

Need for Speed

Reducing Short-Lived Climate Pollutants Can Cut the Rate of Global Warming By Half and Arctic Warming by Two-Thirds for the Next 30 to 40 Years

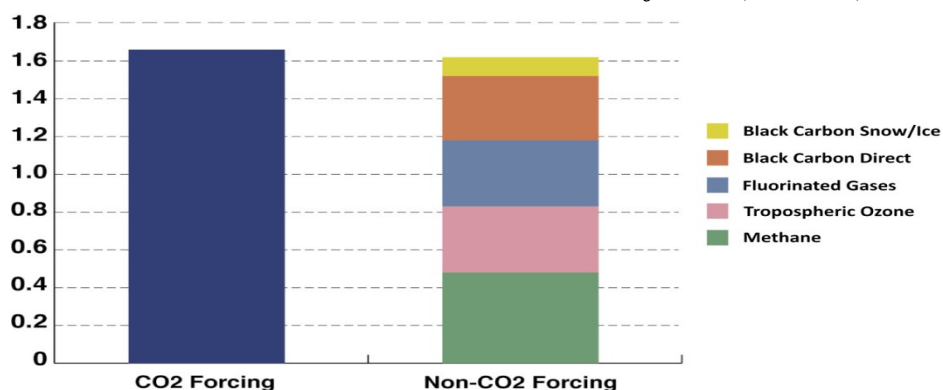
Summary. 30 May 2012. CO₂ is responsible for about 55% of radiative forcing. *See Fig. 1.* Fast and aggressive CO₂ mitigation is essential to combat the resulting climate change. But this is not enough. CO₂ mitigation must be combined with fast and aggressive mitigation of the pollutants causing the other 40-45% of warming. Because these pollutants have atmospheric lifetimes of days to decades, they are referred to as short-lived climate pollutants (SLCPs).

Reducing non-CO₂ short-lived climate pollutants—black carbon, tropospheric ozone and its precursor, methane, and hydrofluorocarbons (HFCs)—can cut the current rate of global warming by half and the rate of warming in the Arctic by two-thirds for the next 30 to 40 years, while producing significant collateral benefits for health, crops, and local air quality. Reductions can be achieved quickly, and in most cases by using existing technologies and existing laws and institutions. The Climate and Clean Air Coalition ([CCAC](#)) to Reduce Short-lived Climate Pollutants, comprised of developing and developed countries, along with UNEP, the European Commission, and the World Bank, was recently launched to pursue these reductions. (The G8 Leaders announced 19 May 2012 that they were joining the Coalition.) *See Appendix 1.*

Reducing black carbon, methane, and tropospheric ozone can be achieved with 14 targeted control measures, and provide global benefits for climate, crops, and health valued at \$5.9 trillion annually, starting in 2030. Phasing down production and use of HFCs can be achieved under the Montreal Protocol, while simultaneously improving the energy efficiency of refrigerators, air conditioners, and other equipment and products that use these chemicals. If combined with substantial CO₂ reductions, these fast actions have a high probability of keeping the increase in global temperature to less than 1.5°C above the pre-industrial temperature for the next 30 years and below the 2°C guardrail for the next 60 years or more, the aspirational goal many heads of State agreed upon to prevent dangerous interference with the climate system. *See Fig. 3.*

Given the profoundly persistent nature of CO₂ (*see Fig. 2*), it also is necessary to deliberately draw down previously emitted CO₂ from the atmosphere on a timescale of decades rather than the millennia of the natural cycle, in order to return to a safe and stable climate by the end of the century. This can be done using CO₂ removal strategies such as bio-sequestration, biochar, and chemical air capture and re-utilization, although these tools need to be further developed at scale.

Fig. 1. Changes in radiative forcing from anthropogenic emissions since the Industrial Revolution of 1750 (in W/m²)



Based on [IPCC](#), WG 1, Fig. 2.21, AR 4 (2007). (Note graph does not include all non-CO₂ forcers.)

A substantial portion of CO₂ emissions remain in the atmosphere for millennia, and warming caused by CO₂ is largely irreversible for a thousand years after emissions stop:

While more than half of the CO₂ emitted is currently removed from the atmosphere within a century, ... about 20% ... remains ... for many millennia. (IPCC, AR4 2007.)

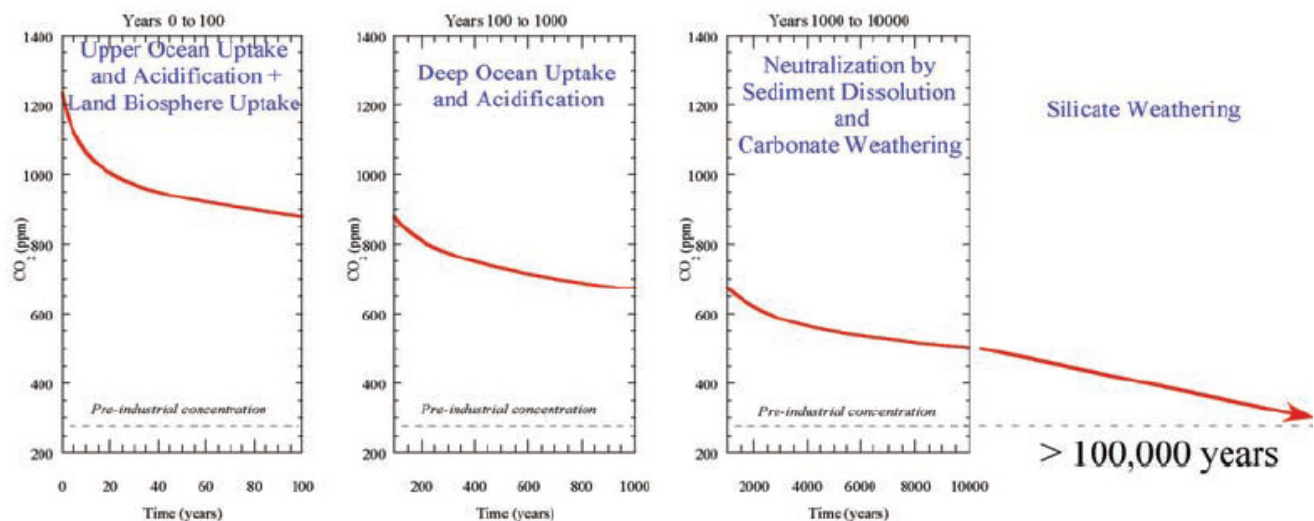
[W]hile approximately half of the carbon emitted is removed by the natural carbon cycle within a century, a substantial fraction of anthropogenic CO₂ will persist in the atmosphere for several millennia. (Matthews & Caldeira, GRL 2008, citing Archer, JGR 2005.)

About one-quarter of fossil fuel CO₂ emissions will stay in the air “forever”, i.e. more than 500 years.... Resulting climate changes would be ... irreversible. (Hansen et al., PTRS 2007.)

[C]limate change that takes place due to increases in carbon dioxide concentrations is largely irreversible for 1,000 years after emissions stop. (Solomon et al., PNAS 2009.)

[A] simplified way to view future warming persistence is that emissions of CO₂ and a handful of other extremely long-lived gases imply warming that is essentially irreversible on human timescales without geoengineering or active sequestration. (Solomon et al., PNAS 2010.)

Fig. 2. Time Scales for Removal of CO₂ from the Atmosphere



Model simulation of atmospheric CO₂ concentration for >100,000 years following a large CO₂ release from combustion of fossil fuels. Different fractions of the released gas recover on different timescales. (NAP 2011.)

