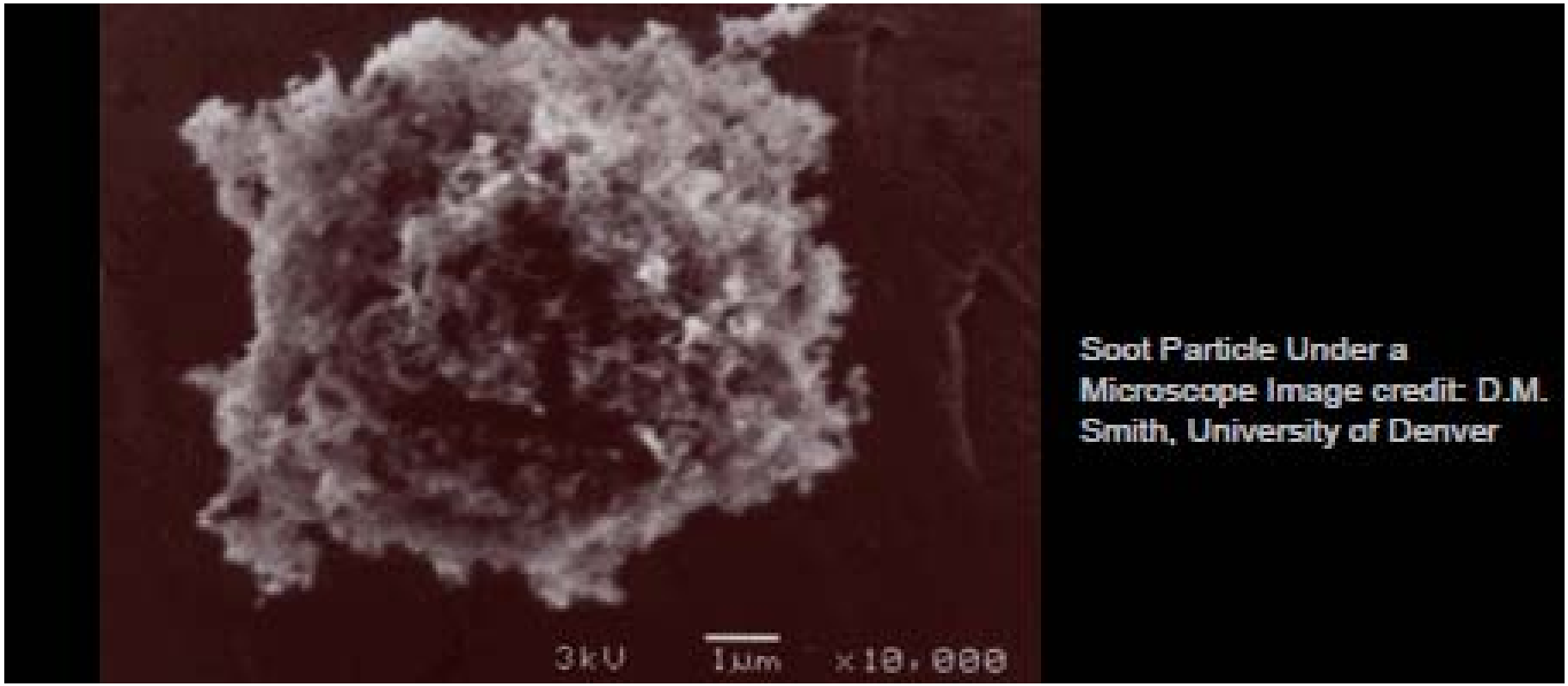
# Black Carbon 101




Soot Particle Under a Microscope Image credit: D.M. Smith, University of Denver

Terry J. Keating, Ph.D., EPA Office of Air & Radiation
Marcus Sarofim, Ph.D., AAAS Environmental Science Fellow

March 6, 2009

# What is Black Carbon?

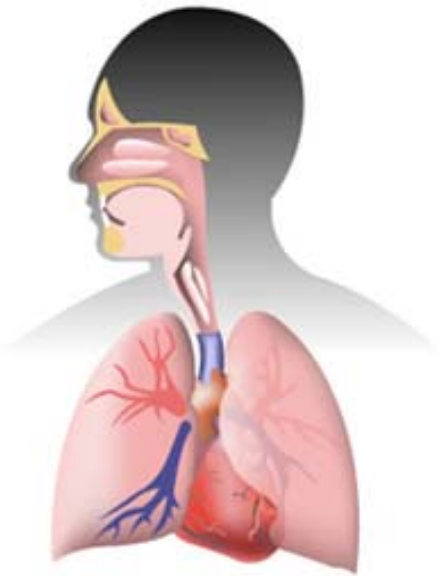
- Small (2.5 micron) light-absorbing graphitic particles produced by incomplete combustion
- Commonly called “soot”
- Distinguished from Organic Carbon (OC)

# Black Carbon Climate Impacts

- **Warming Agent:** BC significantly contributes to warming by directly absorbing sunlight and by darkening ice and snow
- **Short-lived:** immediate climate benefits of BC mitigation are possible due to its short atmospheric lifetime (days to weeks)
- **Spatially:** BC influence is regional and global
- **Co-emitted pollutants:** BC's warming effect is offset somewhat by cooling from reflective pollutants emitted by the same source, especially organic carbon
- **Uncertainties:** emission inventories and net climate impacts are much less known compared to GHGs

# Health Effects of Particle Pollution

- Black carbon is a component of $PM_{2.5}$
  - Typically 5-10% of total annual $PM_{2.5}$ in U.S. cities
- Many scientific studies have linked breathing $PM_{2.5}$ to a series of significant health problems, including:
  - Aggravated asthma
  - Increases in respiratory symptoms like coughing and difficult or painful breathing
  - Chronic bronchitis
  - Decreased lung function
  - Premature death in people with heart and lung disease
- No component of $PM_{2.5}$ is known to be primarily responsible for health effects, nor can any component be eliminated from consideration

