Institute for Governance & Sustainable Development

The Need for Speed

Reducing Short-Lived Climate Pollutants Can Cut the Rate of Global Warming by Almost Half and Arctic Warming by Two-Thirds for the Next 30 Years or More

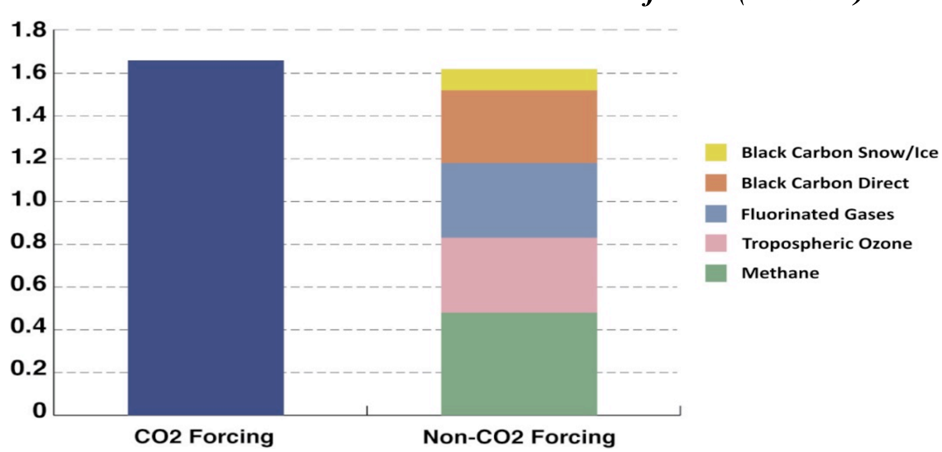
Summary. Cutting non-CO_2 short-lived climate pollutants—black carbon, ground-level ozone and its precursor, methane, and hydrofluorocarbons (HFCs)—can reduce the current rate of global warming by almost half and the rate of warming in the Arctic by two-thirds for the next 30 or more. These cuts can be achieved quickly and in most cases by using existing technologies and existing laws and institutions, as proposed by the global initiative on Climate and Clean Air to Reduce Short-lived Climate Pollutants, launched 16 February 2012 by a coalition of six developing and developed countries, including the U.S.

Cutting black carbon and methane pollutants can be achieved with fourteen targeted control measures, and provide global benefits for climate, agriculture, and health valued at $5.9 trillion USD annually, starting in 2030. Cutting production and use of HFCs can be achieved under the Montreal Protocol. If combined with substantial CO_2 emissions reductions, these fast actions have a high probability of keeping the increase in global temperature to less than 1.5℃ above the pre-industrial temperature for the next 30 years and below the 2℃ guardrail for the next 60 years, the aspirational goal many heads of State agreed upon to prevent dangerous interference with the climate system.

CO_2 is responsible for about 55% of radiative forcing. *See* graph below. Fast and aggressive CO_2 cuts are essential to combat the resulting climate change. But this is not enough. CO_2 cuts must be combined with fast and aggressive cuts in 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).

Given the profoundly persistent nature of CO_2, it also is necessary to deliberately draw down previously emitted CO_2 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 CO_2 removal strategies such as bio-sequestration, biochar, and chemical air capture and re-utilization, although these tools need to be further developed at scale.

Changes in radiative forcing from anthropogenic emissions since the Industrial Revolution of 1750 (in W/m^2)



Based on IPCC, WG 1, Fig. 2.21, AR 4 (2007). (*Note graph does not include all non-CO_2 forcers.*)

