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Residential heating with wood and coal: health impacts and policy options in Europe and North America

Report by the Joint[1] Task Force on the Health Aspects of Air Pollution

Summary

The present thematic report by the Joint Task Force on the Health Aspects of Air Pollution was drafted in response to the request of the Executive Body for the Convention on Long-range Transboundary Air Pollution, as set out in the 2014–2015 workplan for the implementation of the Convention (ECE/EB.AIR/122/Add.2, items 1.2.4 and 1.8.1).

The results presented in the report indicate that it will be difficult to tackle outdoor air pollution problems in many parts of the world without addressing the combustion of biomass for heating at the household level along with other sources. To protect health, there is a need for policymakers in regions that have relatively high levels of outdoor air pollution from household heating-related combustion to provide incentives to switch from solid fuel combustion for heating to gas- or electricity-based heating. Given that residential wood combustion for heating will continue in many parts of the world due to economic considerations and the unavailability of other fuels, there is an urgent need to develop and promote the use of lowest emission/best available combustion technologies.

[1] The Task Force is a joint body of the World Health Organization European Centre for Environment and Health and the Executive Body for the Convention on Long-range Transboundary Air Pollution.

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I. Introduction

1. The present report highlights the health impacts and policy options for residential heating with wood and coal in Europe and North America. In particular, it responds to the request of the Executive Body for the Convention on Long-range Transboundary Air Pollution (Air Convention), as set out in the 2014–2015 workplan for the implementation of the Convention (ECE/EB.AIR/122/Add.2, items 1.2.4 and 1.8.1) for thematic reports providing key messages aimed at policymakers, and for updated data on the evidence of the health impacts of ozone and particulate matter.

2. Solid heating fuels used for residential heating consist primarily of wood and coal, but can also include forestry and agricultural residues and even garbage. Most fuels are burned in small-scale combustion devices, such as household heating stoves or small boilers for apartment buildings or district heating. Open fireplaces are popular in many parts of the developed world, but do not actually provide net heating in most circumstances, so they are often characterized as "recreational use" rather than space heating.

3. Currently most burning of solid fuels for space heating is done in devices that incompletely combust the fuel, due to their low combustion temperature and other limitations. This results in relatively high emissions per fuel unit, including many products of incomplete combustion such as fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO), two major air pollutants. Small-scale solid fuel combustion is also an important source of black carbon (BC) emissions. BC is a component of $PM_{2.5}$ that warms the climate. When coal is used for residential heating, it can also result in emissions of sulphur and other toxic contaminants found in some types of coal; even with good combustion, these contaminants are not destroyed.

4. The amount of heating fuel needed in a particular climate is a function of the fuel efficiency of the stove, as well as the characteristics of the housing itself (insulation infiltration, etc.), an issue not addressed in this report. In developed countries, nearly all space heating devices have chimneys. In some developing countries, much space heating is done with open stoves inside the house. In both cases, most of the emissions end up in the atmosphere and contribute to outdoor air pollution, which is the focus of this report.

5. Seasonal space heating with wood is common in mountainous regions of many middle-income and poor countries, Chile and Nepal, for example, and coal is used for space heating in the parts of middle-income countries lying in temperate zones, such as Mongolia and China. Due to time and resource constraints, and the relative lack of data on usage and emissions in Asia and Latin America, however, this report focuses on Europe and North America.

Box 1
New Indoor Air Quality Guidelines from the World Health Organization

The World Health Organization (WHO) is expected to shortly release indoor air quality guidelines for household fuel combustion.[2] The guidelines describe the household combustion technologies and fuels (and associated performance levels) needed to prevent the negative health effects that are currently attributable to this source of air pollution. With regard to household space

[2] See http://www.who.int/indoorair/publications/background/en/.

heating, the guidelines:

(a) Set emission rate targets for both vented and unvented household stoves ($PM_{2.5}$ and CO);

(b) Encourage Governments to accelerate efforts to meet air quality guidelines, in part by increasing access to and encouraging sustained use of clean fuels and improved stoves, including maintenance and replacement of the stoves over time;

(c) Urge that unprocessed coal should not be used as a household fuel, given that indoor emissions from household combustion of coal are carcinogenic to humans.[3] (Unprocessed coal is distinguished here from so-called "clean" or "smokeless" coal, for which less research on health effects exists.);

(d) Discourage household combustion of kerosene, given that there is strong evidence that heating with kerosene leads to indoor concentrations of $PM_{2.5}$, nitrogen dioxide and sulphur dioxide (SO_2) that exceed WHO guidelines;

(e) Encourage Governments to maximize health gains while designing climate-relevant household energy actions.

6. The dangers of coal burning for residential heating in cities in developed countries were slowly recognized over centuries, but a major policy response was triggered by the Great Smog of London in December 1952, which caused thousands of premature deaths within a short period. Wood heating, though still a common practice even in some urban areas, has not received the same attention as coal, though it is also a major source of ambient air pollution during the heating season in nearly all parts of the world where wood is available. For example, wood space heating was responsible for 11% of California's annual average $PM_{2.5}$ and 22% of winter $PM_{2.5}$ emissions in 2012.

7. Residential heating with wood is a sector in which $PM_{2.5}$ and BC emissions can potentially be reduced with greater cost-effectiveness than other emissions reduction options. However, within Europe and North America, only a few countries or states in the United States have set legal limits for minimum combustion efficiency or maximum emissions of PM and harmful gaseous compounds like CO (see chapter V).

8. In 2012, Parties to the United Nations Economic Commission for Europe Air Convention adopted emission reduction targets for $PM_{2.5}$ in participating countries. They decided to prioritize $PM_{2.5}$ mitigation measures, with a focus on BC reductions, primarily because of the strong climatic influence of BC and the opportunity to "provide benefits for human health and the environment".

