Primer on Short-Lived Climate Pollutants

Slowing the rate of global warming over the near term by cutting short-lived climate pollutants to complement carbon dioxide reductions for the long term

IGSD

Institute for Governance & Sustainable Development

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About IGSD

IGSD's mission is to promote just and sustainable societies and to protect the environment by advancing the understanding, development, and implementation of effective, accountable, and democratic systems of governance for sustainable development.

Beginning in 2005, IGSD embarked on a "fast-action" climate mitigation campaign that will result in significant reductions of greenhouse gas emissions and will limit temperature increase and other climate impacts in the near term. The focus is primarily on strategies to reduce non-CO_2 climate pollutants, to complement cuts in CO_2, which is responsible for more than half of all warming. It is essential to reduce both non-CO_2 pollutants and CO_2. Neither alone is sufficient to limit the increase in global temperature to a safe level.

IGSD's fast-action strategies include reducing emissions of short-lived climate pollutants—black carbon, methane, tropospheric ozone, and hydrofluorocarbons. They also include measures to capture, reuse, and store CO_2 after it is emitted, including biosequestration and strategies to turn biomass into more stable forms of carbon for long-term storage.

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Executive Summary

Carbon dioxide (CO_2) emissions are responsible for 55-60% of anthropogenic radiative forcing.[1] Fast and aggressive CO_2 mitigation is essential to combat the resulting climate change. But this is not enough. CO_2 mitigation must be combined with fast and aggressive reductions of the pollutants causing the other 40-45% of forcing.[2] These pollutants include black carbon, tropospheric ozone, methane, and hydrofluorocarbons (HFCs). Because these pollutants have atmospheric lifetimes of only days to a decade and a half, they are referred to as short-lived climate pollutants (SLCPs). Some of the SLCPs have a particularly powerful impact in the regions where they are emitted.[3] Reducing SLCPs is critical for slowing the rate of climate change over the next several decades and for protecting the people and regions most vulnerable to near-term climate impacts through the end of the century.

Although we have known about SLCPs for more than thirty-five years,[4] the following scientific developments have catapulted them to the front lines in the battle against climate change:

- *First* is the recognition that we have already added enough greenhouse gases to warm the planet by 2.4°C or more during this century.[5] Much of this warming has been masked by cooling aerosols, primarily sulfates, which are being reduced under current air pollution policies. These reductions, while important for protecting public health and ecosystems, are contributing to near-term warming by un-masking warming already in the climate system. Without fast-action mitigation to cut SLCPs, by mid-century warming may cross the 1.5° to 2°C threshold considered the outer limit for an acceptable climate. Reducing SLCPs is the most effective strategy for constraining warming and associated impacts in the near term, since most of their warming effect disappears within weeks to a decade and a half after reductions.

- *Second* is the recognition that in addition to being climate forcers, three of the four SLCPs are also air pollutants that damage public health and ecosystems. Reducing them will prevent millions of premature deaths every year, protect tens of millions of tonnes of crops, as well as forests and other plants that absorb CO_2, and contribute to sustainable development.
- *Third* is the recognition that the benefits for health, crops, forests, and sustainable development will accrue primarily in the nations or regions that take action to mitigate these pollutants, due to the stronger impacts black carbon and tropospheric ozone have in the regions where they are emitted.
- *Fourth* is the recognition that there are practical and proven ways to reduce all four of these climate pollutants and that existing laws and institutions are often available to support immediate reductions.

A number of recent studies analyzing model-generated climate scenarios have concluded that cutting SLCPs can prevent a significant amount of additional warming in this century.[6] Reducing SLCPs has the potential to avoid 0.6°C global average warming by 2050[7] and more than 0.84°C of warming in the Arctic by 2070.[8] This would cut the current rate of global warming by half, the rate of warming in the Arctic by two thirds, and the rate of warming over the elevated regions of the Himalayas and Tibet by at least half.[9] By the end of the century, cutting SLCPs could avoid as much as 1.5°C of warming, comparable to an aggressive mitigation effort for carbon dioxide.[10]

Reducing SLCPs will in turn:

- Help stabilize regional climate systems and reduce heat waves, droughts, fires, floods, and hurricanes in mid-latitudes, and slow shifts in monsoons, expansion of desertification, and increases in cyclones in the tropics.
- Slow the melting of glaciers and Arctic sea ice.[11]
- Cut the rate of sea-level rise by a quarter and cumulative sea-level rise by more than 20%.[12]
- Slow the pace of other climate impacts and provide critical time to adapt to unavoidable impacts.

The primary direct local benefits for developing countries from reducing SLCPs include:

- Saving millions of lives a year and significantly reducing other illnesses.
- Improving food security.
- Expanding access to sustainable energy for the billions who depend on traditional fuels for cooking and heating.
- Protecting infrastructure and providing low-lying states at risk from sea-level rise more time to adapt.

Reductions in all of these SLCPs can be achieved quickly, and in most cases by using existing technologies and existing laws and institutions. Using existing technologies and institutions to reduce these non-CO_2 climate pollutants may offer the best near-term protection for the countries that are most vulnerable to climate change impacts, including island nations, countries with low-lying coastal areas, and agriculture-dependent countries in Asia and Africa already suffering droughts, floods, and shifting rainfall. Slowing the rate of climate change and reducing near-term impacts is a critical complement to adaptation strategies and to sustainable development, with the potential to provide global benefits for climate, crops, and health valued at $5.9 trillion annually, starting in 2030.

In addition to supporting efforts to negotiate an agreed outcome under the UNFCCC by 2015 to go into effect by 2020 with legal force applicable to all Parties, many countries, including the members of the G20[13] and G8,[14] have acknowledged the important role that 'international cooperative [or complementary] initiatives'[15] (ICIs) can play in meeting the challenge of climate change. ICIs include a wide variety of initiatives including the use of other relevant treaties such as the Montreal Protocol, the International Civil Aviation Organization (ICAO), and International Maritime Organization (IMO), as well as forums such as the Major Economies Forum (MEF) and Clean Energy Ministerial (CEM), and the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC).[16] ICIs that focus on SLCPs can help deliver near-term climate benefits and build broader support for more aggressive CO_2 mitigation.[17]

The CCAC, launched in February 2012 by the United States, Mexico, Canada, Ghana and Bangladesh, along with the UN Environment Programme (UNEP), focuses on reductions of short-lived climate pollutants (SLCPs), including black carbon, methane, tropospheric ozone, and hydrofluorocarbons (HFCs). As of September 2013, the Coalition has 72 Partners who have endorsed the Framework for the Coalition and agreed to meaningful action to reduce short-lived climate pollutants.[18] The G8 countries joined the Coalition in May 2012 and requested the World Bank to study how to integrate SLCP reductions into its programs.[19] At the CCAC third High Level Assembly (HLA) in September 2013 the World Bank announced that it had invested approximately $18 billion on SLCP-relevant activities between

2007 and 2012,[20] and agreed to work with CCAC Partners to establish a 'pay-for-performance' fund to finance methane emissions reductions, emphasizing those projects that also reduce black carbon emissions.[21]

In addition to being included in the CCAC, HFCs are addressed in the Rio + 20 declaration, *The Future We Want*, where world leaders supported phasing down HFC production and use.[22] Such a phase down can be achieved through the Montreal Protocol, while simultaneously improving the energy efficiency of refrigerators, air conditioners, and other equipment and products that use these chemicals, thus reducing CO_2 emissions as well. The Federated States of Micronesia, the Kingdom of Morocco, and the Maldives have made a formal proposal to amend the Montreal Protocol to do this,[23] as have the North American Parties (Mexico, Canada, and the U.S.).[24] Support for the phase-down is steadily growing,[25] including in the G20 St. Petersburg *Leaders' Declaration* which expressed support for initiatives that are complementary to efforts under the UNFCCC, including using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs, while leaving accounting and reporting under the UNFCCC.[26] Both China and India have also separately agreed to address HFCs, with China agreeing with the U.S. to open formal negotiations on the details of an amendment, and India agreeing immediately convene an India-U.S. Task Force on HFCs.[27] HFCs are also being addressed at national and regional levels, including through the European Union's regulatory efforts,[28] as well as through such voluntary efforts as the Consumer Goods Forum.[29]

Reducing SLCPs is essential for reducing near-term warming and climate impacts, but it is not sufficient. Aggressive reduction of CO_2 emissions also is essential for limiting temperature rise. However, in contrast to SLCPs, only about half of CO_2 emissions are removed from the atmosphere in the first hundred years, with a significant fraction lasting for several millennia.[30] Reducing CO_2 emissions now, in line with 450 parts per million (ppm) or stricter scenarios, can avoid approximately 0.1°C of additional warming by 2050 compared to the warming expected from a business-as-usual (BAU) scenario, increasing more than ten-fold to 1.1°C by 2100.[31] Cuts to CO_2 alone would still not prevent temperatures rising above the 2°C guardrail by the middle of the century (*see* Fig. 4 & 6). However, if large-scale reductions of both CO_2 and SLCPs are undertaken now there is a high probability of keeping the increase in global temperature to less than 1.5°C above the pre-industrial temperature for the next 30 years and to less than 2°C above for the rest of the century (s*ee* Fig. 4).[32]

Introduction to Short-Lived Climate Pollutants

CO_2 in the atmosphere account for 55-60% of current anthropogenic radiative forcing that warms the climate. 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 to SLCPs, which are causing the other 40-45% of global warming.

Black Carbon

Black carbon is a potent climate-warming aerosol that remains in the atmosphere for only a few days or weeks.[33] It is a component of soot and is a product of the incomplete combustion of fossil fuels, biofuels, and biomass.[34] Black carbon contributes to climate change in several ways: it warms the atmosphere directly by absorbing solar radiation and emitting it as heat, it contributes to melting by darkening the surfaces of ice and snow when it is deposited on them, and it can also affect the microphysical properties of clouds in a manner that can perturb precipitation patterns. On a 100-year time scale, black carbon has a global warming potential 900 (100-1700) times greater than CO_2, and 3200 (270-6200) greater on a time scale of 20 years.[35] Recent estimates of black carbon's radiative forcing confirm that it is the second leading cause of global warming.[36] The current best estimate of total climate forcing of black carbon is 1.1 (0.17 to 2.1) Wm^{-2},[37] second only to CO_2 (1.82 [±0.19] Wm^{-2}).[38]

Black carbon also harms human health. It is a primary component of fine particle air pollution (PM2.5), and can cause or contribute to a number of adverse health effects, including asthma and other respiratory problems, low birth weights, heart attacks, and lung cancer.[39] Black carbon also harms plants. When it lands on leaves it increases their temperature and impedes growth.[40] In addition, black carbon also reduces the amount of solar radiation reaching the earth, which also reduces photosynthesis.[41]

The main sources of black carbon are open burning of biomass, diesel engines, and the residential burning of solid fuels such as coal, wood, dung, and agricultural residues.[42] In 2000, global emissions of black carbon were estimated at approximately 7.5 (2-29) million tons.[43]

Black carbon is co-emitted with other pollutants, some of which are light in color and cause cooling by scattering solar radiation back into the atmosphere.[44] The type and quantity of co-pollutants differs by source, and a high ratio of warming to cooling pollutants indicates the most promising sources to target for producing fast cooling.[45] A recent assessment of black carbon confirmed that emissions from diesel engines and some industrial and residential coal sources have the highest ratio of black carbon to lighter co-emitted pollutants compared to other black carbon sources.[46] A three-year study of black carbon in California, calculated that the state had reduced average concentrations of black carbon by as much as 50% since the late 1980, largely through controls on diesel engines.[47] Similar reductions in co-emitted cooling aerosols such as sulfates were not seen in this study, which used California's extensive network of air pollution monitors, as well as aircraft, satellites, and computer models to analyze black carbon emissions. This provides further support that cutting emission from diesel engines can produce fast climate mitigation.[48]

Recent research shows that some organic carbon co-emitted with black carbon from biomass sources also strongly absorbs solar radiation at specific wavelengths. This "brown carbon" is also a potent climate forcer.[49] Climate models have largely ignored the forcing from brown carbon, with some implicitly including some or all in the total forcing of black carbon, but most excluding it completely, which has lead them to the conclusion that the combination of organic carbon co-pollutants with black carbon causes net global cooling.[50] Brown carbon's warming effect appears to be offsetting some or all of the lighter organic carbon particles' cooling effect.[51] This, in turn, means that reducing emissions from black carbon sources that have a high proportion of organic carbon co-emitted pollutants, such as the open burning of biomass, may still reduce warming.[52] Finally, recent research indicates that wildfires, previously thought to cause net cooling, may also be causing warming, which could have broad climate implications as the Intergovernmental Panel on Climate Change (IPCC) expects wildfires to increase in this century.[53]

Over areas of snow and ice, such as the Arctic, even sources with a large proportion of pollutants that normally cause cooling still produce significant warming.[54] This is because deposition of both darker and lighter particles, including dust, reduces the reflectivity (albedo) of snow and ice, allowing more solar radiation to be absorbed, which causes local warming and increases surface melting.[55] A recent study indicates that the powerful warming effect of black carbon soot from the industrial revolution in Europe may be responsible for the previously unexplained rapid retreat of the approximately 4,000 Alpine glaciers, beginning in the middle of the 19th century, during the period known as the Little Ice Age.[56] In addition to impacts, all particle pollutants harm human health.[57]

Thanks to modern pollution controls and fuel switching, black carbon emissions in North America and Europe were significantly curbed in the early 1900s. However, mobile sources, particularly diesel vehicles, continue to be a major source category for these regions.[58] Black carbon sources in developing countries are significantly different from those in North America and Europe.

In developing countries, a much larger proportion of black carbon emissions come from residential heating and cooking, and industry.[59] According to UNEP, global emissions of black carbon are expected to remain relatively stable through 2030, with continuing reductions in North America and Europe largely offset by continued growth in other parts of the world.[60]

Methane

Methane is a powerful greenhouse gas with a 100-year global warming potential 28 times that of CO_2, and an atmospheric lifetime of approximately 12 years.[61] About 60% of global methane emissions are due to human activities.[62] The main sources of anthropogenic methane emissions are oil and gas systems; agriculture, including enteric fermentation, manure management, and rice cultivation; landfills; wastewater treatment; and emissions from coal mines. Methane is the primary component of natural gas, with some emitted to the atmosphere during its production, processing, storage, transmission, and distribution.[63]

The radiative forcing of methane in 2011 was 0.48 W/m^2 [±0.05], which is more than a quarter of CO_2 radiative forcing.[64] According to a recent UNEP and WMO assessment, anthropogenic methane emissions are expected to grow 25% over 2005 levels by 2030, driven by increased production from coal mining and oil and gas production, and growth in agricultural and municipal waste emissions.[65] However, recent analysis suggests that current estimates of methane emissions from gas extraction, transmission, and distribution may be substantially underestimated, which could have a large impact on emissions estimates as world consumption of natural gas is expected to increase by 64% by 2040.[66]

Methane is also an important precursor gas of the powerful air pollutant, tropospheric ozone. Globally, increased methane emissions are responsible for half of the observed rise in tropospheric ozone levels.[67] While methane does not cause direct harm to human health or crop production, it can be attributed to as much as 15% of premature mortalities due to air pollution, and more than 20% of respiratory mortalities associated with tropospheric ozone in South America, Europe, Africa, the Middle East, and Asia.[68]

Tropospheric Ozone

Tropospheric ozone is the main component of 'smog.' It is a major air and climate pollutant, which causes warming, and a highly reactive oxidant, which harms human health and crop production.[69] (In contrast, ozone in the upper atmosphere (stratosphere) provides a shield against dangerous ultraviolet radiation.) Tropospheric ozone is the third most important greenhouse gas behind CO_2 and methane, with an estimated radiative forcing of 0.40 [± 0.20] W/m^2.[70]

Ozone is known as a 'secondary' pollutant because it is not emitted directly, but instead forms when precursor gases react in the presence of sunlight.[71] Major ozone precursor gases include carbon monoxide (CO), oxides of nitrogen (NOx), and non-methane volatile organic compounds (NMVOCs), and methane. NOx, NMVOCs, and CO are produced primarily when fossil fuels like gasoline, oil or coal are burned or when some chemicals, like solvents, evaporate.[72] Due to its large role as a precursor gas, reducing emissions of methane will lead to significant reductions in tropospheric ozone and its damaging effects.[73]

Ozone concentrations are strongly influenced by temperature, solar radiation, wind patterns, and other meteorological factors, and peak ozone levels typically occur during hot, dry, stagnant summer and springtime conditions of the kind expected to increase as global temperatures continue to warm.[74] Concentrations are typically highest in areas downwind from concentrated sources of precursor gases, such as suburban or rural areas close to traffic-filled urban areas or power plants.[75] There is always some ozone in ground-level air, known as the 'background' concentration. While tropospheric ozone is known primarily as a local pollutant, it can last in the atmosphere long enough to be transported across continents, and precursor gases can also travel long distances before converting to ozone, making tropospheric ozone a transboundary pollution issue.[76]

Breathing ozone is particularly dangerous to children, older adults, and people with lung diseases or cardiovascular disease, and can cause bronchitis, emphysema, asthma, and may permanently scar lung tissue.[77] Recent studies have also linked both short-term and long-term ozone exposure to early death, heart attacks, strokes, heart disease, congestive heart failure, and possible reproductive and developmental harm.[78]

Ozone's impacts on plants include lower crop yields and a reduced ability to absorb CO_2 and sequester carbon. Ozone enters plants and reacts to form oxidising chemicals that can damage cell membranes and key processes such as photosynthesis.[79] This leads to reduced growth, and smaller lower-quality seeds and tubers with less oil and protein.[80] During longer ozone episodes, ozone exposure can cause visible damage to sensitive species.[81] Reduced photosynthesis and plant growth is a major food security concern, which also leads to less CO_2 being taken up by vegetation, producing a positive feedback on atmospheric CO_2.[82] Studies in Europe indicate that in 2000 exposure to tropospheric ozone reduced carbon sequestration from trees by up to 16.2%.[83] One modelling study indicated that the indirect impact of tropospheric ozone on global warming via its impacts on vegetation might be contributing as much to global warming as its direct effect.[84]

Hydrofluorocarbons (HFCs)

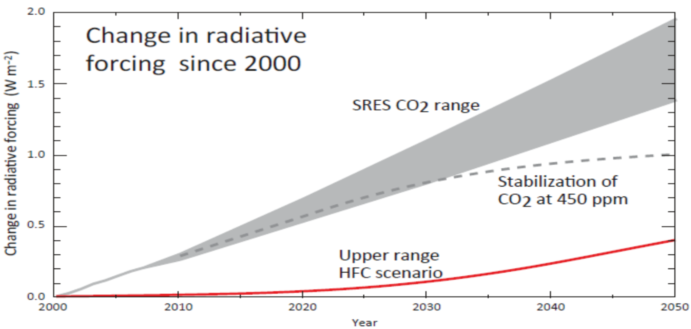
HFCs are factory-made chemicals used primarily in refrigeration and insulating foams. They have a warming effect hundreds to thousands of times more powerful than CO_2. The average lifetime of the mix of HFCs, is 15 years, with an average GWP of 1600, weighted by usage.[85]

While HFCs have caused less than 1% of total global warming to date, production, consumption, and emissions of these factory-made gases are growing at a rate of 10 to 15% per year.[86] Measured in terms of radiative forcing, HFCs are on course to increase as much as twenty-fold by 2050, from a forcing of 0.02 Wm^{-2} to as much as 0.40 Wm^{-2}.[87] The forcing of HFCs nearly doubled between 2005 and 2011 from 0.01 Wm^{-2} to 0.02 Wm^{-2}.[88] Continued growth in HFCs will add up to 0.1°C of global average temperature rise by mid-century, and up to 0.5°C by 2100.[89]

HFCs and other fluorinated gases, which include sulfurhexafluoride (SF_6) and perfluorocarbons (PFCs), are the fastest growing climate pollutants in many countries, including the U.S., EU, Australia, China, and India.[90] HFC growth is accelerating as HFCs replace chlorofluorocarbons (CFCs), which were phased out under the Montreal Protocol, and hydrochlorofluorocarbons (HCFCs), which are now being phased out.[91] In addition, the demand for air conditioning and refrigeration is increasing as the world warms and as wealth increases, particularly in developing countries where HFC emissions are projected to be as much as 800% greater than in developed countries in 2050.[92]

If left unchecked, by 2050 forcing from HFCs could be equivalent to 20% of the growth of CO_2 forcing since 2000, under a business-as-usual (BAU) scenario, and up to 40% of CO_2 forcing under a 450 ppm CO_2 stabilization scenario (*see* Fig. 1).[93] Without action, by 2050 uncontrolled growth of HFCs would cancel much of the climate benefit observable by 2050 under an aggressive CO_2 450 ppm mitigation scenario (In Fig. 1 *compare* radiative forcing reduced from CO_2 mitigation *with* radiative forcing increased from HFC growth).

Figure 1: By 2050 forcing from HFCs could equal 20-40% of the growth of CO_2 forcing since 2000



Projected radiative forcing of climate by HFCs and CO_2 since 2000, when the influence of HFCs was essentially zero. The HFC climate forcing for an upper range scenario is compared with the CO_2 forcing for the range of scenarios from IPCC-SRES and the 450 ppm CO_2 stabilization scenario. Clearly, the contribution of HFCs to radiative forcing could be very significant in the future; by 2050, it could be as much as a quarter of that due to CO_2 increases since 2000, if the upper range HFC scenario is compared to the median of the SRES scenario. Alternatively, the contribution of HFCs to radiative forcing could be one fifth the radiative forcing due to CO_2 increases since 2000, if the upper range HFC scenario is compared to the upper range of the SRES scenario.[94]

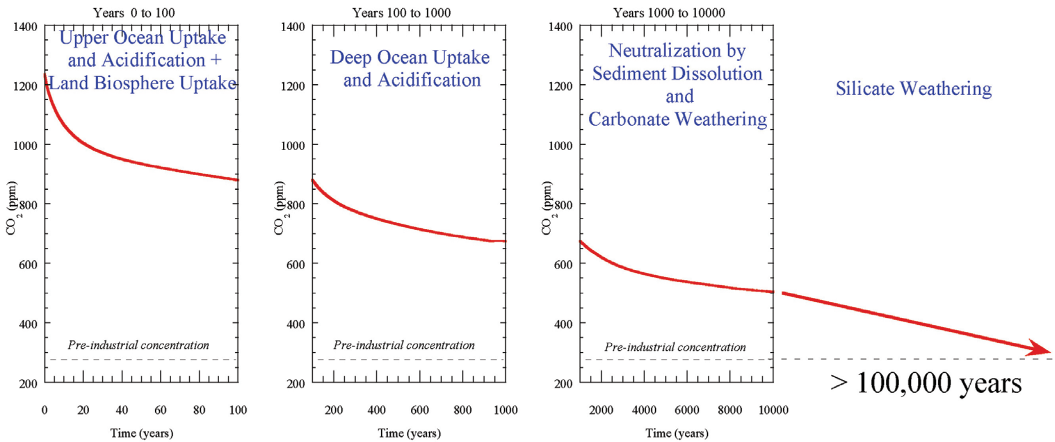
Both CO_2 Mitigation and SLCP Mitigation Are Critical for Climate Safety

Importance of Immediate CO_2 Mitigation

CO_2 is the single most significant climate forcer, accounting for 55-60% of present climate forcing. Atmospheric concentrations of CO_2 have increased by approximately 40% since 1750, and now exceed the highest concentrations recorded in ice-cores from the past 800,000 years.[95] Substantial and immediate reductions in CO_2 emissions are necessary to slow further global temperature rise, although CO_2 reductions are less effective than SLCPs for limiting warming in the near term. For example, if CO_2 concentrations were held to a peak of 440 ppm by mid-century and reduced to 420 ppm by 2100, this would avoid only 0.1°C in warming by 2050,[96] and global temperatures would still rise above 2°C by the middle of the century (*see* Fig. 4 & 6). By the end of the century, however, the warming avoided by cutting CO_2 will increase more than ten-fold to ~1.1°C.[97]

CO_2 emitted into the atmosphere will continue to cause warming over the long term because of its long lifetime in the atmosphere and the thermal inertia of the oceans. While approximately 50% of CO_2 is removed from the atmosphere within a century, a substantial portion (20-40%) remains in the atmosphere for millennia (*see* Fig. 2).[98] In addition, much of the heat trapped by CO_2 emissions is stored in the deep oceans and once CO_2 emissions are reduced the heat is returned to the atmosphere on a multiple-century timescale.[99] The result of this is that the warming and resulting impacts caused by CO_2 that has already been, and will be emitted, is effectively irreversible on human timescales (Fig. 3 black line), absent more aggressive efforts to remove the CO_2 from the ambient atmosphere (or geo-engineering).[100]

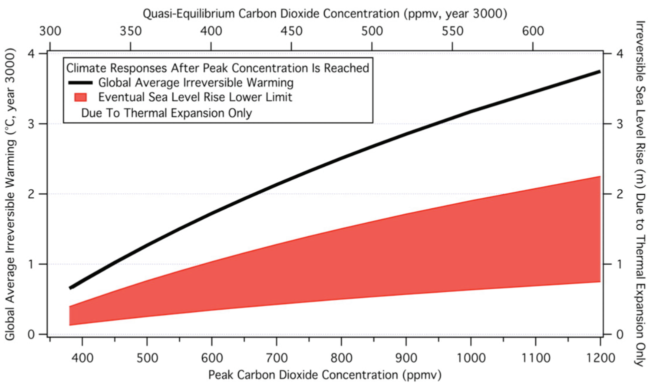
Figure 2: Time Scales for Removal of CO_2 from the Atmosphere



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.[101]

The longer the world waits to make significant cuts in CO_2 emissions, the more severe the permanent impacts will be, including impacts from changes in the frequency and severity of extreme weather events and from sea-level rise.[102] Committed sea-level rise from thermal expansion alone could be as high as one meter (~3 feet) if atmospheric CO_2 concentrations are allowed to exceed 600 ppm (*see* Fig. 3 red band).[103] On 9 May 2013, atmospheric CO_2 concentrations reached 400.03 ppm, a level unseen in the past three million years.[104] Atmospheric CO_2 concentrations could reach as high as 1,100 ppm by the end of this century under some BAU scenarios.[105]

Figure 3: Irreversible Sea-Level Rise and Warming from CO_2



The black line shows irreversible global average surface warming based upon peak atmospheric CO_2 concentrations. The red band shows lower limit range of corresponding sea-level rise from thermal expansion only, due to peak atmospheric CO_2 concentrations. The black line depicts committed warming due to increasing peak CO_2 emissions, which will be irreversible on human timescales.[106]

Moreover, significantly reducing CO_2 emissions requires decarbonizing global energy systems[107] through a portfolio of actions including conservation and efficiency improvements to reduce the carbon intensity of energy use, along with the replacement of fossil fuels with renewables, carbon capture, reuse, and storage, and numerous other steps.[108] Building the new low-carbon energy system, however, will require the continuing use of the current energy system with associated CO_2 emissions.[109] This, plus the ocean-thermal inertia, means that even aggressive efforts to build the clean energy systems alone will not be able to reduce climate impacts significantly through 2050.[110]

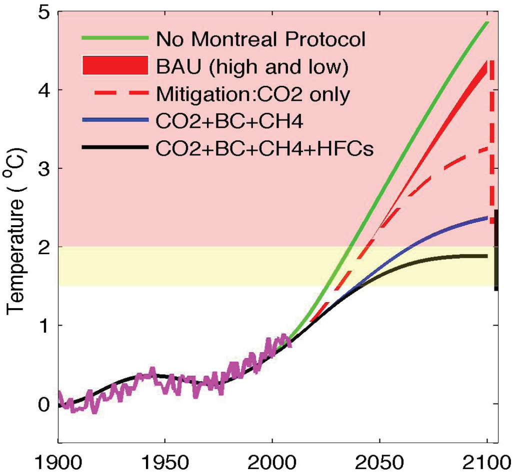
Importance of Immediate SLCP Mitigation

Cutting SLCPs is a critical climate strategy for reducing near-term global warming and its impacts at least through the end of the century, particularly in regions most vulnerable to climate change, as well as for offsetting the near-term warming that will result from reductions of cooling aerosols such as sulfates, which are important to reduce to protect public health and ecosystems despite the warming this un-masking will cause.

