Chapter 11

Mitigation Approaches for Open Biomass Burning

11.1 Summary of Key Messages

- Open biomass burning is the largest source of BC emissions globally, affecting 340 million hectares/year. However, total emissions of OC are seven times higher than total BC emissions from this sector, and better and more complete emissions inventory data are needed to characterize the impacts of open biomass burning and evaluate the effectiveness of mitigation measures for reducing BC emissions.
  - Wildfires account for a large portion of BC emissions from open biomass burning: in the United States, for example, wildfires account for 68% of BC emissions from open biomass burning.
  - The regions of the world responsible for the majority of BC emissions from open biomass burning are Africa, Asia, and South America, with significant contributions from Russia/Central Asia and North America. There is large interannual and regional variability in these emissions.
  - BC emissions from open biomass burning (predominately from widespread agricultural burning and large wildfires occurring in the northern latitudes) have been tied to reduced snow and ice albedo in the Arctic.
- Certain emissions reductions techniques may yield reductions in BC emissions from open biomass burning; however, most of these techniques were developed to reduce total $PM_{2.5}$ emissions from fires and there is still substantial uncertainty about their effectiveness for reducing BC emissions specifically, especially given diverse, site-specific burning conditions.
- Appropriate mitigation measures depend on the timing and location of burning, resource management objectives, vegetation type, and available resources. It is important to note that fire plays an important ecological role in many ecosystems, and prescribed burning is one of the basic tools utilized to achieve multiple land-management objectives in fire-dependent ecosystems.
- Expanded wildfire prevention efforts may help to reduce BC emissions from wildfire both domestically and globally. Successful implementation of mitigation approaches in world regions where biomass burning is widespread will require training in proper burning techniques and tools to ensure effective use of prescribed fire.

11.2 Introduction

This chapter presents currently available information regarding mitigation efforts and techniques that may help reduce particle emissions from open biomass burning (agricultural burning, prescribed burning, and wildfires). The effectiveness of these controls on emissions of BC and OC (including brown carbon) requires further study. In addition, given the importance of planned fire as a land management tool, there are important tradeoffs that must be considered in evaluating mitigation options for open biomass burning.

11.3 Emissions from Open Biomass Burning

Open biomass burning, as discussed in this report, encompasses three main categories of burning: agricultural burning, prescribed burning, and wildfire.[1] Table 11-1 describes each type of open biomass burning, the land types on which they may occur, and examples of typical resource management objectives each burning type is designed to achieve. In some cases, there are slight differences in how these terms apply to domestic and international burning practices.

The Joint Research Centre of the European Commission estimates that 350 million hectares (865 million acres) of land were affected by

[1] Categories of contained biomass combustion, including residential heating and cooking and industrial biomass combustion, are addressed in previous chapters.

Table 11-1. Types of Open Biomass Burning. (U.S. EPA, 1998)

Type of Burning	Description	Land Type	Typical Resource Management Objective(s)
Agricultural	The planned burning of vegetative debris from agricultural operations. (Domestic)	Forestland, cropland, rangeland, grassland, wetlands	Restore and/or maintain fire-dependent ecosystems; control weeds, pests, and disease; manage lands for endangered species; promote various vegetation responses; reduce fuel loading to reduce catastrophic wildfire risk; improve crop yield; control invasive species; facilitate crop rotation; remove crop residue.
	The use of fire as a method of clearing land for agricultural use or pastureland. (International)	Forestland, rangeland, grassland, wetlands	Conversion of land into cropland or pastureland.
Prescribed	The planned burning of vegetation under controlled conditions to accomplish predetermined natural resource management objectives. Conducted within the limits of a fire plan and prescription that describes the acceptable range of weather, moisture, fuel, fire behavior parameters, and the ignition method to achieve the desired effects.	Forestland, rangeland, grassland, wetlands	Restore and/or maintain fire-dependent ecosystems; control weeds, invasive species, pests, and disease; manage lands for endangered species; promote various vegetation responses; reduce fuel loading to reduce catastrophic wildfire risk.
Wildfire	An unplanned wildland fire (such as a fire caused by lightning), unauthorized human-caused fires (such as arson or acts of carelessness by campers), or escaped prescribed burn projects (escaped control due to unforeseen circumstances).	Forestland, rangeland, grassland, wetlands	Fire suppression or other appropriate management response.

