PRINCETON UNIVERSITY
WOODROW WILSON SCHOOL
of Public & International Affairs

Complements to Carbon:
Opportunities for Near-Term Action on Non-CO_2 Climate Forcers

Authors
Miklos Bankuti, Brian Ellis, Matthew Frades, David Kanter,
Jenna Losh, Ilissa Ocko, Joseph Roy-Mayhew, Paige Shevlin,
Clare Sierawski, Aliza Wasserman, Julia Zuckerman

Project Advisor
Denise Mauzerall, Ph.D.

Presentation to U.S. DOE and EPA
January 7, 2011
Washington D.C.

Authors and Project Advisor

Authors

Miklos Bankuti is a second-year master in public affairs candidate. He previously worked as an oil market analyst for the International Energy Agency and as an associate at the Clinton Foundation where he supported the development of large-scale carbon capture and storage projects.

Brian Ellis is a PhD student in the Civil and Environmental Engineering Department and a Princeton Environmental Institute Science Technology and Environmental Policy Fellow. His thesis research is focused on understanding brine acidification and the ensuing water-rock interactions related to geologic carbon sequestration and investigating how these interactions will impact the risk of CO2 leakage.

Matthew Frades is a second-year masters student of policy and economics of natural resources and the environment at the Woodrow Wilson School. His involvement in policy followed an education in geology and hydrology

David Kanter is a second year PhD student in the Science, Technology and Environmental Policy program at the Woodrow Wilson School. He focuses on the role of the Montreal Protocol in future international climate policy. He has previously worked for Greenpeace and UNEP.

Jenna Losh is a fourth-year PhD student in the Geosciences Department studying the response of marine phytoplankton to increasing carbon dioxide, with a background in biochemistry. She is also a Science, Technology, and Environmental Policy fellow with the Princeton Environmental Institute, investigating challenges and opportunities for a new US ocean policy.

Ilissa Ocko is a third-year PhD student in the Atmospheric and Oceanic Sciences program. Her research focuses on quantifying the radiative impacts of sulfate and black carbon aerosols on the globe and Arctic by using global climate models.

Joseph Roy-Mayhew is a third-year PhD student in the Department of Chemical and Biological Engineering. He is also pursuing a certificate in Science, Technology, and Environmental Policy. His doctoral work focuses on improving dye sensitized solar cells by incorporating graphene nanostructures

Paige Shevlin is a second-year masters student at the Woodrow Wilson School. She has worked in economic policy at both the Congressional Budget Office and the Department of Labor and is concentrating on labor policy and public finance at Woodrow Wilson

Clare Sierawski is currently finishing her Masters degree at the Woodrow Wilson School. She spent the last two years as the Special Assistant to the U.S. Special Envoy for Climate Change, where she worked on the international climate negotiations, including COP15 in Copenhagen, and on various bilateral and multilateral initiatives, with a particular focus on bilateral cooperation with China.

Aliza Wasserman is a Masters of Public Affairs Candidate focusing on domestic climate policy. Her background includes corporate social responsibility consulting, local food distribution, and municipal climate policy advocacy

Julia Zuckerman is a second-year Master in Public Affairs candidate at the Woodrow Wilson School, focusing on economics and environmental policy. She previously worked as a budget analyst for the City of New York.

Project Advisor

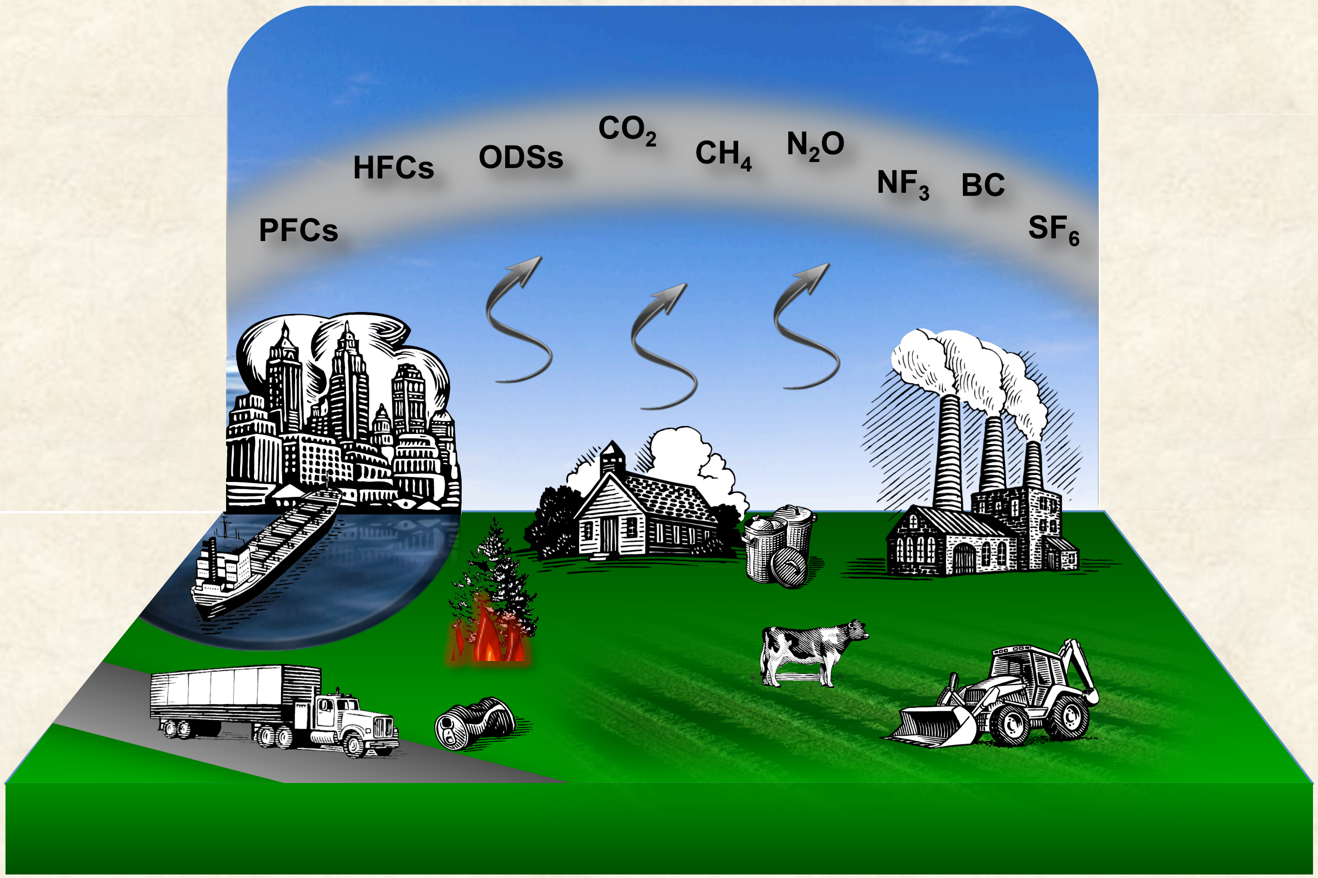
Denise Mauzerall, Associate Professor of Environmental Engineering and International Affairs, Woodrow Wilson School and Department of Civil and Environmental Engineering. PhD, Atmospheric Chemistry, Harvard University.