SLCPs account for approximately 40-45% of present climate forcing.[111] In contrast to $CO_{2,}$ the short atmospheric lifetimes of SLCPs means that reducing them will prevent as much as 90% of their predicted warming within a decade, with the final 10% delayed for hundreds of years due to ocean thermal inertia. Reducing all four SLCPs has the potential to avoid 0.6°C global warming by 2050[112] and up to 1.5°C of warming by 2100 (in Fig 4., the difference between dashed red line and black line).[113] Reducing the three air pollutants—black carbon and methane and tropospheric ozone—has the potential to avoid more than 0.84°C of warming in the Arctic by 2070,[114] which can cut the rate of global warming by half, the rate of Arctic warming by two thirds, and reduce warming in the high altitude Himalayan-Tibetan Plateau by at least half.[115] (During the past half century, the rate of global warming has been about 0.13°C per decade.[116] The rate of warming in the Arctic is currently at least twice the global average, and the rate in the Himalayas and Tibet is about three times the global average.[117])

While the measured warming from climate pollutants is presently about 0.8°C above preindustrial levels, the total warming that is committed but yet not fully realized from historic emissions through 2005 is estimated to be 2.4°C (1.4 - 4.3°C).[118] Up to 1.15°C of this committed warming is currently being masked by emissions of cooling aerosols, primarily sulfates, from fossil fuel and biomass combustion which are now being rapidly reduced to protect human health and ecosystems.[119] Un-masking this committed warming could push global temperatures over the 2°C guardrail by mid-century.[120] Constraining temperature rise from HFCs, black carbon, tropospheric ozone, and methane can help offset the possible rapid temperature increase from ongoing reductions of sulfates.

Figure 4: Warming Avoided Through Combined SLCP and CO_2 Mitigation



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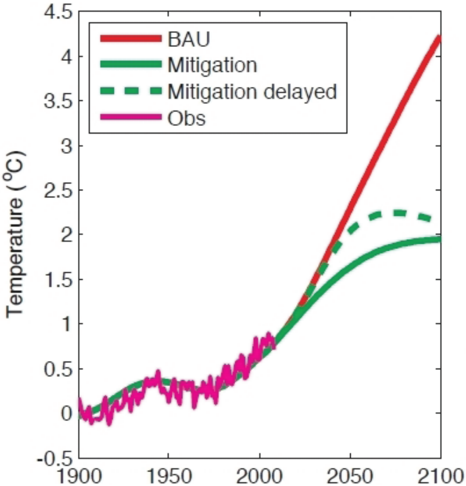
Model simulated temperature change under various mitigation scenarios that include CO_2 and SLCPs (BC, CH_4, HFCs). BAU case (red solid line with spread) considers both high and low estimates of future HFC growth. Note this uncertainty of temperature projection related to HFC scenarios is around 0.15°C at 2100. The vertical bars next to the curve show the uncertainty of temperature projection at 2100 due to climate sensitivity uncertainty.[121]

If reductions in SLCPs are delayed until 2030, it will be more difficult if not impossible to keep warming under 2°C by the end of the century (Fig. 5 dashed green line).[122]

Figure 5: Temperature Consequences of Delayed SLCP Mitigation

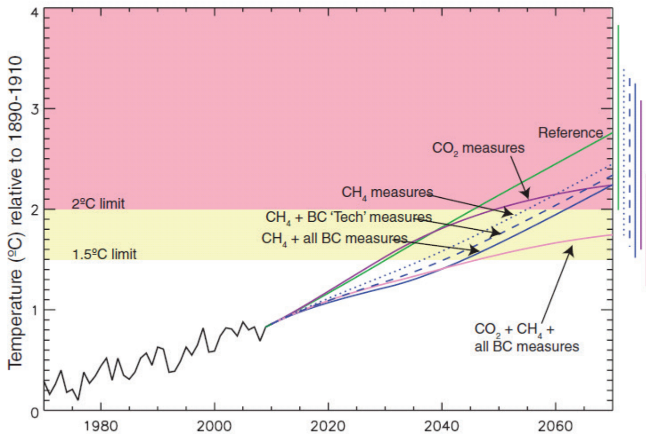


The figure depicts predicted temperature rise for three scenarios: BAU (red); full CO_2 and SLCP mitigation (solid green); and full CO_2 and SLCP mitigation with either methane mitigation beginning in 2030 or black carbon mitigation beginning in 2040 (dashed green). The pink line depicts observed temperature change and sea-level rise from 1900 to 2011.[123]

Benefits of Combined CO_2 and SLCP Mitigation

CO_2 and SLCPs can be thought of as two separate control knobs for temperature increase that operate independently and on different timescales.[124] Both must be turned down simultaneously and immediately as part of a comprehensive climate strategy to reduce near-term impacts, as well as the risk of abrupt climate change[125] and long-term climate destabilization. The combination of CO_2 mitigation and SLCP mitigation can avoid as much as 0.6°C of additional warming by mid-century, and as much as 2.6°C by 2100, compared to the reference scenario.[126] This combined mitigation provides the greatest chance of keeping global temperatures below 1.5°C for the next 30 to 40 years and global temperatures below the 2°C guardrail through 2100.[127]

Figure 6: Temperature Rise Predictions Under Various Mitigation Scenarios



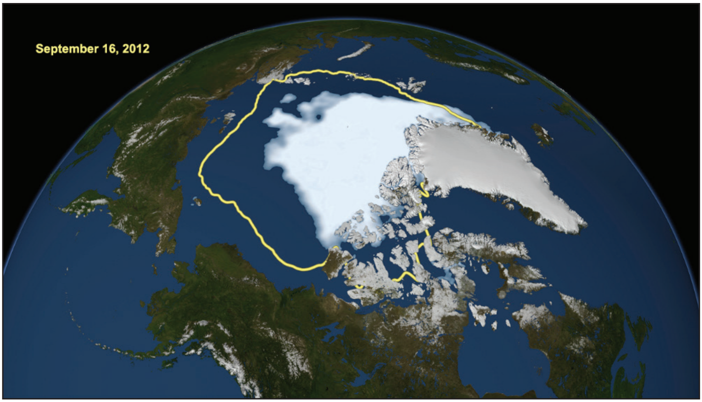
Observed temperatures through 2009 and projected temperatures thereafter under various scenarios to 2070, all relative to the 1890–1910 mean. Results for future scenarios are the central values from analytic equations estimating the response to forcings calculated from composition-climate modeling and literature assessments. The rightmost bars give 2070 ranges, including uncertainty in radiative forcing and climate sensitivity. A portion of the uncertainty is systematic, so that overlapping ranges do not mean there is no significant difference.)[128] (Note: HFC mitigation is not included in this graph, although it is included in Fig. 4, above.)

Benefits for Climate Vulnerable Regions

Global warming is expressed as a global average increase in surface temperature, but warming is experienced unevenly across different regions, with some of the world's most vulnerable regions warming much faster than the global average rate.[129] For example, Africa is warming about one and a half times faster than the average, and the Himalayan-Tibetan plateau is warming three times the average global rate.[130] The Arctic is warming at twice the global rate, due to a phenomenon known as 'Arctic amplification,'[131] and is expected to warm more than any other region as global temperatures continue to rise.[132] Snow and ice covered areas of the world, known as the cryosphere, which include the Arctic, Himalayas, Andes and East Africa, are particularly vulnerable to enhanced regional warming and are experiencing some of the most dramatic climate impacts.[133] Therefore, it is particularly important that SLCP reductions may be able to rapidly reduce the rate of regional warming in places such as the Arctic, the high elevation regions of the Himalayas and Tibet,[134] and other regions with vulnerable climates, including those where enhanced warming may trigger amplifying feedbacks and the passage of potential climate tipping points–the points at which a chain of events escalate such that it is impossible to return to former conditions.

Warming in the Arctic and Himalayan-Tibetan plateau in particular could lead to dangerous climate feedbacks that cause warming to accelerate past tipping points. One example of such a feedback is the melting of Arctic snow and sea ice, which reached a record low in September 2012.[135] As the reflective ice and snow is replaced with darker heat-absorbing land and ocean, warming can amplify,[136] which in turn further reduces ice and snow cover, creating the dangerous feedback loop.[137] Over the past thirty years the minimum extent of Arctic summer sea ice has decreased by 13% per decade, reaching a new record minimum in 2012, nearly 50% less than the 1979 to 2000 average (Fig. 7).[138] Scientists now predict that BAU emissions could lead to an Arctic free of summer sea ice within a few decades.[139]

Figure 7: Record Minimum Arctic Summer Sea Ice Extent



Source: NASA/Goddard Scientific Visualization Studio

Image of minimum Arctic sea-ice on September 16, 2012, the record minimum recorded Arctic sea-ice according to the National Snow & Ice Data Center. The sea-ice extent dropped to 3.41 million square kilometers (1.32 million square miles), 18% lower than the previous record minimum of 4.17 million square kilometers (1.61 million square miles) set September 18, 2007, and the first time Arctic sea-ice has shrunk below 4 million kilometers. The yellow line signifies the average minimum Arctic summer sea-ice extent between 1979 and 2010.[140] According to NASA the 2013 Arctic winter sea-ice maximum on 15 February was the fifth lowest in the past 35 years; nine of the ten lowest winter sea-ice maximums have occurred in the past ten years.[141]

Arctic warming also thaws permafrost—perennial frozen ground—that underlies as much as 25% of the land area in the Northern Hemisphere and extends under parts of the Arctic Ocean.[142] Terrestrial permafrost contains nearly twice as much carbon trapped in frozen biomass as the entire atmospheric carbon pool.[143] Climate models project that Northern Hemisphere near-surface permafrost could recede between 12 and 26% by 2035.[144] A release of only 1% of the reservoir of methane trapped in under-water permafrost could risk triggering abrupt climate change.[145]

Black carbon is estimated to be responsible for 50% of Arctic warming, or almost 1°C of the total 1.9°C increase between 1890 and 2007.[146] Approximately 50% of the warming on the Himalayan-Tibetan plateau has also been attributed to black carbon..[147] Cutting black carbon, tropospheric ozone, and methane can cut the rate of warming in the Arctic by two thirds and the rate of warming over the elevated regions of the Himalayan-Tibetan plateau by at least half.[148] Recent research indicates that Arctic surface temperature is nearly five times more sensitive to black carbon emitted from within the Arctic than to emissions from mid latitudes, making emissions from increased shipping and oil and gas exploration in the region critical targets for black carbon mitigation.[149] Reducing black carbon emissions could prevent more than 1°C of additional warming in the Arctic by 2050, preventing up to 40 percent of projected summer sea ice loss and 25 percent of springtime snow cover loss compared to business as usual emissions.[150] Cutting SLCPs is essential though not sufficient for saving the Arctic and other vulnerable places in the near term.[151] Further, due to the heightened effects of black carbon and tropospheric ozone near emissions sources, these benefits, including much of the climate mitigation benefits, are accrue largely to the regions making the cuts. For example, eliminating emissions of black carbon from traditional solid biomass stoves with improved cook stoves would have a major impact in reducing black carbon and its direct climate effects over South Asia by about 60%.[152]

Benefits for Human Health

In addition to climate benefits, reducing SLCPs provides strong benefits for public health. Both black carbon and tropospheric ozone are major air pollutants contributing to more than six million deaths annually, including 3.5 million deaths from household air pollution from solid fuels, 3.1 million deaths from ambient particulate matter pollution, and 0.2 million deaths from ambient ozone pollution.[153] Globally, air pollution is the fourth leading preventable risk factor for death, behind poor diet, and high blood pressure, and about the same as tobacco smoke.[154] A recent study estimates that as much as 95% and 85% of air pollution-related mortalities from PM2.5 and tropospheric ozone respectively, are due to emissions of short lived air pollutants and their precursors.[155] In South Asia, which includes India, indoor air pollution alone is the leading preventable risk factor for the burden of disease, which is defined as early mortality and years lived at less than full health,[156] while in Eastern, Central, and Western Sub-Saharan Africa it is ranked second, and third in South East Asia.[157] This is a significant drag on sustainable development. For example, air pollution is estimated to cost China 1.2% of its gross domestic product every year.[158]

Indoor air pollution has been linked to a number of health effects in infants, including low-birth weight and neonatal death.[159] This is particularly acute for India, which has the highest global rate of births, infant deaths, and low birth weights, and where coal and biomass remains the primary source of household fuel for over 70% of households, and as much as 95% in poorer rural areas.[160]

Globally, indoor and ambient PM2.5 air pollution are the two leading risks factors for death for children in the first six days of life.[161]

Air pollution is not limited to the developing world. While both the EU and the U.S. report that tropospheric ozone pollution has decreased on average since reporting began, tropospheric ozone levels continue to be above national public health standards.[162] According to the American Lung Association, 38% of Americans (119 million) live in areas that experience tropospheric ozone pollution above healthy levels.[163] During the summer of 2012, 17 EU Member States and five other European countries reported tropospheric ozone levels above healthy levels for 25 or more days.[164]

Global deployment of a suit of fourteen black carbon and methane mitigation measures (discussed below) can prevent up to 4.7 million air pollution related deaths each year.[165] According to one study, the deaths avoided from technically possible reductions in black carbon and methane would represent "1-8% of cardiopulmonary and lung cancer deaths among those age 30 years and older, and 1-7% of all deaths for all ages."[166] It is estimated that providing access to modern cooking fuels alone, will prevent approximately 1.2 million premature deaths annually and greatly enhance human well-being, particularly among women and children.[167]

Benefits for Food Security

Reducing SLCPs will also have a significant positive effect on global forests and other vegetation, agricultural production, and food security. Tropospheric ozone in particular is known to produce a variety of negative effects in plants including suppressing photosynthesis, reducing food quality, and suppressing the ability of forests and other plants to sequester carbon.

Air pollution is estimated to reduce global crop yields of four major staple grains between 4-15% for wheat, 6-16% for soybeans, 3-4% for rice, and 2-6% for corn, causing a combined economic loss of between $11-26 billion. [168] By 2030 estimated losses could reach 5.4-26% for wheat, 15-19% for soybeans, and 4.4-8.7% for corn, at an economic loss of between $17-35 billion annually. [169] Tropospheric ozone related losses of wheat and tomatoes in Europe alone were estimated at $4.3 billion and $1.3 billion respectively in 2000, and could be as high as $2.7 billion and $0.8 billion in 2020 even with current legislation to reduce ozone pollution. [170]

Recent studies comparing the vulnerability Asian crops to those in Europe and North America have shown significantly higher vulnerability of important Asian food crops to tropospheric ozone.[171] Current levels of tropospheric ozone in South Asia are estimated to be reducing quality and yields of local crops by between 10-20%.[172] Tropospheric ozone levels in China's Yangtze River Delta are estimated to be reducing yields of rice by 3%, wheat 17%, and rapeseed by 6%.[173] Economic losses in South Asia from reduced yields of wheat, rice, soybeans, and potatoes are estimated to be $4 billion per year, with the largest losses occurring in the Indo-Gangetic plain, home to more than one billion people.[174]

Beyond the direct decreases in production, reductions in the quality of crops can have significant indirect consequences for food security. Prolonged exposure to tropospheric ozone has been shown to decrease carbohydrates but increase protein concentrations in wheat and potatoes; reduce the protein and oil content of rapeseed (the world's third largest source of vegetable oil); reduce the sugar content and juice quality of grapes; and reduce the sweetness of watermelons.[175] Tropospheric ozone can also decrease the nutritional value of forage plants, which can lead to lower milk and meat production of grazing animals, harming some of the world's most vulnerable populations.[176] In 2004, nearly one billion livestock were kept by more than 600 million small farmers and herders globally, 95% of whom were living in extreme poverty and dependent upon their livestock for survival.[177]

Reducing SLCP air pollution through the global deployment of fourteen methane and black carbon measures (discussed below) can improve global crop yields by as much as 135 million metric tonnes a year by 2030.[178] Improvements in crop yields are estimated to be up to 4% of total annual global production of the four major staple grains: maize, rice, soybeans, and wheat.[179]

Benefits for Reducing Sea-Level Rise

According to the IPCC, the accelerating rate of global sea-level rise since the mid-1800s has been faster than the mean rate in the previous two thousand years.[180] The potential impact of rising oceans is one of the most visible and costly effects of climate change. Rising sea-levels will impact key sectors in coastal and island states, including water resources, agriculture, fisheries and infrastructure, and will increase vulnerability to flooding and storm surges, which are expected to become more frequent and stronger as temperatures increase.[181] Sea levels are projected to rise between 0.56 and 2 meters (~2 to 6 feet) in this century.[182] Global changes in sea-level do not occur uniformly, with some regions experiencing much greater levels of sea-level rise than others, with the Indian Ocean and the Western Pacific expected to see 10-20% higher sea-level rise than the global average.[183]

According to a new modeling study, aggressively cutting SLCPs now can reduce the rate of sea-level rise by approximately 18% by 2050 and 24% by the end of the century.[184] In contrast, the benefit of cutting CO_2 on reduced sea-level rise accrues very slowly in the first half of the century, but increases rapidly after 2050 to equal the rate reduction of SLCPs by 2100, bringing the total reduction in the rate of sea-level rise to nearly 50%.[185] Combined SLCP and CO_2 mitigation will reduce cumulative sea-level rise by 31% by 2100, with SLCPs providing 71% of the total (41% from methane measures; 13% from HFC measures; and 17% from black carbon (Fig. 8)).[186] The remaining 29% is from CO_2 measures.

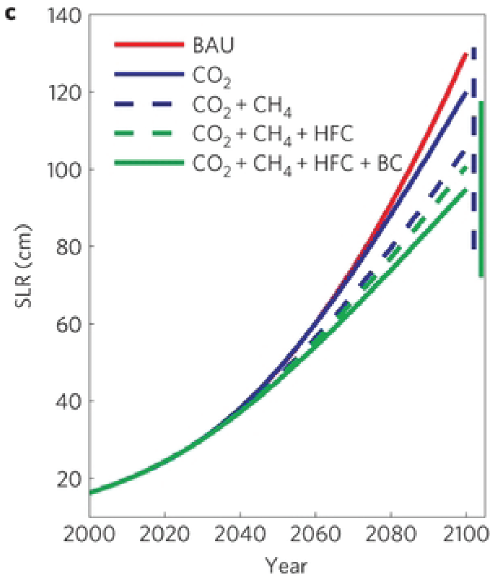
A recent OECD report ranked the top twenty at-risk cities (out of 130 key port cities worldwide) with assets and population that will be at the greatest risk from storm and flood damage due to climate change and sea-level rise of only one meter (~3 feet), and estimated that $35 trillion in assets and 150 million people will be at risk in the top 20 cities in 2070.[187] Eight of the top ten cities with assets exposed and nine of the top ten with populations at risk are in Asian countries (Table 1).

Table 1: Top 10 Cities Exposed to Coastal Flooding Damages in 2070[188]

Assets Exposed in 2070			Population Exposed in 2070		
	City	Assets ($Billion)		City	Population
1	Miami (USA)	3,513.04	1	Calcutta (India)	14,014,000
2	Guangzhou (China)	3,357.72	2	Mumbai (India)	11,418,000
3	New York-Newark (USA)	2,147.35	3	Dhaka (Bangladesh)	11,135,000
4	Calcutta (India)	1,961.44	4	Guangzhou (China)	10,333,000
5	Shanghai (China)	1,771.17	5	Ho Chi Minh City (Vietnam)	9,216,000
6	Mumbai (India)	1,598.05	6	Shanghai (China)	5,451,000
7	Tianjin (China)	1,231.48	7	Bangkok (Thailand)	5,138,000
8	Tokyo (Japan)	1,207.07	8	Rangoon (Myanmar)	4,965,000
9	Hong Kong (China)	1,163.89	9	Miami (USA)	4,795,000
10	Bangkok (Thailand)	1,117.54	10	Hai Phong (Vietnam)	4,711,000

Reducing the extent of sea-level rise in this century will limit some of the worst predicted impacts of climate change and slowing the rate of rise will give vulnerable countries and populations critical extra time to adapt. Delaying mitigation of SLCPs by 25 years (to 2040) will decrease the impact of both CO_2 and SLCP mitigation on sea-level rise this century by ~30% and could increase sea-level rise by up to 11%.[189]

Figure 8: Predicted Reductions in 21st Century Sea-Level Rise Due to SLCP and CO_2 Mitigation



Projected sea-level rise in the 21st century from BAU emissions and mitigation scenarios. The solid green line depicts full mitigation of CO_2 (peaking at 440 ppm and reducing to 420 ppm by 2100) and SLCPs (50% reductions in CO emissions and 30% in methane emissions by 2030, and 50% in black carbon emissions by 2050) beginning immediately. The solid blue line depicts reductions in cumulative sea-level rise from CO_2 mitigation alone, and the dashed blue and dashed green lines depict reductions from the inclusion of methane, and methane with HFCs respectively. Uncertainties in the reduction of sea-level rise are shown for the CO_2 + CH_4, and CO_2 + CH_4 + HFC + BC scenarios.[190]

Mitigation Measures for Short-Lived Climate Pollutants

Black Carbon and Methane Mitigation

Recent studies have identified fourteen mitigation measures targeting emissions of black carbon and methane that can provide immediate benefits.[191] These measures are capable of reducing global methane emissions by ~38% and emissions of black carbon by ~77%, realizing "nearly 90% of the maximum reduction in net GWP," from these sources.[192]

Table 2: 14 Methane and Black Carbon Control Measures

Methane Control Measures	Black Carbon Control Measures
• Control fugitive emissions from oil and gas production	• Install particulate filters on diesel vehicles
• Control emissions from coal mining	• Modernize brick kilns
• Control fugitive emissions from long distance gas transmission	• Modernize coke ovens
• Capture gas from municipal waste ans landfills	• Ban open burning of biomass
• Capture gas from livestock manure	• Eliminate high emitting on and off-road diesel vehicles
• Intermittent aeration of contantly floodes rice paddies	• Provide global access to modern cooking and heating

Reducing diesel black carbon emissions along with other key sources, including brick kilns can quickly reduce warming because of the low levels of co-emitted cooling aerosols from these sources.[193]

Other black carbon reduction measures include replacing the millions of kerosene-fueled simple wick lamps used in many developing countries, with low cost and low-emission lamps.[194] A recent study commissioned by the International Maritime Organization identified a number of abatement options for black carbon emissions from international commercial shipping, which represents 1-2% of global emissions, and concluded that emissions can be dramatically reduced at a cost savings by converting to liquefied natural gas to fuel ships, and combining slower ship speeds with electronically controlled engines.[195]

Most of the control measures for reducing black carbon, and for reducing tropospheric ozone by reducing one of its precursors, methane, can be implemented today with existing technologies, and often with existing laws and institutions, including through enhancement and enforcement of existing air quality regulations.[196]

Half of the identified black carbon and methane measures can be implemented with a net cost savings averaged globally.[197] Recent analysis indicates that approximately 64% of potential reductions in methane from the identified measures can be achieved for less than $250 per metric ton, well below the estimated ~$1100 per metric ton value gained from climate mitigation, improved health outcomes, and crop production.[198] A 2013 World Bank study found that in developing countries alone, as much as 8.2 $GtCO_2$-eq in methane emissions reductions are achievable by 2020 at less than $10 per tonne in incremental cost financing.[199] One study of shale gas wells in the U.S. found that capturing fugitive emissions can produce profits in as much as 95% of the cases.[200]

For black carbon, improved efficiencies from modernizing brick kilns and replacing traditional wood burning stoves can lead to a net cost savings, and together account for approximately half of possible black carbon reductions.[201] Recent research indicates that a large portion of the remaining black carbon mitigation measures will likely cost substantially less than the value of the health, climate, and crop benefits achieved (*see* Table 1).[202] All of these mitigation measures are ultimately cost effective when the $5.9 trillion annual benefits that start in 2030 are taken into account, and can be achieved by linearly phasing in the identified fourteen targeted control measures from 2010 through 2030 (*see* Table 1).[203]

Table 3: Valuation of Global Benefits from Full Implementation of 14 SLCP Measures [204]

