



MAJOR ECONOMIES AND CLIMATE
CHANGE RESEARCH GROUP

SHORT-LIVED CLIMATE FORCERS

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ACRONYMS AND ABBREVIATIONS

AD	Anaerobic Digesters
BAU	Business as usual
BC	Black carbon
CDM	Clean Development Mechanism
CDQ	Coke dry quenching
CFCs	Chlorofluorocarbons
CGF	Consumer Goods Forum
CH ₄	Methane
CMM	Coal Mine Methane
CNISP	Chinese National Improved Stove Program
CO ₂	Carbon Dioxide
CO ₂ eq	Carbon Dioxide equivalent
CWQ	Coke wet quenching
DPFs	Diesel Particulate Filters
ECCAD	Emissions of atmospheric compounds and compilation of ancillary data
EDGAR	Emissions Database for Global Atmospheric Research
EPA	U.S. Environmental Protection Agency
EU	European Union
GHG	Greenhouse gas
GJ	Giga joules
GWP	Global warming potential
HFCs	Hydro fluorocarbons
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
Kts	Kilo tonnes
kWh	Kilowatt per hour
LNG	Liquefied natural gas
MMTs	Million metric tonnes
MtCO ₂ e	Million metric tons of carbon dioxide equivalent
NCDC	U.S. National Clean Diesel Campaign
NGOs	Non-governmental organizations
ODS	Ozone depleting substances
SLCFs	Short-lived climate forcers
SNAP	Significant New Alternatives Policy
tCO ₂ e	Ton carbon dioxide equivalent
UNEP	United Nations Environment Programme
US	United States
VAM	Ventilation Air Methane
VOCs	Volatile organic compounds
VRU	Vapor recovery units

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EXECUTIVE SUMMARY

Immediate mitigation of short-lived climate forcers (SLCFs) has the potential to reduce total warming from climate change significantly over the next 40 years. SLCFs have short atmospheric lifetimes relative to CO₂, meaning that mitigation of SLCFs will slow global warming faster than mitigation of CO₂. This report focuses on black carbon (BC), methane (CH₄), and hydrofluorocarbons (HFCs) to pinpoint mitigation opportunities that are significant as well as economically, politically, and culturally viable. The report analyzes barriers in these areas and suggests mechanisms for overcoming obstacles.

BLACK CARBON

Black carbon, which is produced by inefficient combustion of carbon-based fuels, is emitted most heavily in the residential, transport, and industrial sectors. This paper looks into each of these areas, recommending economically viable interventions, as well as strategies to overcome barriers to action.

- **Residential:** Inefficient combustion of biomass for cooking is a major source of black carbon throughout the developing world. There have been many initiatives promoting the adoption of more efficient cook stoves, including cook stoves using liquefied natural gas (LNG), with varying levels of success. Barriers in this space include lack of market accessibility, high upfront costs, and cultural barriers, mostly centering around the required behavioral change of using new technology and new fuels. This report recommends a focus on more efficient biomass burning stoves, which lessen both the effects of behavioral barriers and the effect of poor fuel supply chains because they do not require the use of new fuel types. Assuming a diffusion rate of approximately 60 % (consistent with the most successful cook stove initiatives), approximately 2684 MtCO₂e could be mitigated by 2030.
- **Transport:** Black carbon emissions from transport primarily come from inefficient diesel engines. These emissions are spread over a large geographic area; however, producers of diesel engines are relatively concentrated. Additionally, the majority of on-road high emitting diesel engines belong to trucking companies and bus fleets, which further concentrates the issue. By focusing on diesel particulate retrofits and stringent engine standards for new vehicles, approximately 2060.7 MtCO₂e of black carbon emissions could be mitigated by 2030.
- **Industry:** Coke production makes up 80 % of China's industrial black carbon emissions. China has aggressively promoted coke-dry quenching technology to reduce black carbon emissions and has reached adoption rates of approximately 90 % among large steel conglomerates. Smaller firms, however, which make up about 60 % of the market lack the capital necessary to invest in cleaner technologies. Through adopting policies to make coke-dry quenching affordable for these smaller producers, China could reduce their industrial black carbon emissions by 80 %. Global adoption of coke-dry quenching would result in a 197.3 MtCO₂e reduction in black carbon emission by 2030.

METHANE

The most promising areas for reduction of methane emissions are in the energy production and municipal waste sectors. This paper explores potential reductions in the agricultural sector as well.

- **Energy Production:** Total process emissions from oil and gas production make up 20% of global methane emissions. In the oil and gas sector fugitive emissions come about during the production, processing, and distribution stages. Associated gas can be captured through the instillation of vapor recovery units (VRU) at oil and gas production sites and turned into fuel or energy. The emissions reduction potential by 2030 for capture of vented associated gas is 643 MtCO₂e for oil and 50.4 MtCO₂e for gas. However, upfront costs and lack of technical capacity for installing VRUs could prove to be barriers in some regions.
- **Coal mining activity** is responsible for 6% of global methane emissions. China, which emits close to seven times more coal mine methane (CMM) than the next highest emitter, does not have adequate technology for capture, especially of low-concentration CMM. The emissions reduction potential from pre-mine degasification and capture of coal-mine methane in 2030 is 368 MtCO₂e.
- **Municipal Waste:** The storage and treatment of municipal solid waste in landfills produces 11% of total global methane emissions. Sorting and treatment of biodegradable municipal waste could potentially reduced emissions by 584 MtCO₂e in 2030. In the US, where the most landfill methane is produced globally, political barriers often prevent the creation of incentives or regulations to promote reduction of landfill waste.

HYDROFLUOROCARBONS

If no action is taken on HFCs by 2050, annual HFC emissions could be equivalent to 20% of annual carbon dioxide emissions under a BAU scenario – a 0.5 degree increase in global temperature.

- The largest barrier to the passage of the HFC Amendment to the Montreal Protocol is India's refusal to sign on. India, as well as other developing countries, has not emitted nearly as many HFCs as developed countries and does not want to be forced into implementing changes before fully developing.
- This report recommends the adoption of the US/Mexico/Canada HFC amendment to the Montreal protocol. China does not have the same political or cultural barriers as India to make progress on HFC reductions, therefore, it may be possible for China to pressure India to agree to the Montreal Protocol if China and other big emitters (Russia, US, EU, Japan) sign on. In tons, the reduction potential of this amendment is 8.8 billion tons of CO₂ per year by 2050. The cumulative total by 2050 will be equivalent to 100,000 MtCO₂e in avoided emissions, the range being between 76-134,000 MtCO₂e.

INTRODUCTION

This report discusses the potential for reduction of emissions from short-lived climate forcers (SLCFs). SLCFs are atmospheric substances that contribute to global warming. The short lifespans (relative to CO₂) of SLCFs means that their mitigation can slow global warming in the near-term. The SLCFs addressed in the report are black carbon, tropospheric ozone, methane, and hydrofluorocarbons (HFCs).

SLCF	Lifespan
Black Carbon	3-8 days
Tropospheric Ozone	4-18 days
Methane	12 years
Hydrofluorocarbons	varies (~13-222 years)

Source: UNEP

For each SLCF, the report highlights sectors that have the greatest potential for emissions reductions and further breaks these sectors down into specific interventions. The report goes on to analyze costs, benefits, and potential barriers to each of these mitigation measures. In countries identified as major SLCF contributors, the report identifies specific policy options for emissions reduction.

The first section of the report will address black carbon and the emissions reductions possible in that space, focusing on increased-efficiency biomass-burning cook stoves, diesel retrofits and standards in transportation, and cleaner technologies for coke production. The next section will discuss mitigation of anthropogenic methane, primarily through recovery and utilization, in oil and gas production, coal mining, agriculture, and municipal waste. Finally, the report highlights the potential for phase out of HFCs through adoption of international agreements.

The main goals of this report are to:

- Provide a sectoral break down of SLCF emissions.
- Outline mitigation measures that are both cost effective and politically feasible, suggesting financing mechanisms and country-specific policies to facilitate emissions reduction interventions.
- Highlight the mitigation potential of proposed interventions, using estimates from UNEP for reduction potential in 2030.
- Discuss possible barriers to implementation of mitigation measures, including financial, technical, market, political, and cultural barriers.

BLACK CARBON & TROPOSPHERIC OZONE

Black carbon and tropospheric ozone are both potent climate forcers whose mitigation could serve to curb present warming while presenting benefits to human health and agricultural yields. While difficult to quantify, both impact regional climatic cycles, and so contribute significantly. This section will give a short overview of black carbon and tropospheric ozone, including their effects on climate and human systems. It will then look at the global distribution of emissions, and provide justification for the countries on which this section focuses.

BLACK CARBON

Black carbon (BC) consists of particles of carbon less than 2.5 micrometers, emitted from incomplete combustion of carbon sources such as biomass or fossil fuels. It is not a gas, and as such operates differently than other climate forcers, absorbing energy from sunlight and warming the surrounding air.¹ Black carbon is short-lived, settling out of the air between 3-8 days after its emission; however, despite its short lifetime it is a potent climate forcer that affects both regional weather patterns and glacial melting rates.

EFFECTS OF BLACK CARBON

Weather patterns and melting rates

Despite only having a short atmospheric lifetime, black carbon's heat-absorbing power creates significant asymmetries in atmospheric heating patterns, which can have huge effects on regional weather patterns.² This is especially important in South Asia, where high black carbon emissions significantly affect monsoon patterns. Additionally, because of its short lifetime, black carbon quickly settles out of the atmosphere, bringing the heat it traps with it. This is a big problem in areas with exposed ice such as the Himalayas and the Arctic, because the dark soot lowers the reflective capacity of the ice and causes higher melting rates.

Human health

Black carbon emissions negatively affect human health, especially in developing urban areas where concentrations are generally highest. It is linked to asthma, lung cancer, bronchitis, and other respiratory disease. According to the World Health Organization, black carbon contributes to over 1.8 million deaths a year, most of which are in developing countries.³

¹ UNEP, 2011.

² UNEP, 2011.

³ Kandlikar et al., 2009.

TROPOSPHERIC OZONE

Ozone is a gas that is found both in the stratosphere (upper layer of the atmosphere) and in the troposphere (0 – 15 km above sea level). It is highly reactive, so, while it beneficially blocks UV radiation in the stratosphere, it can negatively affect life in the troposphere and is an effective greenhouse gas. It forms in the atmosphere through the reaction of pollutants such as volatile organic compounds (VOCs), nitrogen oxides, methane, and carbon monoxide; so much of its mitigation relies on preventing emissions of its precursors. VOCs, nitrogen oxides, and carbon monoxide are produced through incomplete combustion of carbon-based fuels, so many of the mitigation strategies for tropospheric ozone mirror those of black carbon. Because many of these similarities, this report will focus on black carbon, with the understanding that any mitigation efforts will have the compounding effect of lowering tropospheric ozone levels.

EFFECTS OF TROPOSPHERIC OZONE

Human health and food security

Ozone is a highly reactive compound, and as such can cause a variety of health problems, including asthma, bronchitis, and emphysema. Chronic exposure to ozone can permanently scar lung tissue and may increase the likelihood of developing lung or heart disease. High tropospheric ozone similarly effect plants and so can have a significant impact on crop yields.

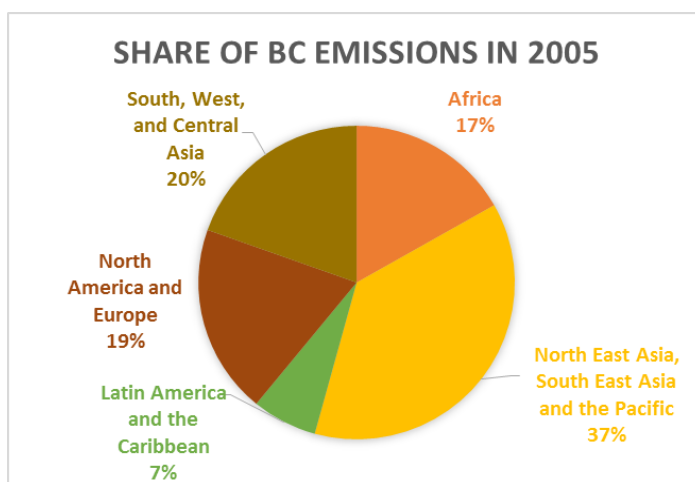
DISTRIBUTION OF GLOBAL EMISSIONS BY REGION

While it is difficult to measure BC in terms of its atmospheric effects, estimates of absolute values do exist. The UNEP 2011 synthesis report on short-lived climate forcers estimated black carbon emissions for different regions and sectors throughout the world. According to these data, North East Asia, South East Asia and the Pacific emit the most black carbon by a sizable margin, followed by South, West and Central Asia, and North America and Europe.

The information in table 2 gives 2005 values for black carbon emissions by broad regions; however, to pinpoint the most problematic countries, a more granular representation is necessary. The below map, produced using the MACCity database in ECCADs interactive mapping platform,⁴ shows average anthropogenic global black carbon emissions for 2012 in Tg/year.

