Institute for Governance & Sustainable Development

需要速度

减排短期气候污染物可以在未来 30 年或者更长时间内将全球变暖速度减半，北极升温减少三分之二

简介

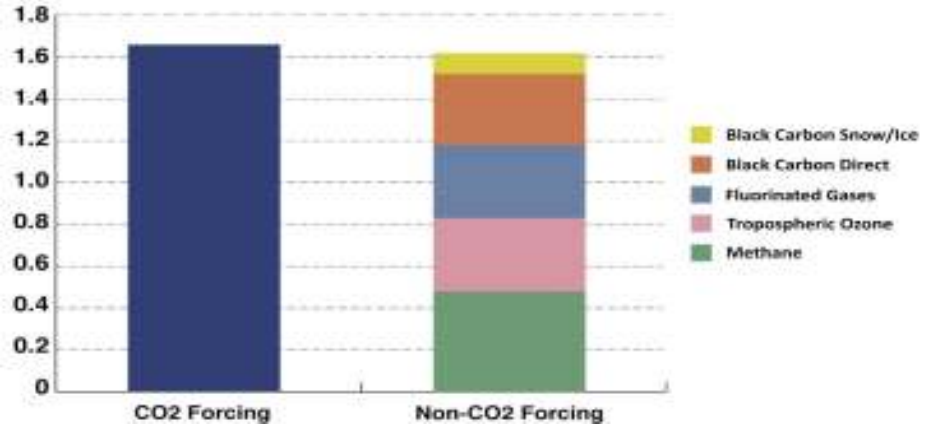
（2012 年 4 月 9 日）减排非二氧化碳的短期气候污染物——黑炭，地面臭氧和它的前体物甲烷，以及氢氟碳化合物——能够在未来 30 年或者更长时间内将全球变暖的速度减半，将北极变暖的速度减缓三分之二。同时，还可以带来巨大的健康，农作物和空气质量的附带收益。根据 2012 年 2 月 16 日由包括美国在内的六个发展中和发达国家成立的减排短期气候污染物的全球气候和清洁空气计划的提议，在大多数情况下，可以利用现有技术和现存法律制度和机构来迅速实现这些减排。

利用 14 项专项控制措施可以减排黑炭和地面臭氧/甲烷污染物。同时，从 2030 年起，每年可在全球范围内带来价值高达 5.9 万亿美元的气候，农作物和健康收益。利用《蒙特利尔议定书》控制氢氟碳化合物的生产和使用可同时提高冰箱，空调以及其他使用这些化学物质的设备和产品的能效。如果结合有效的二氧化碳减排措施，这些迅速的减排措施很可能在未来 30 年将全球升温保持在超出工业化前温度 1.5℃ 以下，未来 60 年的全球升温保持在 2℃ 以下。在两年前的哥本哈根会议，很多国家元首都认可了 2℃ 是避免对气候系统造成危险性干扰的目标值。参看图 3。

二氧化碳造成了 55%的辐射强迫。参看图 1。迅速有效地减排二氧化碳是对抗气候变化的必要组成，但是却并不足够。二氧化碳减排必须与迅速有效地减排造成另外 40-45%的升温的污染物并行。由于这些污染物在大气中的寿命仅为几天到几十年，他们被称为短期气候污染物。

由于二氧化碳在空气中寿命持久，为了能在本世纪末之前恢复一个安全稳定的气候体系，我们还需要在几十年内主动清除大气中已有的二氧化碳，而非等待数千年的自然周期。可以利用二氧化碳清除技术，例如生物封存，生物炭，和化学空气捕集和再利用来实现这一目的。不过这些技术需要进一步的规模性研发。

图 1. 自 1750 年工业革命以来人为排放造成的辐射强迫变化(单位：W/m^2)



依据 IPCC, WG 1, Fig. 2.21, AR4 (2007). (本图表并不包括所有的非二氧化碳强迫物质。)