Outline

1. Project introduction
2. Scientific overview of non-CO_2 climate forcers
3. Survey of non-CO_2 climate forcers
    - ✧ Emissions
    - ✧ Sources
    - ✧ Scale of impact
    - ✧ Existing policies
    - ✧ Policy recommendations
4. Top policy recommendations
5. Research acknowledgements
6. Discussion

Contributors to Climate Change

- CO_2 is the major contributor to climate change
- However, other gases, aerosols and activities also contribute to climate change
- Opportunities exist for fast action to reduce climate change by reducing forcing from non-CO_2 agents



Non-CO_2 Climate Forcers

- **Abundant GHGs**: non-CO_2 greenhouse gases that that are abundant in the atmosphere
  - Methane (CH_4)
  - Nitrous Oxide (N_2O)
- **Trace GHGs with high GWP**: non-CO_2 greenhouse gases with high global warming potentials (GWPs) but are less abundant in the atmosphere
  - Ozone-depleting substances (ODSs) – particularly CFCs and HCFCs
  - Hydrofluorocarbons (HFCs)
  - Perfluorocarbons (PFCs)
  - Sulfur Hexafluoride (SF_6)
  - Nitrogen Trifluoride (NF_3)
- **Black Carbon:** aerosol that absorbs solar radiation, affects properties of clouds, and decreases surface albedo when deposited on snow/ice
- **Surface Albedo:** changes in surface reflectivity can cool or warm the Earth
  - Cool Roofs and Pavements: increase surface albedo

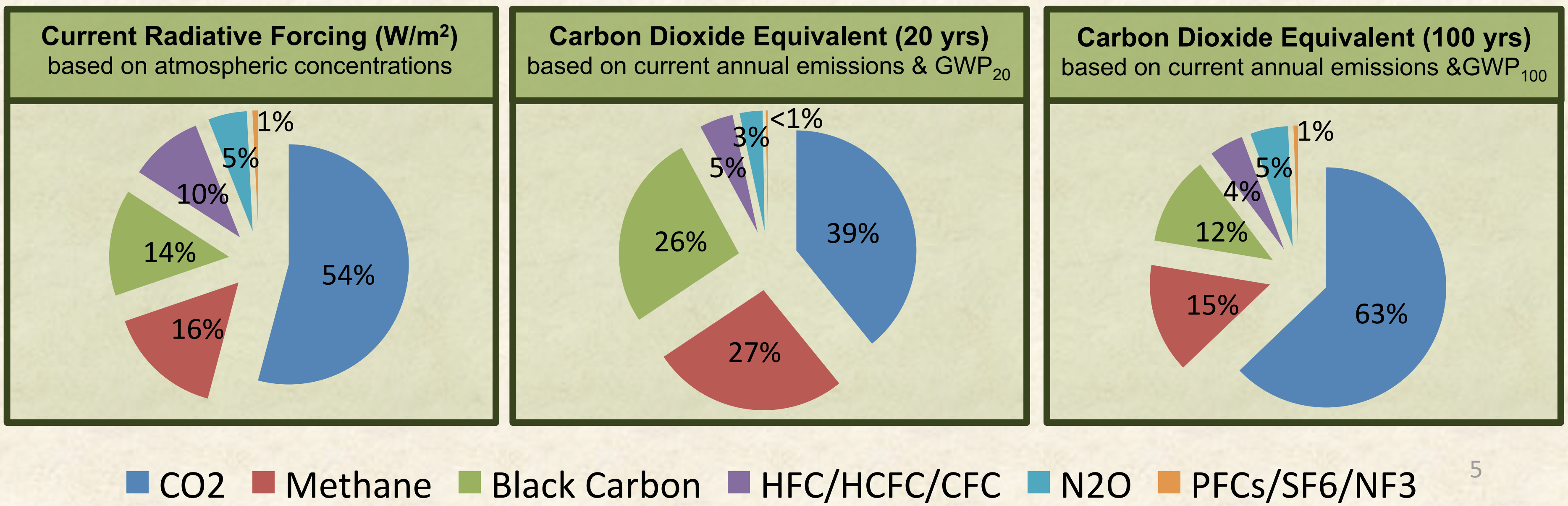
CONTRIBUTIONS TO CLIMATE CHANGE

✧ Several metrics quantify and compare the warming "impact" of a climate forcer

1. Radiative Forcing – Physical measure of energy added (positive value) to the climate system from the presence of a climate forcer in W/m^2

2. Global Warming Potential (GWP) – Derived scalar used to describe the warming potential of a gas relative to CO_2 over a specified period of time; Typically 20 or 100 year periods

3. Carbon Dioxide Equivalent (CO_2eq) – The amount of CO_2 that would have the same GWP as another climate forcer; Mass of forcer multiplied by GWP



Survey of non-CO_2 Climate Forcers

Slide 1

Forcer

GWP$_{20}$ & GWP$_{100}$
Atmospheric Lifetime

Historical Emissions

Forcer X%

Non-CO_2 Forcers
CO_2eq(GWP$_{100}$)

Sources

GLOBAL U.S.

Impacts

Current Policies

Survey Format

- 3-4 slides per forcer
  1) Science background/current policies
  2) All policy options
  3) Top policy options

Slide 2

Forcer

Policy Options

- ✧**Best policy options**
- ✧Other policy options

Slides 3-4

Forcer – Best Policy Option(s)

- ✧**Best policy option**
  - ✧Advantages
  - ✧Challenges

Best Policy Opportunities

✧ **Criteria for choosing best policies**

- Potential impact on the climate, including consideration of emissions growth rates
- Cost
  - Government
  - Private sector
- Speed of implementation
  - Maturity of technology
  - Existing authority
- Co-benefits

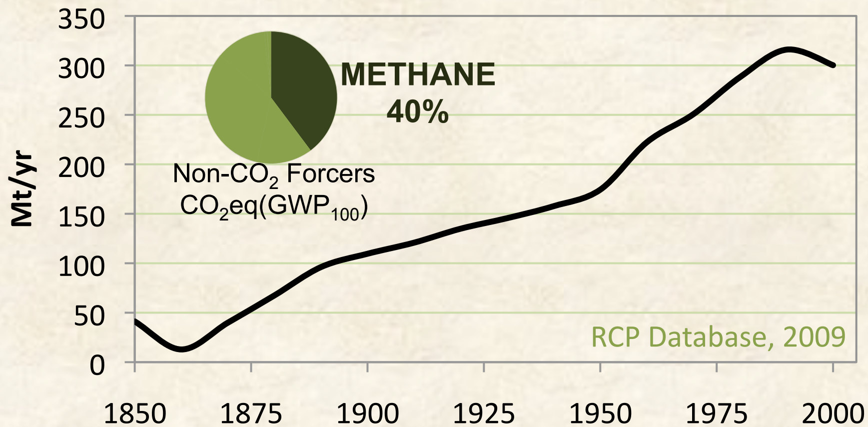

DOE Cash for Appliances Program, Detroit, MI


National Geographic

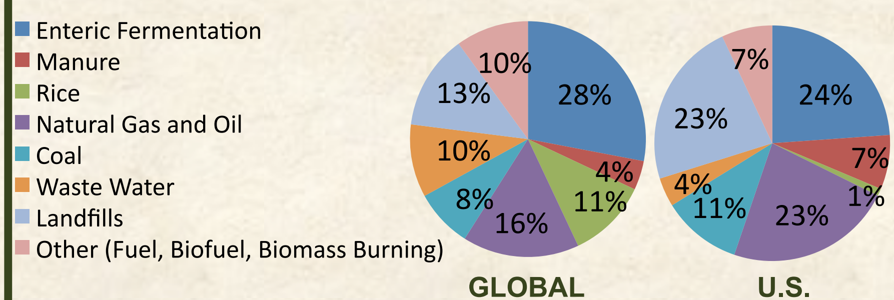
METHANE

GWP_{20} = 78
GWP_{100} = 25
ATMOSPHERIC LIFETIME = 12 YEARS

HISTORICAL EMISSIONS



SOURCES



- **IMPACTS:** climate warming, air quality, pre-mature mortality, agricultural yields. Specifically a global precursor for surface ozone which has adverse impacts on human health, ecosystems and agriculture
- **CURRENT POLICIES:**
  - EPA's Global Methane Initiative facilitates sharing of cost-effective technologies to reduce methane emissions
  - EPA regulates methane emissions from a small fraction of landfills above certain size
  - EU-27 Commitments creates Mandatory diversion of biodegradable waste away from landfills
  - UNFCCC Kyoto Protocol controlled gas
    - Methane reductions from waste and coal mine are approved methodologies

