

AMAP

Sources and Mitigation Opportunities to Reduce Emissions of Short-term Arctic Climate Forcers

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The Arctic Monitoring and Assessment Programme (AMAP) was established in June 1991 by the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States) to implement parts of the Arctic Environmental Protection Strategy (AEPS). AMAP is now one of six working groups of the Arctic Council, members of which include the eight Arctic countries, the six Arctic Council Permanent Participants (indigenous peoples' organizations), together with observing countries and organizations.

AMAP's objective is to provide 'reliable and sufficient information on the status of, and threats to, the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions to reduce adverse effects of contaminants and climate change'.

AMAP produces, at regular intervals, assessment reports that address a range of Arctic pollution and climate change issues, including effects on health of Arctic human populations. These are presented to Arctic Council Ministers in 'State of the Arctic Environment' reports that form a basis for necessary steps to be taken to protect the Arctic and its inhabitants.

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I. Background and Summary of Key Results

The Arctic is warming at twice the rate of the earth as a whole. Increases in the rate of sea ice and Greenland ice sheet melt have led to concerns that the Arctic is reaching a “tipping point,” with global implications. Reductions in CO₂ emissions, while essential for long-term global (and Arctic) climate stabilization, cannot impact the Arctic sufficiently in the near term due to CO₂'s long atmospheric lifetime. Fortunately, short-lived climate forcers – notably black carbon, tropospheric ozone, and methane have nearly the same temperature impact on the Arctic as CO₂. Because these pollutants have short atmospheric lifetimes (days, months or a decade, respectively), reductions could have near-term benefits to slow warming, especially by delaying the onset of spring melt. This could “buy time” by slowing Arctic warming and ice melt while the longer-term benefits of CO₂ reductions take effect.

As a result, curbing short-lived climate forcing agents, through rapid international action and Arctic nation leadership, may prove to be the best and perhaps only viable strategy for slowing Arctic warming in the time frame of years to a decade. This paper focuses on mitigation options for short-lived Arctic climate-forcers, with particular emphasis on those reduction efforts most relevant to Arctic Council members.¹

Emission Trends and Sources

This study analyzes emissions inventories for each of the five pollutants – black carbon (BC), methane, and precursors of tropospheric ozone: nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), and carbon monoxide (CO) – to help identify the most promising mitigation options.² Due to the short atmospheric lifetime of these pollutants and near-term focus of desired Arctic impact, we used 20-year global warming potentials (GWP)³ to weight each emissions inventory.⁴ Based on this analysis, the greatest climate impacts on the Arctic are from black carbon and methane, with tropospheric ozone precursors having a far lesser effect.

Most Promising Mitigation Options

Emissions of all short-lived forcers from northern hemisphere sources, and in some cases global sources, have a significant impact in the Arctic. As a well-mixed greenhouse gas, methane reduced anywhere on the globe will benefit the Arctic. Atmospheric heating from BC and tropospheric ozone also result in transport of heat to the Arctic. As a result, while targeted mitigation efforts by Arctic Council and near-Arctic nations will benefit the Arctic, so would reduction of sources from outside of this region.

Black Carbon and Ozone: Reductions of BC and most ozone precursor emissions north of 40 degrees latitude (i.e., Europe, Canada, parts of the U.S. and northern Asia⁵) have priority, as they can impact both forcing and ice/snow melt within the Arctic and lie within the purview of Arctic Council member nations. The most promising options include:

- Reduce BC emissions by adopting diesel particulate control measures (ultra-low sulfur diesel (ULSD) fuel plus particulate traps); and through effective improvements in household energy use (solid fuel combustion) in northern Asia, and to a lesser extent in Eastern Europe.
- Identify and reduce industrial BC emissions in North America, Europe and Northern Asia.
- Reduce BC (and some CO) emissions by reducing and/or changing the timing of agricultural burning in Europe and northern Asia, and converting to biochar production and utilization.
- Reduce CO, NO_x and NMVOC emissions by adopting vehicle and fuel storage emissions control measures (such as exhaust catalysts or vehicle inspection and maintenance).
- Reduce NO_x emissions by installing/requiring vehicle and small combustion source exhaust catalysts and other control devices. Many techniques used to reduce vehicle CO and NMVOC emissions also reduce NO_x emissions, such as mass transit programs and exhaust catalysts.
- Curb NO_x emissions through more stringent regulations, such as emission performance standards that apply to all new generation emitters, increased funding for the development and deployment of cleaner generators, and use of cleaner fuels.

¹A detailed discussion of short-lived climate forcers, and sources of emissions can be found in the The Impact of Short-Lived Pollutants on Arctic Climate (State of Science), prepared for AMAP (AMAP Technical Report No.1 (2008)).

²See Annex I for detailed information on emissions sources and magnitude.

³The global warming potential (GWP) of a gas is a measure of how much a certain quantity of that gas is expected to contribute to global warming when compared to carbon dioxide.

⁴IPCC has not given GWP values for aerosols and ozone precursors. However, this paper draws on GWPs derived from individual sources. Twenty-year GWPs are much higher than the 100 year GWPs usually used. Specific 20 year GWPs used for each pollutant are located in Table 2, found on page 4 below.

⁵Northern Asia is defined as areas north of 40 degrees latitude - Mongolia, North Korea, and the northern 1/3 to 1/4 of China (areas north of Beijing).

- Reduce NMVOCs emissions by adopting industrial process capture and incineration systems, reducing consumer product emissions and installing solvent recovery systems.

Methane: Although a short-lived forcer, methane still has a much longer atmospheric lifetime than the other four pollutants discussed above; thus reductions made anywhere can have significant Arctic benefits. With this in mind, Arctic nations should strongly consider additional and substantial means above and beyond Kyoto and post-Kyoto commitments to reduce methane emissions worldwide, focusing on the following measures:

- Reduce methane emissions through coal mine degasification and mine ventilation air capture.

- Reduce emissions from natural gas systems through leak reduction activities, replacement of high-bleed pneumatic devices, and enhanced inspection and maintenance programs.
- Reduce emissions through improved agricultural practices and use anaerobic digesters to process manure and efficiently use the products.
- Reduce emissions by adopting solid waste management activities to capture and flare or, preferably, productively use landfill gas.
- Reduce emissions by improving wastewater treatment practices.