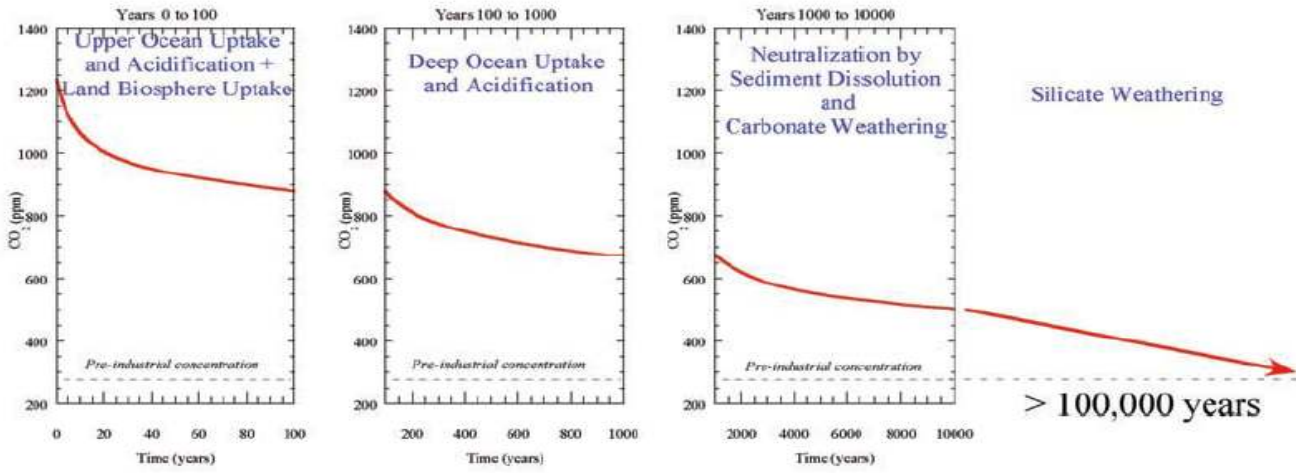
排放的二氧化碳中很大一部分会在大气中存在数千年时间：

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.)

图 2. 二氧化碳从大气中消除的时间表



模型模拟化石燃料燃烧释放的大量二氧化碳在大气中>100,000 年的浓度变化。释放的气体的不同部分需要不同的时长来消除。(NAP 2011.)

即使排放停止，二氧化碳造成的升温在一千年内也几乎无法逆转。即使我们今天停止所有的二氧化碳排放，过去的二氧化碳排放所造成的气候变化仍将持续将近 1000 年，以及将继续升温 100 年:

Climate 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.)

尽管减排二氧化碳对控制升温至关重要，但减排短期气候污染物对于在未来几十年减缓升温则尤为重要。为了减缓目前的影响，我们应当在减排二氧化碳的同时迅速减排短期气候污染物。减排短期气候污染物可以迅速产生效果，包括在几十年内将北极升温速度减缓三分之二，以及将全球变暖速度减半或更多。联合国环境规划署和世界气象组织合作的评估报告（2011）从 2000 多个备选措施中挑选了 16 项优先控制措施以减排黑炭和地面臭氧；Shindell *et al.* (2012) 将这些措施合并为 14 项（参看第 7 页列表）

> *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 [16 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.)