Reasons for concern

Effects on ambient air pollution and health

9. The types of fuel used for residential heating is an important determinant of both outdoor (ambient) and indoor air quality in many countries. Burning solid fuel in homes

[3] See http://www.iarc.fr/en/media-centre/pr/2006/pr172.html and in French: http://www.iarc.fr/fr/media-centre/pr/2006/pr172.html.

produces more neighbourhood-level particulate matter pollution than using electricity, natural gas, or liquid fuels for heating. Burning conditions are often inefficient and there are often no household-level emissions controls or regulations.

10. WHO reported[4] that, in 2012, 3.7 million premature deaths occurred due to exposure to outdoor (ambient) particulate air pollution, including 482,000 in Europe and 94,000 in Canada and the United States. Household use of solid fuels for heating is a contributor to this outdoor air pollution (see chapter III).

Climate policy

11. Many countries in North America and Europe are actively encouraging residential heating with wood (and other biomass). Biomass is being touted, in some cases, as a renewable fuel that can assist with climate change mitigation and contribute to energy security. For example, the United Kingdom of Great Britain and Northern Ireland Renewable Heat Incentive,[5] introduced in 2014, explicitly includes payment to households using biomass boilers as part of the strategy to reduce the country's greenhouse gas emissions by 80% (from 1990 levels) by 2050. Biomass fuels were also included in the European Commission strategy for reaching the "2020" targets (20% reduction in greenhouse gas emissions, 20% of final energy consumption from renewable energy, and 20% increase in energy efficiency by 2020), although much new biomass use in the EU has been for electricity production rather than household heating.

12. Household wood combustion for heating seems to be rising in some countries due to government incentives/subsidies, the increasing costs of other energy sources and the public perception that it is a "green" option. As emissions from other sources (such as ground transportation, industry and power plants) are in many areas either already controlled or legislation is in place to reduce emissions from these sources, residential biomass combustion is expected to gain prominence as a source of $PM_{2.5}$, especially if no efforts are made to encourage (or incentivize) use of modern and efficient residential wood heating devices. The World Bank noted in 2013 that "there is an urgent need to design and implement an effective approach to limiting BC emissions from home heating sources as their use continues to rise".[6]

Economic downturns and fuel-switching

13. Some families revert to heating with solid fuels (such as discarded furniture, wood scrap, and coal) in response to economic hardship. This has happened recently in Greece and other European countries. A 2012 study by the International Energy Agency concluded that, even in the absence of a global climate change agreement, biomass use in the residential energy sector will increase. In the United States, the number of households (especially low and middle income) heating with wood grew 34% between 2000 and 2010, faster than any other heating fuel, and in two states the number of households heating with wood more than doubled.

14. Motivated by the threat of increasing emissions due to a push for more bioenergy combustion — driven by renewable energy and energy security considerations and climate

[4] See http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

[5] See http://www.rhincentive.co.uk/.

[6] See Pam Pearson and others, *On Thin Ice : How Cutting Pollution Can Slow Warming and Save Lives*, Joint report of the World Bank and the International Cryosphere Climate Initiative (Washington, D.C.: World Bank, 2013). Available from http://documents.worldbank.org/curated/en/2013/10/18496924/thin-ice-cutting-pollution-can-slow-warming-save-lives-vol-1-2-main-report.

change mitigation policies without proper consideration of health effects — this report addresses several concurrent factors: persistent levels of emissions from residential solid fuel combustion for heating (see chapter III); growing evidence of health effects from exposure to PM from this source sector in epidemiological studies (see chapter IV); and a lack of regulation of solid fuel use for residential heating in most places (see chapters VI, VII and table 1). Note that this report does not represent a full systematic review of all the relevant literature, but relies primarily on recent comprehensive reviews, reports and WHO guidelines to present a general policy-relevant overview of these topics.

Table 1
Focus of this document

Category of Information	*Focus of this report*	*Less emphasis*
Geographic scope (regions)	Europe and North America	Other countries where residential heating is required, including China and India
Type of fuel	Wood and coal	Other solid fuels, such as charcoal, peat, agricultural waste, and garbage
Type of heating	Single-home residential heating	District heating
Type of exposure	Population-level exposure to ambient air pollution from heating appliances	Indoor (in-home) air pollution; emissions from cooking with solid fuels

II. How important is the use of solid fuels for residential heating as a source of air pollution?

A. Residential combustion of solid fuels is major source of fine particulate matter

15. Worldwide, less than 10% of total ambient $PM_{2.5}$ comes from residential heating stoves and boilers. About half of that comes from biomass heating, while most of the rest comes from household coal burning for heating (see box 2). (Note that these figures do not include district heating.) While the residential sector, as a whole, represents about 40% of global anthropogenic $PM_{2.5}$ emissions, the majority of this portion (about 80% of the $PM_{2.5}$ produced directly by household combustion) comes from cook-stoves (rather than heating stoves) in developing countries (see box 3). However, in several specific regions of the world residential combustion of solid fuels (biomass and coal) for heating makes a substantial contribution to total ambient $PM_{2.5}$ emissions: Europe (13%–21% in 2010, with Central Europe being the highest); the United States and Canada (10%); and Central Asia (10%) (see chapter IV).

Box 2
Heating with coal

Coal has been used for residential heating for centuries. In the 1960s, coal and

coke (a coal derivative) were the residential heating fuels of choice in Germany (84%) and France (68%), respectively, and were second only to oil in Denmark (33%) and Canada (22%). But by the 1980s, residential coal/coke use was virtually nonexistent (<0.5%) in Canada, Norway, and Sweden. In the Netherlands, coal was the major heating fuel in the 1950s and 1960s, but disappeared by the mid-1970s primarily due to domestically available oil and natural gas resources.

In the United States, 55% of homes used coal/coke for space heating in 1940, but this fell to 12% in 1960, below 5% in the early 1970s, and below 1% from the early 1980s onward. One study estimates that reductions in the use of bituminous coal for heating in the United States from 1945–1960 decreased winter all-age mortality by 1% and winter infant mortality by 3%, saving nearly 2,000 lives per winter month, including 310 infant lives.