While reducing CO₂ is essential for limiting warming, reducing SLCPs is essential for reducing warming in the next few decades; together, they provide the best chance to keep temperature below the 2C° guardrail. To slow current temperature increases and associated impacts, we need to complement cuts in CO₂ with fast action to reduce SLCPs. Reducing SLCPs will have fast effects, including cutting the rate of Arctic warming by two-thirds and the rate of global warming by up to half or more within decades. The [UNEP-WMO](#) (2011 & [2011](#)) assessment selected 16 priority control measures from over 2,000 possible measures to cut black carbon and ground-level ozone; [Shindell et al.](#) (2012) consolidated these into 14 measures (see below at page 7 for list):

*We identified 14 measures targeting methane and BC emissions that reduce projected global mean warming ~0.5°C by 2050 *** BC albedo and direct forcings are large in the Himalayas, where there is an especially pronounced response in the Karakoram, and in the Arctic, where the measures reduce projected warming over the next three decades by approximately two thirds.... (Shindell et al., SCI 2012.)*

When all [control] measures are fully implemented, warming during the 2030s relative to the present day is only half as much as if no measures had been implemented. *** This could reduce warming in the Arctic in the next 30 years by about two-thirds compared to the projections of the Assessment's reference scenario. ([UNEP-WMO](#) 2011.)

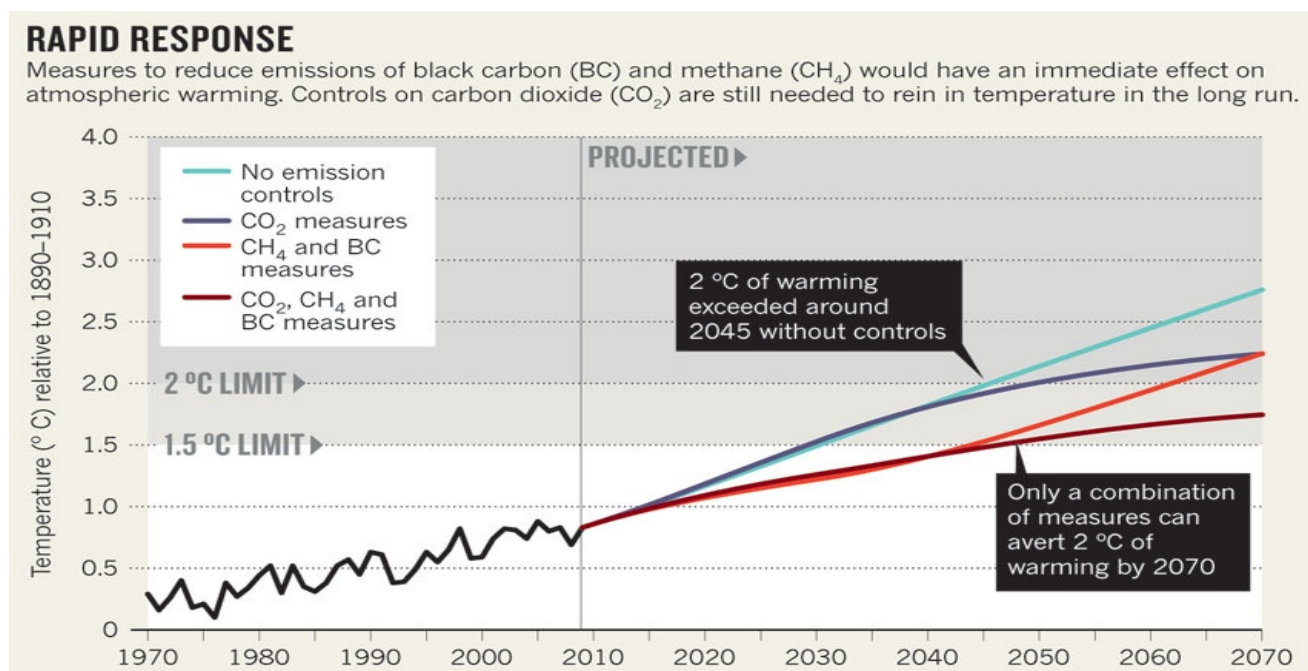
The combination of CO₂ mitigation and SLCP mitigation provides the greatest chance of keeping global temperatures below 1.5°C for the next 30 years and below 2°C through 2100, according to [Ramanathan & Xu](#) (PNAS 2010), as confirmed by [Shindell et al.](#) (SCI 2012) and [UNEP-WMO](#) (2011 & 2011):

The combination of CH₄ and BC measures along with substantial CO₂ emissions reductions [under a 450 parts per million (ppm) scenario] has a high probability of limiting global mean warming to <2°C during the next 60 years, something that neither set of emissions reductions achieves on its own.... ([Shindell et al.](#), SCI 2012.)

[T]he combination of CO₂, CH₄, and BC measures holds the temperature increase below 2°C until around 2070... [and] adoption of the Assessment's near-term measures (CH₄ + BC) along with the CO₂ reductions would provide a substantial chance of keeping the Earth's temperature increase below 1.5°C for the next 30 years. ([UNEP-WMO](#) 2011.)

These actions [to reduce emissions of SLCPs including HFCs, methane, black carbon, and ground-level ozone], even if we are restricted to available technologies ... can reduce the probability of exceeding the 2°C barrier before 2050 to less than 10% and before 2100 to less than 50% [when CO₂ concentrations are stabilized below 441 ppm during this century]. ([Ramanathan & Xu](#), PNAS 2010.)

Fig. 3. Temperature Rise Predictions Under Various Mitigation Scenarios



([Tollefson](#), NAT 2012, based on [Shindell et al.](#), SCI 2012, which in turn is based on [Ramanathan & Xu](#), Fig 1D, PNAS 2010.¹) (Note: HFC mitigation is not included in this graph, although it is included in [Ramanathan & Xu](#), Fig. 1D.)

¹ The science of SLCPs dates back to the 1970s. A major WMO-UNEP-NASA-NOAA report in 1985 concluded that non-CO₂ greenhouse gases in the atmosphere are adding to the greenhouse effect by an amount comparable to the effect of CO₂. ([Ramanathan et al.](#), 1985.) This finding has been confirmed and strengthened in the following decades by hundreds of studies culminating in IPCC reports ([IPCC](#) 1990; [IPCC](#) 1995; [IPCC](#) 2001; [IPCC](#) 2007). In short, we have had at least 25 years to carefully develop the science of SLCPs and assess the findings.

Many vulnerable regions are warming faster than the global average warming. Global warming is expressed as an average increase in surface temperature but is experienced unevenly in different regions, with some of the world's most vulnerable regions warming much faster than the global average:

The increase in annual average temperature since 1980 has been twice as high over the Arctic as it has been over the rest of the world. ([AMAP](#) 2011.)

The proximate cause of the changes now being felt on the [Tibetan] plateau is a rise in temperature of up to 0.3 °C a decade that has been going on for fifty years — approximately three times the global warming rate. ([Qiu](#), NAT 2008.)

In all four regions [of Africa] and in all seasons, the median temperature increase [between 1980 and 2009] lies between 3°C and 4°C, roughly 1.5 times the global mean response. ([IPCC](#) 2007.)

Warming in the Arctic could lead to dangerous climate feedbacks that cause warming to accelerate past tipping points. The term 'tipping element' on a basic level is a chain of events that escalate to a point where it is impossible to return to former conditions. Some examples include Arctic sea-ice melt, permafrost melt, and Himalayan glacial melt:

*The word tipping element suggests the existence of a self-amplification process at the heart of the tipping dynamics. *** A prominent example of such self-amplification is the ice-albedo feedback ... in the Arctic sea-ice region and on mountain glaciers such as the Alps and the Himalayas: An initial warming of snow- or ice-covered area induces regional melting. This uncovers darker ground, either brownish land or blue ocean, beneath the white snow- or ice-cover. Darker surfaces reflect less sunlight inducing increased regional warming, the effect self-amplifies. ([Levermann et al.](#), CC 2012.)*

A variety of tipping elements could reach their critical point within this century under anthropogenic climate change. The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet, and at least five other elements could surprise us by exhibiting a nearby tipping point. ([Lenton et al.](#), PNAS 2008.)