fire, worldwide, in 2000 (Food and Agriculture Organization of the United Nations, 2007). However, given the lack of an international standard for fire terminology and the lack of consistent data reporting and collection, it is not possible to distinguish among the fractions of land area that were subject to agricultural versus prescribed burning or wildfire (Food and Agriculture Organization of the United Nations, 2007). Generally, the mass of BC emitted from open biomass burning will depend on the size and duration of the fire, fuel type, fuel conditions, fire phase, and the meteorological conditions on the day of the burn. The emissions estimates presented in Chapter 4 indicate that open biomass burning represents a potentially large, though poorly quantified portion of the U.S. BC emissions inventory. As with the international fire emissions inventories, available data are limited regarding the percentage of land area affected by different types of burning. It is also important to note that emissions of OC are seven times higher than BC emissions from this sector. Preliminary research suggests that the OC fraction may be dominated by BrC, which also absorbs light. More focused research is needed to clarify the composition and quantity of emissions from different types of fires.

As the estimates in Chapter 4 indicate, open biomass burning is the largest BC source in Africa, Central and South America, and Asia, and is one of the largest sources of BC in Russia/Central Asia (the former USSR) and North America. However, there is considerable variation in the type of open burning that dominates in different regions. Fires in sub-Saharan Africa are primarily due to slash-and-burn practices for clearing agricultural sites, burning of crop residues, escaped planned burning, acts of carelessness, and arson (Food and Agriculture Organization of the United Nations, 2007). The primary causes of fire in Central and South America include large-scale conversion of moist tropical forest to rangeland and agriculture, arson, negligence, and hunting (Food and Agriculture Organization of the United Nations, 2007). Available information suggests that the majority of fires in China and other East Asian countries are uncontrolled wildfires, typically caused during land conversion, or by arson and acts of carelessness (Food and Agriculture Organization of the United Nations, 2007). Prescribed burning is used to some degree in China to reduce catastrophic wildfire risk (Morgan, 2009). In India, and other South and Southeast Asian countries, fire emissions stem from agricultural burning, rangeland clearing, escaped planned burning, or acts of carelessness (Food and Agriculture Organization of the United Nations, 2007). Agricultural burning in Kazakhstan, southern Russia, Central and Eastern Europe is a seasonal occurrence, typically starting at the end of April and lasting for a few weeks (Warneke et al., 2009; Stohl et al., 2007). Wildfires in Russia (Siberia) are primarily caused by lightning, escaped planned burning, or acts of carelessness (Food and Agriculture Organization of the United Nations, 2007), and occur from late April throughout the summer (Warneke et al., 2009; Generoso et al., 2007). Russia experiences many smoldering fires in drained or dry peatlands that burn for long periods and produce large quantities of smoke (Food and Agriculture Organization of the United Nations, 2007). In the Far East and southern Siberian portions of Russia, extensive prescribed burning of the grasslands has been used in the spring to reduce highly flammable surface fuels (Food and Agriculture Organization of the United Nations, 2007).