⁴ MACCity database: ECCAD, Emissions of atmospheric Compounds and Compilation of Ancillary Data, has an interactive website that allows data visualization for a number of different emission databases. The data in the MACCity dataset consists of emissions from burning of biomass, but does not incorporate emissions from inefficient combustion of fossil fuels. The metadata can be found at:
http://eccad.sedoo.fr/eccad_extract_interface/JSF/page_login.jsf

Figure 1. Breakdown of black carbon emissions in 2005 by region.



Source: UNEP 2011

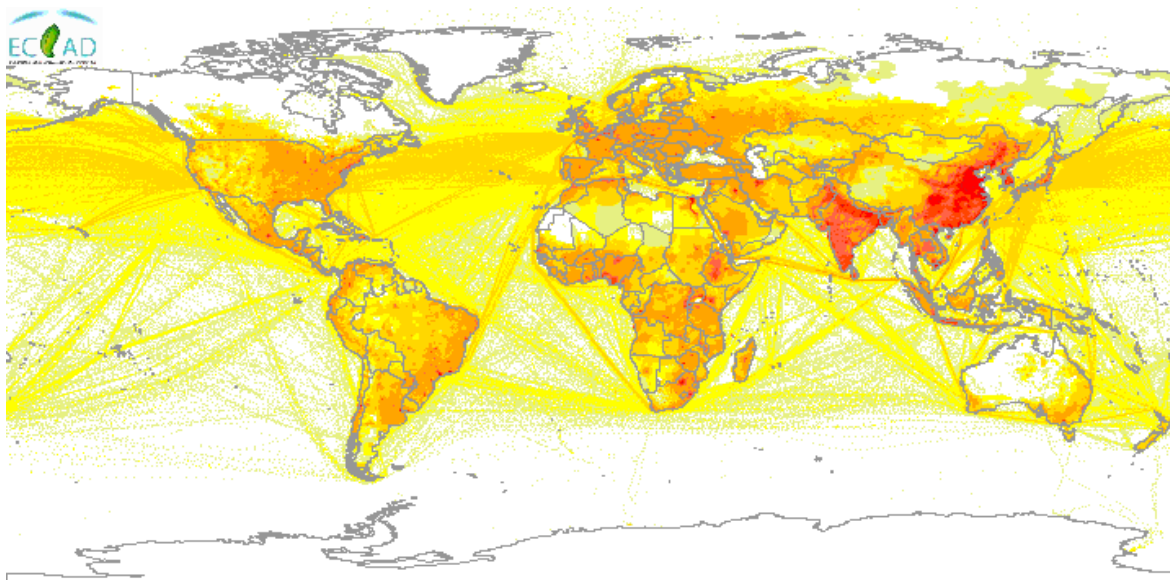
Problematic areas within the Northeast and Southeast Asian region and the South, West and Central Asian region become immediately apparent; China and India are the major emitters throughout, with Laos, Cambodia, Vietnam, and Thailand also contributing sizably. Areas of Africa, like Ethiopia, South Africa, Egypt, and Nigeria show high emissions, however, the regions overall emissions are the lowest aside from Latin America and the Caribbean. The United States and Europe both show moderately high emissions.

Table 2. Black Carbon emissions by region in 2005.

Region	BC Emissions MtCO ₂ e
Africa	1962.4
North East Asia, South East Asia and the Pacific	4382.4
Latin America and the Caribbean	778.8
North America and Europe	2281.4
South, West, and Central Asia	2285.8

Source: UNEP 2011

Figure 2. Map showing emissions from atmospheric compounds.



Source: MACCity Database

This report will focus on low-cost mitigation measures within high emission sectors, with a focus on countries with the highest black carbon emissions levels and capacity for mitigation, namely China and India. The report will also address mitigation measures that are appropriate for mid-level emitters, such as the EU, Russia, and North America, especially within the transport sector. Black carbon mitigation is particularly important in these regions because of their proximity to the Arctic or, in the case of China and India, glaciers on which large populations depend. Increased melting rates in both areas are likely to have large ramifications for human systems, especially in terms of flooding.

IMPACT OF BLACK CARBON

The actual mass of black carbon emitted is relatively low, but it is a potent warming agent. It has a global warming potential (GWP₂₀) of 2200, meaning that over 20 years a specific mass of black carbon will trap 2200 times more heat than the same mass of CO₂. To get the CO₂ equivalent (CO₂e), the global warming potential is multiplied by the mass of the gas in question. This report uses GWP₂₀ = 2200, the value used commonly by the Clean Air Taskforce.⁵ This GWP was used in with data from the UNEP 2011 report on black carbon emissions to estimate total megatons CO₂e. Regional black carbon emissions estimates are in figure 3 and table 3.⁶

⁵ Hill, 2009.

⁶ Data: UNEP 2011, megatons CO₂ equivalent calculated using GWP₂₀ = 2200.

Figure 3. 2005 BC Emissions by Sector.

2005 Emissions in Megatons CO₂ Equivalent



Source: UNEP 2011

Table 3. 2005 emissions in MTCO₂e

Region	Transport MtCO ₂ e	Residential MtCO ₂ e	Industry MtCO ₂ e	Agriculture MtCO ₂ e	BC total MtCO ₂ e
Africa	147.4	1504.8	8.8	63.8	1962.4
North East Asia, South East Asia and the Pacific	1062.6	2248.4	642.4	248.6	4382.4
Latin America and the Caribbean	334.4	264	8.8	74.8	778.8
North America and Europe	1135.2	671	46.2	123.2	2281.4
South, West, and Central Asia	433.4	1188	244.2	167.2	2285.8

For comparison, in 2005 the U.S.—the largest emitter in the world at the time—emitted about 6600 megatons CO₂ equivalent in total.⁷ The scale of black carbon impact in terms of CO₂e is significant and warrants action. According to the 2011 UNEP report on short-lived climate forcers, black carbon emissions are likely to increase, on average:

Figure 4. 2030 projected emissions in MtCO₂e by source and region

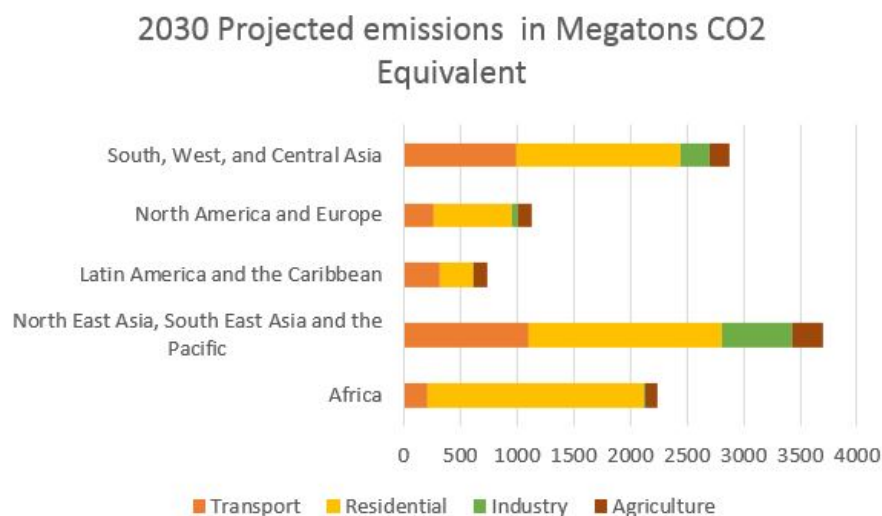


Table 4. 2030 projections for black carbon emissions in MtCO₂e

Region	Transport MtCO ₂ e	Residential MtCO ₂ e	Industry MtCO ₂ e	Agriculture MtCO ₂ e	BC total MtCO ₂ e
Africa	213.4	1911.8	8.8	101.2	2435.4
North East Asia, South East Asia and the Pacific	1102.2	1709.4	622.6	270.6	3880.8
Latin America and the Caribbean	323.4	288.2	11	114.4	811.8
North America and Europe	259.6	695.2	52.8	118.8	1359.6
South, West, and Central Asia	990	1452	259.6	180.4	3022.8

The same report suggests that high levels of mitigation are possible between now and 2030. Mitigation potential translates to 8806 MtCO₂e.

⁷ McKinsey & Company, *Climate Desk*

Figure 5. 2030 mitigation potential in MtCO₂e by source and region

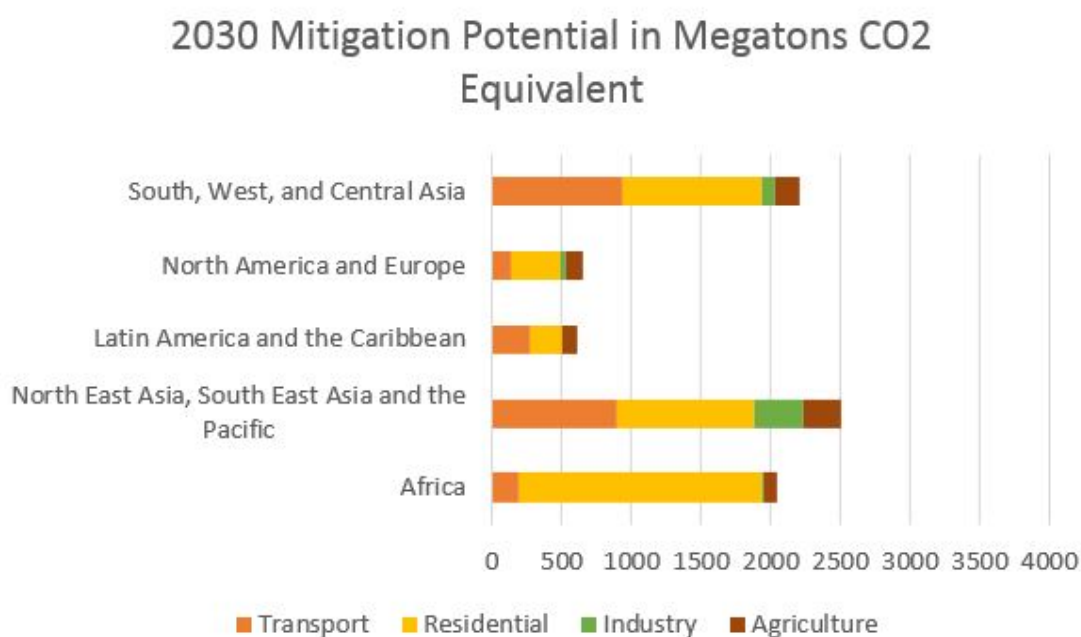


Table 5. 2030 projections for BC emissions reductions in MtCO₂e

Region	Transport MtCO ₂ e	Residential MtCO ₂ e	Industry MtCO ₂ e	Agriculture MtCO ₂ e	BC total MtCO ₂ e
Africa	195.8	1746.8	2.2	101.2	2087.8
North East Asia, South East Asia and the Pacific	895.4	992.2	341	270.6	2978.8
Latin America and the Caribbean	268.4	233.2	2.2	114.4	620.4
North America and Europe	134.2	349.8	44	118.8	741.4
South, West, and Central Asia	930.6	1007.6	92.4	180.4	2378.2
Total	2424.4	4329.6	481.8	785.4	8806.6

Source: UNEP 2011

RATIONALE

SECTOR BREAKDOWN

The vast majority of black carbon and tropospheric ozone emissions come from four sectors: residences, transportation, industry, and agriculture. Each has different mitigation measures, as well as barriers to mitigation that present varying levels of difficulty to overcome. Many of the mitigation measures are cost-effective relative to CO₂ mitigation measures and have positive economic and health benefits.

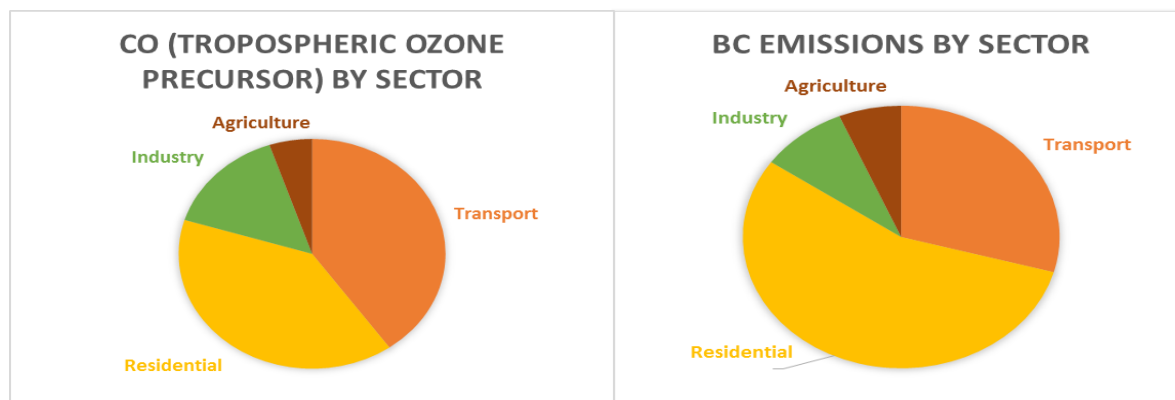
RESIDENTIAL

This sector is the largest sector contributing to black carbon emissions and tropospheric ozone. Main sources in this sector include inefficient burning of biomass or coal for residential heating and cooking, and burning of residential waste. Residential emissions are very diffuse and, in rural regions, difficult to reach. In addition, cook stove styles vary incredibly from region to region and replacements that are more efficient must be adapted regionally to fit cultural needs.