Coal typically requires a higher ignition and combustion temperature and has a higher content of sulphur and nitrogen than wood and other biomass. This means that residential coal combustion is a source of SO_2 and nitrogen oxides (NO_x) (4% of SO_2 and 1% of NO_x, globally), as well as toxic pollutants adsorbed or absorbed to PM. In China (where residential coal combustion accounts for 7%–8% of national SO_2) and some central European countries that use substantial amounts of coal for heating, the proportion can be much higher. To make matters worse, coals mined in certain geographical regions contain toxic elements (e.g., fluorine, arsenic, selenium, mercury and lead). Burning these types of coal in households has been associated with poisoning from the toxic compounds released during the combustion.

Based on this, and evidence that indoor emissions from household combustion of coal are carcinogenic to humans, the latest WHO Indoor Air Quality Guidelines[7] strongly recommend against the residential use of unprocessed or raw coal, including for heating. WHO currently makes no recommendation about the residential use of processed coal, but calls for future research to examine the content, emissions of, and exposure to pollutants, including toxic contaminants, in "clean" or "smokeless" coal.

B. Observed outdoor pollution levels from residential heating

16. In areas where wood combustion for residential heating is prevalent, studies have found relatively high short-term $PM_{2.5}$, PM with a size less than or equal to 10 microns in diameter (PM_{10}) and volatile organic compound (VOC) concentrations. Residential heating with solid fuels represent up to 90% of the seasonal $PM_{2.5}$ observed across urban, suburban and rural areas. In some places, wood combustion is the major source of ambient $PM_{2.5}$, especially during the heating season. Source apportionment studies generally indicate that wood combustion accounts for 20%–30% of local heating season ambient $PM_{2.5}$ levels, although this estimate varies greatly by location.

[7] See WHO Regional Office for Europe, *WHO guidelines for indoor air quality: selected pollutants* (Copenhagen, 2010). Available from http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2010/who-guidelines-for-indoor-air-quality-selected-pollutants.

Europe

17. In Italy, one study found that, in 2008, residential heating with wood caused 3% of PM_{10} in Milan, 18%–76% in seven other urban areas and 40%–85% in three rural areas. Another study found that wood burning accounted for 8% of PM_{10} in Milan in the winter months of 2006/07, and about 23% in alpine/subalpine towns (Sondrio and Cantù) nearby.

18. In Austria, during the winter months of 2004, wood smoke caused about 10% of PM_{10} near Vienna and ~20% at rural sites in two densely forested regions (Salzburg and Styria).

19. A study in a small village in the Czech Republic, where the only major wintertime source of particulate air pollution was residential combustion of wood, coal and household waste, found that average winter PM_{10} was higher in the village (~40 micrograms per cubic metre ($\mu g/m^3$)) than in Prague (~33 $\mu g/m^3$) in 1997/98 and 1998/99.

North America

20. In Seattle, 31% of $PM_{2.5}$ measured at an outdoor monitoring site close to residential areas was apportioned to wood combustion and other vegetative burning. During heating season the contribution has been as high as 62% at neighbourhood measurement sites.

Box 3
Residential cooking with solid fuels

Approximately 40% of the world's population, some 2.8 billion people, cook with solid fuels. The resulting indoor $PM_{2.5}$ air pollution, which shares the same constituents produced by residential heating with solid fuels, is associated with an estimated 3.5 million deaths per year. In addition, residential cooking accounts for approximately 12% of all outdoor $PM_{2.5}$ pollution worldwide (a much higher proportion in some regions), and about 370,000 premature deaths each year due to exposure to outdoor $PM_{2.5}$ pollution worldwide.

In two regions, East Asia (including China) and South Asia (including India) a large proportion of $PM_{2.5}$ comes from both residential heating and cooking. When considered alongside their high population numbers, these two regions represent high priority areas for shifting people away from residential solid fuel use and toward grid (electricity) connections or access to piped natural gas or liquefied petroleum gas.

C. Residential heating emissions compared with other sectors

21. The fraction of total $PM_{2.5}$ emissions due to residential heating with solid fuels has greatly increased in many regions between 1990 and 2005, partly due to the greatly increased use of biomass fuels and partly because of the reduction of emissions from other sources, like industry, power plants and ground transportation in Europe and North America. Ground transportation, in particular, has historically generated a significant amount of $PM_{2.5}$ (now partially controlled) and continues to be a top source of air pollutants, including those that contribute to the formation of tropospheric ozone.

D. Future trends in residential biomass emissions

22. In general, if current trends continue, primary $PM_{2.5}$ emissions from biomass combustion for household heating are expected to increase into the future, due to the push for climate change mitigation (with biomass being considered a renewable fuel under some climate policies), the potential for economic hardships to increase dependence on solid fuels, slow adoption of state-of-the-art technologies and the lack of strong incentives to exchange the current inefficient stoves and boilers in use. These $PM_{2.5}$ emissions include BC, which is a potent climate-warming substance.

III. Is there evidence linking solid fuel heating emissions to health effects?

23. Recent studies suggest that short-term exposure to residential wood combustion is associated with effects on the cardiovascular system. Short-term exposure to particles from wood combustion appears to be as harmful to health as particles from the combustion of fossil fuels. At least 28 pollutants present in smoke from solid fuel use have been shown to be toxic in animal studies, including 14 carcinogenic compounds and four cancer-promoting agents. Undifferentiated PM was recently declared carcinogenic,[8] including from household combustion of coal and household use of solid fuels. The results of studies such as these were taken into account in the development of the WHO Indoor Air Quality Guidelines (see box 1) and are summarized in supporting documents.

24. Several approaches have been taken to understand the effects of solid fuel heating emissions on human health: epidemiological studies that track the health effects of air pollution in human populations; studies of other biomass burning such as forest fire smoke; and clinical and toxicological studies.