	Methane Measures	Black Carbon Measures	Total
Climate Benefit[205]	*$331 (449 – 213)*	*$225 (343 – 13)*	*$556 (792 – 226)*
Crop Benefit[206]	*$4.2 (5.4 – 3)*	*$4 (7.2 – 0.8)*	*$8.2 (12.6 – 3.8)*
Health Benefit[207]	*$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)*

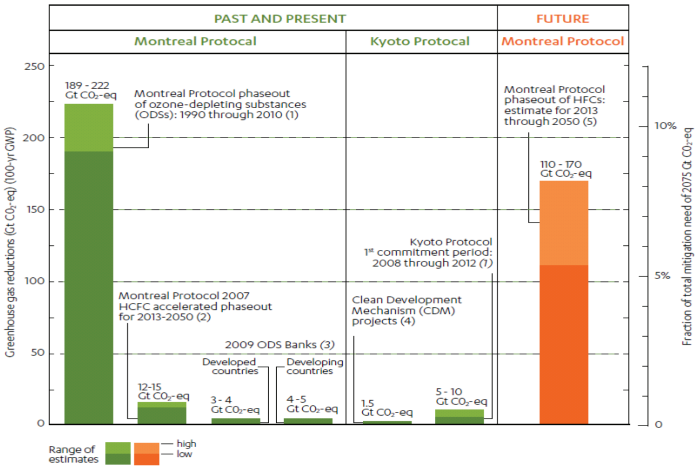
HFC Mitigation

The mitigation approach for reducing HFCs is different from that for black carbon and methane. Because they are manmade, HFCs can be most effectively controlled through a phase down of their production and consumption, which could take place under the Montreal Protocol.[208] The successful phase out of CFCs and the ongoing phase out of HCFCs have made the Montreal Protocol the world's most effective climate treaty.[209] Between 1990 and 2010 the Montreal Protocol reduced CO_2-eq emissions nearly twenty times more than the initial commitment period of the Kyoto Protocol (*see* Fig. 9).[210]

There have been two proposals put forth to phase down high-GWP HFCs under the Montreal Protocol, one by the Federated States of Micronesia, co-sponsored by Morocco and the Maldives, and the other by the North American countries, Mexico, Canada and the U.S..[211] The proposals are similar, and each would reduce 85-90% of HFC production and use, providing climate mitigation equivalent to 100 billion tonnes of CO_2 emissions by 2050 (range of 76-134 billion tonnes) (*see* Fig. 10), at very low cost. The HFC amendments would substantially eliminate the global warming caused by one of the six Kyoto Protocol greenhouse gases by avoiding the production and use of high-GWP HFCs, providing up to 7% of the total CO_2-eq mitigation needed to have a 75% chance of staying below the 2˚C guardrail.[212]

In addition to the direct climate benefits from HFC mitigation, a global HFC phase down will also provide indirect benefits through improvements in the energy efficiency of the refrigerators, air conditioners, and other products and equipment that use these chemicals. These efficiency gains will significantly reduce CO_2 emissions as well. Depending on the application, emissions from electricity use can account for between 70-95% of total climate emissions attributable to products using refrigerants.[213] For example, the U.S. EPA estimates that CFC-free chillers were up to 50% more energy efficient in the U.S. and over 30% more efficient in India than the CFC-based machines they replaced.[214] Similar improvements are expected with an HFC phase down.[215] Currently, low-GWP alternatives exist for all major sectors that achieve at least equal energy efficiency and more often result in energy savings.[216]

Figure 9: Climate Protection of the Montreal Protocol and the Kyoto Protocol



UNEP (2012) Climate Protection of the Montreal Protocol and the Kyoto Protocol.[217]

HFCs are now the fastest growing GHG pollutant in the U.S. and in many other countries. This is due in part to their being used as replacements for HCFCs, which are now being phased out, and in part to the growing global demand for air conditioning and refrigeration.[218] This demand is increasing as the world warms and as the population grows and gets richer. If left unchecked, high-end HFC growth scenarios predict that by 2050 warming from annual emissions of HFCs could be equivalent to 20% of warming from annual CO_2 emissions under a BAU scenario, and up to 45% of the warming from annual CO_2 emissions under a 450 ppm CO_2 stabilization scenario.[219]

Many national governments have taken action to reduce HFCs. Such action includes: creating national databases of equipment containing HFCs in Hungary, Slovenia, and Estonia; mandatory refrigerant leakage checks for mobile equipment in Germany, Sweden, and the Netherlands; and producer responsibility schemes requiring producers and suppliers of HFCs to take back recovered bulk HFCs for further recycling, reclamation and destruction in Sweden and Germany.[220] As part of The EU's regulatory regime to control f-gases, the European Directive on mobile air-conditioning systems (MACs) already bans the use of f-gases with GWPs higher than 150; new type vehicles are covered as of 1 January 2013, and all new vehicles by 2017.[221]

In addition to the levies and other restrictions on HFCs in Australia and New Zealand, Japan recently revised its national law to phase down HFCs, promote low-GWP equipment and products, improve containment in commercial equipment, and require registration and approval of fillers and recyclers.[222]

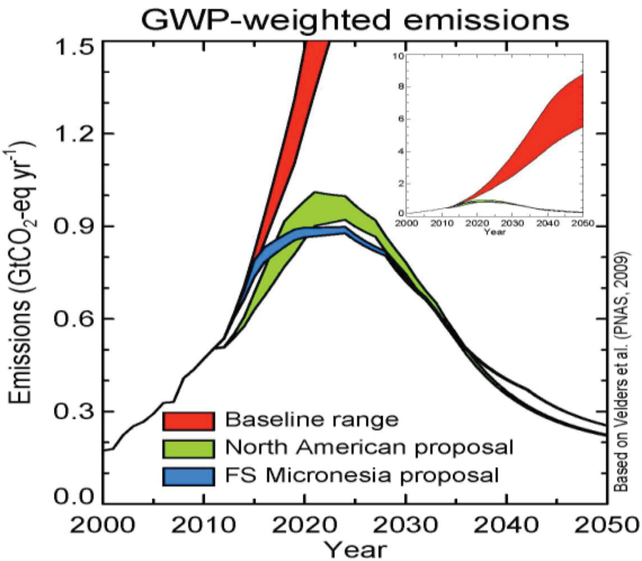
The U.S. has begun efforts to reduce HFC emission growth. In June 2013, President Obama included domestic action on HFCs as part of his *Climate Action Plan*.[223] Congressman Peters introduced the *Super Pollutant Emissions Reduction Act of 2013* to establish a U.S. task force to reduce super climate pollutants under existing authorities.[224] The U.S. allows manufacturers of cars and light-trucks to generate credits towards their compliance with CO_2 emission standards and fuel economy CAFE standards by employing HFC alternative refrigerants in mobile air conditioning systems for model year 2012-2016 vehicles.[225] According to the new rules for model years 2017-2025, U.S. CAFE standards continue to provide HFC alternative credits and include credits for improvements in mobile air conditioner efficiency.[226] Manufacturers can earn similar credits toward compliance with California's Low Emission Vehicles (LEV III) GHG emissions standards for passenger cars, light-duty trucks, and medium-duty vehicles.[227] The U.S. has also adopted standards to control HFC leakage from air conditioning systems in pickups, vans, and combination tractors.[228] The EC is currently strengthening its f-gas regulations.[229]

Private companies are also taking voluntary action to limit HFCs. The Consumer Good Forum, a global network of over 400 retailers, manufactures, service providers, and other stakeholders from over seventy countries has pledged to begin phasing out HFCs in new equipment beginning in 2015.[230] Because the global weighted average lifetime of HFCs now in use is 15 years, HFCs are included in the CCAC.[231]

Support for an HFC amendment is growing rapidly. In the Rio +20 declaration, *The Future We Want*, more than one hundred heads of state recognized the climate damage from HFCs and called for the gradual phase down of their production and consumption.[232] In addition, 108 countries have joined the *Bangkok Declaration* calling for the use of low-GWP alternatives to CFCs and HCFCs.[233] Through May 2012, 112 countries have joined the *Bali Declaration on Transitioning to Low Global Warming Potential Alternatives to Ozone Depleting Substances*.[234] On 6 September 2013 at the eighth annual G-20 Summit in St. Petersburg, Russia, leaders of the world's twenty largest economies announced support for initiatives that are complementary to efforts under the UNFCCC, including using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs.[235] On the margins of the G-20 Summit, China's President Xi Jinping and U.S. President Barack Obama also reached agreement to open formal negotiations on the amendment to phase down HFCs under the Montreal Protocol.[236] On 27 September 2013, Indian Prime Minister Manmohan Singh and President Obama agreed to immediately convene discussions of phasing down HFCs under the Montreal Protocol, leaving accounting and reporting of emissions in the UNFCCC.[237] However a few remaining countries have raised questions about the availability of HFC alternatives and additional financial resources to support a phase-down under the Montreal Protocol.[238]

At the 25th Meeting of the Parties to the Montreal Protocol, which took place from 21 to 25 October 2013 in Bangkok, countries continued to make progress on an international agreement to phase down HFCs under the Montreal Protocol. Significantly, the Africa Group, including South Africa, announced its support for "formal negotiations to enable the amendment process." Brazil and China continued to engage constructively as well, and both played an important role in writing a detailed request to the Protocol's Technology and Economic Assessment Panel (TEAP) to conduct additional research on HFCs and their alternatives.[239] India, along with several other countries, expressed concern over whether technology was available and whether developed countries would be willing to pay for the transition in developed countries as required by the Montreal Protocol. These and other concerns will be address in 2014 as the Amendment negotiations move forward.

Figure 10: Projected HFC Emission Reductions from FSM and NA Proposals



The North American proposal and the Micronesian proposal are similar; both eliminate the cumulative (2016-2050) direct GWP-weighted emissions of HFCs by more than 94 $GtCO_2$-eq.[240] This is equivalent to a reduction from projected annual emissions of 5.5 to 8.8 $GtCO_2$-eq/yr in 2050 to less than ~0.3 $GtCO_2$-eq/yr. (Dr. Velders' undated calculations show that as of 2013 the amendments can provide 76 to 134 billion tonnes CO_2-eq. by 2050.)[241]

Climate & Clean Air Coalition to Reduce SLCPs

Recognizing that mitigating SLCPs is critical to addressing climate change in the near term and complementary to global efforts to reduce CO_2, in February 2012 six countries and UNEP formed the Climate & Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). The objective of the CCAC is to accelerate and scale up actions to reduce SLCPs and to catalyze new actions. It is the first global effort to treat these pollutants as a collective challenge. The CCAC is growing rapidly, and a year after its launch it has 72 Partners (listed below), a High Level Scientific Advisory Panel, a Secretariat based at UNEP's Paris office, and a series of initiatives underway to reduce SLCPs on the ground. IGSD was elected to be the initial NGO representative on the CCAC's Steering Committee.

The CCAC is reducing 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."[242]

Ten targeted initiatives have been approved by the CCAC for rapid implementation:[243]

- Reducing Black Carbon Emissions from Heavy Duty Diesel Vehicles and Engines;
- Mitigating SLCPs and Other pollutants from Brick Production;
- Mitigating SLCPs from Municipal Solid Waste;
- Promoting HFC Alternative Technology and Standards;

- Accelerating Methane and Black Carbon Reductions from Oil and Natural Gas Production;
- Addressing SLCPs From Agriculture;
- Supporting National Planning for Action on SLCPs Initiative (SNAP);
- Financing Mitigation of SLCPs;
- Reducing SLCPs from Household Cooking and Domestic Heating; and,
- Regional Assessments of SLCPs

At the Rio+20 summit in June 2012, the CCAC and the World Bank joined New York City Mayor Michael R. Bloomberg, Chair of the C40 Cities Climate Leadership Group, former U.S. President Bill Clinton, and Rio de Janeiro Mayor Eduardo Paes to announce the launch of the *Solid Waste Network* to help cities reduce methane emissions through solid waste management.[244] In May 2012, at the Camp David Summit, the G8 nations pledged to join and support increasing near-term climate mitigation ambition through the CCAC and other international cooperative initiatives.[245] In March 2013, ten major cities from every region of the world joined the CCAC Municipal Solid Waste Initiative, and dozens of additional cities are expected to join by the end of this year.[246]

At the CCAC's third HLA, in Oslo Norway in September 2013, Ministers from CCAC partner countries, heads of organizations, and other high level representatives, pledged to scale up global efforts to reduce SLCPs and enhance their own action and "work on scaled up action over the coming year, including in line with any National Action Planning processes for reducing SLCPs."[247] Responding to a request by the G8, the World Bank released a report, during the HLA describing how they planned to mainstream reductions of SLCPS in their portfolio,[248] and agreed to work with CCAC Partners to establish a 'pay-for-performance' fund to finance methane emissions reductions, emphasizing those projects that also reduce black carbon emissions.[249] The CCAC commissioned the Finance Initiative to establish a "Black Carbon Finance Study Group composed of interested Partners and other stakeholders to review potential strategies for supporting financial flows towards projects that can significantly reduce black carbon."[250] The Black Carbon Finance Study Group will present their recommendations at the 2014 HLA.

The CCAC Secretariat is hosted by UNEP's Paris office, which manages a dedicated Trust Fund, with an initial contribution of $16.7 million from the U.S., Canada, Sweden, and Norway.[251] In September 2013, Norway announced a pledge of $20 million to support the Coalition, and the U.S. announced that it was increasing its 2013 contribution to $5.5 million.[252]

Table 4: CCAC Partners (as of September 2013)[253]

Country Partners	
• Australia	• Italy
• Bangladesh	• Japan
• Benin	• Jordan
• Canada	• Mexico
• Central African Republic	• Netherlands
• Chile	• New Zealand
• Colombia	• Nigeria
• Cote d'Ivoire	• Norway
• Denmark	• Peru
• Dominican Republic	• Poland
• Ethiopia	• Republic of Korea
• Finland	• Republic of Maldives
• France	• Sweden
• Germany	• Switzerland
• Ghana	• United Kingdom
• Ireland	• United States of America
• Israel	

<table>
<tr><th colspan="2">Inter-Governmental Partners</th></tr>
<tr><td>

- European Commission
- International Centre for Integrated Mountain Development (ICIMOD)
- Inter-American Institute for Cooperation on Agriculture (IICA)
- Nordic Environment Finance Corporation (NEFCO)
- Regional Environmental Center (REC)

</td><td>

- UN Environment Programme (UNEP)
- UN Development Programme (UNDP)
- UN Industrial Development Organization (UNIDO)
- World Bank
- World Health Organization (WHO)

</td></tr>
<tr><th colspan="2">Non-Governmental Partners</th></tr>
<tr><td>

- Bellona Foundation
- Caucasus Environmental NGO Network (CENN)
- Center for Clean Air Policy
- Center for Human Rights & Environment (CEDHA)
- Centre for Science and Environment (CSE)
- Clean Air Initiative for Asian Cities, Inc.
- Clean Air Institute
- Clean Air Task Force
- Climate Market Investment Association (CMIA)
- ClimateWorks Foundation
- Earthjustice
- Environmental Defense Fund (EDF)
- Environmental Investigation Agency (EIA)
- EvK2CNR Committee
- Global Alliance for Clean Cookstoves
- Institute for Advanced Sustainability Studies (IASS)
- Institute for Global Environmental Strategies (IGES)
- Institute for Governance & Sustainable Development (IGSD

</td><td>

- International Climate Change Partnership (ICCP)
- International Council on Clean Transportation (ICCT)
- International Cryosphere Climate Initiative (ICCI)
- International Institute for Sustainable Development (IISD)
- International Solid Waste Association (ISWA)
- International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA)
- Local Governments for Sustainability (ICLEI)
- Molina Center for Strategic Studies in Energy & the Environment
- Natural Resources Defense Council (NRDC)
- Stockholm Environment Institute (SEI)
- Swiss Foundation for Technical Cooperation (Swisscontact)

</td></tr>
</table>

Other Regional and Global SLCP Mitigation Initiatives

In addition to the CCAC there are a number of other global and regional initiatives that target SLCPs.[254] For example, the Executive Body of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) recently approved an amendment to the Gothenburg Protocol adopting new PM requirements and including specific language on black carbon, making it the first international treaty to act on the link between air pollution and climate change.[255] The Global Alliance for Clean Cookstoves and the Global Methane Initiative are both specifically targeting some of the largest global sources of black carbon and methane emissions.[256] UNEP's Atmospheric Brown Cloud program is also addressing black carbon and tropospheric ozone, with a focus on Asia and plans to expand to Latin America and Africa.[257] The International Maritime Organization (IMO) is currently considering whether to control black carbon emissions from ships[258] and recently completed an investigation on control measures to reduce black carbon from international shipping.[259]

The Arctic Environment Ministers recently called for "urgent action" to reduce SLCPs to protect the Arctic and reduce the risk of feedback mechanisms that accelerate warming and lead to irreversible impacts, and encouraged the Arctic Council to consider a new "instrument or other arrangements to enhance efforts to reduce emissions of black carbon from the Arctic States" for decision at the 2015 Arctic Ministerial meeting.[260] The Arctic Council also supports phasing down HFCs under the Montreal Protocol and national black carbon emission inventories for the Arctic.[261] And, as noted previously, the EU is moving forward with new regulations on HFCs.[262]

National SLCP Mitigation Initiatives

There are a number of ongoing national initiatives to reduce individual SLCPs, including national laws addressing air pollutants, as well as laws addressing HFCs, several of which are described above.[263] In the U.S., President Obama's *2013 Climate Action Plan* specifically targets SLCPs using his executive authority.[264] U.S. NGOs have also called for an Inter-Agency Task Force to Reduce SLCPs, using existing authorities to identify and implement rapid mitigation strategies and best practices for SLCPs inside and outside the U.S. government.[265]

Conclusion

Reducing SLCPs will reduce near-term climate impacts, including sea-level rise, slow dangerous feedbacks, allow more time to adapt, and reduce the risk of passing tipping points that could lead to irreversible climate damage. In addition to providing near-term climate benefits, cutting SLCPs would also provide major benefits for human health and food security, would contribute to sustainable development goals, and would protect the significant gains in poverty reduction that otherwise will be reversed by near-term climate change impacts.[266] Cutting SLCPs to achieve near-term climate benefits is an important complement to reducing CO_2 emissions—indeed, cutting SLCPs builds a broader on-ramp to more aggressive CO_2 mitigation. But SLCP reductions are not a substitute for the immediate action urgently needed to reduce CO_2. Reducing both CO_2 and SLCPs provides the best chance of limiting global temperature rise to below 2°C through 2100; aggressive mitigation of CO_2 can avoid 1.1°C of warming by the end of the century, and aggressive mitigation of SLCPs also can avoid as much as 1.5°C in this timeframe.[267] As highlighted by Nobel Laureate Mario Molina and co-authors, regulatory measures in dedicated venues such as the Montreal Protocol are often the preferred way to reduce climate pollutants, including SLCPs.[268]

Appendix

Background on IGSD's fast-action campaign to reduce Short-Lived Climate Pollutants

IGSD's fast-action climate mitigation campaign to reduce SLCPs promotes using existing laws and institutions to achieve immediate climate mitigation, to complement efforts under the UNFCCC. IGSD's strategy was presented in a 2009 article written by Nobel Laureate Mario Molina, Durwood Zaelke, Veerabhadran Ramanathan, Stephen O. Andersen, & Donald Kaniaru, *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*. The paper was written for the *Proceedings of the National Academy of Sciences* as the policy piece in a *PNAS Special Feature* on climate tipping points edited by John Schellnhuber.

The article defines fast-action strategies as those that can be started in two to three years, substantially implemented in five years in developed countries and ten years in developing countries, and can produce a response in the climate system on a timescale of decades, to complement cuts in CO_2, which operate on a longer timescale. Broad implementation of these strategies can cut the rate of global warming in half and the rate of Arctic warming by two-thirds over the next several decades.

The HFC component of this approach was updated in a November 2012 policy paper, *Strengthening Ambition for Climate Mitigation: The Role of the Montreal Protocol in Reducing Short-lived Climate Pollutants*, by Durwood Zaelke, Stephen O. Andersen, & Nathan Borgford-Parnell in RECIEL, and the science component in a June 2013 science paper, *The role of HFCs in mitigating 21st century climate change*, by Yangyang Xu, Durwood Zaelke, Guus J. M. Velders, and Veerabhadran Ramanathan (26 June 2013). The paper calculates that mitigating SLCPs can avoid 1.5°C of warming by end-of-century, comparable to 1.1°C of warming that can be avoided by aggressive CO_2 mitigation by end-of-century. The paper calculates that by 2050 SLCP mitigation can avoid six times more warming than aggressive CO_2 mitigation (0.6°C from SLCP mitigation, compared to 0.1°C from CO_2 mitigation). Up to one-third of the total of 1.5°C in avoided warming from SLCP mitigation, or 0.5°C, will come from cutting HFCs.

Related research led by Ramanathan published April 2013 in Nature Climate Change calculates that cutting SLCPs can reduce the rate of sea-level rise quickly by about 25%, and when coupled with aggressive CO_2 mitigation, can double this. Individual contributions to avoided sea-level rise by 2100 from different mitigation actions are: 29% from CO_2 measures and 71% from SLCP measures (13% from HFC measures, 17% from black carbon measures, and 41% from methane measures). Aixue Hu, Yangyang Xu, Claudia Tebaldi, Warren M. Washington & Veerabhadran Ramanathan, *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change (14 April 2013).

IGSD promotes the importance of reducing SLCP through scientific and policy publications, several of which are listed below. IGSD also promotes the importance of SLCP mitigation in various policy venues, as well as through the media. Op-Eds by IGSD, and others, are listed below, along with a list of Editorials in *Nature*, *The Economist*, *The New York Times*, *The Washington Post*, and *Bloomberg*.

IGSD Publications on SLCPs

1. Yangyang Xu, Durwood Zaelke, Guus J. M. Velders, & Veerabhadran Ramanathan (2013) *The role of HFCs in mitigating 21st century climate change*, Atmos. Chem. Phys. 13:6083-6089.

2. Stephen O. Andersen, Marcel L. Halberstadt, & Nathan Borgford-Parnell (2013) *Stratospheric ozone, global warming, and the principle of unintended consequences – An ongoing science and policy success story*, J. Air & Waste Mgmt. Ass'n. 63(6):607-647.

3. Council on Energy, Environment & Water, Institute for Governance & Sustainable Development, Natural Resources Defense Council, and The Energy and Resources Institute (TERI), in cooperation with the Confederation of Indian Industry (2013) *Cooling India with Less Warming: The Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioners*.

4. Durwood Zaelke, Nathan Borgford-Parnell, & Danielle Fest Grabiel (2013) *Primer on Hydrofluorocarbons*.

5. Durwood Zaelke, Stephen O. Andersen, & Nathan Borgford-Parnell (2012) *Strengthening Ambition for Climate Mitigation: The Role of the Montreal Protocol in Reducing Short-Lived Climate Pollutants*, Rev. Eur. Comp. & Int'l Envtl. Law 21(3):231-242.

6. Mario Molina & Durwood Zaelke (2013), *A comprehensive approach for reducing anthropogenic climate impacts including risk of abrupt climate changes*, Fate of Mountain Glaciers in the Anthropocene, *Proceedings of the Working Group*, 2-4 April 2011, Paul J. Crutzen, Lennart Bengtsson

& Veerabhadran Ramanathan (eds) (Pontifical Academy of Sciences, *Scripta Varia* 118).

7. Mario Molina & Durwood Zaelke (2012), *A Climate Success Story to Build On*, UNEP OzonAction, Protecting our atmosphere for generations to come: 25 years of the Montreal Protocol.

8. Mario Molina, A. R. Ravishankara, & Durwood Zaelke (2011) *At the crossroads*, UNEP Our Planet: Powering Climate Solutions.

9. Romina Picolotti (December 2011) *An equitable arrangement*, UNEP Our Planet: Powering Climate Solutions.

10. Stephen O. Andersen & Kristen Taddonio (December 2011) *Tipping the Balance*, UNEP OzonAction's December 2011 Special Issue.

11. Mario Molina, Durwood Zaelke, Veerabhadran Ramanathan, Stephen O. Andersen, & Donald Kaniaru (2009) *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*, Proc. Nat'l Acad. Sci. USA 106(49):20616-20621.

12. Guus J. M. Velders, David W. Fahey, John S. Daniel, Mack McFarland, & Stephen O. Andersen (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l Acad. Sci. USA 106:10949.

13. Romina Picolotti (15 July 2010) *A Proposal to Change the Political Strategy of Developing Countries in Climate Negotiations,* IISD's MEA Bulletin.

14. Dennis Clare, Kristina Pistone, & Veerabhadran Ramanathan (2010) *Getting rid of black carbon: A neglected but Effective Neart-Term Mitigation Avenue*, Georgetown J. of International Affairs 11(2):99-106.

15. K. Madhava Sarma, Stephen O. Andersen, Durwood Zaelke, & Kristen Taddonio (2009), *Ozone Layer, International Protection*, *in* R. Wolfrum (ed.), The Max Planck Encyclopedia of Public International Law (Oxford University Press, 2008-2012), online edition.

16. Durwood Zaelke, Peter Grabiel, & Elise Stull (6 November 2008), *Avoiding Tipping Points for Abrupt Climate Changes with Fast-Track Climate Mitigation Strategies*, IISD's MEA Bulletin.

17. K. Madhava Sarma & Durwood Zaelke (27 June 2008), *Start, then Strengthen: The Importance of Immediate Action for Climate Mitigation*, IISD's MEA Bulletin.

18. Guus J. M. Velders, Stephen O. Andersen, John S. Daniel, David W. Fahey, & McFarland M. (2007) *The importance of the Montreal Protocol in protecting climate*, Proc. Nat'l Acad. Sci. USA 104:4814-4819.

