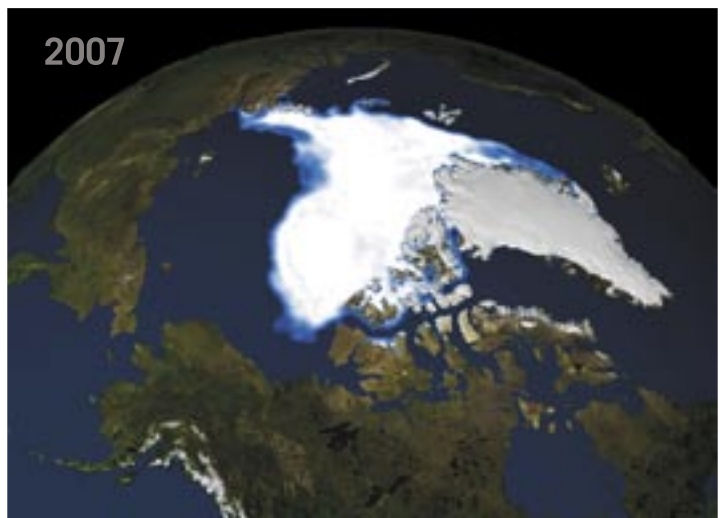
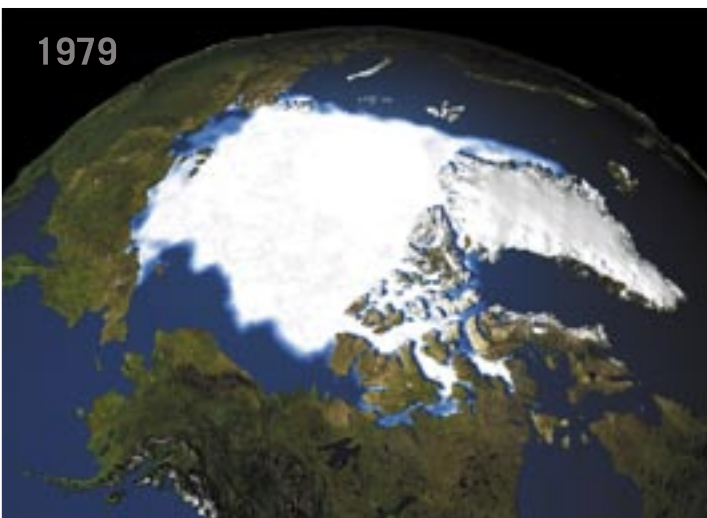


# *Not Too Late to* **Save the Polar Bear**

**A Rapid Action Plan to Address the Arctic Meltdown**



**CENTER *for* BIOLOGICAL DIVERSITY**

# Not Too Late to Save the Polar Bear: A Rapid Action Plan to Address the Arctic Meltdown

A report by the Climate, Air, and Energy Program,  
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The Center for Biological Diversity is a national nonprofit conservation organization with more than 35,000 members dedicated to the protection of endangered species and wild places.

# Table of Contents

|  |    |
|--|----|
| <b>Introduction</b> .....  | 1  |
| <b>I. The Polar Bear, Global Warming, and the Endangered Species Act</b> .....           | 2  |
| <b>II. Reducing Greenhouse Pollutants Rapidly Enough to Address Arctic Melting</b> ..... | 6  |
| A. Carbon Dioxide .....  | 7  |
| B. Methane.....  | 9  |
| C. Black Carbon or Soot.....   | 9  |
| D. Other Non-CO2 Pollutants.....   | 10 |
| E. Reduced CO2 and Non-CO2 Pollutants and the Future Arctic .....                        | 11 |
| <b>III. A New Management Paradigm for a Warming Arctic</b> .....                         | 12 |
| A. Incorporate Global Warming into Federal Agency Decisions .....                        | 13 |
| B. Reduce Other Stressors on Polar Bears and the Arctic .....                            | 14 |
| C. Towards an International Arctic Protection Regime .....                               | 16 |
| <b>IV. Conclusion</b> .....  | 18 |
| <b>V. Literature Cited</b> .....   | 19 |
| <b>Appendix A: Mitigation Strategies for Non-CO2 Pollutants</b>                          |    |

# Introduction

In early 2008, the polar bear will likely be formally declared “threatened” or “endangered” under the Endangered Species Act. But listing of the polar bear under the Endangered Species Act, while hugely significant both legally and politically, will not in and of itself save the polar bear or its Arctic sea-ice habitat. In September 2007, the same month that Arctic sea ice reached a new record minimum extent, government scientists predicted the polar bear would be extinct in Alaska by 2050 if current greenhouse gas emission trends continue.

Predictions of polar bear extinction by 2050 may be optimistic. Recent reports from scientists indicate that global warming impacts are occurring earlier and more intensely than previously projected. Nowhere is this more apparent than in the Arctic where, in 2007, sea-ice extent shrank to a record one million square miles below the average summer sea-ice extent of the past several decades, reaching levels not predicted to occur until mid-century. Not only does the impending loss of Arctic sea ice mean the loss of an entire ecosystem, it will also greatly amplify warming impacts on a global level due to the greater absorption of the sun’s energy by open water compared to reflective ice.



Photo (c) Thomas D. Mangelsen/Imagesofnaturestock.com

The rapid melting of the Arctic should be seen as an early warning of the broader climate crises to come if the United States and the world do not respond to global warming with the necessary urgency. Instead, like beachgoers chasing receding ocean waters to gather exposed shellfish just before a tsunami, nations and industry are racing to the newly ice-free areas to stake claims for fossil fuels and shipping routes that would lead us further down the path to climate catastrophe.

The situation in the Arctic has reached a critical threshold. But with immediate action it is still possible to slow the melting of the Arctic. In addition to broader local, national, and international efforts to reduce U.S. and global carbon dioxide (CO<sub>2</sub>) emissions, saving the Arctic requires prompt reductions of other greenhouse gases, along with specific efforts to address direct threats to the region from industrial activities such as oil development and shipping. Reducing emissions of methane and black carbon, which both have short atmospheric lifetimes and a large warming impact on the Arctic, is a critical component of any effective action plan. Immediate methane and black carbon emissions reductions can buy the world a little more time to achieve the deep reductions in CO<sub>2</sub> emissions that are necessary to protect the Far North. But the window of opportunity to act, like the ice, is shrinking rapidly.

# I. The Polar Bear, Global Warming, and the Endangered Species Act

**P**olar bears are completely dependent upon Arctic sea-ice habitat for survival. Polar bears need sea ice as a platform from which to hunt ringed seals and other prey, to make seasonal migrations between the sea ice and their terrestrial denning areas, and for other essential behaviors such as mating. Unfortunately, the polar bear's sea-ice habitat is literally melting away.

Global warming is impacting the Arctic earlier and more intensely than any other area of the planet. In parts of Alaska and western Canada, winter temperatures have increased by as much as 3.5° C in the past 30 years (Rozenzweig et al. 2007). Over the next 100 years, under a moderate emissions scenario, annual average temperatures in the Arctic are projected to rise an additional 3-5°C over land and up to 7° C over the oceans (Meehl et al. 2007).

This rapid observed and projected warming is reflected in the devastating melt of the Arctic sea ice, which is highly sensitive to temperature changes. Summer sea-ice extent reached an unpredicted and utterly stunning new record minimum in 2007 (NSIDC 2007a,b; Figures 1, 2). At 1.63 million square miles, the minimum sea-ice extent on September 16, 2007 was about one million square miles<sup>1</sup> below the average minimum sea ice extent between 1979 and 2000 (NSIDC 2007a). The 2007 minimum was lower than the sea-ice extent most climate models predict would not be reached until 2050 or later. Leading sea ice researchers now believe that the Arctic could be completely ice free in the summer as early as 2030 (NSIDC 2007b).

Climate change in the Arctic has reached a critical threshold, and the future of the ice-dependent polar bear is grim. Even short of



Figure 1: Arctic Sea Ice Extent on September 21, 1979  
Image source: NASA/Goddard Space Flight Center Scientific Visualization Studio

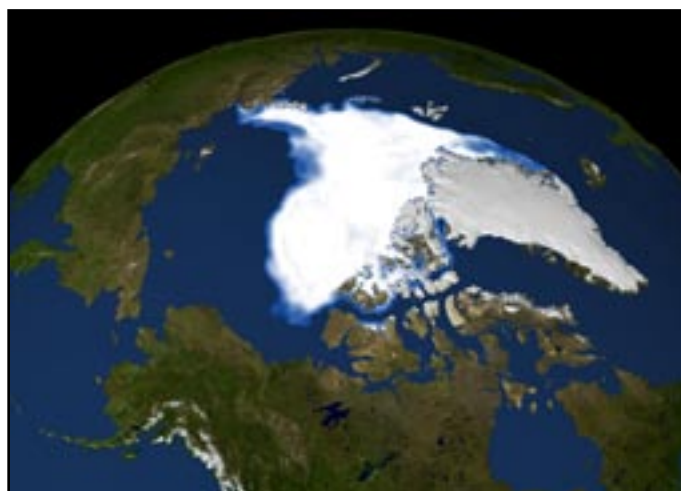


Figure 2: Arctic Sea Ice Extent on September 14, 2007  
Image source: NASA/Goddard Space Flight Center Scientific Visualization Studio

complete disappearance of sea ice, projected impacts to polar bears from global warming will affect virtually every aspect of the species' existence. These impacts include a shortening of the hunting season caused by delayed ice formation and earlier ice break-up, resulting in reduced fat stores, deteriorated body condition, and subsequent reduced survival and reproduction; increased distances between

<sup>1</sup> One million square miles is equal to about the area of Alaska and Texas combined.

the ice's edge and land, making it more difficult for bears to reach preferred denning areas; increased energetic costs of traveling farther between ice and land and through fragmented sea ice; and reduction in ice-dependant prey such as ringed seals and bearded seals (Derocher et al. 2004). Global warming will also increase the frequency of human-bear interactions, as greater portions of the Arctic become more accessible to people and as polar bears are forced to spend more time on land waiting for ice formation (Derocher et al. 2004). More human-bear interactions will almost certainly lead to increased polar bear mortality.



Figure 3: Polar Bear in the Final Stages of Starvation  
photo © Heiko Wittenborn

Five of the world's polar bear populations are now classified as declining, with a 22% decline—from 1,194 bears in 1987 to 935 bears in 2004—in Canada's Western Hudson Bay polar bear population (Aars et al. 2006). Recently, reports of polar bear drownings, cannibalism, and starvation have increased (Amstrup et al. 2006; Regehr et al. 2006; Aars et al. 2006). With the amount of, location of, and access to their ice-dependent seal prey changing rapidly, polar bears are increasingly vulnerable to starvation.

Figure 3 shows a polar bear in the final stages of starvation. This photo was taken on September 4, 2007 on the Caniapiscau River in Canada, 160 km inland from Ungava Bay. While we cannot say for sure that this bear starved to death as a direct result of global warming, as we do not know the bear's history or origin, we do know that global warming will increase the number of bears that suffer this fate. We also know that we have the power

to limit the number of polar bears that starve, drown, and resort to cannibalism, and to save the species from extinction by immediately reducing greenhouse gas pollution.

The Center for Biological Diversity submitted a petition to the Secretary of the Interior and U.S. Fish and Wildlife Service to list the polar bear under the Endangered Species Act due to global warming on February 16, 2005, motivated by the urgent need to reduce greenhouse gas pollution and otherwise protect the species. The Endangered Species Act is our nation's safety net for plants and animals on the brink of extinction, and our strongest and best law for the protection of imperiled wildlife. The Endangered Species Act listing process has already benefited the polar bear, will provide additional protections once the species is formally listed, and is a key component of saving the species.

Critically important for the polar bear and any other species threatened by global warming, the Endangered Species Act requires that all listing decisions be made “solely” on the basis of the “best scientific... data available.” 16 U.S.C. § 1533(b)(1)(A). A decision not to list a petitioned species is subject to judicial review. It is this “best available science” standard that provides a vehicle through the petitioning process to force federal agencies to squarely address the science of global warming. Moreover, once the Endangered Species Act listing process is initiated, strict timelines apply, with an initial finding due within 90 days of the petition, a proposed rule within 12 months of the petition if the Fish and Wildlife Service finds that the species meets the criteria for listing, and a final listing determination within a year from the proposed rule. Species do not receive any regulatory protection under the Act until they are officially listed as threatened or endangered.

A series of administrative and legal events in the listing process have greatly increased public awareness of the polar bear’s plight. In December 2005, ten months after the petition was filed, the Center for Biological Diversity, joined by NRDC and Greenpeace, sued the Department of Interior for failing to issue an initial finding on the petition. In response, a positive initial finding was issued in February 2006, initiating both a public comment period and full status review for the species. The deadline for the second required finding on the petition, due within 12 months of receipt of the petition, was only one week away at the time the first finding was made. The lawsuit was ultimately settled with a court-ordered consent decree setting a deadline of December 27, 2006 for the Fish and Wildlife Service to make the second determination.

On December 27, 2006, Secretary of Interior Dirk Kempthorne announced that listing of the polar bear is warranted and that the Fish and Wildlife Service would be publishing a

proposed listing rule. The proposal to list the polar bear was greeted by worldwide media attention, resulting in over 250 television stories, more than 1000 print stories and over 240 editorials. Over 600,000 comments were submitted during the public comment periods on the proposal. The final listing determination is due on January 9, 2008.

Once the polar bear is listed, the Endangered Species Act requires the Fish and Wildlife Service to identify and designate critical habitat, convene a recovery team and develop and implement a recovery plan. Additionally, the requirement for federal agencies to avoid jeopardizing the species, and a prohibition against unpermitted take (harm and harassment), will take effect. These regulatory protections should provide substantial benefit to the polar bear (Cummings and Siegel 2007). While the polar bear has yet to receive any actual legal protection as a result of the Endangered Species Act listing process, the process has already played an important role by being a catalyst to focus significant new scientific, public, and political attention on the problem of the melting Arctic and global warming.

The listing process has prompted research and analysis on the future of the polar bear, its sea-ice habitat, and the Arctic more generally. Most important among these research efforts are the recent reports released by the Department of Interior’s U.S. Geological Survey (USGS). The Fish and Wildlife Service asked the USGS to do the following in support of the listing process: (1) develop population projections for the Southern Beaufort Sea polar bear population and analyze existing data on two polar bear populations in Canada; (2) evaluate northern hemisphere sea-ice projections, as they relate to polar bear sea-ice habitats and potential future distribution of polar bears; and (3) model future range-wide polar bear populations by developing a synthesis of the range of likely numerical and spatial responses to sea-ice projections. The

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USGS produced nine administrative reports addressing these questions and in doing so significantly advanced the understanding of sea-ice loss and its implications for polar bears.