As described in Chapters 2 and 4, there is strong evidence to suggest that emissions from fires in one world region can significantly impact other world regions through transport and deposition processes. Reduced snow and ice albedo, and increased rates of melting in the Arctic, the Himalayas, and other snow- and ice-covered regions of the world are major impacts of BC deposition, with implications for freshwater resources in regions dependent on snow-fed or glacier-fed water systems. Most of the BC that reaches the Arctic has been traced to sources in the Northern mid-latitudes (AMAP, 2009), with open biomass burning as one of the largest of the sources. A primary determinant of the downwind impact of a large fire on snow- and ice-covered regions is the height to which the plume rises (i.e., its injection height). Fire plumes observed by satellite between 1978 and 2009 have shown that more dense wildfire plumes rose to the level of the free troposphere (i.e., 8 km), where long-range transport can occur more readily, over North America than over Australia, or Russia and Northeast Asia (Guan et al., 2010). This difference has been attributed to the type of wildfire that dominates in North America (i.e., boreal crown fires[2] that are large and very high in temperature). In general, between 5 and 28% of the plumes from large wildfires in North America rise into the free troposphere (Val Martin et al., 2010).

Current emissions projections suggest that direct PM emissions from open biomass burning will continue to dominate global BC inventories. In addition, several major climate change science assessments have concluded that large, catastrophic wildfires will likely increase in frequency over the next several decades because of climate warming (Field, 2007; Ryan et al., 2008; Wiedinmyer and Hurteau, 2010; Littell et al., 2010). General climate warming encourages wildfires by extending the summer period that dries fuels and promoting easier ignition and faster spread (Field, 2007). Earlier spring snowmelt has led to longer growing seasons and drought, especially at higher elevations where the increase in wildfire activity has been greatest (Field, 2007). Increased temperature in the future will likely extend fire seasons throughout the western United States, with more wildfires occurring both earlier and later than is currently typical, and will increase the total area burned in some regions (Field, 2007). Within Arctic regions, climate change is expected to shift the treeline northward, with forests replacing a significant portion of land that is currently tundra and tundra vegetation moving into currently unvegetated polar deserts (ACIA, 2004). Changes in Arctic climate are also expected to increase the frequency, severity, and duration of wildfires in boreal forests and dry peat lands, particularly after melting of permafrost (Schneider et al., 2007; ACIA, 2004).[3] These climate-related changes in wildfire location, duration, and frequency will affect both BC and OC emissions.

11.4 Fire as a Resource Management Tool

Fires play an important ecological role across the globe, benefiting those plant and animal species that depend upon natural fires for propagation, habitat restoration, and reproduction. Most North American plant communities evolved with recurring fire and are dependent on recurring fire for maintenance. Ecosystem fire regime analysis includes information about the necessary fire return interval which may vary from one to two years for prairies, three to seven years for some long-needle pine species, 30-50 years for species such as California chaparral, and over 100 years for species such as Lodgepole pine and coastal Douglas-fir.

Natural fires also reduce fuel load, unnatural understory, and tree density, helping to reduce the risk of catastrophic wildfires. In many parts of the United States, historical land management practices during the late 19th and early 20th centuries (e.g., fire suppression, logging, and livestock grazing)

[2] Crown fires occur in the tops of trees and are spread more quickly than ground fires. Boreal forests are generally defined as those occurring at high northern latitudes across North America and Eurasia, below the Arctic tundra.

[3] Peat fires are also becoming more common in the lower 48 states, as illustrated by the Evans Road Fire (2008) and Pains Bay Fire (2011), both of which occurred in North Carolina. Peat fires have very high emissions relative to fires involving other types of fuels.

have altered the natural fire regime, changed forest structure, and led to heavy fuel accumulation in forests. This, in turn, has increased the size of wildfires and total area burned (Miller et al., 2009; Noss et al., 2006; Allen et al., 2002; McKelvey and Busse, 1996). Accumulated fuel loads will likely continue to affect the size and frequency of large wildfires in the coming decades.

In the United States, prescribed burning is one of the basic tools relied upon by land owners and managers to achieve multiple management objectives in fire-dependent ecosystems. When one management objective is to maintain a fire-dependent ecosystem, the effects of fire cannot be duplicated by other tools. Prescribed fire can also be used to reduce heavy fuel loads, which has the benefit of helping to prevent catastrophic wildfires.