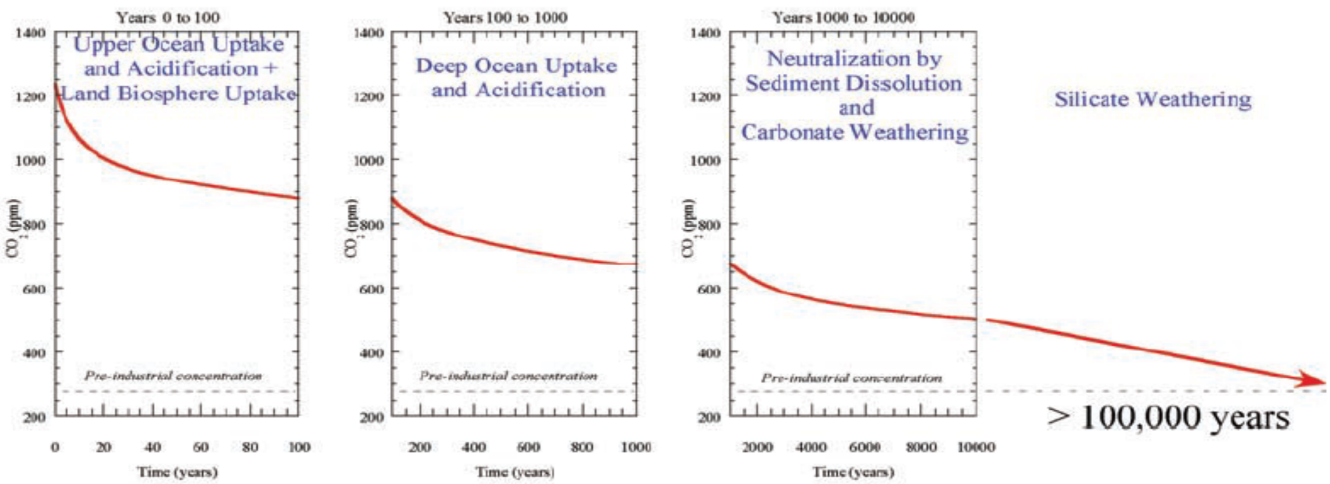
A substantial portion of CO_2 emissions remain in the atmosphere for millennia:

> *While more than half of the CO_2 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 CO_2 will persist in the atmosphere for several millennia.* (Matthews & Caldeira, GRL 2008, citing Archer, JGR 2005.)

> *About one-quarter of fossil fuel CO_2 emissions will stay in the air "forever", i.e. more than 500 years…. Resulting climate changes would be … irreversible.* (Hansen *et al.*, PTRS 2007.)

Time Scales for Removal of CO_2 from the Atmosphere



Model simulation of atmospheric CO_2 concentration for >100,000 years following a large CO_2 release from combustion of fossil fuels. Different fractions of the released gas recover on different timescales. (NAP 2011.)

The warming caused by CO_2 is largely irreversible for a thousand years after emissions stop. Even if we stopped all CO_2 emissions today, climate change from past CO_2 emissions would persist for nearly 1,000 years, and indeed, would continue to rise for 100 years:

> *[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.)

> *If anthropogenic CO_2 emissions are halted … without any direct removal of atmospheric CO_2, there is… continued warming for about 100 years.* (Cao & Caldeira, ERL 2010.)

> *[A] simplified way to view future warming persistence is that emissions of CO_2 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.)

> *The impact of carbon emissions persists longer than that of nuclear waste, the archetypical long-lived waste product. … After 10^4 years, nuclear waste is ~3000 times less radioactive than it was a year after discharge from the reactor, whereas the temperature impact of a large carbon perturbation driven by exponentially growing emissions is reduced from its peak by only about a factor of 2 to 4.* (Keith, SCI 2009.)

> *The climatic impacts of releasing fossil fuel CO_2 to the atmosphere will last longer than Stonehenge, longer than time capsules, longer than nuclear waste, far longer than the age of human civilization so far*. (Archer 2009.)

While cutting CO_2 is essential for limiting warming, cutting SLCPs is essential for reducing warming in the next few decades. To slow current impacts, we need to complement cuts in CO_2 with fast action to reduce SLCPs. Cutting SLCPs will have fast effects, including reducing 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) 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 page 8 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.)

> *Limiting their presence [black carbon and ground-level ozone] in the atmosphere is an easier, cheaper, and more politically feasible proposition than the most popular proposals for slowing climate change—and it would have a more immediate effect.* (Wallack & Ramanathan, FA 2009.)