Common mitigation strategies in this sector include replacing traditional cook stoves with stoves designed to burn more efficiently, or fuel switching from biomass to coal briquettes, or (preferably) liquefied natural gas (LNG). While LNG would be the cleanest fuel to switch to, LNG switching would require dissemination of new stove models and the establishment of market linkages to very hard to reach areas. Furthermore, LNG stove-use requires a switch from wood to pre-packaged fuel—a large lifestyle change—making adoption less likely. Because of this, successful initiatives in the past, such as the Chinese National Improved Stove Program (CNISP), have focused on improved-efficiency biomass cook stoves dissemination, as opposed to LNG.⁸ This report recommends that those working in this area focus first on dissemination of increased-efficiency biomass-burning stoves, especially in rural areas, where alternative fuel supplies may be difficult to maintain.

⁸ Smith, K et al., 1993.

Figure 6. Breakdown of Carbon Monoxide and BC by sector in 2005.



Source: UNEP 2011

TRANSPORTATION

The transportation sector is the second largest sector contributing to black carbon emissions and competes for first place in some regions in terms of emissions of tropospheric ozone precursors (carbon monoxide). The primary source of black carbon and tropospheric ozone in transportation are emissions from diesel engines, especially inefficient diesel engines, or those that use high sulfate fuels. Because many sectors of transit rely on diesel, addressing emissions from diesel means adapting technologies to a wide range of vehicles, including trucks, off-road vehicles, and shipping vessels.

Suggested measures in this space include requiring new vehicles to meet certain engine and efficiency standards, retiring high-emitting vehicles, and retrofitting those currently on the road with Diesel Particulate Filters (DPFs). For shipping vessels, both retrofitting and conversion to LNG fueled ships could greatly reduce emissions; however, switching to LNG presents a high level of up-front investment and coordination between industries that may not be feasible in the short term. This report will focus on retrofit technologies for old diesel engines in the urban developing world.

INDUSTRIAL

Industry is generally the third largest source of black carbon, mostly in regions using less efficient technologies. Production of coke, an essential component to the process of manufacturing steel, is a major emitter in this space. Primitive coke ovens, which essentially transform coal into coke by baking off many of the impurities, emit huge amounts of black carbon and tropospheric ozone precursors. In 2008, 60% of coke production took place in China with primitive models producing approximately 20% of Chinese coke. Traditional brick kilns also produce a large amount of BC emissions throughout China and India.

Replacing both brick kilns and traditional coke ovens with modern technologies has the potential to lower black carbon emissions in this sector by approximately 200 Kts per year in Asia alone, which amounts to about 50% of industrial emissions.⁹ In areas where traditional coke ovens have already been replaced, technologies such as coke dry quenching (CDQ), which further lower black carbon emissions, should be installed. This report will focus on the feasibility of installing CDQ technology in China, which produces 60% of the world's coke.

AGRICULTURE

The majority of black carbon emissions in the agricultural sector come from the burning of agricultural residue post-harvest. This is a common practice, particularly in Africa, Asia, and parts of Europe. The agricultural sector's contribution to total black carbon emissions is relatively small compared to the other sectors.

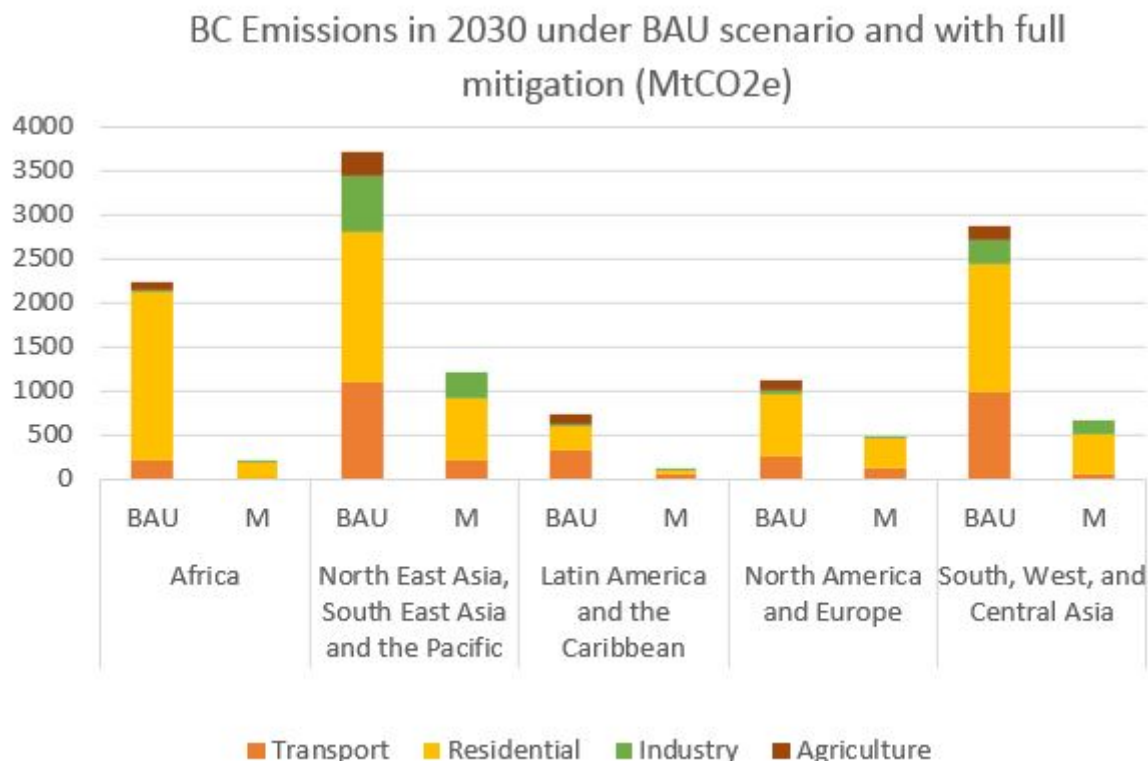
The burning of agricultural residue is a widespread and often culturally entrenched practice. Regulations banning the burning of residue have the potential to mitigate some emissions in this sector in countries with high law enforcement capacity; however, the diffuse nature of these emissions and the fact that rural areas with weak law enforcement are responsible for the vast majority of these emissions make mitigation through policy unlikely. Furthermore, the burning of agricultural residue emits black carbon, but also emits a large amount of organic carbon, which is a cooling agent. Thus, burning of agricultural residue has less of an effect on warming than other sources of black carbon.¹⁰

Figure 7 shows projections for the breakdown of black carbon emissions (MtCO₂e) by region and sector in 2030, both in terms of BAU and with full implementation of some of the above measures. In areas where mitigation strategies overlap, calculations used the most efficient strategy; therefore, Figure 6 shows the ideal scenario. For example, in the residential sector, many fuels are cleaner than biomass, but mitigation in figure 7 represents the ideal scenario in which all fuel is LNG.

⁹ UNEP, 2011.

¹⁰ Kandlikar et al., 2009.

Figure 7. Black carbon projections for 2030, BAU and with full mitigation (M)



Source: UNEP 2011

Mitigation strategies to be discussed in this section are the measures with the highest emissions reductions potential in the three largest sectors contributing to black carbon emissions: residential, transportation, and industrial sectors. The greatest potential comes from the transportation and industrial sectors, as emissions are more concentrated and mitigation strategies have already been successful in some regions. Improved-efficiency stoves are not likely to be fully implemented; however, the size of possible reduction in this space is so large that it is necessary to include them in this analysis. Below is a table with each mitigation strategy, possible emissions reductions and major issue areas.

Table 6. Mitigation interventions, potential, and emissions concentration by sector.

Sector	Mitigation intervention	Mitigation potential (% of total BAU emissions in 2030)	Emissions diffuse (spread over a number of actors) or concentrated, relevant regions
Residential	Improved-efficiency cook stoves dissemination	62% if all biomass stoves were replaced with improved efficiency biomass-burning stoves.	Diffuse, with biggest reductions in West (65% of residential BC emissions) and East (54% of residential BC emissions) Asia.
Transportation	Standards for new and imported vehicles, plus retrofitting delivery fleets with diesel particulate filters (DPFs)	Diesel is the largest contributor to transportation emissions. DPF alone can lower emissions by 85%-95%.	Diffuse, but approaching producers and trunking fleets allows for top-down coordination. Biggest problem areas: West and Eastern Asia.
Industrial	Implementation of clean coke production technologies, esp. coke dry quenching (CDQ) tech	Replacing old coke ovens with cleaner technologies globally could lower industrial emissions by 41%.	60% of the worlds coke is produced in China. The intervention could lower industrial BC emissions in China 80%.

INTERVENTIONS

RESIDENTIAL

CLEAN COOK STOVES

The residential sector is, by far, the biggest contributor to black carbon emissions. Residential fuel use, mostly biomass used for cooking, is responsible for approximately 60 % of black carbon emissions in Asia.¹¹ This section will discuss the barriers to high-efficiency cook stove adoption, and some of the steps international organizations, governments, the private sector, and non-profits are taking to weaken these barriers.

If all households were to switch to LNG by 2030, projected global black carbon emissions in the residential sector would decrease by 71%.¹² If all households switched to higher efficiency wood-burning stoves, Asia could reduce residential black carbon emissions by 60 %. In addition to lowering black carbon emissions drastically, such measures would improve public health; the World Health Organization has estimated that smoke inhalation caused by indoor traditional stoves causes over two million deaths a year.¹³ Awareness over the impact of household fuel use on human health and the environment has prompted international promotion of clean cook stoves; however, due to a number of barriers these efforts have, to date, had little success.

COST

According to the IEA's 2011 World Energy Outlook report, investment in the clean cook stove sector will need to be approximately US\$ 4.5 billion.¹⁴ In the context of funding combating other health threats, such as malaria, or mitigation costs of many carbon dioxide abatement measures, this is not a prohibitive amount of money. A 2011 UNEP report on short-lived climate forcers found that cook stoves are the most cost effective strategy for black carbon abatement, with positive returns even without accounting for health benefits.¹⁵ The report calculated the climate cost effectiveness to be approximately -\$6 per mitigated ton CO₂ equivalent (tCO₂e).¹⁶

Intervention	Cost (\$/tCO ₂ e)	Other Benefits
Adoption of cleaner-burning stoves	-\$6/ tCO ₂ e	health benefits, crop protection

¹¹ EPA, 2013.

¹² UNEP, 2011. data appendix.

¹³ GACS, 2011. p. 4.

¹⁴ Ibid. p.15.

¹⁵ UNEP, 2011. p.14.

¹⁶ Kandlikar et al., 2009. p.12.

Despite the fact that the estimated capital investment necessary for clean cook stoves are far lower than other measures aimed at abating carbon dioxide or black carbon emissions, finding sources for capital investment presents a large barrier to action. Unlike other abatement measures with high upfront costs, there was little private sector involvement in this space until recently, which left governments, international organizations, and NGOs footing the bill.¹⁷

BARRIERS

Market Barriers

Knowledge and demand

One of the largest barriers to cook stove adoption is the lack of knowledge about the economic and health benefits of improved cook stoves. The health benefits are not immediately obvious, and, because wood is free in rural areas, households see little value in improved cook stoves. This assessment is supported by the fact that cook stove programs have proven to be much more successful in urban settings, where families must buy their firewood.¹⁸ The lack of understanding in terms of the benefits of improved cook stoves has lowered demand, which, in turn, has resulted in a market with few suppliers. Low numbers of suppliers and product diversity relative to the diversity of consumer preferences reinforces low demand.¹⁹

Absence of standards

Absence of reliable testing mechanisms or international standards makes it possible for many manufacturers to claim health and efficiency benefits that may or may not be true for their product. This uncertainty has hampered the market's growth and the political will of governments to promote adoption.²⁰ Without such standards, development organizations may distribute stoves that actually present little benefit, hurting their credibility and the health of those they are trying to help.

Lack of financing

Lack of credit and financing institutions in many rural areas presents a huge barrier to cook stove adoption. Sustainable cook stove dissemination and adoption is most likely to happen through the building of real markets and supply chains to rural areas. This, however, requires that households themselves pay the relatively large upfront cost. Without access to credit, many households cannot afford such large investments, even if they understand the ultimate pay-offs.

¹⁷ GACS, 18.

¹⁸ Slaski and Thurber. *Research note: Cook stoves and Obstacles to Technology Adoption by the Poor*. (Freeman Spogli Institute for International Studies, October 2009), 7.

¹⁹ GACS, 17.

²⁰ GACS, 17.

Political Barriers

Coordination

Inefficient biomass-fueled stoves and their associated environmental and health impacts are an issue throughout the developing world. The diffuse nature of this problem—the fact that mitigation involves reaching a large number of individual residences throughout the developing world—makes it difficult to tackle, especially given that many of the areas in greatest need are also the most difficult to reach. The diffuse nature of the issue results in a lack of coordination between organizations disseminating cleaner-burning stoves. For the last 20 years, approaches have primarily been piecemeal project-based efforts between NGOs, governments, private firms, and international organizations.²¹ As a result, efforts have been inefficient and ineffective.