Permafrost—permanently frozen ground—underlies most of the Arctic land area and extends under parts of the Arctic Ocean. Temperatures in the permafrost have risen by up to 2°C over the past two to three decades.... The southern limit of the permafrost retreated northward by 30 to 80 km in Russia between 1970 and 2005, and by 130 km during the past 50 years in Quebec. ([AMAP](#) 2011.)

The thaw and release of carbon currently frozen in permafrost will increase atmospheric CO₂ concentrations and amplify surface warming to initiate a positive permafrost carbon feedback (PCF) on climate. ([Schaefer et al.](#), TELLUS B 2011.)

Reducing emissions of black carbon and tropospheric ozone and its precursor methane is critical for saving the Arctic and other vulnerable places in the short term. Black carbon is estimated to be responsible for 50% of the increase in Arctic warming, or almost 1°C of the total 1.9°C increase from 1890 to 2007. ([Jacobson](#), JGR 2010; [Shindell & Faluvegi](#), NG 2009.) Roughly 50% of the warming in the elevated Himalayan region has been attributed to the direct black carbon heating of the atmosphere and the surface. ([Ramanathan et al.](#), JGR 2007; [Flanner et al.](#), ACPD 2009; [Xu et al.](#), CB 2009; [Menon et al.](#), ACP 2010) Thus, reducing black carbon and other SLCPs is critical for slowing down the warming and glacier melting in the Arctic, the Himalayan-Tibetan region, and other vulnerable places ([Menon et al.](#), ACP 2010; [Ramanathan & Xu](#), PNAS 2010.):

BC albedo and direct forcings are large in the Himalayas, where there is an especially pronounced response in the Karakoram, and in the Arctic, where the measures reduce projected warming over the next three decades by approximately two thirds. ([Shindell et al.](#), SCI 2012.)

Controlling FS [fossil-fuel soot] and BSG [solid-biofuel soot and gases] may be a faster method of reducing Arctic ice loss and global warming than other options, including controlling CH₄ or CO₂, although all controls are needed. ([Jacobson](#), JGR 2010.)

Mitigating SLCPs is more effective if done sooner rather than later due to the thermal inertia of the deep oceans:

[M]ultiple centuries are required to warm or cool the deep ocean.... Maintaining a forcing for a longer period of time transfers more heat to the deep ... ocean, with a correspondingly longer timescale for release of energy if emissions were to be halted.... [T]he slow timescales of the ocean imply that actions to mitigate the climate impacts of these warming agents [SLCPs] would be most effective if undertaken sooner; conversely such actions would become less effective the longer the radiative forcing is maintained. ([Solomon et al.](#), PNAS 2010.)

Reducing the current rate of warming and returning to a safe climate requires fast-action mitigation for both CO₂ and SLCPs, along with deliberate CO₂ removal from the atmosphere on a timescale of decades, starting with bio-sequestration, including biochar:

We define “fast-action” to include regulatory measures that can begin within 2–3 years, be substantially implemented in 5–10 years, and produce a climate response within decades. We discuss strategies for short-lived non-CO₂ GHGs and particles, where existing agreements can be used to accomplish mitigation objectives. Policy makers can amend the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs) with high global warming potential. Other fast-action strategies can reduce emissions of black carbon particles and precursor gases that lead to ozone formation in the lower atmosphere, and increase biosequestration, including through biochar. These and other fast-action strategies may reduce the risk of abrupt climate change in the next few decades by complementing cuts in CO₂ emissions. ([Molina et al.](#), PNAS 2009.)

Fast-action strategy 1 is to strengthen climate protection under the Montreal Protocol stratospheric ozone treaty by phasing down high GWP HFCs. The Montreal Protocol has successfully phased out 97% of nearly 100 ozone-depleting and climate-warming chemicals. This has provided mitigation of up to 222 billion tonnes of CO₂-eq. and delayed warming by up to 12 years worth of CO₂ emissions. The 197 Parties to the treaty are now phasing out ozone-depleting and climate-damaging HCFCs. Unfortunately, high-GWP HFCs are growing 10 to 15% per year as they are used as substitutes in an increasing number of applications. In 2005, the US emitted 34% of global HFC emissions and the EU 15%. ([CAIT](#) 2012.) A coalition of 650 companies in the Consumer Goods Forum has pledged to avoid HFCs beginning in 2015. ([CGF](#) 2012.) Phasing down production and use of high GWP HFCs would substantially reduce one of the six Kyoto gases and achieve mitigation of over 100 billion tonnes of CO₂-eq. by 2050 through a treaty that has always succeeded, and at a cost that could be pennies of public funding per tonne of CO₂-eq. Historically, such transitions under the Montreal Protocol also have significantly improved the energy efficiency of the refrigerators, air conditioners, and other products and equipment using refrigerants. Unless HFCs with high GWP are phased down, the climate mitigation already achieved by the Montreal Protocol will be cancelled. ([Velders et al.](#), SCI 2012; [UNEP](#) 2011.):

Total avoided net annual ODS emissions [under the Montreal Protocol] are estimated to be equivalent to about 10 Gt CO₂/year in 2010, which is about five times the annual reduction target of the Kyoto Protocol for 2008–2012. This climate benefit of the Montreal Protocol may be reduced or lost

*completely in the future if emissions of ODS substitutes with high GWPs, such as long-lived HFCs, continue to increase. ****

The atmospheric abundances of major HFCs used as ODS substitutes are increasing 10 to 15% per year in recent years.... In an upper-range scenario, global radiative forcing from HFCs increases from about 0.012 W/m² in 2010 to 0.25 to 0.40 W/m² in 2050. This corresponds to 14 to 27% of the increase in CO₂ forcing under the range of Intergovernmental Panel on Climate Change (IPCC) business-as-usual scenarios from 2010 to 2050.... If the current mix of HFCs with an average lifetime of 15 years (average GWP of 1600) were replaced by HFCs with life-times less than 1 month (GWP less than ~20), the total HFC radiative-forcing contribution in 2050, even under the high-emission scenario, would be less than the current forcing from HFCs (see the graph). Such choices are currently available. ([Velders et al.](#), SCI 2012.)

Substitutes for HFCs already exist for many uses and others are expected soon:

Approaches to reduce climate forcing from future HFC use and to preserve climate benefits provided by the Montreal Protocol include....: (i) replacing high-GWP HFCs with substances that have low impact on climate (e.g., hydrocarbons, CO₂ or certain HFCs) and alternative technologies (e.g., fiber insulation materials) and (ii) reducing HFC emissions (e.g., by changing the design of equipment and capturing and destroying HFCs when equipment reaches the end of its useful life).... Low-climate-impact substitutes are already in commercial use in several sectors. ([Velders et al.](#), SCI 2012.)

Technology is available to leapfrog high-GWP HFCs in some applications, which would avoid a second transition out of HFCs and complications of an increasingly large inventory of HFC equipment requiring servicing with HFCs that may be expensive or not easily available. ([TEAP](#) 2010.)

Vulnerable island States have proposed phasing down production and use of high-GWP HFCs under the Montreal Protocol, leaving control of emissions of HFCs in the Kyoto Protocol. ([UNEP](#) 2012.) The US, Mexico, and Canada made a similar proposal ([UNEP](#) 2012), and 108 Parties have expressed support ([Montreal Protocol](#) 2010 & [2011](#)):

The FSM's 2012 Proposed Amendment will strengthen climate protection under the Montreal Protocol by phasing down the production and consumption of HFCs, a group of super-greenhouse gases. Phasing down HFCs is essential to fulfilling obligations under the Vienna Convention to limit the adverse environmental effects, including effects on the climate system, of actions taken to protect the ozone layer. The resulting benefit will be up to 100 billion tonnes of CO₂-eq. mitigation by 2050 under a treaty that has successfully phased out nearly 100 other chemicals. ([UNEP](#) 2012.)