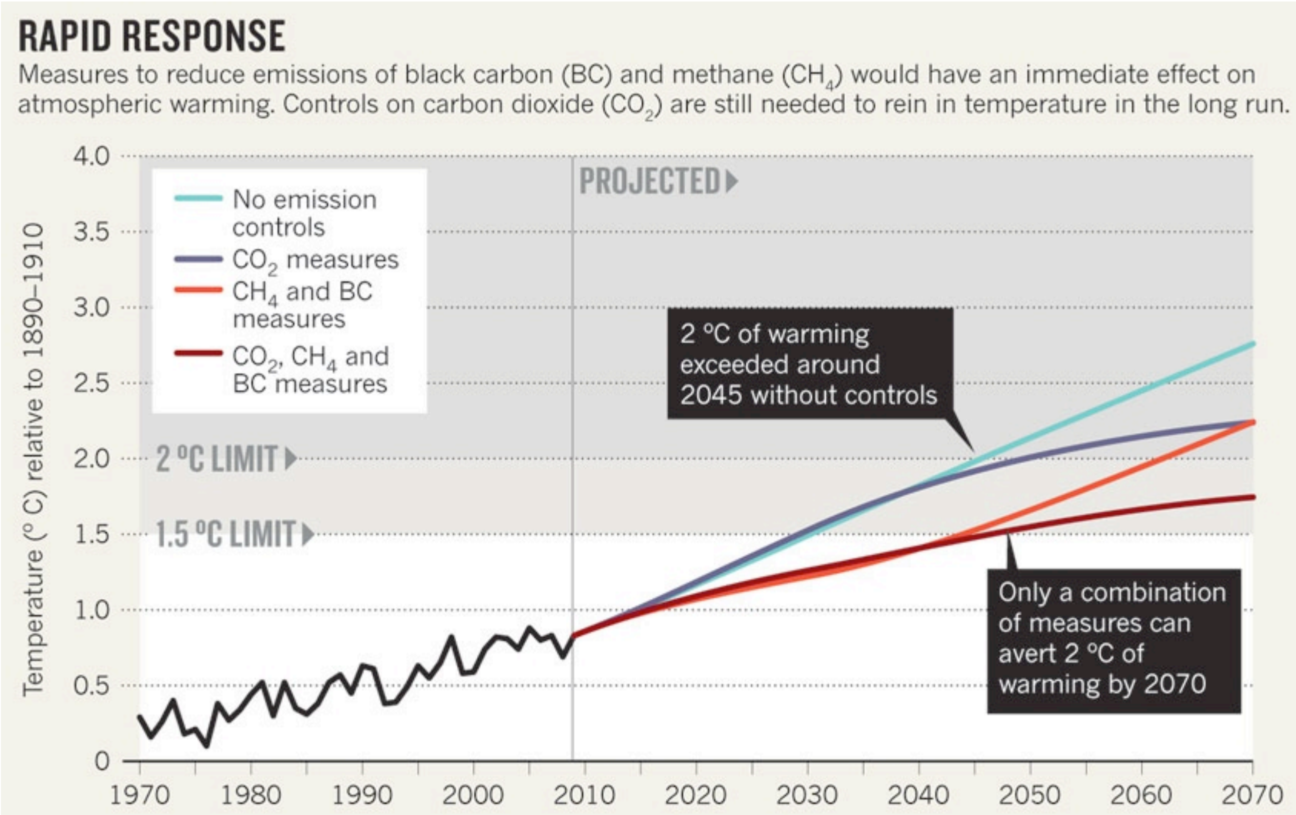
The combination of CO_2 mitigation and SLCP mitigation provides the greatest chance of keeping global temperatures below 1.5°C for the next 30 years and below 2°C through 2100, according to Ramanathan & Xu (PNAS 2010), as confirmed by Shindell *et al.* (SCI 2012) and UNEP-WMO (2011):

> *The combination of CH_4 and BC measures along with substantial CO_2 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 CO_2, CH_4, and BC measures holds the temperature increase below 2˚C until around 2070… [and] adoption of the Assessment's near-term measures (CH_4 + BC) along with the CO_2 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 CO_2 concentrations are stabilized below 441 ppm during this century].* (Ramanathan & Xu, PNAS 2010.)