II. Key Mitigation Assumptions from 'State of Science' Paper

The following conclusions from the "State of Science" paper⁶ underlie the mitigation recommendations that follow in Sections III and IV:

1. Arctic stabilization entails slowing not only warming, but also melting since reductions in the length and magnitude of the melt season are needed to best protect the integrity of Arctic snow and ice. This also means that some mitigation measures can be seasonal in nature.
2. As outlined above, this study largely focuses on measures that reduce BC and ozone precursor emissions (CO, NO_x and VOCs) above 40 degrees latitude, and on global methane emissions.
3. In contrast to global climate stabilization, Arctic stabilization requires near-term measures of effectiveness. Global Warming Potentials (GWPs) in CO₂ equivalents (CO₂e) typically compare impacts over a one hundred year period (GWP100). The practice of using a GWP100, however, severely undervalues the necessary and immediate Arctic benefits of reducing short-lived forcing pollutants. Table 1 shows the lifetime of the key Arctic climate forcers, highlighting the different impacts of short-lived pollutants:

For Arctic stabilization, a GWP of 20 years (GWP20) will more accurately measure the needed impact of mitigation. Table 2 compares 100 year and 20 year GWPs for the short-lived climate forcers. Table 3 shows the global magnitude of emissions compared with the overall forcing effect of

Table 1: Pollutant Lifetime and Distribution

Pollutant	Lifetime	N/40 Reduction Impacts in Arctic	Global Reduction Impacts
BC	~ several days	These sources can cause atmospheric warming and can deposit within the Arctic, causing snow/ice melting	These sources can cause atmospheric warming that affects the Arctic
O ₃ (Formed from NO _x , NMVOC, CO & CH ₄)	~ O ₃ lifetime is weeks to a month – 1 to 2 weeks in the summer, and 1 to 2 months in the winter. Precursor lifetimes vary.	Reduces ozone transport into the Arctic	Northern hemisphere ozone warming affects global climate system, including the Arctic,
Methane	~ 9 years	Not geographically relevant to Arctic warming	Affects the Arctic wherever emitted

those emissions in GWP20. These 20-year figures demonstrate the dominance of short-lived forcers in near-term warming:

4. NO_x has a complex impact on the climate system. It serves as a significant ozone precursor, but also shortens the lifetime of methane, which has a cooling effect. These dual impacts raise the issue of whether reducing NO_x emissions will benefit the Arctic climate. Nevertheless, this study assumes that pursuing a balanced ozone reduction strategy, one that includes NO_x, VOCs and CO, together with significant methane reductions will benefit the Arctic climate. Such a strategy would favor the short-term benefits of ozone reduction over the longer-term negative impact from increased life of methane.

⁶The AMAP "State of Science Paper" (AMAP Technical Report No.1 (2008)) provides an in-depth discussion of characteristics and the Arctic impacts of the short-lived climate forcers.

Table 2: Global Warming Potential of Arctic Climate Forcers

Pollutant	100 year GWP	20 year GWP
BC ⁷	680	2,000
Methane ⁸	25	72
NO _x ⁹	1	1
NMVOCs ¹⁰ (range: 1.1-6.2)	3.65	10.95
CO ¹⁰ (range: 1-3)	2	6

Table 3: Absolute and Weighted Anthropogenic Emissions of Short-Lived Climate Forcers¹¹

Pollutant	Absolute Emissions (as of 2000, in Tera-grams)	20 Year CO ₂ e
Black carbon (1996)	5	10,000
CO	549	3,294
Methane	287	20,664
NMVOOC	140	1,540
NO _x	102	102
Totals	1,083	35,600

5. All BC sources emit a combination of BC and organic carbon aerosols (OC) that reflect sunlight due to their light color, and thus have a cooling effect. Measures available to reduce BC emissions typically also reduce OC emissions from the same source. BC reduction measures described in this paper focus on those sources where the ratio of BC to OC is such that reductions from that source will cool the Arctic climate. For some sources such as boreal forest fires, climate impact of fires remains unclear. For other sources such as emissions from ship-

ping, reductions may actually result in atmospheric warming due to higher OC; yet the BC emitted may deposit on Arctic snow or ice at a sensitive time period and induce melting, which would still indicate a benefit from its reduction.

- Some sources may emit multiple short-lived pollutants, with varying effects. For the shipping example noted above, ship stacks also emit ozone precursors that could result in local ozone formation, as shipping routes open up in the summer months. This could indicate benefits from targeted seasonal reductions.
- We have not addressed additional, potentially significant sources of BC for which BC measurements do not yet exist (for example, home heating with oil). These also require immediate exploration because, if found to be significant, BC reductions could occur relatively easily. In addition, while we have used the best available BC emissions and mitigation information, we anticipate improved BC emissions inventories and future emissions projections from Dr. Tami Bond in the fall of 2008, which should better identify opportunities for plausible reductions. Also, for both black carbon and tropospheric ozone efforts, continuing modeling and measurement work will better identify specific emissions sources and seasons to target for reductions.

Table 4 below summarizes relevant climate and non-climate properties and characteristics of each of the five pollutants targeted in this paper.

Table 4: Summary of Arctic Forcer Impacts, Sources and Potential Reductions

	Black Carbon	Methane	Nitrogen Oxides (NO_x)	Non-Methane Volatile Organic Compounds (NMVOCs)	Carbon Monoxide
Pollutant Description	A form of particulate air pollution from incomplete combustion, often referred to as soot. It is a type of aerosol.	A colorless, odorless greenhouse gas emitted from anaerobic decomposition of organic material or fugitive emissions of natural gas.	NO _x is the common term for several highly reactive gases containing nitrogen and oxygen in varying amounts formed in the combustion process.	NMVOCs are organic compounds that differ in their chemical composition and contribute to the formation of ozone and other photochemical oxidants in the atmosphere.	CO is a colorless and odorless gas produced during the partial combustion of carbon-containing compounds.
Major Identified Sources	Biomass burning, residential cooking or heating with coal or biomass, diesel exhaust, certain industrial facilities.	Solid waste landfills, natural gas systems, enteric fermentation, coal mining, wastewater treatment, rice cultivation, iron and steel production.	Fossil fuel combustion (transportation, power generation, etc.), wildfires, industrial processes.	Combustion of fossil fuels, consumer products (paints, solvents), industrial processes and fuel storage (fugitive emissions).	Mobile sources, biomass burning, residential cooking and heating, iron and steel production.
Major Geographic Sources	Asia, Africa, India, Russia, North America, EU	East Asia, South Asia, Latin America, U.S. and the former USSR.	U.S., East Asia (China), Africa (forest fires), shipping lanes.	Africa & Latin America (wildfires), former USSR and the U.S.	U.S., Asia, Africa, and Latin America.