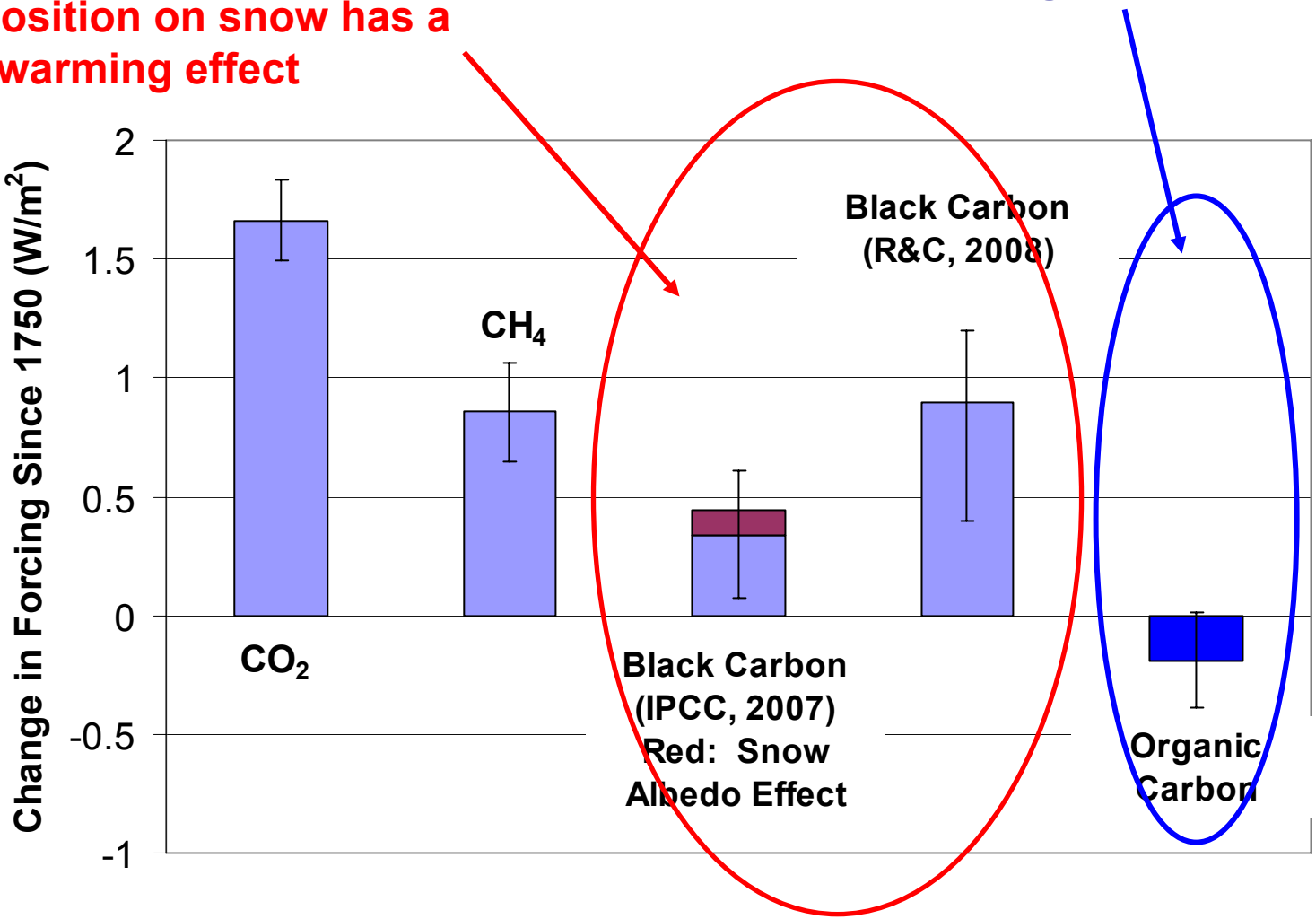


# BC has a Significant Impact on Global Warming

**Direct BC warming is large at the global (and regional) scale**

**BC deposition on snow has a strong warming effect**

**Co-emissions of organic carbon and/or other particles may partially offset BC warming**



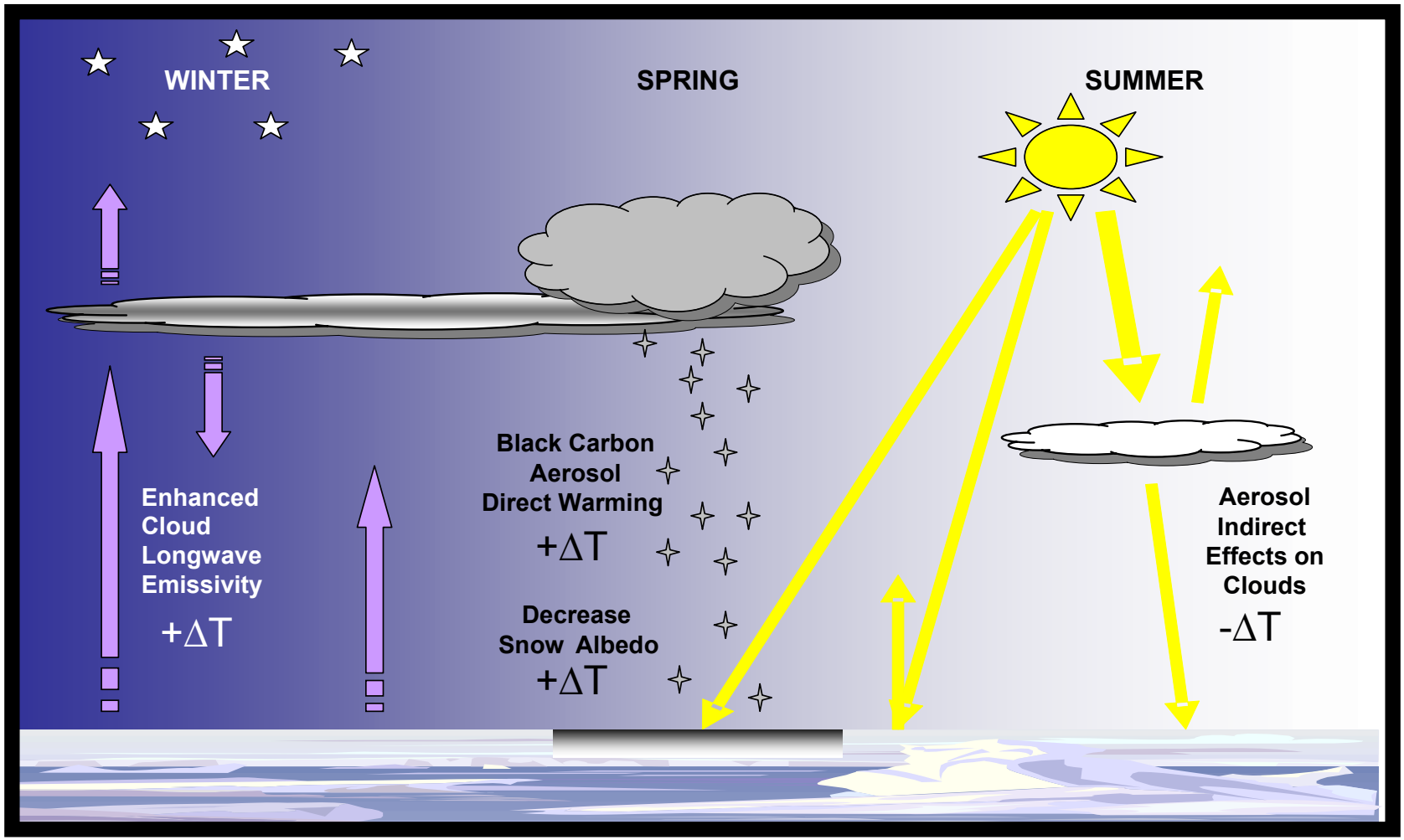

Sources: IPCC AR4 WG1 2007 for all except Ramanathan & Carmichael 2008 BC bar

# BC Net Warming and Uncertainties

- BC's warming effect is offset somewhat by cooling from reflective pollutants emitted by the same source, especially organic carbon
  - BC warms much more than OC cools, per ton
  - OC is also a component of $PM_{2.5}$, with adverse health effects
- Uncertainties in determining net climate effects of BC+OC include:
  - Impacts depend on location and timing of emissions
  - BC's short atmospheric lifetime
  - BC and OC interactions with clouds is very uncertain
  - As BC mixes with other compounds in the air, its properties change
  - Global inventories are estimated to have factor of 2 uncertainty

# BC's Role in Arctic Warming

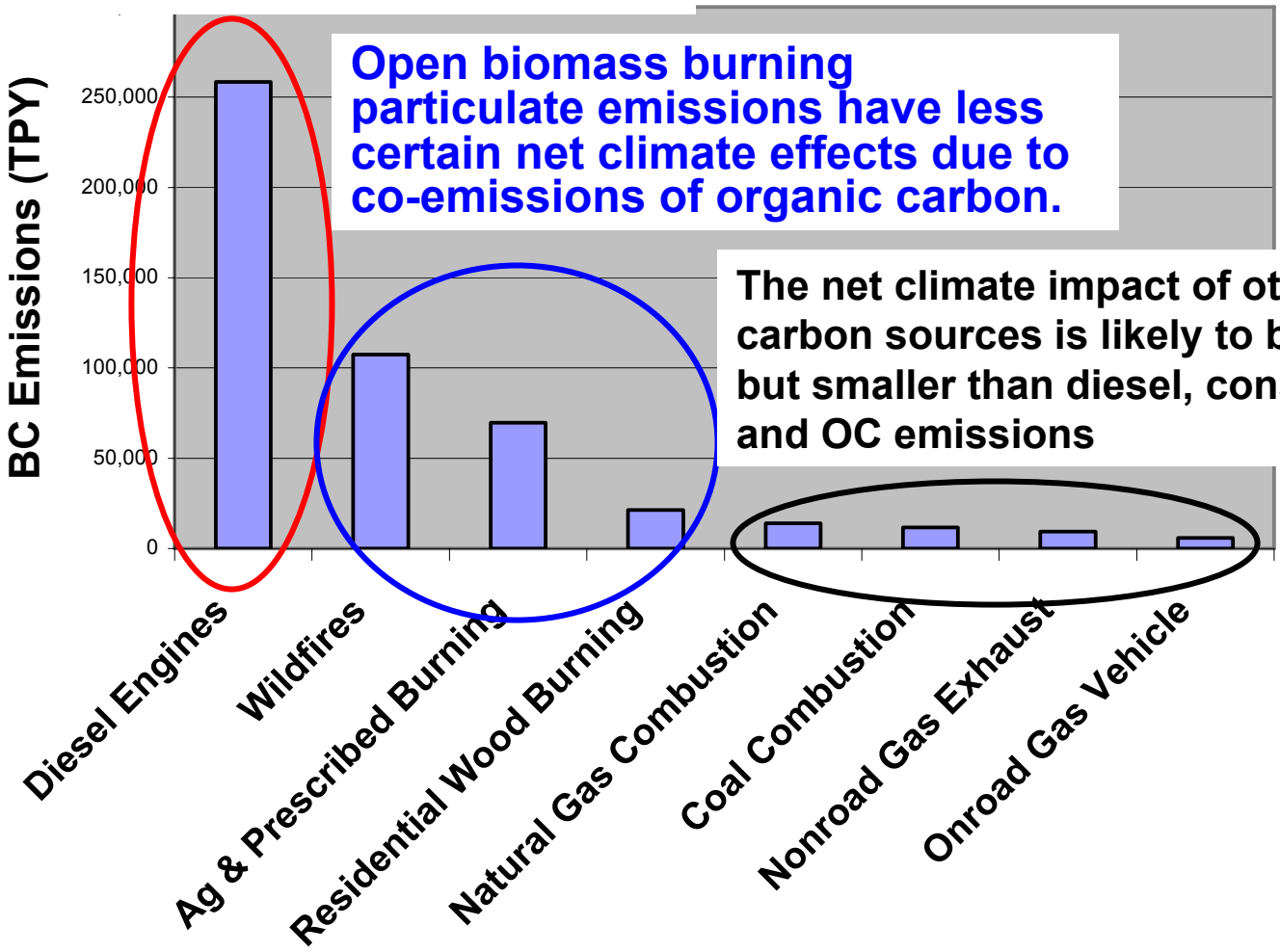
BC aerosol warms the atmosphere directly, decreases reflectivity of snow and ice, and accelerates snow and ice melting.