The USGS conducted polar bear population modeling based on 10 climate models that most accurately simulate future ice conditions. The USGS used the Intergovernmental Panel on Climate Change (IPCC) A1B “business as usual” scenario of future emissions to run the climate models. In the A1B scenario, atmospheric carbon dioxide concentrations reach 717 parts per million by 2100. These sea-ice projections were used in a number of applications, including in a Bayesian Network model developed by the USGS to most accurately project the future range-wide status of the polar bear. The results are disturbing.

The USGS (Amstrup et al. 2007) projects that two-thirds of the world’s polar bears, including all of the bears in Alaska, will be extinct by 2050. The “good news” is that polar bears may survive in the high Canadian Archipelago and portions of northwest Greenland through the end of this century. However, their extinction risk is still extremely high, at over 40% in the Archipelago and over 70% in northwest Greenland (Amstrup et al. 2007: Table 8).

Moreover, the USGS emphasizes repeatedly that because all of the available climate models have to date underestimated the actual observed sea-ice loss, the assessment of risk to the polar bear may be conservative. Perhaps most worrisome is the observation that part of an area in the Canadian Archipelago expected to provide an icy refuge for the polar bear in 2100 lost its ice in the summer of 2007.

The USGS projections of polar bear extinction risk are based on the IPCC A1B “business as usual” scenario, near the center of the distribution of all IPCC scenarios, in which atmospheric carbon dioxide concentrations reach 717 parts per million by

2100 (Nakićenović 2000). If future emissions meet or exceed the A1B scenario, the eventual extinction of polar bears is virtually guaranteed, as extinction risk will exceed 40% even in the high Canadian Archipelago in 2100, and warming will continue after 2100. The USGS reports, however, do not address the question of how much polar bear extinction risk can be reduced if greenhouse gas emissions are curtailed significantly below those assumed in the A1B scenario. Decreasing greenhouse gas emissions substantially can limit the Arctic sea-ice melt and therefore lower extinction risk for the polar bear.

While not explicitly making an Endangered Species Act listing recommendation, the information contained in the USGS reports definitively answers the question of whether the polar bear is in fact in danger of extinction and therefore warrants the protections of the Act with an emphatic and distressing “yes.” Any decision by the Fish and Wildlife Service to deny or delay listing would be patently unlawful. The point of the Endangered Species Act, however, is not simply to add species to the list, but to actually save them. If “business as usual” emissions trends continue, the polar bear will be driven extinct irrespective of Endangered Species Act listing or any other management actions. Business as usual is simply no longer an option. If the polar bear is to have a future, we as a nation and as a global community must immediately begin implementing deep greenhouse gas emissions reductions as well as change our management paradigms to reflect the new realities presented by a warming Arctic. The remainder of this paper sets forth an action plan to do so.



## II. Reducing Greenhouse Pollutants Rapidly Enough to Address Arctic Melting

The essential first component of an action plan to save the polar bear is a mandatory reduction in CO<sub>2</sub> pollution. Beginning CO<sub>2</sub> reductions immediately and eventually reducing them to a small fraction of current levels so that atmospheric CO<sub>2</sub> concentrations never rise above about 450 ppm is essential to saving polar bears. But the Arctic has reached such a critical threshold that CO<sub>2</sub> reductions alone, even if undertaken immediately and with determination, will almost certainly not be enough to slow and reverse the warming and melting trend. This is because CO<sub>2</sub>, once emitted, tends to remain in the atmosphere for centuries (Archer 2005), and therefore the benefits of reductions today will not be fully felt for some time.

Our window of opportunity to save polar bears relates to the fact that the warming impact of “non-CO<sub>2</sub>” pollutants including methane, tropospheric ozone, and black carbon (soot) is larger in the Arctic than it is globally. The non-CO<sub>2</sub> pollutants are responsible for at least half of the warming in the Arctic (Hansen et al. 2007), as opposed to about 30% globally (Forster and Ramaswamy 2007; Figure 4). Black carbon has a disproportionately large warming impact in the Arctic, and both black carbon and methane have much shorter atmospheric lifetimes than CO<sub>2</sub>. This means that immediately reducing these pollutants can buy some desperately needed time and presents our best opportunity for slowing and reversing the Arctic melting before it is too late.<sup>2</sup>

Fortunately, there are many feasible reduction measures available today for these pollutants, with literally hundreds of millions of metric tons of CO<sub>2</sub>eq “no-cost”

reductions on the table, including many that could be undertaken at a net economic benefit (Tables 1-4, Figure 5). According to conservative projections by the U.S. EPA, about 500 MtCO<sub>2</sub>eq of global methane emissions reductions could be achieved globally by 2020 at a cost benefit or no cost (EPA 2006; Table 4, Figure 7). Nearly 70 MtCO<sub>2</sub>eq of these available reductions are in the United States (EPA 2006; Table 2, Figure 6). The EPA estimates total technically feasible methane reductions for 2020 at over 2400 MtCO<sub>2</sub>eq globally and nearly 280 MtCO<sub>2</sub>eq in the United States, many of which can be achieved at low cost (EPA 2006; Tables 2 and 4; Figures 6,7).

Reductions in CO<sub>2</sub>, methane, and black carbon will have major public health benefits as well. Many of the measures necessary to reduce global warming pollution, including increasing energy efficiency, increasing the use of renewable energy and phasing out fossil fuels, and ultimately changing our land use, transportation, and consumption patterns, will improve our quality of life, improve our economy, and make the world a healthier, safer, and more equitable place. Congress should act immediately to explicitly cap and then rapidly reduce not only CO<sub>2</sub>, but also the non-CO<sub>2</sub> pollutants.

Below we review necessary reductions in greenhouse gas pollutants and opportunities for targeted actions to protect the Arctic. Further detail on mitigation strategies for methane, black carbon, nitrous oxide, and the high global warming potential gases is found in Appendix A.

<sup>2</sup> For ease of comparison, the volume of each pollutant is expressed as its “carbon dioxide equivalent” in millions of metric tons. Thus, 1 million metric tons of methane is equivalent to 21 million metric tons of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>eq).

## A. Carbon Dioxide

Because CO<sub>2</sub> is the most important greenhouse gas, the rapid and mandatory reduction of CO<sub>2</sub> emissions is the backbone of any plan to slow the Arctic melt (Quinn et al. 2007) and thus save the polar bear. If carbon dioxide concentrations are not controlled soon, polar bears will have little chance of future survival regardless of what else is done. Leading scientists warn that CO<sub>2</sub> concentrations must be kept below about 450 ppm in order to keep the climate system within the range of variability of the past 650,000 years and minimize the chance of triggering major climate feedbacks, such as a large-scale release of methane from the Arctic permafrost, that would greatly amplify anthropogenic warming (Hansen et al. 2006; Hansen et al. 2007). Scientists further warn that the 450 ppm limit may need to be reduced further in the future (Hansen and Sato in prep.). Keeping global CO<sub>2</sub> concentrations below 450 parts per million would require the United States to begin reducing its emissions quickly, and to reduce them to 80% or more below 1990 levels by the middle of this century.

It is essential that the United States rejoin the U.N. Framework Convention on Climate Change negotiating process and participate in global solutions. The Bush administration has been blocking progress at the international level for over six years, and the United States and Australia are the only developed countries that have refused to ratify the Kyoto Protocol, the first mandatory greenhouse gas reduction agreement under the Framework Convention process. The United States should commit to meeting its Kyoto target of reducing its emissions to 7% below 1990 levels between 2008 and 2012, and join negotiations for much deeper emissions reductions after 2012.

Congress must pass legislation that caps and rapidly reduces greenhouse gas pollution with mandatory measures. Fortunately, there are several bills introduced that if passed,

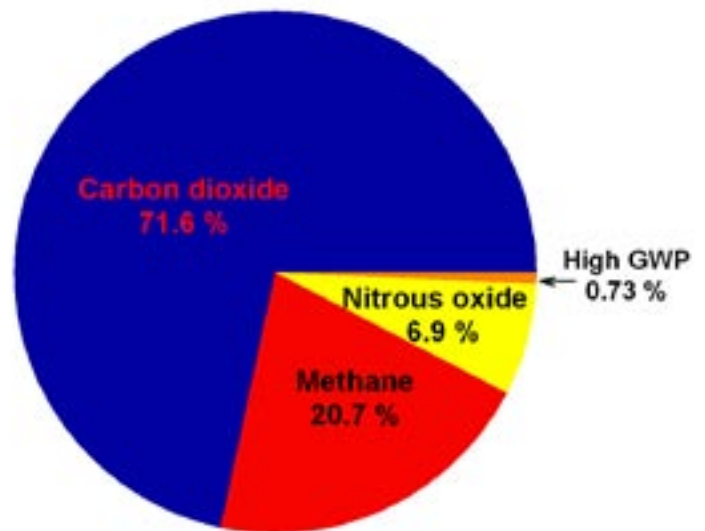


Figure 4: Radiative Forcing Contribution of Greenhouse Gases (chart does not include forcing from black carbon, which is a solid particle, not a gas)

Data from Forster and Ramaswamy 2007: Table 2.1

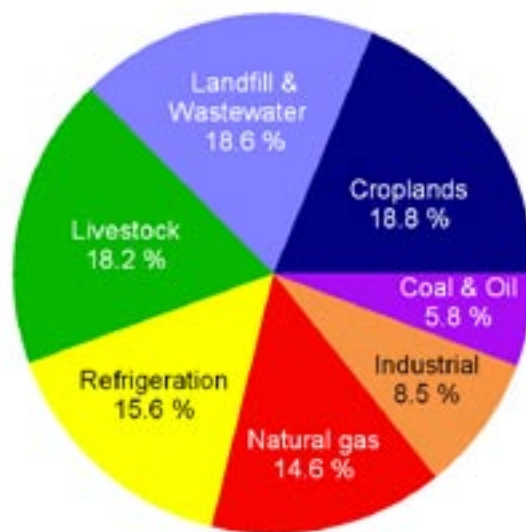


Figure 5: Non-CO<sub>2</sub> Emissions in the United States in 2010 by Sector

Data from EPA 2006

enacted, and fully enforced, would result in emissions dropping to approximately 80% below 1990 levels by 2050, including the Safe Climate Act (H.R. 1590, Waxman) and the Global Warming Pollution Reduction Act (S. 309, Sanders). The survival of the Arctic sea ice and the polar bear depends upon one of these bills or something similar becoming law soon.

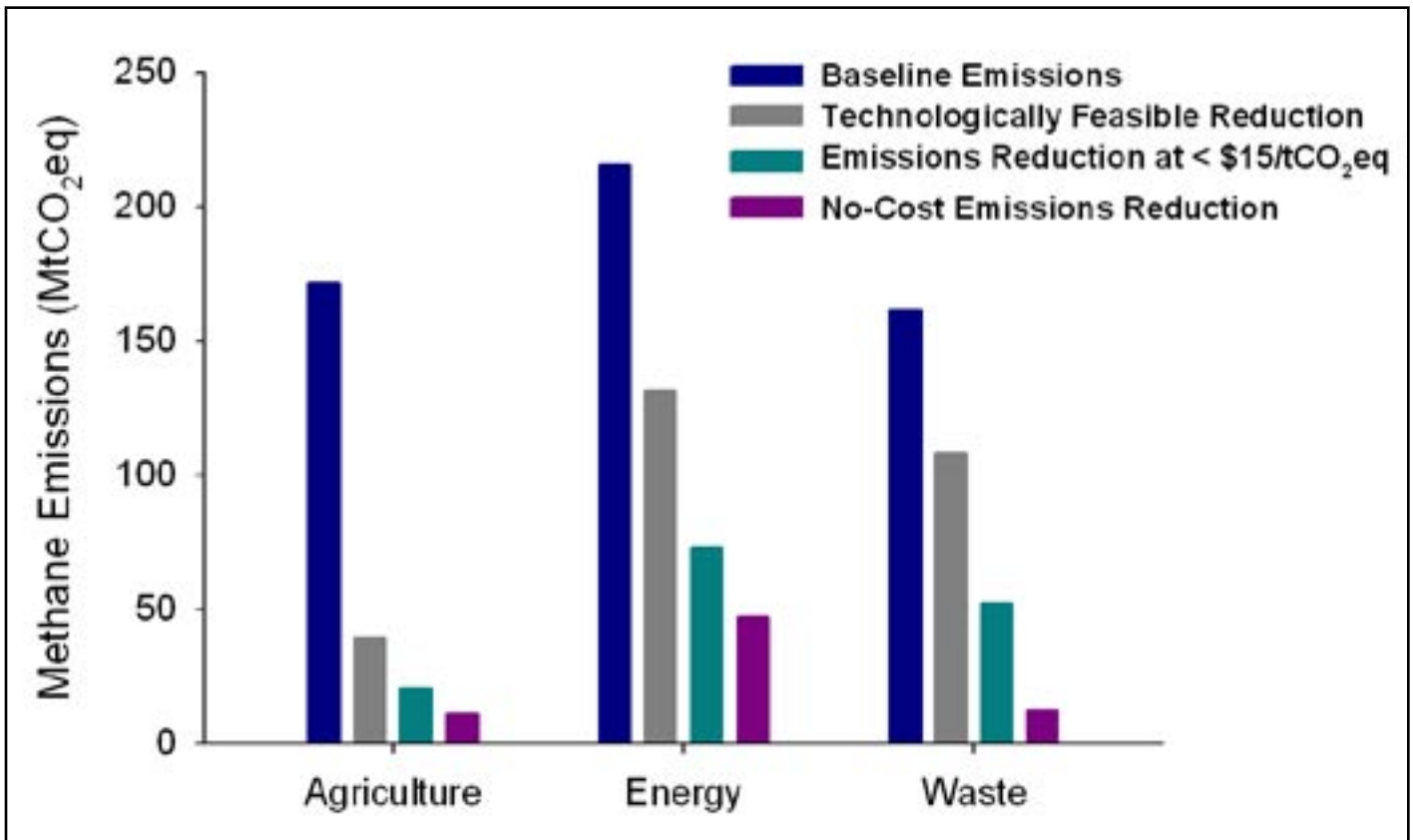


Figure 6: Methane Emissions and Potential Reductions for the United States in 2020  
Data from EPA 2006 and Table 2