Cultural Barriers

Life-style change

One of the biggest barriers to technology adoption by the poor is the level of engagement required.²² Even if adoption of a given technology leads to savings in terms of time and money, the level of engagement necessary for an individual to become accustomed to it can prevent adoption. Cook stove adoption requires household members to change their daily routines, and in the case of LPG stoves, alter the entire process of fuel attainment and meal preparation. This life-style change makes adoption difficult and often leads to non-linear adoption.

Non-linear adoption

Adoption, when it does occur, does not happen linearly, because stoves do not meet the households' cultural needs. For example, households often use multiple stoves at a time for different tasks, so while some households may be using improved stoves, they are often using tradition stoves in tandem. As a result, even adoption of improved stoves can have little overall impact (See Box I).²³

²¹ GACS, 2011. p.18

²² Slaski and Thurber. N.d.

²³ Edwards RD et al.. 2007.

BOX 1. NON-LINEAR ADOPTION IN ACTION

During the 1980s China's National Improved Stove Program was able to achieve over 50% adoption and has since been hailed as an example of successful cook stove dissemination. The initiative managed to distribute over 129 million high efficiency biomass cook stoves between 1982 and 1992.¹ An evaluation of the program in 2001, however, showed that particulate matter emission levels were still far above the level acceptable for human health in many of the villages using the stoves. It turned out that villagers were using the improved cook stoves in conjunction with traditional stoves, with use dependent on seasonal and daily factors. Emissions overall were lower, but indoor pollution levels were similar as those in households without clean stoves.² As a result, despite the program's success in terms of dissemination and adoption, adoption did not necessarily result in better health or environmental outcomes.

1. Smith et al., 941

2. Edwards et al., 189.

ACTORS TODAY

Recent trends have decreased the potency of some of the aforementioned barriers. The founding of the Global Alliance for Clean Cook stoves by 19 major cook stove-oriented organizations, increased levels of coordination and shifted the focus from cook stove distribution to a market oriented strategy. The new strategy emphasizes building demand and supply linkages, both for cook stoves and for cleaner cook stove fuels, as well as establishing international standards.²⁴

Current developments in the cook stove private sector are promising. Through a number of innovative business models and the advent of carbon finance, private domestic firms have succeeded in creating affordable, standardized, cook stoves targeted at the poor. Manufacturers have sprung up in Cambodia, China, Ethiopia, Ghana, Guatemala, India, Kenya, Peru, Uganda, among others, and manufacturers in China and India are even creating stoves for export.²⁵

²⁴ GACS, 2011. p. 24

²⁵ Ibid. p.21.

RECOMMENDATIONS FOR ADDRESSING BARRIERS

Overall, cook stove adoption throughout the developing world still faces many barriers symptomatic of less-developed regions as a whole, such as insufficient infrastructure and lack of access to financing. Many of these barriers will weaken as income rises and rural areas become more connected to markets, but population is rising faster than income is.²⁶ Through the development of consumer demand and market linkages, current efforts may increase cook stove adoption, especially if these focus on cook stoves that use traditional fuels and involve smaller life-style changes. Impressive international coordination efforts over the last decade have greatly increase the likelihood of success in this space, but full implementation of this measure by 2030 is highly unlikely.

TRANSPORTATION

Experts project that the transportation sector will make up approximately 27 % of all black carbon emissions in 2030.²⁷ The majority of black carbon emitted from the transportation sector is from inefficient or malfunctioning diesel engines. This section will suggest interventions that can lower emissions from on-road diesel, with an emphasis on regulation, and retrofiting. While the focus of this section is on road diesel, black carbon emissions from off-road vehicles and diesel fueled shipping vessels present similar issues.

DIESEL ENGINES

The biggest and most diffuse source of black carbon in transportation is inefficient on-road diesel engines, particularly in developing countries where standards are often more lax and enforcement is often more challenging. Retrofitting vehicles with diesel particulate filters has the potential to eliminate 95% of black carbon from diesel vehicles. Looking forward, retrofitting combined with new vehicle standards and air quality standards has the potential to quickly phase out high emitting on-road diesel vehicles, especially because—when compared to other areas—there are a relatively small number of diesel manufacturers. In 2011, one producer, Cummins, supplied 40% of the diesel engines used by U.S. manufacturers.²⁸ Improving engines at the supplier level, and retrofitting those currently on the road could dramatically reduce emissions from the transportation sector. Depending on the type of filter, retrofitting may require fuel switching to low sulfur diesel, which also lowers particulate matter emissions.

²⁶ GACS, 2011. P.17

²⁷ UNEP, 2013.

²⁸ Ward's Automotive Group, 2011. <http://wardsauto.com>.

COST

Retrofitting diesel engines is not necessarily low cost, but when combined with incentive programs and regulations on new engines such as those in the U.S.'s Clean Air Act, 2007 Heavy Duty Rule, or the Non-road Tier 4 standards, retrofits can be cost-effective. A report by the Copenhagen Consensus Center estimated the climate cost-effectiveness of installing diesel particulate filters to be approximately \$115 per tCO₂e,²⁹ while an EPA study estimated that fleet retrofits to be a cost effective technology for reducing particulate emissions, especially when paired with incentive programs.³⁰

Table 7. Possible interventions and costs

Intervention	Cost (\$/tCO₂e)	other benefits
Diesel Particulate Filters (DPF)	\$115/tCO ₂ e	health benefits, crop protection
Euro 6 standards for heavy duty vehicles plus DPF	\$300/tCO ₂ e	health benefits, crop protection
Euro 6 standards for light duty vehicles plus DPF	\$180/tCO ₂ e	health benefits, crop protection

BARRIERS

Market Barriers

Cost

Compared to cook stove interventions, retrofitting has few barriers besides cost. Because of the high capital investment costs, most currently functioning diesel retrofit programs are funded by grants from government agencies or international organizations. In the absence of regulations to make retrofits cost-effective, international development organizations often provide avenues for funding.

Diffuse offenders

Diesel engines are diffuse—that is, there are a lot of users of the technology—however, diesel engine production and imports are concentrated, making production and import standards relatively easy to enforce. For example, the EPA works with U.S. Customs Service to ensure that sub-standard vehicles are not entering through U.S. ports, which act as a choke point for incoming vehicles.³¹ Vehicles needing diesel retrofits to meet standards present a slightly larger problem. One way this has been addressed in the U.S. is through the creation of the *National Clean Diesel Campaign: Clean Agriculture, Clean Construction, Clean Ports, Clean School Bus, and*

²⁹ Kandlikar et al., 2009. P.14.

³⁰ EPA, 2006. <http://www.epa.gov/diesel/documents/420s06002.pdf>.

³¹ EPA, 2000.

Smartway Transport in 2000.³² The program uses incentives to encourage voluntary adoption of clean diesel technologies. The program verifies and standardizes technologies that lower emissions and provides funding for private firms to install DPF through grants and innovative financing methods. Through regional collaboratives, involving non-profits, industry, and state, local, and municipal governments, the campaign retrofitted over 400,000 existing diesel engines between 2000 and 2011. To put it in perspective, there were 15 million diesel vehicles in the U.S. in 2005; their retrofit efforts reached approximately 2.6% of diesel engines. Funding has been the major constraint to the program. In 2009, the program was allocated \$300 million dollars—five times more than the previous year—and it received over \$2 billion worth of applications with state promises to match. Underfunded, the NCDC was forced to sit on \$1.7 billion worth of demand.³³

³² Chang, 2011. P.7

³³ Ibid. p.8.

BOX 2. EMISSIONS STANDARDS

Emissions standards are regulations set on industry that limit the amount of pollutants that can be legally released into the environment. Most governments have their own system for classifying automobile emissions standards, but they generally have different standards for different types of vehicles (light on-road vs. heavy-duty off-road) and different types of fuels (diesel vs. petrol). Many countries, including India and China, have made their systems parallel to the European Union's system, which consists of 6 different levels. The adopted emissions standard represents the maximum emission levels that all vehicles sold in a given country must meet for a given pollutant. They don't, however, apply to vehicles already on the road.

Tier	Carbon Monoxide g/kWh	Hydrocarbons g/kWh	NO _x g/kWh	Particulate Matter g/kWh
Euro I	4.5	1.1	8	.36
Euro II	4	1.1	7	.15
Euro III	2.1	.66	5	.13
Euro IV	1.5	.46	3.5	.02
Euro V	1.5	.46	2	.02
Euro VI	1.5	.13	.4	.01

Political Barriers

Political will: Regulations

One of the biggest barriers to retrofit programs is political will, in terms of both regulation and funding. Diesel retrofits become cost-effective under regulatory frameworks that fine individuals or firms who do not meet standards; without such regulation or available funding avenues, fleet managers do not have a strong enough monetary incentive to retrofit. If the government lacks the will to create such regulations or the capacity to enforce them, retrofits remain more of a cost than a benefit. Governments are generally more likely to have political will in areas where the health impacts are apparent.

China is currently active in employing emissions standards, especially in cities, which are required to abide by different regulations. Their emissions standards system mirrors those of the EU. Most of the country is held to China III (similar to Euro III) while Beijing is subject to China V (Euro V) regulations. In early 2013, China's State Council established a timeline for

adoption of stricter diesel standards, including a limit of sulfur content to 10 ppm.³⁴ Beijing oil companies, such as China National Petroleum Corp, which are both powerful and state-owned, have historically opposed more stringent emission regulations; however, the recent increase in concern over air quality has outweighed their influence.³⁵

India, as well, has adopted the Euro IV emissions standards for light duty vehicles and heavy duty diesel vehicles in 11 of its biggest cities as of 2010.³⁶ Enforcement within India, however, is diffuse, with the Ministry of Road Transport and Highways, state governments, and individual municipalities all having some enforcement authority.

Political will: Funding

Funding for support agencies, as seen in the U.S. case, is vital. It is necessary that producers have access to grants or low interest loans that will allow them to invest in DPFs, which do provide long-run benefits. Until political will for lowering diesel emissions increases, government-run programs will continue to be underfunded and less effectual than they could be.

RECOMMENDATIONS FOR ADDRESSING BARRIERS

One way to deal with budgetary constraints is to aim programs at areas with the highest risk. This also works to grow political will for funding; high-risk areas are typically urban areas with large populations, which makes large budget allocations more palatable. Many municipal governments worldwide are taking this approach, focusing on municipality-owned fleets, such as bus fleets.³⁷ China has used this approach in upgrading many of its vehicle fleets to electric and LNG-run vehicles; however retrofitting has not been widely implemented.³⁸ Entirely replacing vehicles is expensive and not a reasonable response for dealing with the entire diesel fleet of most Chinese cities; investing funds in diesel retrofits for older vehicles would reach more vehicles, and therefore have a larger effect on lowering particulate matter concentrations.

Other funding mechanisms

The EPA and the World Resources Institute have a number of projects that provides funding for bus fleet diesel retrofits in developing countries such as China, India, and Mexico.³⁹ Diesel retrofit programs are also included under the Clean Development Mechanism (CDM), which allows developed countries to fund clean projects in developing countries in exchange for emissions credits.

³⁴ Finamore, 2013.

³⁵ Back and Tejada, 2013.

³⁶ Emission Standards, India. N.d.

³⁷ UNEP, 2009.

³⁸ Legislative Council Panel on Environmental Affairs, 2013.

³⁹ UNEP, 2009.

INDUSTRY

COKE OVENS

Coke is a super clean fossil fuel made through pyrolysis of coal used in industrial processes requiring very high heat, such as iron production. Coke itself burns very cleanly, however its production emits large concentrations of particulate matter. This section focuses on coke dry quenching (CDQ), a technology that can significantly lower black carbon emissions from coke production. CDQ adoption in China is particularly of interest, as China produces 60% of the world's coke,⁴⁰ approximately 428 MMTs in 2011.

Black carbon from coke production makes up approximately 15% of China's total black carbon emissions.⁴¹ High emissions from coke production have negative health impacts for those working in and living around production areas, including increased incidence of cancer.⁴² The Chinese government has implemented numerous policies to eliminate old, low energy-efficiency coking technologies, promote new coking systems, and raise environmental standards (Table below).

Table 8. Chinese policies directed at eliminating older coking technologies.

Year	Policy
1999	State Economic and Trade Commission of China outlawed use of indigenous ovens for new projects.
2004	Required Criteria for Market Entry: Chambers must be taller than or equal to 4.3 m and production capacity greater than or equal to 0.6 MMT/year
2006	National Development and Reform Commission of China required phasing out of indigenous coke technologies by local authorities. (NDRC 2006)
2006	Mandatory elimination of small coke ovens with chamber height less than 4.3 m
2008	Norm of energy consumption per unit product of coke GB21342-2008: Dictated energy efficiency requirement of less than 125 kg of coal equivalent per ton of coke produced.
2008	Required Criteria for Market Entry: Chambers must be taller than or equal to 6.0 m

These policies caused a large, very quick, technological shift from indigenous to mechanized technologies, which produce far less black carbon. From 1990 to 1995, 70% of China's coke was produced using indigenous ovens; by 2010, this had shifted to 99% from coke machinery ovens.⁴³ Despite this huge success, black carbon emissions in the industry still make up 15% of China's black carbon emissions, and have been steadily increasing—a direct result of intense growth within the industry.