Cumulative benefits of the HFC phasedown estimated by the U.S. Government amount to reductions of 2,200 million metric tons of carbon dioxide equivalent (MMT CO₂eq) through 2020, and about 85,000 MMTCO₂eq through 2050.... Cumulative benefits from HFC-23 byproduct emissions controls as estimated by the U.S. Government amount to an additional 11,300 MMTCO₂eq through 2050.... The proposal leaves unchanged the provisions of the UNFCCC/Kyoto Protocol that govern HFC emissions. Parties could follow Montreal Protocol obligations to meet certain UNFCCC obligations ([UNEP](#) 2012.)

[Bali] Declaration on the global transition away from hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs).... [The 108 Party signatories] Encourage all Parties to promote policies and measures aimed at selecting low-GWP alternatives to HCFCs and other ozone-depleting substances;... Declare our intent to pursue further action under the Montreal Protocol aimed at transitioning the world to environmentally sound alternatives to HCFCs and CFCs. ([Montreal Protocol](#) 2010 & [2011](#).)

Fast-action strategy 2 is to cut black carbon, tropospheric ozone and its precursor, methane—local air pollutants that harm public health, crops, ecosystems, and carbon sinks, and that also cause climate change. Unlike CO₂, black carbon, tropospheric ozone and its precursor, methane, disappear quickly from the atmosphere once emissions are cut. Reducing these local air pollutants can cut the rate of global warming by up to half and the rate of Arctic warming by up to two-thirds over the next thirty years. In addition to producing fast climate results, cutting these local air pollutants also delivers strong collateral benefits for public health, food security, and ecosystems, including carbon sinks, providing independent justification for fast action. These benefits, including much of the climate mitigation benefits, are enjoyed by the regions making the cuts. For example, eliminating emissions of black carbon from traditional solid biomass stoves with improved cook stoves would have a major impact in reducing black carbon direct climate effects over South Asia (by about 60%) ([Ramanathan & Carmichael](#), NG 2008.):

Reducing black carbon, methane and tropospheric ozone now will slow the rate of climate change within the first half of this century.... A small number of emission reduction measures targeting black carbon and ozone precursors could immediately begin to protect climate, public health, water and food security, and ecosystems. (UNEP-WMO 2011.)

These measures can accomplish about 38 per cent reduction of global methane emissions and around 77 per cent of black carbon emissions, if implemented between now and 2030, relative to a 2030 ‘reference’ emission scenario. (UNEP 2011.)

This small number of mitigation measures is capable of realizing “nearly 90% of the maximum reduction in net GWP.” ([Shindell et al.](#), SCI 2012.) They include the following 14 measures:

Methane Control Measures

- Control fugitive emissions from oil and gas production
- Control emissions from coal mining
- Control fugitive emissions from long distance gas transmission
- Capture gas from municipal waste and landfills
- Capture gas from wastewater treatment facilities
- Capture gas from livestock manure
- Intermittent aeration of constantly flooded rice paddies

Black Carbon Control Measures

- Install particulate filters on diesel vehicles
- Replace traditional cooking stoves with clean burning biomass stoves
- Modernize brick kilns
- Modernize coke ovens
- Ban open burning of biomass
- Eliminate high emitting on and off-road diesel vehicles
- Provide global access to modern cooking and heating

([Shindell et al.](#), SCI 2012.)

Full implementation of the identified measures [by 2030] would reduce future global warming by 0.5°C (within a range of 0.2–0.7°C)... by 2050.... Full implementation of the identified measures... could reduce warming in the Arctic in the next 30 years by about two-thirds compared to the projections of the Assessment’s reference scenario, [in addition to providing substantial benefits in] the Himalayas and other glaciated and snow-covered regions. (UNEP-WMO 2011.)

In addition to climate benefits, reducing SLCs provides strong collateral benefits for public health and food security.

We estimate that, for PM_{2.5} [black carbon] and ozone respectively, fully implementing these [14] measures could reduce global population-weighted average surface concentrations by 23-34% and 7-

17% and avoid 0.6-4.4 and 0.04-0.52 million annual premature deaths globally in 2030. Over 80% of the health benefits are estimated to occur in Asia.... Based on our estimates, avoided deaths would represent 1-8% of cardiopulmonary and lung cancer deaths among those age 30 years and older, and 1-7% of all deaths for all ages, assuming constant baseline mortality rates. ([Anenberg et al.](#), EHP 2012.)

This strategy avoids 0.7 to 4.7 million annual premature deaths from outdoor air pollution and increases annual crop yields by 30 to 135 million metric tons due to ozone reductions in 2030 and beyond. ([Shindell et al.](#), SCI 2012.)

Full implementation of the identified measures could avoid ... the loss of 52 million tonnes (within a range of 30–140 million tonnes), 1–4 per cent, of the global production of maize, rice, soybean and wheat each year. ([UNEP-WMO](#) 2011.)

Air pollution is set to become the world's top environmental cause of premature mortality, overtaking dirty water and lack of sanitation. Air pollution concentrations in some cities, particularly in Asia, already far exceed World Health Organization safe levels, and they are projected to deteriorate further to 2050.... The number of premature deaths from exposure to particulate matter ... is projected to more than double worldwide, from just over 1 million today to nearly 3.6 million per year in 2050, with most deaths occurring in China and India.... The absolute number of premature deaths from exposure to ground-level ozone is to more than double worldwide (from 385 000 to nearly 800 000) between 2010 and 2050. Most of these deaths are expected to occur in Asia, where the ground-level ozone concentrations as well as the size of the exposed population are likely to be highest. ([OECD](#) 2012.)

Most of the control measures for reducing black carbon and tropospheric ozone and its precursor, methane, can be implemented today with existing technologies and often with existing laws and institutions.

BC can be reduced by approximately 50% with full application of existing technologies by 2030.... Strategies to reduce BC could borrow existing management and institutions at the international and regional levels, including existing treaty systems regulating shipping and regional air quality. ([Molina et al.](#), PNAS 2009.)

National efforts to reduce SLCFs can build upon existing institutions, policy and regulatory frameworks related to air quality management, and, where applicable, climate change. *** Regional air pollution agreements, organizations and initiatives may be effective mechanisms to build awareness, promote the implementation of SLCF mitigation measures, share good practices and enhance capacity. *** Global actions can help enable and encourage national and regional initiatives and support the widespread implementation of SLCF measures. A coordinated approach to combating SLCFs can build on existing institutional arrangements, ensure adequate financial support, enhance capacity and provide technical assistance at the national level. ([UNEP](#) 2011.)

Many other policy alternatives exist to implement the CH₄ [methane] and BC measures, including enhancement of current air quality regulations. ([Shindell et al.](#), SCI 2012.)

Regulatory policies and forums exist to reduce non-CO₂ warming agents. The Montreal Protocol with modifications for HFC regulations can be an effective tool for reducing watts attributable to HFCs. National policies exist to limit CO and other ozone-producing gases. ([Ramanathan & Xu](#), PNAS 2010.)

These measurements ... provide a direct link between regulatory control policies and the long-term impact of anthropogenic emissions. Our model calculation indicates that the decrease in BC in California has lead to a cooling of 1.4Wm⁻² (±60%). The regulation of diesel fuel emissions in

California therefore has proven to be a viable control strategy for climate change in addition to mitigating adverse human health effects. ([Bahadur et al.](#), AE 2011.)

Half of the identified measures can be implemented with a net cost savings to those making the investment, and all are ultimately cost-effective when the \$5.9 trillion annual benefits that start in 2030 are taken into account:

About 50 per cent of both methane and black carbon emission reductions can be achieved through measures that result in net cost savings (as a global average) over their technical lifetime. The savings occur when initial investments are offset by subsequent cost savings from, for example, reduced fuel use or utilization of recovered methane. A further third of the total methane emission reduction could be addressed at relatively moderate costs. ([UNEP](#) 2011.)