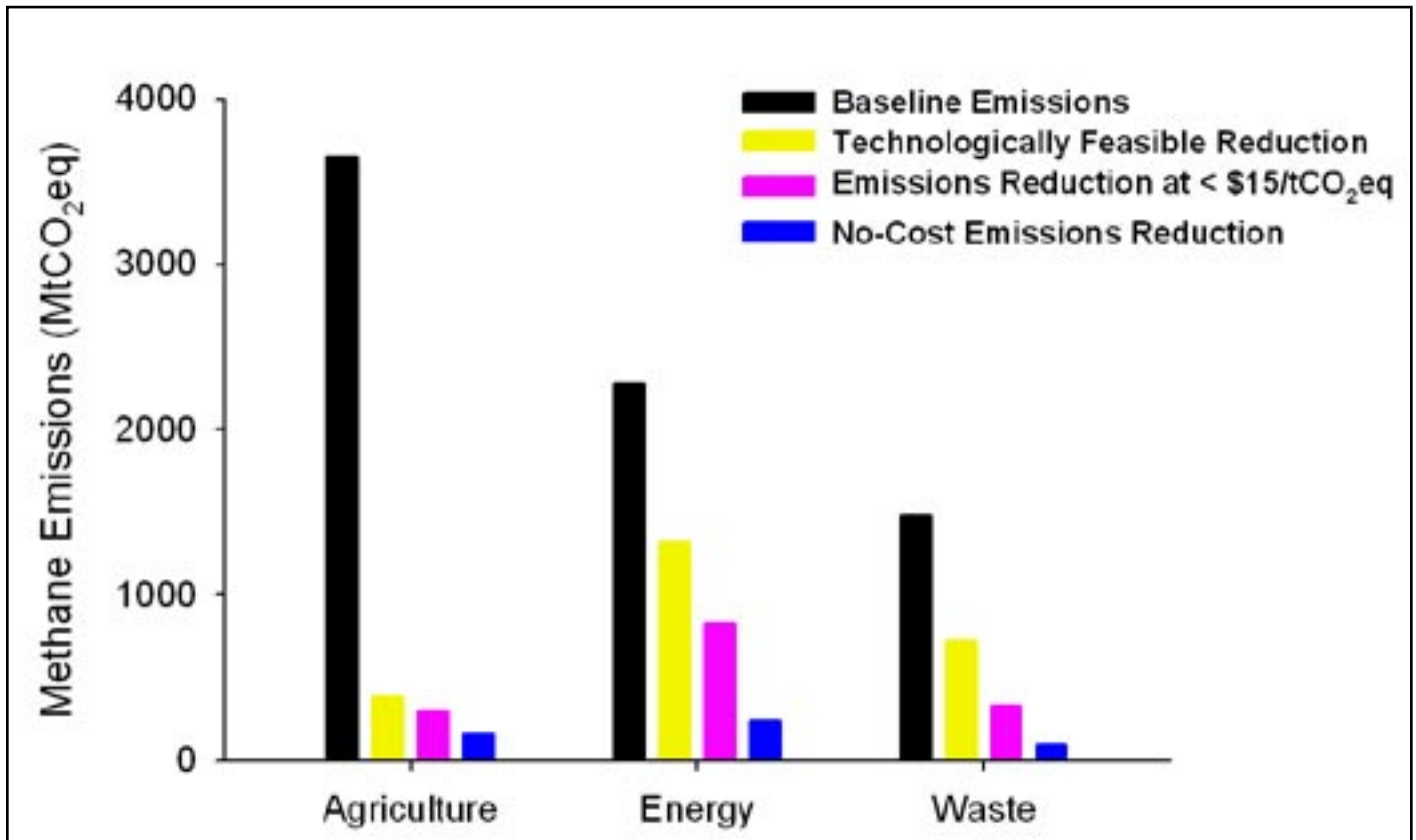


Figure 7: Global Methane Emissions and Potential Reductions in 2020  
Data from EPA 2006 and Table 4

However, the Arctic melt has advanced so far towards a tipping point that while CO<sub>2</sub> reductions are necessary, they are not sufficient to save polar bears. In addition to current legislative proposals, Congress must target other pollutants, including methane and black carbon, to provide the necessary short-term climate benefit to the Arctic.

## **B. Methane**

Methane is the most important of the non-CO<sub>2</sub> pollutants, with a global warming potential 21 times greater than carbon dioxide, and an atmospheric lifetime of 12 years (Forster and Ramaswamy 2007). Methane constitutes approximately 20% of the anthropogenic greenhouse effect globally, the largest contribution of the non-CO<sub>2</sub> gases. As a precursor to tropospheric ozone, methane emissions have an even more powerful impact on climate. In the Arctic this impact is strongest in winter months, when it can result in an acceleration of the onset of spring melt (Shindell 2007). Tropospheric ozone, unlike other greenhouse gases, absorbs both infrared radiation and shortwave radiation (visible light). Thus, tropospheric ozone is a particularly powerful greenhouse gas over highly reflective surfaces like the Arctic, because it traps shortwave radiation both as it enters the Earth's atmosphere from the Sun and when it is reflected back out again by snow and ice. Reducing global methane emissions will reduce ozone concentrations in the Arctic, providing a double benefit to the region.

According to conservative projections by the U.S. EPA, about 500 MtCO<sub>2</sub>eq of methane emissions reductions could be achieved globally by 2020 at a cost benefit or at no cost (EPA 2006; Table 4, Figure 7). That is the equivalent of taking almost 90 million cars and light trucks off the road. Nearly 70 MtCO<sub>2</sub>eq of these available reductions are in the United States (EPA 2006; Table 2, Figure 6). That is the equivalent of taking over 12 million cars and light trucks off the road. The EPA estimates

total technically feasible methane reductions for 2020 at over 2400 MtCO<sub>2</sub>eq globally and nearly 280 MtCO<sub>2</sub>eq in the United States, many of which can be achieved at low cost (EPA 2006; Tables 2 and 4; Figures 6,7).

The EPA's cost projections are conservative for a number of reasons, including the use of a 10% discount rate. Using a lower discount rate would result in additional cost benefit or no-cost reductions. Moreover, the EPA analysis does not account for the value of significant air quality and health benefits that would accompany methane reductions. West et al. (2006) found that reducing global methane emissions by 20% would save 370,000 lives between 2010 and 2030, due to the reduction in ozone-related cardiovascular, respiratory, and other health impacts. Methane reductions would also decrease ozone-related damage to ecosystems and agricultural crops (West et al. 2006). Methane is the primary component of natural gas, and many abatement options include the use of captured methane to generate energy. The benefits of displacing other fossil fuel energy sources with captured methane are also not captured in the EPA (2006) analysis.

While the EPA (2006) may underestimate available no-cost and low-cost methane (and other non-CO<sub>2</sub> gas) mitigation options, even this conservative analysis shows the enormous opportunities available to us today (Tables 1-4; Figures 6-7). These reductions can be achieved with currently available technology, as described in Appendix A. Moreover, mandatory greenhouse gas regulation will speed the development and deployment of new technology and mitigation options, making much deeper reductions feasible in the very near future.

## **C. Black Carbon or Soot**

Black carbon, or soot, consists of particles or aerosols released through the inefficient burning of fossil fuels, biofuels,

and biomass (Quinn et al. 2007). Black carbon warms the atmosphere, but it is a solid, not a gas. Unlike greenhouse gases, which warm the atmosphere by absorbing longwave infra-red radiation, soot has a warming impact because it absorbs shortwave radiation, or visible light (Chameides and Bergin 2002). Black carbon is an extremely powerful greenhouse pollutant. Scientists have described the average global warming potential of black carbon as about 500 times that of carbon dioxide over a 100-year period (Hansen et al. 2007; see also Reddy and Boucher 2007). This powerful warming impact is remarkable given that black carbon remains in the atmosphere for only about four to seven days, with a mean residence time of 5.3 days (Reddy and Boucher 2007).

Black carbon contributes to Arctic warming through the formation of “Arctic haze” and through deposition on snow and ice, which increases heat absorption (Quinn et al. 2007; Reddy and Boucher 2007). Arctic haze results from a number of aerosols in addition to black carbon, including sulfate and nitrate (Quinn et al. 2007). The effects of Arctic haze may be to either increase or decrease warming, but when the haze contains high amounts of soot, it absorbs incoming solar radiation and leads to heating (Quinn et al. 2007).

Soot also contributes to heating when it is deposited on snow because it reduces reflectivity of the white snow and instead tends to absorb radiation. A recent study indicates that the direct warming effect of black carbon on snow can be three times as strong as that due to carbon dioxide during springtime in the Arctic (Flanner 2007). Black carbon emissions that occur in or near the Arctic contribute the most to the melting of the far north (Reddy and Boucher 2007; Quinn et al. 2007).

Reductions in black carbon therefore provide an extremely important opportunity to slow Arctic warming in the short term, and mitigation strategies should focus on within-Arctic sources and northern hemisphere

sources that are transported by air currents most efficiently to the Arctic. Black carbon reductions will also provide air quality and human health benefits. Conversely, allowing black carbon emissions to increase in the Arctic as the result of increased shipping or industrial activity will accelerate loss of the seasonal sea ice and extinction of the polar bear.

Despite its significance to global climate change and to the Arctic in particular, black carbon has not been addressed by the major reports on non-CO<sub>2</sub> gas mitigation, nor is it addressed in current global warming bills in the 110th Congress. Black carbon reductions are an essential part of saving the Arctic sea ice and the polar bear, and should be addressed by Congress in this session. Abatement opportunities are discussed further in Appendix A.

#### **D. Other Non-CO<sub>2</sub> Pollutants**

Nitrous oxide and the high global warming potential gases do not have the same heightened impacts in the Arctic as methane and black carbon. Nevertheless, because these gases have high global warming potentials and long atmospheric lifetimes, and because there are many readily available mitigation measures to reduce them, they present important opportunities for reducing global warming overall and are therefore an important part of saving the Arctic and the polar bear.

Nitrous oxide has a global warming potential 310 times that of carbon dioxide and an atmospheric lifetime of approximately 114 years (Forster and Ramaswamy 2007). It constitutes the second-largest proportion of anthropogenic non-CO<sub>2</sub> gases at 7%. The main sources of nitrous oxide emissions are agriculture, wastewater, fossil fuel combustion, and industrial adipic and nitric acid production.

High global warming potential (High-GWP) gases fall into three broad categories:

hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>). Hydrofluorocarbons were developed to replace ozone-depleting substances used in refrigeration and air conditioning systems, solvents, aerosols, foam production, and fire extinguishing. HFCs have global warming potentials between 140 and 11,700 times that of carbon dioxide, and their atmospheric lifetimes range from one year to 260 years (EPA 2006).

Perfluorocarbons are emitted during aluminum production and semiconductor manufacture (EPA 2006). Their global warming potential ranges from 6,500 to 9,200 times that of carbon dioxide. In addition, they have extremely long atmospheric lifetimes (e.g. 10,000 and 50,000 years for two common PFCs).

The highest global warming potential exists in sulfur hexafluoride at 23,900 times that of carbon dioxide. Sulfur hexafluoride remains in the atmosphere for 3,200 years. Sulfur hexafluoride is used: (1) for insulation and current interruption in electrical power transmission and distribution; (2) during semiconductor manufacture; and (3) to protect against burning in the magnesium industry.

Further information on abatement options for these pollutants is found in Appendix A.

### **E. Reduced CO<sub>2</sub> and Non-CO<sub>2</sub> Pollutants and the Future Arctic**

As discussed above, keeping CO<sub>2</sub> levels below 450 ppm and substantially reducing all non-CO<sub>2</sub> forcings is essential if we are to keep global temperatures from rising more than 1° C above 2000 levels and thereby minimize the risk of triggering major climate feedbacks which would lead to significantly elevated warming (Hansen et al. 2006). Achieving such greenhouse gas reductions is therefore critical if we are to not only prevent the extinction of the polar bear, but avoid the most catastrophic impacts of global warming. But even under such a scenario, the Arctic will

still undergo significant additional warming with the concomitant additional loss of sea ice. Approximately 0.6° C of additional warming is already in the pipeline due to the excess energy in the Earth's climate system from past greenhouse gas emissions (Hansen et al. 2005; Alley et al. 2007). Additional warming will follow rising CO<sub>2</sub> levels even if we keep such levels below 450ppm. As with the warming observed to date, the Arctic will continue to warm more rapidly than the global average. Substantial additional reduction of Arctic sea ice over the course of this century is therefore likely unavoidable. For the polar bear, things are going to get much worse before they begin to get better.

As grim as the outlook for the polar bear is, it is not hopeless. Unlike the terrestrial ice sheets of Greenland, the melting of which may become irreversible on human-relevant timeframes, the Arctic sea ice, portions of which melt and reform every year, may be capable of relatively rapid recovery following climate stabilization. Assuming greenhouse gas emission targets can be met, the climate can be stabilized, and with subsequent reductions in atmospheric CO<sub>2</sub> levels, the Arctic sea ice can recover to levels supporting long-term viable populations of polar bears and other ice-dependant species. The key to polar bear persistence, then, is weathering the very bumpy ride through the next half-century. To shepherd the polar bear through the ensuing decades, we must reduce all other stressors on the species and its habitat and tailor national and international management of the sensitive Arctic ecosystem to the new reality of a rapidly changing Arctic.

### III. A New Management Paradigm for a Warming Arctic

As the September 2007 sea-ice minimum starkly illustrates, global warming in the Arctic is not a future problem that can be shunted off to the next generation of decision-makers. It has arrived and is already leaving starving and drowning polar bears, melting permafrost, and coastal erosion in its wake.

While implementing the rapid reductions in emissions of both CO<sub>2</sub> and non-CO<sub>2</sub> pollutants described above is essential to avoid runaway future warming in the Arctic and elsewhere, if polar bears are to survive we also have to adapt policy measures to the warming that has already occurred, that is unavoidably in the pipeline, and that will inevitably come with projected rising atmospheric CO<sub>2</sub> levels. The Arctic of 2007 is very different from the Arctic of just a decade ago; the Arctic of 2050 will be virtually unrecognizable.

While the ongoing changes in the Arctic are now readily apparent, for the most part, U.S. federal agencies have utterly failed to incorporate this new reality into their decision-making affecting the Arctic. With the possible exception of the Department of Defense (see, e.g. ONR 2001), federal agencies are making planning decisions and issuing permits, authorizations, and leases in and affecting the Arctic with a near-total disregard for the rapidly changing conditions in the region. This is leading to uninformed and unwise decision-making negatively affecting the polar bear and the entire Arctic ecosystem.

If U.S. agencies have been slow to recognize and respond to new conditions as the sea ice

recedes, the rest of the world has been quick to claim the spoils of a warming Arctic. Russia, Norway, and Denmark have all recently staked competing territorial claims to portions of the oil-rich Arctic seabed, while Canada has asserted sovereignty over the increasingly ice-free Northwest Passage. Similarly, the specter



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of a seasonally ice-free Arctic carries with it the likelihood of greatly increased shipping in the region.

Many of these elements of a changing Arctic carry a double threat to the polar bear. Increased oil and gas development in the Arctic threatens not just to degrade important polar bear habitat, but will also lead to further fossil fuel commitments, making emissions reduction targets all the more difficult to reach. Increased shipping in the Arctic carries increased risks of oil spills and further disruptions of the polar bear's habitat, but also, perhaps more importantly, it would lead to a substantial injection of additional black carbon directly where it would do the most damage to the

Arctic climate. Finally, territorial disputes in the Arctic will lead to an increased military presence in the Arctic leading to disruption and pollution from vessels and aircraft as well as increasingly frequent polar bear-human interactions — encounters that the polar bears almost always lose.