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.)

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.)

> *There is ... evidence that Africa is warming faster than the global average, and this is likely to continue. The warming occurs for all seasons of the year… The 21 Atmosphere ocean general circulation models analyzed by [IPCC] mostly agree that northern and southern Africa are likely to become much hotter (as much as 4°c or more) over the next 100 years….* (Conway, GICC 2009.)

[1] The science of SLCPs dates back to the 1970s. A major WMO-UNEP-NASA-NOAA report in 1985 concluded that non-CO_2 greenhouse gases in the atmosphere are adding to the greenhouse effect by an amount comparable to the effect of CO_2. (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.

In all four regions [of Africa] and in all seasons, the median temperature increase [between 1980 and 2099] lies between 3°C and 4°C, roughly 1.5 times the global mean response. (IPCC 2007.)

Warming in the Arctic and Himalayas could lead to dangerous climate feedbacks that cause warming to accelerate. 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 CO_2 concentrations and amplify surface warming to initiate a positive permafrost carbon feedback (PCF) on climate. (Schaefer *et al.*, TELLUS B 2011.)

The warming climate is accelerating the retreat of Tibetan Plateau glaciers, threatening the water supply of billions of people in Asia:

The Tibetan Plateau…. is melting fast. In the past half-century, 82% of the plateau's glaciers have retreated. In the past decade, 10% of its permafrost has degraded. As the changes continue, or even accelerate, their effects will resonate far beyond the isolated plateau, changing the water supply for billions of people and altering the atmospheric circulation over half the planet. (Qiu, NAT 2008.)

[A] substantial amount of glacial ice is considered to be melting in the Asian high mountains. Gravimetry by GRACE satellite during 2003–2009 suggests the average ice loss rate in this region of 47 ± 12 Gigaton (Gt) yr^{-1}, equivalent to ~0.13 ± 0.04 mm yr^{-1} sea level rise. This is twice as fast as the average rate over [the last] ~40 years…. (Matsuo, EPSL 2010.)

The Himalayan glaciers…store water, which is released into the rivers of India, China and neighboring countries. Current water supply during the dry season in these countries with more than two billion inhabitants depends on this storage mechanism…[T]he Himalayas are vulnerable to global warming through…the albedo-feedback…. (Levermann *et al.*, CC 2012.)

Reducing emissions of black carbon and ground-level (tropospheric) ozone and its precursor methane is critical for saving the Arctic and Himalayas 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 and the Himalayan-Tibetan region (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 CH_4 or CO_2, 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 current warming and returning to a safe climate requires fast-action mitigation for both CO_2 and SLCPs, along with deliberate CO_2 removal from the atmosphere on a timescale of decades, starting with bio-sequestration, including biochar. Most SLCP mitigation can be done with existing technologies, and through existing laws and institutions:

> *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.)

Strategy One: Strengthening climate protection under the Montreal Protocol ozone treaty. 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 CO_2-eq. and delayed warming by up to 12 years worth of CO_2 emissions. The 197 Parties to the treaty are now phasing out ozone-depleting and climate-damaging HCFCs. Unfortunately, high-GWP HFCs are being used as substitutes in an increasing number of applications. 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). The US, Mexico, and Canada made a similar proposal, and 108 Parties have expressed support. Phasing down production and use of HFCs would substantially reduce one of the six Kyoto gases and achieve mitigation of over 100 billion tonnes of CO_2-eq. by 2050 through a treaty that has always succeeded, and at a cost that could be pennies of public funding per tonne of CO_2-eq. Unless HFCs with high global warming potential are phased down, most of 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 CO_2/ 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 CO_2 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, CO_2 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.)

Strategy Two: Cutting black carbon, ground-level ozone and its precursor, methane—local air pollutants that harm public health, crops, ecosystems, and carbon sinks, and that also cause climate change. Unlike CO_2, 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 warming by up to half and up to two thirds in the Arctic 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, providing independent justification for fast action. For example, eliminating emissions of black carbon from traditional solid biomass stoves with improved cook stoves would have a major impact (about 60%) in reducing black carbon direct climate effects over South Asia (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 traditions 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.)