Select Editorials and Op-Eds on HFCs and the Montreal Protocol

Editorials:

1. *Nature*, Editorial, "All together now' (30 October 2013)

2. *The New York Times,* Editorial, "At Last, an Action Plan on Climate" (25 June 2013)

3. *The New York Times,* Editorial, "Fresh Start for a Critical Relationship" (10 June 2013)

4. *The New York Times,* Editorial, "Climate Warnings, Growing Louder" (18 May 2013)

5. *Bloomberg*, Editorial, "How to Make Air Conditioners Less Guzzling and More Green" (23 Sept 2012)

6. *The Washington Post,* Editorial, "Ways to fight warming: Strategies that would reduce emissions" (26 Feb 2012)

7. *The New York Times*, Editorial, "A Second Front in the Climate War" (17 Feb 2012)

8. *The Economist*, Editorial, "Piecemeal possibilities" (17 Feb 2011)

9. *Nature*, "More in Montreal: Momentum builds for ozone treaty to take on greenhouse gases" (3 Nov 2011)

10. *The Economist*, Editorial, "Unpacking the problem" (3 Dec 2009)

11. *Nature*, Editorial, "Time for early action" (1 July 2009)

Op-Eds:

1. *Los Angeles Times*, Op-Ed, D. Zaelke & P. Bledsoe, "Climate policy's twin challenges' (16 Aug 2013)

2. *The New York Times,* Op-Ed, W. Ruckelshaus, L. Thomas, W. Reilly, & C. T. Whitman, "A Republican Case for Climate Action" (1 Aug 2013)

3. *Washington Post,* Op-Ed, J. Yong Kim, "U.S. takes key climate change steps, but the world must do more" (27 June 2013)

4. *Roll Call,* Op-Ed, D. Zaelke & P. Bledsoe, "India Can Join the U.S. and China to Cut Super Greenhouse Gases" (20 June 2013)

5. *The Hill,* Op-Ed, D. Zaelke & P. Bledsoe, "A climate victory waiting for presidents Obama and Xi" (6 June 2013)

6. *Real Clear Politics,* Op-Ed, D. J. Weiss, "U.S. Must Cut Climate Pollutants" (21 May 2013)
7. *The Hill,* Op-Ed, Sen. C. Murphy, "What's missing from climate debate" (13 May 2013)
8. *The New York Times,* Op-Ed, D. Zaelke & V. Ramanathan, "Going Beyond Carbon Dioxide" (7 Dec 2012)
9. *The International Herald Tribune,* Op-Ed, M. Molina & D. Zaelke, "A Climate Success Story to Build On" (26 Sept 2012)
10. *The Hill*, Op-Ed, D. Zaelke & A. Light, "Rio meeting can still produce a key climate outcome" (20 June 2012)
11. *U-T San Diego*, Op-Ed, V. Ramanathan & D. Zaelke, "Earth Day: Saving out planet, saving ourselves" (21 April 2012)
12. *The Hill,* Op-Ed, M. Molina & D. Zaelke, "How to cut climate change in half" (14 Feb 2012)
13. *New York Times*, Op-Ed, V. Ramanathan and D. Victor, "To Fight Climate Change, Clear the Air" (28 Nov 2010)
14. *The Guardian*, Op-Ed, A. Steiner, "CO_2 is not the only cause of climate change," (11 Sept 2009)

Endnotes

[1] Forster P., *et al.* (2007) Changes in Atmospheric Constituents and in Radiative Forcing, *in* Solomon S. *et al.* (2007) Climate Change 2007: Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 2.21.

[2] *Id.*

[3] Myhre G., *et al.* (2013) Chapter 8: Anthropogenic and Natural Radiative Forcing, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ8.2 ("Unlike carbon dioxide and other WMGHG, tropospheric ozone and aerosols may only last in the atmosphere for a few days to a few weeks, though indirect couplings within the Earth system can prolong their impact. These pollutants are usually most potent near their area of emission or formation, where they can force local or regional perturbations to climate, even if their globally averaged effect is small.").

[4] The science of SLCPs dates back to the 1970s. *See e.g.*, Ramanathan V. (1975) *Greenhouse effect due to chlorofluorocarbons: climatic implications*, Sci. 190:50-52; *see also* Wang *et al*. (1976) *Greenhouse effects due to man-made perturbations of trace gases*, Sci. 194:685-690. 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) *Trace gas trends and their potential role in climate change*, J. Geophys. Res. 90:5547-5566. This finding has been confirmed and strengthened in the following decades by

hundreds of studies culminating in IPCC reports (IPCC (1990) Overview Chapter, in IPCC (1990) FIRST ASSESSMENT REPORT; IPCC (1995) SECOND ASSESSMENT REPORT: CLIMATE CHANGE 1995; IPCC (2001) THIRD ASSESSMENT REPORT: CLIMATE CHANGE 2001; *and* IPCC (2007) CLIMATE CHANGE 2007: SYNTHESIS REPORT.) In short, researchers have had at least 25 years to carefully develop the science of SLCPs and assess the findings. Bond, *et al.* is the most recent assessment in this field. Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552.

[5] Ramanathan V. & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, PROC. NAT'L ACAD. SCI. USA 107:8055-8062, 8056 ("CO_2 (1.65 Wm^{-2}) and the non-CO_2 GHGs (1.35 Wm^{-2}) have added 3 (range: 2.6–3.5) Wm^{-2} of radiant energy since preindustrial times.…. The 3 Wm^{-2} energy should have led to a warming of 2.4°C (14). The observed warming trend (as of 2005) is only about 0.75 °C (15), or 30% of the expected warming. Observations of trends in ocean heat capacity (16) as well as coupled ocean–atmosphere models suggest that about 20% (0.5°C warming) is still stored in the oceans (17). The rest of the 50% involves aerosols or particles added by air pollution.").

[6] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734; *see also* Xu Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, ATMOS. CHEM. PHYS., 13:6083-6089; *and* Ramanathan V. & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, PROC. NAT'L ACAD. SCI. USA 107:8055-8062. Two earlier studies only modeled temperatures out to 2070, but still show significant avoided warming from SLCP mitigation. *See* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term*

climate change and improving human health and food security, SCI. 335(6065):183-189; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[7] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 731 ("By 2050, on the other hand, the SLCPs reduce projected warming by 0.6°C and CO_2 only about 0.1°C."); *see also* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 183 ("We identified 14 measures targeting methane and BC emissions that reduce projected global mean warming ~0.5°C by 2050."); Bond T. C., *et al.*, and accompanying press release. Bond T. C. *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552; *and* Press Release, American Geophysical Union, *Black carbon is much larger cause of climate change than previously assessed* (15 January 2013).

[8] *See* United Nations Environment Programme & World Meteorological Organization (herein after UNEP/WMO) (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, Table 5.2.

[9] During the past half century, the rate of global warming has been about 0.13°C per decade. Solomon S., *et al.* (2007) TECHNICAL SUMMARY *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 36. The rate of warming in the Arctic is currently at least twice the global average and in the Himalayas and Tibet three times the average. Arctic Monitoring and Assessment Programme (2011) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC, EXECUTIVE SUMMARY AND KEY MESSAGE, 4. Average global surface temperatures have increased by 0.8°C, over the 1880–1920 average, and under business-as-usual it could increase by an additional 2°C by 2070.

Hansen J., *et al.* (2010) *Global surface temperature change*, REV. GEOPHYS. 48:4004; Solomon S., *et al.* (2007) TECHNICAL SUMMARY *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 36; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[10] Mitigation of 1.1°C derived from Table 1 projected warming between 2005 and 2100 from SLCP only mitigation (1.1°C) compared to BAU (3.5°C). Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734; *see also* Xu Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, ATMOS. CHEM. PHYS., 13:6083-6089; *and* Ramanathan V. & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, PROC. NAT'L ACAD. SCI. USA 107:8055-8062. Two earlier studies only modeled temperatures out to 2070, but still show significant avoided warming from SLCP mitigation. *See* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[11] For analysis of these impacts *see* Schneider, S. H., *et al.* (2007) ASSESSING KEY VULNERABILITIES AND THE RISK FROM CLIMATE CHANGE, *in* Parry M. L., *et al.* (2007) CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY 779-810; *and* IPCC (2012) MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS TO ADVANCE CLIMATE CHANGE ADAPTATION: SPECIAL REPORT OF WORKING GROUPS I AND II OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE.

[12] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-

734, 732 ("The SLCP mitigation would contribute about 24% of the SLRfull rate reduction [in 2100]…. With both the CO_2 and the SLCP mitigation, the projected SLR_{full} (from 2005 to 2100) is reduced by 31% from the BAU case; about 9% of that 31% is due to CO_2 mitigation and the balance of 22% is due to SLCPs.").

[13] In the St. Petersburg *G20 Leaders' Declaration*, the leaders of the world's twenty largest economies, as well as heads of State from six invited observer States, expressed their support for initiatives that are complementary to efforts under the UNFCCC, including using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs, while retaining HFCs within the scope of the UNFCCC and its Kyoto Protocol for accounting and reporting of emissions. G20 (2013) G20 Leaders' Declaration ("We are committed to support the full implementation of the agreed outcomes under the United Nations Framework Convention on Climate Change (UNFCCC) and its ongoing negotiations.... We also support complementary initiatives, through multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs), based on the examination of economically viable and technically feasible alternatives. We will continue to include HFCs within the scope of UNFCCC and its Kyoto Protocol for accounting and reporting of emissions.").

[14] G8 (2013) G8 Leaders' Communique ("57. We will pursue ambitious and transparent action, both domestically and internationally, in the UNFCCC, complemented by actions addressed through other relevant fora, including but not limited to: the Major Economies Forum (MEF), where we will work with our partners to secure progress on the MEF Action Agenda and to overcome differences on the road to the global deal in 2015; the International Civil Aviation Organisation (ICAO), where we call for the agreement at the Assembly in September 2013

on an ambitious package related to both market-based and non-market based measures to address rising aviation emissions; the International Maritime Organisation (IMO), where we continue to work together on further measures to address the issue of shipping emissions; the Climate and Clean Air Coalition which we all committed to join at our last Summit, where we will build on the eight global initiatives already begun and further develop the scientific evidence base and private sector involvement.").

[15] UNEP (2013) THE EMISSIONS GAP REPORT, viii ("International cooperative initiatives - Initiatives outside of the United Nations Framework Convention on Climate Change aimed at reducing emissions of greenhouse gases by promoting actions that are less greenhouse gas intensive, compared to prevailing alternatives.").

[16] UNFCCC, Compilation of information on mitigation benefits of actions, initiatives and options to enhance action: list of selected cooperative initiatives.

[17] UNEP (2013) THE EMISSIONS GAP REPORT, ("There is an increasing number of international cooperative initiatives, through which groups of countries and/or other entities cooperate to promote technologies and policies that have climate benefits, even though climate change mitigation may not be the primary goal of the initiative. These efforts have the potential to help bridge the gap by several $GtCO_2e$ in 2020.").

[18] Climate and Clean Air Coalition to Reduce Short Lived Climate Pollutants, About.

[19] Press Release, G8, *Camp David Declaration* (19 May 2012); *and* Press Release, US Dept. of State, *G8 Foreign Ministers' Meeting Statement* (11 April 2013).

[20] World Bank (2013) INTEGRATION OF SHORT-LIVED CLIMATE POLLUTANTS IN WORLD BANK ACTIVITIES, 30 ("SLCP-relevant activities in energy, transport, roads, agriculture, forestry, and urban waste and wastewater. Going forward, the goal will be to transform as much of the SLCP-relevant activities as possible into

SLCP reducing activities. Specific commitments for the World Bank on SLCP-reducing activities will be articulated as part of the climate action planning process which is expected to conclude in 2014.").

[21] CCAC (2013) Third Meeting of the High Level Assembly: Communique, Oslo Norway; *see also* Press Release, World Bank, *Cutting Short-Lived Climate Pollutants: A Win-Win for Development and Climate* (3 September, 2013) ("According to the report, reductions of as much as 8,200 million tons of CO_2 equivalent could be delivered in developing countries at less than $10 per ton in incremental cost financing – a gap which can be closed by pay-for-performance mechanisms."); *and* World Bank (2013) Methane Finance Study Group Report.

[22] United Nations (2012) Resolution adopted by the General Assembly: The future we want, A/res/66/288.

[23] Proposed Amendment to the Montreal Protocol (submitted by the Federated States of Micronesia) (16 April 2013).

[24] Proposed Amendment to the Montreal Protocol (submitted by Mexico, Canada and the United States) (16 April 2013); *see also* U.S. Envtl. Prot. Agency (2013) Benefits of Addressing HFCs under the Montreal Protocol.

[25] As of May 2013, more than 112 Parties have expressed support. European Council (2013) Submission by Ireland and the European Commission of the European Union and its Member States ("The 2011 Bali Declaration under the Montreal Protocol lists 112 signatories committed to explore further and pursue effective means of transitioning to environmentally friendly alternatives to high GWP HFCs.").

[26] The G-20 declaration included Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and the European Union, as well as support from invited non-member countries: Ethiopia, Spain,

Senegal, Brunei, Kazakhstan, and Singapore. G-20 (2013) G20 Leaders' Declaration ("101. We are committed to support the full implementation of the agreed outcomes under the United Nations Framework Convention on Climate Change (UNFCCC) and its ongoing negotiations.... We also support complementary initiatives, through multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs), based on the examination of economically viable and technically feasible alternatives. We will continue to include HFCs within the scope of UNFCCC and its Kyoto Protocol for accounting and reporting of emissions.").

[27] Press Release, White House Office of the Press Secretary, *United, China, and Leaders of G-20 Countries Announce Historic Progress Toward a Global Phase Down of HFCs* (6 September 2013) ("We reaffirm our announcement on June 8, 2013 that the United States and China agreed to work together and with other countries through multilateral approaches that include using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs, while continuing to include HFCs within the scope of UNFCCC and its Kyoto Protocol provisions for accounting and reporting of emissions. We emphasize the importance of the Montreal Protocol, including as a next step through the establishment of an open-ended contact group to consider all relevant issues, including financial and technology support to Article 5 developing countries, cost effectiveness, safety of substitutes, environmental benefits, and an amendment. We reiterate our firm commitment to work together and with other countries to agree on a multilateral solution."). The US-China agreement builds upon more than four months of high-level negotiations between the two nations including the first-ever summit between President Obama and President Xi on 8 June 2013 where they agreed to "work together and with other countries to

use the expertise and institutions of the Montreal Protocol to phase down the consumption and production of hydrofluorocarbons (HFCs)." *See* Press Release, The White House Office of the Press Secretary, *United States and China Agree to Work Together on Phase -Down of HFCs* (8 June 2013). *And* Press Release, White House Office of the Press Secretary, *U.S.-India Joint Statement* (27 September 2013) ("The two leaders agreed to immediately convene the India-U.S. Task Force on hydrofluorocarbons (HFCs) to discuss, inter alia, multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the consumption and production of HFCs, based on economically-viable and technically feasible alternatives, and include HFCs within the scope of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol for accounting and reporting of emissions…. They also supported complementary initiatives, through multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the production and the consumption of HFCs, based on the examination of economically viable and technically feasible alternatives. They will continue to include HFCs within the scope of UNFCCC and its Kyoto Protocol for accounting and reporting of emissions.").

[28] European Commission (2012) Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, COM(2012)0643 final; European Parliament, Committee on the Environment, Public Health and Food Safety (2013) Draft Report on the proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases, 2012/0305(COD); *and* Schwarz W., *et al.* (2011) Preparatory Study for a Review of Regulation (EC) No 842/2006 on Certain Fluorinated Greenhouse Gases: Final Report.

[29] Consumer Goods Forum (2012) Better Lives Through Better Business, 10; *see also* The Consumer Goods Forum,

Sustainability Pillar; *and* Refrigerants, Naturally!, What we do.

[30] Solomon S., *et al.* (2007) CLIMATE CHANGE 2007: PHYSICAL SCIENCE BASIS, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change ("While more than half of the CO_2 emitted is currently removed from the atmosphere within a century … about 20% … remains … for many millennia."); *see also* Archer D., *et al.* (2009) *Atmospheric lifetime of fossil fuel carbon dioxide*, ANNU. REV EARTH PLANET. SCI. 37:117-134, 131 ("Equilibration with the ocean will absorb most of it [CO_2] on a timescale of 2 o 20 centuries. Even if this equilibration were allowed to run to completion, a substantial fraction of the CO_2, 20-40%, would remain in the atmosphere awaiting slower chemical reactions with $CaCO_3$ and igneous rocks."); Matthews H. D. & Caldeira K. (2008) *Stabilizing climate requires near-zero emissions*, J. GEOPYSICAL RES. 35(4):L04705 ("[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."); *and* Hansen J., *et al*. (2007) *Climate change and trace gases*, PHIL. TRANS. R. SOC. 365:1925-1854, 1938 ("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.").

[31] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 732 ("For the CO_2 emission path, we adopt the Representative Concentration Pathway (RCP)6.0 scenario, which we consider as the CO_2 business as usual (BAU) case, and the RCP2.6 for the mitigation case… By the end of the twenty-first century, the effect of CO_2 mitigation on temperature increases by tenfold to ~1.1°C compared with the mitigation of 0.1°C by 2050."); *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 241 ("For example, mitigation of

0.15°C due to CO_2 measures takes place only around 2050 (Figure 6.1) under the CO_2 measures scenario; 30 years after emissions begin to decline rapidly. The influence of the CO_2 reductions grows rapidly, however, so that they mitigate roughly 0.5°C by 2070. Hence a delay of 20 years in implementation of those CO_2 reductions would mean that only ~0.15°C of warming mitigation relative to the reference scenario would be achieved within the 2070 timeframe examined here. Thus delayed CO_2 measures plus all the near-term measures examined here would lead to warming of about 2.1°C in 2070 rather than the 1.75°C shown in Figure 6.1. Conversely, a delay in reducing emissions of short-lived species would have a large impact on near-term warming rates, but little effect on 2070 temperatures (see Figure 5.12).").

[32] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 732 ("By the end of the twenty-first century, the effect of CO_2 mitigation on temperature increases by tenfold to ~1.1°C compared with the mitigation of 0.1°C by 2050. This, in conjunction with the SLCP mitigation, is sufficient to avoid reaching the 2°C threshold until 2100."). Mitigation of 2.3°C derived from Table 1 projected warming between 2005 and 2100 from full mitigation (1.2°C) compared to BAU (3.5°C).

[33] U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON; *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[34] U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON; *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[35] Myhre G., *et al.* (2013) CHAPTER 8: ANTHROPOGENIC AND NATURAL RADIATIVE FORCING, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Table 8.A.6; *citing* Bond T. C., *et al.* (2013)

Bounding the role of black carbon in the climate system: a scientific assessment, J. of Geophys. Res. –Atmos. 118(11):5380-5552.

[36] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. of Geophys. Res. –Atmos. 118(11):5380-5552, 5381 ("We estimate that black carbon, with a total climate forcing of +1.1 W m^{-2}, is the second most important human emission in terms of its climate-forcing in the present-day atmosphere; only carbon dioxide is estimated to have a greater forcing."). This study confirms earlier estimates by Jacobson (2001) and Ramanathan and Carmichael (2008), which also concluded that black carbon is the second largest contributor to global warming after CO_2. *See also* Jacobson M. Z. (2001) *Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols,* Nat. 409:695–679; *and* Ramanathan V. & Carmichael G. (2008) *Global and regional climate changes due to black carbon*, Nat. Geosci. 1:221-227*; and* U.S. Envtl. Prot. Agency (2012) Report to Congress on Black Carbon, 4, 18 ("The sum of the direct and snow/ice albedo effects of BC on the global scale is likely comparable to or larger than the forcing effect from methane, but less than the effect of carbon dioxide; however, there is more uncertainty in the forcing estimates for BC….").

[37] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. of Geophys. Res. –Atmos. 118(11):5380-5552, 5381 ("The best estimate of industrial-era climate forcing of black carbon through all forcing mechanisms, including clouds and cryosphere forcing, is +1.1 W m^{-2} with 90% uncertainty bounds of +0.17 to +2.1 W m^{-2}. "); The IPCC AR5 handles black carbon differently from Bond *et al.*, chosing only to estimate the radiative forcing of black carbon from fossil and biofuel burning, and cryosphere forcing. The radiative forcing from other sources of black carbon, such as open burning, are combined with the radiative forcing of co-emitted aerosols.

Bond *et al.* also includes black carbon-cloud interactions in their forcing estimate, whereas the IPCC estimates these interactions for all aerosols combined. Artaxo P., *et al.* (2013) Chapter 7: Clouds and Aerosols; *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 147 ("RF from BC is evaluated in different ways in the literature. The BC RF in this report is from fossil fuel and biofuel sources, while open burning sources are attributed separately to the biomass-burning aerosol, which also includes other organic species. BC can also affect clouds and surface albedo…. We use our expert judgement here to adopt a BC RF estimate that is halfway between the two estimates and has a wider uncertainty range from combining distributions. This gives a BC RF estimate from fossil fuel and biofuel of +0.4 (+0.05 to +0.8) W m^{-2}…. For this [black carbon snow and ice] RF, we adopt an estimate of +0.04 (+0.02 to +0.09) W m^{-2} and note that the surface temperature change is roughly three (two to four) times more responsive to this RF relative to CO_2.").

[38] Myhre G., *et al.* (2013) Chapter 8: Anthropogenic and Natural Radiative Forcing, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Table 8.2.

[39] Janssen N., *et al.* (2012) Health effects of black carbon, World Health Organization; *see also* Smith K. R., *et al.* (2009) *Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants*, The Lancet 274(9707):2091-2103.

[40] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Little is known about the direct impacts of black carbon on vegetation. Black carbon generally increases

leaf temperature which will affect plant growth and physiology. (Road) dust in general might block stomata, affecting stomatal function. Increases in leaf temperature, transpiration and uptake of gaseous pollutants have been reported….").

[41] Harmens H., *et al.* (2011) AIR POLLUTION AND VEGETATION: ICP VEGETATION ANNUAL REVIEW 2010/2011, Centre for Ecology & Hydrology (", together with decreases in photosynthesis due to shading or impeded diffusion after exposure to dust. Indirect effects of black carbon on vegetation include atmospheric warming and a change in direct-to-diffuse radiation ratio, affecting plant photosynthesis.").

[42] U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON.

[43] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552, 5405 ("With this method, a bottom-up estimate of total global emissions in the year 2000 is about 7500 Gg BC yr-1, with an uncertainty range of 2000 to 29000 Gg yr-1."); *see also* U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON.

[44] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552; *see also* U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON.

[45] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552; *see also* U.S. Envtl. Prot. Agency (2012) REPORT TO CONGRESS ON BLACK CARBON.

[46] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, Accepted J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552, 5406 ("Major sources of BC, ranked in order of increasing POA:BC [primary organic aerosol:black carbon] ratio, are diesel vehicles, residential

burning of coal, small industrial kilns and boilers, burning of wood and other biomass for cooking and heating, and all open burning of biomass. A few of these sources also emit significant quantities of SO_2.").

[47] Ramanathan V., *et al.* (2013) BLACK CARBON AND THE REGIONAL CLIMATE OF CALIFORNIA: REPORT TO THE CALIFORNIA AIR RESOURCES BOARD, Contract 08-323.

[48] *Id.*

[49] Feng Y., Ramanathan V., & Kotamarthi V. R. (2013) *Brown carbon: a significant atmospheric absorber of solar radiation*, ATMOS. CHEM. PHYS. 13:8607-8621; *see also* Andreae M. O. & Ramanathan V. (2013) *Climate's dark forcings*, SCI. 340(6130):280-281; Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552; Feng Y., *et al.* (2013) *Brown carbon: a significant atmospheric absorber of solar radiation?*, ATMOS. CHEM. PHYS. DISCUSS. 13:2795-2833; *and* Bahadur R., *et al.* (2012) *Solar absorption by elemental and brown carbon determined from spectral observations*, PROC. NATL. ACAD. SCI. 109(43):17366-17371.

[50] Andreae M. O. & Ramanathan V. (2013) *Climate's dark forcings*, SCI. 340(6130):280-281, 280 ("BrC is sometimes included implicitly in climate models constrained by BC measurements, because different BC measurement techniques may include some or all BrC. However, most models have ignored BrC absorption and, as a result, concluded that the combination of BC and nonabsorbing organic carbon leads to net cooling.").

[51] Ramanathan V., *et al.* (2013) BLACK CARBON AND THE REGIONAL CLIMATE OF CALIFORNIA: REPORT TO THE CALIFORNIA AIR RESOURCES BOARD, Contract 08-323.

[52] Chung C. E., Ramanathan V., & Decremera D. (2012) *Observationally constrained estimates of carbonaceous aerosol radiative forcing*, PROC. NATL. ACAD. SCI. USA, 109(29):11624-

11629; *see also* Feng Y., Ramanathan V., & Kotamarthi V. R. (2013) *Brown carbon: a significant atmospheric absorber of solar radiation*, Atmos. Chem. & Phys. Disc. 13:2795-2833.

[53] Researchers at the U.S. Los Alamos National Laboratory, found that the black and organic carbon emitted by the fires are covered in an organic coating which acts like a lens to focus sunlight, increasing the warming by a factor of 2 or more. Further, wildfires emit tiny, black balls of tar, at a rate ten times higher than these other particles. China S., *et al.* (2013) *Morphology and mixing state of individual freshly emitted wildfire carbonaceous particles*, Nature Communications 4(2122); *and* IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change.

[54] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. of Geophys. Res. –Atmos. 118(11):5380-5552, 5464 ("Light-absorbing particles in snow can significantly reduce snow albedo. Because of the high albedo of snow, even aerosol with relatively high single-scatter albedo (*e.g.,* aerosol with a high OA:BC ratio) causes positive radiative forcing.").

[55] *Id.*

[56] Painter T. H., *et al.* (2013) *End of the Little Ice Age in the Alps forced by industrial black carbon*, Proc. Natl. Acad. Sci. USA (in press) ("Glaciers in the European Alps began to retreat abruptly from their mid-19th century maximum, marking what appeared to be the end of the Little Ice Age. Alpine temperature and precipitation records suggest that glaciers should instead have continued to grow until circa 1910. Radiative forcing by increasing deposition of industrial black carbon to snow may represent the driver of the abrupt glacier retreats in the Alps that began in the mid-19th century. Ice cores indicate that black carbon concentrations increased abruptly in the mid-19th

century and largely continued to increase into the 20th century, consistent with known increases in black carbon emissions from the industrialization of Western Europe.... These results suggest a possible physical explanation for the abrupt retreat of glaciers in the Alps in the mid-19th century that is consistent with existing temperature and precipitation records and reconstructions."); *see also* Schiermeier Q., *How soot killed the Little Ice Age*, Nature News (2 September 2013).