METHANE

POLICY OPTIONS

- EPA regulation methane emissions under the Clean Air Act
- Financial incentives landfill and coal mine gas electricity generation
- State facilitation of grid connection of landfill and coal mine gas
- Sharing of best practice policies within the Global Methane Initiative
- Federal model for local waste management policies
- Support for campaigns to reduce meat consumption in government cafeterias
- Agricultural methane emissions reductions research

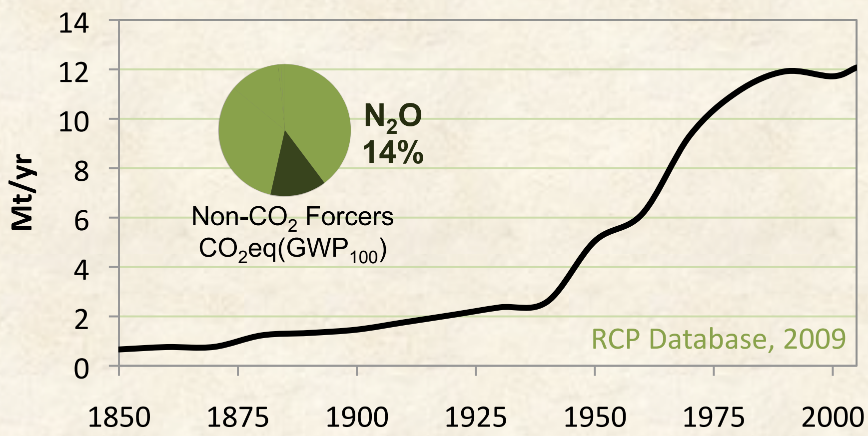
METHANE – Best Policy Option

- **EPA regulation methane emissions under the Clean Air Act**
  - **Advantages**
    - *High impact* – Based on EPA's estimates of mitigation costs, emissions could be reduced by 177 Mt CO_2eq (GWP_{100}) in 2030 and would cost at most \$20/tCO_2eq
    - *Established technology* – EPA reports that the technology for capturing methane from coal mines, landfills reducing leakage from gas and oil systems has been demonstrated at significant scale at costs below \$20/tCO_2eq
    - *Low cost to government* – Low marginal cost to the government given existing monitoring and enforcement protocols for air pollution control.
    - *Co-benefits* – Methane emissions increase surface ozone levels which leads to premature mortalities, degradation of materials and reduction in agricultural yields. 61 Mt CO_2eq (GWP_{100}) reduction of methane per annum would avoid 30,000 premature mortalities in 2030.
  - **Challenges**
    - Project developers may opt for minor modifications. Startup dates for new landfill and coal mine projects could face delays if permission to supply power to grid is required

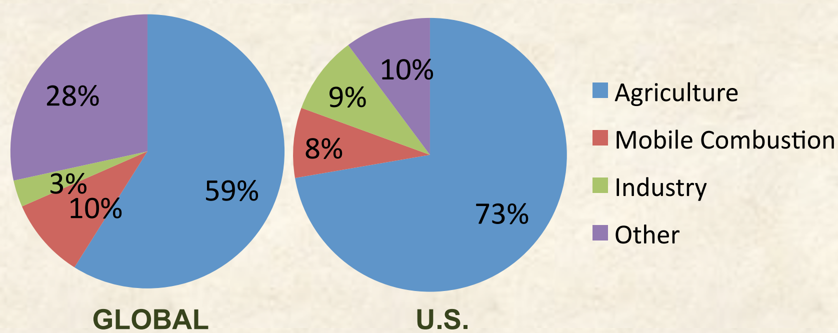
N_2O

GWP_{20} = 289
GWP_{100} = 298
Atmospheric Lifetime = 114 years

Historical Emissions



Sources



- **Impacts**: climate warming, ozone layer depletion
- **Current Policies:**
  - EPA/DoT tailpipe emissions cap
  - Required EPA reporting of N_2O emissions from nitric/adipic acid plants
  - Alberta, Canada offset protocol stimulating N_2O reductions
  - EU Emissions Trading Scheme introducing credits for N_2O reduction from nitric acid plants available from 2013. 90% emission reductions expected by 2020
  - UNFCCC Kyoto Protocol controlled gas

N_2O

POLICY OPTIONS

- **Establish N_2O performance standards under the Clean Air Act**
- Amendment of the Montreal Protocol to include N_2O
- Expansion of light-duty vehicle N_2O cap to all vehicle classes
- Establish a N_2O task force under the Major Economies Forum
- Identification and development of methodologies for the measurement of agricultural N_2O emissions
- Creation of an offset protocol for N_2O emissions from nitric acid production

N_2O – Best Policy Option

✧ **N_2O Performance Standard under the Clean Air Act**

Emulate the EU "average best 10%" policy on N2O emissions from nitric acid

✧ **Advantages**

- *High impact* – Potential U.S. emissions reductions of 25 million tons $CO_2eq(GWP_{100})$ per year by 2020
- *Low cost* – Cost estimates range from less than $1 per ton $CO_2eq(GWP_{100})$ to $61 per ton $CO_2eq(GWP_{100})$
- *Quick implementation* – Only 35 nitric acid plants in the U.S. Easily targeted
  - *Technology exists* – Abatement technologies already being used in many new plants
  - *Regulatory authority* – Existing authority under the Clean Air Act and the endangerment finding for the EPA to regulate N_2O either as a GHG or ODS
- *Co-benefits* – Many abatement technologies also reduce NOx emissions, a key constituent of air pollution

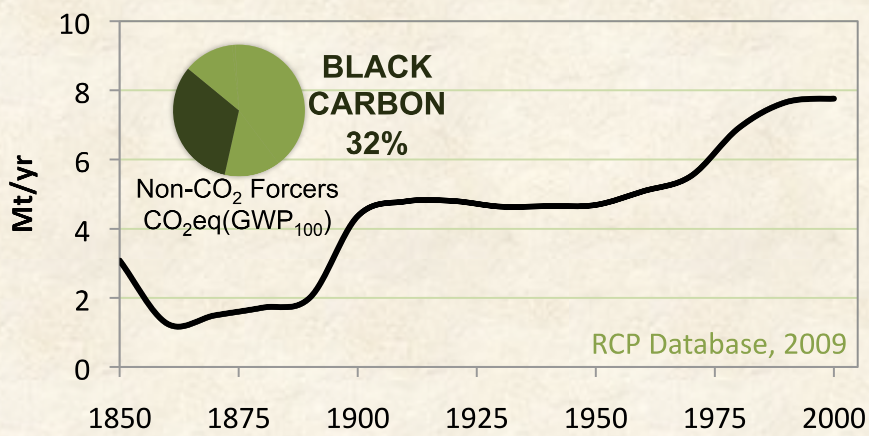
✧ **Challenges**

- Costs to manufacturers and pushback from ENGOs regulating N_2O as an ODS instead of a GHG.