The following section includes an outline of strategies that can be used for conducting prescribed and agricultural burning in a manner that protects air quality by reducing smoke emissions, and managing burning conditions to protect downwind populations. In addition, the importance of fire prevention is discussed. These methods may also be applied with the goal of reducing BC emissions overall, and/or the goal of reducing downwind deposition of BC on snow and ice. As will be discussed, the techniques listed may be more useful in some ecosystems than in others. Further study is needed to identify appropriate strategies to apply under each circumstance.

11.5 Smoke Mitigation Technologies and Approaches in the United States

Appropriate mitigation of BC from open biomass burning depends on the type, timing, and location of burning and must balance multiple objectives including resource management, climate protection, and health protection. Currently available literature is extremely limited regarding the effectiveness of any given mitigation practice for reducing BC emissions from the three general types of burning. More research is needed to better understand the efficacy, potential unintended consequences, and cumulative effects arising from the implementation of any proposed mitigation techniques.

As a starting point, however, it is appropriate to consider how approaches currently used to manage the air quality impacts of open biomass burning may be applicable to BC. Most U.S. domestic policies and programs at the local, state, and federal level focus on protecting air quality and public health by managing smoke and minimizing PM emissions.

There are two basic approaches that are commonly applied to manage the air quality impacts from open biomass burning: (1) use techniques that reduce the emissions produced for a given area; and/or (2) redistribute the emissions through meteorological scheduling and by sharing the airshed (Ottmar et al., 2001).

One common approach in the United States for limiting the impacts of open biomass burning is the development and application of smoke management programs. The Interim Air Quality Policy on Wildland and Prescribed Fires (U.S. EPA, 1998)[4] recognizes the role fire plays as a resource management tool. The policy addresses wildland and prescribed burning managed for resource benefits on public, tribal, and privately-owned wildlands. The policy integrates two public policy goals: (1) to allow fire to function, as nearly as possible, in its natural role in maintaining healthy wildland ecosystems and, (2) to protect public health and welfare by mitigating the impacts of fire emissions on air quality and visibility. The policy encourages state and tribal authorities to adopt and implement smoke management programs to mitigate the public health and welfare impacts from prescribed fires and promote communication and coordination of prescribed burning among land owners. A smoke management program can be extensive and detailed, or can simply identify basic smoke management practices for minimizing emissions and controlling impacts from a prescribed fire.

Based on regulations, the EPA allows the use of basic smoke management practices in lieu of smoke management programs, where appropriate. The Agency intends to issue guidance on the use of basic smoke management practices in the revised Air Quality Policy on Wildland and Prescribed Fires when it is finalized. Basic smoke management practices could include, among other practices, steps to minimize air pollutant emissions during and after the burn, evaluate dispersion conditions to minimize exposure of sensitive populations, and identify procedures to ensure that burners are using basic smoke management practices. USDA recently issued a technical document outlining some potential basic smoke management practices.[5]

A smoke management program establishes a basic framework of procedures and requirements for

[4] As discussed in EPA's 2007 Final Rule on the Treatment of Data Influenced by Exceptional Events (72 *Federal Register* 13560), the Interim Air Quality Policy on Wildland and Prescribed Fires is currently under revision.

[5] See http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046311.pdf.

planning and managing smoke from prescribed fires. It is typically developed by a state/tribal agency with cooperation and participation by various stakeholders (e.g., public/private land owners/managers, the public). If a state/tribe determines that a smoke management program is needed, they may choose to develop a program using an array of smoke management practices/emissions reduction techniques that they believe will prevent air quality violations and address visibility impairment. A smoke management program can range from a purely voluntary program to a program where prescribed fires are regulated by a permitting authority that analyzes meteorological conditions and air quality considerations and authorizes burning by time of day, fire location/size and anticipated duration. The more-structured program may include enforceable requirements on who may burn and when burning may occur.