A. Epidemiological studies

25. Studies using source-apportionment techniques suggest that short-term exposure to particles from wood combustion can be as harmful to health as particles from combustion of fossil fuels. Hundreds of epidemiological time-series studies, conducted in different climates and populations, link daily increases in outdoor PM concentration with increased mortality and hospitalizations.

26. Long-term (years of) PM exposure appears to more strongly influence health outcomes than short-term (days of) exposure, though there have been few studies on the longer-term exposures. Exposure to PM leads not only to acute exacerbation of disease, these studies suggest, but may also accelerate or even initiate the development of chronic diseases. Long-term high-level exposures to wood smoke in low-income countries has been associated with lower respiratory infections (including pneumonia) in children, chronic obstructive pulmonary disease, reduced lung function and lung cancer in women, stillbirths and low birth weight of newborns.

27. Despite the fact that there are relatively few studies on the health effects of residential wood combustion in developed countries specifically, there is evidence of an association between wood combustion and respiratory symptoms in children. Ambient levels of particulate air pollution from wood combustion appear to be associated with

[8] See www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf and in French: http://www.iarc.fr/fr/media-centre/pr/2013/pdfs/pr221_F.pdf.

exacerbation of respiratory diseases, especially asthma and chronic obstructive pulmonary disease, and including bronchiolitis and otitis media (beginning as an upper respiratory infection). A systematic review of the health effects of particles from biomass combustion concluded that there was no reason to consider PM from biomass combustion less harmful than particles from other urban sources, but that there were limited studies on the cardiovascular effects.

B. Health effects of black carbon

28. Wood smoke is rich in BC: biomass fuels combusted for household heating and cooking contribute an estimated 34%–46% of total global BC emissions.[9] There is sufficient evidence of both short-term and long-term health effects of BC. A recent review of all available toxicological studies suggested that BC may carry a wide variety of chemicals to the lungs, the body's major defence cells, and the circulatory system more generally, though BC itself may not be a major toxic component of $PM_{2.5}$. Reducing exposure to $PM_{2.5}$ that contains BC should lead to a reduction in the health effects. Researchers found associations between daily outdoor concentrations of BC and all-cause mortality, cardiovascular mortality and cardiopulmonary hospital admissions, as well as associations between long-term BC concentrations and all-cause and cardiopulmonary mortality.

IV. What is the burden of disease due to the ambient air pollution from residential heating with wood and coal?

29. Household space heating with biomass-based solid fuels (wood, crop residues, etc.) creates outdoor air pollution that in turn results in an important public health burden (both in terms of premature deaths and in healthy life years lost) across many regions of the world. Europe is among the regions with the most serious challenges in this regard: the fraction of outdoor $PM_{2.5}$ caused by household space heating with wood and coal is especially high across many parts of Europe (see table 2).

Table 2
Residential heating contribution to outdoor $PM_{2.5}$ and burden of disease

	$PM_{2.5}$ from residential heating (%)		*$PM_{2.5}$ from residential heating ($\mu g/m^3$)*		*Premature deaths, per year*		*Disability-adjusted life years (DALYs), per year*	
Selected regions	***1990***	***2010***	***1990***	***2010***	***1990***	***2010***	***1990***	***2010***
Central Europe	11.1	21.1	3.5	3.4	18 000	20 000	370 000	340 000
Eastern Europe	9.6	13.1	2.0	1.4	24 000	21 000	480 000	410 000
Western Europe	5.4	11.8	1.3	1.7	17 000	20 000	280 000	290 000
High-income North America	4.6	8.3	0.9	1.1	7 500	9 200	140 000	160 000
Central Asia	9.9	8.3	2.4	1.6	5 500	4 200	180 000	110 000
Global	3.0	3.1	0.9	0.7	120 000	110 000	2 800 000	2 200 000

[9] See T. C. Bond and others, "Bounding the role of black carbon in the climate system: A scientific assessment", *Journal of Geophysical Research: Atmospheres*, vol. 118, No. 11 (June 2013), pp. 5380–5552.

30. In 2010, an estimated 61,000 premature deaths in Europe were caused by outdoor $PM_{2.5}$ pollution originating from residential heating with solid fuels (wood and coal), about the same number as in 1990. This represents 55% of all deaths worldwide that can be attributed to exposure to outdoor air pollution from residential heating with wood and coal. Outdoor air pollution from household heating with solid fuels also caused 1 million disability-adjusted life years (DALYs) across Europe in 2010 (47% of the global total), down from 1.3 million DALYs in 1990.[10]

31. In North America, exposure to outdoor air pollution ($PM_{2.5}$) caused by residential heating with solid fuels resulted in 9,200 deaths in 2010, an increase from 7,500 in 1990. This pollution also caused 160,000 DALYs in 2010, up slightly from 140,000 DALYs in 1990. Reducing the use of biomass for space heating or reducing the emissions though better combustion, or pollution capture, would lessen this burden.

32. Globally, Europe has the highest percentages of outdoor $PM_{2.5}$ emissions attributable to household heating with solid fuels, with 12% of total $PM_{2.5}$ in Western Europe, 21% in Central Europe and 13% in Eastern Europe in 2010. This corresponds to average population-weighted $PM_{2.5}$ concentrations of 1.7, 3.4, and 1.4 $\mu g/m^3$, respectively. In comparison, 8% of the total ambient $PM_{2.5}$ in North America (Canada and the United States) comes from household heating with solid fuels (1.1 $\mu g/m^3$).

V. Which interventions have been shown to decrease emissions, improve outdoor and indoor air quality, and improve human health?

33. National, state/provincial and local regulatory agencies have implemented a large number of regulatory air quality management efforts targeted at reducing ambient concentrations of pollutants emitted from residential wood combustion. These include actions focused on combustion technology (stove exchange), fuel switching, in-home high-efficiency particulate air (HEPA) filtration and educational efforts focused on burning practices. There have been comparatively few studies to assess the effectiveness of these actions, and only a subsection assess resulting health benefits.