*Modified from Quinn, ACPD, 2007*

# U.S. Black Carbon Emissions, 2002

**In the United States, diesel engines particulate emissions have the strongest warming impact due to large BC and small OC emissions**

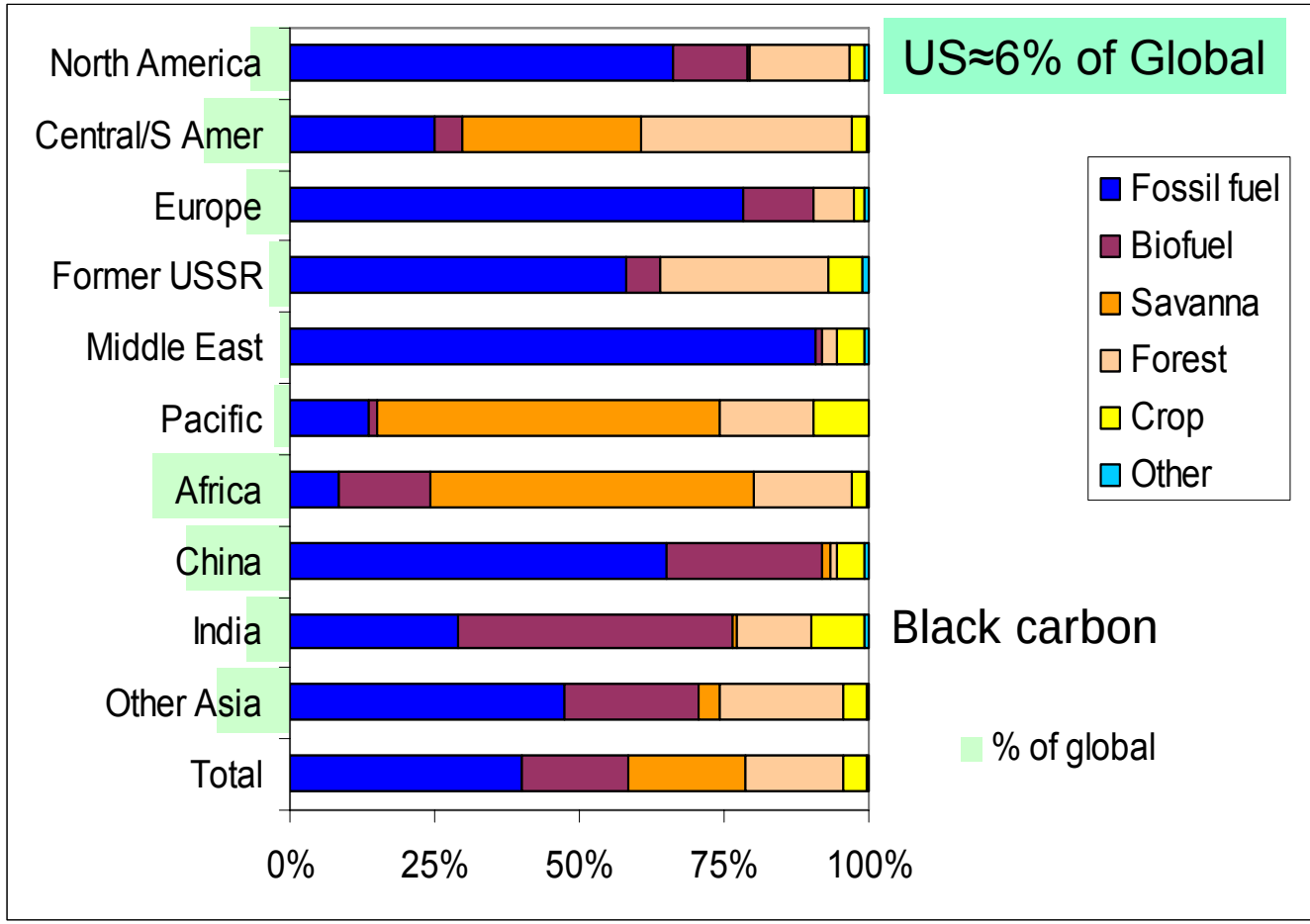



**Open biomass burning particulate emissions have less certain net climate effects due to co-emissions of organic carbon.**

**The net climate impact of other black carbon sources is likely to be warming, but smaller than diesel, considering BC and OC emissions**

# International BC Emissions

- Africa, China and Rest of Asia represent largest emission sources
- Portfolio of emission categories, and thus mitigation strategies, varies by region
- In N. America and Europe, diesels are largest source but are projected to decline. Transportation emissions are projected to increase in other world regions
- Residential cooking and heating large sources in Asia and Africa




Source: Bond et al. (2004) "A technology-based global inventory of black and organic carbon emissions from combustion," *J. Geophys. Res.*

# Science Summary:
## Potential for Multiple, Near-Term Benefits

- **Decreasing BC yields important health benefits**
- **Climate benefits appear significant, but key uncertainties remain**
- **BC controls offer one of the few climate mitigation strategies with near-term impacts**
- **Internationally, opportunities for significant climate and health benefits**
  - Addressing near-term Arctic climate concerns
  - Addressing key developing country sources

# Diesel Vehicle Emissions of Black Carbon: *Important and Solveable*

Michael Walsh, Board Chair, ICCT

Black Carbon 101: Science, Sources, Solutions

Friday, March 6, 2009

US Senate Visitor Center





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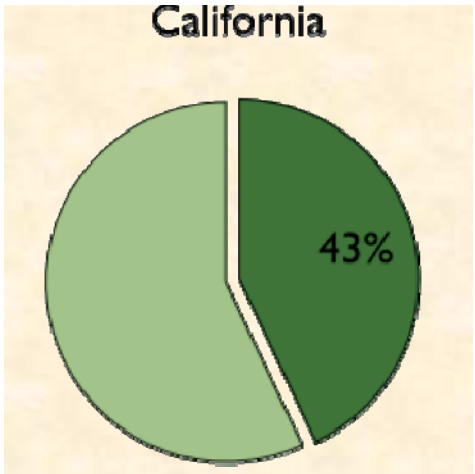
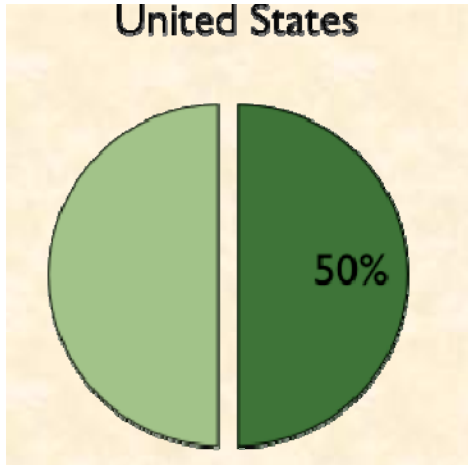
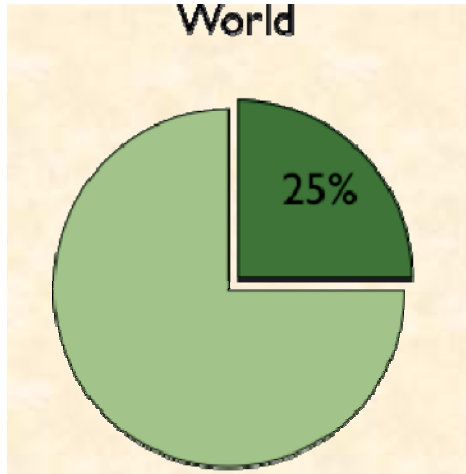
# Why Diesels Are Important

## Diesel Share of BC emissions




## Health Impacts from Diesel PM

Premature death
Lung Cancer
Decreased lung function
Chronic bronchitis

Increased hospitalization
Aggravated Asthma
Increased respiratory symptoms
Lost work days
Reduction in visibility