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.)

Most of the control measures for reducing black carbon and ground-level 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 nearly 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.)

Valuation of Global Benefits from 14 SLCP Measures

	METHANE MEASURES	BLACK CARBON MEASURES	TOTAL
CLIMATE BENEFIT	*$331 (449 – 213)*	*$225 (343 – 13)*	*$556 (792 – 226)*
CROP BENEFIT	*$4.2 (5.4 – 3)*	*$4 (7.2 – 0.8)*	*$8.2 (12.6 – 3.8)*
HEALTH BENEFIT	*$148 (247 – 49)*	*$5142 (9853 – 1564)*	*$5290 (10100 – 1613)*
TOTAL	*$483.2 (701.4 – 265)*	*$5371 (10203.2 – 1577.8)*	*$5854.2 (10904.6 – 1845.2)*

Numbers based on Shindell *et al.*, SCI 2012; all numbers in billions $US annually starting in 2030.

Strategy Three: Given the profoundly persistent nature of CO_2, it is necessary to deliberately remove excess CO_2 from the atmosphere on a timescale of decades rather than millennia in order to return to a safe and stable climate. Reducing CO_2 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 CO_2 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 CO_2, including biochar, can match and ultimately exceed CO_2 emissions to achieve a net drawdown of CO_2 on a timescale of decades rather than the millennia timescale of the natural cycle, assuming aggressive CO_2 mitigation as well:

A combined approach of deliberate CO_2 removal (CDR) from the atmosphere alongside reducing CO_2 emissions is the best way to minimize the future rise in atmospheric CO_2 concentration, and the only *timely way to bring the atmospheric CO_2 concentration back down if it overshoots safe levels.... By mid-century, the CDR flux together with natural sinks could match current total CO_2 emissions, thus stabilizing atmospheric CO_2 concentrations. By the end of the century, CDR could exceed CO_2 emissions, thus lowering atmospheric CO_2 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 CO_2 from the atmosphere…on the 2050 timescale. (Lenton & Vaughan, ACP 2009.)

Strong mitigation, i.e. large reductions in CO_2 emissions, combined with global-scale air capture and storage, afforestation, and bio-char production, i.e. enhanced CO_2 sinks, might be able to bring CO_2 back to its pre-industrial level by 2100, thus removing the need for other geoengineering. (Lenton & Vaughan, ACP 2009.)

Other CO_2 removal strategies include direct air capture and capture at smokestacks. The captured CO_2 then requires permanent storage, or re-utilization, for example as calcium carbonate, which could be used as a substitute for a portion of ordinary Portland cement or of aggregate:

While about half of the anthropogenic CO_2 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, CO_2 capture at the emission source is not practical and/or economical. A possible pathway to deal with these emissions is to capture CO_2 directly from the air. One of the advantages of CO_2 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 CO_2 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 CO_2. (APS 2011.)

Calera … can capture up to 90% of CO_2 from power plants…and can convert the CO_2 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 CO_2 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 and to reduce the risk of passing tipping points that could lead to irreversible climate impacts. Reducing CO_2 remains a top priority, but we also need to simultaneously reduce SLCPs for near-term benefits that will keep us from losing the climate battle before serious CO_2 cuts are made. We also need to perfect and implement strategies to deliberately reduce excess CO_2 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.

The Climate and Clean Air Coalition

to

Reduce Short-Lived Climate Pollutants

The initiative on Climate and Clean Air to Reduce Short-lived Climate Pollutants launched on 16 February 2012 is the first-ever global coalition 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 coalition is seeking to reduce SLCPs by supporting and coordinating existing programs such as the Clean Cookstove Initiative and the Global Methane Initiative, while "driving development of national action plans and the adoption of policy priorities; building capacity among developing countries; mobilizing public and private action; raising awareness globally; fostering regional and international cooperation, and; improving scientific understanding of the pollutant impacts and mitigation." (US DoS 2012.)