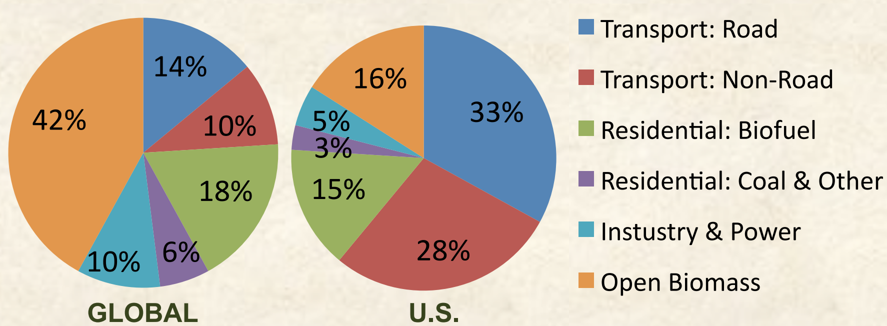
BLACK CARBON

GWP_{20} = 3230
GWP_{100} = 917
ATMOSPHERIC LIFETIME = 1-2 WEEKS

HISTORICAL EMISSIONS



SOURCES



- **IMPACTS**: climate warming particularly in the Arctic and glacial regions, air quality, human health
- **CURRENT POLICIES:**
  - U.S. set strict PM2.5 emission standards for on-road vehicles in 2010 and off-road vehicles in 2013
  - EPA has a Diesel Retrofit Technology Verification program which currently lists EPA tested retrofit technologies
  - EPA has a BC report to Congress due to be released in 2011
  - California has implemented several diesel particulate filter retrofit programs
  - United Nations Environment Programme (UNEP) will soon release an integrated assessment report on black carbon
  - Global Alliance for Clean Cookstoves

Black Carbon

Policy Options

- **Continued support of retrofit projects with a focus on heavy duty vehicles**
- **International cooperation to reduce black carbon emissions that reach "hot spots"**
- **International cooperation to address black carbon emissions from brick kilns**
- Engage in international collaboration to share diesel and non-diesel fuel technologies with developing countries
- Host annual international meeting on black carbon
- Improve vehicle efficiency standards to mitigate black carbon emissions
- Expand funding for retrofit programs by providing loan guarantees for retrofits to small fleet operators and farms
- Add black carbon mitigation to the list of potential GEF projects

BLACK CARBON – Best Policy Options

- **Policy support for installation of diesel particulate filters in heavy-duty vehicles**
  - **Advantages**
    - *Existing authority* – potential initial progress by expanding EPA's Diesel Retrofit Technology Verification program
    - *Established technology* – diesel particulate filters can capture over 90 percent of black carbon emissions from vehicles
    - *Significant impact* – retrofitting 8,000 heavy duty vehicles would reduce emissions by ~1 $MtCO_2eq$ (GWP_{100}) and black carbon has a lifetime of only a few weeks so effects would be almost immediate.
    - *Co-benefits* – reducing black carbon emissions will improve air quality and reduce lung related health consequences
  - **Challenges**
    - Would cost about $77/tCO2eq ($GWP_{100}$) or $10,000 per vehicle and would require new funding for financial support

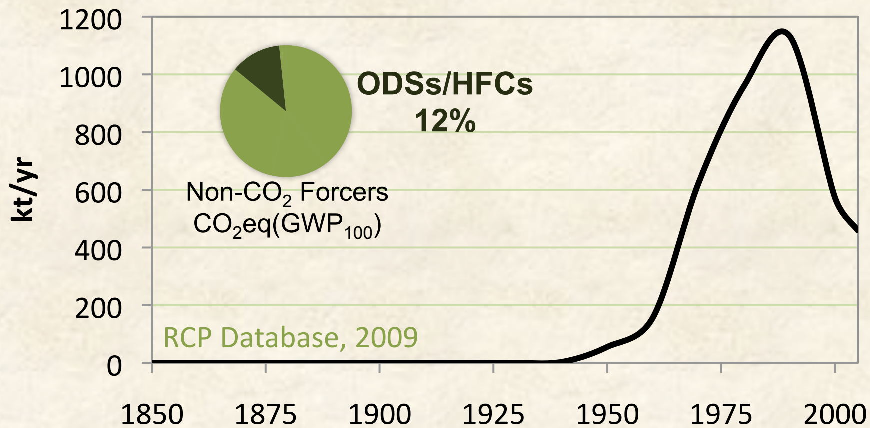
BLACK CARBON – Best Policy Options

- **Focus international cooperation to reduce black carbon emissions that reach "hot spots"**
  - **Advantages**
    - *Existing authority* – the Arctic Council and the Convention on Long-range Transboundary Air Pollution
    - *Significant impact* – snow and ice (Arctic and Himalaya) magnify warming caused by black carbon leading to further warming from positive feedbacks
    - *Co-benefits* – benefits to air quality, respiratory illness reduction, and water resources
  - **Challenges**
    - Political and technical difficulty in reducing emissions from hot spot emissions sources including bunker and HD vehicles
- **International cooperation to address black carbon emissions from brick kilns**
  - **Advantages**
    - *Established technology* – Modern brick kilns use 75 percent less fuel and emit less black carbon
    - *Rapid sector growth* – In developing countries, brick production growth rates are high and likely to continue to rise.
    - *Net negative cost to private sector* – modern kilns significantly reduce energy costs
    - *High impact* – Under 10 percent of brick kilns globally use modern technology, global reduction potential is 85 $MtCO_2eq$ (GWP_{100}), and brick kilns are concentrated in black carbon "hot spots"
    - *Co-benefits* – reducing black carbon emissions will improve local air quality and reduce respiratory illness
  - **Challenges**
    - Working with poor rural or semi-rural communities in developing countries

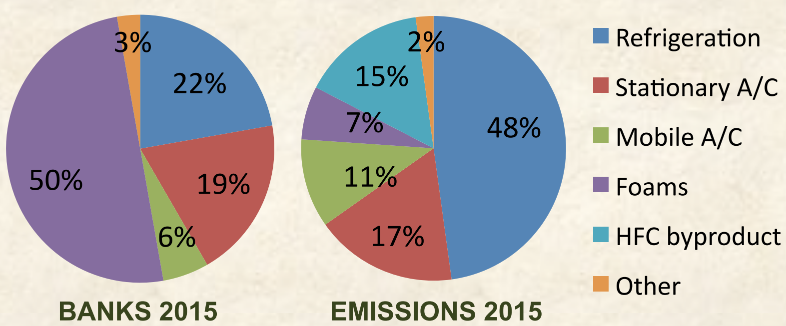
ODS Banks

GWP$_{100}$ = 1,500-11,000
Atmospheric Lifetime = 1-100 years

Historical Emissions



Bank Sizes & Emissions (ODSs/HFCs)



- **Impacts**: climate warming, ozone layer depletion; majority of trapped ODSs will be released in the next 5-10 years, and so removal now is critical!
- **Current Policies:**
  - Management programs in several countries
  - Destruction technology in existence and 28 countries contain destruction facilities
  - The MLF has financed over 100 projects to disperse methodology and technology worldwide to developing countries

ODS Banks

Policy Options

- **DOE expansion and modification of Cash for Appliances program**
- Establish financial support for ODS bank removal projects in developing countries
  1. Revenue from carbon markets associated with the destruction of banks in developed countries
  2. The Multilateral Fund (MLF)
  3. A separate funding facility for ODS bank recovery and destruction partnered with the MLF under the Montreal Protocol
  4. Taxation of imports or sales of synthetic refrigerants with high GWP

ODS BANKS – Best Policy Option

✧ **DOE Expansion and Modification of Cash for Appliance and Similar Programs**

Require retailer participants to join EPA's Responsible Appliance Disposal (RAD) program

✧ **Advantages**

- *High impact*
- *Moderate cost* – estimated cost of ODS removal is \$10-\$35/tCO_2eq(GWP$_{100}$). A program that aimed to reduce 10 percent of the emissions expected in 2015 would cost \$398 million to \$1.4 billion, depending on the cost of mitigation per ton CO_2eq.
- *Quick implementation*
  - *Established technology* – destruction equipment that can destroy 99.99 percent of the refrigerants it processes is already in use at over 100 sites in 26 countries
  - *Fast acting* – many stimulus programs currently exist and provide an opportunity for quick disposal of ODS banks
- *Co-benefits* – ODS bank destruction would have obvious co-benefits for the ozone layer. These ozone benefits must be accounted for when considering the cost of managing ODS banks, as they will save billions of dollars worldwide in health-care costs associated with skin cancer, eye cataracts, and other ozone-related ailments.