*Benefits of methane emissions reductions are valued at \$700 to \$5000 per metric ton, which is well above typical marginal abatement costs (less than \$250). *** ... [T]he bulk of the BC measures could probably be implemented with costs substantially less than the benefits given the large valuation of the health impacts. ([Shindell et al.](#), SCI 2012.)*

Fast-action strategy 3 is to deliberately remove excess CO₂ from the atmosphere on a timescale of decades rather than millennia in order to return to a safe and stable climate. Reducing CO₂ concentrations to a level consistent with a safe and stable climate requires that sinks ultimately exceed sources. Strategies for enhancing sinks include protecting and expanding forests, wetlands, grasslands, and other sources of biomass that are removing CO₂ from the atmosphere, as well as pyrolysis of waste biomass (cooking with limited oxygen) to produce a permanent form of carbon called biochar that can safely return carbon to permanent storage for hundreds to thousands of years. Bio-sequestration of CO₂, including biochar, can match and ultimately exceed CO₂ emissions to achieve a net drawdown of CO₂ on a timescale of decades rather than the millennia timescale of the natural cycle, assuming aggressive CO₂ mitigation as well:

A combined approach of deliberate CO₂ removal (CDR) from the atmosphere alongside reducing CO₂ emissions is the best way to minimize the future rise in atmospheric CO₂ concentration, and the only timely way to bring the atmospheric CO₂ concentration back down if it overshoots safe levels.... By mid-century, the CDR flux together with natural sinks could match current total CO₂ emissions, thus stabilizing atmospheric CO₂ concentrations. By the end of the century, CDR could exceed CO₂ emissions, thus lowering atmospheric CO₂ concentration and global temperature. ([Lenton](#), CM 2010.)

In the most optimistic scenarios, air capture and storage by BECS [bioenergy and carbon sequestration], combined with afforestation and bio-char production appears to have the potential to remove ≈100 ppm of CO₂ from the atmosphere...on the 2050 timescale. ([Lenton & Vaughan](#), ACP 2009.)

Strong mitigation, i.e. large reductions in CO₂ emissions, combined with global-scale air capture and storage, afforestation, and bio-char production, i.e. enhanced CO₂ sinks, might be able to bring CO₂ back to its pre-industrial level by 2100, thus removing the need for other geoengineering. ([Lenton & Vaughan](#), ACP 2009.)

Other CO₂ removal strategies include direct air capture and capture at smokestacks. The CO₂ captured from smokestacks then requires permanent storage, or re-utilization, for example as calcium carbonate, which can be used as a substitute for a portion of ordinary Portland cement or of aggregate:

While about half of the anthropogenic CO₂ emissions are the result of large industrial sources such as power plants and cement factories, the other half originate from small distributed sources such as

cars, home heating, and cooking. For those, CO₂ capture at the emission source is not practical and/or economical. A possible pathway to deal with these emissions is to capture CO₂ directly from the air. One of the advantages of CO₂ capture from the atmosphere is that the needed infrastructure can be placed anywhere, preferably where it has the least impact on the environment and human activities or close to CO₂ recycling centers. ([Goeppert et al.](#), JACS 2011.)

DAC [Direct Air Capture] is one of a small number of strategies that might allow the world someday to lower the atmospheric concentration of CO₂. ([APS](#) 2011.)

Calera ... can capture up to 90% of CO₂ from power plants...and can convert the CO₂ into stable calcareous material and bicarbonate solution with an energy penalty ranging from about 10% to 40%.... The ... calcareous material ... [can] replace a portion of either the product called “Ordinary Portland Cement” (OPC) or to replace or reduce OPC ingredients in blended cement, and thus potentially avoiding CO₂ emissions from cement manufacture... In some cases, the combined reductions in greenhouse gas emissions from power plant CCS and avoided cement production are potentially greater than the total emissions of either process alone.... ([Zaelke et al.](#), 2011.)

Conclusion. All of these strategies are necessary to reduce current climate impacts, to slow dangerous feedbacks, and to reduce the risk of passing tipping points that could lead to irreversible climate impacts. Reducing CO₂ remains the top priority, but we also need to simultaneously reduce SLCPs for near-term benefits that will keep us from losing the climate battle while serious CO₂ mitigation is being achieved. We also need to perfect and implement strategies to deliberately reduce excess CO₂ from the atmosphere on a time scale of decades. The take-away message from the science and the growing impacts is *the need for speed* and the importance of fast-action mitigation to address all causes of climate change.

Appendix 1: The Climate & Clean Air Coalition to Reduce Short-Lived Climate Pollutants

19 May 2012. The Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants ([CCAC](#)), launched on 17 February 2012, held its inaugural Ministerial Meeting in Stockholm on 24 April and agreed on five new initiatives aimed at accelerating and scaling-up action against SLCP.

The Coalition has 18 members from both developing and developed countries including: the US, Canada, Mexico, Ghana, Japan, Bangladesh, Sweden, Norway, Nigeria, Colombia, the World Bank, the European Commission, and UNEP. The G8 agreed to join 19 May 2012, adding Russia, Italy, France, the UK, and Germany.

The CCAC Secretariat is hosted by UNEP's Paris office, and will manage a dedicated Trust Fund with an initial contribution of \$16.7 million from the U.S., Canada, Sweden, and Norway. The World Bank has also announced that it has \$12 billion in its portfolio contributing to the CCAC's goals.

The CCAC is the first-ever global effort specifically dedicated to reducing emissions of SLCPs as a collective challenge. The targeted climate pollutants include black carbon (soot), ground-level ozone and its precursor methane, and hydrofluorocarbons (HFCs), used as refrigerants and to make insulating foams. The CCAC goals are:

- Raising awareness of short lived climate pollutant impacts and mitigation strategies;
- Enhancing and developing new national and regional actions, including by identifying and overcoming barriers, enhancing capacity, and mobilizing support;
- Promoting best practices and showcasing successful efforts; and
- Improving scientific understanding of short-lived climate pollutants impacts and mitigation strategies.

Five initiatives were approved during the April 24 Ministerial meeting in Stockholm:

- Fast action on diesel emissions including from heavy-duty vehicles and engines, through the freight supply chain, city action plans, and lower sulfur fuels.
- Upgrading old inefficient brick kilns, including the 20,000 small and medium sized one in Mexico, and the 6,000 in Bangladesh.
- Accelerating the reduction of methane emissions from landfills, by improving municipal solid waste planning.
- Speeding up cuts in methane and other emissions from the oil and gas industry, by stopping venting and flaring.
- Accelerating alternatives to HFCs, by fast-tracking environmentally safe alternatives.

The CCAC Coalition will be developing additional proposals, starting with one by Ghana on open burning and by one by Bangladesh on cookstoves.

Three leading SLCP scientists will advise on the formation of a Science Advisory Panel: Drew Shindell of NASA's Goddard Institute for Space Studies, Mario Molina, the distinguished Mexican chemist and 1995 Nobel Prize co-winner, and Veerabhadran Ramanathan, chair of the UNEP Atmospheric Brown Cloud project and Distinguished Professor of Atmospheric and Climate Sciences at the Scripps Institution of Oceanography, University of California San Diego.

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G8 Camp David Declaration (Camp David, USA, 19 May 2012)

14. Recognizing the impact of short-lived climate pollutants on near-term climate change, agricultural productivity, and human health, we support, as a means of promoting increased ambition and complementary to other CO2 and GHG emission reduction efforts, comprehensive actions to reduce these pollutants, which, according to UNEP and others, account for over thirty percent of near-term global warming as well as 2 million premature deaths a year. Therefore, we agree to join the Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants.