If we are to respond to the warming Arctic in a manner compatible with the long-term survival of the polar bear, we must directly confront the changes taking place in the region. Federal agencies must incorporate the best available information about global warming and its impacts on the Arctic into all decisions directly or indirectly affecting the Arctic. We must also reduce direct impacts on polar bears and their habitat from shipping and industrial activities through such measures as a moratorium on the expansion of such activities in areas subject to U.S. control. Finally, because protecting the polar bear and the Arctic is only possible with the cooperation of not only all Arctic nations, but with the global community more broadly, we should initiate and engage in proactive multilateral efforts to protect the Arctic and its resources so they remain largely unspoiled for future generations in a manner similar to what has been accomplished under the Antarctic Treaty. Each of these measures is described in more detail below. All are necessary if polar bears are to survive in the very different Arctic we have given them.

### **A. Incorporate Global Warming into Federal Agency Decisions**

Congressional action and new laws explicitly capping and reducing CO<sub>2</sub> and non-CO<sub>2</sub> pollutants are clearly necessary if we are to slow and ultimately reverse global warming and save the Arctic and the polar bear. Nevertheless, existing law allows, and in some cases requires, the executive branch to take significant action to address the current and future impacts of global warming on vulnerable human landscapes, natural ecosystems, plants, and wildlife. Use of this authority

will benefit all imperiled species, including the polar bear. Unfortunately, such statutory mandates have largely been underutilized, ignored, or explicitly rejected by the current administration.

Existing laws governing federal agencies that relate to global warming and the Arctic fall into three broad categories: laws requiring the compilation and analysis of information relevant to decision makers; laws requiring analysis and in some cases mitigation of the contribution of a given agency decision or action to greenhouse gas emissions and global warming; and laws requiring the changing status of species and resources in a warming climate be properly considered in decision-making. Several laws address more than one of these categories. Examples of each, relevant to the polar bear, and which the administration has ignored or underutilized, are briefly discussed below.

#### *Information-generating statutes:*

The Global Change Research Act (GCRA) requires the administration to provide to Congress and agencies an assessment of the trends and effects of global climate change on the United States, to be updated every four years. 15 U.S.C. Sec. 2936(2)-(3). The last such assessment was prepared in 2000. The administration is under court order to prepare a new assessment by May 2008, as the result of a lawsuit brought by the Center for Biological Diversity, Friends of the Earth, and Greenpeace.

The Marine Mammal Protection Act (MMPA) requires regularly updated stock assessment reports that summarize the current status of all marine mammals subject to U.S. jurisdiction. 16 U.S.C. § 1361 et seq. Updated stock assessments for polar bears and walrus are two years overdue. Stock assessments for ice-dependant seals relied upon by polar bears for food, while regularly updated, do not incorporate recent information on global warming and sea-ice declines.



*Analysis of greenhouse gas emissions from federal actions:*

The Outer Continental Shelf Lands Act (OCSLA) governs the leasing of tracts for offshore oil development in federal waters, including those areas of the Beaufort and Chukchi seas utilized by polar bears. In approving the 2007-2012 Program covering all offshore leasing in the United States, the Secretary of Interior refused to quantify the greenhouse gas emissions from the oil and gas expected to be produced under the program and failed to monetize CO<sub>2</sub> and non-CO<sub>2</sub> pollutants in calculating the economic costs and benefits of the program.

The National Environmental Policy Act (NEPA) requires the preparation of an environmental impact statement analyzing all significant impacts of proposed federal actions. Few NEPA documents for significant greenhouse gas-generating projects prepared to date analyze the impacts of such emissions. None that we are aware of analyze the impacts of greenhouse gas or black carbon emissions on Arctic warming or the polar bear.

The Endangered Species Act (ESA) requires each federal agency to ensure through consultation with the Fish and Wildlife Service that any federal action does not jeopardize the continued existence of any listed species or destroy or adversely modify its critical habitat. 16 U.S.C. § 1536. To date, despite the fact that existing regulations require consultation on any action “directly or indirectly causing modifications to the land, water, or air,” 50 C.F.R. § 402.02, no federal agency has ever engaged in consultation regarding the impacts of greenhouse gas emissions flowing from a given agency action.

*Analysis of the changing Arctic in federal decision-making:*

Each of the statutes mentioned above require informed decision-making and the use

of the best available science. Nevertheless, few if any agency decisions directly affecting the polar bear’s Arctic habitat have properly taken into account the changing status of the species in a melting Arctic. For example, in August 2006, the Fish and Wildlife Service issued regulations under the MMPA allowing unlimited take of polar bears from all oil- and gas-related activities in the Beaufort Sea region for a period of five years. Despite a request from the Marine Mammal Commission to consider the impacts of global warming in making the required determination of “negligible impact” under the statute, the Service issued the authorization, assuming that impacts would be similar to those documented when similar authorizations were issued more than a decade previously and prior to the substantial changes of sea ice and polar bear population size and distribution evidenced by recent scientific observations. See 71 Fed. Reg. 43926 (Aug. 2, 2006).

As the above examples demonstrate, management decisions directly affecting the polar bear have not caught up with the science demonstrating significant changes in the status of the species and its Arctic ecosystem. As uninformed decision-making is often unwise decision-making, the polar bear will continue to be harmed by federal agency actions until and unless all relevant agencies start incorporating the most recent information regarding global warming and its impacts on the Arctic into their decision-making. Climate-informed decision-making is already the law; now it needs to be translated into action.

**B. Reduce Other Stressors on Polar Bears and the Arctic**

While a business-as-usual warming scenario would doom the polar bear to extinction and render any other conservation efforts irrelevant, saving the polar bear will require not just dramatically changing greenhouse gas emission trajectories but also addressing other cumulative threats to the species. While

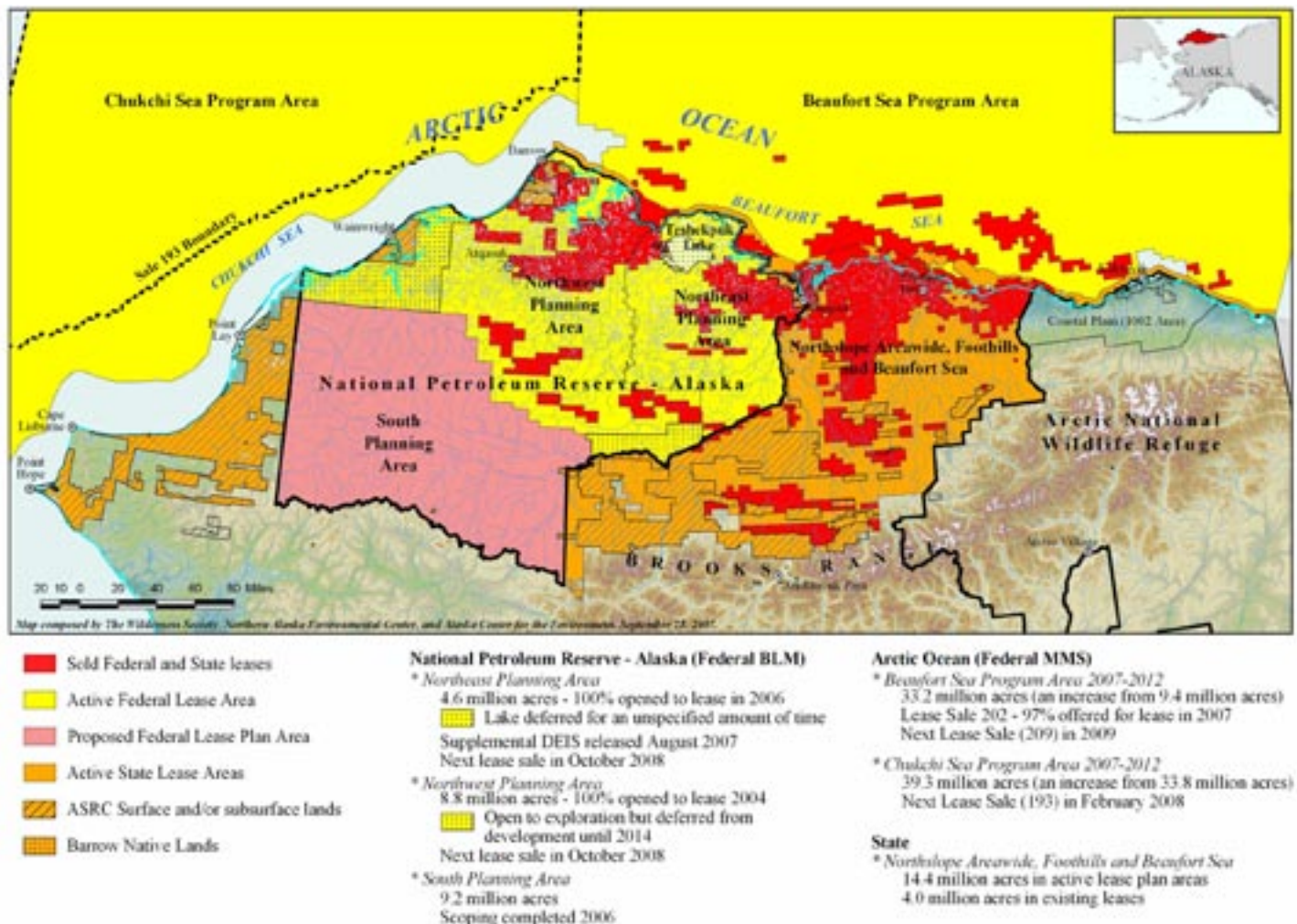
climate-informed decision-making will probably be better decision-making and will reduce cumulative impacts to the polar bear, certain activities, no matter how thoroughly vetted, should simply no longer be allowed in polar bear habitat. Among these are activities that directly add black carbon to the Arctic (e.g. shipping) and activities that directly disturb polar bears and degrade their essential habitats (e.g. oil and gas development).

In 2003 the National Research Council noted that “[c]limate warming at predicted rates in the Beaufort Sea region is likely to have serious consequences for ringed seals and polar bears, and those effects will accumulate with the effects of oil and gas activities in the region.” (NRC 2003). Since the NRC report, both the impacts of global warming on the polar bear and the cumulative impacts of oil and gas

activities have greatly accelerated. With the lease sales in the Beaufort and Chukchi seas scheduled under the 2007-2012 Program and the ongoing rapid leasing and development of the NPR-A, the vast majority of polar bear habitat subject to U.S. jurisdiction, whether at sea or on land, is now open for oil and gas leasing and development. See Figure 8 (Map of existing and proposed leases in the Beaufort and Chukchi seas).

Polar bears in the Beaufort Sea and elsewhere are already undergoing food stress, and as a consequence resorting to cannibalism or simply starving (Amstrup et al. 2006; Regehr et al. 2006; Aars et al. 2006). Cub survival is down (Regehr et al. 2006; Aars et al. 2006). Denning has shifted from occurring mostly on ice to mostly on land and numerous bears now congregate on land pending the fall freeze-up

Figure 8: Current and Proposed Oil & Gas Prices on Alaska’s North Slope



of the sea-ice (Regehr et al. 2006; Aars et al. 2006). At the same time, the Beaufort Sea coast is becoming increasingly industrialized. This combination is potentially devastating for the species. Denning bears with reduced fat stores from a shorter hunting season are both more vulnerable to disturbance from oil industry activities and increasingly dependant upon areas subject to such industrial development. Similarly, hungry bears, trapped on land, are more likely to wander into oil camps and facilities looking for food, where their odds of being directly killed by humans acting in self-defense or being exposed to oil and other chemicals increases dramatically.

In addition to direct impacts on polar bears, oil industry activity also impacts their prey, such as ice seals, which may be exposed to seismic surveys, icebreakers, and other disturbances that could either harm these animals or render them less available for bears to hunt. Oil industry activity also results in methane and black carbon emissions in the Arctic from production activities, and of course substantial CO<sub>2</sub> emissions from the ultimate combustion of the recovered oil and gas.

Given the rapidly changing Arctic, the precarious status of polar bears, and the numerous adverse impacts of oil and gas industry activities on the species, we believe that there should be a moratorium on new oil and gas leasing and development in the range of the polar bear. Such a moratorium should be implemented immediately and remain in effect until and unless such activity can be demonstrated to not have adverse impacts on the polar bear, and any greenhouse emissions directly or indirectly associated with such activities are shown to be consistent with a comprehensive national plan to reduce CO<sub>2</sub> and non-CO<sub>2</sub> pollutants to levels determined necessary to avoid the continued loss of sea ice.

In addition to oil and gas activities, a growing cumulative threat to the polar bear is likely to be increased shipping in the Arctic,

which brings with it black carbon emissions, the risk of oil spills, and direct disruption and disturbance of polar bears and their prey. The United States should work in appropriate international fora such as the International Maritime Organization and the Arctic Council to prevent the establishment of new shipping routes in the Arctic. Simultaneously, the United States should require that any vessel transiting Arctic waters subject to U.S. jurisdiction utilize fuels and engine technologies that minimize black carbon emissions (see, e.g. Ballo and Burt 2007), and apply for take authorizations to ensure operations are consistent with the MMPA and ESA so as to minimize direct impacts to polar bears and their prey.

Finally, persistent organic pollutants (POPs) represent a significant threat to polar bears and other Arctic species. As polar bears operate in an increasingly food-stressed state, they are likely to metabolize body fat containing unhealthy concentrations of POPs. The impact of POPs on individual polar bears can have both lethal and sub-lethal effects. As polar bear populations decline and individual bears become more vulnerable, the disruptive cumulative effects of POPs on the species are likely to grow. Reduction or elimination of these compounds, both through application of U.S. law and international effort, will likely provide substantial benefits to polar bears.

While many of the cumulative threats to the polar bear are subject to direct regulation by the United States and can and must be addressed immediately, the ultimate survival and recovery of the polar bear will require international efforts, not just to reduce greenhouse gas emissions and stabilize the climate system, but to protect the fragile Arctic habitat upon which the polar bear depends.

### **C. Towards an International Arctic Protection Regime**

Ultimately, the protection of the polar bear and its Arctic habitat is the shared

responsibility of not only the United States, or even the five Arctic nations with polar bear populations, but of the broader global community. As global warming transforms and increases human access to the Arctic, we must be as proactive as possible in protecting this area. Since much of the Arctic is beyond any country's control, and many portions are now contested by competing national claims, a key component of an Arctic protection strategy rests in the international arena (See Figure 9). Just as the Antarctic Treaty arose

in the context of competing national claims to that continent, the territorial disputes that are shaping up in the Arctic as the sea ice recedes — and as commercial exploitation of the region becomes foreseeable — present not just a threat, but an opportunity. Given that we are entering the International Polar Year, the time is ripe to push for international action to permanently protect the shared treasure of the Arctic. The United States should proactively promote the large-scale protection of the Arctic through all existing international mechanisms, including the International Agreement for the Conservation of Polar Bears, the Arctic Council, and the United Nations Convention on the Law of the Sea. The United States cannot remain a spectator as other nations compete to divide up the resources of a newly accessible Arctic. We need to become participant, not to stake our own claims, but to lead efforts to render any such claims irrelevant, and to shepherd the Arctic and the polar bear through the rapid changes of the coming decades.