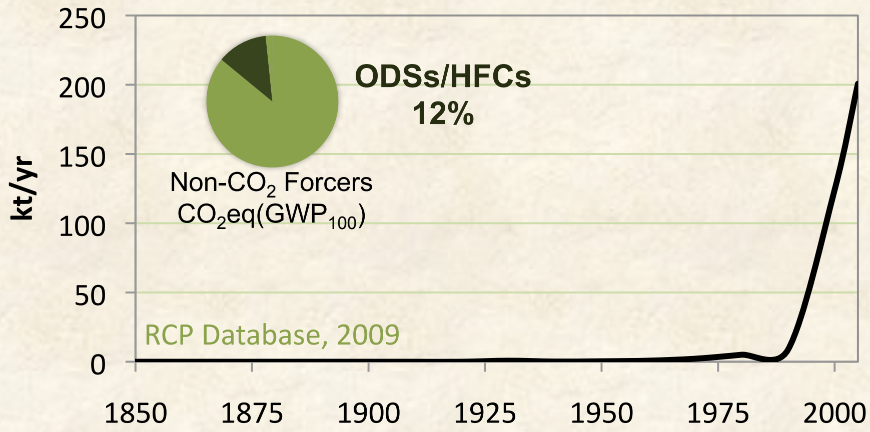
✧ **Challenges**

- Costs of incentivizing the purchase of new appliances is not included

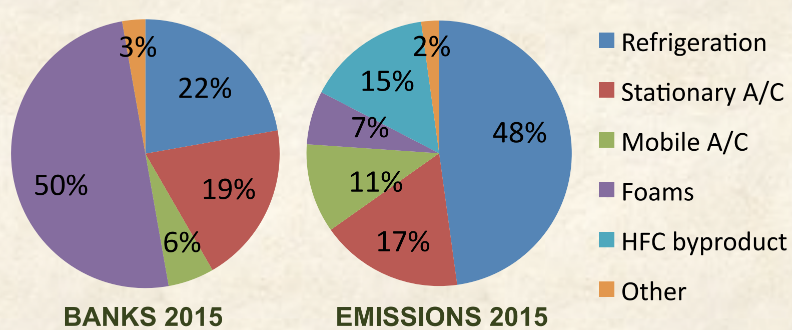
HFCs

GWP_{20} = 4,000-10,000
GWP_{100} = 1,500-11,000
ATMOSPHERIC LIFETIME = 1-100 YEARS

HISTORICAL EMISSIONS



BANK SIZES & EMISSIONS (ODSs/HFCs)



- **IMPACTS**: climate warming
- **CURRENT POLICIES:**
  - EPA Significant New Alternatives Program (SNAP)
  - Clean Air Act provides fuel economy credits to auto manufacturers for low-GWP refrigerants for light duty vehicles
  - California Air Resources Board HFC Emissions Reduction Measures for Mobile Air Conditioning
  - European Commission ‘F-gas Directive’
  - Consumer Goods Forum to ban the use of high-GWP refrigerants by 2015
  - UNFCCC Kyoto Protocol controlled gas

HFCs

POLICY OPTIONS

- **EPA withdrawal of SNAP approval of HFC-134a**
- **EPA and NHTSA incorporation of low-GWP refrigerant credits in medium duty, heavy duty, and off-highway vehicle classes**
- **Engagement with large commercial cooling and retail food refrigeration industries to reduce HFC leakage in existing and new equipment**
- Establish voluntary GWP standards for refrigerants under the EPA Greenchill partnership
- Climate impact labeling
- Mandatory certification for HFC sales and service
- Mandatory HFC-23 destruction
- Pass the North American Proposal under the Montreal Protocol
- Introduction of the HFC components of the Kerry Lieberman Climate Bill as a separate bill
- DOE support for research and development of HFC alternatives

HFCs – Best Policy Options

- **EPA withdrawal of SNAP approval of HFC-134a**
  - **Advantages**
    - *Moderate impact* – high growth rate, targets all sectors, 0.2 $GtCO_2eq$ potential
    - *Low cost to private sector* – ~$4/$tCO_2eq(GWP_{100})$, for incorporating low-GWP alternatives
    - *Quick implementation*
      - *Existing authority* – SNAP program
      - *Established technology* – low-GWP alternatives approved for multiple uses
    - Political Feasibility – similar policies in CA and EU
  - **Challenges**
    - SNAP approval pending for low-GWP alternatives for MVAC, large-scale uses
    - Safety and flammability concerns for low-GWP alternatives
- **EPA and DOT incorporation of low-GWP refrigerant credits in medium duty, heavy duty, and off-highway vehicle classes**
  - **Advantages**
    - *Moderate impact* – high growth rate, these three classes account for ~9% US GHG emissions
    - *Low cost to private sector* – for incorporating low-GWP alternatives ~$4/$tCO_2eq(GWP_{100})$
    - *Quick implementation* –
      - *Regulatory authority* – EPA and DOT can set GHG emissions standards
      - *Established technology* – low-GWP alternative HFC-152a approved
  - **Challenges**
    - SNAP approval pending for low-GWP alternatives for MVAC
    - Safety and flammability concerns for low-GWP alternatives

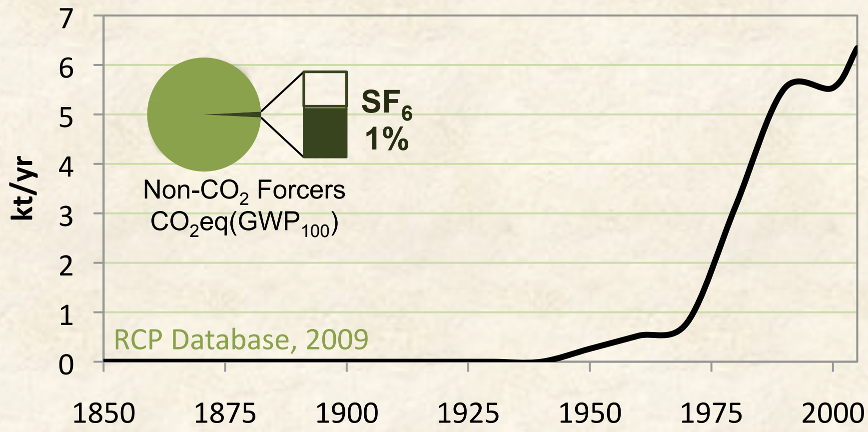
HFCs – Best Policy Options

- **Engagement with large commercial cooling and retail food refrigeration industries to reduce HFC leakage in existing and new equipment**
  - **Advantages**
    - *Moderate impact* – high growth rate, targets refrigeration and air conditioning sectors, 0.3 $GtCO_2eq$ potential
    - *Net negative cost to private sector* – less leakage ➔ less chemical needed
    - *Quick implementation* –
      - Regulatory authority – EPA's Greenchill partnership, DOE and energy efficiency
      - Technology exists – secondary loop and distributed systems technology are readily available