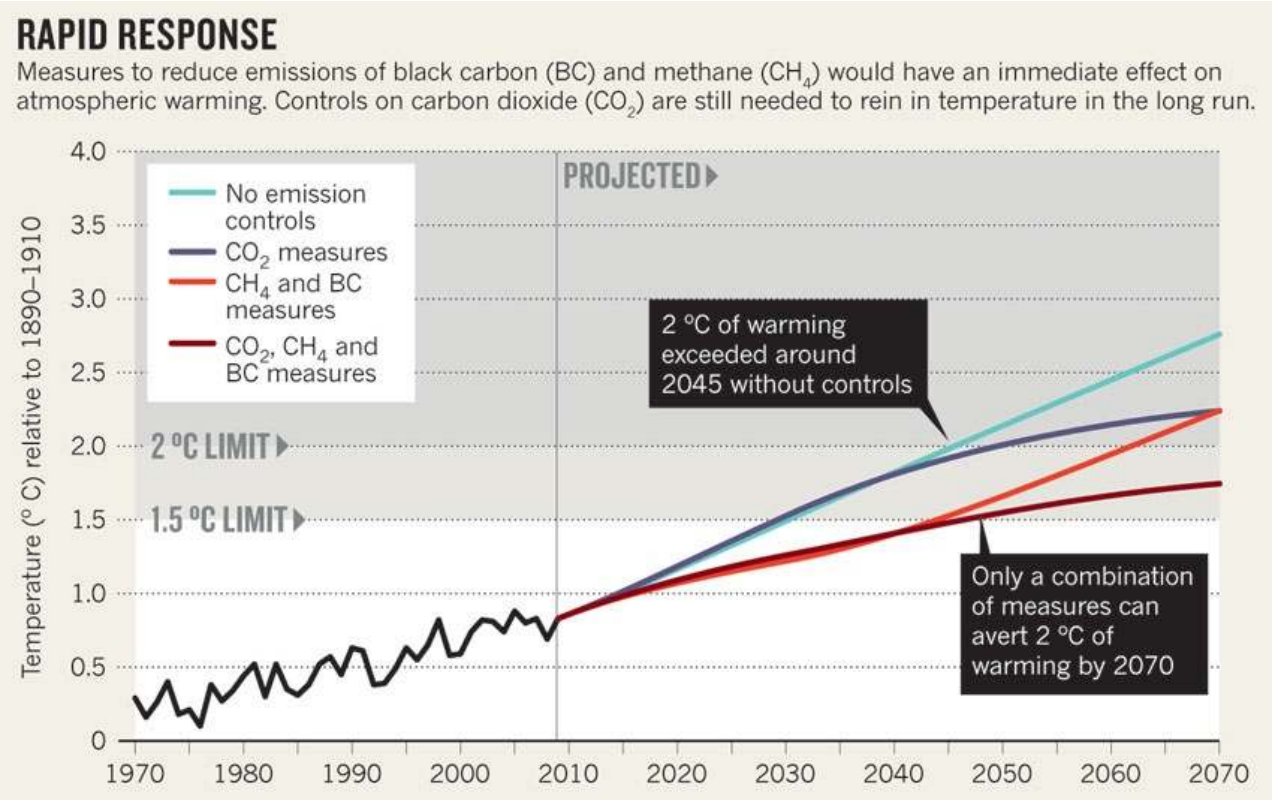
根据 Ramanathan & Xu (PNAS 2010)，并经 Shindell *et al.* (SCI 2012) 和 UNEP-WMO (2011) 确认：在有效减排二氧化碳的同时减排短期气候污染物是最有可能将全球升温在未来 30 年内保持在 1.5°C 以下，以及到 2100 年将升温保持在 2°C 以下。

> *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%.* (Ramanathan & Xu, PNAS 2010.)

图 3. 各种减排方案下的升温预测



(Tollefson, NAT 2012, based on Shindell *et al.*, SCI 2012, which in turn is based on Ramanathan & Xu, Fig 1D, PNAS 2010.[1]) (注：上图不包括减排氢氟碳化合物，虽然 Ramanathan & Xu 文章中的 Fig. 1D 包括了氢氟碳化合物减排。)

很多脆弱地区的升温高于全球平均水平。全球变暖是一个平均值，但是事实上不同地区的升温并不相同。有些脆弱地区的升温远高于全球平均水平：

> *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.)

> *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.)

北极和喜马拉雅地区的升温可能会导致危险的气候反馈，从而进一步加速升温。“临界要素”简单讲是指一系列一旦严重到一定程度就无法恢复以前状态的事件，例如北极浮冰消融，冻土融化以及喜马拉雅冰川融化：

[1] 短期气候污染物的科学研究可追溯至 20 世纪 70 年代。1985 年，一份关键性的 WMO-UNEP-NASA-NOAA 合作报告指出大气中的非二氧化碳的温室气体造成的温室效应可与二氧化碳相比拟。(Ramanathan *et al.*, 1985.) 之后几十年间，数百篇论著不断确认和强化了这一结论，尤其是 IPCC 的报告(IPCC 1990; IPCC 1995; IPCC 2001; IPCC 2007)。简言之，我们认真从事短期气候污染物的科学研究以及科研结果认证已经有至少 25 年的历史。

*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.)

气候变暖正在加速青藏高原的冰川消融，从而威胁亚洲地区数十亿计人口的水源供应：

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.)