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⁷Bond, T. and Haolin, Sun. "Can Reducing Black Carbon Emissions Counteract Global Warming?" ES&T, August 2005. p. 5921.

⁸Forster, P., V. Ramaswamy, et al. 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

⁹Baum, Ellen. Clean Air Task Force. July 2008.

¹⁰Prather, Michael. "Climate Change Impacts of the Non-Kyoto Greenhouse Gas and Aerosols." Presentation to CARB. 28 June 2008.

¹¹See Annex I, page 3, for information on emissions inventory sources.

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	Black Carbon	Methane	Nitrogen Oxides (NO_x)	Non-Methane Volatile Organic Compounds (NMVOCs)	Carbon Monoxide
Atmospheric and Climate Behavior	BC is an "absorbing" aerosol and thus absorbs sunlight and transfers it to the atmosphere as heat. When deposited on snow and ice, it reduces surface albedo and accelerates melting.	Potent GHG and contributor to ozone formation. Methane is removed from the atmosphere by reacting with hydroxyl radicals (OH).	Contributes to higher tropospheric ozone formation when NO _x , VOCs, CO, and methane react in the presence of sunlight. Also through production of the hydroxyl radical shortens the lifetime of methane. Nitrate aerosols are a reflecting aerosol.	NMVOCs contribute to ozone formation	CO is a contributor to ozone. Reductions in CO reactions reduce methane lifetime through reduced competition for hydroxyl (OH) radicals in the atmosphere.
Warming Potential/Melting Effect	Could be as high as 60% of the current warming effect of CO ₂ . Estimated 20-year GWP for BC is 2000. When deposited on snow or ice can cause melting.	72 times more potent as a greenhouse gas than CO ₂ on a 20-year basis. Methane represents 9% of total GHG emissions.	A GWP for NO _x has not been derived, but is likely to be climate neutral due to its complex atmospheric chemistry.	Estimated 20 year GWP is about 11.	Estimated 20 year GWP is 6.
Climate benefits of reductions	Affects regional climate impacts through changes in surface radiation, cloudiness, and precipitation. Global cooling from reduced atmospheric warming. Reduced deposition to snow and ice can potentially slow melting.	Because methane has a relatively long atmospheric lifetime (compared to other ozone precursors) of about 8-10 years, it is well mixed in the atmosphere. World-wide reductions would reduce radiative forcing globally. Reducing methane also reduces tropospheric ozone concentrations everywhere (global surface O ₃ responds fairly linearly to changes in CH ₄) – which will reduce radiative forcing – providing additional climate benefits.	Reducing NO _x can help reduce tropospheric ozone concentrations.	NMVOC reductions help reduce ozone concentrations.	Can help reduce tropospheric ozone concentrations. Reductions can result in short lifetime of methane.
Non-climate Co-Benefits	Inhalation from smoke, indoor cooking/heating and diesel exhaust have significant health impacts. The World Health Organization has estimated that indoor exposures to particulate matter lead to an estimated 2.5 million deaths each year in rural and urban developing countries.	Ozone concentration reductions resulting from reduced methane emissions have health and non-climate environmental benefits.	Reductions improve the health of human respiratory systems, vegetation and ecosystems.	Reductions improve respiratory health.	CO reduces the amount of oxygen carried by red blood cells, which results in inadequate blood supply to the brain, nervous tissues, heart, and other organs.
Climate Disbenefits from reductions	BC is co-emitted with other aerosols, some of which have a cooling effect. Some reduction measures like diesel particulate filters can increase CO ₂ emissions by reducing fuel efficiency.	No disbenefit.	NO _x produces the OH radical - an atmospheric sink for methane and CO. Some NO _x is transformed to nitrates – a reflective, cooling aerosol	No disbenefit.	No disbenefit.
Regions where reductions will have significant Arctic benefits	Northern Europe, Northern Asia, and North America will have the greatest Arctic benefits as these regions contribute most to BC that is deposited to snow and ice. Reductions south of 40 degrees can reduce global warming, which will also reduce Arctic warming.	Global, since methane is well-mixed in the atmosphere.	Europe, the U.S., Canada and China.	Former USSR, U.S., Europe, Canada and China.	U.S., China, & former USSR are likely to achieve the greatest benefits.

III. Emissions Reduction Opportunities

Many “north of 40” governments already have made substantial efforts to reduce the pollutants identified above for air quality and climate purposes and to evaluate the potential for deep additional reductions of these pollutants. This paper draws upon much relevant information gathered from this collected work.

The air quality regulation community previously has carried out a number of particulate and tropospheric ozone concentration reduction efforts, so reduction information for these pollutants reflects the varying economic cost-benefit frameworks already adopted by this community (with benefits primarily defined as health improvements).

In contrast, most work exploring methane emissions reductions has occurred within the climate

community and typically reflects the standard “100 year” GWP economic framework. Both frameworks could significantly undervalue the relatively immediate climate benefits of reductions and in particular, their Arctic climate stabilization benefits.

The remainder of this paper summarizes the body of knowledge about reducing short-lived Arctic climate forcers, to allow more easy comparison of forcers and reduction opportunities. It attempts to identify the most important source categories and associated emissions reduction measures for reducing Arctic climate pollutants by considering the magnitude of specific emissions sources, their specific Arctic benefits, and geographic areas where emissions reductions will have the greatest Arctic climate benefits.

Table 5 below summarizes and discusses major emissions reduction opportunities for each pollutant by source groups and associated reductions measures.