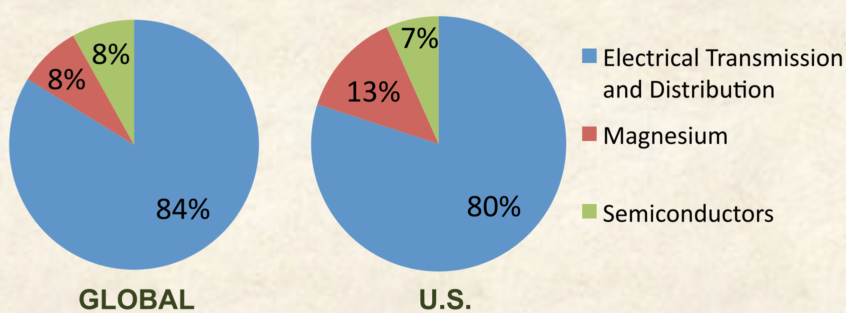
SF_6

GWP_{20} = 16,300
GWP_{100} = 23,400
ATMOSPHERIC LIFETIME = 3,200 YEARS

HISTORICAL EMISSIONS



SOURCES



- **IMPACTS**: climate warming
- **CURRENT POLICIES:**
  - EPA SF_6 Emissions Reduction Partnership for Electric Power Systems
  - EPA SF_6 Emissions Reduction Partnership for the Magnesium Industry
  - Norway, Switzerland, Iceland, and Japan mandate leak detection, repair programs, and SF_6 recycling programs
  - EU's F-Gas Directive mandates replacement of SF_6 with SO_2, leakage control, end-of-life recollection and recycling, and bans the use of SF_6 as a filler gas
  - UNFCCC Kyoto Protocol controlled gas
  - 5 Clean Development Mechanism (CDM) projects registered, 1 under review

SF_6

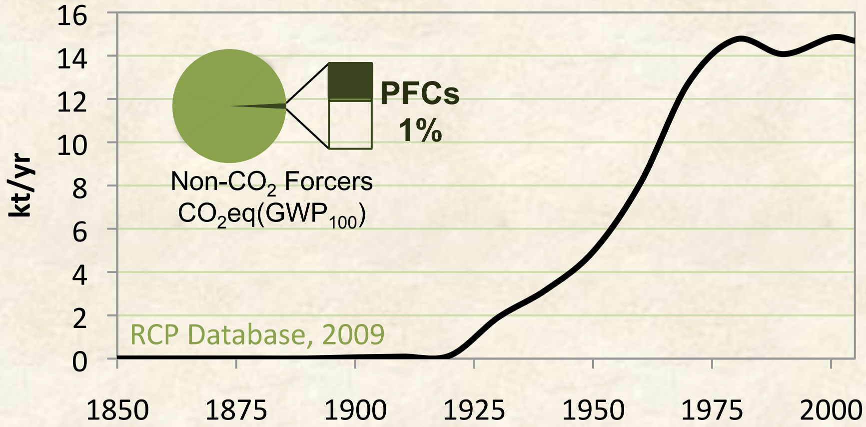
Policy Options

- Agency administration of SF_6 recycling programs and required leak detection and repair programs in the electric power system sector
- Partnership with industry to support efforts to reduce SF_6 emissions from semiconductor and thin film manufacturing
- International engagement to promote alternative cover gases in magnesium production

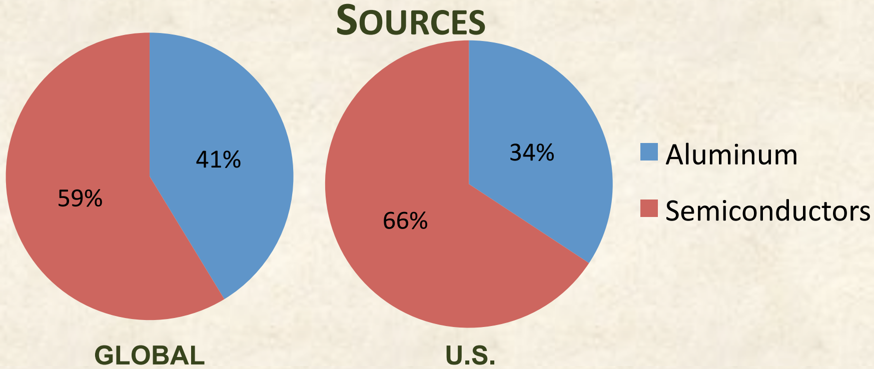
PFCs

GWP_{20} = 5,000-8,500
GWP_{100} = 7,000-12,000
ATMOSPHERIC LIFETIME = 10,000-50,000 YEARS

HISTORICAL EMISSIONS



SOURCES



- **IMPACTS:** climate warming
- **CURRENT POLICIES/ACTIVITIES:**
  - World Semiconductor Council
  - EPA Voluntary Aluminum Industrial Partnership
  - EU F-Gas Initiative
  - Kyoto Protocol / Inclusion under the EU ETS starting in 2013
  - International Aluminum Institute (IAI)
  - Protocols for Aluminum Sector Emissions (EPA, WRI, WBCSD, IAI)

PFCs

Policy options:

- **International cooperation to identify financing mechanisms for aluminum smelter retrofits**
- **International cooperation to reduce PFC emissions from electronics and semiconductor manufacturing**
- **R&D on cost-effective technologies to reduce PFC emissions from electronics and semiconductor manufacturing**
- Establish ambitious domestic and international aluminum recycling goals
- Develop international standards for anode effects during aluminum production

PFCs – Best Policy Options

- **International Cooperation: ID Financing for Al Smelter Retrofits**
  - **Advantages**
    - *Moderate impact* – industry-wide retrofits could reduce PFC emissions by 63 $MtCO_2eq$/year
    - *Low-cost*
    - *Well-established technology*
    - *Co-benefits* – increases plant efficiency = cost savings for companies and reductions in CO_2 emissions
  - **Challenges**
    - Many demands on international funding to mitigate climate change. Employing an ESCO-like mechanism for retrofits could overcome this challenge.

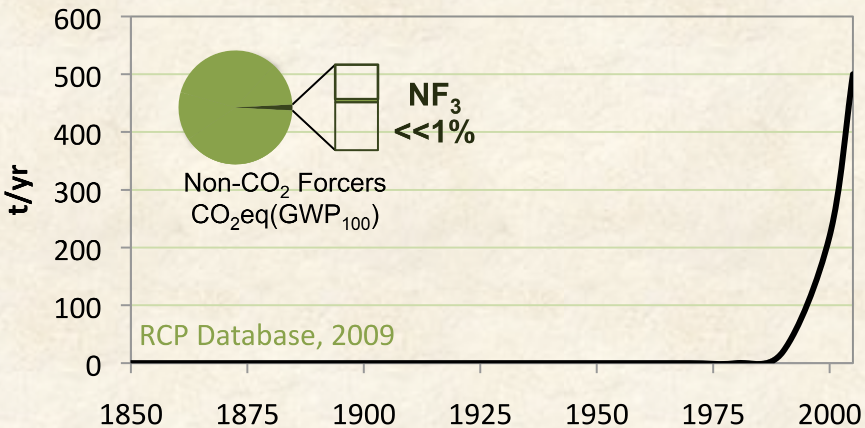
PFCs – Best Policy Options

- **International Cooperation to reduce PFC emissions from electronics and semiconductor manufacturing**
  - **Advantages**
    - *Moderate impact* – industry-wide use of post-use destruction technology could reduce PFC emissions by 0.1 $GtCO_2eq$/year
    - *Well-established technology* can reduce emissions over 95 percent
    - *Political feasibility* – the semiconductor industry previously willing to collaborate
  - **Challenges**
    - No international governmental cooperation in this area, so difficult to know with certainty the impact in terms of emission reductions