减排黑炭和地面臭氧及其前体物甲烷对短期内拯救北极和喜马拉雅地区至关重要。黑炭约造成了 5 0 %的北极升温，约为 1890－2007 年间的 1.9°C 升温中的 1°C。(Jacobson, JGR 2010; Shindell & Faluvegi, NG 2009.) 喜马拉雅高原地区大约 5 0 %的升温可以归因为黑炭对大气和地表的直接加热。(Ramanathan *et al.*, JGR 2007; Flanner *et al.*, ACPD 2009; Xu *et al.*, CB 2009; Menon *et al.*, ACP 2010) 因此，减排黑炭和其他短期气候污染物对于减缓北极和喜马拉雅地区的变暖和冰川消融至关重要。(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.)

由于深海的热惰性，越早采取行动减排短期气候污染物，就越有效：

> *[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.)

减缓气候变化，恢复安全的气候系统需要迅速减排二氧化碳和短期气候污染物，同时在几十年内主动清除大气中的二氧化碳，首先采取的措施是生物封存，包括生物炭。大多数短期气候污染物的减排可以利用现有技术以及现行法律制度和机构来完成：

> *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-CO_2 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 CO_2 emissions.* (Molina *et al.*, PNAS 2009.)

策略一是在平流层臭氧公约《蒙特利尔议定书》下通过逐步淘汰高全球变暖潜能值的氢氟碳化合物加强气候保护。《蒙特利尔议定书》已经成功地淘汰了将近１００种臭氧层消耗和气候变暖化学物质中的９７％。这带来了多达 2220 亿吨 CO_2-eq.的气候缓解效应，推迟了相当于长达１２年的二氧化碳排放的变暖效应。本公约下的１９７个缔约方正在致力于淘汰消耗臭氧层和损坏气候的氢氯氟烃化合物(HCFCs)。然而，高全球变暖潜能值的氢氟碳化合物却因在越来越多的领域被用作替代物而以每年 10-15%的速度增加。2005 年，全球氢氟碳化合物排放量中美国占 34%，欧盟占 15.21% (CAIT 2012)。650 家企业已联合承诺从 2015 年起避免氢氟碳化合物 (CGF 2012)。脆弱的岛屿国家也已经提议在《蒙特利尔议定书》下淘汰氢氟碳化合物的生产和使用（将氢氟碳化合物的排放留在《京都议定书》下规制）。美国，墨西哥和加拿大也提出了一个类似的提案，并获得了 108 个缔约方的支持。利用一个一贯成功的条约，以每吨 CO_2-eq 几美分的公共资金成本，淘汰氢氟碳化合物的生产和使用可以有效地消除六种《京都议定书》气体之一。到 2050 年，可以带来超过 1000 亿吨 CO_2-eq.的减排效应。历史上，在《蒙特利尔议定书》下的这种转变还可以极大地提高冰箱，空调和其他使用制冷剂的产品和设备的能效。反之，如果不淘汰具有高全球变暖潜能值的氢氟碳化合物，《蒙特利尔议定书》已经取得的气候减缓效应将会被抵消大半：

> *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/m^2 in 2010 to 0.25 to 0.40 W/m^2 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.)

很多氢氟碳化合物的应用领域现已有其替代物，其他的也不久即可研发成功：

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.)

策略二是减排黑炭，地面臭氧及其前体物甲烷。这些污染物不仅导致气候变化，还有害公共健康，农作物，生态系统和碳汇。与二氧化碳不同，黑炭，地面臭氧及其前体物甲烷一旦被减排，就会迅速从大气中消失。减排这些空气污染物可以在未来 30 年内将全球变暖速度减半，北极变暖速度减缓三分之二。除了带来迅速的气候效应，减排这些空气污染物还有益公共健康，粮食保障和生态系统，包括碳汇，这些本身就可以作为减排的理由。这些收益，包括大部分的气候缓解效益都是由进行减排的地区获得。例如，用改良版炉灶替代传统固体生物质炉灶，从而消除黑炭排放对减少黑炭在南亚地区的直接气候影响作用重大（大约 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.)

以下这些减排措施能够实现“全球变暖潜能值最大减少净值的将近90%。”(Shindell *et al.*, SCI 2012.) 他们包括以下14项措施：

甲烷控制措施

- 控制原油和燃气生产时的逃逸性排放
- 控制煤矿的排放
- 控制燃气远距离运输时的逃逸性排放
- 捕集城市垃圾填埋的排放
- 捕集污水处理系统的排放
- 捕集牲畜粪便的排放
- 对水稻田间歇通风

黑炭控制措施

- 为柴油机动车安装微粒过滤器
- 用清洁的生物质炉灶替代传统炉灶
- 现代化砖窑
- 现代化炼焦炉
- 禁止露天焚烧生物质
- 淘汰高排放的道路和越野柴油机动车
- 在全球范围内普及现代化烧饭和取暖设备

(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 substantial benefits in the Himalayas and other glaciated and snow-covered regions. (UNEP-WMO 2011.)