The basic elements of a smoke management program include guidelines or requirements regarding authorization to burn, coordination and scheduling, and air quality assessment (U.S. EPA, 1998). In cases where smoke management programs are developed, these generally focus on: (1) actions to minimize emissions (emission reduction techniques); (2) evaluation of predicted smoke dispersion; (3) public notification; (4) contingency measures to reduce exposure; and (5) fire monitoring and plume dispersion characteristics. In addition, smoke management programs frequently lay out guidelines or requirements for recordkeeping and reporting; public education and awareness; surveillance and enforcement; and program evaluation.

In developing a smoke management program, authorities have a number of options available for reducing emissions (e.g., emissions reduction techniques (ERTs)) and managing smoke that can be applied under different circumstances. It is important to note, however, that decisions regarding the appropriate use of different techniques are influenced by a number of considerations—including but not limited to air quality impacts, water quality impacts, Endangered Species Act requirements, and basic resource management objectives. It is also important to note that land managers take safety into consideration when choosing smoke management strategies and ERTs. The following section provides an overview of the current practices employed for mitigating air quality impacts.

11.5.1 Managing Smoke

Many methods for managing smoke, including emissions reduction techniques, may offer the benefits of reduced BC emissions and reduced downwind impacts related to BC deposition on snow and ice, although there are significant uncertainties regarding transport of prescribed fire emissions to the Arctic regions. However, there is still substantial uncertainty about the applicability and effectiveness of these emissions reduction techniques for reducing BC under diverse, site-specific burning conditions. The appropriateness of a given mitigation practice and its effectiveness at reducing $PM_{2.5}$ and/or BC will depend on the type of fuel being burned (e.g., crop residue or forest), the management objectives of the burn, and the seasonal timing and geographic location of the burn. An additional consideration is that open biomass burning occurs on land under various ownership (i.e., federal, state, tribal, and private), which affects management decisions and the types of burning practices implemented on those lands. Currently available literature identifies a number of current fire management practices to address air quality impacts of PM emissions from agricultural and prescribed burning. These practices are listed below.

11.5.1.1 Agricultural Burning PM Mitigation Techniques

- Reduce the number of acres burned
    - Reduce burning through conservation tillage, soil incorporation, or collecting and hauling crop residues to central processing sites (WRAP, 2002).
    - Apply alternate year burning which involves alternating open field burning with various mechanical removal techniques. The period may involve burning every other year or every third year (U.S. EPA, 1992).
- Increase combustion efficiency
    - Use bale/stack for agricultural residue. The bale/stack burning technique is designed to increase the fire efficiency by stacking or baling the fuel before burning. Burning in piles or stacks tends to foster more complete combustion, thereby reducing PM emissions. This control is applicable to field burning where the entire field would be set on fire, and can be applied to all crop types (U.S. EPA, 2005b).
    - Use propane flamers as an alternative to open field burning.

- – Use backing fires ("backburning"). Flaming combustion is cleaner than smoldering combustion. Backburning ensures more fuel is consumed in the flaming phase (Ottmar et al., 2001).

- Reduce fuel loadings
    - – Remove straw/stubble before the burn.

- Change burn timing from early spring to either winter or summer to reduce higher impact of BC on snow/ice. Quinn et al. (2008) suggest that this technique may be especially important for mitigating climate impacts in the Arctic, to reduce springtime deposition when the snow and icepack is large. Applicability of this technique will be limited by the type of crop, the resource objectives sought, and biological and operational constraints.

- Convert Land Use
    - – Convert from a crop that requires burning to a crop that does not.
    - – Convert land to non-agricultural use.

- Educate Farmers
    - – Provide training to farmers on proper burning techniques that reduce emissions.

11.5.1.2 Prescribed Burning PM Mitigation

- Reduce the area burned
    - – Use mosaic burning. Landscapes often contain a variety of fuel types that are non-continuous and vary in fuel moisture content. Prescribed fire prescriptions and lighting patterns can be assigned to use this heterogeneity in fuel and fuel moisture to mimic a natural wildfire and create patches of unburned areas or burn only selected fuels (Ottmar et al., 2001).