A. Fuel switching

Ireland

34. A study in Ireland found that banning the marketing, sale, and distribution of coal (specifically bituminous coals) improved both air quality and health, including reducing deaths from respiratory and cardiovascular causes. Average black smoke concentrations in Dublin declined by 35.6 grams per cubic metre (g/m^3) (70%) when coal sales were banned, and adjusted non-trauma death rates decreased by 5.7%. Respiratory deaths fell by 15.5%, and cardiovascular deaths by 10.3%. About 116 fewer respiratory deaths and 243 fewer cardiovascular deaths were seen per year in Dublin after the ban. In subsequent reanalyses, the original authors concluded that the statistical approach did not adequately control for a downward secular trend in the outcome, and that the results were therefore biased away from the null; however, the reanalysis still showed a significant decrease in respiratory mortality. The work also showed that, where the ban was extended to other Irish cities, significant improvements in air quality were detected and that there were reductions in

[10] Z. A. Chafe and others, "Ambient air quality ($PM_{2.5}$) and human health effects of household combustion of solid fuels (wood, coal) for space heating" (in preparation).

morbidity and mortality, especially for respiratory outcomes. As mentioned above, the WHO Indoor Air Quality Guidelines for household combustion will strongly recommend that raw unprocessed coal snot be used as a household fuel.

B. Heater and wood-stove exchanges

United States

35. In the United States, a successful community wood-stove exchange programme in Libby, Montana, replaced 95% (1,100) older (non-Environmental Protection Agency (EPA) certified) wood-stoves with EPA-certified appliances or other heating sources over the course of four years. Before the exchange, residential wood-stoves contributed about 80% of ambient $PM_{2.5}$ in the airshed in winter months. Compared to the pre-intervention winter, average winter $PM_{2.5}$ mass was reduced by 27%, and source-apportioned wood smoke-related $PM_{2.5}$ by 28%. Lower ambient $PM_{2.5}$ was also associated with reduced odds for reported respiratory infections. Compared with a two-year baseline period, established prior to the stove exchange, the intervention produced a 26.7% reduced odds of reported wheeze for each 5 $\mu g/m^3$ decrease in $PM_{2.5}$ in schoolchildren.

36. Results of studies evaluating the impacts on indoor air quality of stove exchanges have been inconclusive. In Libby, Montana, all homes in which stoves were changed showed decreases in $PM_{2.5}$ concentrations (of varying magnitude), with a mean 71% decrease in 24-hour indoor $PM_{2.5}$ concentrations, and decreases in concentrations of organic carbon and levoglucosan. However, a substantial difference in ambient temperature between the pre- and post-exchange sampling might have affected infiltration rates and general wood-burning behaviour within the community. To address these concerns, and to assess longer-term impacts of the stove exchanges, a follow-up study was conducted in the two subsequent winters with sampling designed to match the temperatures of the pre-exchange measurements. In this analysis a crude 53% reduction in mean $PM_{2.5}$ was observed (mean reduction of $-18.5\ \mu g/m^3$) when adjusted for ambient $PM_{2.5}$, ambient temperature and several other household factors that might influence indoor PM levels. Reductions across homes and years were highly variable, and a subset of homes did not experience a reduction in $PM_{2.5}$ following the stove exchange. Similar to the initial study, reductions were observed for organic carbon, elemental carbon and levoglucosan.

37. A small stove exchange on a Native American reservation in Idaho, United States, improved indoor air quality, with a 52% reduction in median indoor $PM_{2.5.}$ Similar to the Libby studies, decreases in levoglucosan and other compounds were observed. Five of the fifteen homes did not show evidence of improvements in indoor air quality.

Canada

38. In Canada, another source apportionment study, conducted in Golden, British Columbia, found that wood smoke-associated source contributions to $PM_{2.5}$ levels decreased by a factor of four following a wood stove change-out programme. During the programme, the proportion of homes using advanced (United States EPA-certified) wood stoves increased from 25% to 41%. In the same period, however, there was an overall increase (from 29% to 32%) in homes using conventional wood stoves. Health outcomes were not studied.

39. Another small wood-stove change-out study, in northern British Columbia, Canada, found that there was not a consistent relationship between stove technology upgrades (from conventional non-certified wood-stoves to EPA-certified wood-stoves) and outdoor or indoor concentrations of $PM_{2.5}$ or levoglucosan in homes where the stoves were exchanged. Measurements were conducted in 15 homes during the same heating season before and after

the change-out (including approximately a one-month period for participants to become familiar with their new stoves) and results were controlled for infiltration and ambient temperature.

Potential limitations of change-out initiatives

40. The Canadian Council of Ministers of the Environment evaluated 12 stove exchange and educational efforts conducted in Canada and concluded that exchange programmes may have limitations relating to the cost of new technologies and the long service life of appliances once installed. The assessment supported the use of regulation to effectively curb the sale of high emission appliances. This approach is used in a number of provinces in Canada and states in the United States.

41. The Canadian National Collaborating Centre for Environmental Health found that emissions standards (based on best available technologies) are needed to ensure that the newer devices installed through change-out programmes are among the cleanest available in the marketplace. Without these standards, change-out programmes may in fact be lost opportunities to install cleanest-available wood burning devices, given that they will be in use for years to come. The study, published by Environment Canada in 2006, also found that removal of conventional non-certified appliances (through exchanges, time limits or prior to the sale or transfer of a property) was the most effective strategy included in a model municipal by-law for mitigation of residential wood smoke (see sect. D below) .