⁴⁰ Huo et al., 2012.

⁴¹ Ibid.

⁴² EPA, 2000.

⁴³ Hou et al., 2012.

COKE DRY QUENCHING

To meet stringent emissions standards recently approved by the Central Government of China, another technological shift is necessary. One technology that has the potential to lower black carbon emissions resulting from coke production is coke dry quenching (CDQ). The process uses inert gas to cool coke after pyrolysis, as opposed to the traditional process, coke wet quenching (CWQ), which uses water and produces significantly more black carbon emissions. Additionally, CDQ recovers the heated inert gas used in quenching and uses it to make steam for electricity generation.⁴⁴ CDQ improves the coke production efficiency and lower black carbon emissions by up to 80 % when compared to CWQ;⁴⁵ however, in 2010 only 23 % of China's coke production used this technology.⁴⁶

COST

Coke dry quenching is relatively expensive in terms of installation, costing approximately US\$109.50 per ton of coke; however it provides a large amount of savings in terms of energy and CO₂ reductions.⁴⁷ Approximately 0.55 GJ of electricity per ton of coke can be recovered, resulting in a global CO₂ reduction potential of about 25 MtCO₂e.⁴⁸ This process has the potential to reduce energy costs by 40%, and produces higher quality coke.⁴⁹ According to a report by the New Energy and Industrial Technology Development Organization in Japan (NEDO) on energy saving technologies, it takes about 3.6 years for an operation to recoup costs of installing a dry coke quenching system. Energy savings, water savings and health benefits make this technology viable if government provides economic incentives; currently, costs are the biggest barrier to adoption. Japan, which has far higher energy costs and therefore a favorable cost-benefit ratio, has installed over 27 units, representing more than 90 % of the industry in that country.⁵⁰

Intervention	Cost (\$/tCO ₂ e)	Other Benefits
Replacing traditional coke ovens with modern recovery ovens	\$0.4/tCO ₂ e	more cost effective production, energy savings

⁴⁴ NEDO, 2008.

⁴⁵ EGTEI, 2012.

⁴⁶ Huo et al, 2012.

⁴⁷ EPA Office of Air and Radiation, 2012.

⁴⁸ International Energy Agency, 2007.

⁴⁹ Worrell et al., 2010.

⁵⁰ NEDO, 2008.

BARRIERS

Market barriers

There are few market barriers in terms of CDQ adoption, aside from funding. In most coke producing regions, major steel and iron conglomerates are responsible for coke production, making the issue relatively concentrated and therefore easy to address. This was the case in China prior to 2008. Since 2008, however, the Chinese government has actively promoted adoption of coke dry quenching technologies. The Ministry of Industry and Information Technology of China started the *Program of Promoting Coke Dry Quenching Technology in Iron & Steel Industry and Coke Industry* in 2010, with the goal of increasing adoption to 90% within the main iron and steel manufacturers—40% of producers overall—by 2013. This program, with financial support from the government has reached an adoption rate of over 80% of the primary iron and steel manufacturers, amounting to about 23% of China's coke producers. The majority of the remaining 77% of producers are relatively diffuse and less able to afford CDQ technology, making further dissemination of CDQ more difficult.

Technological barriers

For those producers who have not adopted CDQ, maintenance remains the primary technological barrier. Because CDQ in China is relatively new, there are few technical training agencies available to provide support to new users.⁵¹ The last 5 years of increased market penetration have significantly weakened this barrier, a trend that is expected to continue as CDQ becomes more common.

Political barriers

As discussed earlier, the government fully supports the adoption of CDQ technologies, and the majority of the political players in the iron and steel industry have adopted the technology. The remaining coke producers are not particularly powerful politically, making regulations that are more stringent a viable option for CDQ promotion.

RECOMMENDATIONS FOR ADDRESSING BARRIERS

CDM

CDQ projects are included under the CDM system; China currently has 14 CDQs funded by this mechanism.⁵² Current plans to restructure or replace the CDM system may make funding through the CDM more difficult; however, CDQ will likely be included under the new mechanism as well.

⁵¹ UNFCCC, 2013.

⁵² Ibid.

A new policy focus

The centralized and authoritarian nature of the Chinese government makes CDQ a question of political commitment. Previously the government had implemented a number of policies to deal with overcapacity in the coke industry, including policies that limit financing available from banks. Beijing has recently produced a new plan of action for approaching overcapacity, this time from the perspective of environmental protection. The new plan uses market mechanisms combined with strict environmental and energy standards for industry, including closure targets for producers using outdated technology. The plan will work in tandem with the national pollution action plan 2013-2017, which also stresses energy efficiency and environmental protection in industry. In addition to these new plans, the Chinese government recently implemented the World Health Organization's Interim Target-I standards for particulate matter, with the goal of reaching an annual average of 35 $\mu\text{g}/\text{m}^3$ by the end of 2015.⁵³ The strong policy emphasis on industry and environment indicates that government funding may be another viable option for CDQ funding.⁵⁴

SUMMARY CHART OF RECOMMENDED INTERVENTION COSTS

Table 8. Summary chart of recommended interventions for BC

Intervention	Cost \$/ (tCO₂e)	Other Benefits
Adoption of cleaner-burning stoves	-\$6	Health benefits, crop protection
Replacing traditional coke ovens with modern recovery ovens	\$0.4	More cost effective production, energy savings
Diesel Particulate Filters (DPF)	\$115	Health benefits, crop protection
Euro 6 standards for light duty vehicles plus DPF	\$180	Health benefits, crop protection
Euro 6 standards for heavy duty vehicles plus DPF	\$300	Health benefits, crop protection

⁵³ Huo et al., 2012.

⁵⁴ Stanway, 2013.

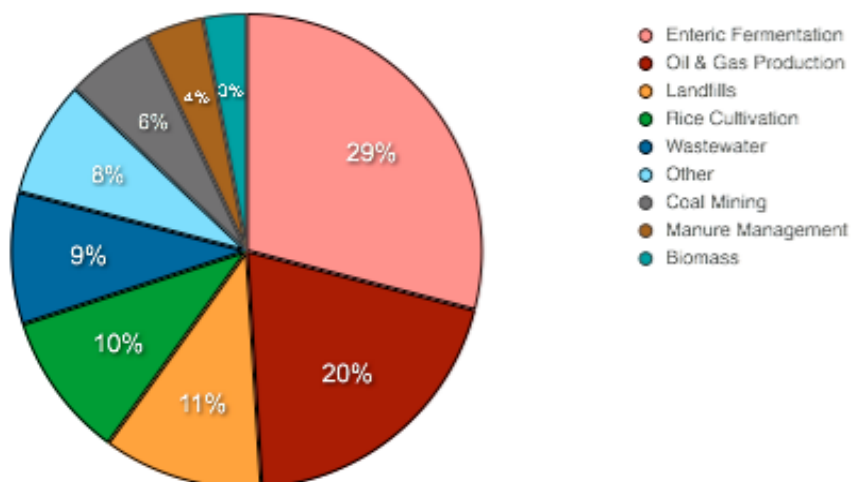
METHANE

OVERVIEW

Aside from CO₂, methane (CH₄) is the most prevalent GHG. According to the CAIT 2.0 database, 7,195.56 MtCO₂e of CH₄ are emitted globally per year (2010). Methane is estimated to have a lifespan of approximately 12 years. Because methane is a potent radiative forcer but only remains in the atmosphere briefly (relative to CO₂), efforts to mitigate methane emissions have great potential for near-term effects.

This section of the report will present a sectoral breakdown of methane emissions as well as possible interventions to capture and utilize methane, or otherwise reduce these emissions. It will primarily focus on interventions in the energy production, agriculture, and municipal waste sectors. Proposed interventions include: capture of vented associated gas in oil and gas production; pre-mining degasification and capture of vented coal mine methane; installation of anaerobic digestion facilities for manure management; increased uptake of paddy field aeration in rice cultivation; and separation and treatment of municipal waste prior to landfill delivery. The recommendations that follow were primarily chosen on the basis of cost savings or energy production opportunities they will introduce. The feasibility of adoption of the suggested mitigation measures hinges on the appeal of these co-benefits to public and private actors within each sector. Each section includes a discussion of potential barriers to implementation of these interventions, focusing on the highest methane-emitting countries in the highlighted sectors—China, Russia, India, and the United States. The main foreseeable challenges to implementation will be financing upfront costs and overcoming technical barriers to adoption.

Figure 8. Methane emissions by sector



Source: EPA 2011

RATIONALE

This section of the report outlines highest emitting activities in each of the major sectors. % of global emissions referenced in this section are from EPA 2011 data and national emissions data are from EDGAR.⁵⁵

ENERGY PRODUCTION

According to the EPA, more than one quarter of all methane emissions originate in energy production.⁵⁶ The highest contributing activities within this sector are oil and gas production and coal mining.

Oil and Gas Production - 20%

Total process emissions from oil and gas production make up 20% of global methane emissions. Due to the size and disparate nature of the oil and gas industry, however, emissions in this sector are difficult to accurately quantify (See Box 3).⁵⁷ Gas released during oil and gas production is referred to as “associated gas” (or “associated petroleum gas”). The composition of associated gas varies, but is comprised of mostly methane.⁵⁸

The IPCC defines fugitive emissions as “an intentional or unintentional release of gases from anthropogenic activities excluding the combustion of fuels.”⁵⁹ In the oil and gas sector, fugitive emissions come about during the production, processing, and distribution stages. Emissions are released through faulty or outdated equipment, leaky pipelines, or are intentionally vented. Vented associated gas is often released into the atmosphere during oil and gas production to reduce the risk of fire or explosion from potentially volatile gases.

Coal Mine Methane - 6%

Coal mining activity is responsible for 6% of global methane emissions. During coal extraction, Coal Mine Methane (CMM), which is trapped in the coal seam, is released into the air supply. Generally, CMM is classified into four concentrations:

- High-Concentration CMM is 80% methane or more.
- Medium-Concentration CMM is between 30-80% methane.
- Low-Concentration CMM is less than 30% methane.

⁵⁵ For each sector, see Table 2 for national-level emissions data.

⁵⁶ EPA, 2011.

⁵⁷ Picard, 2001.

⁵⁸ PFC Energy, 2007.

⁵⁹ IPCC, 1996.

- Ventilation Air Methane (VAM) is released from mine ventilation shafts as air with a highly diluted (<1%) concentration of methane.

At lower concentrations CMM becomes much more volatile. The explosive range of CMM is between 5-15%, so it is often diluted to a safe concentration of less than 1% and then either flared or released as VAM.

AGRICULTURE

The agricultural sector makes up roughly half of total methane emissions globally (See Box 3). While the majority of agricultural methane comes from enteric fermentation (ruminant livestock), there are serious cultural and financial challenges to mitigation in this area. These barriers will be discussed further in the next section. Other prominent methane-emitting agricultural activities, which will be detailed in this report, are manure management and rice cultivation.

Box 3. NAS Study on Methane Emissions[‡]

A new study, published by the National Academy of Sciences in October 2013, claims that previous estimates of US methane emissions, both from the Environmental Protection Agency (EPA) and the Emissions Database for Global Atmospheric Research, may be significantly underestimated. The study estimates the spatial distribution of methane through the use of comprehensive atmospheric methane observations, extensive spatial datasets, and a high-resolution atmospheric transport model. The study says that previous estimates of total emissions in the US could be biased downwards by 50%, and possibly more within specific sectors. In particular, the study finds that emissions in the agricultural and oil and gas sectors are potentially higher by a factor of two or more than previously thought. The study indicates that some agricultural methane emissions, mainly from enteric fermentation and manure management, are actually twice as high as indicated in existing data. It also finds that oil and gas production in some regions could be responsible for almost 5 times more methane emissions than cited in EDGAR.*

Emissions in these sectors are difficult to quantify, but estimates of emissions levels have important implications for prioritization of abatement measures. Further research on the discrepancy between the findings of the NAS study and previous reported methane emissions levels will inform the policy recommendations laid out in this report.

[‡] <http://www.pnas.org/content/early/2013/11/20/1314392110>

* EDGAR, the most comprehensive database of global methane emissions, is the source of all national-level, sector disaggregated data in this report.

Manure Management - 4%

The decomposition of animal waste in anaerobic conditions contributes to GHG emissions through the production of biogas, of which 70% is methane.⁶⁰ Methane is produced when livestock and poultry manure is stored as liquid, or slurry, in anaerobic conditions, like pits or lagoons.⁶¹ This is primarily a concern on large-scale farms, the majority of which are located in the US. With appropriate technologies, it is possible to capture and utilize the biogas produced by manure management systems.

Rice Cultivation - 10%

Rice cultivation makes up 10% of global methane emissions and 20% of agricultural methane.⁶² Anaerobic respiration in wet paddy field conditions produces methane. When flooded, organic material in the fields essentially decomposes through methanogenesis. Methane is then released either through the plant or from the soil after water has been drained.