NF_3

GWP$_{20}$ = 12,200
GWP$_{100}$ = 16,800
ATMOSPHERIC LIFETIME = 740 YEARS

HISTORICAL EMISSIONS



SOURCES

- ✧ Semiconductors
- ✧ Electronics
- ✧ Thin film manufacturing processes
  - plasma etching
  - chemical vapor deposition chamber cleaning

✧ **IMPACTS**: climate warming

✧ **CURRENT POLICIES:**

- ✧ EPA requires reporting of NF_3 emissions from electronics manufacturing and fluorinated gas production facilities that emit large amount
- ✧ AOSIS parties to the climate negotiations have called for NF_3 to be included in Kyoto basket of GHGs

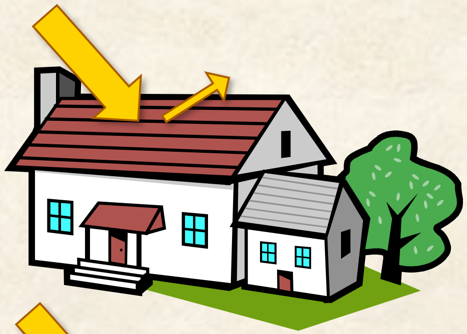
NF_3

POLICY OPTIONS

- Collaboration on NF_3 emissions reductions in a Non-CO_2 Climate Task Force under the MEF
- EPA expansion of NF_3 emissions reporting requirement to all sectors
- Establish sectoral cap on NF_3 emissions

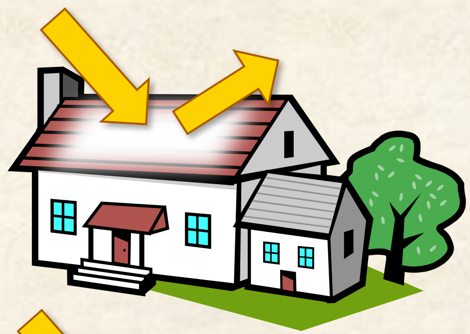
Cool Roofs and Pavements

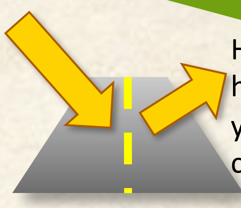
Low Albedo Surfaces



Low reflection, low emissivity; traps energy in

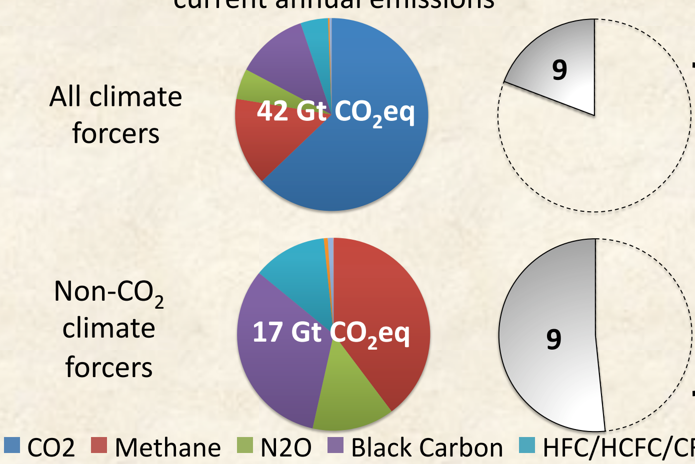
High Albedo Surfaces





Higher reflection, higher emissivity; yields cooling of climate system

$CO_2eq(GWP_{100})$
current annual emissions



9 Gt CO_2eq reduction for 0.25 increase in roof albedo and 0.1 increase in pavement albedo of all urban roofs and pavements for 20 years; one-time offset

- **Impacts**: climate cooling, energy usage, human health
- **Current Policies:**
  - DOE released a draft roadmap for policy and R&D work on cool roofs and pavements in Nov. 2010
  - Several voluntary energy efficiency and green building standards offer credits for cool roofs
  - California, Florida, Hawaii, New York City, Atlanta, Chicago and Philadelphia are developing customized policies for cool roofs
  - No current policies on high-albedo pavements in the U.S. or abroad

Cool Roofs and Pavements

Policy Options

- **Analysis of the potential scale of cost-effective cool roof deployment through federally funded building construction and roof repairs**
- **Promotion of high-albedo paving material use for local roads with light traffic**
- Support for adoption of model building codes by state and local governments
- Analysis of cool roof programs as a demand reduction strategy to avoid the need for new power plants
- Addition of cool roofs to the criteria for ranking of state and municipality DOE grants
- Inclusion of cool pavements in the work plan for the Global Superior Energy Performance Partnership
- Establishment of DOE authority to regulate roofing materials
- Establishment of enhanced financial incentives for cool roof investments
- Diversification of research institutions funded to research cool roofs and pavements
- Research on potential value of cool roof and cool pavement projects in future carbon markets

COOL ROOFS & PAVEMENTS – Best Policy Options

✧ **Analyze cost & scale of cool roof deployment in federally funded building construction**

✧ **Advantages**

- *Quick implementation* – Already funding WAP (300K homes), BetterBuilding ($486M), HUD (5M units)
    - *Technology exists* – Well-established and third-party certified by CRRC
    - *Regulatory authority* – Clearly exists since federally-funded projects
- *Low cost* – Only proceed when cost-effective (new construction, roof work underway, low-sloped)
- *Co-benefits* – energy savings, CO_2 saved, peak demand, urban heat island effect, smog, roof quality

✧ **Challenges**

- *Low-Moderate impact* – If reach 50,000 homes 75 ktCO_2eq and 500,000 homes to 0.75 MtCO_2eq
- Not cost-effective to retrofit all buildings; unknown labor costs as part of larger project

COOL ROOFS & PAVEMENTS – Best Policy Options

- **Promote high-albedo paving material use for local roads with low traffic**
  - **Advantages**
    - *Low cost* – high-albedo substitutes cost no more than conventional materials, can produce savings by reducing need for maintenance and repaving
    - *Quick implementation*
      - *Well-established technology* – for both asphalt and cement concrete pavements
      - *Existing authority* – DOE could write model codes or procurement policies for state and local governments
    - *Co-benefits* – Air quality benefits from reduced need for new asphalt applications
  - **Challenges**
    - *Low to moderate impact* – Not easily scalable, as most authority rests with state and local governments

CROSS-CUTTING POLICIES

✧ Consideration of life cycle emissions

- "Cradle to cradle" emissions policy could reduce emissions at each point in its life cycle
- This would allow for improved reporting and tracking, and likely create an incentive for emission reductions at each point in a gas' life

CROSS-CUTTING POLICIES

✧ **Non-CO2 Climate Forcer Task Force/Initiative under MEF/CEM**

MEF/CEM Task Force or Initiative on High-GWP industrial gases under GSEP:

- **Black Carbon:**
  - Establish goals and financing to reduce BC emissions from brick kilns
  - Cooperation to reduce BC emissions that affect the Arctic and Himalayas
- **N_2O:**
  - Standards & technology sharing for abatement technologies from nitric acid plants
  - Transnational research to monitor and reduce agricultural emissions
- **High GWP Industrial Gases (PFCs, SF_6 and NF_3):**

  Work with WSC/industry to establish:
  - Emissions reporting protocols
  - Best practice sharing for limiting emissions in end-use and production
  - Emission reduction goals
  - R&D on cost-effective technologies to reduce future emissions
- **Best Practice sharing on reducing F-gas emissions from electricity transmission**
- **Identify financing for aluminum smelter retrofits in developing countries**
- **Promote use of alternative cover gases in magnesium production**