C. District heating

Sweden

42. District heating was introduced, for health, efficiency and comfort reasons, in Sweden in the 1940s to avoid the use of coke and sulphur containing oil close to cities and towns where people live, and at the same time to support the production of electricity (combined heat and power production). It was estimated in the 1970s that levels of sulphur dioxide levels were two to five times less in towns where district heating was common, compared with similar towns without district heating. Since then heavy oil as a fuel has been abandoned because of sulphur, energy and carbon taxes. With stringent emission control, a number of different fuels have been introduced, dominated by different biofuels. Today, district heating and cooling is mainly based on the use of excess heat from the production of electricity or industrial processes, and is considered one of the most environmentally friendly ways to use biofuels. Other energy sources are also used, such as, for instance, heat pumps that use heat from sea, river or sewage water. The most common heating method in multi-family dwellings and non-residential premises in Sweden is currently district heating. As a result of this and other changes, the ambient air concentration of soot (BC) in the second largest city, Gothenburg, has decreased from almost 50 $\mu g/m^3$ in 1965 to about 5 $\mu g/m^3$ in 1995. Another example is from central Stockholm, where SO_2 levels were dramatically reduced from more than 200 $\mu g/m^3$ in 1965 to less than 25 $\mu g/m^3$ in 1990. The environmental aspects of district heating have been described in detail. It has been estimated that the whole energy need for heating in the EU could be met by using excess energy from power production to district heating.

D. High-efficiency particulate air filtration

Canada

43. While household- or individual-level strategies are not typically part of air quality management programmes, two studies from Canada[11,12] indicate that in-home HEPA filtration might reduce health impacts from wood smoke. An initial single-blind randomized crossover study of 21 homes during winter, in an area impacted by residential wood combustion as well as traffic and industrial sources, reported a mean 55% (standard deviation +/-38%) reduction in indoor PM levels when HEPA filters were operated. This study was followed by a randomized intervention, blinded crossover study which included both exposure measures and assessment of potential health benefits associated with HEPA filter operation. Use of the HEPA filters reduced indoor $PM_{2.5}$ and levoglucosan concentrations by 60% and 75%, respectively. Use of HEPA filtration for one week was associated with improved endothelial function and decreased levels of disease-related biomarkers in adults. No associations were observed for urinary markers of oxidative stress. These studies indicate the potential for portable room air cleaners to reduce exposures and health impacts associated with residential wood combustion.

E. Educational campaigns

United States

44. The EPA has set up a “Burn Wise” programme to educate people to burn the right wood (dry, seasoned hardwood, no trash), the right way (hot and not smouldering fire, not overloading the appliance, not when outdoor air quality is poor), in the right, efficient appliance. Educational campaigns, run at the city, county and national levels can also encourage switching to alternative energy sources and avoiding unnecessary, recreational combustion.

45. In general, environmental education campaigns have only moderate success in generating pro-environmental behaviour and there is little evidence of their effectiveness in peer-reviewed literature. There are no quantitative estimates describing how improved wood burning practices, without exchanging the combustion appliances, can reduce health impacts of wood combustion. Very few studies have evaluated why even increased awareness of health risks of wood combustion doesn’t always cause beneficial changes in behaviour.

46. Educational campaigns may fail if they only provide information on risks but don’t try to affect the positive image of wood combustion. Many associate wood combustion at home with innate feelings of comfort, goodness, happiness and warmth. Decisions on whether to burn wood or not, when an individual has the ability to choose, may rather be based on intuitive positive feeling than on logical calculation of risks. Wood smoke seems to be perceived as less health-threatening than many other environmental stressors, although there is little evidence for or against this notion.

[11] Barn P, Larson T, Noullett M, Kennedy S, Copes R, Brauer M. 2008. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. Journal of Exposure Science and Environmental Epidemiology 18: 503-11.

[12] Allen RW, Carlsten C, Karlen B, Leckie S, van Eeden S, et al. 2011. An air filter intervention study of endothelial function among healthy adults in a woodsmoke-impacted community. American journal of respiratory and critical care medicine 183: 1222-30.

47. Increasing the perceived health risk associated with solid fuel heating can be one motivation to change behaviour, though awareness of risks does not automatically lead to beneficial changes in behaviour. Tobacco smoking is an encouraging example of an activity whose image has been altered, at least in part, due to active campaigning. Bans on smoking in bars has been shown to lead to beneficial changes in respiratory and cardiovascular health of populations.

VI. What regulatory and voluntary measures are available to reduce emissions from wood heating in developed countries?

48. This section focuses on the regulatory and voluntary measures that are now available or hold the potential to reduce death/injury associated with residential solid fuel heating. Note that the section does not focus on interventions specific to coal burning because the WHO Indoor Air Quality Guidelines for household solid fuel use will strongly discourage any coal use. The assumption here is that any options available to reduce coal combustion in homes should be used.

A. Regulatory emissions limits

European Union (proposed ecodesign emissions limits)

49. Over the past decade, the European Commission has worked towards the possibility of regulating solid fuel local space heaters and solid fuel boilers, particularly those that use various forms of woody biomass fuel (wood logs, pellets and biomass bricks). Broader policy initiatives have now set the stage for the EU work in this arena, and specific regulation for addressing energy efficiency and emissions are currently being developed for solid fuel space heaters (ENER Lot 20) and for solid fuel boilers (ENER Lot 15) under the Ecodesign Directive.[13]

50. According to the Commission proposals, implementation of ecodesign standards would lead to significant reductions of $PM_{2.5}$ emissions from solid fuel local space heaters and boilers compared with baseline projections. The draft regulation for local space heaters[14] states that, in 2020, the proposed requirements for those products are expected to reduce PM emissions by 20 kilotons a year (kton/year), reduce organic gaseous compounds emissions by 32 kton/year and reduce CO emissions by 78 kton/year. By 2030, the proposed requirements for solid fuel boilers are expected to save approximately 22 petajoules (PJ)[15] (approximately 0.5 megaton of oil equivalent (Mtoe))[16] of energy each year — corresponding to about 200 kilotons of carbon dioxide (CO_2) emissions — resulting

[13] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. See also Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances and Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC.