Figure 9: Arctic Territorial Claims

## IV. Conclusion

**W**e are committed to saving the polar bear from the ravages of global warming for its own sake, as well as ours. Because the Arctic is the Earth's early warning system, what is happening to the polar bear now is a harbinger of what will happen to the rest of the world if business-as-usual politics and emissions continue. We cannot allow this to happen. It is not too late to save the Arctic — if we take action today. Immediate reductions in both CO<sub>2</sub> and non-CO<sub>2</sub> pollutants, along with protection of the Arctic from direct physical incursions, offer a true window of opportunity and hope. Acting to reduce greenhouse emissions in a timeframe rapid enough to save the polar bear will also provide us with the necessary urgency to tackle the challenge of global warming before its impacts drown not only polar bears but entire cities. We must begin immediately.



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# Appendix A: Mitigation Strategies for Non-CO<sub>2</sub> Pollutants

The primary non-CO<sub>2</sub> pollutants are methane, black carbon (soot), nitrous oxide, and the high global warming potential gases (Figure 4). The global warming potential of each of these pollutants is more powerful than carbon dioxide—21 (methane) to 23,000 (sulfur hexafluoride) times as powerful over a 100 year period (Forster and Ramaswamy 2007). The duration over which each of the gases is present in the atmosphere and contributing to the greenhouse effect varies from 12 years (methane) to centuries (fluorinated gases). For ease of comparison, the volume of each pollutant is expressed throughout this report as its “carbon dioxide equivalent” in millions of metric tons. Thus, 1 million metric tons of methane is equivalent to 21 million metric tons of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>eq).

## A. Methane

Methane is the most important of the non-CO<sub>2</sub> pollutants, with a global warming potential 21 times greater than carbon dioxide, and an atmospheric lifetime of 12 years (Forster and Ramaswamy 2007). Methane constitutes approximately 20% of the anthropogenic greenhouse gas effect globally, the largest contribution of the non-CO<sub>2</sub> gases. However, methane emissions anywhere in the world will have a disproportionate warming impact in the Arctic, due to the fact that methane is also an ozone precursor. Tropospheric ozone, unlike other greenhouse gases, absorbs both infrared radiation and shortwave radiation (visible light). Thus, tropospheric ozone is a particularly powerful greenhouse gas over highly reflective surfaces like the Arctic, because it traps shortwave radiation both as it enters the Earth’s atmosphere from the sun and when it is reflected back out again by snow and ice. Reducing global methane emissions will reduce ozone concentrations in the Arctic, providing a double benefit to the region.

According to conservative projections by the U.S. EPA, about 500 MtCO<sub>2</sub>eq of global methane emissions reductions could be achieved globally by 2020 at a cost benefit or no cost (EPA 2006; Table 4, Figure 7). Nearly 70 MtCO<sub>2</sub>eq of these available reductions are in the United States (EPA 2006; Table 2, Figure 6). The EPA estimates total technically feasible methane reductions for 2020 at over 2400 MtCO<sub>2</sub>eq globally and nearly 280 MtCO<sub>2</sub>eq in the US, many of which can be achieved at low cost (EPA 2006; Tables 2 and 4; Figures 6,7).

The EPA’s cost projections are conservative for a number of reasons, including the use of a 10% discount rate. Using a lower discount rate would result in additional cost benefit or no-cost reductions. Moreover, the EPA analysis does not account for the value of significant air quality and health benefits that would accompany methane reductions. West et al. (2006) found that reducing global methane emissions by 20% would save 370,000 lives between 2010

and 2030, due to the reduction in ozone related cardiovascular, respiratory, and other health impacts. Methane reductions would also decrease ozone-related damage to ecosystems and agricultural crops (West et al. 2006). Methane is the primary component of natural gas, and many abatement options include the use of captured methane to generate energy. The benefits of displacing other fossil fuel energy sources with captured methane are also not captured in the EPA (2006) analysis.

While EPA (2006) may underestimate available no-cost and low cost methane (and other non-CO<sub>2</sub> gas) mitigation options, even this conservative analysis shows the enormous opportunities available to us today (Tables 1-4; Figures 6-7). These reductions can be achieved with technology available today. Moreover, mandatory greenhouse gas regulation will speed the development and deployment of new technology and mitigation options, making much deeper reductions feasible in the very near future.

## 1. The Waste Sector

Methane produced in the waste sector comes from two main sources: landfills and wastewater. Landfills produced approximately 12% of all global methane emissions in 2000. Landfills provide one of the largest single sources of available emissions reductions, as the EPA (2006) estimates that 88% of landfill methane emissions could be abated with existing technology. Methane is produced in managed (sanitary) landfills due to the anaerobic decomposition of organic waste. Approximately 50% of landfill gas is methane and the other 50% is largely made up of carbon dioxide. Sanitary landfills are found predominately in developed countries. Open dumps that do not promote anaerobic conditions are more common in developing nations, but these countries are rapidly adopting landfill management techniques because of the many advantages of sanitary waste disposal. In the US, large landfills with capacity exceeding 2.5 megagrams (2.8 million short tons) are regulated under the Clean Air Act.<sup>1</sup> Despite the current programs in place, the US is the largest source of landfill methane in the world, producing in 2000 nearly 3 times as much landfill emissions as the next largest producer, China (EPA 2006: III-5).

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<sup>1</sup> In March of 1996, EPA promulgated guidelines (61 Fed. Reg. 9905) for controlling the emissions from existing Municipal Solid Waste landfills and the New Source Performance Standards for new or modified Municipal Solid Waste landfills under authority of Section 111 of the Clean Air Act. Although there are some differences in requirements for landfills constructed or expanded under different stages of the development of the regulations, in general the guidelines required the following:

1) Installation of gas collection and control systems for new and modified landfills designed to hold 2.755 million tons or more of waste over their lifetime, and that could be expected to emit more than 50 megagrams per year of non-methane organic compounds (NMOC).

2) When any landfill reaches the above thresholds, it must within 30 months install a gas collection and control system that covers all portions of the landfill. The collected landfill gas must be combusted at a high enough temperature to destroy 98 percent of the toxics.

3) Three conditions be met prior to capping or removal of the collection and control system: (1) The landfill must be permanently closed; (2) the collection and control system must have been in continuous operation a minimum of 15 years; and (3) the annual NMOC emission rate routed to the control device must be less than 50 megagrams per year.

Landfill methane can be abated either through capture and flaring or use for energy generation, or by diverting organic material from landfills and into composting and recycling-reuse programs. Landfill gases are already captured and flared at a number of U.S. landfills. A preferable option is to use the methane directly for electricity or heat generation, or to sell it to industrial users for energy use (EPA 2006). Using methane for energy generation, as opposed to simply flaring it, has the additional benefit of displacing the emissions that would have resulted from otherwise supplying the energy created.

The second source of waste emissions is wastewater. Wastewater contributes approximately nine percent of global methane emissions (EPA 2006). Domestic wastewater processing involves removing organic matter, solids, pathogens, and chemicals. These produce a biomass “sludge” that is digested either anaerobically to produce methane, or aerobically to produce carbon dioxide. Approximately 45% of the sludge is usually digested, and the remainder is sent to landfills. The amount of methane produced is proportional to the organic content of the sludge.

Industrial sources with especially high organic content include meat and poultry processing, pulp and paper processing, and produce processing industries. The EPA estimates that 77% of meat and poultry wastewater degrades anaerobically due to use of lagoons. Similarly, lagoons are used for pulp and paper processing.

The abatement options for wastewater include: (1) reduced anaerobic digestion and (2) collection and subsequent flaring or utilization. Reductions in anaerobic digestion can be accomplished through aeration and reduced usage of settling lagoons. Collection is used in series with an anaerobic digester. The collected methane can be flared, or preferably used for energy generation. EPA (2006) states that because most centralized wastewater treatment facilities already either flare or use captured methane for safety reasons, the “add-on” abatement options to existing systems are limited. Large abatement opportunities depend primarily on the creation of managed wastewater treatment systems in developing countries, which will require large-scale structural changes in wastewater management practices (EPA 2006). Because the primary motivation for the installation of improved wastewater treatment has historically been the direct public health benefits from disease prevention, EPA (2006) did not calculate cost estimates. The increasing use of centralized wastewater treatment facilities worldwide is clearly necessary and will bring enormous benefits both for public health and climate change mitigation.

## **2. The Energy Sector**

Enormous methane mitigation potential exists in the energy sector. The three main sources globally are natural gas systems (16 % of total methane emissions), coal mining (6 %) and oil (0.95%). Abatement opportunities from natural gas systems are particularly promising as natural gas is a rational transition fuel as the global economy is decarbonized. Oil is more

carbon-intensive than natural gas, and coal the most carbon-intensive of all. Coal-fired power plants, and therefore coal mining, must be reduced and then eliminated. Nevertheless, methane abatement opportunities currently exist and should be implemented wherever mining continues. Mitigation opportunities are also available for abandoned coal mines.

The United States is the top consumer of natural gas and is second only to the Russian Federation in methane emissions from natural gas systems. Methane emissions occur during production, processing, transmission and storage, and distribution of natural gas. There are a variety of mitigation options that address each of these stages.

During extraction, the gas is passed through dehydrators to remove water and other liquids. It is then transported through lines to a processing facility for further refinement. The processed gas, which is 95% methane, is then compressed and transmitted to storage and distribution facilities. Finally, the gas is decompressed to be distributed for home or commercial use.

Leakage from lines and equipment is the main source of methane emissions. These emissions can be abated through a variety of methods, which can be broadly categorized as changes in operational practice, equipment upgrade and replacement, and though direct inspection and maintenance. A number of these measures will actually save the operator money, on the order of 20-25\$/tCO<sub>2</sub>eq (EPA 2006:II-27).

The second largest source of energy sector methane emissions is coal mining. Methane is produced as organic matter turns to coal. It accumulates in pockets near a coal seam, and is eventually released during the mining process. More methane is produced by deeper seams. Because methane is dangerous, it is extracted and usually vented to the atmosphere. Some methane is also produced during coal processing and from abandoned mines.

Abatement of mining-related emissions may be through one of three broad methods: (1) degasification, where methane is captured but not vented prior to operations; (2) enhanced degasification, which involves special drilling techniques and capture and use of methane; and (3) oxidation of ventilation air methane (VAM) to produce energy (EPA 2006). Approximately 57% of the methane obtained through degasification—the drilling of wells or boreholes prior to mining—can be piped out and sold for energy. If additional enrichment techniques are used to further refine the methane obtained during degasification, called enhanced degasification, approximately 77% of the methane may be sold for energy. Finally, approximately 97% of ventilation air methane, which is a much lower concentration, can be mitigated through oxidation and use for local energy. Due to its low concentration of methane, this gas is not suitable for distribution.

Because the captured methane can be used or sold for energy, approximately 17% of emissions can be abated at no cost or positive economic benefit. At a cost of less than 15\$ per

tCO<sub>2</sub>eq, approximately 80% of emissions from coal mining could be eliminated. Profitable options have been addressed in EPA's Coalbed Methane Outreach Program started in 2001 to reduce and use coal mine methane (<http://www.epa.gov/cmop/resources/webbrochure.html>).

The third major energy-sector source of methane is oil production. Fugitive emissions are released during crude oil production, transportation, and refining (EPA 2006). Oil production accounts for approximately 97% of these methane emissions. Methane emissions from onshore oil production are more easily captured and transported than those from offshore production.

The major sources of production emissions are: volatilization of high pressure crude oil as it enters the holding tank, equipment leaks and vessel blowdowns (removal of liquids through pressurization), and fugitive leaks and combustion during flares (EPA 2006).

There are three abatement options: (1) flaring instead of venting; (2) direct use for energy; and (3) reinjection of the methane to the oilfield to enhance later oil recovery. Safety considerations make flaring more feasible at onshore facilities. This measure has the potential to reduce methane emissions by 98% over 15 years. Flaring is the least preferred mitigation option as it does not produce energy, thereby displacing other emissions, yet results in additional CO<sub>2</sub> emissions. The second option is the direct use of the methane for energy at offshore platforms, and has the potential to reduce 90% of methane emissions. The third option is to re-inject the methane into the oilfield. This can reduce methane emissions by 95% over 15 years.

### **3. The Agricultural Sector**

Agriculture accounts for approximately 52% of global methane emissions, and these are expected to increase by 30% in 2020 (over 2000 levels). The main agricultural sources of methane are rice fields and livestock. Methane emissions from rice fields occur due to anaerobic decomposition of organic matter in flooded rice fields. The majority (90% of emissions) of rice production occurs in Asia. Management practices that include variation in the timing of field flooding, tilling practices, and fertilization can reduce the amount of methane production.<sup>2</sup>

The second major source of agricultural methane is livestock. This includes both methane gas emitted by ruminants as a result of digestion (enteric fermentation) and methane emitted by manure. While all ruminants produce some methane, the majority of global methane emitted due to enteric fermentation comes from cows used for beef and dairy production. Switching to higher quality feed and lower volumes of feed can reduce methane

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<sup>2</sup> Some agricultural practices which reduce methane emissions lead to an increase in nitrous oxide production, and thus mitigation options must be carefully tailored so that only measures resulting in a net decrease in greenhouse gas emissions are implemented.

from enteric fermentation because high quality feed increases the proportion of energy that is available for use by the animal and consequently reduces the amount that is wasted as methane.<sup>3</sup> As a result, these mitigation options actually have a net economic benefit for the producer.

Methane is also produced by manure during anaerobic decomposition. These conditions occur when liquid manure is stored in lagoons, ponds, tanks, and pits. The trend in the U.S. is to increasingly store manure under these conditions. Furthermore, duration of time stored in this manner and temperature affect the amount of methane that is produced.

The mitigation options for manure methane involve different types of methane digesters that can capture the methane and produce energy. A manure digester is a system of containers to collect and biologically treat manure with naturally occurring microorganisms. The anaerobic environment facilitates the generation and capture of methane. The methane can then be burned to convert to CO<sub>2</sub>, and to produce heat and/or electricity. Digesters may also include systems to collect and separate solids. Large-scale digesters can be used for capture and off-site energy use while temperature digesters can be used at smaller facilities where the energy is used on-site.

### **C. Black Carbon or Soot**

Black carbon, or soot, consists of particles or aerosols released through the burning of fossil fuels, biofuels, and biomass (Quinn et al. 2007). Black carbon warms the atmosphere, but it is a solid, not a gas. Unlike most greenhouse gases that warm the atmosphere by absorbing longwave infra-red radiation, soot warms the atmosphere by absorbing visible light (Chameides and Bergin 2002). Black carbon is an extremely powerful greenhouse pollutant. Scientists have described the average global warming potential of black carbon as about 500 times that of carbon dioxide over a 100 year period (Hansen et al. 2007; *see also* Reddy and Boucher 2007; Bond and Sun 2005). This powerful warming impact is remarkable given that black carbon remains in the atmosphere for only about four to seven days, with a mean residence time of 5.3 days (Reddy and Boucher 2007).