Table 5: Major Emissions Reduction Opportunity Areas

Major Source Group Targets	Associated Measures	Comments
Black Carbon		
Diesel combustion	<p>BC can be reduced by transitioning to ULSD fuel and requiring high-efficiency diesel particulate traps on new diesel engines or retrofitting with particle traps on existing engines.</p> <p>Some potential may exist to develop medium efficiency particle traps that can function on conventional, higher sulfur diesel fuel.</p>	<p>ULSD and new engine particulate traps are in the process of being required for all new mobile sources in the US, Canada and the EU. The US and EU are exploring programs to retrofit some existing diesel engines.</p> <p>Transitioning to ULSD reduces sulfur emissions from diesel combustion and associated sulfate reflective (cooling) aerosol production. Particulate traps can reduce fuel efficiency and thus increase CO₂ emissions. However, net climate benefits are believed to be beneficial for many decades after installing particle traps.</p> <p>Specifics of opportunities and challenges to reducing diesel BC emissions in developing countries will vary greatly among these countries.</p>
Residential cooking and heating with biomass or coal – about half the world’s households today use biomass or coal in simple stoves for cooking and heating. These sources are primarily in Africa and Asia.	<p>Technology exists to reduce or eliminate BC emissions from the household energy sector – through more efficient stoves or by transitioning to clean fuels like propane, natural gas or, depending on the source, electricity.</p>	<p>Considerable experience in attempting to transition households to clean stove technology exists – which to date has largely demonstrated that:</p> <ul style="list-style-type: none"> a. Many cultural and infrastructure constraints exist; and b. Conditions that must be considered in designing effective “transition” programs will vary across countries and cultures, suggesting that practical emissions reduction solutions will require many, narrowly targeted programs. <p>The health benefits of transitioning to cleaner household energy will be enormous – particularly to women and children. These transitions will also reduce CO emissions.</p>
Agricultural burning.	<p>Alternative agriculture practices, community fire management programs, production of biochar and regulation in some countries have some potential to reduce agricultural burning.</p>	<p>Cultures and their agricultural practices of conducting agricultural burning vary greatly – suggesting that practical emissions reduction solutions will require many, narrowly targeted programs.</p> <p>Work remains to be done to explore effective programs to reduce agricultural burning.</p> <p>Reductions in agricultural burning will also reduce CO emissions.</p> <p>Biochar production is an important emerging technology, but is not yet commercially available.</p>

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Industrial facilities.	Certain industrial facilities – including stoker coal boilers, coke ovens, blast furnaces and brick kilns – primarily in developing countries and the former Soviet Union <i>may</i> be significant sources of BC emissions. Emissions control technologies, capture and use of blast furnace gas and modern processes can reduce BC emissions to low levels from these sources.	Additional work is needed to assess confidence in the presence and magnitude of these sources and practical emissions reduction opportunities at such facilities.
Methane		
Coal mining.	Practices for removing most methane from coal seams before mining occurs have been commercially demonstrated. Equipment exists that can remove most methane from coal mine ventilation air. The application of these practices/ technology can reduce methane emissions from coal mining to very low levels.	The amount of methane in coal seams varies greatly. The capability to apply effective coal seam methane degasification may be limited in certain countries. Institutional obstacles may exist to coal seam degasification in some countries.
Natural gas and oil production	Many specific practices and technologies are available that can reduce methane emissions from oil and natural gas production	Practices to reduce methane emissions from natural gas production have been expanding recently as the value of captured methane increases and as concern about corporate GHG emissions increases. The U.S. EPA has done much work on methane emissions reduction practices in this area to support EPA's Natural GasStar program.
Natural gas energy systems	Many specific practices and technologies are available that can reduce methane emissions from natural gas energy systems (see some examples in Annex).	Practices to reduce methane emissions from natural gas energy systems have been expanding recently as the value of captured methane increases.
Solid waste landfilling	Technology exists to capture and either flare or productively utilize landfill gas (LFG). This technology has been widely applied in developed countries. Opportunities may exist to substantially increase the fraction of LFG recovered from landfills by advanced leak detection and termination activities. Opportunities also exist to shift solid waste management practices from landfilling to incineration with adequate environmental controls.	
Wastewater treatment	Technology exists to treat wastewater and reduce associated methane emissions. Some improvements can be made to certain existing treatment systems to reduce future emissions from this source.	More work needs to be done to better understand emissions reduction opportunities from this major source.
Animal manure	Methane emissions from this source can be reduced either by anaerobic digesters or by processing manure to produce biochar.	Conditions influencing effective design of programs to install these technologies vary greatly among countries, agricultural practices and cultures. Biochar production is an important emerging technology, but is not yet commercially available.
Enteric fermentation	While this is a large methane source, reduction measures may be limited to certain developed country animal production activities.	
Rice cultivation	Alternative cultivation practices can reduce methane emissions.	Rice cultivation and associated methane emissions have not been increasing. Changing farmer cultivation practices has proven challenging.
Carbon Monoxide		
Mobile source gasoline engines.	Exhaust catalysts can reduce CO emission by >85%.	Can also reduce NMVOC and NO _x emissions.
Iron and steel production	Emissions reduction can be achieved through capture and reuse of byproduct streams.	The fuel value of the CO can help make these measures cost-effective.
NO_x		
Large industrial boilers, power plants and large marine propulsion systems.	Several technologies are available including selective catalytic converters and selective non-catalytic converters systems that can reduce NO _x emissions. Less expensive combustion control technologies are available that can moderately reduce NO _x emissions.	Marine shipping is a major source of global NO _x emissions (about 15%). Regulation has been an effective approach to installing NO _x controls in developed countries.

IV. Summary of the Best Mitigation Options

Using a ranking system that can be found in Annex 2¹², the following options emerge as the most promising mitigation efforts.