SUMMARY OF BEST POLICY OPTIONS

	Best Policy Options	High Impact	Low Cost	Quick Implementation	Co-Benefits
Methane	EPA regulation of landfill and coal mine methane emissions	✓	✓	✓	✓
N2O	Establish N_2O performance standards under the Clean Air Act	✓	✓	✓	✓
Black Carbon	Continued support of retrofit projects with a focus on heavy duty vehicles of model year 1998-2009	✓		✓	✓
	International cooperation to address black carbon emissions from brick kilns	✓	✓	✓	✓
	International cooperation to reduce black carbon emissions that reach "hot spots"	✓		✓	✓
ODS Banks	DOE expansion and modification of Cash for Appliances program	✓		✓	✓
HFCs	EPA withdrawal of SNAP approval of HFC-134a		✓	✓	
	EPA and NHTSA incorporation of low-GWP refrigerant credits in medium duty, heavy duty, and off-highway vehicle classes		✓	✓	
	Engagement with large commercial cooling and retail food refrigeration industries to reduce HFC leakage in existing and new equipment		✓	✓	
PFCs	International cooperation to identify financing mechanisms for aluminum smelter retrofits		✓	✓	✓
	International cooperation to reduce PFC emissions from electronics and semiconductor manufacturing			✓	
Cool Roofs and Pavements	Analysis of the potential scale of cost-effective cool roof deployment through federally funded building construction and roof repairs		✓	✓	✓
	Promotion of high-albedo paving material use for local roads with low traffic		✓	✓	✓

ACKNOWLEDGEMENTS

BANGKOK, THAILAND

Steve Anderson, Executive Director, *Refrigerants Australia*
Atul Bagai, Regional Network Coordinator, South Asia, *UNEP*
Tom Batchelor, Director, *TouchDown Consulting*
Suely Carvalho, Chief, Montreal Protocol Unit, Principal Technical Adviser-Chemicals Energy and Environment Group, Bureau for Development Policy, *UNDP*
David Doniger, Policy Director, Climate Center, *Natural Resources Defense Council*
Brent Hoare, Executive Director, *Green Cooling Association*
Drussilla Hufford, Director, Stratospheric Protection Division, *EPA*
Marco Gonzalez, Co-Chair, Ozone Secretariat, *United Nations*
Steve Gorman, GEF Executive Coordinator and Team Leader (Recently Retired), POPs/Montreal Protocol Operations, Environment Department, *The World Bank*
Peter Grabiel, Senior Law Fellow, *Institute for Governance and Sustainable Development*
Lambert Kuijpers, Co-Chair, *TEAP*, Co-Chair, *Refrigerants Technical Committee*
Janos Mate, Director of Greenfreeze and Ozone Projects, *Greenpeace International Climate Campaign*
Mack McFarland, Global Environmental Manager, Fluorochemicals, *DuPont Chemicals and Fluoroproducts*
William F. McQuade, Director, Government and Industrial Affairs; Chiller Solutions Building Efficiency, *Johnson Controls*
Jeff Moe, Director, Global Policy and Advocacy, Center for Energy Efficiency and Sustainability, *Ingersoll Rand*
A. R. Ravishankara, Director, Chemical Sciences Division, *NOAA Earth System Research Laboratory*
Mark V. Stanga, Owner, *Competition Advocates, LLC*
Helen K. Tope, Principal Consultant, *Energy International Australia*
Fionnuala Walravens, Campaigner, *EIA*
Durwood Zaelke, President, *Institute for Governance and Sustainable Development*

Acknowledgements

Beijing & Shanghai, China

Sang Fengyu and Liu Wenge, China Coal Institute (CCII)
Yongming Niu, Mark Spatz, Akshay Bellare, Bai TieJun, Terry Mo Haocheng, Honeywell
Dick Dong, Dupont
Philip Wong, Suntech
Wang Baiyu, Capital Carbon
Jenny Chu, Azure
Professor Li Zheng, Tsinghua-BP Clean Energy Research and Education Center
Alvin Lin, Natural Resources Defense Council
Deborah Seligsohn, World Resources Institute (WRI) China
Junda Lin and Qiyong Cao, China GreenTech Institute (CGTI)
Jing Cao, Qinghua Center for China and the World Economy, Department of Economics
Jiang Kejun, Energy Research Institute (ERI)
Kevin Mo, The Energy Foundation
Vance Wagner, Ministry of Environmental Protection – air quality/vehicles
Daniel Enking, Chinese Academy of Sciences
Zhou Weiqi and Hu Yuhong, National Center for International Cooperation in Work Safety

Acknowledgements

Brussels, Belgium & Berlin, Germany

Axel Friedrich, Former Head of German Environment Ministry
Catherine Witherspoon, Climate Works

Potsdam Institute for Climate (PIK)
- **Prof. Schellnhuber**, Advisor to Merkel, head of PIK
- **Daniel Klingenfeld** + friends (Env. Policy PhDs)

IPCC
- **Ottmar Edenhofer** (Chair)
- **Jae Edmunds** (Technology Model datasets)
- **Tom Kram** (Integrated models)

Peter Linton, **Karen Massin** (Burson Marsteller - PR Firm)
Louis Bono (US Mission to the EU, State Dept)
Simon Marr (German EPA – National and European Climate Division)
Tomas Velghe (EC Environment: ETS carbon trading)
Jeffries Brigginshaw (Trans Atlantic Business Dialogue, industry lobby group)
Eirik Norheim (European Aluminum Association)
Christianna Papazahariou (Shecco, natural refrigerant lobby)
Jason Anderson (WWF Europe Climate Change Policy)
David Harmon (EC Research, Innovation & Science Office)

Marc Lafrance, Technology Development Manager, Department of Energy
Amy Dickie, Senior Associate, California Environmental Associates

Acknowledgements

Washington D.C. and California, USA

Payam Bozorgchami, High Performance Buildings and Standards Development Office, California Energy Commission
Ana Unruh Cohen, Deputy Staff Director, House Select Committee on Energy Independence and Global Warming
Bart Croes, Chief, Research Division, California Air Resources Board
Haley Gilbert, Senior Research Associate, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory
Rachel Goldstein, Team Leader, EPA Landfill Methane Outreach Program, U.S. Environmental Protection Agency
Peter L. Gray, Partner, McKenna Long & Aldridge LLP
Sherry Hao, Administrative Manager, Cool Roof Rating Council
Ronnen Levinson, Research Scientist, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory
Alan Lloyd, President, International Council on Clean Transportation
David McCabe, Atmospheric Science Specialist, Clean Air Task Force
Andrew McConville, Fellow, White House Office Of Energy and Climate Change/USEPA
Surabi Menon, Staff Scientist, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory
Ray Minjares, Policy Analyst, International Council on Clean Transportation
Melvin Pomerantz, Staff Scientist, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory
Arthur Rosenfeld, Guest Researcher, Lawrence Berkeley National Laboratory and Professor Emeritus of Physics, University of California, Berkeley
Jonah Steinbuck, Professional Staff Member, House Select Committee on Energy Independence and Global Warming
Evelyn Swain, Environmental Protection Specialist, Stratospheric Protection Division, U.S. Environmental Protection Agency
Kristen Taddonio, Manager, Strategic Climate Projects, U.S. Environmental Protection Agency
John Weyant, Professor of Management Science and Engineering, Stanford University
Erik White, Assistant Division Chief, Mobile Source Division, California Air Resources Board
Catherine Witherspoon, Consultant, ClimateWorks Foundation