Fact Sheet: G-8 Action on Energy and Climate Change (Camp David, USA, 19 May 2012):

Address Climate Change, Including By Reducing Short-Lived Climate Pollutants

- *In the spirit of increasing mitigation efforts, we agree to collectively join the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, launched on February 16, 2012. This new initiative will enhance our collective ambition in addressing climate change by complementing efforts to address CO2 emissions. By developing strategies to reduce short term pollutants – chiefly methane, black carbon, and hydrofluorocarbons – we can help reduce global warming, improve health, and increase agricultural productivity, as well as energy security.*
- *Commission the World Bank to prepare a report on ways to integrate reduction of near-term climate pollution into their activities and ask the World Bank to bring together experts from interested countries to evaluate new approaches to financing projects to reduce methane, including through pay-for-performance mechanisms.*

In its role as 2012 Chair of the G-8, the United States intends to work with G-8 partners to develop mechanisms for following up these actions over the course of 2012.

UNEP Press Release, New Climate and Clean Air Coalition Expands to 13 Members (Stockholm, Sweden, 24 April 2012):

Further momentum was catalyzed with the announcements of Colombia, Japan, Nigeria, Norway and the European Commission that they are joining the Coalition along with the World Bank.

It brings to 13 the number of partners who have joined, expanding the initial membership founded by Bangladesh, Canada, Ghana, Mexico, Sweden and the United States and the UN Environment Programme (UNEP)....

Delegates took forward five to be approved for rapid implementation by Ministers on the final day.

Outcome Document, Stockholm +40 – Partnership Forum for Sustainable Development (Stockholm, Sweden):

13. Showing by example is a powerful tool for achieving sustainable development. The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants is a valuable example where a number of actors have decided on joint actions to raise awareness, develop measures and improve the scientific understanding of short-lived climate pollutants.

Press Release, European Commission joins Climate and Clean Air Coalition (25 April 2012):

Connie Hedegaard, European Commissioner for Climate Action, said: "The European Commission is very pleased to join this Coalition. This initiative should complement the efforts needed under the UN climate change convention to cut global greenhouse gas emissions to a level that will limit global

temperature increase to below 2°C. The Commission is willing to consider further support to concrete projects in developing countries to reduce emissions from short-lived climate pollutants."

Press Release, World Bank Joins Climate and Clean Air Coalition (24 April 2012):

The Climate and Clean Air Coalition puts a practical new deal on the table – one that helps slow global warming while reducing the soot and smog that is damaging food crops and health worldwide, undermining growth and development, said Rachel Kyte, Vice President for Sustainable Development, The World Bank.

Remarks by Secretary of State Hilary Rodham Clinton at the launch of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (Washington, DC, 16 Feb. 2012):

It's a very big honor for me to have you here for the purpose of launching the Climate and Clean Air Coalition, our new global effort to fight climate change, protect health, improve agricultural productivity, and strengthen energy security....

By focusing on these pollutants [HFCs, black carbon, methane, and tropospheric ozone] – how to reduce them and, where possible, use them for energy – we can have local and regional effects that people can see and feel. They can see those effects and become convinced that this commitment is one we all must all undertake....

This coalition – the first international effort of its kind – will conduct a targeted, practical, and highly energetic global campaign to spread solutions to the short-lived pollutants worldwide. It will mobilize resources, assemble political support, help countries develop and implement a national action plan, raise public awareness, and reach out to other countries, companies, NGOs and foundations. ([Clinton](#), 2012.)

Press Release, Remarks by UNEP Executive Director Achim Steiner on Reducing Short-Lived Climate Pollutants (Nairobi, Kenya):

Fast action on short lived climate forcers can deliver quick wins in a world often frustrated by the glacial pace at which sustainability challenges appear to be being addressed.

Selected Press on the Climate and Clean Air Coalition

1. *Forbes*, "[G8 Takes On Short-Lived Climate Pollutants](#)" (30 May 2012)
2. *The Telegraph*, "[G8: Leaders open up vital new front in the battle to control global warming](#)" (21 May 2012)
3. *Ghana Business News*, "[New Climate and Clean Air Coalition expands to 13 members](#)" (30 April, 2012)
4. *Green Conduct News*, "[The Climate And Clean Air Coalition To Reduce Short-Term Climate Pollutants](#)" (26 April, 2012)
5. *U-T San Diego*, Op-Ed by V. Ramanathan & D. Zaelke, "[Earth Day: Saving out planet, saving ourselves](#)" (21 April 2012)
6. *Washington Post*, Editorial, "[Ways to fight warming: Strategies that would reduce emissions](#)" (26 February 2012)
7. *The New York Times*, Editorial, "[A Second Front in the Climate War](#)" (17 February 2012)
8. *Nature*, "[Coalition launches effort on 'short-lived' climate pollutants](#)" (16 February 2012)
9. *The New York Times*, "[U.S. Pushes to Cut Emissions of Some Pollutants That Hasten Climate Change](#)" (15 February 2012)
10. *Washington Post*, "[U.S. will lead new effort to cut global warming from methane, soot](#)" (15 February 2012)
11. *The Hill*, Op-Ed by M. Molina & D. Zaelke, "[How to cut climate change in half](#)" (14 February 2012)

Appendix 2: Statements of support for reducing SLCPs from key international, regional, and bilateral policy meetings

2012 G8 Camp David Declaration (Camp David, USA):

14. Recognizing the impact of short-lived climate pollutants on near-term climate change, agricultural productivity, and human health, we support, as a means of promoting increased ambition and complementary to other CO₂ and GHG emission reduction efforts, comprehensive actions to reduce these pollutants, which, according to UNEP and others, account for over thirty percent of near-term global warming as well as 2 million premature deaths a year. Therefore, we agree to join the Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants.

Fact Sheet: G-8 Action on Energy and Climate Change. (Camp David, USA, 19 May 2012):

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- *In the spirit of increasing mitigation efforts, we agree to collectively join the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, launched on February 16, 2012. This new initiative will enhance our collective ambition in addressing climate change by complementing efforts to address CO₂ emissions. By developing strategies to reduce short term pollutants – chiefly methane, black carbon, and hydrofluorocarbons – we can help reduce global warming, improve health, and increase agricultural productivity, as well as energy security.*
- *Commission the World Bank to prepare a report on ways to integrate reduction of near-term climate pollution into their activities and ask the World Bank to bring together experts from interested countries to evaluate new approaches to financing projects to reduce methane, including through pay-for-performance mechanisms.*

In its role as 2012 Chair of the G-8, the United States intends to work with G-8 partners to develop mechanisms for following up these actions over the course of 2012.

2012 Joint Statement by the Danish EU Presidency and Commissioner Potocnik welcoming new international agreement to tackle air pollution (Brussels, Belgium):

Today the EU reached an international agreement to ... [amend] the Gothenburg Protocol [to the Convention on Long-range Transboundary Air Pollution], setting more ambitious targets to reduce trans-boundary air pollution. The revised objectives of the Protocol will see a reduction in EU emissions of around 60% for sulphur, 40% for nitrogen oxides (NO_x), 30% for volatile organic compounds (VOCs), 6% for ammonia and 20% for particulate matter compared to 2005 levels. There's also agreement to act on so called 'Black Carbon', a pollutant with short-lived climate forcing characteristics.

"This is a significant step forward in protecting citizens' health and the environment. For the first time, we have an international agreement that acknowledges the link between air pollution and climate change. By agreeing to regulate one of the contributors to climate change, 'Black Carbon', we will see positive impacts at both local and international level", said Janez Potočnik, European Commissioner for the Environment.

The draft amendment approved by the Convention's Executive Body is [here](#).

