emissions can be expected to provide climate benefits within the next several decades, and may be particularly important for sensitive regions such as the Arctic.
- Reductions in BC and GHGs are complementary strategies for mitigating climate change.
- The health and environmental benefits of BC reductions are also substantial.
  - Average public health benefits of reducing directly emitted $PM_{2.5}$ in the U.S. are estimated to range from $290,000 to $1.2 million per ton $PM_{2.5}$ in 2030.
  - Globally, $PM_{2.5}$ reductions due to BC mitigation measures could potentially lead to hundreds of thousands of avoided premature deaths each year.

Science-policy reports on short-lived climate forcers







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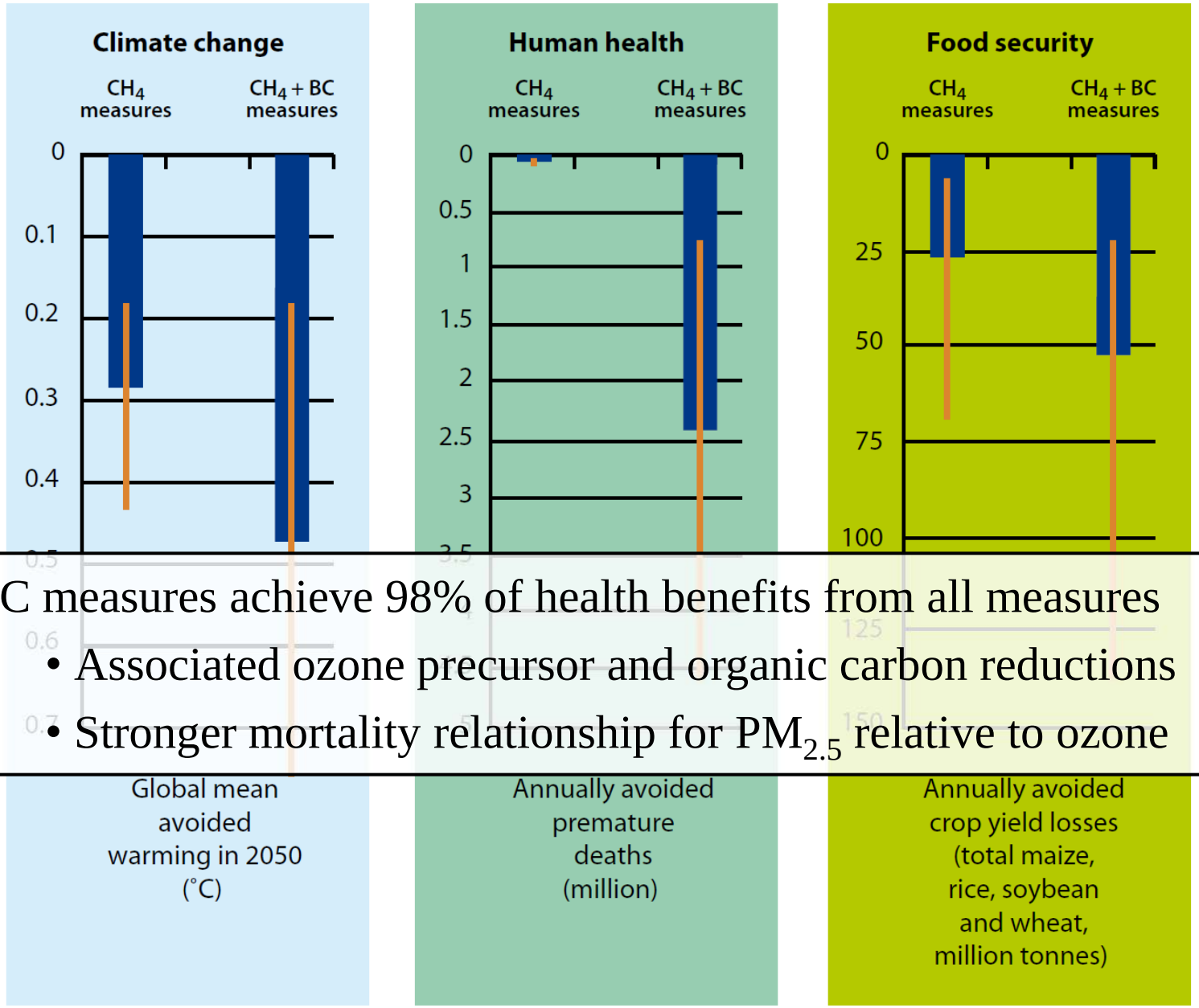