除了积极的气候收益，减排短期气候污染物还可以带来巨大的公共健康和粮食保障收益。

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.)

大多数减排黑炭，地面臭氧及其前体物甲烷的措施都可以利用现有技术，法律制度和机构进行实施。

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.)

上述措施中的一半可以使投资者实现净成本节约，上述所有措施最终都是高成本收益的，如果考虑到从 2030 年开始每年 5.9 万亿美元的收益：

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.)

14项短期气候污染物减排措施的全球收益值

	甲烷减排措施	黑炭减排措施	总数值
气候收益	*$331 (449 – 213)*	*$225 (343 – 13)*	*$556 (792 – 226)*
农作物收益	*$4.2 (5.4 – 3)*	*$4 (7.2 – 0.8)*	*$8.2 (12.6 – 3.8)*
健康收益	*$148 (247 – 49)*	*$5142 (9853 – 1564)*	*$5290 (10100 – 1613)*
总数值	*$483.2 (701.4 – 265)*	*$5371 (10203.2 – 1577.8)*	*$5854.2 (10904.6 – 1845.2)*

数值来自Shindell *et al.*, SCI 2012; 所有数值单位为十亿美元，数值为从2030年起每年的收益。

策略三是为了恢复一个安全稳定的气候系统，在数十年内而非千年内，主动清除大气中多余的二氧化碳。要将二氧化碳浓度降低到稳定安全的气候系统要求的水平就需要碳汇超过碳排放。增加碳汇的策略包括保护和扩大森林，湿地，草原以及其他从大气中移除二氧化碳的生物质来源。还包括高温分解生物质废料（在少量氧气下加热），制造一种名为生物炭的永久的碳，从而安全地将碳储存数百年至数千年。与二氧化碳的有效减排相配合，二氧化碳的生物封存，包括生物炭可以持平并最终超过二氧化碳排放，最终在几十年时间内减少二氧化碳的总量，而无需等待千年的自然循环：

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.)

其他清除二氧化碳的策略还包括直接大气捕集和烟囱捕集。捕集的二氧化碳应永久封存或再利用，例如作为碳酸钙，可以代替一部分普通硅酸盐水泥或成分：

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.)

结论

为了减缓目前的气候效应，减少越过会带来不可逆转的气候效应的临界点的风险，我们需要采纳上述所有策略。减排二氧化碳仍然是最优先的，但是我们还需要同时减排短期气候污染物来获取近期效益，避免我们在有效减排二氧化碳的同时就输掉这场气候之战。我们还需要完善和实施在数十年内主动清除多余的二氧化碳的策略。从科学研究和日益加

剧的气候影响中我们得出的结论就是*需要速度*，以及采取快速行动解决所有气候变化缘由的重要性。

减排短期气候污染物的气候和清洁空气联盟

2012 年 2 月 16 日成立的减排短期气候污染物的气候和清洁空气计划是首个专门致力于共同减排短期气候污染物的国际联盟。该联盟针对的气候污染物包括黑炭（煤烟），地面臭氧及其前体物甲烷，以及用作制冷剂和制作绝缘泡沫塑料的氢氟碳化合物。

该联盟力图通过以下几项措施减排短期气候污染物：支持和协调现有的项目，例如清洁炉灶计划和全球甲烷计划；“推动国家行动方案的制定和政策的优先采纳；推动发展中国家的能力建设；调动公共和私人行动；在全球范围内提高意识；推动地区和国际合作，以及推动对污染物影响和减排的科学研究。”(US DoS 2012.)