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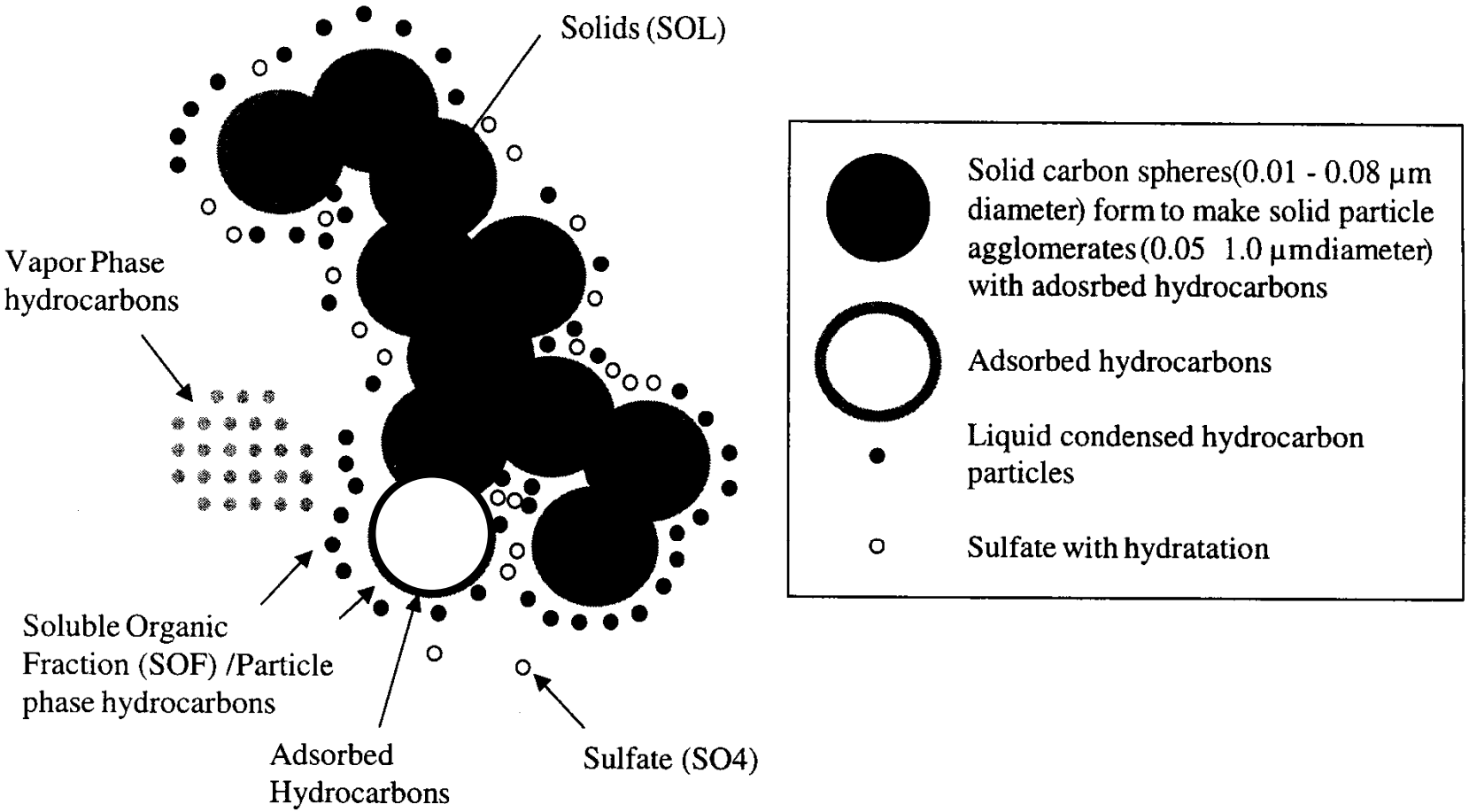
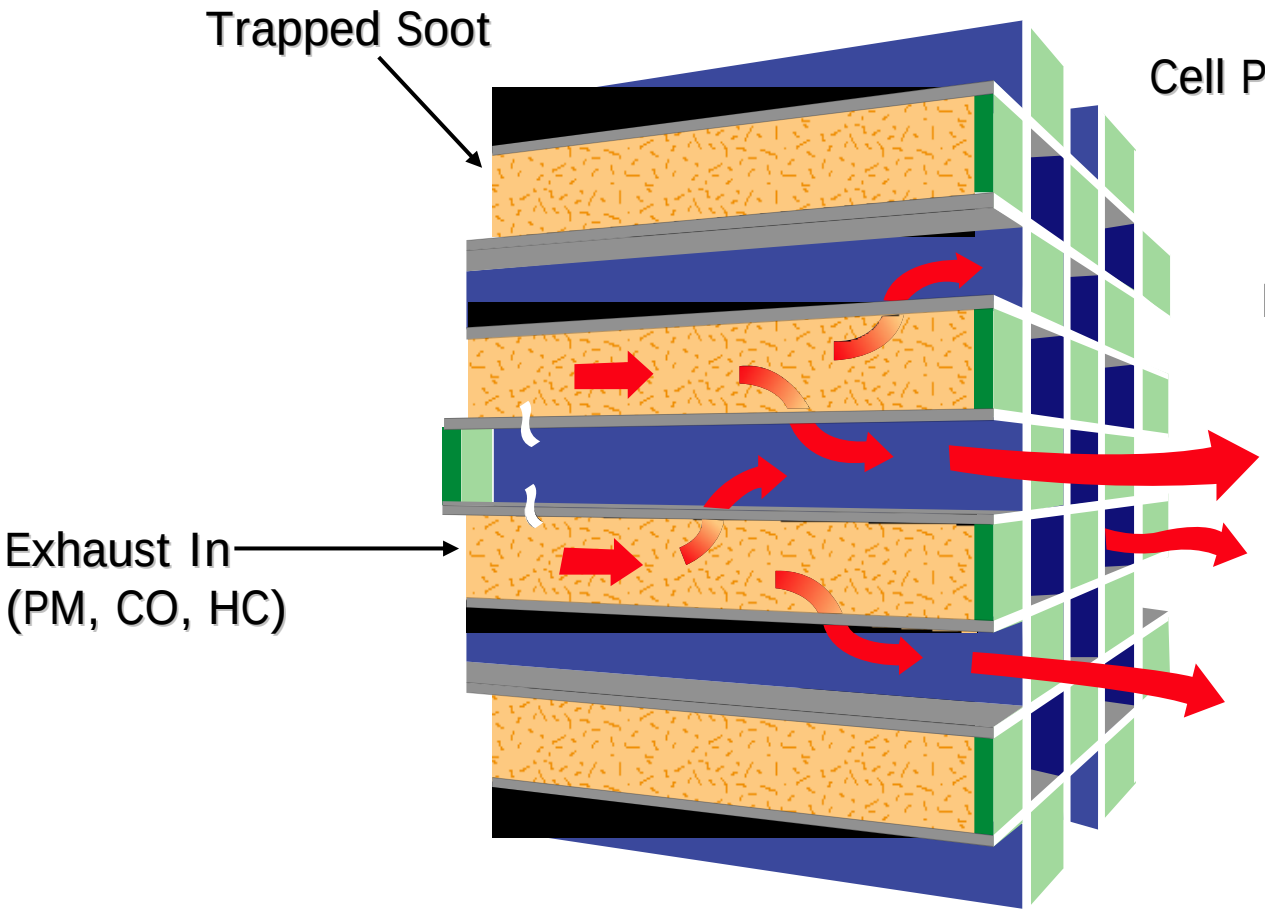
# Black Carbon Core of Diesel PM



# The Solution Exists: Diesel Particulate Filters (DPFs)




*Removes 90+% BC, PM; also HC and CO

*Requires Ultralow Sulfur Diesel (ULSD)

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# Stringent Standards for New Vehicles Have Been Adopted by US EPA

## Highway

Tier 2
Light-duty
(1999)

2007/2010
Heavy-duty
(2001)

## *Common Aspects--*

- Systems approach– fuel change enables clean technologies
- Large environmental benefits
- Responsive to needs of States to meet air quality goals

## Nonroad

Tier 4 diesel (2004)

## Locomotive/Marine

2008

# Retrofits Are Critical

- US has best standards in the world for new vehicles
  - Europe is following US standards but more slowly
  - ROW lags even more: China, India, Brazil, etc
- Existing vehicles can remain on the road for 30+ years
- EPA Goal: *Reduce emissions from the legacy fleet of over 11 million diesel engines*
- Voluntary Program Lacks Sufficient Funding
- CARB Has A Mandatory Program!