[57] *Id.* ("Evidence supporting the link between particles and adverse respiratory and cardiovascular health continues to mount. High human exposures to particulate matter in urban settings are linked to sources that emit black carbon and to intense exposures in indoor air. Thus, reducing particulate matter is desirable to improve human welfare, regardless of whether those reductions reduce climate warming.") (internal citations omitted).

[58] U.S. Envtl. Prot. Agency (2013) Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2011, Table ES-2.

[59] U.S. Envtl. Prot. Agency (2012) Report to Congress on Black Carbon.

[60] UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone.

[61] The 100-yr GWP of methane is estimated to be 28, and on the shorter timeframe of 20-yr the GWP is estimated at 84. If carbon-cycle feedbacks are included the 100-yr GWP of methane is 34. Myhre G., *et al.* (2013) Chapter 8: Anthropogenic and Natural Radiative Forcing, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Table 8.A; *and* Alexander L., *et al.* (2013) Summary for Policymakers, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

[62] IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; *see also* U.S. Envtl. Prot. Agency (2010) Methane and Nitrous Oxide Emissions from Natural Sources, ES-2.

[63] UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone.

[64] When methane's contribution to the production of tropospheric ozone, CO_2, and stratospheric water vapour are included, its radiative forcing is much higher at 0.97 Wm^{-2}. Alexander L., *et al.* (2013) Summary for Policymakers, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Emissions of CO_2 alone have caused an RF of 1.68 [1.33 to 2.03] W m^{-2} (see Figure SPM.5). Including emissions of other carbon-containing gases, which also contributed to the increase in CO_2 concentrations, the RF of CO_2 is 1.82 [1.46 to 2.18] W m^{-2}.... Emissions of CH_4 [methane] alone have caused an RF of 0.97 [0.74 to 1.20] W m^{-2} (see Figure SPM.5). This is much larger than the concentration-based estimate of 0.48 [0.38 to 0.58] Wm^{-2} (unchanged from AR4). This difference in estimates is caused by concentration changes in ozone and stratospheric water vapour due to CH_4 emissions and other emissions indirectly affecting CH_4.").

[65] UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone.

[66] Leifer I., *et al.* (2013) *Transcontinental methane measurements: Part 2, Mobile surface investigation of fossil fuel industrial fugitive emissions*, Atmos. Env't 74:432-441; *see also* Peischl R., *et al.* (2013) *Quantifying sources of methane using light alkanes in the Los Angeles basin, California*, J. of Geophys. Res. – Atmos. 118(10):4974-4990; Townsend-Small A. (2012) *Isotopic measurements of atmospheric methane in Los Angeles, California,*

USA reveal the influence of "fugitive" fossil fuel emissions, J. of Geophys. Res. (in press) doi:10.1029/2011JD016826; O'Sullivan F. & Paltsev S. (2012) *Shale gas production: potential versus actual greenhouse gas emissions*, Environmental Res. Lett. 7(4): 044030; and Allen D. T., *et al.* (2013) *Measurements of methane emissions at natural gas production sites in the United States*, Proc. Natl. Acad. Sci. USA (in press).

[67] UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone, 57; *see also* UNEP (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers ("Methane contributes around 50 per cent of the increases in background ozone, with smaller contributions from non-methane volatile organic compounds and carbon monoxide"); Royal Society (2008) Ground-level Ozone in the 21st Century: Future Trends, Impacts and Policy Implications: Science Policy Report; *and* Myhre G., *et al.* (2013) Chapter 8: Anthropogenic and Natural Radiative Forcing, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ8.2 ("Controls on anthropogenic emissions of methane (FAQ 8.2, Figure 1) to lower surface ozone have been identified as "win-win" situations. Consequences of controlling other ozone precursors are not always as clear. Nitrogen oxide emission controls, for instance, might be expected to have a cooling effect as they reduce tropospheric ozone, but their impact on methane lifetime and aerosol formation is more likely instead to cause overall warming.").

[68] Fang Y., *et al.* (2013) *Air pollution and associated human mortality: the role of air pollution emissions, climate change and methane concentration increases from the preindustrial period to present*, Atmos. Chem. Phys 13: 1377-1394, 1377, 1390 ("[C]hanging climate and increasing CH_4 concentrations also

contribute to premature mortality associated with air pollution globally (by up to 5% and 15 %, respectively.... Increased CH_4 concentrations alone contribute more than 20% to respiratory mortalities associated with industrial O_3 exposure over South America, Europe, Africa, Middle East and Rest of Asia.... CH_4 is projected to increase in almost all SRES and RCP emission scenarios (except RCP2.6 and SRES B2). As a result, the relative contribution of increased CH_4 to O_3 mortality will likely continue to rise, increasing the relative health benefits of CH_4 mitigation.)."

[69] U.S. Envtl. Prot. Agency (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F.

[70] Hartmann D. L., *et al.* (2013) CHAPTER 2: OBSERVATIONS: ATMOSPHERE AND SURFACE, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; *see also* Bowman K. W. *et al.* (2013) *Evaluation of ACCMIP outgoing longwave radiation from tropospheric ozone using TES satellite observations*, ATMOS. CHEM. PHYS. 13:4057-4072, 4057 ("Removing these models leads to a mean ozone radiative forcing of 394 ± 42 m Wm^{-2}. The mean is about the same and the standard deviation is about 30 % lower than an ensemble ozone RF of 384 ± 60 m Wm^{-2} derived from 14 of the 16 ACCMIP models reported in a companion ACCMIP study.") (10,000 mWm^{-2} converts to 10 Wm^{-2}); *and* Forster P. *et al.* (2007) CHANGES IN ATMOSPHERIC CONSTITUENTS AND IN RADIATIVE FORCING, *in* Solomon S. *et al.* (2007) CLIMATE CHANGE 2007: PHYSICAL SCIENCE BASIS, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; U.S. EPA (2013) INTEGRATED SCIENCE ASSESSMENT FOR OZONE AND RELATED PHOTOCHEMICAL OXIDANTS, EPA 600/R-10/076F ("The impact of the tropospheric O_3 change since pre-industrial times on climate has been estimated to be about 25-40% of the

anthropogenic CO_2 impact and about 75% of the anthropogenic CH_4 impact according to the Intergovernmental Panel on Climate Change (IPCC), ranking it third in importance after CO_2 and CH_4 according to the IPCC").

[71] U.S. Envtl. Prot. Agency (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F; *see also* European Envtl. Agency (2013) Air Pollution by ozone across Europe during summer 2012.

[72] NOx is emitted from power plans, motor vehicles and other sources of high-heat combustion. VOCs are emitted from motor vehicles, chemical plants, refineries, factories, gas stations, paint and other sources, CO is primarily emitted from motor vehicles. U.S. EPA (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F.

[73] Reducing other ozone precursors can have varying effects on the climate, for example cutting non-methane VOCs can provide some additional cooling but reducing NOx is predicted to produce warming due to its importance for removing methane from the atmosphere. UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone, 57; *see also* Fang Y., *et al.* (2013) *Air pollution and associated human mortality: the role of air pollution emissions, climate change and methane concentration increases from the preindustrial period to present*, Atmos. Chem. Phys 13:1377-1394, 1390 ("As the benefit of CH_4 reduction does not depend on its location, for cleaner regions, such as "Europe, South America and Australia (where we find mortality burdens are more sensitive to CH_4 concentrations than other regions), identifying low-cost CH_4 mitigation options internationally may be an effective method of reducing local premature mortalities associated with O_3 exposure. Our study highlights the benefits of controlling CH_4 emissions as part of air quality policy.").

[74] U.S. Envtl. Prot. Agency (2013) INTEGRATED SCIENCE ASSESSMENT FOR OZONE AND RELATED PHOTOCHEMICAL OXIDANTS, EPA 600/R-10/076F; *see also* Myhre G., *et al.* (2013) CHAPTER 8: ANTHROPOGENIC AND NATURAL RADIATIVE FORCING, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ8.2 ("Some couplings between the targeted emissions and climate are still poorly understood or identified, including the effects of air pollutants on precipitation patterns, making it difficult to fully quantify these consequences. There is an important twist, too, in the potential effect of climate change on air quality. In particular, an observed correlation between surface ozone and temperature in polluted regions indicates that higher temperatures from climate change alone could worsen summertime pollution, suggesting a "climate penalty". This penalty implies stricter surface ozone controls will be required to achieve a specific target.").

[75] U.S. Envtl. Prot. Agency (2013) INTEGRATED SCIENCE ASSESSMENT FOR OZONE AND RELATED PHOTOCHEMICAL OXIDANTS, EPA 600/R-10/076F ("The highest O_3 concentrations are not found in urban areas close to the concentrated sources of its precursors such as traffic, but rather in suburban and rural areas downwind of these sources. Reaction of O_3 with NO in fresh motor vehicle exhaust depletes O3 in urban cores; but O_3 can be regenerated during transport downwind of urban source areas. Also O_3 tends to be more uniform in rural than in urban areas because O_3 production occurs over large areas and because the concentrated sources of NO depleting O_3 in urban cores are generally lacking (except near power plants and other strong sources of NO)."

[76] Amann M., *et al.* (2008) HEALTH RISKS OF OZONE FROM LONG-RANGE TRANSBOUNDARY AIR POLLUTION, World Health Organization ("On a larger scale, O_3 can last in the atmosphere long enough that it can be transported from continent to continent.").

[77] U.S. Envtl. Prot. Agency (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F; *see also* Zanobetti A, & Schwartz J. (2008) *Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States*, Am. J. Respir. Crit. Care Med. 177:184-189; Katsouyanni K., *et al.* (2009) Air pollution and health: A European and North American approach (APHENA), Health Effects Institute; *and* Samoli E., *et al.* (2009) *The temporal pattern of mortality responses to ambient ozone in the APHEA project*, J. Epidemiol. Community Health. 63:960-966.

[78] U.S. Envtl. Prot. Agency (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F; *see also* Zanobetti A., & Schwartz J. (2008) *Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States*, Am. J. Respir. Crit. Care Med 177:184-189; Rich D. Q., *et al.* (2006) *Increased Risk of Paroxysmal Atrial Fibrillation Episodes Associated with Acute Increases in Ambient Air Pollution*, Environ. Health Perspect. 114:120-123; Ruidavets J-B., *et al.* (2005) *Ozone Air Pollution is Associated with Acute Myocardial Infarction*, Circulation 111:563-569; *and* Morello-Frosch R., *et al.* (2010) *Ambient air pollution exposure and full-term birth weight in California*, Environ Health 9:44.

[79] UNEP (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers; *see also* Reilly J., *et al.* (2007) *Global economic effects of changes in crops, pasture, and forests due to changing climate, carbon dioxide, and ozone*, Energy Policy 35(11):5370-5283.

[80] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology.

[81] U.S. Envtl. Prot. Agency (2013) Integrated Science Assessment for Ozone and Related Photochemical Oxidants, EPA 600/R-10/076F

[82] Harmes H., *et al.* (2012) AIR POLLUTION AND VEGETATION: ICP VEGETATION ANNUAL REPORT 2011/2012, Centre for Ecology & Hydrology; *see also* Sitch S., *et al.* (2007) *Indirect radiative forcing on climate change through ozone effects on the land-carbon sink*, NATURE 448:791-794; *and* Stocker T., *et al.* (2013) TECHNICAL SUMMARY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("There is strong evidence that tropospheric ozone also has a detrimental impact on vegetation physiology, and therefore on its CO_2 uptake. This reduced uptake leads to an indirect increase in the atmospheric CO_2 concentration. Thus a fraction of the CO_2 RF should be attributed to ozone or its precursors rather than direct emission of CO_2, but there is a low confidence on the quantitative estimates.").

[83] Harmes H., *et al.* (2012) AIR POLLUTION AND VEGETATION: ICP VEGETATION ANNUAL REPORT 2011/2012, Centre for Ecology & Hydrology ("When applying a standard parameterisation for deciduous and conifer trees, current ambient ground-level ozone was estimated to reduce C sequestration in the living biomass of trees by 12.0 to 16.2% (depending on ozone, meteorological and climate input data) in the EU27 + Norway + Switzerland in 2000.... Although a decline in stomatal ozone flux was predicted in 2040, C sequestration in the living biomass of trees will still be reduced by 12.6% (compared to 16.2% in 2000).").

[84] Sitch S., *et al.* (2007) *Indirect radiative forcing on climate change through ozone effects on the land-carbon sink*, NATURE 448:791-794, 793 ("Suppression of the land-carbon sink results in additional anthropogenic CO_2 emissions accumulating in the atmosphere, and therefore an indirect radiative forcing of climate change by O_3 effects on the terrestrial biosphere.... The indirect forcing by 2100 is estimated at $0.62 Wm^{-2}$ and $1.09 Wm^{2}$ for the 'low' and 'high' plant ozone sensitivity runs, respectively, which

compares with a mean direct radiative forcing from 11 atmospheric chemistry models of $0.89Wm^{-2}$. Although the absolute values of radiative forcing are dependent on our choice of emissions scenario, the relative importance of direct and indirect radiative forcing is much less sensitive to the uncertainty in emissions. As such, these results suggest that ozone effects on vegetation could double the effective radiative forcing due to increases in tropospheric ozone, significantly increasing the importance of changes in atmospheric chemistry as a driver of twenty-first-century climate change.").

[85] Velders G. J. M., *et al.* (2012) *Preserving Montreal Protocol Climate Benefits by Limiting HFCs*, Sci. 335:922-923, 923 ("If the current mix of HFCs with an average lifetime of 15 years (average GWP of 1600) were replaced by HFCs with lifetimes 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…. Such choices are currently available."); *and* UNEP (2011) HFCs: A Critical Link in Protecting Climate and the Ozone Layer.

[86] Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954. Recent measurements of changes in atmospheric abundances of the HFCs, confirm the growth rates calculated by Velders. Dr. McFarland M., *The Montreal Protocol and Hydrofluorocarbons (HFCs)*, Capitol Visitors Center, Washington DC, (16 September 2013) 5, *citing* preliminary atmospheric measurement data by Montzka S. National Oceanic and Atmospheric Administration. *But see* other earlier analysis, which predicts HFC growth-rates lower that the Velders calculations. *See* Gschrey B., *et al.* (2011) *High increase of global F-gas emissions until 2050*, Greenhouse Gas Measurement & Management 1:85–92.

[87] Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954.

[88] Myhre G., *et al.* (2013) CHAPTER 8: ANTHROPOGENIC AND NATURAL RADIATIVE FORCING, *in* IPCC (2013) CLIMATE CHANGE 23013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 8.3.2.4.2 ("The RF of HFCs is 0.02 W m^{-2} and has close to doubled since AR4 (2005 concentrations). HFC-134a is the dominant contributor to RF of the HFCs with a RF of 0.01 W m^{-2}.").

[89] Xu Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, ATMOS. CHEM. PHYS., 13:6083-6089; *see also* Hare B. *et al*. (2013) CLOSING THE 2020 EMISSIONS GAP: ISSUES, OPTIONS AND STRATEGIES.

[90] According to the World Resources Institute, Climate Analysis Indicators Tool (CAIT) CO_2-eq emissions of f-gases in China increased by 111% between 2000 and 2005, compared to a 68% increase in CO_2, 8% increase in methane, and 6% increase in N_2O. F-gas emissions increased by 78% in India over the same period, compared to 19% for CO_2, 10% for methane, and 6% for N_2O. F-gas emissions in the US increased by 30% between 2000 and 2005 compared to 1.5% for CO_2, and a 5% decrease in methane and N_2O. Note that f-gases include emissions of HFCs, SF_6, and PFCs. According to the US EPA (2013) INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990 – 2011, emissions of HFCs increased by 5.48% between 2005 and 2010, emissions all other greenhouse gases decreased over that period (CO_2 -6.1%; methane -0.2%; N_2O -3.43%; PFC -4.8%; SF_6 -32.7%). EU CO_2-eq emissions of HFCs increased by 298% between 1990 and 2011, and are the only greenhouse gases, measured by CO_2-eq emissions, that have increased every year over that period. According to the Australian Government's 2011 submission to the UNFCCC, HFC emissions in Australia increased by 578.5% between 1990 and 2011; the only other two greenhouse gas emissions to increase over that period were CO_2 and N_2O, which

increased 46.3% and 36.1% respectively. Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (2011) Australian National Greenhouse Accounts: National Inventory Report 2011, Vol. 1; *see also* European Environment Agency (2013) Annual European Union greenhouse gas inventory 1990 – 2011 and inventory report, No 8/213.

[91] Montreal Protocol Technology and Economic Assessment Panel (2009) Task Force Decision XX/8 Report: Assessment of Alternatives to HCFCs and HFCs and Update of the TEAP 2005 Supplement Report Data.

[92] Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954; *see also* Montzka S. A. (2012) HFCs in the Atmosphere: Concentrations, Emissions, Impacts, ASHRAE.

[93] UNEP (2011) HFCs: A Critical Link in Protecting Climate and the Ozone Layer – A UNEP Synthesis Report.

[94] *Id.*

[95] Alexander L., *et al.* (2013) Summary for Policymakers, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("The atmospheric concentrations of carbon dioxide (CO_2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. CO_2 concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions.").

[96] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change 3:730-734, 732 ("By the end of the twenty-first century, the effect of CO_2 mitigation on temperature increases by tenfold to ~1.1°C compared with the mitigation of 0.1°C by 2050…. In the CO_2

mitigation case, CO_2 emissions are reduced as in RCP2.6 with CO_2 concentration peaking at 440 ppm by mid-twenty-first century and reducing to 420 ppm at the end of the twenty-first century.“).

[97] *Id.*

[98] Solomon S., *et al.* (2007) CLIMATE CHANGE 2007: PHYSICAL SCIENCE BASIS, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (“While more than half of the CO_2 emitted is currently removed from the atmosphere within a century … about 20% … remains … for many millennia.”); Archer D., *et al.* (2009) *Atmospheric lifetime of fossil fuel carbon dioxide*, ANNU. REV EARTH PLANET. SCI. 37:117-134, 132 (“Equilibration with the ocean will absorb most of it [CO_2] on a timescale of 2 o 20 centuries. Even if this equilibration were allowed to run to completion, a substantial fraction of the CO_2, 20-40%, would remain in the atmosphere awaiting slower chemical reactions with $CaCO_3$ and igneous rocks.”); Matthews H. D. & Caldeira K. (2008) *Stabilizing climate requires near-zero emissions*, GEOPHYSICAL RES. LETT. 35(4):L04705 (“[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.”); *and* Hansen J., *et al*. (2007) *Climate change and trace gases*, PHIL. TRANS. R. SOC. 365:1925-1954, 1938 (“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.”); *and* Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ 12.3 (“CO_2 is more complicated as it is removed from the atmosphere through multiple physical and biogeochemical processes in the ocean and the land; all operating

at different time scales. For an emission pulse of about 1000 PgC, about half is removed within a few decades, but the remaining fraction stays in the atmosphere for much longer. About 20% of the CO_2 pulse is still in the atmosphere after 1000 years.")

[99] Solomon S., *et al.* (2010) *Persistence of climate changes due to a range of greenhouse gases*, Proc. Natl. Acad. Sci. USA 107(43):18354-18359, 18356, 18358 ("[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."); *see also* Matthews H. D. & Solomon S. (2013) *Irreversible Does Not Mean Unavoidable*, Science 340:438-439.

[100] CO_2's long atmospheric lifetime combined with the thermal inertia of the ocean, which causes heat trapped in the oceans to be released over many centuries, means that if CO_2 emissions were to cease, while continued warming would slowly decrease, more than 80% of the temperature increase caused by CO_2 would persist for a 1,000 years of years. Arblaster J. M., *et al.* (2013) Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("A large fraction of climate change is largely irreversible on human time scales, unless net anthropogenic carbon dioxide emissions were strongly negative over a sustained period. For scenarios driven by carbon dioxide alone, global average temperature is projected to remain approximately constant for many centuries following a complete cessation of

emissions. The positive commitment from CO_2 may be enhanced by the effect of an abrupt cessation of aerosol emissions, which will cause warming. By contrast cessation of emission of short-lived greenhouse gases will contribute a cooling."); *and* UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone, 6 ("In the case of an SLCF this means that, when its concentration and hence its radiative forcing is reduced by emission controls, the global mean temperature will achieve most of its decrease towards a new equilibrium value in about a decade. About 10 per cent of the full decrease will not be realized for hundreds of years, since the redistribution of heat stored in the deep ocean while the SLCF was active, and hence its upwards transport, will continue for hundreds of years …. In the case of CO_2, more than 80 per cent of the expected decrease in global mean temperature after emission reductions will not be realized for hundreds of years. This is because the drawing down of atmospheric CO_2 into the deep ocean, and hence the decrease in its radiative forcing, is roughly offset by the upward transport of heat to the surface, since both phenomena are achieved by the same physics of deep-ocean mixing…."); *citing* Solomon S. *et al.* (2009) *Irreversible climate change due to carbon dioxide emissions,* Proc. Natl. Acad. Sci. USA 106:1704-1709, 1704 ("[C]limate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop. Following cessation of emissions, removal of atmospheric carbon dioxide decreases radiative forcing, but is largely compensated by slower loss of heat to the ocean, so that atmospheric temperatures do not drop significantly for at least 1,000 years."); *and* Matthews D & Weaver J. (2010) *Committed climate warming*, Nat. Geosci. 3:142-143.

[101] Solomon S., *et al.* (2011) Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia, National Research Council.

[102] Solomon S., *et al.* (2011) CLIMATE STABILIZATION TARGETS: EMISSIONS, CONCENTRATIONS, AND IMPACTS OVER DECADES TO MILLENNIA, National Research Council ("Climate changes that occur because of carbon dioxide increases are expected to persist for thousands of years even if emissions were to be halted at any point in time."); *see also* Solomon S., *et al.* (2010) *Persistence of climate changes due to a range of greenhouse gases*, PROC. NATL. ACAD. SCI. USA 107(43):18354-18359, 18356 ("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 S., *et al.* (2009) *Irreversible climate change due to carbon dioxide emissions*, PROC. NATL. ACAD. SCI. USA 106(6):1704-1709, 1707, 1708 ("Anthropogenic carbon dioxide will cause irrevocable sea level rise…. An assessed range of models suggests that the eventual contribution to sea level rise from thermal expansion of the ocean is expected to be 0.2–0.6 m per degree of global warming (5). Fig. 4 uses this range together with a best estimate for climate sensitivity of 3 °C (5) to estimate lower limits to eventual sea level rise due to thermal expansion alone. Fig. 4 shows that even with zero emissions after reaching a peak concentration, irreversible global average sea level rise of at least 0.4–1.0 m is expected if 21st century CO_2 concentrations exceed 600 ppmv and as much as 1.9 m for a peak CO_2 concentration exceeding 1,000 ppmv."); Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Global temperature equilibrium would be reached only after centuries to millennia if radiative forcing were stabilised. Continuing greenhouse gas emissions beyond 2100, as

in the RCP8.5 extension, induces a total radiative forcing above 12 W m–2 by 2300. Sustained negative emissions beyond 2100, as in RCP2.6, induces a total radiative forcing below 2 W m–2 by 2300. The projected warming for 2281–2300, relative to 1986–2005, is 0.0°C–1.2°C for RCP2.6 and 3.0°C–12.6°C for RCP8.5 (*medium confidence*). In much the same way as the warming to a rapid increase of forcing is delayed, the cooling after a decrease of radiative forcing is also delayed. [12.5.1, Figures 12.43, 12.44]"); *and* Hansen J., *et al.* (2007) *Dangerous human-made interference with climate: a GISS model study*, ATMOSPH. CHEM. PHYS. 7:2287-2312, 2302, 2308 ("CO_2 emissions are the critical issue, because a substantial fraction of these emissions remain in the atmosphere "forever", for practical purposes…. The principal implication is that avoidance of dangerous climate change requires the bulk of coal and unconventional fossil fuel resources to be exploited only under condition that CO_2 emissions are captured and sequestered.").

[103] Solomon S., *et al.* (2009) *Irreversible climate change due to carbon dioxide emissions*, PROC. NATL. ACAD. SCI. USA 106(6):1704-1709; *see also* The World Bank (2012) TURN DOWN THE HEAT: WHY A 4°C WARMER WORLD MUST BE AVOIDED; *see also* The World Bank (2013) TURN DOWN THE HEAT: CLIMATE EXTREMES, REGIONAL IMPACTS, AND THE CASE FOR RESILIENCE; *and* Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Some aspects of climate will continue to change even if temperatures are stabilised. Processes related to vegetation change, changes in the ice sheets, deep ocean warming and associated sea level rise and potential feedbacks linking for example ocean and the ice sheets have their own intrinsic long timescales and may result in

significant changes hundreds to thousands of years after global temperature is stabilized. [12.5.2–12.5.4]”).

[104] Press Release, NOAA Research, CO_2 at NOAA’s Mauna Loa Observatory reaches new milestone: Tops 400 ppm (10 May 2013); *see also* Scripps Institution of Oceanography (2013) The Keeling Curve; *and* National Oceanic & Atmospheric Administration, Trends in Atmospheric Carbon Dioxide; *and* Kunzig R., *Climate Milestone: Earth’s CO_2 level Passes 400 ppm: Greenhouse gas highest since the Pliocene, when sea level were higher and the Earth was warmer*, National Geographic News (9 May, 2013).

[105] Solomon S., *et al.* (2007) Climate Change 2007: Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[106] Solomon S., *et al.* (2009) *Irreversible climate change due to carbon dioxide emissions*, Proc. Natl. Acad. Sci. USA 106(6):1704-1709.

[107] International Energy Agency (2012) World Energy Outlook 2012; *and* Edenhofer O., *et al.* (2009) The Economics of Decarbonization. (“Stabilization requires a radical shift from conventional fossil to low-carbon energy sources, including renewables, carbon capture and storage (CCS), and, to a lesser extent, nuclear…. The relative importance of energy efficiency improvements, particularly in the short to medium term, increases with more ambitious stabilization levels and under more pessimistic assumptions about the availability of low-carbon technologies.”).