- Reduce fuel consumed (Ottmar et al., 2001)
    - – Burn fuel when moisture content is high. Fuel consumption and smoldering can be minimized by burning under conditions of high fuel moisture of duff, litter, and large woody fuels.
    - – Conduct burns before precipitation. Scheduling a prescribed burn before a precipitation event may limit the consumption of large woody material, snags, stumps, and/or organic ground matter.

- Reduce fuel loadings (Ottmar et al., 2001)
    - – Burn outside the growing season, burn after timber harvest, and burn frequently. Prescribed burning at appropriate times can help reduce the size and magnitude of wildfires.
    - – Expand the use of biomass. Harvesting and selling or trading the biomass is one alternative to prescribed burning. Woody biomass can be used in various industries such as pulp and paper, methanol production, and garden bedding. This alternative is most applicable in areas that have large diameter woody biomass and the biomass is plentiful and accessible so as to make biomass utilization economically viable. Small-diameter biomass can be used as posts, poles, or tree stakes. Neary and Zieroth (2007) documented a successful USDA Forest Service project in Arizona to remove and sell small-diameter trees for use in small power plants that burn wood fuel pellets. Biomass can also be pyrolyzed to produce biochar, a fine-grained charcoal, for use as a soil amendment (i.e., to improve physical properties of the soil, such as water retention, permeability, water infiltration, drainage, aeration and structure).[6]
    - – Use other fuel treatments such as mechanical treatments/removal. Mechanical treatments may be appropriate when management objectives are to reduce fuel density to reduce a wildfire hazard, or to remove logging waste materials (slash) to prepare a site for replanting or natural regeneration. On-site chipping or crushing of woody material, removal of slash for off-site burning or biomass utilization, whole tree harvesting, and yarding (pulling out) of unmerchantable material may accomplish these goals. Mechanical treatments are normally limited to accessible areas, terrain that is not excessively rough, slopes of 40% or less, sites that are not wet, areas not designated as national parks or wilderness, areas not protected for threatened and endangered species, and areas without cultural or paleological resources.

[6] See http://www.biochar.org.

  - Use chemical treatments. When the management objective is to preclude, reduce, or remove live vegetation and/or specific plant species from a site, chemical treatments may be appropriate tools. However, other potential environmental impacts caused by applying chemicals must also be considered.

  - Use animal grazers. Increasing grazing by sheep, cattle, or goats before burning on rangelands and other lands can reduce grassy or brushy fuels prior to burning, and can help reduce burn frequency.

- Increase combustion efficiency

  - Use mass-ignition techniques that produce short-duration fires (e.g., aerial ignition). Mass ignition can shorten the duration of the smoldering phase and reduce the amount of fuel consumed. However, mass-ignition may also increase plume rise. Therefore, all methods should be evaluated specifically for BC.

  - Use backing fires (see above).

  - Burn piles or windrows. Fuels concentrated into clean and dry piles or windrows generate greater heat and burn more efficiently.

  - Use air curtain incinerators, which are large metal containers or pits with a powerful fan device to force additional oxygen into the fire, to produce a very hot and efficient fire with very little smoke. Air curtain incinerators offer a useful alternative to current fuel reduction and disposal methods, providing the benefits of producing lower smoke emissions compared to pile or broadcast burning; burning a greater variety, amount, and size of materials from dead to green vegetation; reducing fire risk; operating with fewer restrictions in weather and burn conditions; and containing burn area to a specific site.[7]

- Education for Resource Managers

  - Train resource managers on proper burning techniques to reduce emissions.