Approximately 90% of rice land is flooded, for at least part of the year, contributing significantly to agricultural methane emissions.⁶³ Fields are flooded because higher water content in rice production can boost crop yields. While it is possible to grow rice in several different land conditions (see Box 4), more water increases soil fertility—by raising the nitrogen and phosphorous content of the soil—and as a result increases plant productivity. This capacity for higher yields, clearly, is a deterrent for farmers to grow rice in drier, more climate-friendly production environment.

Box 4. Rice in Different Conditions.

Rice is typically grown in one of five ways, with wetter methods producing significantly higher levels of methane emissions:[‡]

- Upland, or dry, rice is grown with minimal water. It is primarily rainfed and highly drought tolerant.
- Lowland rice mainly subsists on rain or groundwater, but because of its low elevation, it is also flood prone.
- Decrue rice (derived from the French, *décru*, or flood recession) is predominantly grown in Africa, where it is planted on river banks and flooded when seasonal rains come.
- Lowland, irrigated rice is what we traditionally think of when imagining rice cultivation. This rice is planted in paddy field and then, once the seedlings have sprouted, the field is flooded to promote growth.
- Deep water, or floating, rice grows in conditions of 20 or more inches of water.

[‡] <http://www.ucl.ac.uk/rice/historyofrice>

⁶⁰ Global Methane Initiative. “Agricultural Methane: Reducing Emissions, Advancing Recovery and Use Opportunities,” (2011). https://www.globalmethane.org/documents/ag_fs_eng.pdf

⁶¹ Global Methane Initiative. “Global Methane Emissions and Mitigation Opportunities,” (2011). https://www.globalmethane.org/documents/analysis_fs_en.pdf

⁶² Yusuf, Rafiu O. et al. “Methane emission by sectors: A comprehensive review of emission sources and mitigation methods,” *Renewable and Sustainable Energy Reviews*, Volume 16, Issue 7, (September 2012), 5059–5070.

⁶³ Wassmann, Reiner, Yasukazu Hosen, and Kay Sumfleth. “Reducing Methane Emissions from Irrigated Rice,” *Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen*. (Focus 16: Brief 3, 2009).

MUNICIPAL WASTE

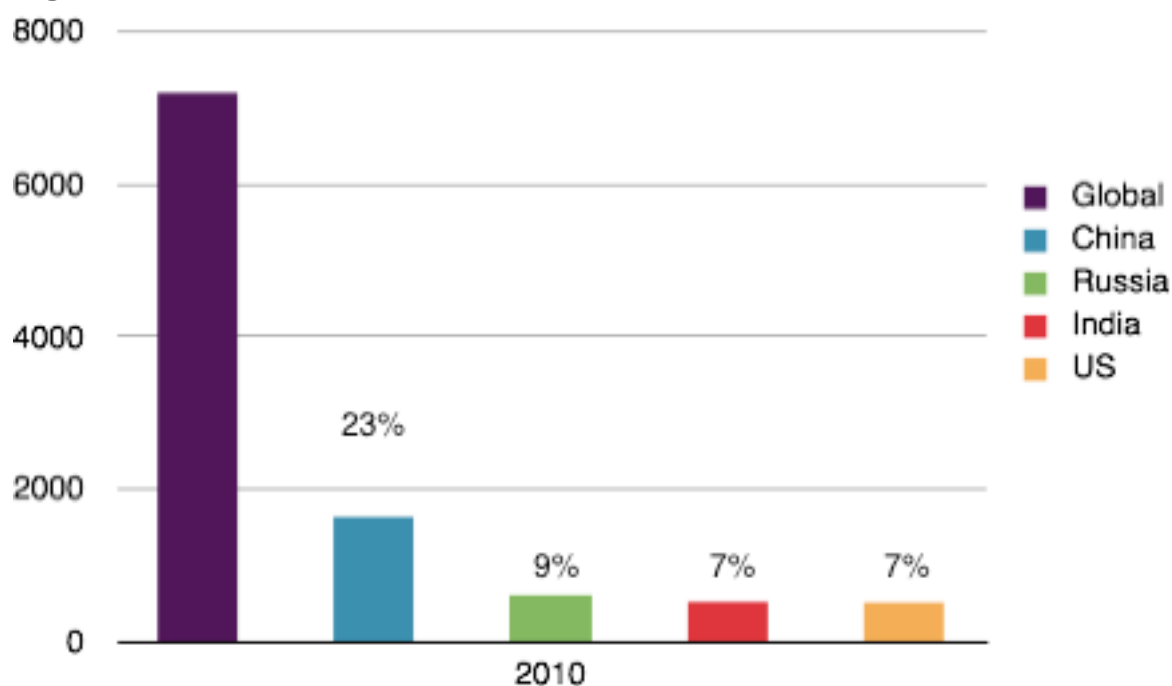
Landfill Leakage - 11%

The storage and treatment of municipal solid waste in landfills produces 11% of total global methane emissions. Anaerobic conditions in landfills cause organic material to decompose, releasing methane. These emissions can be mitigated either through methane capture or by ex ante reducing the amount of waste delivered to landfills through recycling or composting.

INTERVENTIONS

This section presents potential interventions for the mitigation of methane emissions. The sectors chosen are among the highest emitting sectors and emissions are concentrated in a small number of countries, making action more probable. The US, India, Russia, and China are the countries responsible for the majority of methane emissions in the sectors of each of the selected interventions described in this section. Actions in chosen sectors seem most plausible, based on cost-benefit analysis and potential barriers, and are most likely to have near-term benefits. For example, while enteric fermentation represents the largest percentage of methane emissions (29%), cultural and behavioral barriers to reducing meat consumption and financial barriers to improving livestock feed are prohibitive to intervention in this sector, thus it has been excluded. The final section of this chapter will further explore potential barriers.

Figure 9. Methane emissions in MtCO₂e



Source: IEA 2010

ENERGY PRODUCTION

Capture of vented associated gas in oil and gas production

Associated gas can be captured through the installation of vapor recovery units (VRU) at oil and gas production sites.⁶⁴ VRUs capture vaporized associated gases and condense them back into liquid form. The resulting liquid gas can then be sold, used on-site for fuel, or converted to energy. VRU installation has a high return on investment. Through monetization of captured associated gas and energy cost savings, most units pay for themselves within six months of use.⁶⁵

Focusing on vented associated gas during oil and gas production, and not including fugitive emissions from transport and distribution, has a comparatively favorable cost-benefit analysis. Capturing and utilizing associated gas during production is relatively inexpensive (more so for oil than for gas)⁶⁶ and has the co-benefit of providing methane for energy use or fuel, whereas the cost of retrofitting pipelines outweighs the monetary benefits of avoiding leakage.

The emissions reduction potential by 2030 for capture of vented associated gas is 643 MtCO₂e for oil and 50.4 MtCO₂e for gas.⁶⁷ Russia emits roughly three times more vented methane from oil and gas production than any other country. The US is the second highest emitter of vented methane in the oil and gas sector.

BARRIERS

Cost/Financial

Upfront costs of Vapor Recovery Units, or other methods of capturing vented associated gases, can be prohibitively expensive. However, in a relatively short time, benefits from methane capture should balance out initial investment. Public financing or tax rebates are one way to incentivize recovery of vented methane. Manufacturers of VRUs or associated technologies could also offer loans to cover initial costs, both increasing their customer base and reducing emissions.

Technical

Some of the major emitting countries in the oil and gas industry do not have access to adequate technology to recover associated gases. UNFCCC Clean Development Mechanism (CDM)

⁶⁴ Global Methane Initiative, 2011.

⁶⁵ Hy-Bon. N.d.

⁶⁶ See Table 2. Cost for capture of vented gas during oil production is -150\$/t CH₄, cost during gas production is -690/t CH₄

⁶⁷ UNEP, 2011.

projects are one possible method of financing technology transfer for low- to middle-income countries.⁶⁸

Pre-mining degasification and capture of vented coal mine methane

CMM emissions can be avoided through several different drainage processes. Drainage, or degasification, of coal mines can occur pre- or post-mining. Degasification drains methane from the coal seam, through the use of boreholes, or methane can be collected from “gob,” or coal debris.⁶⁹ Gob gas is typically removed from mines through ventilation systems.⁷⁰ The process of capturing vented gob gas is similar to that of vented associated gas capture (described above). Recovered CMM, through drainage or ventilation, can also be converted into energy or used as fuel. Costs are significantly higher for pre-mining degasification, compared to ventilation, owing to a lack of appropriate technologies.⁷¹

China is the predominant emitter of CMM. 2010 estimates for CMM in China were 28.4 Mt CH₄, nearly seven times more than the second highest emitter, the US. China has several policies in place to reduce CMM emissions, including tax incentives and regulations which compel mines to use CMM recovery techniques. Coal mines in China are required to use recovered CMM that has a concentration of 30% or above. However, due to safety considerations when handling or transporting low-concentration CMM, any recovered CMM under 30% concentration can be released. Thus mines are incentivized to dilute their CMM so it can be released without consequence. This both introduces more methane emissions into the atmosphere and presents a safety hazard.

Most of China’s CMM is released in the form of ventilation air methane (VAM) and more than 70% of recovered CMM is low-concentration.⁷² China is currently lacking adequate technology for the safe capture, transport, and conversion these volatile low-concentration emissions. Transfer of technology to allow for a safe recovery process for low-concentration CMM could curb the incentive for mines to dilute CMM to release VAM into the atmosphere. Additionally, pre-mining degasification of low-concentration CMM could reduce the incidence of mine explosions and provide safer working conditions for China’s miners.

The cost of coal mine degasification technologies and equipment make it unattainable for countries like China that would benefit most. CDM projects are one way of financing coal mine degasification. Currently, 95% of the world’s CMM CDM projects take place in China, but have mainly targeted high-concentration CMM.

⁶⁸ UNFCCC, n.d.

⁶⁹ World Coal Association, n.d.

⁷⁰ Clarke Energy. N.d.

⁷¹ See Table 2. Cost for pre-mining degasification is 1300\$/t CH₄, cost for ventilation is 280/t CH₄

⁷² International Energy Agency, 2009.

Technical

Low-concentration CMM is highly volatile and capture is dangerous. China, where the majority of CMM is produced, does not have adequate technology for capture, especially of low-concentration CMM. It is cheaper and easier to dilute and release methane than to capture it. Technology transfer could help reduce these emissions.

Cultural/Behavioral

Western countries are reluctant to recover low-concentration CMM because of potential volatility. However, since the majority of CMM is low-concentration, in order to efficiently mitigate CMM, Western countries will have to focus more attention on developing safe recovery technologies.

AGRICULTURE

Installation of Anaerobic Digestion facilities for manure management

Manure management systems can capture methane using anaerobic digestion (AD) facilities. AD systems include small-scale digesters, covered anaerobic lagoons, plug flow digesters, complete mix digesters, and advanced digesters. Once captured, AD systems convert biogas into energy, heat, or fuel, which can generate revenue or be used for on-farm energy needs. Agricultural waste-to-bioenergy strategies, by employing AD technologies, also reduce waste and contribute to better air and water quality.

EDGAR estimates that US manure management emissions in 2010 were 2.2 Mt CH₄. The US EPA operates a voluntary, educational program, the AgSTAR Program, to promote manure management systems that capture and utilize methane. AgSTAR estimates that there are 2020 AD systems operating on commercial farms in the US and that these projects produces more than 650 million kWh/year of energy.⁷³

BARRIERS

Cost/Financial

Benefits from anaerobic digestion tanks take a long time to balance out upfront costs. Farm owners often have limited access to financing mechanisms. CDM is an option for financing in China and India. In the US, tax incentives could potentially be offered for farm owner who adopt AD systems.

⁷³ Environmental Protection Agency, n.d.

Technical

In many countries, AD equipment must be imported and there is often a lack of technical capacity and experience to operate it. Another technical barrier is that utilization or monetization of captured methane can be problematic if there are no nearby venues for distribution.

Cultural/Behavioral

Perceived high risk of AD by banks and investors can make it difficult for farm owners to secure financing.⁷⁴

Uptake of aeration of paddy fields in rice cultivation

Midseason drainage and intermittent irrigation conserve water and reduce the length of time in which methane-producing conditions exist in paddy fields. Methane is produced in rice cultivation because of anaerobic conditions in wet paddy fields, so drier rice-growing conditions are the most obvious mitigation measure. However, if improperly implemented, reducing water in rice cultivation can have a regressive effect on farmers' incomes. More effective water management, though, can reduce methane emissions and conserve water, while maintaining crop yields.

China, by far the top emitter of rice paddy methane, has managed to cut down on emissions through mid-season draining of rice fields.⁷⁵ This process involves flooding the fields initially, and then, once the rice plants have absorbed the benefits of the flooded fields during the early growing process, draining water from the fields and allowing plants to grow in drier conditions for the rest of the season.

Intermittent irrigation is another practice for more efficient management of water in rice cultivation. This method applies less frequent, more targeted irrigation to conserve water and limit anaerobic paddy field conditions.

BARRIERS

Cost/Financial

Based on UNEP cost estimates (see Table 9), mid-season drainage might not be a viable option. However, it is likely that those cost estimates are variable, because mid-season drainage has been common practice in parts of China since the 1980s.⁷⁶ Different techniques might be able to achieve drainage at lower costs.