Reductions of **black carbon and most ozone precursor emissions** north of 40 degrees latitude (i.e., northern Asia, Europe, Canada and parts of the U.S.) are a priority as they can impact forcing and ice/snow melt within the Arctic, and they can be controlled by Arctic Council member nations:

- Reduce BC emissions by adopting diesel particulate control measures (ULSD fuel plus diesel particulate traps)
 - GWP: Significant climate response; has a direct melting impact due to soot deposits on ice.
 - Magnitude: Significant, especially in near-Arctic (Eastern Europe and northern Asia)
 - Technical Feasibility: ULSD requirements have already been adopted in North America and Europe.
 - Costs: Moderate; will be challenging in northern Asia.
 - Implementation Issues: Willingness to address long-established fuel usage practices and enforcement issues along with cost constraints.
- Reduce BC emissions through effective improvements in household energy technology in Eastern Europe (and if at all possible northern Asia)
 - GWP: Significant climate response; has a direct melting impact.
 - Magnitude: Significant, especially in near-Arctic (Eastern Europe and northern Asia).
 - Technical Feasibility: Cleaner and alternative fuel stoves have been demonstrated and are readily available.
 - Costs: Moderate, costs are low for most measures, but dissemination program costs are quite high.
 - Implementation Issues: Willingness to address long-established home energy-use practices and cost constraints.
- Reduce BC (and some CO) emissions by reducing and/or changing the timing of agricultural burning in Europe and northern Asia and converting to biochar production and utilization.
 - GWP: Moderate climate response, but significant direct melting impact especially in the spring when soot is deposited on ice.
 - Magnitude: Significant, especially in near-Arctic (Eastern Europe and northern Asia).

- Technical Feasibility: Well-established burning management programs. Biochar technology is not yet commercially available.
 - Costs: Relatively low (education and enforcement funding).
 - Implementation Issues: Willingness to address long-established practices and enforcement issues.
- Reduce CO, NO_x, and NMVOC emissions (O₃ precursors) by adopting vehicle and fuel storage emissions control measures (exhaust catalysts, vehicle inspection and maintenance, addition of oxygen containing compounds to gasoline, etc.).
 - GWP: Low to moderate climate response.
 - Magnitude: Moderate.
 - Technical Feasibility: Oxidation catalysts and other techniques are well-established in industrialized countries.
 - Costs: Moderate, industrialized countries have already applied regulations/control technologies.
 - Implementation Issues: Moderate, costs for retrofitting/controlling emissions from existing vehicles can be high.

Arctic nations should focus also on measures/policies to support worldwide methane reductions.

Mitigation options include the following:

- Reduce methane emissions through coal mine degasification and mine ventilation air capture.
 - GWP: Significant.
 - Magnitude: Significant, methane is the largest climate forcer of the pollutants reviewed.
 - Technical Feasibility: Core technology has been demonstrated and is readily available; however, coal seam degasification capability may be limited.
 - Costs: Moderate, most applications are economic.
 - Implementation Issues: Moderate, legal and energy market issues may hinder its application.
- Reduce emissions from natural gas systems through leak reduction activities, including options including replacing high-bleed pneumatic devices, and enhanced inspection and maintenance programs.
 - GWP: Significant.
 - Magnitude: Significant.
 - Technical Feasibility: Demonstrated and readily available in most countries.
 - Costs: Low or even negative based on the high value of recovered gas
 - Implementation Issues: Moderate, inefficient energy markets and other constraints.

¹²Table 2: Weighted Ranking of Mitigation Options is found in Annex 2, on pages 12-14.

V. Issues for Discussion

As the seriousness of Arctic warming and necessity for quick action have become apparent, focus has turned towards targeting mitigation options that might achieve both near-term and significant results. Reducing short-lived climate forcers such as black carbon, methane, and tropospheric ozone would achieve these near-term climate benefits by slowing warming and melting, and as a result “buy time” while the longer-term benefits of CO₂ reductions take effect. The mitigation options listed in this paper should serve as a starting point for discussion at the AMAP meeting on non-CO₂ Drivers in Oslo, Norway on September 15-16th, 2008. Goals of the upcoming meeting are to refine and/or add to the mitigation options listed above, and to receive insights into what is the best framework to go about further implementing promising mitigation strate-

gies. A brief, but not conclusive list of questions for the mitigation break-out group to address includes:

- Are there additional mitigation options to pursue?
- Which are the areas in which the greatest potential for reductions still exists, i.e., what are Arctic Council member nations already doing in the identified mitigation options to control these short-lived pollutants?
- Where do gaps exist for which existing technologies could be readily deployed to achieve reductions?
- In which areas is more information needed, including short-lived pollutant impacts, technical feasibility of certain options, etc.?

Answers to these questions will then drive discussion on the next steps, i.e., what are the best mechanisms to achieve significant, near-term reductions in Arctic climate forcers?

Annex I: Additional Figures on Emissions Sources, Amounts and Impacts:

This Annex provides summary figures with additional information on Arctic forcing emissions, such as sources, magnitude of emissions by source and country and/or region and how sources in varying geographic areas have different Arctic climate impacts.