[108] Metz B., *et al.* (2007) Climate Change: Mitigation of Climate Change, Contribution Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 19-22.

[109] International Energy Agency (2013) Tracking Clean Energy Progress 2013.

[110] International Energy Agency (2013) TRACKING CLEAN ENERGY PROGRESS 2013; *see also* Myhrvold N. P. & Caldeira K. (2012) *Greenhouse gases, climate change and the transition from coal to low-carbon electricity*, ENVIRON. RES. LET. 7:014019, 1 ("The use of current infrastructure to build this new low-emission system necessitates additional emissions of greenhouse gases, and the coal-based infrastructure will continue to emit substantial amounts of greenhouse gases as it is phased out. Furthermore, ocean thermal inertia delays the climate benefits of emissions reductions.... We show that rapid deployment of low-emission energy systems can do little to diminish the climate impacts in the first half of this century.").

[111] UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 6, 159 ("In the case of an SLCF this means that, when its concentration and hence its radiative forcing is reduced by emission controls, the global mean temperature will achieve most of its decrease towards a new equilibrium value in about a decade. About 10 per cent of the full decrease will not be realized for hundreds of years, since the redistribution of heat stored in the deep ocean while the SLCF was active, and hence its upwards transport, will continue for hundreds of years…. Over the longer term, from 2070 onwards, there is still a reduction in warming in the early measures case, but the value becomes quite small. This reinforces the conclusions drawn from previous analyses that reducing emissions of O_3 precursors and BC can have substantial benefits in the near term, but that long-term climate change is much more dependent on emissions of long-lived GHGs such as CO_2.").

[112] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 731 ("By 2050, on the other hand, the SLCPs reduce projected warming by 0.6°C and CO_2 only about 0.1°C.");

[113] Mitigation of 1.1°C derived from Table 1 projected warming between 2005 and 2100 from SLCP only mitigation (1.1°C) compared to BAU (3.5°C). Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734; *see also* Institute for Advanced Sustainability Studies (2012) SHORT LIVED CLIMATE FORCERS: PATHWAYS TO ACTION – WORKSHOP SUMMARY ("… inclusion of HFCs mitigation would further reduce the warming by another 20% (about 0.1°C), thus increasing the total reduction of warming between now and 2050 to about 0.6°C"; *citing* Ramanathan V & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues,* PROC. NAT'L ACAD. SCI. USA 107:8055-8062, 8055 ("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].").

[114] UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, Table 5.2.

[115] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 183, 185 ("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 and where regional temperature response patterns correspond fairly closely to albedo forcing…"); *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 3 ("If

the measures were to be implemented by 2030, they could halve the potential increase in global temperature projected for 2050 compared to the Assessment's reference scenario based on current policies and energy and fuel projections… 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").

[116] Solomon S., *et al.* (2007) Technical Summary *in* Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 36 ("The rate of warming averaged over the last 50 years (0.13°C ± 0.03°C per decade) is nearly twice that for the last 100 years.").

[117] Arctic Monitoring and Assessment Programme (2011) Snow, Water, Ice and Permafrost in the Arctic, Executive Summary and Key Message, 4 ("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."); *see also* Qiu J. (2008) *China: The third pole*, Nature 454:393-396, 393 ("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.").

[118] Ramanathan V. & Feng Y. (2008) *On avoiding dangerous anthropogenic interference with the climate system: formidable challenges ahead*, Proc. Nat'l Acad. Sci. USA 105:14245-14250; *see also* Schellnhuber H. J. (2008) *Global warming: stop worrying, start panicking?* Proc. Nat'l Acad. Sci. USA 105:14239-14240.

[119] Ramanathan V & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, Proc. Nat'l Acad. Sci. USA 107:8055-8062.

[120] Xu, Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, Atmos. Chem. Phys. 13:6083-6089.

[121] Xu, Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, Atmos. Chem. Phys. 13:6083-6089; *see also* Hu A. *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change 3:730-734, Figure 1.

[122] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change 3:730-734, 733 ("If, for example, we postpone CH_4 and black carbon mitigation until 2030–2040 instead of 2015, the longer-term warming increases by another 0.2°C and the pre-industrial to year 2100 warming will exceed 2°C by mid-century. According to the projections, the delayed actions can increase SLR by 9–11%.").

[123] *Id.*, Supplemental Materials Figure SF9.

[124] National Research Council of the National Academies (2011) Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia, 3; *see also* UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone; *and* United Nations Environment Program (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers.

[125] The National Research Council provides two definitions for abrupt climate change. The first definition describes abrupt climate change in terms of physics: "an abrupt climate change occurs when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause." The second definition describes abrupt climate change in terms of impacts, "an abrupt change is one that takes place so rapidly and unexpectedly that human or natural systems have difficulty adapting to it." National Research Council Committee on Abrupt Climate Change (2002) Abrupt Climate Change: Inevitable Surprises, 14.

[126] Xu Y., *et al.* (2013) *The role of HFCs in mitigating 21st century climate change*, Atmos. Chem. Phys. 13:6083-6089; *see also* Hu A.,

et al. (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734.

[127] Ramanathan V & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, PROC. NAT'L ACAD. SCI. USA 107:8055-8062, 8055 ("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]"*)*; *see also* Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734; UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE: SUMMARY FOR DECISIONS MAKERS, 12 ("[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) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 240 ("Hence adoption of the near-term measures analyzed in this Assessment would increase the chances for society to keep the Earth's temperature increase below 1.5°C for the next 40 years if these measures were phased in along with CO_2 reductions."); *and* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 184 ("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….").

[128] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE; based on Ramanathan V. & Xu Y. (2010) *The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues*, PROC. NAT'L ACAD. SCI. USA 107: 8055-8062.

[129] Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Temperature change will not be regionally uniform. There is *very high confidence2* that globally averaged changes over land will exceed changes over the ocean at the end of the 21st century by a factor that is *likely* in the range 1.4–1.7. In the absence of a strong reduction in the Atlantic Meridional Overturning, the Arctic region is projected to warm most (*very high confidence)*."); *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE, 99 ("While global mean temperatures provide some indication of climate impacts and their simplicity makes them widely used indicators, temperature changes can vary dramatically from place to place…. In the case of the short-lived climate forcing by aerosols and O_3, the forcing itself is also very unevenly distributed, and hence can cause even greater regional contrasts in the temperature response.").

[130] Qiu J. (2008) *China: The third pole*, NATURE 454:393-396, 393 ("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"); *see also* Cruz R. V., *et al.* (2007) ASIA, *in* CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY, Contribution of Working Group II to the Fourth Assessment

Report of the Intergovernmental Panel on Climate Change 475 ("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."); *and* World Bank & International Cryosphere Climate Initiative (hereafter WB & ICCI) (2013) On Thin ice: How Cutting Pollution Can Slow Warming and Save Lives, 11 ("Annual mean surface temperature across the Himalayan region has increased by 1.5.C 2 over pre-industrial average temperatures—similar to increases seen in the Arctic and Antarctic Peninsula (Shrestha, Gautam, and Bawa 2012). Measuring the impacts of this temperature rise on the Himalayan cryosphere has proved challenging because of the complicated topography that makes each glacier and region unique and difficult to study, even using satellite technology").

[131] Kirtman B., *et al.* (2013) Chapter 11: Near-term Climate Change: Projections and Predictability, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 11.3.4.3 ("Of principal importance is "Arctic Amplification" (see Box 5.2) where surface temperatures in the Arctic are increasing faster than elsewhere in the world"); *see also* Serreze M. C. & Barry R. G. (2011) *Processes and impacts of Arctic amplification: A research synthesis*, Global Planet Change 77:85-96, 85 ("Arctic amplification is now recognized as an inherent characteristic of the global climate system, with multiple intertwined causes operating on a spectrum of spatial and temporal scales. These include, but are not limited to, changes in sea ice extent that impact heat between the ocean and the atmosphere, atmospheric and oceanic heat transports, cloud cover and water vapor that alter the longwave radiation flux to the surface, soot on snow and heightened black carbon aerosol concentrations. Strong warming over the Arctic Ocean during the past decade in autumn and winter, clearly associated with

reduced sea ice extent, is but the most recent manifestation of the phenomenon. Indeed, periods of Arctic amplification are evident from analysis of both warm and cool periods over at least the past three million years. Arctic amplification being observed today is expected to become stronger in coming decades, invoking changes in atmospheric circulation, vegetation and the carbon cycle, with impacts both within and beyond the Arctic."); *and* WB & ICCI (2013) On Thin ice: How Cutting Pollution Can Slow Warming and Save Lives.

[132] Arctic Monitoring and Assessment Programme (2011) Snow, Water, Ice and Permafrost in the Arctic, Executive Summary and Key Message, 4 ("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"); *and* Christensen J. H., *et al*. (2013) Chapter 14: Climate Phenomena and their Relevance for Future Regional Climate Change, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("The surface and lower troposphere in the Arctic and surrounding land areas show regional warming over the past three decades of about 1°C/decade—significantly greater than the global mean trend (Figures 2.22 and 2.25). Temperatures averaged over the Arctic over the past few decades are significantly higher than any seen over the past 2000 years (Kaufman et al., 2009)…. For RCP4.5, ensemble-mean winter warming rises to 4.6°C over pan-Arctic land areas by the end of the 21st century (2081–2100), and about 7.4°C over the Arctic (Table14.1)…."); Arblaster J. M., *et al.* (2013) Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("There is *very high confidence2* that globally averaged

changes over land will exceed changes over the ocean at the end of the 21st century by a factor that is *likely* in the range 1.4–1.7. In the absence of a strong reduction in the Atlantic Meridional Overturning, the Arctic region is projected to warm most (*very high confidence)*.").

[133] WB & ICCI (2013) ON THIN ICE: HOW CUTTING POLLUTION CAN SLOW WARMING AND SAVE LIVES ("Rapid changes in the cryosphere observed during the first decade of this century are continuing or accelerating. With the exception of a one-percent increase in Antarctic sea ice extent and a very few growing glaciers, nowhere in the peer-reviewed literature is there evidence that the rapid warming documented in the cryosphere beginning in the 1990s is slowing. In most cases, warming and melting are accelerating.").

[134] Wallack J. S. and Ramanathan V. (2009) *The other climate changes, why black carbon also matters*, FOREIGN AFFAIRS 88(5):105-113.

[135] According to passive microwave data analyzed by the National Snow and Ice Data Center and NASA, on 16 September 2012 the Arctic reached a new record minimum of 1.32 million square miles, 18% less than the previous record minimum set in 2007 and nearly 50% less than the 1979 to 2000 average. National Snow & Ice Data Center, *Arctic sea ice extent settles a record seasonal minimum*, (16 September 2012); *and* Derksen C. & Brown R. (2012) *Spring snow cover extent reductions in the 2008-2012 period exceeding climate model projections*, GEOPHYS. RES. LETT. 39(19).

[136] Flanner M. G., *et al.* (2011) *Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2008*, NAT. GEOSCI. 4:151-155; *see also* Arctic Monitoring and Assessment Programme (2011) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC, EXECUTIVE SUMMARY AND KEY MESSAGE; and Stroeve J., *et al.* (2007) *Arctic sea ice decline: faster than forecast*, GEOPHYS. RES. LETT. 34:L09501.

[137] Lenton T. M. (2011) *2°C or not 2°C? That is the climate question*, Nature 473(7).

[138] Press Release, National Snow & Ice Data Center, *Arctic sea ice settles at record seasonal minimum* (19 September 2012); *and* AchutaRao K. M., *et al.* (2013) Chapter 10: Detection and Attribution of Climate Change: from Global to Regional, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Based on a sea ice reanalysis and verified by ice thickness estimates from satellite sensors, it is estimated that three quarters of summer Arctic sea ice volume has been lost since the 1980s. There was also a rapid reduction in ice extent, to 37% less in September 2007 and to 49% less in September 2012 relative to the 1979–2000 climatology. Unlike the loss record set in 2007 that was dominated by a major shift in climatological winds, sea ice loss in 2012 was more due to a general thinning of the sea ice. All recent years have ice extents that fall at least two standard deviations below the long term sea ice trend.").

[139] Overland J. E. & Wang M. (2013) *When will the summer Arctic be nearly sea ice free?*, Geophys. Res. Lett. 40(10):2097-2101 ("Recent data and expert opinion should be considered in addition to model results to advance the very likely timing for future sea ice loss to the first half of the 21st century, with a possibility of major loss within a decade or two"); *see also* Stroeve J. C., *et al.* (2012) *Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations*, Geophys. Res. Lett. 39:L16502 ("While quantification of the role of external forcing depends on many assumptions, it is nevertheless becoming increasingly clear in both the observations … and model studies … that if greenhouse gas concentrations continue to rise, the Arctic Ocean will eventually become seasonally ice free. However, results from the CMIP5 models do not appear to have appreciably reduced

uncertainty as to when this may be realized. Nevertheless, CMIP5 arrives at a seasonally ice-free Arctic sooner than CMIP3, leading to the conclusion that a seasonally ice-free Arctic Ocean within the next few decades is a distinct possibility."); Kirtman B., *et al.* (2013) CHAPTER 11: NEAR-TERM CLIMATE CHANGE: PROJECTIONS AND PREDICTABILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 11.3.4.1 ("By scaling six CMIP3 models to recent observed September sea ice changes, a nearly ice free Arctic in September is projected to occur by 2037, reaching the first quartile of the distribution for timing of September sea ice loss by 2028."); *and* WB & ICCI (2013) ON THIN ICE: HOW CUTTING POLLUTION CAN SLOW WARMING AND SAVE LIVES ("More important than the extent of sea ice is the fact that overall thickness, volume, and age of sea ice has decreased by 80 percent since 1979. Older, thicker multi-year ice used to cover much of the Arctic; today virtually all of the sea ice in the Arctic Ocean is new, from the previous one or two winters, and thus quite thin and vulnerable to melt. Because the ice is very thin, most scientists believe an ice-free Arctic Ocean in summer is inevitable within the next decade or two. … The last time the Arctic Ocean was regularly ice-free in summer was 125,000 years ago, during the height of the last major interglacial period (the Eemian). Temperatures in the Arctic today are coming close to those reached during the Eemian maximum, when sea level was 4–6 meters higher because of partial melting on both Greenland and the West Antarctic Ice Sheet (WAIS).").

140 Press Release, NASA, *Arctic sea ice hits smallest extent in satellite era* (19 September 2012).

141 Press Release, NASA, *2013 Wintertime Arctic Sea Ice Maximum Fifth Lowest on Record* (3 April 2013).

142 Callaghan T. V., *et al.* (2011) CHANGING PERMAFROST AND ITS IMPACTS, *in* Arctic Monitoring and Assessment Programme (2011)

Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere; *see also* UNEP (2012) Policy Implications of Warming Permafrost; *and* WB & ICCI (2013) On Thin ice: How Cutting Pollution Can Slow Warming and Save Lives, 17 ("Temperatures in some parts of the Arctic permafrost have risen by up to 2 degrees over the past 30 years, faster than surface air temperatures. In AR5, the IPCC noted with "high confidence" that permafrost temperatures have increased in most regions since the early 1980s, with observed permafrost warming of up to 3°C in parts of Northern Alaska, and up to 2°C in parts of the European Russia, with a considerable reduction in thickness and extent of permafrost in both regions.").

[143] Arblaster J. M., et al (2013) Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Since the IPCC AR4, estimates of the amount of carbon stored in permafrost have been significantly revised upwards (Tarnocai et al., 2009), putting the permafrost carbon stock to an equivalent of twice the atmospheric carbon pool…."); *and* Schuur E. A. G., *et al.* (2008) *Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle*, BioSci. 58(8):701-714, 704 ("Overall, this permafrost C pool estimate is more than twice the size of the entire atmospheric C pool, and it is more than double previous estimates of high-latitude soil C….").

[144] Ciais P., *et al.* (2013) Chapter 6: Carbon and Other Biogeochemical Cycles, *in* IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("Virtually all near-term projections indicate a substantial amount of near-surface permafrost degradation (typically taking place in the upper 2–3 m, see Callaghan et al. (2011) and see

glossary for detailed definition), and thaw depth deepening over much of the permafrost area. As discussed in more detail in Section 12.4.6.2, these projections have increased credibility compared to the previous generation of models assessed in the AR4 because current climate models represent permafrost more accurately. The reduction in annual mean near-surface permafrost area for the 2016–2035 time period compared to the 1986–2005 reference period for the CMIP5 models for the Northern Hemisphere for the four RCP scenarios is 21% ± 5% (RCP2.6), 18% ± 6% (RCP4.5), 18% ± 3% (RCP6.0), and 20% ± 5% (RCP8.5).”); *see also* Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

[145] Based upon current scientific knowledge of permafrost dynamics and projections from climate models, the IPCC does not consider permafrost degassing a source of abrupt climate change in this century; defined as “a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems.” However, permafrost destabilization could be irreversible on a century to millennia timescale, and become a net source of greenhouse gases within this century. Arblaster J. M., *et al.* (2013) CHAPTER 12: LONG-TERM CLIMATE CHANGE: PROJECTIONS, COMMITMENTS AND IRREVERSIBILITY, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 12.5.5.4 (“However, the existing modelling studies of permafrost carbon balance under future warming that take into account at least some of the essential permafrost-related processes do not yield coherent results beyond the fact that present-day

permafrost might become a net emitter of carbon during the 21st century under plausible future warming scenarios (*low confidence*). This also reflects an insufficient understanding of the relevant soil processes during and after permafrost thaw, including processes leading to stabilization of unfrozen soil carbon, and precludes a firm assessment of the amplitude of irreversible changes in the climate system potentially related to permafrost degassing and associated global feedbacks at this stage."); *see also* Callaghan T. V., *et al.* (2011) CHANGING PERMAFROST AND ITS IMPACTS, *in* Arctic Monitoring and Assessment Programme (2011) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC (SWIPA): CLIMATE CHANGE AND THE CRYOSPHERE ("Furthermore, recent work has shown that carbon pools in permafrost soils are much larger than previously recognized: around 1400 to1850 gigatonnes (Gt) of carbon are located in terrestrial permafrost regions…. In addition, Arctic coastal seas underlain by subsea permafrost host an extremely large carbon pool: the Arctic continental shelf could contain around 1300 Gt of carbon, of which 800 Gt is CH_4, some of which could be available for sudden release under the appropriate conditions. A release of only 1% of this reservoir would more than triple the atmospheric mixing ratio of CH_4, potentially triggering abrupt climate change."); UNEP (2012) POLICY IMPLICATIONS OF WARMING PERMAFROST ("If the permafrost thaws, the organic matter will thaw and decay, potentially releasing large amounts of CO_2 and methane into the atmosphere. This organic material was buried and frozen thousands of years ago and its release into the atmosphere is irreversible on human time scales. Thawing permafrost could emit 43 to 135 Gt of CO_2 equivalent by 2100 and 246 to 415 Gt of CO_2 equivalent by 2200. Uncertainties are large, but emissions from thawing permafrost could start within the next few decades and continue for several centuries, influencing both short-term climate (before 2100) and long-term climate (after 2100)."); *and* Schaefer K., *et al.* (2011) *Amount* *and timing of permafrost carbon release in response to climate warming*, TELLUS B. 63(2):165-180.

[146] Jacobson M. (2010) *Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health*, J. GEOPHYS RES. 115: D14209.

[147] Menon S., *et al.* (2010) *Black carbon aerosols and the third polar ice cap*, ATMOS. CHEM. PHYS., 10:4559-4571; *see also* Ramanathan V., *et al.* (2007) *Atmospheric brown clouds: Hemispherical and regional variations in long range transport, absorption, and radiative forcing*, J. OF GEOPHYS. RES., 12:D22S21; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE.

[148] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 183, 185 ("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 and where regional temperature response patterns correspond fairly closely to albedo forcing…"); *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE: SUMMARY FOR DECISIONS MAKERS, 3 ("If the measures were to be implemented by 2030, they could halve the potential increase in global temperature projected for 2050 compared to the Assessment's reference scenario based on current policies and energy and fuel projections. *** 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"); *and* WB & ICCI (2013) ON THIN ICE: HOW CUTTING POLLUTION CAN SLOW WARMING AND SAVE LIVES, 2 ("Climate benefits for cryosphere regions from black carbon reductions

carry less uncertainty than they would in other parts of the globe and are sometimes very large. This is because emissions from sources that emit black carbon—even with other pollutants—almost always lead to warming over reflective ice and snow.").

[149] Sand M., *et al.* (2013) *Arctic surface temperature change to emissions of black carbon within Arctic or midlatitudes*, J. of Geophys. Res. 118(14):7788-7798, 7788 ("The climate model includes a snow model to simulate the climate effect of BC deposited on snow. We find that BC emitted within the Arctic has an almost five times larger Arctic surface temperature response (per unit of emitted mass) compared to emissions at midlatitudes. Especially during winter, BC emitted in North-Eurasia is transported into the high Arctic at low altitudes. A large fraction of the surface temperature response from BC is due to increased absorption when BC is deposited on snow and sea ice with associated feedbacks"); *see also* Stohl A., *et al.* (2013) *Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions*, Atmos. Chem. Phys. 13:8833-8855.

[150] WB & ICCI (2013) On Thin ice: How Cutting Pollution Can Slow Warming and Save Lives.

[151] Menon S., *et al.* (2010) *Black carbon aerosols and the third polar ice cap*, Atmos. Chem. Phys. 10:4559-4571.

[152] Ramanathan V. & Carmichael G. (2008) *Global and regional climate changes due to black carbon*, Nat. Geosci. 1:221-227.

[153] Lim S., *et al.* (2012) *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990—2010: a systematic analysis for the Global Burden of Disease Study 2010*, the Lancet 380(9859):2224–2260; *and* Fang Y., *et al.* (2013) *Air pollution and associated human mortality: the role of air pollution emissions, climate change and methane concentration increases from the preindustrial period to present*, Atmos. Chem. Phys 13:1377-

1394, 1377 ("Most air pollution mortality is driven by changes in emissions of short-lived air pollutants and their precursors (95% and 85% of mortalities from PM2.5 and O_3 respectively). However, changing climate and increasing CH_4 concentrations also contribute to premature mortality associated with air pollution globally (by up to 5% and 15 %, respectively).").

[154] Institute for Health Metrics and Evaluation, Global Burden of Disease (GDB) Visualizations (2013) (this website, launched in 2013, provides access to data and interactive visualizations of the findings of the 2010 Global Burden of Diseases, Injuries, and Risk Factors Study,); *see also* Lim S., *et al.* (2012) *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990—2010: a systematic analysis for the Global Burden of Disease Study 2010*, THE LANCET 380(9859):2224 – 2260.

[155] Fang Y., *et al.* (2013) *Air pollution and associated human mortality: the role of air pollution emissions, climate change and methane concentration increases from the preindustrial period to present*, ATMOS. CHEM. PHYS 13:1377-1394, 1377 ("Most air pollution mortality is driven by changes in emissions of short-lived air pollutants and their precursors (95% and 85% of mortalities from PM2.5 and O_3 respectively). However, changing climate and increasing CH_4 concentrations also contribute to premature mortality associated with air pollution globally (by up to 5% and 15 %, respectively).").

[156] World Health Organization, About the Global Burden of Disease (GDB) project (2013) (The World Health Organization calculates the global burden of disease using disability-adjusted life year (DALY), which measures the combined years lost due to premature mortality, known as years of life lost (YLLs), and years of life lost due to time lived in states of less than full health, known as years lived with disability (YLD). One DALY is equal to one lost year of health life.).

[157] Lim S., *et al.* (2012) *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990—2010: a systematic analysis for the Global Burden of Disease Study 2010*, THE LANCET 380(9859):2224 – 2260.

[158] Asian Development Bank (2012) TOWARD AN ENVIRONMENTALLY SUSTAINABLE FUTURE COUNTRY ENVIRONMENTAL ANALYSIS OF THE PEOPLE'S REPUBLIC OF CHINA ("The increased demand for energy, growing vehicular fleet, and industrial expansion have led to serious air quality deterioration in the PRC, which, in turn, has adverse effects on human health and ecosystems. A recent study by the World Bank (2007) estimated that air pollution could be imposing annual economic costs in the PRC equivalent to as much as 1.2% of GDP based on cost-of-illness valuation and 3.8% of GDP based on willingness to pay"); *citing* World Bank (2007) COST OF POLLUTION IN CHINA: ECONOMIC ESTIMATES OF PHYSICAL DAMAGES ("Total health costs associated with air pollution are 1.2 percent (using AHC) and 3.8 percent (using VSL) of GDP."); *see also* Chen Y., *et al.* (2013) *Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy*, PROC. NAT'L ACAD. SCI. USA, published ahead of print July 8, 2012.

[159] Epstein M. B., *et al.* (2013) *Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal*, INTERNATIONAL JOURNAL OF HYGIENE AND ENVIRONMENTAL HEALTH 216:523-532 ("We find that type of household fuel used is linked with adverse neonatal outcomes—in particular, with LBW and neonatal death. Our results suggest that there is a higher likelihood of LBW and neonatal death in households using coal and kerosene, and of LBW in homes that use biomass, compared to households primarily using gas to cook and heat the home. using gas to cook and heat the home.... Mean birth weights of infants born in homes using high-pollution fuels—

kerosene, coal, and biomass—were significantly lower than mean birth weights in households using gas (Table 3). Comparatively, the risk of LBW among births in homes using biomass, coal and kerosene was greater than in homes using gas ($p < 0.05$). Coal- and kerosene-reliant households were associated with the lowest mean birth weights (compared to gas, the mean birth weight was −110 g for coal, −107 g for kerosene, and −78 g for biomass)").

[160] Epstein M. B., *et al*. (2013) *Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal*, International Journal of Hygiene and Environmental Health 216:523-532 ("This is particularly significant because India has the world's largest share of births (20%), infant deaths (30%), and a rate of LBW estimated as high as 30–40%. Furthermore, coal and biomass remain the primary sources of household fuel for over 70% of Indian households (90–95% in poorer, rural areas."); *see also* The United Nations Children's Fund (UNICEF) (2006) The State of the World's Children 2007, New York, USA, United Nations; Ramji S. (2009) *Impact of infant & young child feeding & caring practices on nutritional status & health*, Indian J. Med. Res. 130(5):624–626; *and* George K., *et al.* (2009) *Perinatal outcomes in a South Asian setting with high rates of low birth weight*, BMC Pregnancy Childbirth 9:5.