# Targets

- On-road
  - School buses
  - Class 8 Trucks
  - Commercial vehicles
- Off-road
  - tractors
  - service vehicles

Loader

Backhoe Loader

Belt Loader

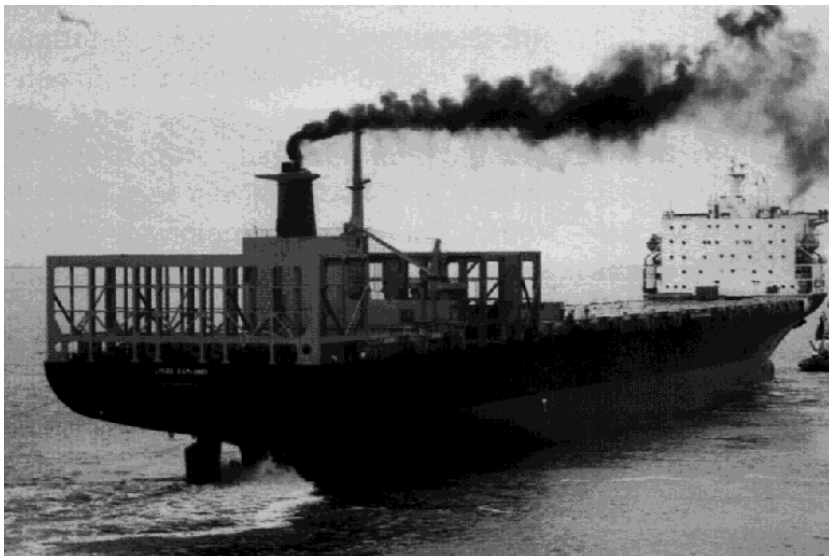
Skid Steer

# International Efforts

- Demonstration Projects
- EPA involved with diesel retrofit projects in
  - Mexico City, Bangkok, Beijing, Santiago Chile, Pune India
- Generally, EPA provides modest funding, technical expertise and support to local partners, help with program design, access to information and vendors
- Technical panel and stakeholder group to advise the project "in country"; help build local support
- European Effort Recently Launched

Following the pilot project, Chinese retrofit over 6000 vehicles in Beijing

# Marine Black Carbon



- Concerns with deposition on snow, especially Arctic
- Control Strategies
  - Technologies (e.g. diesel particulate filter)
  - Fuel switching (e.g. marine diesel oil)
  - Operation (e.g., speed control & emissions control areas
- Ongoing research on climate impacts

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# Thank you!

## International Council on Clean Transportation

- Goal of the ICCT is to dramatically reduce conventional pollutant and greenhouse gas emissions from all transportation sources in order to improve air quality and human health, and mitigate climate change.
- The Council is made up of leading regulators and experts from around the world.

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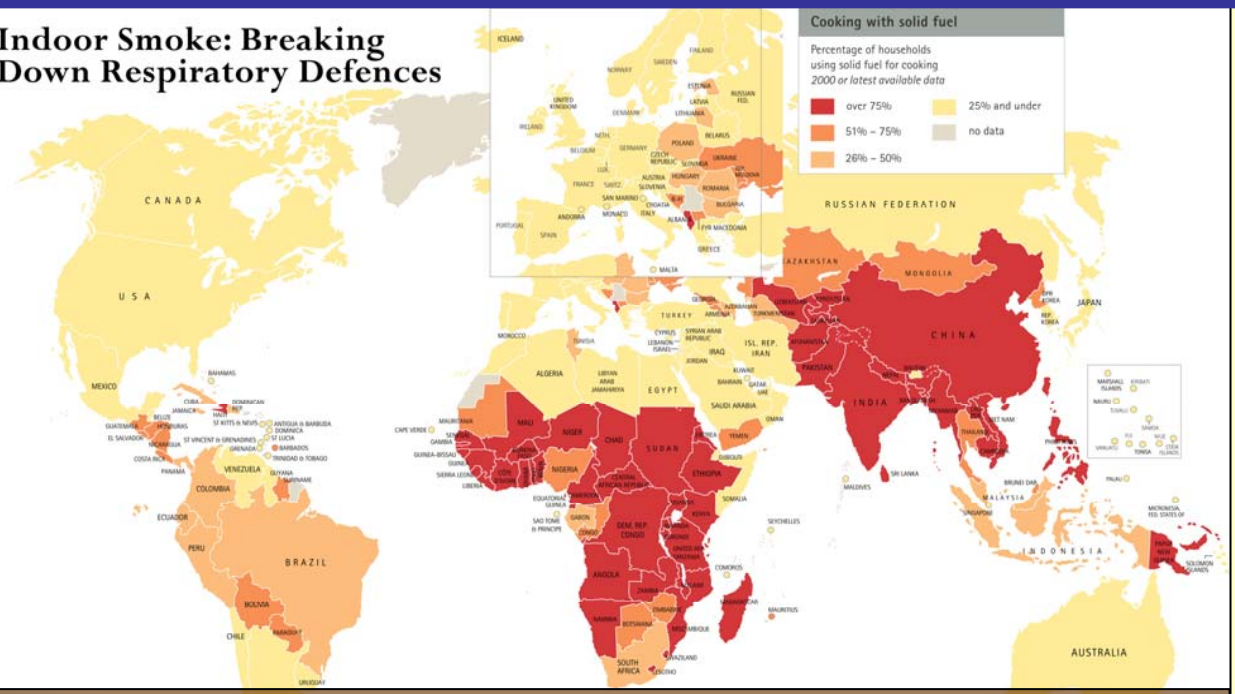
# Partnership for Clean Indoor Air

# Cookstoves, Indoor Smoke, & Climate

Jacob Moss, U.S. EPA

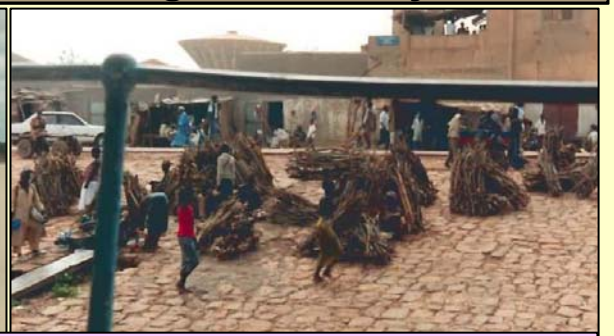
March 6, 2009

# Solid Fuel Use and Collection




**Half the world cooks with solid fuels (wood, dung, coal,...).**

**200 million more people will be using biomass by 2030.**



**Fuelwood transport and sale (Niger River, Mali)**

**Making dung patties (India)**

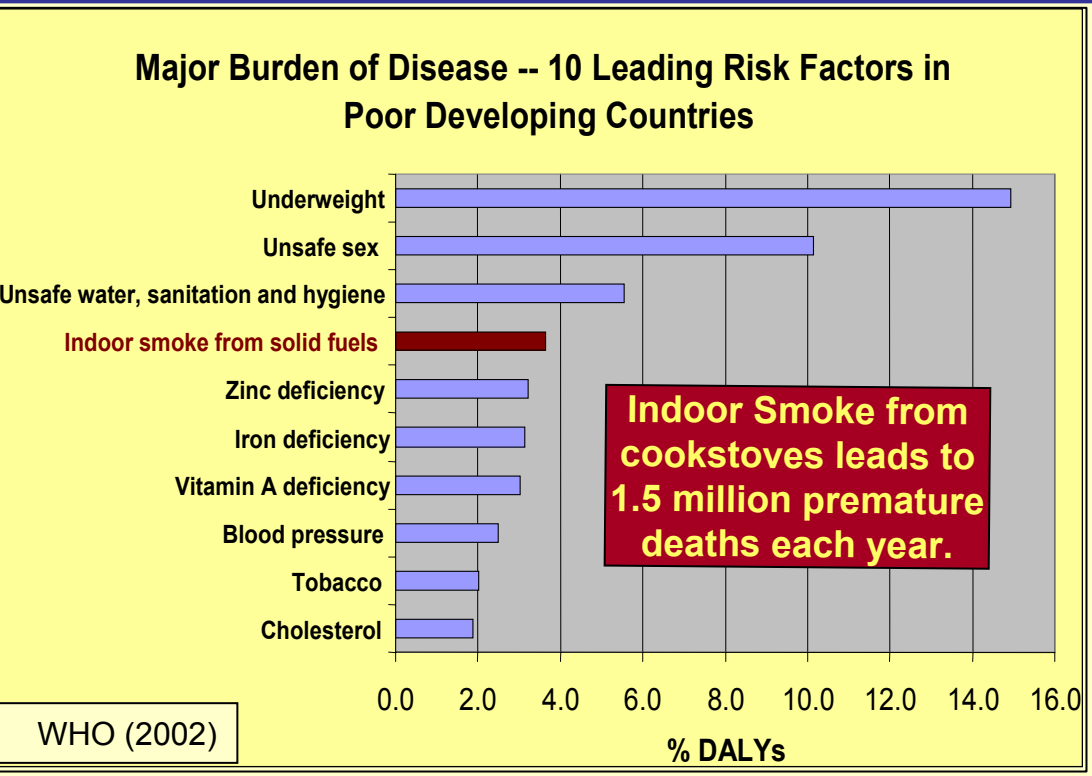
**Collecting fuelwood (Togo)**

**Charcoal on sale (Togo)**



Sources: WHO (2002); IEA (2007)