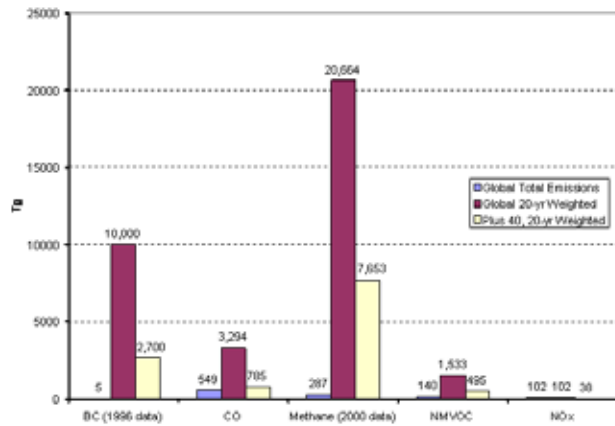


Figure 1. Anthropogenic Arctic Forcer Emissions, 20 year GWP

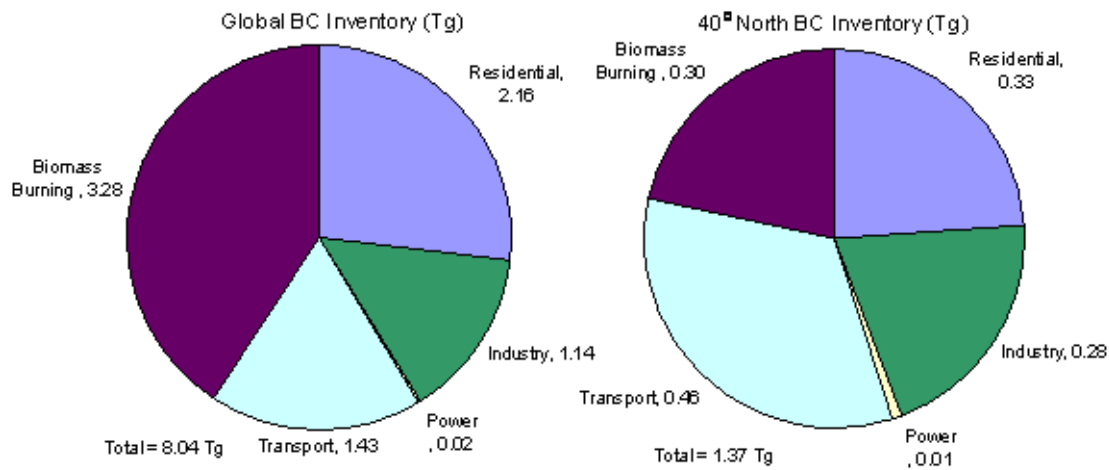


Figure 2. Black Carbon: Global and Plus 40° BC Inventories

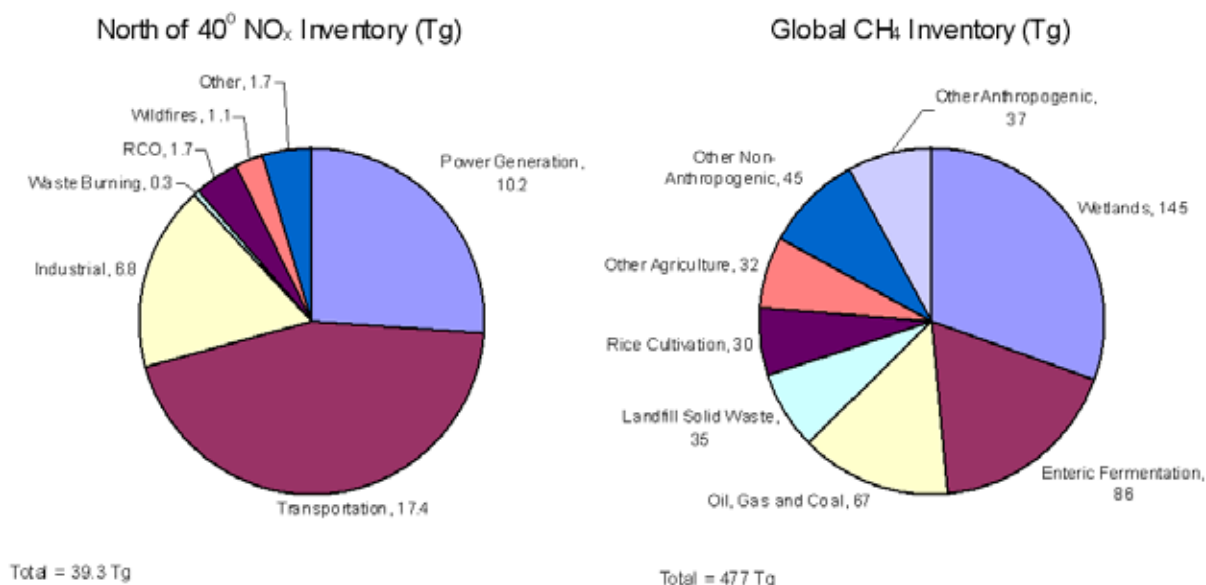
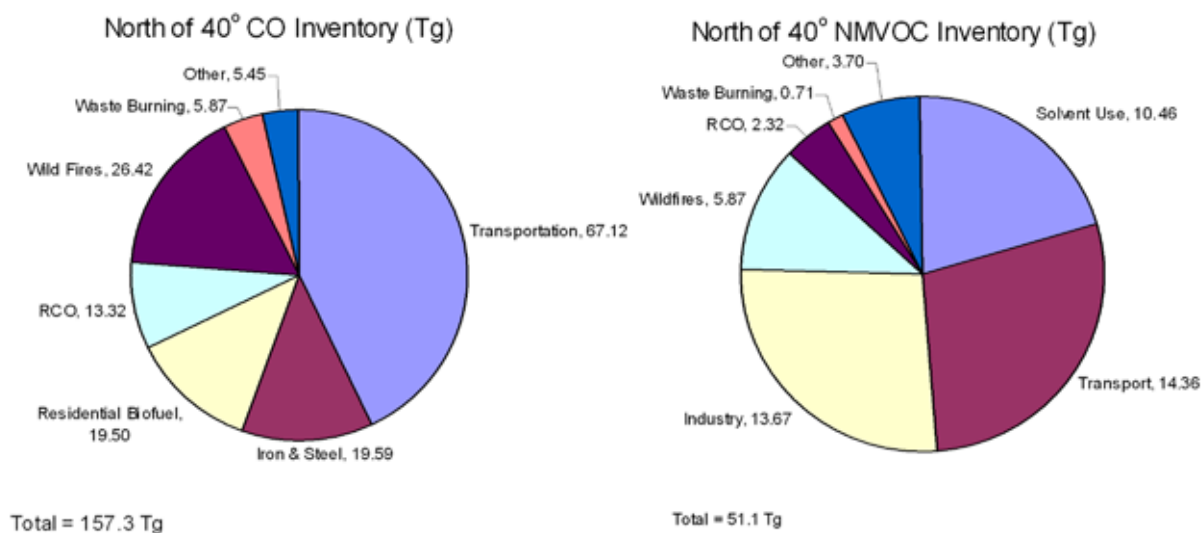
Figure 3. NO_x and Methane (CH₄): North of 40° Inventories

Figure 4. CO and NMVOC: North of 40° Inventories

Figures 5 through 10 below provide more detail from IIASA's EDGAR inventories on total worldwide emissions of BC and methane; and of north of 40° latitude emissions for CO, BC, NO_x and NMVOCs.

For worldwide methane emissions (Figure 5), the largest sources overall are from enteric fermentation, gas production, wild fires, and rice cultivation.