[161] Institute for Health Metrics and Evaluation, Global Burden of Disease (GDB) Visualizations (2013).

[162] American Lung Association (2013) State of the Air 2013; *and* European Environment Agency (2013) Air pollution by ozone across Europe during summer 2012: Overview of exceedances of EC ozone threshold values for April-September 2012.

[163] American Lung Association (2013) State of the Air 2013 ("Nearly 4 in 10 people in the United States (38%) live in areas with unhealthful levels of ozone. Counties that were graded F for ozone levels have a combined population of over 119.3 million.

These people live in the 191 counties where the monitored air quality places them at risk for premature death, aggravated asthma, difficulty breathing, cardiovascular harm and lower birth weight. The actual number who breathe unhealthy levels of ozone is likely much larger, since this number does not include people who live in adjacent counties in metropolitan areas where no monitors exist.”).

[164] European Environment Agency (2013) AIR POLLUTION BY OZONE ACROSS EUROPE DURING SUMMER 2012: OVERVIEW OF EXCEEDANCES OF EC OZONE THRESHOLD VALUES FOR APRIL-SEPTEMBER 2012 (“During summer 2012, TV exceedances occurred at stations in 17 EU Member States (Austria, Bulgaria, Cyprus, the Czech Republic, France, Germany, Greece, Hungary, Italy, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia and Spain) and five other countries (Albania, Croatia, the former Yugoslav Republic of Macedonia, Serbia and Switzerland). TV exceedances occurred at 21 % of all monitoring stations providing reports. This corresponded to approximately 18 % of the area assessed, affecting approximately 15 % of the total population.”).

[165] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 183 (“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.”); *see also* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE: SUMMARY FOR DECISIONS MAKERS; *and* UNEP (2011) NEAR-TERM CLIMATE PROTECTION AND CLEAN AIR BENEFITS: ACTIONS FOR CONTROLLING SHORT-LIVED CLIMATE FORCERS.

[166] Anenberg S. C., *et al.* (2012) *Global air quality and health co-benefits of mitigating near-term climate change through methane and black carbon emission controls*, ENVTL. HEALTH PERSPECTIVES, 120:831-839, 831, 838 (“We estimate that, for $PM_{2.5}$

[black carbon] and ozone respectively, fully implementing these [14] measures could reduce global population-weighted average surface concentrations by 23-34% and 7-17% and avoid 0.6-4.4 and 0.04-0.52 million annual premature deaths globally in 2030. More than 80% of the health benefits are estimated to occur in Asia…. Based on our estimates, avoided deaths would represent 1-8% of cardiopulmonary and lung cancer deaths among those age 30 years and older, and 1-7% of all deaths for all ages, assuming constant baseline mortality rates.”).

[167] Pachauri S., *et al.* (2013) *Pathways to achieve universal household access to modern energy by 2030*, Environ. Res. Lett 8:024015; *and* WB & ICCI (2013) On Thin ice: How Cutting Pollution Can Slow Warming and Save Lives, 36 (“The models used to estimate health impacts in this report only capture health impacts for ambient (outdoor) air pollution arising from cookstoves. The Global Burdens of Disease estimates, meanwhile, tell us that on a global scale exposure to cookstove pollution *within* the household causes about seven times more premature deaths…. The test case used exposure reduction scenarios consistent with fan-assisted and LPG/ biogas cookstove measures. Results indicated that full implementation of the fan-assisted cookstove measure could avoid 8,500 (range 7,400–9,800) premature deaths in Nepal and 12,900 (11,400–14,700) in Peru. Full implementation of the LPG/ biogas measure could result in 16,400 (13,400–20,900) premature deaths avoided annually in Nepal and 24,900 (20,300–31,600) in Peru. These results come from ideal scenarios in which everyone uses new stoves 100 percent of the time and operates them properly. This is similar to the assumptions in this report used in the modeling of ambient (outdoor) air impacts from cookstoves. These outdoor impacts have been estimated at 11,000 deaths avoided in Nepal from either measure due to outdoor air quality impacts alone, and approximately 500 deaths avoided in Peru using the BenMap tool.”).

[168] Van Dingenen R., *et al.* (2009) *The global impact of ozone on agricultural crop yields under current and future air quality legislation*, ATMOSPHERIC ENVIRONMENT 43(3):604-618; *see also* Avnery S. (2011) *Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage*, ATMOSPHERIC ENVIRONMENT 45:2284-2296; *and* Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Current global yield losses are estimated to be between 4 - 15% for wheat, 6 - 16% for soybean, 3 - 4% for rice and 2.2 - 5.5% for maize, with global economic losses estimated to be in the range $11 - $26 billion.").

[169] Avnery S., *et al.* (2011) *Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O_3 pollution*. ATMOSPHERIC ENVIRONMENT 45:2297-2309; *and* Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Under the IPCC SRES A2 Scenario (IPCC, 2007), global yield losses for the year 2030 due to ozone are predicted to range from 5.4 - 26% for wheat, 15 - 19% of soybean, and 4.4 - 8.7% for maize, with total global agricultural losses in the range $17 - $35 billion annually. Even under the lower emission scenario B1, less severe impacts will nevertheless be in the range $12 - $21 billion annually.").

[170] Natural Environment Research Council (2013) OZONE POLLUTION – A HIDDEN THREAT TO FOOD SECURITY ("Using a recently-developed modelling method that calculates the amount of ozone plants take up through their stomata over a whole growing season, we predicted that around €3.2 billion was lost in 2000 due to ozone effects on wheat yield. Even with current legislation to reduce ozone pollution in Europe, we predict losses will still be €2 billion in 2020. These numbers are based on wheat prices and production in 2000; given the rising price of wheat, economic

losses could end up substantially higher. The biggest impacts were predicted in areas of France, Germany, the UK and Italy. Losses for tomatoes, an important crop in southern Europe and the Netherlands, are estimated at more than €1 billion in 2000, and predicted to fall to €0.63 billion in 2020."); *see also* Harmens H., *et al.* (2011) AIR POLLUTION AND VEGETATION: ICP VEGETATION ANNUAL REVIEW 2010/2011, Centre for Ecology & Hydrology.

[171] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Comparison of the Asian data with European and North American dose-response relationships show that, almost without exception, Asian crops would appear to experience a higher sensitivity to equivalent ozone concentrations. Hence, Asian crop yield and economic loss assessments made using North American or similar European based dose-response relationships may underestimate the damage caused by ozone. As such, there is an urgent need for co-ordinated experimental field campaigns to assess the effects of ozone across Asia to allow the development of dose-response relationships for Asian cultivars and growing conditions.").

[172] Emberson L. D., *et al.* (2009) *A comparison of North American and Asian exposure–response data for ozone effects on crop yields*, ATMOSPHERIC ENVIRONMENT 43:1945-1953; *see also* Mills, G. *et al.* (2011) OZONE POLLUTION: A HIDDEN THREAT TO FOOD SECURITY, Programme Coordination Centre for the ICP Vegetation, Centre for Ecology and Hydrology, Bangor, UK.

[173] Yao F. F., *et al.* (2008) *Assessing the impact of ambient ozone on crop ecosystem: a case study in the Yangtze Delta, China*, ASIAN JOURNAL OF ECOTOXICOLOGY 3:189-195 189 ("current ambient O_3 concentration in the region of Yangtze River Delta induced yield losses of 3% in rice, 17% in wheat and 6% in oilseed rape, and the total economic loss was estimated to be 0.15 billion US dollars.").

[174] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Economic losses are estimated to be in the region of US$ 4 billion per year for 4 staple crops (wheat, rice, soybean and potato) for the South Asian countries of Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. The largest losses are found in the fertile, agriculturally important Indo-Gangetic plain").

[175] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("In wheat and potato, prolonged exposure to elevated ozone causes a limitation of the carbohydrate supply and increase in protein concentrations of tubers and grains. This improves the baking quality of wheat. Generally, seed quality of oilseed rape, in terms of crude protein and oil content, is reduced by elevated ozone, which represents an additional economic loss to the decrease in seed yield. Contrasting results have been reported for the impacts of ozone on the seed quality of soybean. Seed quality of mustard in terms of nutrients, protein and oil content was reduced, whereas impacts of ozone on market grade characteristics was small in peanut. In grapes a reduction in sugar content and juice quality has been reported, whereas in watermelon sweetness was reduced due to ozone exposure.").

[176] Harmens H., *et al.* (2011) Air Pollution and Vegetation: ICP Vegetation Annual Review 2010/2011, Centre for Ecology & Hydrology ("Decreases in forage quality of grasslands have been observed, which has economic implications for their use by ruminant herbivores. Decreased nutritive quality of forage can lead to lower milk and meat production from grazing animals. Forage quality is determined by its digestibility (largely dependent on cell-wall components as cellulose, hemicellulose and lignin), nutrient content (proteins, sugars, starch, minerals) and the presence/absence of anti-nutrients (e.g. tannins, nitrates, alkaloïds cyanoglycosides, oestrogens, mycotoxins). A decline in digestibility of forage due to

ozone might be caused by direct effects on cell wall components, enhanced leaf scenensce (resulting in increased lignification and a decreased leaf/stem ratio) or a change in species composition, in particular a decline in the legumes:grass ratio.”).

[177] International Fund for Agricultural Development, *et al.* (2004) Livestock services and the poor: A global initiative collecting, coordinating and sharing experiences (“Still, most livestock keepers – about 95 percent – live well below the poverty Line.... Livestock keeping is crucial for rural poor people. Nearly one billion head of livestock are believed to be held by more than 600 million poor smallholders. Livestock not only carry heavy loads, help cultivate fields and provide transportation, they also represent an important asset for rural people. Livestock are a form of currency, often given as loans or gifts, and their sale can provide quick cash in times of need. Income from livestock and their products enables poor families to put food on the table, improve their nutrition, send their children to school and buy medicine for themselves and their animals.”).

[178] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, Sci. 335(6065):183-189, 183 (“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.”); *see also* UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decisions Makers; *and* UNEP (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers.

[179] UNEP/WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decisions Makers, 3 (“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.”).

[180] Alexander L., *et al.* (2013) SUMMARY FOR POLICYMAKERS, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (“The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence)…. It is very likely that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 and 2010 and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010. Tide-gauge and satellite altimeter data are consistent regarding the higher rate of the latter period.”).

[181] IPCC (2012) MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS TO ADVANCE CLIMATE CHANGE ADAPTATION: SUMMARY FOR POLICYMAKERS. (“[Precipitation] There have been statistically significant trends in the number of heavy precipitation events in some regions. It is *likely* that more of these regions have experienced increases than decreases, although there are strong regional and subregional variations in these trends. … [Tropical Cyclones] There is *low confidence* in any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity (i.e., intensity, frequency, duration), after accounting for past changes in observing capabilities. It is *likely* that there has been a poleward shift in the main Northern and Southern Hemisphere extratropical storm tracks… [Flooding] There is *limited* to *medium evidence* available to assess climate-driven observed changes in the magnitude and frequency of floods at regional scales because the available instrumental records of floods at gauge stations are limited in space and time, and because of confounding effects of changes in land use and engineering. Furthermore, there is *low agreement* in this evidence, and thus overall *low confidence* at the global scale regarding even the sign of these changes…. [Coastal High Water] It is *likely* that there has

been an increase in extreme coastal high water related to increases in mean sea level."). The bold words are added for clarity.

[182] The large range for 21st century sea-level rise highlights the uncertainties involved in sea-level rise projections; however, the consensus is that substantial long-term sea-level rise will continue for centuries to come. AchutaRao K. M., *et al.* (2013) CHAPTER 10: DETECTION AND ATTRIBUTION OF CLIMATE CHANGE: FROM GLOBAL TO REGIONAL, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("It is *very likely* that there is a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s. It is *likely* that sea level rise has an anthropogenic contribution from Greenland melt since 1990 and from glacier mass loss since 1960's. Observations since 1971 indicate with *high confidence* that thermal expansion and glaciers (excluding the glaciers in Antarctica) explain 75% of the observed rise"); *and* Rahmstorf S., Foster G., & Cazenave A. (2011) *Comparing climate projection to observations up to 2011*, ENVIRON RES LETT 7(4). The 2013 IPCC AR5 projects that sea levels could rise 0.75 m (0.53-0.97 m) by 2100 under a high emissions scenario, or 0.43 m (0.41-0.79 m) under the most aggressive mitigation scenario. Cazenave A., *et al.* (2013) CHAPTER 13: SEA LEVEL CHANGE, *in* IPCC (2013) CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In 2009, Vermeer & Rahmstorf, using a semi-empirical method, predicted sea-levels could rise by up to 190 cm (75 – 190 cm) by 2100. Vermeer M. & Rahmstorf S. (2009) *Global sea level linked to global temperature*, PROC. NATL. ACAD. OF SCI. 106(51):21527-21532. In 2010 the National Research Council estimated that sea levels could rise by up to 200 cm (56 - 200 cm); and a 2012 National Research Council study estimated

that global sea levels could rise by up to 167 cm (42 – 167 cm) over 2000 levels by 2100 (~60 - 185 cm over pre-industrial sea levels). National Research Council (2010) ADVANCING THE SCIENCE OF CLIMATE CHANGE; *and* National Research Council (2012) SEA-LEVEL RISE FOR THE COASTS OF CALIFORNIA, OREGON, AND WASHINGTON: PAST, PRESENT, AND FUTURE; In 2011, based on observed melting of Arctic glaciers, ice caps, and the Greenland ice-sheet, the Arctic Monitoring and Assessment Programme of the Arctic Council estimated that sea-level rise could reach as much as 160 cm (90 - 160 cm) by the end of the century. Arctic Monitoring and Assessment Programme (2011) SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC: EXECUTIVE SUMMARY; In 2013, Hu A. *et al.* has estimated that sea levels could rise by up to 164.1 cm (130.1±34 cm) over pre-industrial levels. Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734.

[183] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 733 ("Owing to changes in ocean circulation in response to global warming and changes of the ice-sheet mass and associated gravity effect, certain regions would expect SLR significantly above the global average."); *see also* Perrette M., *et al.* (2013) *A scaling approach to project regional sea level rise and its uncertainties*, EARTH SYST. DYNAM. 4:11-29, 11 ("However, several consistent and robust patterns emerge from our analysis: at low latitudes, especially in the Indian Ocean and Western Pacific, sea level will likely rise more than the global mean (mostly by 10–20 %). Around the northeastern Atlantic and the northeastern Pacific coasts, sea level will rise less than the global average or, in some rare cases, even fall."); National Research Council (2012) SEA-LEVEL RISE FOR THE COASTS OF CALIFORNIA, OREGON, AND WASHINGTON: PAST, PRESENT, AND FUTURE; *and* Cazenave A., *et al.* (2013) CHAPTER 13: SEA LEVEL CHANGE, *in*

IPCC (2013) Climate Change 2013: The Physical Science Basis, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("It is very likely that in the 21st century and beyond, sea level change will have a strong regional pattern, with some places experiencing significant deviations of local and regional sea level change from the global mean change.").

[184] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change 3:730-734, 732 ("In comparison with the BAU case, mitigation of SLCPs can reduce the SLR_{full} rate [in 2050] by about 18% (from 1.1 cm yr^{-1} to about 0.9 cm yr^{-1})…. The SLCP mitigation would contribute about 24% of the SLR_{full} rate reduction … at 2100.").

[185] *Id* ("With mitigation of both SLCPs and CO_2, the projected SLR rate is reduced by close to 50% for SLR_{full}.").

[186] *Id*. Contributions from the each individual SLCP and CO_2 to reduced cumulative sea-level rise in 2100 are derived by the authors from Figure 2(c).

[187] Note that the study estimated risk of exposure based upon a 50 cm sea-level rise in 2070. This is within the range of predicted sea-level rise for the 21st century but 33% lower than the mean sea-level rise in 2070 predicted by Hu A. *et al.* (2013). Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, Nature Climate Change 3:730-734.

[188] OECD (2010) Cities and Climate Change; *citing* Nicholls R. J., *et al.* (2008) Ranking of the World's Cities Most Exposed to Coastal Flooding Today and in the Future: Exposure Estimates, *OECD Environment Working Paper Series*, No 1, OECD, Paris. A new study analyzing a lower sea-level rise in 2050 (20-40 cm), estimated aggregate losses from flooding in the world's top 136 port cities at more than $1 trillion per year, if no coastal protection is undertaken. Coastal protection measures can reduce annual losses to flooding to $58 billion. Hallegatte S.,

et al. (2013) *Future flood losses in major coastal cities*, NATURE CLIMATE CHANGE, advance online publication.

[189] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 733 ("A delayed SLCP mitigation by about 25 years could reduce the impact of the CO_2 and SLCP mitigation on SLR by about 30%.").

[190] *Id*, Figure 2(c).

[191] The UNEP/WMO and Shindell *et al.* studies analyzed the 1650 individual control measures in the technology and emission databases of the IIASA Greenhouse gas: Air pollution Interactions and Synergies (GAINS) climate model. These were grouped into 400 categories, which were then analyzed for their impacts on emissions of methane, carbon monoxide, black carbon, organic carbon, sulfur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and carbon dioxide. The measures were further analyzed to determine the net effect of the changes in global radiative forcing (RF) due to changes in emissions of the studied gases and aerosols, and ranked according to their efficacy at reducing global RF. 130 measures were shown to reduce global RF and the top 16 of those measures were shown to produce almost 90% of the total mitigation potential. Shindell *et al.* combined four measures into two larger categories of measures, reducing to 14 the original 16 measures. *See* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189; *and* UNEP/WMO (2011) INTEGRATED ASSESSMENT OF BLACK CARBON AND TROPOSPHERIC OZONE: SUMMARY FOR DECISIONS MAKERS.

[192] UNEP (2011) NEAR-TERM CLIMATE PROTECTION AND CLEAN AIR BENEFITS: ACTIONS FOR CONTROLLING SHORT-LIVED CLIMATE FORCERS ("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."); *see also* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189.

[193] Bond T. C., *et al.* (2013) *Bounding the role of black carbon in the climate system: a scientific assessment*, J. OF GEOPHYS. RES. –ATMOS. 118(11):5380-5552.

[194] Jacobson A., *et al.* (2013) BLACK CARBON AND KEROSENE LIGHTING: AN OPPORTUNITY FOR RAPID ACTION ON CLIMATE CHANGE AND CLEAN ENERGY FOR DEVELOPMENT; *and* Lam N., *et al.* (2012) *Household light makes global heat: high black carbon emissions from kerosene wick lamps*, ENVIRON. SCI. TECHNOL. 46(24): 13531-13538, 13531 ("Kerosene-fueled wick lamps used in millions of developing-country households are a significant but overlooked source of black carbon (BC) emissions. We present new laboratory and field measurements showing that 7-9% of kerosene consumed by widely used simple wick lamps is converted to carbonaceous particulate matter that is nearly pure BC…Kerosene lamps have affordable alternatives that pose few clear adoption barriers and would provide immediate benefit to user welfare. The net effect on climate is definitively positive forcing as co-emitted organic carbon is low. No other major BC source has such readily available alternatives, definitive climate forcing effects, and co-benefits. Replacement of kerosene-fueled wick lamps deserves strong consideration for programs that target short-lived climate forcers.").

[195] Lack D. A. & Thusen J. (2012) INVESTIGATION OF APPROPRIATE CONTROL MEASURES (ABATEMENT TECHNOLOGIES) TO REDUCE BLACK CARBON EMISSIONS FROM INTERNATIONAL SHIPPING ("Simply reducing vessel speed will not achieve any BC emissions reductions, and may in fact increase emissions unless the engine has electronically controlled injection and can adjusts to the load. Here, the

assessment is done [in] the case where slow steaming is achieved with de-rating and the technology is actually generating savings of approximately USD 2.6 per reduced g of BC…. The use of natural gas as fuel for propulsion of ships is considered attractive in terms of its potential for reduction of SO_X and NO_X, but it has considerable potential for BC reduction also. However, the barriers are high for introduction, since the ships must undergo extensive retrofitting and may lose commercial space onboard, in addition to a widespread lack of bunkering facilities. The advantage, besides the reduction of emissions, is a fuel bonus rendering LNG a most cost-effective remedy generating savings of approximately USD 1.7 per gram BC reduced.”).

[196] Molina M., *et al.* (2009) *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*, Proc. Natl. Acad. Sci. USA 106(49):20616-20621, 20619 (“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.”); *see also* Molina M. & Zaelke D. (2013) *A comprehensive approach for reducing anthopogenic climate impacts including risk of abrupt climate changes*, *in* Pontifical Academy of Sciences (2013) *Fate of Mountain Glaciers in the Anthropocene*, Scripta Varia 118; UNEP (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers (“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."); *and* Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335:183-189, 188 ("Many other policy alternatives exist to implement the CH_4 [methane] and BC measures, including enhancement of current air quality regulations.").

[197] UNEP (2011) NEAR-TERM CLIMATE PROTECTION AND CLEAN AIR BENEFITS: ACTIONS FOR CONTROLLING SHORT-LIVED CLIMATE FORCERS ("About 50 per cent of both methane and black carbon emissions 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 emissions reduction could be addressed at relatively moderate costs.").

[198] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, SCI. 335(6065):183-189, 186 ("using \$430 for climate and discounted health and agricultural values, gives a total benefit of ~\$1100 per metric ton of CH_4 (~\$700 to \$5000 per metric ton, using the above analyses). IEA estimates (37) indicate roughly 100 Tg/year of CH_4 emissions can be abated at marginal costs below \$1100, with more than 50 Tg/year costing less than 1/10 this valuation (including the value of CH_4 captured for resale). Analysis using more recent cost information in the GAINS model (38, 39) finds that the measures analyzed here could reduce 2030 CH_4 emissions by ~110 Tg at marginal costs below \$1500 per metric ton, with 90 Tg below \$250. The full set

of measures reduce emissions by ~140 Tg, indicating that most would produce benefits greater than—and for approximately two-thirds of reductions far greater than—the abatement costs. Of course, the benefits would not necessarily accrue to those incurring costs.").

[199] World Bank (2013) Methane Finance Study Group Report: Using Pay-for-Performance Mechanisms to Finance Methane Abatement ("In total, by summing the potential of these five sectors [coal mines, landfills/waste management, wastewater, oil and gas, livestock management] between 2013 and 2020 with a $10 or less financial incentive per ton, it is estimated that emissions could be reduced by 8,200 million tons of CO_2e.... [T]he Group found an immediate opportunity to jumpstart some of the 1,200 new methane mitigation projects that were initiated, but not implemented, under carbon offset standards in developing countries, representing at least 850 Mt of CO_2e in emission reductions over the period 2013–2020.").

[200] O'Sullivan F. & Paltsev S. (2012) *Shale gas production: potential versus actual greenhouse gas emissions*, Environmental Res. Lett. 7(4):044030 ("If the cost of reduced emission completion is $1000 per day as stated by Devon (2008), 95% of the 2010 Barnett wells yielded positive net revenues, i.e., operators added to the value of their wells by capturing the potential fugitive emissions. Even at twice this reported capture cost, $2000 per day, 83% of the 2010 Barnett wells would still positive net revenues, and this trend is repeated in the all the other shale plays.... The aggregate gross value of the gas produced during fl("If t from the 3948 shale wells considered in this study amounts to $320 million [in 2010].").

[201] Shindell D., *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, Sci. 335(6065):183-189, 186 ("GAINS estimates show that improved efficiencies lead to a net cost savings for the brick

kiln and clean-burning stove BC measures. These account for ~50% of the BC measures' impact.").

[202] *Id.,* 186 ("The regulatory measures on high-emitting vehicles and banning of agricultural waste burning, which require primarily political rather than economic investment, account for another 25%. Hence, the bulk of the BC measures could probably be implemented with costs substantially less than the benefits given the large valuation of the health impacts.").

[203] *Id.*

[204] Shindell D. *et al.* (2012) *Simultaneously mitigating near-term climate change and improving human health and food security*, Sci. 335(6065):183-189, 186 ("Global impacts of measures on climate, agriculture, and health and their economic valuation. Valuations are annual values in 2030 and beyond, due to sustained application of the measures, which are nearly equal to the integrated future valuation of a single year's emissions reductions (without discounting). Climate valuations for CH_4 use GWP100 and an SCC [social coast of carbon] of $265 per metric ton.").

[205] *Id.*, 186 ("Global impacts of measures on climate, agriculture, and health and their economic valuation. Valuations are annual values in 2030 and beyond, due to sustained application of the measures, which are nearly equal to the integrated future valuation of a single year's emissions reductions (without discounting). Climate valuations for CH_4 use GWP100 and an SCC [social cost of carbon] of $265 per metric ton.... As noted in the main text, a GWP-based valuation neglects differences in the regional effects of these pollutants on temperatures, precipitation and sunlight available for photosynthesis relative to CO_2. As Figure 2 in the main text shows, regional effects can be quite distinct in the case of the BC measures. Additionally, the SCC includes some CO_2-specific factors such as fertilization of ecosystems which would not be present with forcing from methane or other short-lived species. As damages are often though to scale as a power of temperature change, there may also be

somewhat less valuation of near-term changes than of later changes in a warmer future world and the climate valuation would grow more sharply with time for short lived species than for CO_2. Further work is clearly needed to better define appropriate techniques for valuation of non-CO_2 climate impacts.”).

[206] *Id.* (“Valuation of crop yield changes uses year 2000 global market prices from the Food and Agriculture Organization (faostat.fao.org)….”).

[207] *Id.* (“Valuation of premature mortalities is based on the value of a statistical life (VSL) approach. The relationship between mortality risks and willingness-to-pay (WTP) is used to determine the VSL, which is an expression of the value that people affix to small changes in mortality risks in monetary terms. We employ the United States Environmental Protection Agency’s (USEPA) preferred VSL of $9,500,000 for 2030…Valuations in the main text are presented using country-specific VSLs.”) (internal citations omitted).