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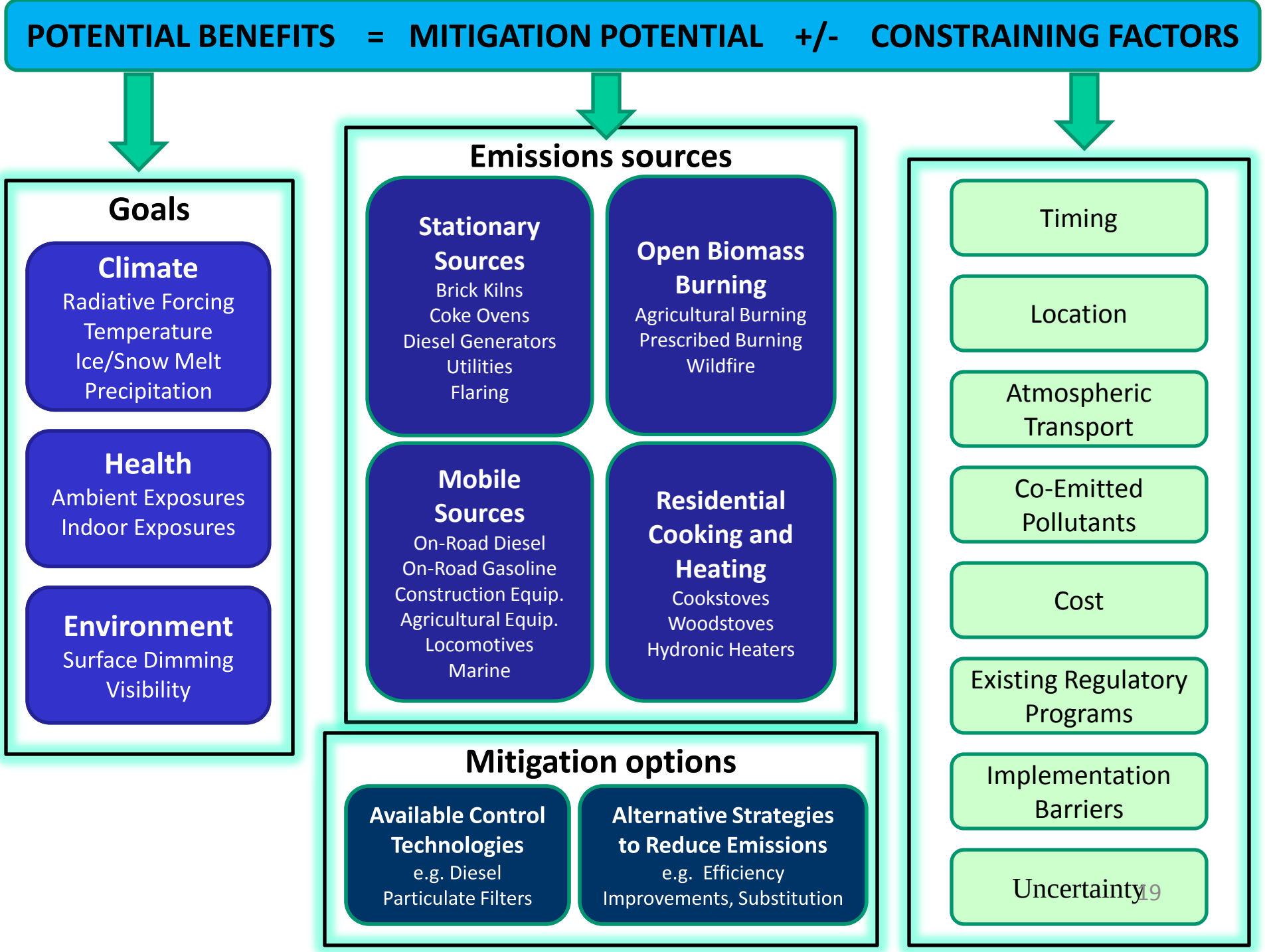
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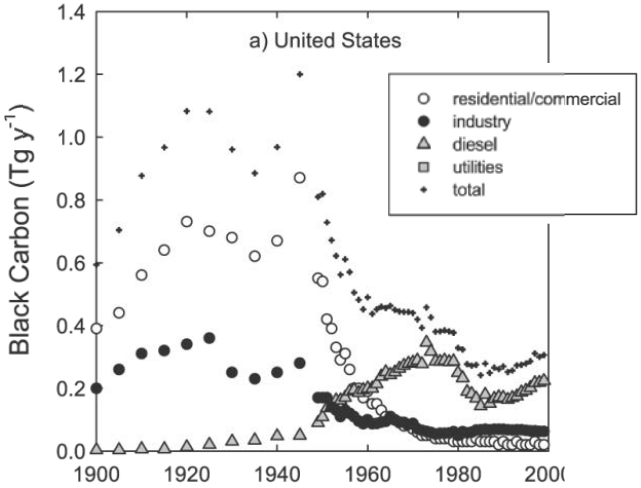