Black carbon contributes to Arctic warming through the formation of “Arctic haze” and through deposition on snow and ice, which increases heat absorption (Quinn et al. 2007; Reddy and Boucher 2007). Arctic haze results from a number of aerosols in addition to black carbon, including sulfate and nitrate (Quinn et al. 2007). Arctic haze may either increase or decrease warming, but when the haze contains high amounts of soot, it absorbs incoming solar radiation and leads to heating. In addition, aerosols may interact with clouds changing droplet number and size, which in turn can alter albedo, or reflectivity.

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<sup>3</sup> High-energy feed, such as grain, can also increase the methane produced by the manure. However, the need for a trade-off between lower enteric fermentation emissions and manure emissions will be eliminated if manure emissions are mitigated through the use of digesters.

Soot also contributes to heating when it is deposited on snow because it reduces reflectivity of the white snow and instead tends to absorb radiation. A recent study indicates that the direct warming effect of black carbon on snow can be three times as strong as that due to carbon dioxide during springtime in the Arctic (Flanner 2007). Black carbon emissions that occur in or near the Arctic contribute the most to the melting of the far north (Reddy and Boucher 2007; Quinn et al. 2007).

Reductions in black carbon therefore provide an extremely important opportunity to slow Arctic warming in the short term, and mitigation strategies should focus on within-Arctic sources and northern hemisphere sources that are transported by air currents most efficiently to the Arctic. Conversely, allowing black carbon emissions to increase in the Arctic as the result of increased shipping or industrial activity, will accelerate loss of the seasonal sea ice and extinction of the polar bear. Black carbon reductions will also provide air quality and human health benefits.

Despite its significance to global climate change and to the Arctic in particular, black carbon has not been addressed by the major reports on non-CO<sub>2</sub> gas mitigation, nor is it explicitly addressed in current global warming bills in the 110<sup>th</sup> Congress. Black carbon reductions are an essential part of saving the Arctic sea ice and the polar bear, and should be addressed by Congress in this session.

The highest priority sources for regulation include the following: diesel generators and residential stoves within the Arctic, ships operating in or near Arctic waters, diesel truck and automobile engines, and biomass burning.

Specific measures that should be implemented include replacing diesel generators with alternative energy sources, improving the efficiency and/or particulate matter traps on residential stoves, or fuel switching in residential stoves.

Ships operating in or near Arctic waters can introduce black carbon directly into the region and should therefore be stringently regulated. One of the simplest ways to reduce black carbon emissions from ships is simply to slow them down (Ballo and Burt 2007:26). A ten percent reduction in speed can result in a 23.3 percent reduction in emissions (Ballo and Burt 2007:27). Requiring ships to switch to cleaner, lower sulphur content fuels will also reduce black carbon emissions (Ballo and Burt 2007:29). There are a variety of design changes available to increase the efficiency of ships and therefore decrease their emissions (Kleiner 2007). Finally, shipping should be stringently limited in the Arctic, as discussed above.

All diesel engines are a significant contributor to black carbon emissions. Emissions from diesel cars and trucks should be more stringently regulated (Jacobson 2002). Abatement options include upgrading vehicles, installing end of the pipe filters, better vehicle maintenance, and buy out/buy back programs for super emitters.

Emissions reductions from biomass burning and other sources are most important when the Arctic ice extent is relatively large (Quinn et al. 2007), and therefore regulating both the amount and timing of anthropogenic biomass burning can also reduce black carbon levels in the Arctic.

Much more attention needs to be focused on identifying and implementing black carbon emissions from all sources.

#### **D. Nitrous Oxide**

Unlike methane and black carbon, nitrous oxide and the high global warming potential gases discussed below do not have a disproportionate impact on the Arctic. Nevertheless, because these gases have high global warming potential, long atmospheric lifetimes, and because there are many readily available mitigation measures to reduce them, they present important opportunities for reducing global warming overall and are therefore an important part of saving the Arctic and the polar bear.

Nitrous oxide has a global warming potential 310 times that of carbon dioxide and an atmospheric lifetime of approximately 120 years. It constitutes the second largest proportion of anthropogenic non-CO<sub>2</sub> gases at 7%. The main sources of nitrous oxide emissions are: agriculture, fossil fuel combustion, and industrial adipic and nitric acid production.

##### **1. Agriculture**

Agriculture is the largest source of anthropogenic nitrous oxide (84%) (EPA 2006). These emissions are projected to increase by 37% in 2020 (over 2000 levels). Agricultural nitrous oxide is produced primarily (1) through the processes of nitrification and denitrification of soil, (2) by livestock manure, and (3) from rice farming.

Nitrous oxide emissions occur as a result of addition of nitrogen to the soil through fertilization, nitrogen-fixing crops, retention of crop residues, and cultivation of high organic content soil (peat or histosol) (EPA 2006). Nitrous oxide emissions can also result from volatilization of applied nitrogen and runoff.

In 2000, the United States' soil nitrous oxide emissions were second only to the former Soviet Union, and are predicted to surpass the FSU by 2010. Practices such as irrigation, drainage, tillage, and fallowing all influence nitrous oxide emissions.

An important consideration when selecting abatement options is that a number of practices may reduce nitrous oxide emissions while increasing carbon dioxide emissions, resulting in a net increase in greenhouse gases. The abatement options presented below are those that do not result in increased carbon dioxide emissions.



The options include reduced fertilization or more efficient fertilization, and no-till management to maintain at least 30% of the ground covered by crop residue after planting. The most effective fertilization option is the use of a fertilizer that includes a nitrification inhibitor. No-till, or conservation tillage, is effective primarily because it reduces carbon loss. The net reductions potential for croplands is approximately 24%, with 15% possible at zero net cost.

Rice fields produce both methane and nitrous oxide. The cycle, however, is different for each of the gases so that some methods that reduce one gas may increase the other. Thus, management practices must be considered carefully to balance the effects. Shallow flooding, off-season straw, and ammonium sulfate are the management practices that can reduce nitrous oxide emissions as well as methane emissions. The practice of mid-season drainage reduces methane substantially while increasing nitrous oxide. Yet, due to the magnitude of methane reduction, this practice results in a net reduction of equivalent greenhouse gases.

The final major agricultural source of nitrous oxide is livestock manure. The practices outlined above for reductions in methane emissions from livestock manure also apply to reductions in nitrous oxide.

## **2. Industrial production**

The production of nitric and adipic acid account for approximately 5% of nitrous oxide emissions. Nitric acid accounts for approximately 67% and adipic acid accounts for approximately 33% of emissions. Nitric acid is used in fertilizers as well as explosives, metal processing, and etching. Adipic acid is a component of nylon, synthetic lubricants and plastics, polyurethane resins, and plasticizers. It is also used in some artificial foods to impart a “tangy” flavor.

Plants that produce nitric acid and do not employ nonselective catalytic reduction may generate up to 19 kilograms of nitrous oxide per ton of nitric acid. The majority of plants in the US do not use this technology, and approximately 80% of plants worldwide do not use it. Nitric acid plants can reduce their emissions by 90 to 95% through high-temperature or low-temperature catalytic reduction. The costs are minor: approximately \$2-\$6/tCO<sub>2</sub>eq. The high-temperature option is less expensive and reduces nitrous oxide by 90%. The low-temperature option costs slightly more and reduces emissions by 95%.

The abatement option for adipic acid plants is thermal destruction. This option costs only \$0.50/tCO<sub>2</sub>eq and can reduce nitrous oxide emissions by 98 to 99%.

## **E. High Global Warming Potential Gases**

High global warming potential (High-GWP) gases fall into three broad categories: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride. Hydrofluorocarbons were developed to replace ozone-depleting substances used in refrigeration and air conditioning systems, solvents, aerosols, foam production, and fire extinguishing. HFCs have global warming potentials between 140 and 11,700 times that of carbon dioxide, and their atmospheric lifetimes range from one year to 260 years, respectively.

Perfluorocarbons are emitted during aluminum production and semiconductor manufacture (EPA 2006). Their global warming potential ranges from 6,500 to 9,200 times that of carbon dioxide. In addition, they have extremely long atmospheric lifetimes, e.g. 10,000 and 50,000 years for two common PFCs.

The highest global warming potential exists in sulfur hexafluoride at 23,900 times that of carbon dioxide. Sulfur hexafluoride remains in the atmosphere for 3,200 years. Sulfur hexafluoride is used: (1) for insulation and current interruption in electrical power transmission and distribution; (2) during semiconductor manufacture; (3) to protect against burning in the magnesium industry.

### **1. Hydrofluorocarbons**

#### **a. Refrigeration and Air Conditioning**

Hydrofluorocarbons are used for refrigeration and air conditioning, solvents, foam manufacture, aerosols, and in fire extinguishers. The emission of hydrofluorocarbons related to refrigeration occurs during manufacturing and servicing, leaks during operation, and disposal. An indirect effect of using these systems is the use of energy and resulting emission of carbon dioxide. Thus, mitigation measures should be evaluated both for direct HFC emissions as well as carbon dioxide emissions.

There are a variety of uses for refrigeration systems: household refrigeration, car air-conditioning, chillers for large spaces such as shopping malls as well as submarines and nuclear reactors, retail food refrigeration, cold storage warehouses, refrigerated transport, industrial refrigeration during manufacture, and residential and commercial air conditioning and heat pumps. Because a number of these systems currently use ozone-depleting substances that are being phased out as equipment ages, the impact of switching systems has been incorporated into the mitigation analysis (EPA 2006).

The abatement options fall into three categories: practice options, alternative refrigerant options, and technology options. Practice includes actions such as leak repair, refrigerant

recovery/recycling, and sales restrictions on HFCs. The alternative refrigerants include ammonia, hydrocarbons such as isobutene, and carbon dioxide.

Many of the abatement options carry a net economic benefit, such that the U.S. alone could reduce over 20 metric tons CO<sub>2</sub>eq emissions by the year 2020 at no cost or at a net economic benefit.

#### b. Solvents

Solvents used in precision and electronic cleaning, and to a much lesser extent metal cleaning, have replaced ozone-depleting substances in a variety of ways, including substitution of HFCs and PFCs. There are three main mitigation options: (1) improved solvent containment and use of carbon absorption; (2) use of aqueous or semi-aqueous cleaning processes; and (3) conversion to different low-global warming potential compounds or organic compounds.

The conversion to alternative compounds is a no-cost abatement option that could reduce baseline emissions by approximately 25% by the year 2020. Similarly, conversion to semi-aqueous cleaning processes would only cost approximately \$0.67/tCO<sub>2</sub>eq.

#### c. Foam manufacture

HFCs are used during the blowing process to produce foam. These emissions are expected to rise dramatically in coming years. Another ozone -depleting substance, hydrochlorofluorocarbons (HCFCs), is still in use in developing countries, but will be phased out with time. The US currently allows the use of HCFC-22, but not HCFC-141b.

Emissions occur during the manufacture process, during foam application, while foams are in use, and when they are discarded. Abatement can be achieved through replacement of the blowing agent used in the manufacture process and proper disposal of appliance foam at end-of-life. Several of the replacement options would bring a net economic benefit. The total possible reduction from the predicted 2020 baseline emissions is approximately 31%.

#### d. Aerosols

Aerosols are used to propel a variety of products. After CFCs were banned in the US, some products began using HFCs as propellants. Medical applications, such as inhalers, currently still use CFCs, but these companies are developing HFC alternatives.

Abatement of non-medical HFC emissions involves replacing current HFCs with other HFCs that have a lower global warming potential, hydrocarbon propellants, and other application methods such as hand pumps, roll-on applicators, and powders. All of these non-

medical options can be achieved at no cost and would reduce current HFC emissions by at least 57% in the year 2020.

Transitioning away from CFCs has proven to be a challenge with medical inhalers. One alternative for some patients, however, is the use of dry powdered inhalers. The use of this application method has the capability of reducing medical propellant HFC emissions by half.

#### e. Fire Extinguishing

Halon was traditionally used in fire extinguishing systems—both portable fire extinguishers and “total flooding” systems that protect large spaces. Due to its ozone depleting characteristics, halon is being replaced in some instances with HFCs.

Depending on the application, HFC systems can be replaced by inert gas systems, water mist systems, or fluorinated ketone systems. In addition, abatement can be achieved through recovery and reuse of HFCs and through improved detection mechanisms to prevent erroneous release in total flooding systems.

#### f. HCFC-22

As mentioned above, HCFC-22 is an ozone depleting substances that is used in refrigeration, some solvents, and synthetic polymer production. One of the byproducts is HFC-23, which has a global warming potential of 11,700 times that of carbon and an atmospheric lifetime of 260 years. The US is close behind China as the second largest producer of HFC-23 emissions resulting from production of HCFC-22.

There are several options for mitigating HFC emissions. Manufacturing optimization can maximize HCFC-22 production and minimize HFC-23 production at very low cost. Thermal oxidation of HFC-23 by product can reduce 95% of HFC emissions. Oxidation costs only about \$0.23/tCO<sub>2</sub>eq and can reduce HFC emissions at existing plants by 88%, even assuming that current plans to minimize HCFC-22 are implemented.

At the commemoration meeting of the Montreal Protocol on September 21, 2007, the U.S. and other developed nations agreed to a schedule of reductions that includes ceasing to use HCFCs by 2020, which is 10 years sooner than previously agreed. Thus, the assumptions upon which the EPA 2006 report were based may be inapplicable.

## **2. Perfluorocarbons**

### **a. Aluminum production**

The aluminum industry is the largest source of PFC emissions. PFCs are emitted when so-called anode effects occur during the smelting process. The amount of PFCs emitted depends directly on the number and duration of such events.

Although the aluminum industry has taken voluntary reductions and has pledged further reductions, there are still mitigation options that should be implemented to further reduce emissions. The two main methods are: installation of computer control systems and installation of alumina point-feed systems. The computer control system is considered a minor retrofit and the alumina point-feed system is considered a major retrofit. The efficacy of these measures depends on the current technology used by the plant. They may reduce PFC emissions by up to 97% when combined at some facilities. The implementation of these options can also come at an economic benefit in some facilities.

### **b. Semiconductor manufacturing**

The manufacture of semiconductors releases PFCs, sulfur hexafluoride, and HFC-23 primarily during plasma etching of thin films and cleaning chemical-vapor-deposition (CVD) chambers. Etching is estimated to account for approximately 20% of emissions, while CVD chamber cleaning accounts for approximately 80%. PFC emissions also occur as a by-product of reactions between other gases. The U.S. is the second largest emitter of PFCs, although it is a member of the World Semiconductor Council, which has committed to voluntary reductions in emissions.