[208] Zaelke D., *et al.* (2012) *Strengthening Ambition for Climate Mitigation: The Role of the Montreal Protocol in Reducing Short-Lived Climate Pollutants*, Rev. Eur. Comp. & Int’l Envtl. Law 21(3):231-242, 238 (“The Montreal Protocol is ideally equipped to ensure a cost-effective, efficient and orderly phase-down of HFCs because HFCs are in the same family of gases, have similar chemical properties and are used in the same sectors as CFCs and HCFCs. The Montreal Protocol is already responsible for the global phase-out of 97% of the consumption and production of nearly 100 ozone-depleting substances and has put the stratospheric ozone layer on a path to recovery by mid-century”); *and* Environmental Investigation Agency (2012) Closing the emissions gap: Time to phase out HFCs (“The Montreal Protocol is uniquely positioned to adopt and implement a phase-out of HFCs. It has the technical, scientific and financial institutions in place, with a proven track record of phasing-out HFC precursors from the exact same industrial sectors

that currently use HFCs. Moreover, the fluorocarbon industry has indicated its support for an HFC phase-down.”).

[209] Velders G. J. M., *et al.* (2007) *The importance of the Montreal Protocol in protecting climate*, Proc. Nat'l. Acad. Sci. USA 104:4814-4819.

[210] UNEP (2012) The Montreal Protocol and the Green Economy: Assessing the contributions and co-benefits of a Multilateral Environmental Agreement.

[211] Proposed Amendment to the Montreal Protocol (submitted by the Federated States of Micronesia) (16 April 2013); Proposed Amendment to the Montreal Protocol (submitted by the United States, Canada, and Mexico) (16 April 2013).

[212] England M. H., *et al.* (2009) *Constraining future greenhouse gas emissions by a cumulative target*, Proc. Nat'l. Acad. Sci. USA 106:16539-16540; Meinshausen M., *et al.* (2009) *Greenhouse-gas emission targets for limiting global warming to 2°C*, Nat. 458:1158-1162; *and* Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954 (The cumulative BAU emission from the 6 Kyoto gases from 2000-50 is about 975 GtC-eq (=650 x 1.5, Fig. 1, Scenario 6 (England *et al.*)), which is equivalent to approximately 3575 Gt CO_2-eq. The cumulative Kyoto-gas emission budget for 2000-50 is 1500 $GtCO_2$-eq. if the probability of exceeding 2˚C is to be limited to approximately 25% (Meinshausen *et al.*, pg. 1160). Therefore, the total mitigation needed by 2050 is approximately 2075 $GtCO_2$-eq. The 87-147 $GtCO_2$-eq. from the proposed HFC phase down represents 4-7% of the total mitigation needed by 2050, and up to 8% if all HFCs are replaced by low-GWP substitutes.).

[213] De Larminat P. (2013) *Development of Climate-Friendly Alternatives for Chillers* (presentation at Bangkok Technology Conference, 29 June 2013).

[214] U.S. Envtl. Prot. Agency (2002) Building owners save money, save the earth: replace your CFC air-conditioning chiller, 7.

[215] There are already a number of examples of energy efficiency gains PepsiCo reports that through equipment re-design, energy efficient components and energy management devices, their new HC refrigerant coolers are 47% more efficient than their HFC coolers six years ago. Tesco began developing CO_2 and other natural refrigeration systems in 1993 and now reports that their commercial coolers are up to 10% more energy efficient than standards HFC systems. The CocaCola Company developed a new Energy Management System (EMS), which improved energy efficiency of its new CO_2 and hydrocarbon coolers by up to 40% over HFC models. Unilever has achieved an average energy reduction of 10% in its freezer cabinets by converting to propane. Consumer Goods Forum (2009) Success Stories About HFC-Free Refrigeration and Energy Efficiency: Barriers and Solutions.

[216] Montreal Protocol Technology and Economic Assessment Panel (2010) TEAP 2010 Progress Report Volume 1 ("Systems using low-GWP alternatives are able to achieve equal or superior energy efficiency in a number of sectors, such as domestic refrigeration, commercial refrigeration and some types of air-conditioning systems. In the case of industrial refrigeration, for example, hydrocarbon and ammonia systems are typically 10-30% more energy efficient than conventional high-GWP HFC systems."); *and* Schwarz W., *et al.* (2011) Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases, Annexes to the Final Report.

[217] UNEP (2012) The Montreal Protocol and the Green Economy: Assessing the contributions and co-benefits of a Multilateral Environmental Agreement; *citing* the following sources listed as they are cited in the figure *(1)* Velders G. J. M., *et*

al. (2007) *The importance of the Montreal Protocol in protecting climate*, Proc. Nat'l. Acad. Sci. USA 104:4814-4819; *(2)* Velders G. J. M., *et al*. (2007) The Montreal Protocol, Celebrating 20 years of environmental progress, ed. Kaniaru D (Cameron May, London, UK); *(3)* Montreal Protocol Technology and Economic Assessment Panel (2009) Task Force Decision XX/7 Interim Report: Environmentally Sound Management of Banks of Ozone-Depleting Substances; *(4)* UNEP Riso (2009) A Primer on CDM Programme of Activities; *(5)* Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954. Note: Estimates are for direct emissions, and do not include CO_2 reductions from energy efficiency improvements.

[218] Montreal Protocol Technology and Economic Assessment Panel (2009) Task Force Decision XX/8 Report: Assessment of Alternatives to HCFCs and HFCs and Update of the TEAP 2005 Supplement Report Data.

[219] Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954, 10949 ("Global HFC emissions significantly exceed previous estimates after 2025 with developing country emissions as much as 800% greater than in developed countries in 2050. Global HFC emissions in 2050 are equivalent to 9–19% (CO_2-eq. basis) of projected global CO_2 emissions in business-as-usual scenarios and contribute a radiative forcing equivalent to that from 6–13 years of CO_2 emissions near 2050. This percentage increases to 28–45% compared with projected CO_2 emissions in a 450-ppm CO_2 stabilization scenario."); *see also* U.S. Envtl. Prot. Agency (2013) Benefits of Addressing HFCs under the Montreal Protocol.

[220] Schwarz W., *et al.* (2011) Preparatory Study for a Review of Regulation (EC) No 842/2006 on Certain Fluorinated Greenhouse Gases: Final Report.

[221] European Commission (2013) Implementation of Directive 2006/40/EC – Questions and Answers.

[222] Ministry of Economy, Trade and Industry of Japan (April 2013) *Cabinet Decision on the Bill for the Act for Partial Revision of the Act on Ensuring the Implementation of Recovery and Destruction of Fluorocarbons concerning Designated Products*.

[223] The President's Climate Action Plan (Executive Office of the President 2013) (mentioning the Significant New Alternatives Policy Program as a policy tool to "encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals while prohibiting certain uses of the most harmful chemical alternatives"), and *Remarks by the President on Climate Change* (The White House Office of the Press Secretary, 25 June 2013). In the U.S., "Eliminating HFCs represents the biggest opportunity for GHG emissions reductions behind power plants," and would provide 23% of the emissions reductions needed to achieve the U.S.'s 2020 reduction goal (17% below 2005 emissions). Bianco, N. *et al*. (2013) Can The U.S. Get There From Here?: Using Existing Federal Laws and State Action to Reduce Greenhouse Gas Emissions, World Resources Institute, 3-4.

[224] H.R. 1943 (2013) SUPER Act of 2013, 113th Congress 1st Session (introduced).

[225] U.S. Envtl. Prot. Agency (2011) EPA and NHTSA Finalize Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks.

[226] U.S. Fed. Reg. (2012) 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards 77:199 ("In addition to the grams-per-mile CO_2-equivalent credits, for the first time the agencies are establishing provisions in the CAFE program that would account for improvements in air conditioner efficiency.

Improving A/C efficiency leads to real-world fuel economy benefits, because as explained above, A/C operation represents an additional load on the engine. Thus, more efficient A/C operation imposes less of a load and allows the vehicle to go farther on a gallon of gas.").

[227] California Air Resources Board, Low-Emission Vehicles (LEV) & GHG 2012; *and* California Air Resources Board (2012) Final Regulation Order: "LEV III" Amendments to the California Greenhouse Gas and Criteria Pollutant Exhaust and Evaporative Emission Standards and Test Procedures and to the On-Board Diagnostic System Requirements for Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles, and to the Evaporative Emission Requirements for Heavy-Duty Vehicles.

[228] U.S. Fed. Reg. (2011) Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy Duty Engines and Vehicles, 76:179.

[229] European Commission (2012) Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, COM(2012)0643 final; *and* European Parliament, Committee on the Environment, Public Health and Food Safety (2013) Draft Report on the proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases, 2012/0305(COD). (In November 2012 the European Commission published a proposal to strengthen their fluorinated greenhouse gas (f-gas) regulations, calling for an economy-wide phase-down of f-gases, managed by a quota system for importers and producers, along with use bans and better equipment seals. In March 2013 the European Parliament's rapporteur, Bas Eickhout, submitted a report containing a number of amendments to the 2012 proposal, including: earlier and additional bans on new refrigeration and air conditioning equipment containing HFCs, bans on "pre-charged" equipment, mandatory destruction of

by-product HFC-23 emissions from the manufacture of f-gases including production of feedstocks, and a faster phase-down schedule. The amendments also call for implementation of a fee system for import and production quotas as well as reporting requirements for the import, export, or production of more than 500 tonnes CO_2-eq of f-gases in a calendar year. The European Parliament will debate the report and it will be voted upon on 19 June 2013, if the proposal does not pass it will be bought for a second vote, likely in 2014, after which it will go through a conciliation process.) Several provisions would impose trade restrictions. *See, e.g.,* Article 12 (pre-charge ban), Article 6 (by-product destruction requirement), Annex III (bans on new HFC-based equipment), and Article 14 (phase downs, which are strengthened over time).

[230] Consumer Goods Forum (2012) BETTER LIVES THROUGH BETTER BUSINESS, 10; *see also* The Consumer Goods Forum, Sustainability Pillar.

[231] Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, PROC. NAT'L. ACAD. SCI. USA 106:10949-10954.

[232] United Nations (2012) RESOLUTION ADOPTED BY THE GENERAL ASSEMBLY: THE FUTURE WE WANT, A/RES/66/288.

[233] UNEP (2011) REPORT OF THE COMBINED NINTH MEETING OF THE CONFERENCE OF THE PARTIES TO THE VIENNA CONVENTION ON THE PROTECTION OF THE OZONE LAYER AND THE TWENTY-THIRD MEETING OF THE PARTIES TO THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER, par 156. The Bangkok Declaration can be found *at* UNEP (2010) TWENTY-SECOND MEETING OF THE PARTIES, ANNEX III: DECLARATION ON THE GLOBAL TRANSITION AWAY FROM HYDROFLOROCARBONS (HCFCS) AND CHLOROFLUOROCARBONS (CFCS).

[234] UNEP (2012) REPORT OF THE TWENTY-FOURTH MEETING OF THE PARTIES TO THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE

the Ozone Layer, par. 189. The Bali Declaration can be found *at* UNEP (2011) Report of the combined ninth meeting of the Conference of the Parties to he Vienna Convention on the Protection of the Ozone Layer and the Twenty-Third Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, Annex IX.

[235] The G-20 declaration included Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and the European Union, as well as support from invited non-member countries: Ethiopia, Spain, Senegal, Brunei, Kazakhstan, and Singapore. G-20 (2013) G20 Leaders' Declaration ("101. We are committed to support the full implementation of the agreed outcomes under the United Nations Framework Convention on Climate Change (UNFCCC) and its ongoing negotiations.… We also support complementary initiatives, through multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the production and consumption of hydrofluorocarbons (HFCs), based on the examination of economically viable and technically feasible alternatives. We will continue to include HFCs within the scope of UNFCCC and its Kyoto Protocol for accounting and reporting of emissions.").

[236] Press Release, White House Office of the Press Secretary, *United, China, and Leaders of G-20 Countries Announce Historic Progress Toward a Global Phase Down of HFCs* (6 September 2013) ("We reaffirm our announcement on June 8, 2013 that the United States and China agreed to work together and with other countries through multilateral approaches that include using the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs, while continuing to include HFCs within the scope of UNFCCC and its Kyoto Protocol provisions for accounting and reporting of emissions.

We emphasize the importance of the Montreal Protocol, including as a next step through the establishment of an open-ended contact group to consider all relevant issues, including financial and technology support to Article 5 developing countries, cost effectiveness, safety of substitutes, environmental benefits, and an amendment. We reiterate our firm commitment to work together and with other countries to agree on a multilateral solution.”””). The US-China agreement builds upon more than four months of high-level negotiations between the two nations including the first-ever summit between President Obama and President Xi on 8 June 2013 where they agreed to “work together and with other countries to use the expertise and institutions of the Montreal Protocol to phase down the consumption and production of hydrofluorocarbons (HFCs).” *See* Press Release, The White House Office of the Press Secretary, *United States and China Agree to Work Together on Phase -Down of HFCs* (8 June 2013).

[237] Press Release, White House Office of the Press Secretary, *U.S.-India Joint Statement* (27 September 2013). (““The two leaders agreed to immediately convene the India-U.S. Task Force on hydrofluorocarbons (HFCs) to discuss, inter alia, multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the consumption and production of HFCs, based on economically-viable and technically feasible alternatives, and include HFCs within the scope of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol for accounting and reporting of emissions…. They also supported complementary initiatives, through multilateral approaches that include using the expertise and the institutions of the Montreal Protocol to phase down the production and the consumption of HFCs, based on the examination of economically viable and technically feasible alternatives. They will continue to include HFCs within the scope of UNFCCC and its Kyoto Protocol for accounting and reporting of emissions.”).

[238] Press Release, Department of Environmental Affairs Republic of South Africa, Joint statement issued at the conclusion of the 16th BASIC Ministerial meeting on climate change (16 September 2013) ("Ministers agreed that hydrofluorocarbons (HFC) should be dealt with through relevant multilateral fora, guided by the principles and provisions of UNFCCC and its Kyoto Protocol. The availability of safe and technically and economically viable alternatives and the provision of additional financial resources by developed countries should also be taken into account.") (The BASIC countries include: Brazil, South Africa, India, and China); *see also* UNEP (2013) Report of the thirty-third meeting of the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer ("155. Several representatives raised concerns over the level of financial support that would need to be available [for an HFC phase down under the Montreal Protocol], especially given developing countries" limited resources and competing priorities for public funding. Several representatives raised their concern over the availability of funding for both HCFC phase-out and potential HFC phase-down and one representative highlighted the inadequate amounts that his country had thus far received for assisting with HCFC phase-out…. 160. Several representatives from high-ambient-temperature regions explained that the matter of the availability of [HFC] alternatives was a particular concern to them. In their countries, summer temperatures could reach as high as 55° C; in such circumstances, air conditioning was not a luxury but a necessity. Concerns over flammability and safety further limited the availability of alternatives to HFCs…. 162. Several representatives, from parties operating under paragraph 1 of Article 5 and from parties not so operating, underlined the need for the latter to take the lead in demonstrating the technical and economic feasibility of new alternatives.").

[239] In the decision requesting action by the TEAP, the Parties agreed to: (1) estimate current and future demand for alternatives, including HFCs, and also requested an assessment of the economic costs and implications, and environmental benefits of various scenarios that avoid high-GWP alternatives to currently used ODS, including, HFCs; (2) convene a workshop back-to-back with the 34th OEWG in summer 2014 to continue discussions on HFC management; (3) provide to the Ozone Secretariat, on a voluntary basis, information regarding the avoidance of HFCs under the existing HCFC phase-out; and (4) request the Executive Committee of the Multilateral Fund to consider whether additional demonstration projects to validate low-GWP alternatives and technologies, and additional activities to maximize the climate benefits in the HCFC production sector, would be useful in assisting developing country Parties in further minimizing the environmental impacts of the HCFC phase-out. UNEP (2013) Draft Report of the Twenty-Fifth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, UNEP/Ozl.Pro.25/L.1; *and* UNEP (2013) Draft decision XXV/[X[: Response to the Report by the Technology and Economic Assessment Panel on information on alternatives to ozone-depleting substances.

[240] U.S. Envtl. Prot. Agency (2013) Benefits of Addressing HFCs under the Montreal Protocol.

[241] Prepared for IGSD by Dr. Guus Velders, based on Velders G. J. M., *et al.* (2009) *The large contribution of projected HFC emissions to future climate forcing*, Proc. Nat'l. Acad. Sci. USA 106:10949-10954; *see also* Velders G. J. M., *et al.* (2007) *The importance of the Montreal Protocol in protecting climate*, Proc. Nat'l. Acad. Sci. USA 104:4814-4819; U.S. Envtl. Prot. Agency (2013) Benefits of Addressing HFCs under the Montreal Protocol; *and* UNEP (2011) HFCs: A Critical Link in Protecting Climate and the Ozone Layer.

[242] Climate and Clean Air Coalition to Reduce Short Lived Climate Pollutants, About; *see also* US Dept. of State, *The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants: Fact Sheet* (16 Feb. 2012).

[243] Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, Actions.

[244] C40 Cities Climate Leadership Group, Video: *C40 Mayors Demonstrate Progress in Greenhouse Gas Reductions and Announce New Actions to Take on Climate Change*, (27 June 2012); Press Release, UNEP, *Cities Join Forces with the Climate and Clean Air coalition to Tackle Solid Waste*, (12 March 2013).

[245] Press Release, G8, *Camp David Declaration* (19 May 2012) ("Recognizing the impact of short-lived climate pollutants on near-term climate change, agricultural productivity, and human health, we support, as a means of promoting increased ambition and complementary to other CO_2 and GHG emission reduction efforts, comprehensive actions to reduce these pollutants, which, according to UNEP and others, account for over thirty percent of near-term global warming as well as 2 million premature deaths a year. Therefore, we agree to join the Climate and Clean Air Coalition to Reduce Short-lived Climate Pollutants.").

[246] Press Release, UNEP, *Cities Join Forces with the Climate and Clean Air Coalition to Tackle Solid Waste* (12 March 2013) ("Participating cities include Rio de Janeiro, Brazil; Cali, Colombia; Viña del Mar, Chile; New York City, USA; Stockholm, Sweden; Accra, Ghana; Lagos, Nigeria; Penang, Malaysia; Dhaka, Bangladesh; Ho Chi Minh, Vietnam; and Tokyo, Japan.")

[247] The Coalition's Country Partners pledge to continue working to achieve CCAC objectives through the ten approved "high-impact global initiatives" including "adopt[ing] domestic approaches to encourage climate-friendly HFC alternative technologies and work toward a phasedown in the production and consumption of HFCs under the Montreal Protocol… [and work]

with international standards organizations to revise their standards to include climate-friendly HFC alternatives." CCAC (2013) Third Meeting of the High Level Assembly: Communique, Oslo Norway; *see also* Press Release, CCAC, Climate and Clean Air Coalition High Level Assembly Announces Ambitions Agenda (3 September 2013).

248 The report calculated that between 2007 and 2012, 7.7% of World Bank commitments (~$18 billion) went to SLCP-relevant activities. World Bank (2013) Integration of short-lived climate pollutants in World Bank Activities ("SLCP-relevant activities in energy, transport, roads, agriculture, forestry, and urban waste and wastewater. Going forward, the goal will be to transform as much of the SLCP-relevant activities as possible into SLCP reducing activities. Specific commitments for the World Bank on SLCP-reducing activities will be articulated as part of the climate action planning process which is expected to conclude in 2014.").

249 CCAC (2013) Third Meeting of the High Level Assembly: Communique, Oslo Norway; *see also* Press Release, World Bank, *Cutting Short-Lived Climate Pollutants: A Win-Win for Development and Climate* (3 September, 2013) ("According to the report, reductions of as much as 8,200 million tons of CO_2 equivalent could be delivered in developing countries at less than $10 per ton in incremental cost financing – a gap which can be closed by pay-for-performance mechanisms."); *and* World Bank (2013) Methane Finance Study Group Report.

250 CCAC (2013) Third Meeting of the High Level Assembly: Communique, Oslo Norway; *see also* Press Release, CCAC, Climate and Clean Air Coalition High Level Assembly Announces Ambitions Agenda (3 September 2013).

251 Press Release, UNEP, *New Climate and Clean Air Coalition Expands to 13 Members* (24 April 2012).

252 CCAC (2013) Third Meeting of the High Level Assembly: Communique, Oslo Norway; *see also* Press Release, CCAC,

Climate and Clean Air Coalition High Level Assembly Announces Ambitions Agenda (3 September 2013).

[253] Climate and Climate Air Coalition to Reduce Short Lived Climate Pollutants, Partners.

[254] There are many international environmental treaties, organizations, and initiatives which directly or indirectly address climate mitigation, which are known collectively as International Cooperative Initiatives (ICIs). Many of these ICIs address SLCPs. The UNFCCC maintains a databse of these ICIs. UNFCCC (2013) International Cooperative Initiatives Database; *see also* UNEP (2013) The Emissions Gap Report, Chapter 5 (for a discussion of the role ICIs can play to catalyze near-term climate mitigation.).

[255] Economic Commission for Europe, (2012) Amendment of annex I to the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, ECE/EB.AIR/111/Add.1.

[256] Global Alliance for Clean Cookstoves, The Alliance; Global Methane Initiative, About the Initiative.

[257] UNEP (2008) Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia, 3 ("1. Five regional ABC hotspots around the world have been identified: i) East Asia; ii) Indo-Gangetic Plain in South Asia; iii) Southeast Asia; iv) Southern Africa; and v) the Amazon Basin. By integrating and assimilating ABC surface observations with new satellite observations and chemistry transport model (CTM), the ABC Science Team produced global maps of ABC hotspots.

[258] International Maritime Organization, Marine Environment Protection Committee (MEPC) *IMO Environment Meeting Completes Packed Agenda* (19 July 2011).

[259] Lack D. A. & Thuesen J. (2012) Investigation of appropriate control measures (abatement technologies) to reduce Black Carbon emissions from international shipping.

[260] Ministry of the Environment Sweden (2013) CHAIRS CONCLUSIONS FROM THE ARCTIC ENVIRONMENT MINISTERS MEETING: ARCTIC CHANGE – GLOBAL EFFECTS, 2.

[261] Arctic Council Secretariat (2013) KIRUNA DECLARATION ON THE OCCASION OF THE EIGHTH MINISTERIAL MEETING OF THE ARCTIC COUNCIL.

[262] European Commission (2012) REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON FLUORINATED GREENHOUSE GASES, COM(2012)0643 final; *and* European Parliament, Committee on the Environment, Public Health and Food Safety (2013) DRAFT REPORT ON THE PROPOSAL FOR A REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON FLUORINATED GREENHOUSE GASES, 2012/0305(COD).

[263] Markowitz K. & Grossman D. (2009) *Cost Effective Management of National Climate Policy: Application of Environmental Compliance and Enforcement Indicators*, *in* International Network for Environmental Compliance and Enforcement (2009) INECE SPECIAL REPORT ON CLIMATE COMPLIANCE ("Reducing Soot Emissions at Ports: One of the primary short-term climate forcing agents is black carbon, which warms the planet by absorbing heat, raising ambient temperatures, and reducing the albedo of the surfaces it falls upon. Many countries currently have, or are developing, laws to control and limit emissions at ports (e.g., emissions from ships, trucks, trains, and other diesel-powered equipment). A number of ports in the United States and Europe could utilize ECE indicators to ensure compliance with the programs they have installed to control speed, to promote retrofitting, and to test emissions").

[264] Executive Office of the President (2013) THE PRESIDENT'S CLIMATE ACTION PLAN (mentioning the Significant New Alternatives Policy Program as a policy tool to "encourage private sector investment in low-emissions technology by identifying and approving climate-friendly chemicals while prohibiting

certain uses of the most harmful chemical alternatives"); *and* Press Release, The White House Office of the Press Secretary, *Remarks by the President on Climate Change* (25 June 2013). In the U.S., "Eliminating HFCs represents the biggest opportunity for GHG emissions reductions behind power plants," and would provide 23% of the emissions reductions needed to achieve the U.S.'s 2020 reduction goal (17% below 2005 emissions). Bianco N., *et al*. (2013) Can The U.S. Get There From Here?: Using Existing Federal Laws and State Action to Reduce Greenhouse Gas Emissions, World Resources Institute, 3-4.

[265] The Connect U.S. Fund, *A Call to the President to Sustain and Enhance U.S. Global Leadership* (8 December 2012) (calling on the President to "Continue action to reduce short-lived climate pollutants (e.g., black carbon, methane, and HFCs), by strengthening bilateral cooperation with major emerging economies at the head of state level; adequately funding and setting goals for the Climate and Clean Air Coalition; pushing for a phase out of HFCs under the Montreal Protocol; and establishing an inter-agency task force to reduce short-lived climate pollutants."); *and* Bachmann J. & Seidel S. (2013) Domestic Policies to Reduce the Near-Term Risks of Climate Change ("As a first step under this initiative, the Administration could issue a new Executive Order, direct agencies to begin advancing the regulatory and program actions identified below, and establish an interagency Short-Lived Climate Pollutant Task Force to coordinate and monitor implementation of this effort and to identify additional actions going forward."). Existing authorities that such a Task Force could use to reduce SLCPs are described in Institute for Governance & Sustainable Development (2013) Proposed US Task Force to Address Short-Lived Climate Pollutants: Overview of abatement options; *see also* World Resources Institute (2013) Can the U.S. Get there from Here? Using Existing Federal Laws and State Action to Reduce Greenhouse Gas Emissions.

[266] United Nations Development Programme (UNDP) (2013) HUMAN DEVELOPMENT REPORT 2013: THE RISE OF THE SOUTH: HUMAN PROGRESS IN A DIVERSE WORLD.

[267] Hu A., *et al.* (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE CLIMATE CHANGE 3:730-734, 732-733 ("By the end of the twenty-first century, the effect of CO_2 mitigation on temperature increases by tenfold to ~1.1°C compared with the mitigation of 0.1°C by 2050. This, in conjunction with the SLCP mitigation, is sufficient to avoid reaching the 2°C threshold until 2100.").

[268] *See* Molina M., *et al.* (2009) *Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions*, PROC. NAT'L ACAD. SCI. USA 106(49):20616-20621.