2012 Joint Statement by North American Leaders (Washington DC, USA):

We also intend to deepen our trilateral cooperation and work with other interested partners to accelerate efforts aimed at reducing emissions of "short-lived climate pollutants," noting the recently

launched Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants in which we are all actively engaged. Reducing our emissions of these substances, which include methane, black carbon, and many hydrofluorocarbons (HFCs), offers significant opportunities to reduce the rate of global warming in the near term, in the context of our broader efforts to address climate change, while also yielding many health, agricultural productivity, and energy security benefits.

2012 [IGBP & IGAC Statement](#), Time to Act: The Opportunity to Simultaneously Mitigate Air Pollution and Climate Change (London, UK):

An integrated approach to addressing air pollution and climate change is essential if society desires to slow the rate of climate change and to protect human health, food/water security and ecosystems. ...

Control of air pollutants and their precursors that lead to warming (such as black carbon, methane and tropospheric ozone) would be a highly effective way to reduce the rate of climate change in the near-term, but would only be effective in the long-term if continued action to reduce long-lived greenhouse gases, notably carbon dioxide (CO₂), are taken in parallel.

2012 [Svalbard Declaration](#) on Shortlived Climate Forcers (Svalbard, Norway):

*We, the environment ministers of Denmark, Finland, the Faroe Islands, Iceland, Norway, Sweden and Åland, discussed what we can do to cut global and Nordic emissions of short-lived climate forcers, such as black carbon and methane ****

Based on our close co-operation and shared values, we, the Nordic environment ministers, will intensify our efforts to reduce emissions of SLCFs at national, regional and global level.

We will act as a driving force and work more closely together in international fora to advocate more ambitious international regulation of emissions of greenhouse gases and SLCFs.

2011 [Fact Sheet](#): The United States and Norway - NATO Allies and Global Partners (Washington DC, USA):

*President Obama hosted Norwegian Prime Minister Jens Stoltenberg for a meeting in the Oval Office on October 20... The leaders renewed their commitments in the following areas: ****

***The Arctic:** In the Arctic Council, the United States and Norway co-chair a task force examining the role of certain greenhouse gases (such as methane and hydrofluorocarbons) and aerosols (such as black carbon), known collectively as "short-lived climate forcers," in causing global climate change...*

2011 [Co-Chairs' Summary](#), Ministerial Meeting on Short-Lived Climate Forcers Near Term Climate and Air Quality Benefits (Mexico City, Mexico):

Because SLCFs are a large fraction of current warming they present an enormous near term mitigation opportunity.... Strong support was expressed during the meeting for a strengthened concerted approach that would support national and regional measures in the form of an action oriented initiative at global level. It was further stressed that any future initiative would need to consider existing work in the field, and it was particularly stressed that action on SLCF should be complimentary to efforts under the UNFCCC, particularly long term CO₂ mitigation. Participants noted the importance of including the private sector and civil society. Given the need to address SLCF, participants agreed to develop an inclusive and voluntary global initiative to increase the political awareness and support future cooperation for action on SLCF.

2011 [Chair's Summary](#), Eleventh Leaders' Representative Meeting of the Major Economies Forum (Washington DC, USA):

[T]he Major Economies Forum should recall its dual-mandate of helping to advance the negotiations, and to facilitate concrete action to cut emissions among this group – such as the cooperation on clean technology that led to the Clean Energy Ministerial – and noted recent interest in short-lived climate forcers.

2011 [European Parliament Resolution](#) on Financing of Reinforcement of Dam Infrastructure in Developing Countries (Strasbourg, France):

30. Urges the EU to widely implement and promote emission reduction measures targeting black carbon, such as the recovery of methane from coal, oil and gas extraction and transport, methane capture in waste management and the use of clean-burning stoves for residential cooking, which will contribute to combating climate change and to reducing glacial retreat;

2011 [European Parliament Resolution](#) on a Comprehensive Approach to Non-CO₂ Climate-Relevant Anthropogenic Emissions (Strasbourg, France):

2. Calls for a comprehensive European climate policy, which can benefit from considering all sources of warming and all mitigation options; stresses that in addition to considering CO₂ emission reductions, it should place emphasis on strategies that can produce the fastest climate response;

3. Notes that fast-action regulatory strategies are available to phase down production and consumption of HFCs and to reduce emissions of black carbon and the gases leading to the formation of tropospheric ozone, and that these can begin within 2–3 years and be substantially implemented within 5–10 years, producing the desired climate response within decades or sooner, in particular for some HFCs at a public price as low as 5 to 10 cents per tonne, whereas the carbon price is currently over EUR 13 per tonne;...

2011 [Pontifical Academy of Sciences Working Group Report](#), Fate of Mountain Glaciers in the Anthropocene (Rome, Italy):

Possible mitigation by reducing the emission of non-CO₂ short-lived drivers: The second part of an integrated mitigation strategy is to cut the climate forcers that have short atmospheric lifetimes. These include black carbon soot, tropospheric ozone and its precursor methane, and hydrofluorocarbons (HFCs). Black carbon (BC) and tropospheric ozone strongly impact regional as well as global warming. Cutting the short-lived climate forcers using existing technologies can reduce the rate of global warming significantly by the latter half of this century, and the rate of Arctic warming by two-thirds, provided CO₂ is also cut.

2011 [Nuuk Declaration](#), Seventh Ministerial Meeting of the Arctic Council (Nuuk, Greenland):

Welcome the Arctic Council reports on Short-Lived Climate Forcers (SLCF), that have significantly enhanced understanding of black carbon, encourage Arctic states to implement, as appropriate in their national circumstances, relevant recommendations for reducing emissions of black carbon, and request the Task Force and the AMAP expert group to continue their work by focusing on methane and tropospheric ozone, as well as further black carbon work where necessary and provide a report to the next Ministerial meeting in 2013, ...

Decide to establish a Short-Lived Climate Forcer Contaminants project steering group that will undertake circumpolar demonstration projects to reduce black carbon and other SLCF emissions....

2011 [Joint Statement](#), Conclusion of the Sixth basic Ministerial meeting on Climate Change (New Delhi, India):

HFC gases are not ozone depleting substances but some of these have high global warming potential. The Ministers felt that the issue of phase down of HFCs with high global warming potential required in-depth examination.

2009 [G8 Declaration](#), Responsible Leadership for a Sustainable Future (L'Aquila, Italy):

66. We recognize that the accelerated phase-out of HCFCs mandated under the Montreal Protocol is leading to a rapid increase in the use of HFCs, many of which are very potent GHGs. Therefore we will work with our partners to ensure that HFC emissions reductions are achieved under the appropriate framework. We are also committed to taking rapid action to address other significant climate forcing agents, such as black carbon. These efforts, however, must not draw away attention from ambitious and urgent cuts in emissions from other, more long-lasting, greenhouse gases, which should remain the priority.

2009 [Tromsø Declaration](#), Sixth Ministerial Meeting of The Arctic Council (Tromsø, Norway):

Urge implementation of early actions where possible on methane and other short-lived climate forcers, and encourage collaboration with the Methane to Markets Partnership and other relevant international bodies taking action to reduce methane and other short-lived forcers,

Decide to establish a task force on short-lived climate forcers to identify existing and new measures to reduce emissions of these forcers and recommend further immediate actions that can be taken and to report on progress at the next Ministerial meeting,

2009 [Remarks by United States Secretary of State Hillary Clinton](#), Joint Session of the Antarctic Treaty Consultative Meeting and the Arctic Council, 50th Anniversary of the Antarctic Treaty (Baltimore, USA):

There are also steps we must take to protect the environment. For example, we know that short-lived carbon forcers like methane, black carbon, and tropospheric ozone contributes significantly to the warming of the Arctic. And because they are short lived, they also give us an opportunity to make rapid progress if we work to limit them.