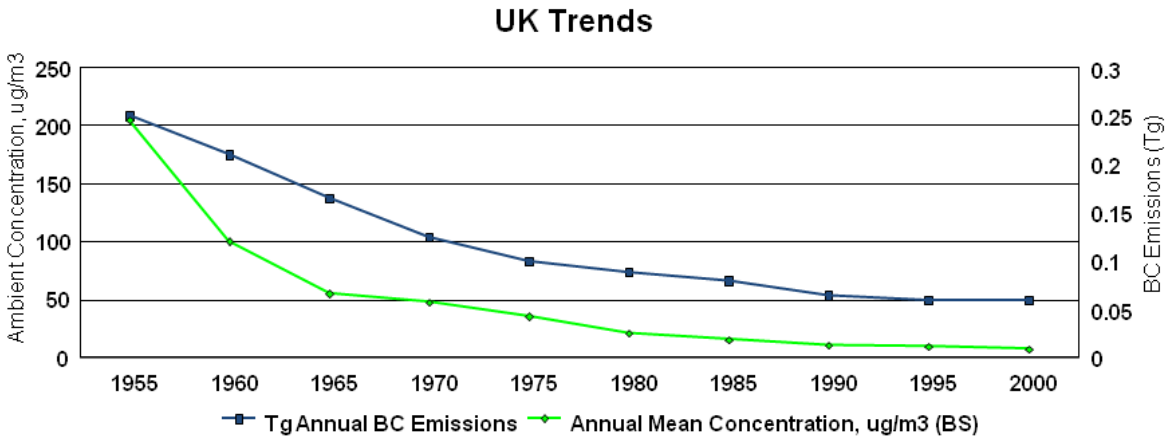

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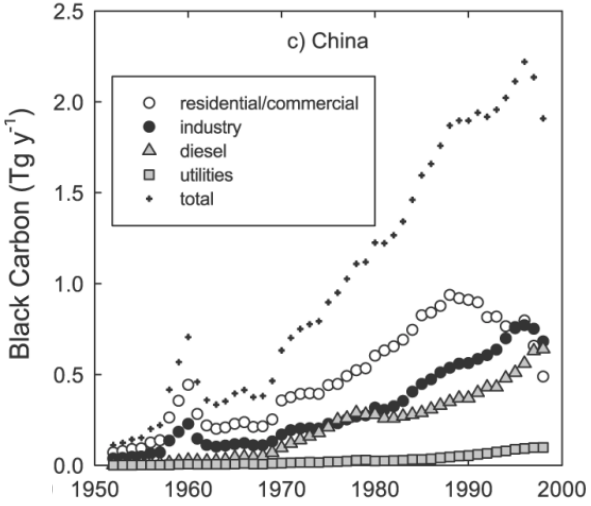

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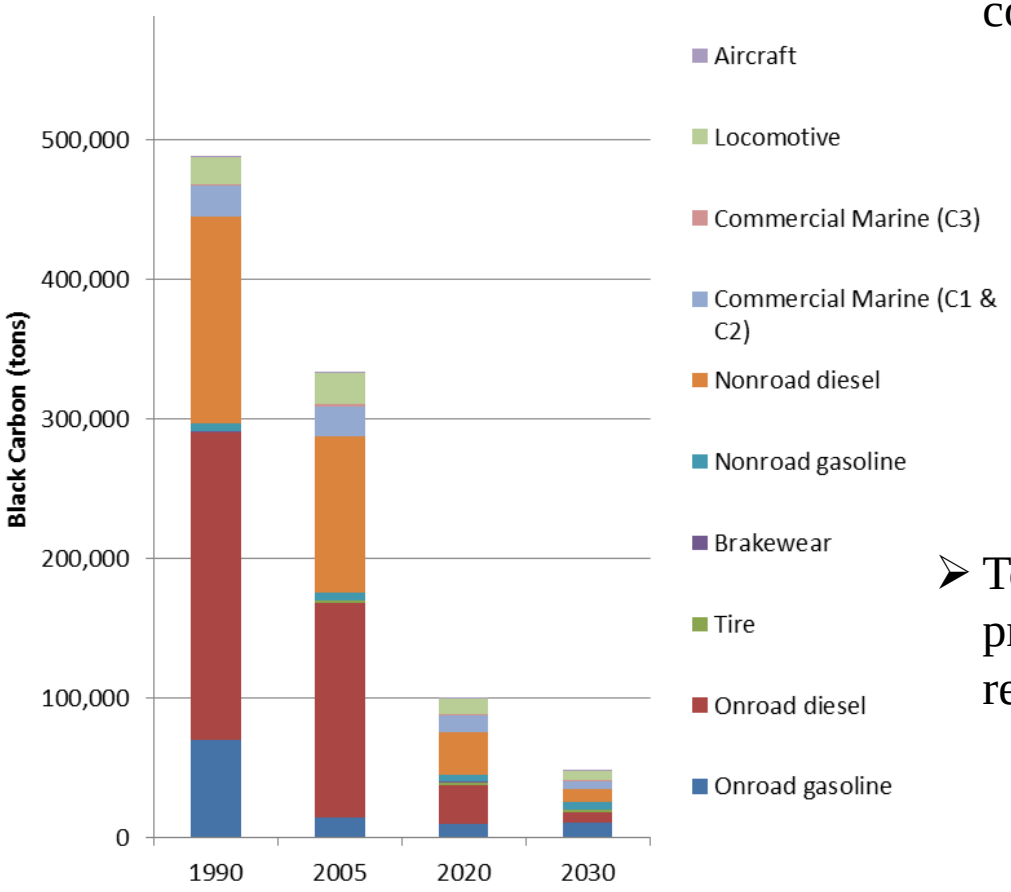

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