# Indoor Smoke from Cookstoves is the 4th Worst Health Risk Factor in Poor, Developing Countries




WHO (2002)

Guatemala home $PM_{2.5}$ = 8670 µg/m³ (peak)

Typical 24-hr Levels : 100s-1000s µg/m³

U.S. 24-hour $PM_{2.5}$ Standard = 35 µg/m³

U.S. Annual $PM_{2.5}$ Standard = 15 µg/m³

# Global warming/cooling from 30% reduction in current regional emissions by sector

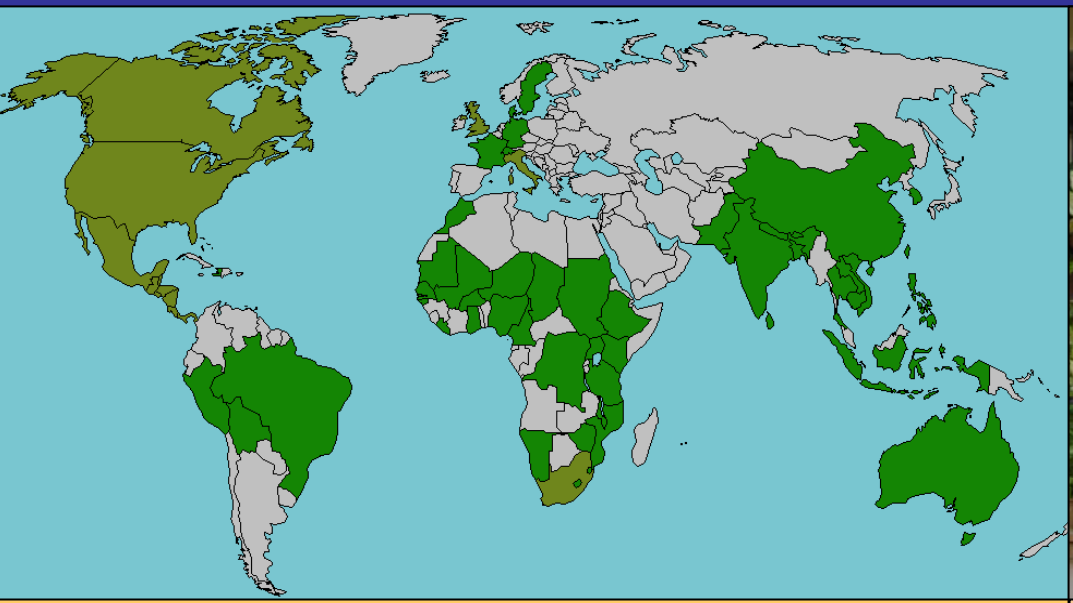
**Table 3.10 Radiative forcing in milliWatts per square meter (mW per m$^2$), from regional emission sector perturbations in the GISS model.**

| Region | Sector | Sulfate | BC | OC | Nitrate | Ozone | Methane (indirect) | All |
|---|---|---|---|---|---|---|---|---|
| North America | Domestic | 0 | -3 | 2 | 1 | 2 | 1 | 4 |
| | Surface Transportation | -3 | -5 | 0 | 1 | -5 | 4 | -9 |
| | Industry/power | 14 | -2 | -1 | 0 | 5 | 2 | 18 |
| Asia | Domestic | 0 | -42 | 13 | 1 | -12 | -2 | -41 |
| | Surface Transportation | 2 | -8 | 1 | 2 | -5 | 7 | -2 |
| | Industry/power | 13 | -4 | 0 | -1 | -1 | 5 | 12 |

**U.S. Climate Change Science Program (September 2008) SAP 3.2**

**From Key Finding #3:** "Reductions of short-lived pollutants from the domestic fuel burning sector in Asia, whose climate impacts in this study are dominated by black carbon (soot), appear to offer the greatest potential for substantial, simultaneous improvement in local air quality and reduction of global warming."

# Partnership for Clean Indoor Air (PCIA)



In 6 years, PCIA has grown from 13 to over 250 partners that work in over 115 countries.

Attendees to 3rd Biennial PCIA Forum in Bangalore, India (March 2007)

- Launched at 2002 World Summit on Sustainable Development
- PCIA Activities to Date Include:
  - projects reaching over 1 million people, with stoves that use 50-70% less fuel and reduce emissions by 60-90%
  - Global Forums:  New York, Marrakech, Bangalore, Uganda
  - stove testing, networking, tools, PCIA website, quarterly bulletins
  - capacity building (e.g., monitoring; stove design; enterprise devo.)

# Draft Future PCIA Business Plan

PCIA Role w/Partners

Not PCIA Role

## PHASE 1: Demonstrate Ability to Reach Scale, 2009 – 2013 (Budget ≈ $30 million)

### PHASE 1a: Demonstrate Success at Regional Scale – Partner Networks to Support Markets

**Users**
- Homes
- Institutions
- Businesses

**Public Awareness**

DEMAND

**Financing**

**Testing Centers**

**Government Policy**

**Manufacturers**
- Local Businesses
- Multi-National Corporations

**Sales/Distribution**
- Local Businesses
- Multi-National Corps
- Local NGOs

SUPPLY

Monitoring & Evaluation

### PHASE 1b: Mature Global Infrastructure

- Standards & Measures
- Global Communications
- Knowledge & Networking

### PHASE 1c: Priority Research

- Health Effects
- Climate Change: Impacts & Remedies
- Economic Metrics
- Clean Stove & Fuel Research

**Goals:** Bring clean cooking practices to 20 million homes (100 million people), and for this group:
- ► Reduce fuel use – and GHG emissions – by 50-70%
- ► Reduce stove emissions – including black carbon – by 60-90%
- ► Reduce daily personal exposure by at least 50% and reduce severe child pneumonia by 30-40%

## PHASE 2: Global Campaign to Reduce Smoke from Cookstoves, 2014 – 2030 (Budget: $100s millions)

- Communicate Results of Local Strategy
- Develop Strategy with Global Leaders
- Identify Global Resources

**Goal:** Eliminate these risks for half of the 3 billion affected people.

# Aprovecho Research Center/ StoveTec

- Burns wood or charcoal
- Design features:
  - Fuel shelf
  - Combustion chamber
  - Skirt
  - Stove top
  - Adjustable airflow doors
- Manufactured in China
- StoveTec claims it can be shipped anywhere in the world for less than $10
- Up to 70% cleaner! ☺
- Only 70% cleaner! ☹

# Industrial and agricultural burning sources of black carbon emissions

Briefing for Senate Staff

Ellen Baum, Senior Scientist
March 6, 2009

# Industrial BC Emissions

- Estimated to be ~ 10 percent of year 2000 black carbon emissions inventory
  - Coke making
  - Kilns (mostly brick making)
  - Boilers, industrial process, steel, lime
- Major source fractions are uncertain, although coke making and brick kilns dominate.
- ***Emissions information for non-boiler sources are quite limited, and based on very few measurements.***
- Also questions about the black carbon emissions from oil and gas flaring, which we are currently trying to investigate.

# Coke Making –concentrated in China

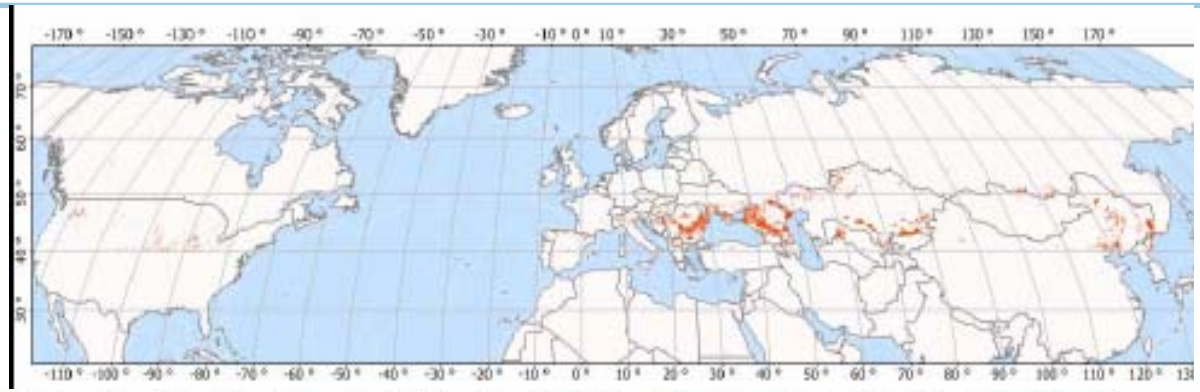
- Relatively small number of global coke making facilities ~ 1500 worldwide
- Recent – 2006 production – is dominated by China
  - China 59%
  - Russian Federation 6%
  - Ukraine 4%
  - US 3%
  - India 2.5%
- Most traditional coke ovens (prevalent through the late 1990s) are probably gone.
- Most coke ovens today support chemicals “recovery” -- need lots of emissions control measures – or “non-recovery” facilities – a much cleaner process.
- Plausible BC emissions reduction measures will come from a complex range of small particulate emissions control, most of which achieve or go beyond current US EPA control levels.