The initiative is starting modestly with a coalition of six countries – three from the developing world and three from the developed world: the United States, Canada, Sweden, Mexico, Ghana and Bangladesh. It is expected to expand rapidly to include at least 40 countries in the first two months. The coalition Secretariat will be hosted by UNEP's Paris office, and a dedicated fund is being raised, with an initial contribution of $12 million from the U.S. and $3 million from Canada for the first two years. The first meeting of the coalition will be 23-24 April 2012 in Stockholm as part of Sweden's celebration of Stockholm + 40, with both Ministerial and Working Group sessions and a scientific seminar planned.

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

> *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 – 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. There will be better health, cleaner air, more productive crops, more energy – in addition to less warming…. [R]educing these pollutants can slow global warming by up to a half degree Celsius by 2050. To put that into context, the world's goal is to limit the rise in global temperature to two degrees. So a half a degree, or 25 percent, is significant.*
>
> ***
>
> *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.)

2012 Press Release, Remarks by UNEP Executive Director Achim Steiner on Reducing Short-Lived Climate Pollutants (Nairobi, Kenya):

> *Today in Washington, ministers from the six countries concerned outlined how, with initial funding of US$10 million, they propose to take the effort forward:*
>
> - *Raise awareness of the urgency and benefits of taking actions to reduce emissions of these short-lived climate pollutants (SLCPs), which include black carbon, methane, and some shorter-lived hydroflourocarbons, or HFCs;*
> - *Identify common approaches to take new action on these pollutants, and reinforce actions in other organizations such as the Arctic Council;*
> - *Promote the development of national or regional SLCP action plans, and track progress;*
> - *Mobilize funding commitments for SLCP mitigation of initially US$10 million in 2012 and provide up-front finance to create enabling environments for action, including leveraging private sector investments in SLCFs mitigation.*
>
> *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.* (Steiner, 2012.)

Additional Information on the Climate and Clean Air Coalition

- **2012 Fact Sheet, The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants** (Washington, DC)
- **2012 Press Release, Mexico and U.S. leads international coalition of climate and clean air** (Mexico City, Mexico)
- **2012 Press Release, Canada's Environment Minister and International Partners Launce New Global Climate and Clean Air Initiative** (Ottawa, Canada)
- **2012 Press Release, Canada' Joins Global Alliance for Clean Cookstoves** (Ottawa, Canada)
- **2012 Press Release, Minister for the Environment Lena Ek to visit Washington** (Stockholm, Sweden)

Selected Press on the Climate and Clean Air Coalition

1. *Washington Post,* Editorial, "Ways to fight warming: Strategies that would reduce emissions" (26 February 2012)
2. *The New York Times*, Editorial, "A Second Front in the Climate War" (17 February 2012)
3. *Ghana Business News*, "Ghana joins US, others to launch global coalition aimed at reducing climate pollutants" (17 February 2012)
4. *Nature,* "Coalition launches effort on 'short-lived' climate pollutants" (16 February 2012)
5. *The New York Times,* "U.S. Pushes to Cut Emissions of Some Pollutants That Hasten Climate Change" (15 February 2012)
6. *Washington Post,* "U.S. will lead new effort to cut global warming from methane, soot" (15 February 2012)
7. *The Hill,* Op-Ed by M. Molina & D. Zaelke, "How to cut climate change in half" (14 February 2012)

Other statements of support for reducing SLCPs from key international, regional, and bilateral policy meetings

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 CO_2 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-CO_2 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-CO_2 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 CO_2 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, US):

> *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.

Select press coverage of SLCPs

1. *Nature,* "Pollutants key to climate fix" (17 January 2012)
2. *New York Times,* "Climate Proposal Puts Practicality Ahead of Sacrifice" (16 January 2012)
3. *Science*, "A Quick (Partial) Fix for an Ailing Atmosphere" (13 January 2012)
4. *National Public Radio,* "To Slow Climate Change, Cut Down on Soot, Ozone" (12 January 2012)
5. *Scientific American,* "How to Buy Time in the Fight against Climate Change: Mobilize to Stop Soot and Methane" (12 January 2012)
6. *Washington Post:* "Study: Simple measures could reduce global warming, save lives" (12 January 2012)
7. *Climate Central*, "Groundbreaking New Study Shows How to Reduce Near-Term Global Warming" (12 January 2012)
8. *Le Monde France*: "A few simple steps to limiting global warming" (12 January 2012)
9. *Agence France-Presse*: "Cut back on soot, methane to slow warming: study" (12 January 2012)
10. *Press Trust of India*: "Simple measures could reduce global warming, save lives: NASA" (12 January 2012)
11. *Nature*, "More in Montreal: Momentum builds for ozone treaty to take on greenhouse gases" (3 Nov 2011)