⁷⁴ Eastern Research Group, 2010.

⁷⁵ Qiu, 2009.

⁷⁶ Ibid.

Cultural/Behavioral

Changing the perception that rice can only thrive in wet conditions will be difficult. Proof of success can help shape farmers' attitudes and promote uptake of mid-season drainage, intermittent irrigation, and dry-seeding.

MUNICIPAL WASTE

In the US, the EPA's New Source Performance Standards and Emission Guidelines requires large landfills to collect and burn landfill gas. Other EPA initiatives, like the Landfill Methane Outreach Program, encourage the use of landfill methane. Because the US (the highest emitter of landfill methane) is already paying significant attention to recovering methane from landfills, this report will focus instead on separation of biodegradable waste.

Separation and treatment of municipal waste prior to landfill delivery

Methane can be extracted from landfills through a series of wells and a vacuum system, which collects gas and directs it to a combustion point to be flared or utilized for energy.⁷⁷ Anaerobic digestion is not currently a viable option in landfills because organic and inorganic materials are not separated.⁷⁸ Improved sorting could allow for the use of AD technologies in extracting landfill methane.

The potential emissions reductions of 584 MtCO₂e by 2030 cited in Table 2, however, only consider benefits from separation and treatment of municipal waste and not recovered landfill methane (barriers to landfill methane capture will be discussed in the following section). Regulations and incentives for sorting municipal waste could divert organic materials from landfills. Organic waste could then be treated in AD tanks to produce energy rather than producing emissions in landfills.

The US emits the most landfill methane globally. The EPA's Landfill Methane Outreach Program promotes adoption of reduced waste and recovery of landfill methane. Already, many states in the US have regulations, like Pay-As-You-Throw, or incentives, like recycling rebates, to reduce waste.⁷⁹ Additionally, some states (California most prominently) have incorporated biogas from AD systems into their energy plans.⁸⁰

⁷⁷ Global Methane Initiative. N.d.

⁷⁸ Global Methane Initiative. 2013.

⁷⁹ *ibid.*

⁸⁰ California Energy Commission, n.d.

BARRIERS

Industrial/Market Barriers

Provision of municipal waste services in many countries is fragmented between public and private service providers. This can complicate efforts to enforce standards on sorting of solid waste. Additionally, many countries have inadequate infrastructure for separating and treating biodegradable waste.

Political

In the US, some incentives and regulations have been put into place to reduce waste (Pay-As-You-Throw, recycling rebates). However, realities of the US political landscape have led to many of these types of programs being underfunded.

Cultural/Behavioral

Increased uptake of composting and recycling would reduce volume of landfill waste and lower levels of landfill methane, but personal preferences for recycling and composting are unlikely to change without incentives or regulation.

Table 9. Summary of interventions, emissions reductions, and cost

Sector	Intervention	Current emissions[‡]	Emission Reduction potential (by 2030)[§]	Cost[*]
Energy Production	Recovery of vented gas during oil and gas production	20% of methane emissions come from oil and gas Russia - 16.3 Mt CH ₄ US - 5.79 Mt CH ₄ Iran - 3.51 Mt CH ₄ China - 2.74 Mt CH ₄ Saudi Arabia - 2.33 Mt CH ₄	Oil: 30.6 Mt CH ₄ (643 MtCO ₂ e)	Oil: -150 \$/t CH ₄ (-730 to 480)
			Gas: 2.4 Mt CH ₄ (50.4 MtCO ₂ e)	Gas: -690 \$/t CH ₄ (-721 to -632)
	Coal mine degasification	6% of methane emissions come from coal mining China - 28.4 Mt CH ₄ US - 4.14 Mt CH ₄ Russia - 2.77 Mt CH ₄ India - 2.17 Mt CH ₄	Ventilation: 25.0 Mt CH ₄ (535 MtCO ₂ e)	Ventilation: 280 \$/t CH ₄ (222 to 2,820)
			Pre-mine degasification: 17.5 Mt CH ₄ (368 MtCO ₂ e)	Pre-mine degasification: 1,300 \$/t CH ₄ (500 to 10,500)
Agriculture	Anaerobic digestion systems on large farms (waste-to-biogas)	4% of methane emissions come from manure management US - 2.2 Mt CH ₄ China - 1.68 Mt CH ₄ India - 1.11 Mt CH ₄	2.2 Mt CH ₄ (46.2 MtCO ₂ e)	-400 \$/t CH ₄ (-2,320 to +1,250)
	Aeration of rice paddies	10% of methane emissions come from rice cultivation China - 15 Mt CH ₄ India - 4.07 Mt CH ₄ Indonesia - 2.75 Mt CH ₄	9.1 Mt CH ₄ (191 MtCO ₂ e)	3,160 \$/t CH ₄ (1,750 to 35,300)
Municipal Waste	Separation and treatment of municipal waste	11% of methane emissions come from landfills US - 5.23 Mt CH ₄ China - 3.79 Mt CH ₄ Russia - 2.11 Mt CH ₄ Turkey 1.41 Mt CH ₄ Canada - 1.36 Mt CH ₄	27.8 Mt CH ₄ (584 MtCO ₂ e)	-1,650 \$/t CH ₄ (-1,840 to -1,450)

[‡] % of global emissions from EPA; national emissions data from EDGAR

[§] UNEP

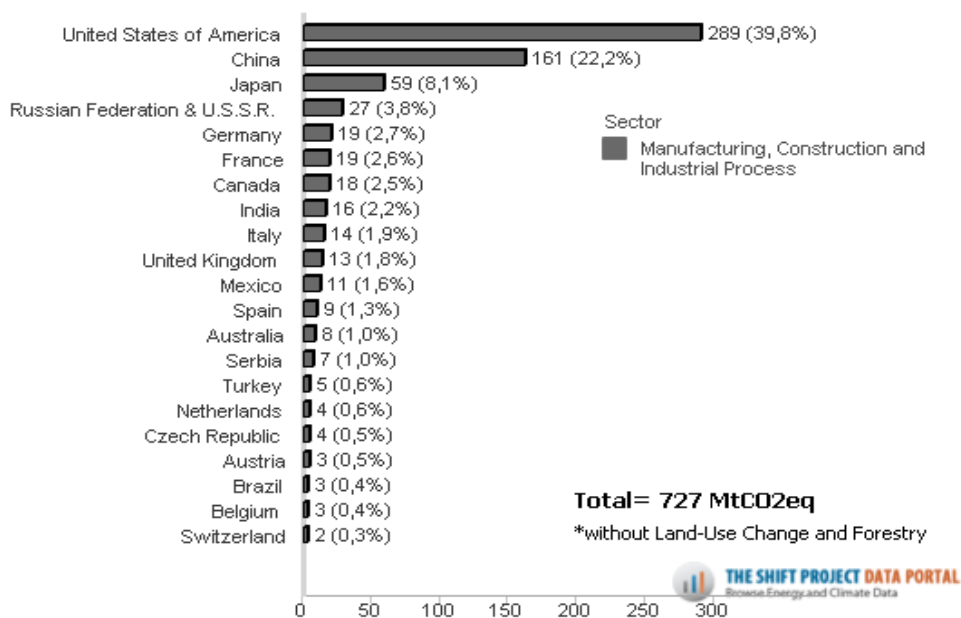
UNEP; ranges in parentheses show regional variations

HYDROFLUOROCARBONS

OVERVIEW

Hydrofluorocarbons are fluorinated gases and have no natural sources; they come only from human related activities. They are emitted through a variety of industrial processes such as aluminum and semiconductor manufacturing, as well as coolants in refrigerators. The United States in 2010 emitted the most HFCs (near 40% of the total), followed by China (at 22%), the EU (at 10%)⁸¹, and finally Japan (at 8%). At this point, each country's emissions were less than 4% (Russia sat at 3.8% and India was at 2.2%). These statistics come from the Shift Project's Data Portal using data from the World Bank. The units are in MTCO₂e. According to the World Bank data, in 2010, HFCs emitted 727 MTCO₂e.⁸²

Figure 10. Top 20 HFCs Emitters in all sectors (MtCO₂e)



⁸¹ The EU is not listed as one entity in this data set. In order to use it as one, the countries in the EU that are also in the top 20 emitters were added together and those numbers were used above.

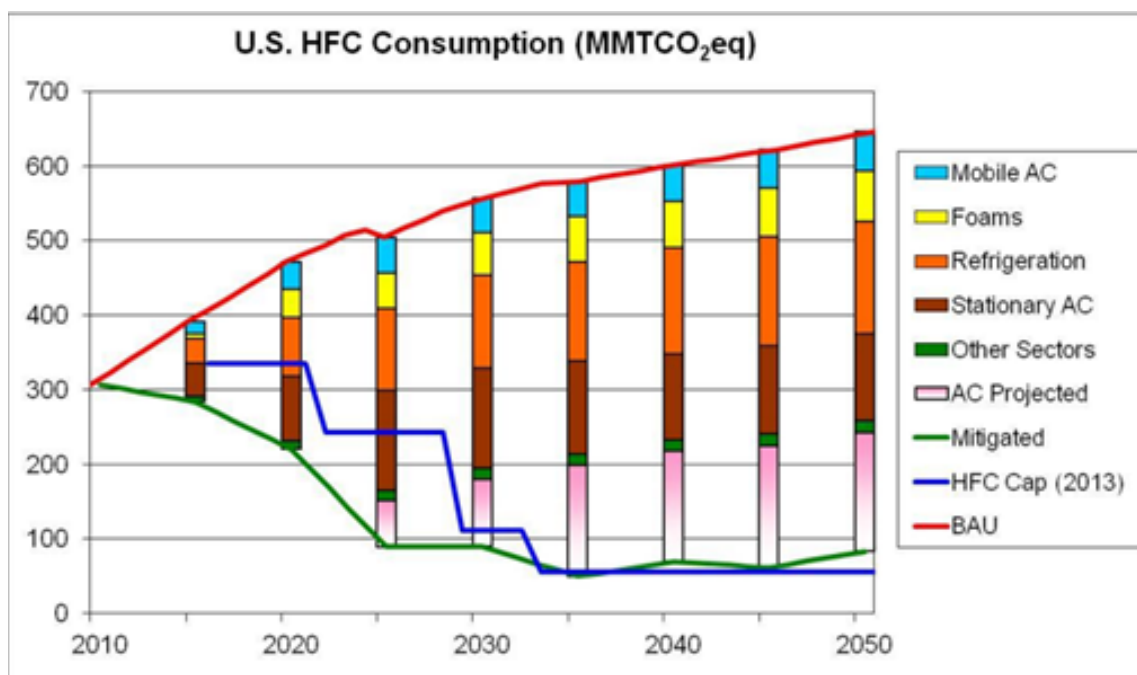
⁸² The shift project also has data from CAIT (climate Analysis Indicators Tool) which reports that from 1990-2004, HFCs emitted 2,898 MTCO₂e. I use the World Bank data set because they have data for individual years instead of blocks of time.

HFCs have caused less than 1% of total global warming thus far, but emissions are growing at a rate of 10-15% per year.⁸³ This continued growth will add up to 0.1 degrees Celsius of global average temperature rise by 2050 and a 0.5 degree Celsius increase by 2100. If no action is taken on HFCs by 2050, annual HFC emissions could be equivalent to 20% of annual carbon dioxide emissions under a business as usual (BAU) scenario, and up to 40% of annual carbon dioxide emissions under a 450 ppm carbon dioxide stabilization scenario.⁸⁴ While most emissions thus far have been by developed countries (US, EU, Japan) and an emerging China, future projections expect emissions in developing countries to exponentially increase, especially in India.

RATIONALE

The main sources of emissions for HFCs are refrigeration and air conditioning units. The graph⁸⁵ below shows potential HFC consumption reductions in the United States:

Figure 11. Potential HFC Consumption Reductions by Sector for the U.S.



Source: US EPA June 2013

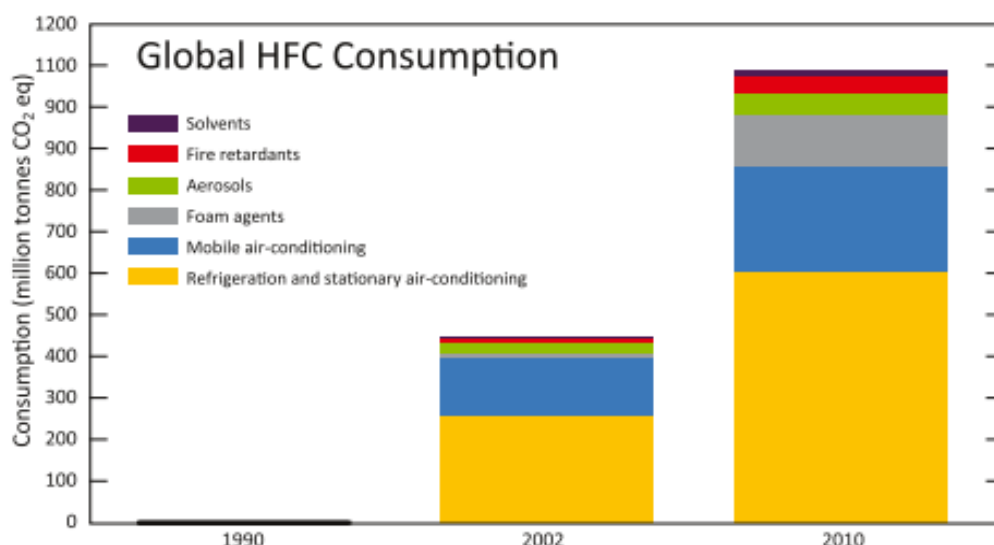
⁸³ Andersen et al., 2013.