[14] The proposed draft regulation sets a PM emission limit value (ELV) of 40 mg/m^3 and an ELV of 20 mg/m^3 for pellet heaters (PM measurement based on "dry" particles) by 2018 for open-fronted local space heaters, closed-fronted local space heaters using solid fuel (but not pellets) and solid fuel cookers.

[15] 1 Petajoule = 10^{15} joules.

[16] 1 Mtoe = 10^6 toe.

in reductions of 14 kilotons of PM, 14 kilotons of organic gaseous compounds and 147 kilotons of CO.

Europe (national emission standards in effect)

51. Some countries (e.g., Austria, Denmark, Germany, Norway and Sweden) have issued national emission standards for small residential heating installations. The most comprehensive at this time is a German law from 2010.

Canada (emissions limits in effect)

52. Canada has country-wide standards for $PM_{2.5}$ and ozone pollution levels, and residential wood-burning has been prioritized as a sector in which contaminant emissions can be reduced. The Canadian Council of Ministers of the Environment (the association of environment ministers from the federal, provincial, and territorial governments) participated in an initiative to update the Canadian Standards Association (CSA) standards for new wood-burning appliances. These standards were adopted in 2010, lowering the PM emission rate to 4.5 grams per hour (g/hr) for non-catalytic wood-heating appliances, and to 2.5 g/hr for catalytic wood-heating appliances. This standard also established emissions limits for of 0.4 and 0.13 grams per megajoule (g/MJ) for indoor boilers/furnaces and outdoor hydronic heaters, respectively.

United States (emissions limits in effect)

53. In the United States, the EPA established a new source performance standard (NSPS) for residential wood stoves under the Clean Air Act in 1988 (7.5 g/hr for non-catalytic wood-heating appliances, and to 4.1 g/hr for catalytic wood-heating appliances), which is expected to be updated in 2014 to a level equivalent to the CSA standard. This standard is currently in effect in the state of Washington.

54. Note that both the CSA standard and the NSPS cover only wood-stoves; neither covers devices installed prior to implementation of the standards, nor do they encompass many increasingly popular residential wood-burning devices, including fireplaces, masonry heaters, pellet stoves (see box 4), indoor and outdoor wood boilers, furnaces and heaters. An EPA voluntary certification standard for low mass fireplaces (5.1 g/hr) and has been proposed under the NSPS revision, as well as a standard for masonry heaters (2.0 g/hr daily average, 0.32 lb/mmBTU[17] [~0.14 g/MJ]), and single burn-rate stoves (3.0 g/hr).

Hydronic heaters

55. A hydronic heater is a wood-fired boiler, often located outside of the building for which it is generating heat, in a shed, for example, that heats a liquid (water or water/ antifreeze mix) and then uses this liquid to circulate heat. To promote the production and sale of cleaner and more efficient outdoor hydronic heaters, the EPA currently runs a voluntary certification programme for manufacturers. At the most stringent certification level ("Phase 2"), certified outdoor hydronic heaters are about 90% cleaner than uncertified models. However, even outdoor hydronic heaters qualifying for Phase 2 certification still emit one to two orders of magnitude more $PM_{2.5}$ on an annual average emission rate basis than residential oil or gas furnaces. Under the proposed revisions to the NSPS, a limit of 0.32 lb/mmBtu (~0.14 g/MJ) for indoor hydronic heaters is proposed for 2014, and 0.15 lb/mmBTU (0.06 g/MJ) for both indoor and outdoor hydronic heaters in 2016. Also, a

[17] 1 lb (pound) = 453.6 g, 1 mmBtu= 10^6 Btu (one million British thermal unit) = 1.055 GJ.

number of state and provincial jurisdictions have adopted setback distances of 30 to 150 metres, depending on emissions certification, for outdoor hydronic heaters.

56. All of the above standards are focused on PM emissions, but the proposed United States standard also includes minimum efficiency requirements for a number of appliances with the aim of reducing CO emissions as well.

Box 4
Pellet stoves

Pellet stoves are stoves that use processed biomass (in pellet form) as a fuel. Some are equipped with automatic pellet-feeding systems, which often run on electricity but occasionally are gravity-fed, and require little attention from the user. They were developed in the 1980s and have become quite popular in Europe, although less so in the United States and Canada.

In several European countries a significant growth in the installation of pellet stoves and boilers in residential and commercial sectors has been observed in the past decade. Annual sales growth rates of 20%–30% per year in Austria, France, Germany, Italy, Sweden (currently the largest market in the world) and Switzerland have been reported, varying a little from year to year owing to changes in the price of fossil fuels compared with stove pellets.

Pellets were originally produced in some European countries as a way of using the waste products from sawmills. Pellet production increased fourfold in the EU between 2001 and 2009 and there is a fluid trade both within the EU and with external producers, particularly Canada, the Russian Federation and the United States There is some concern about the overall carbon footprint of heating with pellets in Europe, as many pellets are currently produced in North America or other regions and exported to Europe to fuel its thriving pellet market.

Pellet stoves are cleaner than many other options, but they may not be cost-effective for users who harvest their own wood for fuel. Prices for these kinds of stoves range from US$ 1,000–US$ 3,000. One estimate suggests that the cost-effectiveness of reductions for replacement of a wood stove ranges from US$ 130/megagrams (Mg) PM for a non-catalytic stove to almost US$ 1,000/ Mg PM for a pellet stove, but is highly dependent on the fuel price and the type of stove or boiler that is being replaced.

In Sweden, a 52% CO_2 tax on fossil fuels shifted consumer choice and led to increased penetration of modern biomass boilers and pellet stoves. Additionally, there are public incentive programmes in several countries in support of modern biomass heating in households to reduce greenhouse gas (GHG) emissions. For example, in France, value-added tax on pellet stoves and boilers was reduced from 19.4% to 5.5%, and there is a tax refund of up to 50% of the installation costs as well as public campaigns. In Germany, beginning in 2008, subsidies for the installation of pellet boilers of >150 kW were increased from €1,500 to up to €2,000 or even €2,500 when combined with solar panels.[18]

[18] United Nations Environment Programme and World Meteorological Organization, *Integrated Assessment of Black Carbon and Tropospheric Ozone* (UNEP/GC/26/INF/20) (Nairobi, 2011).