The most effective abatement option is nitrogen trifluoride remote cleaning technology. This system can reduce emissions by approximately 95%. This option has a net economic benefit and when implemented could reduce baseline emissions by 42%, even assuming the industry meets its voluntary emissions reduction goal. The second most effective option is point-of-use plasma abatement during the etching process.

## **3. Sulfur hexafluoride**

### **a. Electrical industry**

Sulfur hexafluoride is primarily emitted by the electrical industry. Sulfur hexafluoride is used as a dielectric insulator in transmission lines, sub-stations, and transformers. The United States is the largest emitter of sulfur hexafluoride. The electric industry has recently begun reducing its sulfur hexafluoride emissions, however much more remains to be done.

Sulfur hexafluoride emissions can be reduced through sulfur hexafluoride recycling, leak detection and repair, and equipment refurbishment. Recycling presents the greatest opportunity for mitigation, with a net economic benefit and potential for emissions reduction of approximately 43% above and beyond currently planned reductions. Many companies already recycle sulfur hexafluoride. The average efficacy of their systems is 80%, but this could easily be increased to provide for 95% reductions in sulfur hexafluoride emissions. Leak detection and repair can reduce emissions that occur during operation. Finally, equipment refurbishment can also reduce emissions.

#### b. Magnesium production

Sulfur hexafluoride is currently used as a cover gas during magnesium production to prevent spontaneous combustion. Essentially all of the sulfur hexafluoride is emitted into the atmosphere. The International Magnesium Association, representing 80% of the industry, has pledged to eliminate sulfur hexafluoride by 2011. They will do so by substituting different cover gases.

Emissions can be abated by replacing sulfur hexafluoride with either sulfur dioxide or fluorinated gases. New technology has solved the toxicity, corrosion, and odor concerns associated with sulfur dioxide. Thus, it is can fully eliminate emissions that contribute to global warming, and is relatively inexpensive. The replacement of sulfur hexafluoride with fluorinated gases is also possible, although these gases still have global warming effects.

**Table 1: United States Non-CO<sub>2</sub> Emissions and Potential Reductions for 2010**

| <i>Non-CO<sub>2</sub> Gas</i>    | <i>Sector</i>                 | <i>Baseline emissions (MtCO<sub>2</sub>eq)</i> | <i>No-Cost reduction (%)</i> | <i>No-Cost reduction (MtCO<sub>2</sub>eq)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (%)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (MtCO<sub>2</sub>eq)</i> | <i>Technologically feasible reduction (%)</i> | <i>Technologically feasible reduction (MtCO<sub>2</sub>eq)</i> |
|----------------------------------|-------------------------------|--|------------------------------|---|--|---|---|--|
| Methane (CH <sub>4</sub> )       | Livestock                     | 173.0  | <b>6.4</b>                   | 11.1  | <b>9.4</b>                                       | 16.3  | <b>21.4</b>                                   | 37.0   |
|                                  | Landfill                      | 125.4  | <b>10.0</b>                  | 12.5  | <b>42.1</b>                                      | 52.8  | <b>87.3</b>                                   | 109.5  |
|                                  | Wastewater                    | 36.1   | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Coal mining                   | 51.1   | <b>49.2</b>                  | 25.2  | <b>86.0</b>                                      | 43.9  | <b>86.0</b>                                   | 43.9   |
|                                  | Natural gas                   | 138.6  | <b>14.5</b>                  | 20.1  | <b>19.2</b>                                      | 26.7  | <b>54.8</b>                                   | 75.9   |
|                                  | Oil                           | 3.7  | <b>0.0</b>                   | 0.0   | <b>17.7</b>                                      | 0.7   | <b>21.8</b>                                   | 0.8  |
| <b>CH<sub>4</sub> Total</b>      |                               | <b>527.9</b>                                   | <b>13.0</b>                  | <b>68.9</b>                                   | <b>26.6</b>                                      | <b>140.4</b>  | <b>50.6</b>                                   | <b>267.1</b>   |
| Nitrous Oxide (N <sub>2</sub> O) | Wastewater                    | 15.9   | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Croplands (wheat, maize, soy) | 179.0  | <b>21.7</b>                  | 38.8  | <b>25.9</b>                                      | 46.4  | <b>28.5</b>                                   | 51.0   |
|                                  | Nitric acid                   | 15.5   | <b>0.0</b>                   | 0.0   | <b>88.9</b>                                      | 13.8  | <b>88.9</b>                                   | 13.8   |
|                                  | Adipic acid                   | 8.4  | <b>0.0</b>                   | 0.0   | <b>96.0</b>                                      | 8.1   | <b>96.0</b>                                   | 8.1  |
| <b>N<sub>2</sub>O Total</b>      |                               | <b>218.8</b>                                   | <b>17.8</b>                  | <b>38.8</b>                                   | <b>31.2</b>                                      | <b>68.2</b>   | <b>33.3</b>                                   | <b>72.9</b>  |
| HFCs                             | Refrigeration                 | 148.6  | <b>3.8</b>                   | 5.7   | <b>7.7</b>                                       | 11.4  | <b>7.7</b>                                    | 11.4   |
|                                  | Solvents                      | 1.7  | <b>17.6</b>                  | 0.3   | <b>25.3</b>                                      | 0.4   | <b>25.3</b>                                   | 0.4  |
|                                  | Foams                         | 5.7  | <b>3.3</b>                   | 0.2   | <b>3.7</b>                                       | 0.2   | <b>6.8</b>                                    | 0.4  |
|                                  | Aerosols (medical)            | 2.7  | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>5.2</b>                                    | 0.1  |
|                                  | Aerosols (nonmed)             | 12.1   | <b>38.6</b>                  | 4.7   | <b>38.6</b>                                      | 4.7   | <b>38.6</b>                                   | 4.7  |
|                                  | Fire extinguishing            | 1.6  | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>6.9</b>                                    | 0.1  |
|                                  | HCFC-22 production            | 9.3  | <b>0.0</b>                   | 0.0   | <b>86.7</b>                                      | 8.1   | <b>86.7</b>                                   | 8.1  |
| <b>HFC Total</b>                 |                               | <b>181.7</b>                                   | <b>6.0</b>                   | <b>10.8</b>                                   | <b>13.7</b>                                      | <b>24.8</b>   | <b>13.9</b>                                   | <b>25.2</b>  |
| PFCs                             | Aluminum                      | 4.6  | <b>3.9</b>                   | 0.2   | <b>13.9</b>                                      | 0.6   | <b>17.6</b>                                   | 0.8  |
|                                  | Semiconductor                 | 5.5  | <b>58.2</b>                  | 3.2   | <b>58.2</b>                                      | 3.2   | <b>69.1</b>                                   | 3.8  |
| <b>PFC Total</b>                 |                               | <b>10.1</b>                                    | <b>33.5</b>                  | <b>3.4</b>                                    | <b>38.0</b>                                      | <b>3.8</b>  | <b>45.6</b>                                   | <b>4.6</b>   |
| SF <sub>6</sub>                  | Electric power                | 12.8   | <b>35.0</b>                  | 4.5   | <b>41.0</b>                                      | 5.3   | <b>41.0</b>                                   | 5.3  |
|                                  | Mg production                 | 1.2  | <b>0.0</b>                   | 0.0   | <b>97.5</b>                                      | 1.2   | <b>97.5</b>                                   | 1.2  |
| <b>SF<sub>6</sub> Total</b>      |                               | <b>14.0</b>                                    | <b>32.0</b>                  | <b>4.5</b>                                    | <b>45.9</b>                                      | <b>6.4</b>  | <b>45.9</b>                                   | <b>6.4</b>   |
| <b>All Gases</b>                 |                               | <b>952.5</b>                                   | <b>13.3</b>                  | <b>126.4</b>                                  | <b>25.6</b>                                      | <b>243.6</b>  | <b>39.5</b>                                   | <b>376.3</b>   |

All Tables: Emissions and potential reduction for global Non-CO<sub>2</sub> gases. All values are taken from EPA report 430-R-06-005, *Global Mitigation of Non-CO<sub>2</sub> Greenhouse Gases* (2006). As discussed in the text, EPA (2006) calculations are conservative, and thus underestimate the no-cost and low cost mitigation opportunities. The baselines reported here do not account for all emissions; they only account for emissions that EPA determined should be considered for mitigation measures. Some sectors emit multiple types of greenhouse gas. In these instances, the emissions for the sector were attributed to the Non-CO<sub>2</sub> gas that is present in the largest proportion. For industries that have committed to some improvement in technology, the baseline and reductions are based on assumptions that these technologies will be adopted.

**Table 2: United States Non-CO<sub>2</sub> Emissions and Potential Reductions for 2020**

| <i>Non-CO<sub>2</sub> Gas</i>    | <i>Sector</i>                 | <i>Baseline emissions (MtCO<sub>2</sub>eq)</i> | <i>No-Cost reduction (%)</i> | <i>No-Cost reduction (MtCO<sub>2</sub>eq)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (%)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (MtCO<sub>2</sub>eq)</i> | <i>Technologically feasible reduction (%)</i> | <i>Technologically feasible reduction (MtCO<sub>2</sub>eq)</i> |
|----------------------------------|-------------------------------|--|------------------------------|---|--|---|---|--|
| Methane (CH <sub>4</sub> )       | Livestock                     | 171.0  | <b>6.3</b>                   | 10.8  | <b>11.8</b>                                      | 20.2  | <b>23.0</b>                                   | 39.3   |
|                                  | Landfill                      | 123.5  | <b>10.0</b>                  | 12.4  | <b>42.1</b>                                      | 52.0  | <b>87.3</b>                                   | 107.8  |
|                                  | Wastewater                    | 37.8   | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Coal mining                   | 46.4   | <b>49.2</b>                  | 22.8  | <b>86.0</b>                                      | 39.9  | <b>86.0</b>                                   | 39.9   |
|                                  | Natural gas                   | 164.8  | <b>14.5</b>                  | 23.9  | <b>19.2</b>                                      | 31.7  | <b>54.8</b>                                   | 90.2   |
|                                  | Oil                           | 4.5  | <b>0.0</b>                   | 0.0   | <b>17.7</b>                                      | 0.8   | <b>21.8</b>                                   | 1.0  |
| <b>CH<sub>4</sub> Total</b>      |                               | <b>548.0</b>                                   | <b>12.8</b>                  | <b>69.9</b>                                   | <b>26.4</b>                                      | <b>144.6</b>  | <b>50.8</b>                                   | <b>278.3</b>   |
| Nitrous Oxide (N <sub>2</sub> O) | Wastewater                    | 16.3   | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Croplands (wheat, maize, soy) | 200.0  | <b>20.3</b>                  | 40.6  | <b>21.0</b>                                      | 42.0  | <b>26.5</b>                                   | 53.0   |
|                                  | Nitric acid                   | 17.4   | <b>0.0</b>                   | 0.0   | <b>88.9</b>                                      | 15.5  | <b>88.9</b>                                   | 15.5   |
|                                  | Adipic acid                   | 9.8  | <b>0.0</b>                   | 0.0   | <b>96.0</b>                                      | 9.4   | <b>96.0</b>                                   | 9.4  |
| <b>N<sub>2</sub>O Total</b>      |                               | <b>243.5</b>                                   | <b>16.7</b>                  | <b>40.6</b>                                   | <b>27.5</b>                                      | <b>66.9</b>   | <b>32.0</b>                                   | <b>77.9</b>  |
| HFCs                             | Refrigeration                 | 264.6  | <b>11.4</b>                  | 30.3  | <b>29.5</b>                                      | 78.1  | <b>29.5</b>                                   | 78.1   |
|                                  | Solvents                      | 2.0  | <b>37.0</b>                  | 0.7   | <b>52.5</b>                                      | 1.1   | <b>52.5</b>                                   | 1.1  |
|                                  | Foams                         | 11.3   | <b>9.7</b>                   | 1.1   | <b>10.4</b>                                      | 1.2   | <b>21.9</b>                                   | 2.5  |
|                                  | Aerosols (medical)            | 5.5  | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>49.8</b>                                   | 2.7  |
|                                  | Aerosols (nonmed)             | 14.8   | <b>57.0</b>                  | 8.4   | <b>57.0</b>                                      | 8.4   | <b>57.0</b>                                   | 8.4  |
|                                  | Fire extinguishing            | 1.9  | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>38.9</b>                                   | 0.7  |
|                                  | HCFC-22 production            | 8.5  | <b>0.0</b>                   | 0.0   | <b>86.6</b>                                      | 7.4   | <b>86.6</b>                                   | 7.4  |
| <b>HFC Total</b>                 |                               | <b>308.6</b>                                   | <b>13.1</b>                  | <b>40.5</b>                                   | <b>31.1</b>                                      | <b>96.1</b>   | <b>32.7</b>                                   | <b>100.8</b>   |
| PFCs                             | Aluminum                      | 4.4  | <b>4.1</b>                   | 0.2   | <b>14.8</b>                                      | 0.7   | <b>18.4</b>                                   | 0.8  |
|                                  | Semiconductor                 | 4.1  | <b>29.3</b>                  | 1.2   | <b>29.3</b>                                      | 1.2   | <b>31.7</b>                                   | 1.3  |
| <b>PFC Total</b>                 |                               | <b>8.5</b>                                     | <b>16.2</b>                  | <b>1.4</b>                                    | <b>21.8</b>                                      | <b>1.9</b>  | <b>24.8</b>                                   | <b>2.1</b>   |
| SF <sub>6</sub>                  | Electric power                | 11.8   | <b>0.0</b>                   | 0.0   | <b>31.3</b>                                      | 3.7   | <b>31.3</b>                                   | 3.7  |
|                                  | Mg production                 | 1.0  | <b>0.0</b>                   | 0.0   | <b>90.0</b>                                      | 0.9   | <b>90.0</b>                                   | 0.9  |
| <b>SF<sub>6</sub> Total</b>      |                               | <b>12.8</b>                                    | <b>0.0</b>                   | <b>0.0</b>                                    | <b>35.9</b>                                      | <b>4.6</b>  | <b>35.9</b>                                   | <b>4.6</b>   |
| <b>All Gases</b>                 |                               | <b>1121.4</b>                                  | <b>13.6</b>                  | <b>152.4</b>                                  | <b>28.0</b>                                      | <b>314.0</b>  | <b>41.3</b>                                   | <b>463.7</b>   |