# Brick Making

- Many brick kilns ~ 300,000 worldwide
- Primary fuels are coal, plus any low-cost fuel that can be scavenged (tires, battery cases, dung, etc.)
- Most brick kilns in developing countries are primitive and have significant BC and other emissions
- Major brick producing countries – 75% global brick production
  - China: 54% 700 billion bricks/yr
  - India: 10% 144 billion bricks/yr
  - Pakistan: 8% 100 billion bricks/yr
  - Bangladesh: 4% 50 billion bricks /yr
- BC emissions control measures will likely be replacing kilns with improved technology.
- Shifting to improved technology kilns will typically reduce fuel consumption and $CO_2$ emissions.

# Emissions from spring agricultural burns reaching the Arctic

March



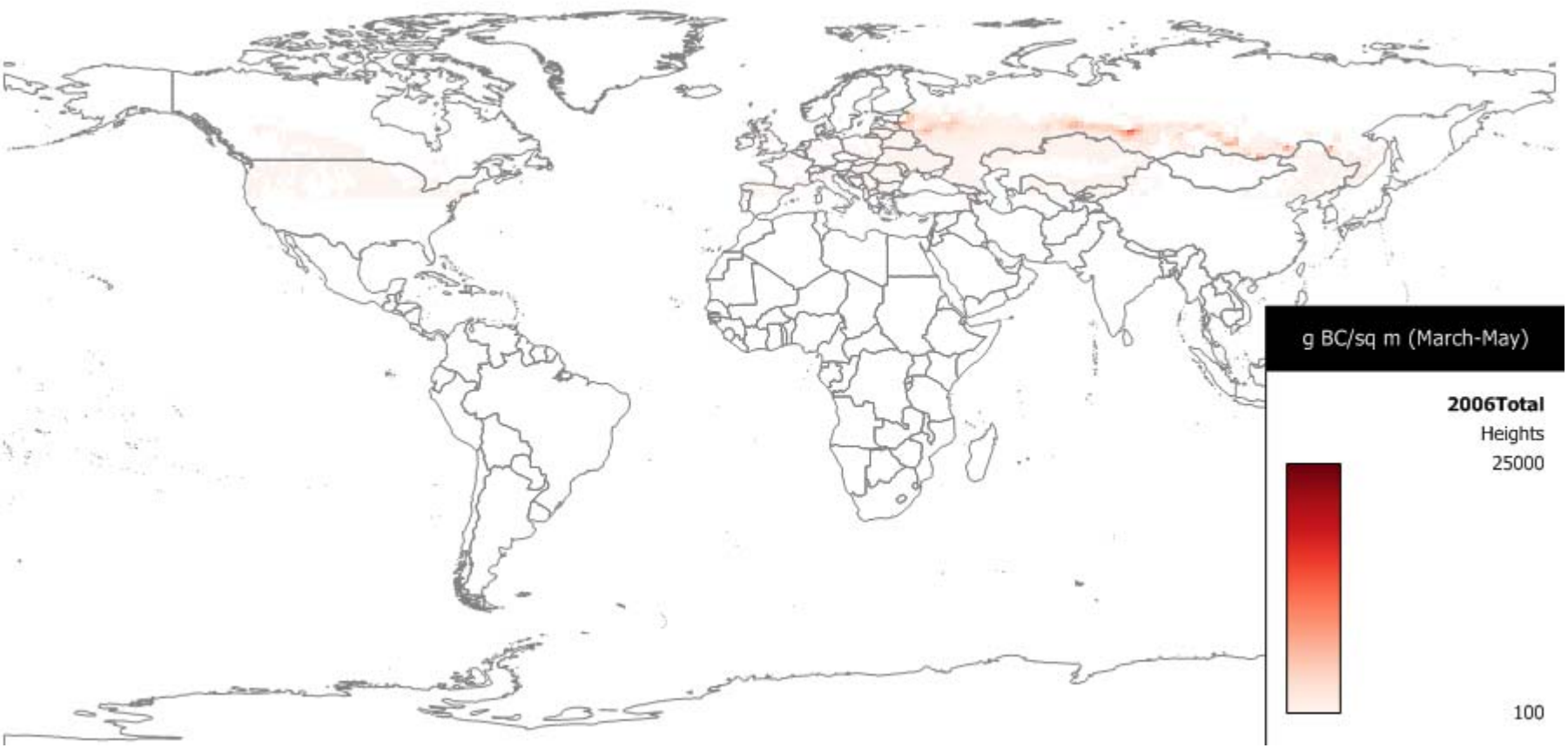
April

May

2006 fire burn locations, on croplands north of 40 degrees latitude, during spring months 2006 is a typical fire year.

*From, MODIS Terra Global Land Cover and Burned Area, 1 km*

# Black carbon emissions from cropland burning, north of 40°, spring 2006




*From Randerson JT, van der Werf GR, Gilgio L, Collatz GJ, Kasibhatla Global Fire Emissions Database, www.geo.vu.nl/users/gwerf/GFED/ index.html and Andreae MO, Merlet P. GBC*

# Hard to reconcile maps and observations with policies

- Russia dominates in terms of black carbon emissions from burning of agricultural lands above 40 degrees latitude in the spring, followed by China, Kazakhstan, Canada, United States, Ukraine
- There is a lot of confusion about the Russian fires, as agricultural burning have been banned in Russia since the 1960s, and it is apparently very difficult to engage in informative conversations about what is happening.
- Some spring burning of wheat fields in the northern plains of the US could be accelerating spring melt in northern Canada and Greenland. Need to take a closer look.

CLEAN AIR TASK FORCE

# Policy Options for Reducing Black Carbon

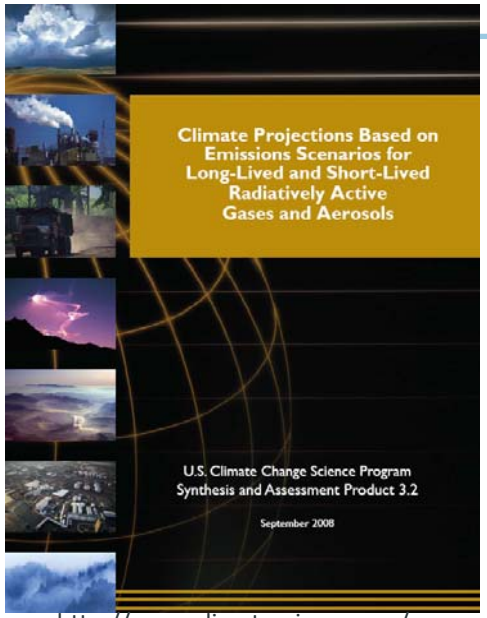
## A Near-Term Climate Strategy

Briefing for Senate Staff

Conrad Schneider, Advocacy Director
March 6, 2009

CLEANAIR TASK FORCE

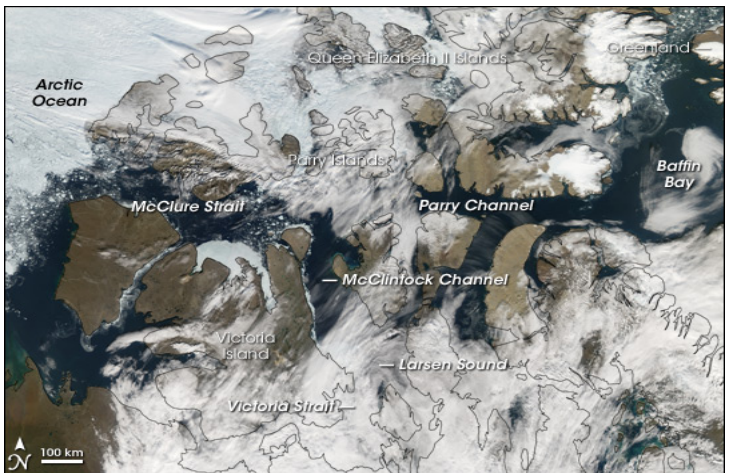
# The Climate is Facing Critical Tipping Points




http://www.climatescience.gov/

- Black carbon has a short life in the atmosphere (weeks) as opposed to CO2 (decades or more).
- Cutting black carbon emissions can yield immediate climate benefits to help avoid near-term tipping points and buy time for $CO_2$ strategies to work.
- Conclusion of US Climate Science Program (Sept 2008): Reductions of short lived gas and particle emissions from the surface transportation in North America offer the greatest potential for substantial, simultaneous improvement in local air quality and reduction of global warming.