Currently available literature is extremely limited regarding the cost of reducing BC emissions from agricultural and prescribed fire. Many of the PM emission reduction techniques described above require substantial infrastructure and resource investment (e.g., roads, machinery, etc.) or the existence of a market for biomass utilization products (e.g., wood pellets or biochar). The availability of the required infrastructure, resources, and markets will vary across the country, making the cost of potential mitigation options highly uncertain and dependent on the technique(s) and the site-specific environmental conditions in which the technique(s) are applied. A recent study (Sarofim, 2010) surveyed currently available literature to develop rough cost estimates for the major categories of PM emission reduction techniques described above (i.e., increase combustion efficiency, reduce fuel consumed, reduce fuel loadings, and reduce the area burned).[8] The authors found that these techniques are on the whole likely to be quite expensive for the amount of BC reduced, although there may be potential for lower cost mitigation approaches in locations where markets for biomass utilization exist.

11.5.2 Fire Prevention Techniques

While wildfires are part of the natural functioning of many ecosystems, increasing fuel loads within the United States over the past century have made wildfires harder to control and more expensive to suppress. In addition, wildfires often pose a dangerous threat to the lives and property of civilians and firefighters. Fire prevention techniques can be effective in helping to prevent unplanned human-caused fires. Wildfire prevention efforts in general can be seen as an important strategy for limiting BC emissions both domestically and globally. A number of studies have discussed the timing and structure of prevention efforts to ensure optimal effectiveness in limiting the extent and severity of wildfires (Prestemon et al., 2010; Butry et al., 2010a; Butry et al., 2010b).

Efforts by the U.S. Forest Service and other resource management agencies are currently underway to turn fire suppression programs into more proactive fire management programs that effectively apply fire prevention and hazardous fuels reduction techniques, extensive public education, and law enforcement (National Interagency Fire Center, 2011).

[7] See *http://www.fs.fed.us/eng/pubs/html/05511303/05511303.html*.

[8] The authors calculated unit emissions reductions of the various mitigation options using emissions factors in tonnes of BC/OC per kilogram of dry matter burned. Because these emissions factors vary according to the particular crop/ecosystem burned and the phase of burning (e.g., flaming or smoldering), there was a range of values each open biomass burning source category. Sarofim et al. (2010) used the median (when multiple data points were available) or the midpoint (when only two data points were available) of the range.

Fire prevention approaches involve a combination of engineering, education, and enforcement.[9] Education strategies often represent low-cost approaches for preventing unplanned fires. Such strategies must include clear planning and communications with regard to subjects such as fire-prone areas where access is closed or restricted; appropriate use of campfires, smoking, and fireworks; and managing the burning of trash and debris. Raising public awareness through education and outreach, including utilizing media such as newspapers, radio, and television, is also important. Such educational campaigns can be highly effective in preventing unwanted fires: the U.S. Forest Service's long-standing Smokey Bear campaign is among the most successful fire prevention awareness and education campaigns ever conducted (National Wildfire Coordinating Group, 2007).

11.6 Mitigation Technologies and Approaches Globally

As discussed in Chapter 2, a number of recent studies have pointed to the importance of reducing international BC emissions from open biomass burning to alleviate effects on the Arctic, the Himalayas, and other key snow and ice-covered regions. Many of the mitigation techniques and approaches described above could also be applied internationally, and such strategies could provide important climate benefits. However, the practical mitigation options available on the ground in different regions are limited for a number of reasons. Critical barriers to implementing mitigation measures internationally fall within three areas: (1) weak governance (e.g., requisite laws and policies at all levels of government to authorize and enforce fire management practices); (2) lack of local capacity (e.g., requisite funding, training, equipment, and human resources to implement fire management); and (3) lack of support infrastructure (e.g., roads and other infrastructure to access rural areas prone to wildfire, monitoring and early warning systems to detect and track fires).