本计划由六国联盟始创——三个发展中国家和三个发达国家：美国，加拿大，瑞典，墨西哥，加纳和孟加拉国。预计在成立后两个月内会迅速增加到至少四十个成员国家。联盟秘书处由联合国环境规划署的巴黎办公室负责。目前正在筹集专用基金。最初两年内，美国出资 1200 万美金，加拿大出资 300 万美金。联盟的首次会议将于 2012 年 4 月 23 至 24 日在斯德哥尔摩举行，会议将作为瑞典庆祝斯德哥尔摩+40 活动的一部分，包括部长级会议和工作组会议，以及一个科学研讨会。

2012 年美国国务卿希拉里．克林顿在减排短期气候污染物的气候和清洁空气联盟的发言（美国华盛顿特区）：

> *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 年新闻稿，联合国环境规划署执行主任 Achim Steiner 关于减排短期气候污染物的发言（肯尼亚内罗毕）：

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.)

有关气候和清洁空气联盟的补充资料

- **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)

有关气候和清洁空气联盟的部分新闻报道

1. *Washington Post,* Editorial, "Ways to fight warming: Strategies that would reduce emissions" (26 February 2012)
2. *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. *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 Dr. Mario Molina & Durwood Zaelke, *"*How to cut climate change in half" (14 February 2012)

其他主要国际，区域和双边政策会议上支持减排短期气候污染物的言论

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, United Kingdom):

> *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 (CO_2), are taken in parallel.*

2012 Svalbard Declaration on Short-Lived 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 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.*

有关短期气候污染物的部分新闻报道

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)
8. *Nature,* "Pollutants key to climate fix" (17 January 2012)
9. *New York Times,* "Climate Proposal Puts Practicality Ahead of Sacrifice" (16 January 2012)
10. *Science*, "A Quick (Partial) Fix for an Ailing Atmosphere" (13 January 2012)
11. *National Public Radio,* "To Slow Climate Change, Cut Down on Soot, Ozone" (12 January 2012)
12. *Scientific American,* "How to Buy Time in the Fight against Climate Change: Mobilize to Stop Soot and Methane" (12 January 2012)

13. *Washington Post:* "Study: Simple measures could reduce global warming, save lives" (12 January 2012)
14. *Climate Central*, "Groundbreaking New Study Shows How to Reduce Near-Term Global Warming" (12 January 2012)
15. *Le Monde France*: "A few simple steps to limiting global warming" (12 January 2012)
16. *Agence France-Presse*: "Cut back on soot, methane to slow warming: study" (12 January 2012)
17. *Press Trust of India*: "Simple measures could reduce global warming, save lives: NASA" (12 January 2012)
18. *Nature*, "More in Montreal: Momentum builds for ozone treaty to take on greenhouse gases" (3 Nov 2011)
19. *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)
20. *The Economist*, "Beating a retreat: Arctic sea ice is melting far faster than climate models predict. Why?" (24 Sept 11)
21. *Sustainable Business News*, "European Parliament calls for fast action to cut non-CO2 climate forcers" (22 Sept 11)
22. *Washington Post*, "Arctic Council to address role of soot in global warming" (11 May 11)
23. *Politico*, "Hot-button issues at Arctic summit" (11 May 11)
24. *Climatewire*, "Green Smoke Is Sighted as Vatican Releases Glacier Report" (6 May 11)
25. *Washington Post*, "Global warming rate could be halved by controlling 2 pollutants, U.N. study says" (23 Feb 11)
26. *New York Times*, "A Stopgap for Climate Change" (22 Feb 11)
27. *The Economist*, "Climate change in black and white" (17 Feb 11)
28. *The Economist*, "Piecemeal possibilities" (17 Feb 11)
29. *The Telegraph*, "Action speaks louder than hot air" (10 Dec 10)
30. *Nature*, "Dispute over carbon offsets continues in Cancun" (8 Dec 10)
31. *Washington Post*, "New front opens in war against global warming" (29 Nov 10)
32. *New York Times*, "To Fight Climate Change, Clear the Air" (28 Nov 10)
33. *New York Times*, "Support Grows for Expansion of Ozone Treaty" (12 Nov 10)
34. *Nature*, "Ozone Talks Delay Action on Climate" (12 Nov 10)
35. *New York Times*, "A Novel Tactic in Climate Fight Gains Some Traction" (9 Nov 10)
36. *Nature*, "Ozone Treaty Could Be Used for Greenhouse Gases" (9 Nov 10)
37. IISD's *MEA Bulletin*, "A Proposal to Change the Political Strategy of Developing Countries in Climate Negotiations" (15 July 10)
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