## 2007: NW Passage Opens




## July 2008: Ice Sheet Breaks Loose

AP Associated Press

### 19-square-mile ice sheet breaks loose in Canada

By CHARMAINE NORONHA – 1 day ago

TORONTO (AP) — A chunk of ice shelf nearly the size of Manhattan has broken away from Ellesmere Island in Canada's northern Arctic, another dramatic indication of how warmer temperatures are changing the polar frontier, scientists said Wednesday.

Derek Mueller, an Arctic ice shelf specialist at Trent University in Ontario, told The Associated Press that the 4,500-year-old Markham Ice Shelf separated in early August and the 19-square-mile shelf is now adrift in the Arctic Ocean.

"The Markham Ice Shelf was a big surprise because it suddenly disappeared. We went under cloud for a bit during our research and when the weather cleared up, all of a sudden there was no more ice shelf. It was a shocking event that underscores the rapidity of changes taking place in the Arctic," said Mueller.

Mueller also said that two large sections of ice detached from the Serson Ice Shelf, shrinking that ice feature by 47 square miles — or 60 percent — and that the Ward Hunt Ice Shelf has also continued to break up, losing an additional eight square miles.

In this July 29, 2008 file photo large pieces of ice are seen drifting off after separating from the Ward Hunt Ice Shelf. A chunk of ice shelf nearly the size of Manhattan has broken away from Ellesmere Island in Canada's northern Arctic, another dramatic indication of how warmer temperatures are changing the polar frontier, scientists said Wednesday, Sept. 3, 2008. (AP Photo/Sam Soja, The Canadian Press)

# Most Important Point

- Reducing Black Carbon and other Short-Lived Pollutants (SLPs) is ***not a substitute*** for deep reductions in CO2.
- Reductions in CO2 and SLPs work on different time scales, but both are needed to stabilize the climate.

CLEANAIR TASK FORCE

# Outline of BC Policy Options

## By Source

- Diesel
- Stoves
- Agricultural Burning
- Industrial

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# Why a Black Carbon Study Bill?

- Because while we know a lot about BC (science, sources, solutions, and potential policies), there is critical information that we don't know.
  - Need to "screen" sources by significance of direction of climate contribution, so need to understand international inventories.
  - Whether to control a source may depend on its BC/OC ratio – where BC dominates (such as with diesel) action to reduce emissions is clearly justified. Where OC dominates (certain biomass burning), reductions could lead to greater warming. There is uncertainty around some sources in the middle.
  - Need equivalency metrics to determine effectiveness and cost-effectiveness, offset eligibility and credit.
- 180-Day report back quick enough to incorporate findings *and policy recommendations* in Climate legislation. Synthesis of current knowledge and data about BC.

# Sources of Black Carbon

Diesels

Industry

Smoking Cookstoves

Burning Fields

Marine Vessels

CLEANAIR TASK FORCE

# Target BC Reduction Strategies

| | | Known Arctic deposition | Atmospheric warming | Mitigation feasibility |
|---|---|---|---|---|
| Diesel | 24% | yes | STRONG | EXISTS / POSSIBLE |
| Stoves | 18% | OPEN Q | STRONG-MOD | EXISTS / POSSIBLE |
| Coal | 6% | OPEN Q | OPEN Q | EXISTS / POSSIBLE |
| Industrial | 10% | yes | OPEN Q | EXISTS / POSSIBLE |
| Ag burning | 4% | yes | OPEN Q | EXISTS / POSSIBLE |
| Open biomass | 38% | yes | OPEN Q | QUESTIONABLE |

*Adapted from Bond et al., 2004 (updated to year 2000 data); GFEDv2 (van der Werf, 2006)*

CLEAN AIR TASK FORCE

# Diesel

- Solutions:
  - Domestic = DPF retrofits
  - International = new engine standards and ULSD, plus DPF retrofits for existing engines.
- Study will provide:
  - Metric for estimating climate benefits and cost-effectiveness of Diesel BC reduction.
  - Recommendations for mandatory programs, needed funding levels, and/or additional statutory authority for EPA.

CLEANAIR TASK FORCE

# Diesel

- Mandates
  - EPA set emissions standards for new engines that require DPFs, but it will take until 2030 for the entire fleet to turnover.
  - EPA has limited authority under CAA to regulate ***existing*** diesel engines
  - Under current CAA Sec. 202(a)(3)(D), EPA may require existing diesel vehicles to meet emission standards consistent with installation of a DPF whenever the engine is rebuilt.
- Funding
- Construction Specifications

CLEANAIR TASK FORCE

# Diesel: Engine Rebuild Rule Benefits

**Starting in 2012, all rebuilt engines on long-haul trucks must meet PM2.5 performance standard consistent with DPF.**

- Long-haul trucks consume ~80% of on-road diesel fuel = 80% of on-road diesel BC pollution.
- 1M trucks cleaned up at $4K per truck.
- 58,500 tons of BC removed = 10X DERA reductions
- **Would Yield CO2e of removing nearly 6M cars from the road.**
- 7,500 avoided deaths
- $45.3B in benefits
- B/C ratio of 15:1

CLEANAIR TASK FORCE

# Diesel

- Mandates
- Funding
  - Diesel Emission Reduction Act (DERA) -- Authorized at $200M/year for 5 years = $1B.  $300M in Stimulus. $60M in House FY09 Omnibus.
  - CMAQ – SAFETEA-LU required diesel retrofits to be given “priority” for CMAQ funding, but few projects actually funded by DOTs and MPOs.  “Priority” should be clarified.
  - Proceeds from Climate bill -- Auction revenues or allowance set asides could be targeted to fund retrofits for public fleets and *leverage* its climate benefits.
- Construction Specifications

CLEANAIR TASK FORCE

# Diesel

- Mandates
- Funding
- Construction Specifications
  - Public Fleets and Public Works
  - “Green” Infrastructure Investment -- New Transportation bill (MAP-21) provides opportunity to ensure that all federally-funded transportation and infrastructure projects are built using “clean diesel” equipment.
  - 1% for Clean Diesel -- Requiring best available controls on construction equipment would add an average of only 1% to project cost.

CLEAN AIR TASK FORCE

# Diesel: International

- Urge foreign governments to adopt stringent fuel and vehicle standards, and implement in-use programs.
- Provide technical resources via the U.S. EPA.
- Provide bilateral funding and establish multi-lateral funding for implementation of such initiatives.

CLEANAIR TASK FORCE

# Diesel: Marine Vessels

- Work with the International Maritime Organization to designate an Arctic Protection Zone, covering ships the traveling in the Arctic and within the Arctic Front regions, generally latitudes higher than 40 degrees north.
- Ships traveling within the boundaries of this designated zone would employ the following measures to reduce black carbon emissions:
  - Reduce vessel speed by one-third, for an estimated 50%+ reduction in BC emissions.
  - Install engines with operational slide valves.

CLEANAIR TASK FORCE

# Stoves

Goal: Achieve the UN Millennium Project's targets to:

"enable the use of modern fuels for 50% of those who at present use traditional biomass for cooking by 2015." Draw on past household energy programs to ramp up to a large scale program."

- Fund from a variety of sources including climate bill ***proceeds and offsets***.

CLEANAIR TASK FORCE

# Stoves: Program Design

Phase 1:

- Develop rigorous metrics for the field, such as stove standards and climate and health benefits
- Conduct cost and CO2e analyses
- Build capacity and infrastructure for delivery; training, and education.
- Develop regional strategies, with public, private and non-profit sectors. This includes financing plans, identification of local manufacturers and service providers and other training and testing.

Phase 2:

- Develop targeted global campaign, with game plans tailored to account for regional differences.

# Agricultural Burning

- **Study U.S. Contribution**: In the US, by January 2010 determine the extent by which emissions from northern latitude springtime burning is transported to the Arctic, thereby accelerating the onset of spring melt. Consider banning spring burning or developing a protocol for protecting the Arctic as part of agricultural waste fire planning.
- **Support Biochar**: Support development and manufacture of low-emitting portable pyrolysis units, capable of converting crop wastes to biochar; char can be applied to croplands as a soil amendment and for carbon storage.
- **International**: Work through Convention on Long-Range Transport of Air Pollutants raise the profile of the role of springtime Ag burning on Arctic warming and work with member nations to impose and/or enforce bans or impose strict standards for Arctic protection.

# Industrial

- For ***brick kilns*** and ***coke ovens***, support cooperative work to better quantify the climate relevant emissions from current facilities and from improved and controlled facilities.
- Conduct an AP-42 study to characterize and cost out emissions control strategies.
- Identify manufacturers of improved brick kilns and begin a strategic planning for kiln replacement.
- Develop strategic plan for coke oven clean up.
- Determine the contribution of black carbon emissions from ***oil and gas flaring*** and develop mitigation plan.

# For more information


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