According to the Food and Agriculture Organization of the United Nations (2007), many African countries particularly in sub-Saharan Africa have no central government fire management policy, and there is a widespread lack of support infrastructure, funding, equipment, and adequately trained human resources for fire management. While most countries in Central, South and Southeast Asia have a government fire policy, limited funding resources restrict their ability to establish or maintain effective fire management programs (Food and Agriculture Organization of the United Nations, 2007). According to Morgan (2009), the Association of Southeast Asian Nations instituted a "zero burning" policy in 1999, but it has been largely ineffective. China, Japan, and South Korea have advanced fire detection systems, including the use of remote sensing (Morgan, 2009), but often at the local level, villages and communities lack resources, adequate training, and professional expertise to control large wildfires (Food and Agriculture Organization of the United Nations, 2007). In many countries in South America, illegal burning even on state-protected lands is widespread due to the absence of enforcement and criminal penalties (Food and Agriculture Organization of the United Nations, 2007). Russia has well-defined laws regulating forest burning practices, but lacks strong enforcement (Food and Agriculture Organization of the United Nations, 2007).

Given these challenges, addressing fundamental barriers to implementation may be just as or more important than identifying and promoting more technological forms of mitigation such as specific burning techniques. Capacity-building efforts may include building basic fire management infrastructure, strengthening governance structures to create and enforce fire policies, and developing economic alternatives to slash-and-burn agriculture. In addition, fire prevention efforts may be important for mitigating wildfire globally. Fire prevention education for the general public and training for workers in the agricultural and forestry sectors in the controlled use of fire will also be important.

There is relatively little information regarding costs of open biomass burning mitigation internationally. Mitigation costs will vary according to country, and will likely be higher in developing countries due to more extensive barriers to implementation as described above. These costs will depend on local environmental conditions, ecosystem type, fire management capacity, and support infrastructure. Costs may also vary within individual countries, according to locality, because authority and responsibility for fire management is often decentralized and is left up to local or regional authorities (Food and Agriculture Organization of the United Nations, 2007).

To address the impact of open biomass burning internationally, the United States has recently initiated research efforts and other international cooperative activities to evaluate and reduce BC emissions from open biomass burning in and around

[9] Additional information on each of these strategies is available on the National Wildfire Coordinating Group's publications page at http://www.nwcg.gov/teams/wfewt/products.htm.

the Arctic. The U.S. State Department is coordinating a $5 million Arctic Black Carbon Initiative that will fund a number of activities, including a project by the U.S. Department of Agriculture (USDA) to address biomass burning emissions in Eurasia. USDA's multi-agency program contains the following components (USDA, 2010):

- **Research Activities:** USDA scientists (led by the U.S. Forest Service and Agricultural Research Service) will seek to improve estimation of emissions and transport of BC from agricultural burning and forest fires by quantifying spatial and temporal patterns of these emissions in Eurasia and conducting an assessment of long-range transport of BC from fires in Russia and adjoining regions to the Arctic. The research will identify meteorological conditions and potential source locations for Arctic transport of smoke and analyze agronomic practices in Eurasia to identify opportunities for reduced use of agricultural burning. Initial results from this project are shown in section 4.5 of this report, which discusses long-range transport of emissions. By examining the ability of the atmosphere to transport emissions to the Arctic, the project can identify which source regions are most likely to contribute to emissions transport to the Arctic. One of the benefits of this project is that the results are independent of source type, and therefore applicable beyond biomass burning. Injection height is shown to be critical (see section 4.5 for more detail).

- **Technical Exchange and Other Cooperative Activities:** The U.S. Forest Service and Foreign Agricultural Service will implement technical exchanges and cooperation between U.S. and Russian experts on BC, agricultural burning, and fire management. These efforts will support training activities and the development and implementation of innovative local-level "pilot" programs designed to illustrate strategies and practices that could be more broadly applied to reduce any negative environmental impacts of agricultural and forest fires. Key issues include interagency cooperation on fire management, fire budgets, and GIS and remote sensing. USDA will also facilitate public-private partnerships to develop local-level fire wardens and fire brigades in Russia and outreach to farmers in Russia to increase awareness of approaches to reduce BC emissions from agricultural burning.