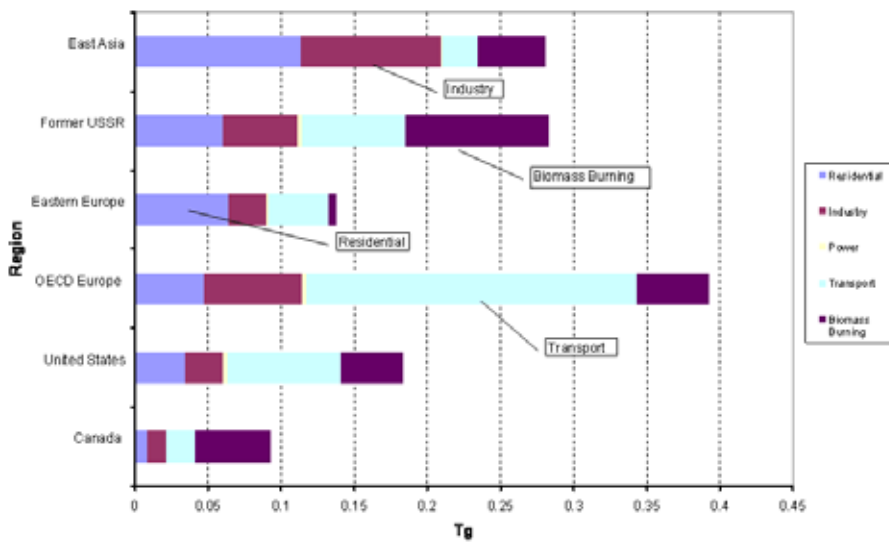
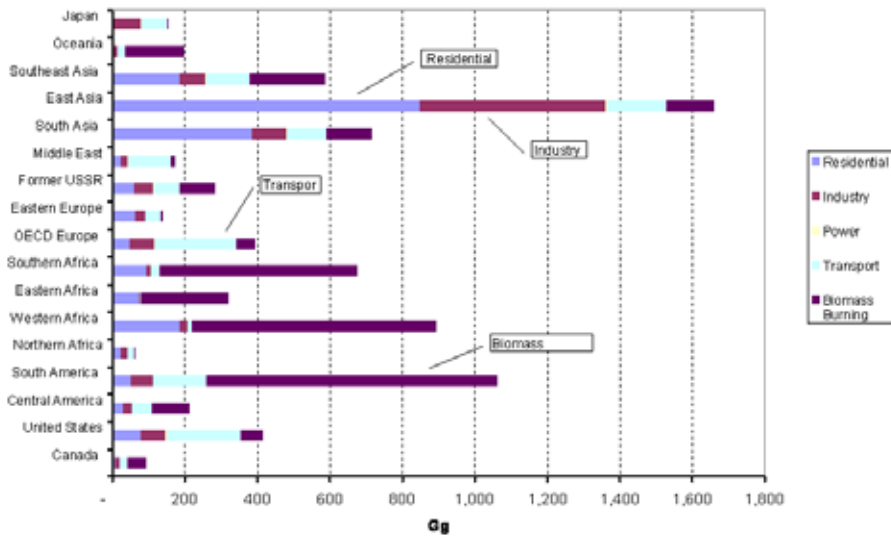
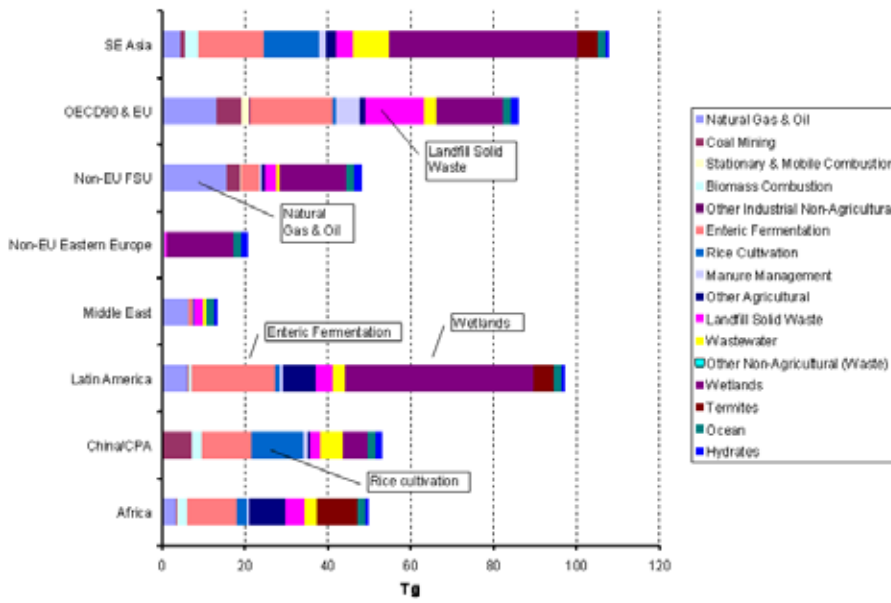
Figure 6 shows worldwide BC emissions, with the largest sources biomass burning, residential energy use, and the transport sector.