**Table 3: World Non-CO<sub>2</sub> Emissions and Potential Reductions for 2010**

| <i>Non-CO<sub>2</sub> Gas</i>    | <i>Sector</i>                 | <i>Baseline emissions (MtCO<sub>2</sub>eq)</i> | <i>No-Cost reduction (%)</i> | <i>No-Cost reduction (MtCO<sub>2</sub>eq)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (%)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (MtCO<sub>2</sub>eq)</i> | <i>Technologically feasible reduction (%)</i> | <i>Technologically feasible reduction (MtCO<sub>2</sub>eq)</i> |
|----------------------------------|-------------------------------|--|------------------------------|---|--|---|---|--|
| Methane (CH <sub>4</sub> )       | Rice                          | 708  | <b>10.5</b>                  | 74.3  | <b>21.9</b>                                      | 155.1   | <b>24.9</b>                                   | 176.3  |
|                                  | Livestock                     | 2548   | <b>3</b>                     | 76.4  | <b>4.4</b>                                       | 112.1   | <b>6.8</b>                                    | 173.3  |
|                                  | Landfill                      | 760.6  | <b>11.7</b>                  | 89.0  | <b>40.5</b>                                      | 308.0   | <b>87.8</b>                                   | 667.9  |
|                                  | Wastewater                    | 594  | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Coal mining                   | 407.6  | <b>16.6</b>                  | 67.7  | <b>79.8</b>                                      | 325.4   | <b>79.8</b>                                   | 325.4  |
|                                  | Natural gas                   | 1271.5   | <b>10.1</b>                  | 128.5   | <b>25.0</b>                                      | 317.6   | <b>53.4</b>                                   | 678.5  |
|                                  | Oil                           | 82.9   | <b>0</b>                     | 0   | <b>28.1</b>                                      | 23.3  | <b>34.7</b>                                   | 28.8   |
| <b>CH<sub>4</sub> Total</b>      |                               | <b>6372.6</b>                                  | <b>6.8</b>                   | <b>436.0</b>                                  | <b>19.5</b>                                      | <b>1241.5</b>   | <b>32.2</b>                                   | <b>2050.1</b>  |
| Nitrous oxide (N <sub>2</sub> O) | Rice                          | 330  | <b>15.8</b>                  | 52.14   | <b>30.8</b>                                      | 101.64  | <b>30</b>                                     | 99   |
|                                  | Wastewater                    | 99.1   | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Croplands (wheat, maize, soy) | 830  | <b>15.4</b>                  | 127.82  | <b>17.6</b>                                      | 146.1   | <b>24</b>                                     | 199.2  |
|                                  | Nitric acid                   | 107  | <b>0</b>                     | 0   | <b>88.9</b>                                      | 95.2  | <b>88.9</b>                                   | 95.2   |
|                                  | Adipic acid                   | 57.6   | <b>0</b>                     | 0   | <b>96</b>  | 55.3  | <b>96</b>                                     | 55.3   |
| <b>N<sub>2</sub>O Total</b>      |                               | <b>1423.7</b>                                  | <b>12.6</b>                  | <b>180.0</b>                                  | <b>28.0</b>                                      | <b>398.2</b>  | <b>31.5</b>                                   | <b>448.7</b>   |
| HFCs                             | Refrigeration                 | 356.4  | <b>4.7</b>                   | 16.6  | <b>8.2</b>                                       | 29.2  | <b>8.9</b>                                    | 31.8   |
|                                  | Solvents                      | 7.7  | <b>10.4</b>                  | 0.8   | <b>23.8</b>                                      | 1.8   | <b>23.8</b>                                   | 1.8  |
|                                  | Foams                         | 15.4   | <b>13.5</b>                  | 2.1   | <b>15.8</b>                                      | 2.4   | <b>22.3</b>                                   | 3.4  |
|                                  | Aerosols (medical)            | 11   | <b>0</b>                     | 0   | <b>0</b>   | 0   | <b>5</b>                                      | 0.6  |
|                                  | Aerosols (nonmed)             | 32.7   | <b>38.5</b>                  | 12.6  | <b>38.5</b>                                      | 12.6  | <b>38.5</b>                                   | 12.6   |
|                                  | Fire extinguishing            | 7.4  | <b>0</b>                     | 0   | <b>0</b>   | 0   | <b>5.3</b>                                    | 0.4  |
|                                  | HCFC-22 production            | 44.7   | <b>0</b>                     | 0   | <b>83.9</b>                                      | 37.5  | <b>83.9</b>                                   | 37.5   |
| <b>HFC Total</b>                 |                               | <b>475.3</b>                                   | <b>6.7</b>                   | <b>32.1</b>                                   | <b>17.6</b>                                      | <b>83.6</b>   | <b>18.5</b>                                   | <b>88.1</b>  |
| PFCs                             | Aluminum                      | 39.1   | <b>2.9</b>                   | 1.1   | <b>13.6</b>                                      | 5.3   | <b>15.7</b>                                   | 6.1  |
|                                  | Semiconductor                 | 36.9   | <b>39</b>                    | 14.4  | <b>40.1</b>                                      | 14.8  | <b>51.5</b>                                   | 19   |
| <b>PFC Total</b>                 |                               | <b>76</b>                                      | <b>20.4</b>                  | <b>15.5</b>                                   | <b>26.5</b>                                      | <b>20.1</b>   | <b>33.1</b>                                   | <b>25.1</b>  |
| SF <sub>6</sub>                  | Electric power                | 46.8   | <b>45.8</b>                  | 21.4  | <b>50.2</b>                                      | 23.5  | <b>50.2</b>                                   | 23.5   |
|                                  | Mg production                 | 3.6  | <b>0</b>                     | 0   | <b>94.4</b>                                      | 3.4   | <b>94.4</b>                                   | 3.4  |
| <b>SF<sub>6</sub> Total</b>      |                               | <b>50.4</b>                                    | <b>42.5</b>                  | <b>21.44</b>                                  | <b>53.4</b>                                      | <b>26.9</b>   | <b>53.4</b>                                   | <b>26.9</b>  |
| <b>All Gases</b>                 |                               | <b>8398</b>                                    | <b>8.2</b>                   | <b>685</b>                                    | <b>21.1</b>                                      | <b>1770.30</b>  | <b>31.4</b>                                   | <b>2638.9</b>  |

**Table 4: World Non-CO<sub>2</sub> Emissions and Potential Reductions for 2020**

| <i>Non-CO<sub>2</sub> Gas</i>    | <i>Sector</i>                 | <i>Baseline emissions (MtCO<sub>2</sub>eq)</i> | <i>No-Cost reduction (%)</i> | <i>No-Cost reduction (MtCO<sub>2</sub>eq)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (%)</i> | <i>&lt; \$15/tCO<sub>2</sub>eq reduction (MtCO<sub>2</sub>eq)</i> | <i>Technologically feasible reduction (%)</i> | <i>Technologically feasible reduction (MtCO<sub>2</sub>eq)</i> |
|----------------------------------|-------------------------------|--|------------------------------|---|--|---|---|--|
| Methane (CH <sub>4</sub> )       | Rice                          | 776.0  | <b>10.5</b>                  | 81.5  | <b>21.9</b>                                      | 169.9   | <b>24.9</b>                                   | 193.2  |
|                                  | Livestock                     | 2867.0   | <b>2.9</b>                   | 83.1  | <b>4.4</b>                                       | 126.1   | <b>6.7</b>                                    | 192.1  |
|                                  | Landfill                      | 816.9  | <b>11.8</b>                  | 96.6  | <b>40.7</b>                                      | 332.3   | <b>87.8</b>                                   | 716.9  |
|                                  | Wastewater                    | 665.0  | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Coal mining                   | 449.5  | <b>14.5</b>                  | 65.2  | <b>79.8</b>                                      | 358.7   | <b>79.8</b>                                   | 358.7  |
|                                  | Natural gas                   | 1695.8   | <b>10.2</b>                  | 172.8   | <b>25.3</b>                                      | 428.2   | <b>53.8</b>                                   | 912.5  |
|                                  | Oil                           | 131.8  | <b>0.0</b>                   | 0.0   | <b>29.0</b>                                      | 38.2  | <b>35.8</b>                                   | 47.2   |
| <b>CH<sub>4</sub> Total</b>      |                               | <b>7402.0</b>                                  | <b>6.7</b>                   | <b>499.2</b>                                  | <b>19.6</b>                                      | <b>1453.5</b>   | <b>32.7</b>                                   | <b>2420.6</b>  |
| Nitrous Oxide (N <sub>2</sub> O) | Rice                          | 286.0  | <b>13.1</b>                  | 37.5  | <b>26.3</b>                                      | 75.2  | <b>27.0</b>                                   | 77.2   |
|                                  | Wastewater                    | 107.2  | <b>N/A</b>                   |   |  |   |   |  |
|                                  | Croplands (wheat, maize, soy) | 893.0  | <b>14.6</b>                  | 130.4   | <b>16.2</b>                                      | 144.7   | <b>22.7</b>                                   | 202.7  |
|                                  | Nitric acid                   | 113.1  | <b>0.0</b>                   | 0.0   | <b>88.9</b>                                      | 100.6   | <b>88.9</b>                                   | 100.6  |
|                                  | Adipic acid                   | 63.5   | <b>0.0</b>                   | 0.0   | <b>96.0</b>                                      | 61.0  | <b>96.0</b>                                   | 61.0   |
| <b>N<sub>2</sub>O Total</b>      |                               | <b>1462.8</b>                                  | <b>11.5</b>                  | <b>167.8</b>                                  | <b>26.1</b>                                      | <b>381.4</b>  | <b>30.2</b>                                   | <b>441.5</b>   |
| HFCs                             | Refrigeration                 | 627.3  | <b>11.7</b>                  | 73.2  | <b>25.8</b>                                      | 161.7   | <b>31.2</b>                                   | 195.8  |
|                                  | Solvents                      | 4.5  | <b>25.8</b>                  | 1.2   | <b>48.9</b>                                      | 2.2   | <b>48.9</b>                                   | 2.2  |
|                                  | Foams                         | 28.6   | <b>16.2</b>                  | 4.6   | <b>19.4</b>                                      | 5.5   | <b>30.8</b>                                   | 8.8  |
|                                  | Aerosols (medical)            | 20.1   | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>50.0</b>                                   | 10.1   |
|                                  | Aerosols (nonmed)             | 39.5   | <b>57.1</b>                  | 22.5  | <b>57.1</b>                                      | 22.5  | <b>57.1</b>                                   | 22.5   |
|                                  | Fire extinguishing            | 13.7   | <b>0.0</b>                   | 0.0   | <b>0.0</b>                                       | 0.0   | <b>27.5</b>                                   | 3.8  |
|                                  | HCFC-22 production            | 66.2   | <b>0.0</b>                   | 0.0   | <b>87.9</b>                                      | 58.2  | <b>87.9</b>                                   | 58.2   |
| <b>HFC Total</b>                 |                               | <b>799.9</b>                                   | <b>12.7</b>                  | <b>101.5</b>                                  | <b>31.3</b>                                      | <b>250.2</b>  | <b>37.7</b>                                   | <b>301.4</b>   |
| PFCs                             | Aluminum                      | 44.7   | <b>3.0</b>                   | 1.3   | <b>14.0</b>                                      | 6.2   | <b>16.2</b>                                   | 7.2  |
|                                  | Semiconductor                 | 28.3   | <b>44.2</b>                  | 12.5  | <b>44.2</b>                                      | 12.5  | <b>51.2</b>                                   | 14.5   |
| <b>PFC Total</b>                 |                               | <b>73.0</b>                                    | <b>19.0</b>                  | <b>13.8</b>                                   | <b>25.7</b>                                      | <b>18.7</b>   | <b>29.8</b>                                   | <b>21.7</b>  |
| SF <sub>6</sub>                  | Electric power                | 57.5   | <b>40.9</b>                  | 23.5  | <b>50.2</b>                                      | 28.9  | <b>50.2</b>                                   | 28.9   |
|                                  | Mg production                 | 4.8  | <b>0.0</b>                   | 0.0   | <b>96.5</b>                                      | 4.6   | <b>96.5</b>                                   | 4.6  |
| <b>SF<sub>6</sub> Total</b>      |                               | <b>62.3</b>                                    | <b>37.7</b>                  | <b>23.5</b>                                   | <b>53.8</b>                                      | <b>33.5</b>   | <b>53.8</b>                                   | <b>33.5</b>  |
| <b>All Gases</b>                 |                               | <b>9800.0</b>                                  | <b>8.2</b>                   | <b>805.9</b>                                  | <b>21.8</b>                                      | <b>2137.4</b>   | <b>32.8</b>                                   | <b>3218.7</b>  |

**Table 5: Global Mean Annual Budget of BC for Different Geographical Regions**

| Region        | Emissions<br>Tg/yr<br>(regional<br>contribution) | Contribution<br>of Biofuels<br>(regional<br>contribution) | Global Dry<br>Deposition<br>(Tg/yr) | Global Wet<br>Deposition<br>(Tg/yr) | Burden x 100<br>Tg (regional<br>contribution) | Residence<br>Time<br>(days) | Contribution to<br>Surface Deposition<br>North to 60N,<br>South to 60S |
|---------------|--|---|-------------------------------------|-------------------------------------|---|-----------------------------|--|
| SAM           | 0.314 (6%)                                       | 5% <sup>c</sup> (25%)                                     | 0.049                               | 0.265                               | 0.452 (6.5%)                                  | 5.28                        | 1%   |
| NAM           | 0.522 (11%)                                      | 6% (20%)  | 0.092                               | 0.430                               | 0.697<br>(10.0%)                              | 4.80                        | 11%  |
| AFR           | 0.483 (10%)                                      | 21% (72%)   | 0.088                               | 0.395                               | 0.947<br>(13.6%)                              | 7.16                        | 1%   |
| EUR           | 0.602 (12%)                                      | 5% (13%)  | 0.128                               | 0.474                               | 0.823<br>(11.8%)                              | 5.01                        | 63%  |
| WCA           | 0.157 (3%)                                       | 1% (11%)  | 0.040                               | 0.117                               | 0.312 (4.5%)                                  | 7.29                        | 2%   |
| SAS           | 0.602 (13%)                                      | 25% (68%)   | 0.120                               | 0.483                               | 1.086<br>(15.6%)                              | 6.59                        | 2%   |
| EAS           | 2.038 (43%)                                      | 36% (29%)   | 0.333                               | 1.708                               | 2.565<br>(36.8%)                              | 4.60                        | 17%  |
| AUP           | 0.036 (1%)                                       | <1% (14%)   | 0.006                               | 0.030                               | 4.062 (0.7%)                                  | 4.62                        | 1%   |
| OCE           | 0.036 (1%)                                       | – (–)   | 0.007                               | 0.029                               | 0.042 (0.6%)                                  | 4.24                        | 2%   |
| <b>Global</b> | <b>4.791</b>                                     | <b>34%</b>  | <b>0.860</b>                        | <b>3.931</b>                        | <b>6.970</b>                                  | <b>5.32</b>                 | –  |

Table 1 from Reddy, M.S. and Boucher, O (2007), Climate impact of black carbon emitted from energy consumption in the world's regions, *Geophysical Research Letters*, 34: L11802. Regional abbreviations: SAM, South America; NAM, North America; AFR, Africa; EUR, Europe; WCA, West and Central Asia; SAS, South Asia; EAS, East Asia; AUP, Australia and Pacific Islands; OCE, Oceanic Regions.