2009 [Co-chairs' Concluding Statement](#) at the High-Level India-EU Dialogue (Delhi, India):

3. We urge the governments of Europe and India to: . . . b) Recognise Black Carbon as a significant climate driver and develop a joint programme to:

- build international support for mitigation of the threat of Black Carbon to the glaciers of the Hindu Kush-Himalaya-Tibet area;*
- support a major clean cook stove initiative, including Project Surya and the application of pyrolysis and biochar.*

2008 [Declaration of Leaders](#), Meeting of the Major Economies on Energy Security and Climate Change (Toyako, Japan):

10. To enable the full, effective, and sustained implementation of the Convention between now and 2012, we will: . . . Continue to promote actions under the Montreal Protocol on Substances That Deplete the Ozone Layer for the benefit of the global climate system; ...

2007 [G8 Declaration](#) on Growth and Responsibility in the World Economy (Heiligendamm, Germany):

59. We will also endeavor under the Montreal Protocol to ensure the recovery of the ozone layer by accelerating the phase-out of HCFCs in a way that supports energy efficiency and climate change objectives. In working together toward our shared goal of speeding ozone recovery, we recognize that the Clean Development Mechanism impacts emissions of ozone-depleting substances.

2005 [G8 Declaration](#), Gleneagles Plan of Action: Climate Change, Clean Energy and Sustainable Development (Gleneagles, United Kingdom):

15. We will encourage the capture of methane, a powerful greenhouse gas, by:

- (a) supporting the Methane to Markets Partnership and the World Bank Global Gas Flaring Reduction Partnership (GGFR), and encouraging expanded participation; and*
- (b) working bilaterally to support an extension of the World Bank's GGFR Partnership beyond 2006.*

Appendix 3: Select press coverage of SLCPs

1. *Forbes*, "[Researchers Argue For Action On Short-Lived Climate Pollutants](#)" (31 May 2012)
2. *Forbes*, "[G8 Takes On Short-Lived Climate Pollutants](#)" (30 May 2012)
3. *The Telegraph*, "[G8: Leaders open up vital new front in the battle to control global warming](#)" (21 May 2012)
4. *U-T San Diego*, Op-Ed by V. Ramanathan & D. Zaelke, "[Earth Day: Saving out planet, saving ourselves](#)" (21 April 2012)
5. *Yale Forum on Climate Change and the Media*, "[Picking Fight with CO2 Bully: OR...Near-Term Effort for Short-Term Gains](#)" (29 March 2012)
6. *Washington Post*, Editorial, "[Ways to fight warming: Strategies that would reduce emissions](#)" (26 February 2012)
7. *The New York Times*, Editorial, "[A Second Front in the Climate War](#)" (17 February 2012)
8. *Ghana Business News*, "[Ghana joins US, others to launch global coalition aimed at reducing climate pollutants](#)" (17 February 2012)
9. *Nature*, "[Coalition launches effort on 'short-lived' climate pollutants](#)" (16 February 2012)
10. *The New York Times*, "[U.S. Pushes to Cut Emissions of Some Pollutants That Hasten Climate Change](#)" (15 February 2012)
11. *Washington Post*, "[U.S. will lead new effort to cut global warming from methane, soot](#)" (15 February 2012)
12. *The Hill*, Op-Ed by M. Molina & D. Zaelke, "[How to cut climate change in half](#)" (14 February 2012)
13. *Nature*, "[Pollutants key to climate fix](#)" (17 January 2012)
14. *New York Times*, "[Climate Proposal Puts Practicality Ahead of Sacrifice](#)" (16 January 2012)
15. *Science*, "[A Quick \(Partial\) Fix for an Ailing Atmosphere](#)" (13 January 2012)
16. *National Public Radio*, "[To Slow Climate Change, Cut Down on Soot, Ozone](#)" (12 January 2012)
17. *Scientific American*, "[How to Buy Time in the Fight against Climate Change: Mobilize to Stop Soot and Methane](#)" (12 January 2012)
18. *Washington Post*, "[Study: Simple measures could reduce global warming, save lives](#)" (12 January 2012)
19. *Climate Central*, "[Groundbreaking New Study Shows How to Reduce Near-Term Global Warming](#)" (12 January 2012)
20. *Le Monde France*: "[A few simple steps to limiting global warming](#)" (12 January 2012)
21. *Agence France-Presse*: "[Cut back on soot, methane to slow warming: study](#)" (12 January 2012)
22. *Press Trust of India*: "[Simple measures could reduce global warming, save lives: NASA](#)" (12 January 2012)
23. *Nature*, "[More in Montreal: Momentum builds for ozone treaty to take on greenhouse gases](#)" (3 Nov 2011)
24. *EnviroLib*, "[European Parliament urges fast cuts in black carbon and ground-level ozone to reduce threats from dangerous glacial dams in Himalayas](#)" (11 Oct 11)
25. *The Economist*, "[Beating a retreat: Arctic sea ice is melting far faster than climate models predict. Why?](#)" (24 Sept 11)
26. *Sustainable Business News*, "[European Parliament calls for fast action to cut non-CO2 climate forcers](#)" (22 Sept 11)
27. *Washington Post*, "[Arctic Council to address role of soot in global warming](#)" (11 May 11)
28. *Politico*, "[Hot-button issues at Arctic summit](#)" (11 May 11)
29. *Climatewire*, "[Green Smoke Is Sighted as Vatican Releases Glacier Report](#)" (6 May 11)
30. *Washington Post*, "[Global warming rate could be halved by controlling 2 pollutants, U.N. study says](#)" (23 Feb 11)
31. *New York Times*, "[A Stopgap for Climate Change](#)" (22 Feb 11)
32. *The Economist*, "[Climate change in black and white](#)" (17 Feb 11)
33. *The Economist*, "[Piecemeal possibilities](#)" (17 Feb 11)
34. *The Telegraph*, "[Action speaks louder than hot air](#)" (10 Dec 10)
35. *Nature*, "[Dispute over carbon offsets continues in Cancun](#)" (8 Dec 10)
36. *Washington Post*, "[New front opens in war against global warming](#)" (29 Nov 10)
37. *New York Times*, "[To Fight Climate Change, Clear the Air](#)" (28 Nov 10)
38. *New York Times*, "[Support Grows for Expansion of Ozone Treaty](#)" (12 Nov 10)

39. *Nature*, "[Ozone Talks Delay Action on Climate](#)" (12 Nov 10)
40. *New York Times*, "[A Novel Tactic in Climate Fight Gains Some Traction](#)" (9 Nov 10)
41. *Nature*, "[Ozone Treaty Could Be Used for Greenhouse Gases](#)" (9 Nov 10)
42. IISD's *MEA Bulletin*, "[A Proposal to Change the Political Strategy of Developing Countries in Climate Negotiations](#)" (15 July 10)
43. *ClickGreen*, "[US Climate Bill 'breaks the mould' of CO2 climate policy](#)" (12 May 10)
44. *Science for Environment Policy*, "[Four fast-action strategies to tackle abrupt climate change](#)" (11 Feb 10)
45. *LA Times*, "[Climate negotiators eye the 'forgotten 50%' of greenhouse gas pollutants](#)" (14 Dec 09)
46. *The Economist*, "[Unpacking the problem](#)" (3 Dec 09)
47. *The Guardian*, "[CO2 is not the only cause of climate change](#)," (11 Sept 09)
48. *The Washington Post*, "[CO2 replacements intensify climate concerns](#)" (20 July 09)
49. *Nature*, "[Time for early action](#)" (1 July 09)
50. *Financial Times*, "[Black-and-white answers to motley puzzle](#)" (18 May 09)
51. *Nature*, "[Time to act](#)" (29 April 09)
52. *Science*, "[New Push Focuses on Quick Ways To Curb Global Warming](#)" (17 April 09)

Appendix 4: Additional background on SLCPs

Molina, M., Zaelke, D., Sarma, K. M., Andersen, S. O., Ramanathan, V., and Kaniaru, D., [*Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO₂ emissions*](#), PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES (2009).

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