12. *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)
13. *The Economist*, "Beating a retreat: Arctic sea ice is melting far faster than climate models predict. Why?" (24 Sept 11)
14. *Sustainable Business News*, "European Parliament calls for fast action to cut non-CO2 climate forcers" (22 Sept 11)
15. *Washington Post*, "Arctic Council to address role of soot in global warming" (11 May 11)
16. *Politico*, "Hot-button issues at Arctic summit" (11 May 11)
17. *Climatewire*, "Green Smoke Is Sighted as Vatican Releases Glacier Report" (6 May 11)
18. *Washington Post*, "Global warming rate could be halved by controlling 2 pollutants, U.N. study says" (23 Feb 11)
19. *New York Times*, "A Stopgap for Climate Change" (22 Feb 11)
20. *The Economist*, "Climate change in black and white" (17 Feb 11)
21. *The Economist*, "Piecemeal possibilities" (17 Feb 11)
22. *The Telegraph*, "Action speaks louder than hot air" (10 Dec 10)
23. *Nature*, "Dispute over carbon offsets continues in Cancun" (8 Dec 10)
24. *Washington Post*, "New front opens in war against global warming" (29 Nov 10)
25. *New York Times*, "To Fight Climate Change, Clear the Air" (28 Nov 10)
26. *New York Times*, "Support Grows for Expansion of Ozone Treaty" (12 Nov 10)
27. *Nature*, "Ozone Talks Delay Action on Climate" (12 Nov 10)
28. *New York Times*, "A Novel Tactic in Climate Fight Gains Some Traction" (9 Nov 10)
29. *Nature*, "Ozone Treaty Could Be Used for Greenhouse Gases" (9 Nov 10)
30. IISD's *MEA Bulletin*, "A Proposal to Change the Political Strategy of Developing Countries in Climate Negotiations" (15 July 10)
31. *ClickGreen*, "US Climate Bill "breaks the mould" of CO2 climate policy" (12 May 10)
32. *Science for Environment Policy*, "Four fast-action strategies to tackle abrupt climate change" (11 Feb 10)
33. *LA Times*, "Climate negotiators eye the 'forgotten 50%' of greenhouse gas pollutants" (14 Dec 09)
34. *The Economist*, "Unpacking the problem" (3 Dec 09)
35. *The Guardian*, "CO2 is not the only cause of climate change," (11 Sept 09)
36. *The Washington Post*, "CO2 replacements intensify climate concerns" (20 July 09)
37. *Nature*, "Time for early action" (1 July 09)
38. *Financial Times*, "Black-and-white answers to motley puzzle" (18 May 09)
39. *Nature*, "Time to act" (29 April 09)
40. *Science*, "New Push Focuses on Quick Ways To Curb Global Warming" (17 April 09)

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 CO_2 emissions*, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES (2009).

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UNEP, HFCS: A CRITICAL LINK IN PROTECTING CLIMATE AND THE OZONE LAYER (November 2011).

UNEP and World Meteorological Organization, INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, SUMMARY FOR DECISION MAKERS (June 2011).

National Research Council of the National Academies, CLIMATE STABILIZATION TARGETS: EMISSIONS, CONCENTRATIONS, AND IMPACTS OVER DECADES TO MILLENNIA (2011).

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Clare, D., Pistone, K., and Ramanathan, V., *Getting Rid of Black Carbon: A Neglected but Effective Near-Term Climate Mitigation Avenue*, GEORGETOWN J. INT'L AFFAIRS (2010).

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Velders G. *et al.*, *The importance of the Montreal Protocol in protecting climate*, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES (2007).