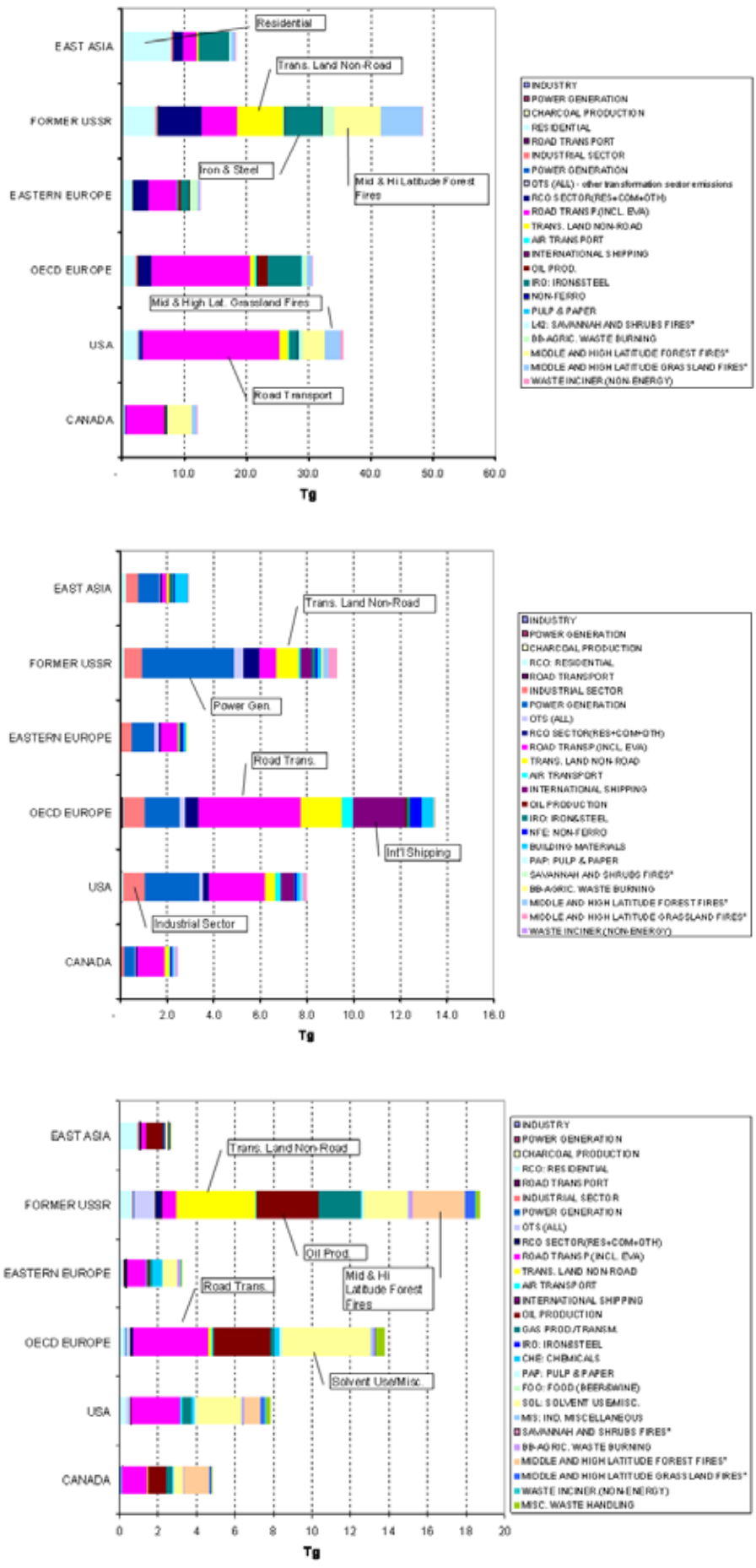
The largest sources north of 40° latitude come from transportation, residential energy use, and biomass burning (Figure 7).

Figure 8 shows north of 40° latitude CO emissions, with the largest sources from road transportation, iron and steel production, and residential energy use. The emissions from iron and steel primarily arise from iron making processes, including coking and blast furnaces. Residential emissions come largely from residential biomass (wood and coal) burning for home heating.

Figure 9 shows NO_x emissions north of 40° latitude, primarily from power generation, road transportation, and non-road transportation.

Figure 10 shows north of 40° NMVOC emissions, with the largest sources from solvent use, road transportation, and oil production.





Figures 5 through 10: A Summary of Edgar Inventories

Annex 2: A Possible Ranking Methodology

A ranking methodology like that outlined in this annex could be used to further prioritize activities and to develop a full supply curve of mitigation opportunities.

- Technical feasibility
- Political feasibility
- Cost

Ranking Mitigation Opportunities:

Mitigation opportunities reflect major emissions sources and associated emissions reduction measures. This below methodology could be used further to develop priority mitigation through a weighted ranking analysis, shown in the table below. This structure evaluates each mitigation option on the basis of several criteria. The criteria proposed here would include:

- GWP
- Magnitude of emissions

Each criterion is given a weighting factor, with 5 being the most important and 1 the least important. Each option is ranked on a scale of 1 through 5 for each criterion with 5 being the best and 1 being the worst. The score for each option is the sum of the scores for each criterion multiplied by the weighting factor for each criterion. The criteria, weights and scores in Table 8 are an example of how this approach can be applied, however, they are offered as an example that can be modified based on further input, research and analysis.

Table 8. Weighted Ranking of Mitigation Opportunities (Rated by importance value with 1=worst and 5=best)

	Global Warming Potential	Magnitude of Emissions	Technical Feasibility	Political/Institutional Feasibility	Cost	Weighted Total
Weighting Factor	5	4	5	4	2	
	Pollutant GWP	Magnitude of current or projected emissions	Is the measure demonstrated and readily available?	Will political or institutional factors significantly limit applicability?.	Measure cost (\$/ton)	
Selected Mitigation Options (currently not listed in order of importance)						
Coal mine degasification and mine ventilation air capture (methane)	4	4	5	4	5	87
High	Large anthropogenic source for methane (8%)	Core technology is demonstrated and readily available; recent advanced coal seam degasification capability may be limited.	Various political issues may constrain rapid deployment of coal seam degasification – typically involving state oil/gas/coal company politics and legal issues. Inefficient energy markets in some countries pose some constraints.	Most applications should be economic.		
Reduction of emissions from natural gas systems (leak reduction, etc.) (methane)	4	4	5	4	5	87
High	Largest anthropogenic source (18%) globally and "North of 40".	Demonstrated and readily available in most countries. Lack of controls knowledge may be a constraint in some countries.	Inefficient energy markets in some countries pose constraints.	Cost is low or even negative for many options due to the high value of recovered gas.		

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	Global Warming Potential	Magnitude of Emissions	Technical Feasibility	Political/Institutional Feasibility	Cost	Weighted Total
Collection and flaring or utilization of landfill gas; or incineration of solid wastes instead of landfilling. (methane)	4	4	5	4	5	87
	High	LFG is a large fraction of global/ North of 40 anthropogenic emissions and the second largest US.	Demonstrated and readily available.	Landfilling and LFG capture costs in developing countries are a constraint.	Negative cost for many measures due to climbing natural gas value.	
Diesel emissions control strategies (ultra low-sulfur diesel –ULSD - fuels and particulate traps). (black carbon)	5	4	4	4	4	85
	Very high. Highest for sources that deposit within the Arctic.	Major contributor north of 40°	Demonstrated and readily available – required for new vehicles in the US, Canada and portions of the EU	Transition to ULSD may be challenging in developing countries	Low to very low-cost using a 20-year GWP. Absolute costs can be substantial – which could constrain use in developing countries.	