⁸⁴ UNEP, 2011.

⁸⁵ EPA, 2012. [Graph].

HFCs have been introduced into commercial use because they are effective substitutes for ozone depleting substances and are applicable substitutes for CFCs and HCFCs. The chemicals are manmade and increasing as a result of global economic development and population growth. UNEP has reported that in 2010, around 55% of total global HFC consumption was in refrigeration and air conditioning equipment in homes, other buildings, and industrial operations (expressed in MT CO_2e). 24% was in air conditioning in vehicles, 11% in foam products, 5% in aerosols, 4% in fire protection systems and less than 1% in solvents.⁸⁶

Figure 12. Global HFC Consumption



HFCs are unique among greenhouse gas pollutants because they have the potential for vast growth, but because of that, significant reductions if immediate action can be taken. While business as usual would lead to a 0.5 degree increase of temperature, phasing out HFCs alone can avoid up to a 0.5 degree warming by 2100 in a high growth scenario and 0.35 degree increase under a low growth scenario.⁸⁷ In tons, the reduction potential is up to 8.8 billion tons of CO_2 per year by 2050. The cumulative total by 2050 will be equivalent to 100 billion tons of CO_2e in avoided emissions, the range being between 76-134 billion tons.⁸⁸ Mitigation of HFCs and the other short lived climate pollutants (SLCP) has the potential to avoid 0.6 degree Celsius of future warming by 2050, and up to 1.5 degrees by 2100.⁸⁹

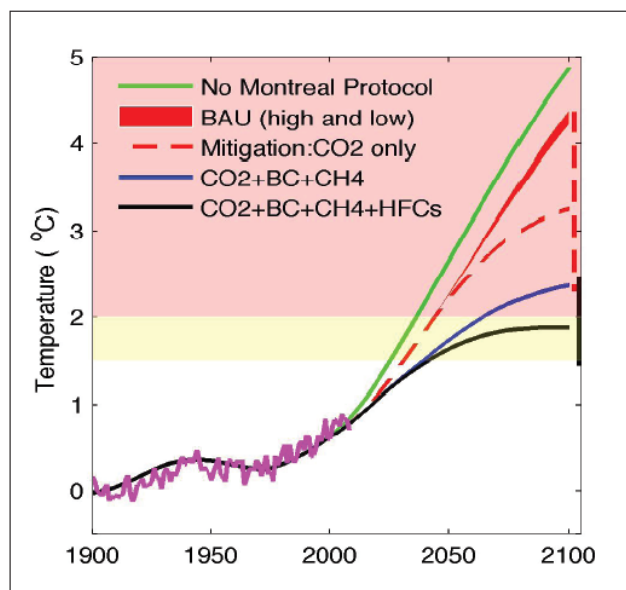
⁸⁶ UNEP, 2011.

⁸⁷ Zaelke et al., 2013.

⁸⁸ Picolotti, 2011.

⁸⁹ Andersen and Taddonio, 2011.

The graph on the right shows⁹⁰ simulated temperature change under various mitigation scenarios that include CO₂ and short-lived climate pollutants (Black Carbon and Methane).⁹¹ The BAU line (solid line with a spread due to uncertainty in growth) looks at both high and low estimates of future HFC growth. This uncertainty of temperature projection related to HFC scenarios is around 0.15°C at 2100. The vertical bars next to the curve show the uncertainty of temperature projection at 2100 due to climate sensitivity uncertainty.⁹²



INTERVENTIONS

There are two actions that are highly recommended: the passage of the HFC amendment to the Montreal Protocol and the passage of the Consumer Goods Forum (CGF) Resolution.

HFC Amendment to the Montreal Protocol

The amendment sponsored by the U.S., Canada, and Mexico would reduce 85-90% of HFC production and consumption. It would also provide climate mitigation equivalent to 100 billion tons of carbon dioxide emissions between 2016 and 2050 at the low cost of less than ten cents per CO₂eq ton.⁹³ The proposal includes binding reduction targets for all countries, and provides access to financial support and extended phasedown time to developing countries.⁹⁴ It is important to note that the proposal acknowledges that some niche areas may never transition, which is why the phasedown ends at 15% of allowable use of HFCs relative to an established baseline. The baseline for Article 5 countries (developing countries) is calculated as 90% of the average 2008-2010 HCFC consumption. It is based on HCFCs since developing countries only began phasing down HFCs in 2013, thus no average is yet available. The baseline for non-Article 5 countries (developed) is calculated as the average, for the years 2008-2010 of HFC consumption plus 85% of HCFC consumption.

⁹⁰ Zaelke et al., 2013.

⁹¹ Y. Xu et al., 2013.

⁹² Zaelke et al., 2013.

⁹³ HFC Primer October IGSD.

⁹⁴ EPA, 2013.

CGF Resolution

The CGF is a group of over 400 private sector companies including Coca-Cola, 3M, Proctor & Gamble, and Unilever from 70 countries. In the resolution, they have pledged to phase out HFC refrigerants in new point-of-sale units and large refrigeration systems starting in 2015. A report recently released by the EIA on the top 12 supermarkets found that commercial refrigeration systems make up 32% of global HFC consumption and that HFC emissions from supermarket refrigeration equipment and associated loss of energy efficiency can account for almost 50% of a supermarket's total greenhouse gas emissions.⁹⁵ The EIA also reports that each US supermarket emits on average 1,556 metric tons of HFCs annually from leaks in their systems. Switching out HFCs for natural refrigerants, such as hydrocarbons, carbon dioxide or ammonia, has the potential to reduce a supermarket's carbon footprint by 25%. And if all supermarkets in the United States did this, HFC emissions in the US could be cut by more than 40%. Voluntary measures have been ineffective, ergo, the enforcement of the CGF resolution is necessary to see the possible reductions. If the US can cut 40% of its HFC emissions by simply having supermarkets switch to natural refrigerants, even more gains can be made globally. A combination of the amendment to the Montreal Protocol and joint action by private supermarkets can have immediate benefits.

BARRIERS

Costs/Financial

The three main replacements for HFCs are carbon dioxide, hydrocarbons, and ammonia. All three of these identified substitutes are cheaper and cost effective alternatives, but there are high investment costs. This high up-front cost deters Article 5 countries from making the switch.

Financial assistance

Under the US, Mexico, Canada amendment to the Montreal protocol, financial assistance is given to Article 5 countries. It would account for lower levels of recovery and recycling of refrigerants.⁹⁶ Some companies have addressed the costs through various approaches including: conventional bank loans and climate protection incentives. For Article 5 countries needing economic assistance, ozone depleting substance (ODS) phase out projects provide financial assistance through the Multilateral Fund and Global Environment Facility projects, and there are climate-related funds and bilateral assistance available.⁹⁷

⁹⁵ EIA, 2013.

⁹⁶ EPA, 2013.

⁹⁷ UNEP, 2011.

Technical

Most identified substitutes have currently available technology, but some require 5-10 additional years of development.⁹⁸ Even with completed technologies, there are risk factors including flammability and toxicity and incompatibility. Ammonia is poisonous in high concentrations and is incompatible with copper pipes. Hydrocarbons are highly flammable. Technicians often lack the knowledge needed to work with the substitute alternatives and the technologies that use them.

Ways to address risk

Ammonia, while highly poisonous at high levels, smells before the level of concentration is dangerous.⁹⁹ Hydrocarbons can be combined with carbon dioxide to be less flammable. More standards are constantly being created by international organizations to help address safety concerns. Another way to address leaks before they reach dangerous levels is to limit refrigerant charge sizes and use automated leak detection and shut-off systems.¹⁰⁰ Investments have been made in safety equipment and training of technicians to handle the substances safely. The US established the Significant New Alternatives Policy (SNAP) in 1994 to encourage a transition from ozone depleting substances to alternatives in industry, commercial and military sectors. It continues to update available options, including new, more low-global warming potential (GWP) and no-GWP alternatives (both HFC and non-HFC options).¹⁰¹ SNAP findings are relevant globally, and can be used by countries as they pick which alternatives fit their specific needs and regulations.

Market Barriers

Private market still voluntary

Action for private companies is still voluntary; there are no mandatory measures in place. The CGF has a resolution set to start in 2015 in which all 400 members agree that new refrigerants must be HFC free.¹⁰² This is a good first step, however, all countries must participate, especially the United States, European Union, China and India. It is and will continue to be difficult to monitor and enforce mandatory action. This area needs more development and research on enforcement in the private market.

Political Barriers

India's refusal to agree to Montreal

⁹⁸ EPA, 2013.

⁹⁹ Goodway blog, 2009.

¹⁰⁰ UNEP, 2011.

¹⁰¹ EPA, 2013.

¹⁰² EIA, 2013.

Possibly the largest political barrier to reductions to HFCs on an international level is India's refusal to sign onto the HFC amendment. India's Environmental Minister, Jayanthi Natarajan, announced at the Climate Talks in Warsaw in November 2013 that India will not sign onto the HFC amendment to the Montreal Protocol. He says that the amendment should be under the protocol of the UNFCCC. In his announcement, he asked for better explanations of costs, safety, identified substitutes, and economic feasibility.¹⁰³ Economic feasibility is the hardest to prove since alternatives are still being invented and are initially expensive to develop.

Possible ways to engage India

India is one of many countries that have yet to sign onto the amendment, but if all the big emitters sign (China, Russia, the US, the EU, and Japan), India may feel enough pressure to join. Natarajan's statement asked for clarification and explanations that many other countries may also be hesitant about. Reports and presentations that break down cost, safety, alternatives and economic feasibility can help dispel reservations.

Cultural Barriers

India & China slowing down progress

Political and cultural barriers hinder progress in India. It does not want to be forced into changes before it has joined the advanced countries and is no longer developing. India, and other developing countries, have historically not emitted nearly as many HFCs as non-article 5 countries. They do not want to have to slow down their development because of the irresponsible actions of the countries that developed before they did. As India's population develops, HFC emissions will only increase. China has agreed to bi-lateral talks with the United States, but does not have to agree to concrete policies as long as India refuses to discuss an amendment to the Montreal Protocol.

Cost effective and energy efficient

All developing countries must sign on to the amendment for it to make a dent in global greenhouse gas emissions. The cost effectiveness and energy efficiencies need to be stressed. In India, 40-60% of peak electricity demands in the summer months are from air conditioning which puts pressure on an aging electricity grid.¹⁰⁴ Efficiency gains catalyzed from the HFC amendment would lower the cost of operating the equipment and save consumers money.

¹⁰³ Bloomberg News, 2013.

¹⁰⁴ IGSD, 2013.

Table 10. HFC Intervention potential

Intervention	Emission Reduction Potential	Climate Mitigation	Cost
US, Mexico, Canada HFC Amendment to the Montreal Protocol	85-90% of HFC production and consumption	100 billion tons of CO ₂ eq (2016-2050)	<.10 cents per CO ₂ e ton

CONCLUSION

Short-lived climate forcers present the world with a fast avenue to dramatically reduce the effects of climate change. Taking immediate action on SLCFs could reduce net global warming by 0.4 degrees Celsius in the year 2050, buying important time for innovation of green energy technologies and increasing the chances of keeping warming below 2 degrees Celsius.¹⁰⁵ Mitigating black carbon and methane—a precursor of tropospheric ozone—present a myriad of benefits external to the climate issue, including human health and food security, making action on these atmospheric constituents even more pressing. This report has outlined a number of mitigation measures through which mitigation of SLCFs can be achieved with low economic and political costs.

The majority of measures for mitigating short-lived climate forcers are politically and economically viable, especially when looking at the long-term benefits and positive externalities. Even more encouraging, there are examples where most of these mitigation technologies or methods have gleaned economic surpluses, energy savings, and product quality. The primary barrier concerning many of the measures suggested in this report are high upfront costs associated with technology adoption and coordination. Some governments have set up programs to assist with these costs, but many are underfunded.

This report discusses methods that are both cheap and have relatively low barriers to implementation. Below is a table of measures discussed in this report, with the most viable—in terms of high impact and low cost—in bold.

¹⁰⁵ UNEP, 2011.

Table I I. Summary of interventions across SLCFs

BLACK CARBON	Dissemination and adoption of increased-efficiency biomass-burning cook stoves
	Adoption of diesel vehicle standards and installation of diesel retrofits
	Installation of coke dry quenching technology in coke production
METHANE	Capture of ventilated associated gas during oil and gas production
	Pre-mine degasification and capture of coal-mine methane
	Installation of anaerobic digestion systems
	Aeration of rice paddy fields
HFCS	Sorting and treatment of biodegradable municipal waste
	Adoption of HFC amendment to Montreal protocol
	Replacement of HFCs with CO₂, ammonia, or hydrocarbon refrigeration

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