B. Fuel switching

Europe (financial incentives)

57. In Austria, biomass combustion (in pellet or woodchip boilers) is being incentivized by a flat rate of €120/kW for 0 kW–50 kW appliances and €60/kW for every additional kW up to a maximum of 400kW. A maximum of 30% of the purchase value of the installation may be covered by this policy. Germany provides grants for buyers of wood-burning appliances, with incentives to guide purchase of automatically fuelled pellet-burning devices. Minimum rebates range from €500 to €2,500 for pellet ovens and boilers, depending on the specific model. In Northern Ireland, a grant of up to €1,260 is available to help low-income households to replace an inefficient boiler (at least 15 years old) with a new wood-pellet boiler. Previously, the Greener Home Scheme in Ireland paid out €19 million in grants for the installation of nearly 6,000 new biomass boilers and stoves.[19] The Swedish Government grants up to 30% of the costs of the labour, materials and installations for heating with biomass. A maximum of 14,000 Swedish crowns (approximately US$ 2,000) per household applies. For apartment owners switching from direct electric heating to systems using district heating, biomass fuels or a geothermal/ground/lake heat pump, a maximum of 30,000 crowns (approximately US$ 3,150) applies.

C. No-burn days (regulatory and voluntary)

United States (Mandatory "no burn" regulations)

58. "No-burn" days are being used in many parts of the United States (and beyond) to reduce residential heating emissions when unfavourable meteorological conditions (low wind speed, temperature inversion) occur. For example, the Bay Area Air Quality Management District in California bans burning when "Spare the Air Tonight" advisories are issued. Bernalillo County (Albuquerque), New Mexico, has a winter advisory/no burn programme from October through February restricting use of non-EPA certified fireplaces or stoves. In Denver, Colorado, there are mandatory bans on "red" advisory days during the annual high air pollution season, with some exceptions. In Puget Sound, Washington, air-quality burn bans temporarily restrict some or all indoor and outdoor burning, usually called when weather conditions are cold and still. San Joaquin County in Southern California limits wood burning on days when air pollution approaches unhealthy levels. Santa Clara County, near San Francisco, uses a two-stage system to issue burn bans: under stage 1, residents can only use certified stoves; under stage 2, they may only use a wood stove if it is a primary heat source.[20]

United States (voluntary no-burn advisories)

59. Lagrande, Oregon, asks for voluntary curtailment of wood stove use for heat based on daily advisories. The Yolo-Solano Air Quality Management District has initiated a voluntary programme called "Don't Light Tonight", which encourages residents not to use wood stoves and fireplaces when air pollution approaches unhealthy levels. The district also encourages cleaner burning techniques and switching to cleaner burning technology.

[19] Ireland, Sustainable Energy Authority, *Greener Homes Scheme Statistics* (2014).

[20] United States, Environmental Protection Agency, *Agencies: Ordinances and Regulations* (2014).

D. Heater exchange regulations

United States (mandatory regulations in effect)

60. In San Joaquin County, in Southern California, existing wood stoves must be replaced with an EPA-certified wood stove when a home is sold, and only pellet stoves, gas stoves, and EPA-certified wood stoves can be sold. There are limits on the number of wood stoves or fireplaces that can be installed in new residential units. In Northern California, Santa Clara County has banned the installation of new wood-burning stoves or fireplaces. Additionally, the Bay Area Air Quality Management District requires that only cleaner-burning EPA-certified stoves and inserts be sold in the Bay Area, and that only pellet stoves, gas stoves and EPA-certified wood stoves be installed in remodelled or newly constructed buildings. They also require emissions labelling for firewood, fire logs, and wood pellets sold.[21]

E. Other regulations and voluntary measures

Canada (model by-laws and codes of practice)

61. The Canadian Council of Ministers of the Environment produced a code of practice for residential wood-burning appliances with a view to reducing the impacts of emissions to air quality and climate, while recognizing the appliances' importance for domestic heating. The code includes a model by-law that municipalities or provinces can adopt for regulatory purposes, as well as guidance on wood burning curtailment in response to air quality advisories, emissions testing for individual sources and complaint-response strategies. The code provides advice and regulatory guidance for six best practices for consideration by jurisdictions in designing policies and programmes to reduce wood-smoke emissions: (a) Regulating Appliance Efficiency; (b) Air Quality Advisories and "No-Burn Days", (c) Limits on Installation or Operation of Wood Burning Appliances; (d) Incentives to Change; (e) Public Outreach and Education; and (f) Performance Management — Planning for and Measuring Success.

Europe (voluntary eco-labelling)

62. Several countries (e.g., Austria, Germany and the Nordic countries) have introduced voluntary eco-labelling of stoves with standards for efficiency and emissions, such as the Nordic Swan label in Sweden.

63. The Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone (Gothenburg Protocol) under the ECE Air Convention, as amended in 2012, also included recommendations on PM emission limit values for residential combustion installations with a rated capacity of less than 500 kilowatt-hours (KWh). The recommended emission limit values for PM depend on the type of fuel (wood: 75 mg/m^3, logs: 40 mg/m^3, pellets and other solid fuels: 50 mg/m^3).[22]

[21] United States, Bay Area Air Quality Management District, Regulation 6, Particulate Matter and Visible Emissions, Rule 3, Wood Burning Devices (2014).

[22] See ECE/EB.AIR/113/Add.1, decision 2012/2.

VII. What are the policy needs regarding future use of biomass for heating and energy production?

64. Residential solid fuel combustion for heating is likely to persist in many parts of the world in the near-term future. The following is a summary of the needs and recommendations regarding biomass and other solid fuel use for heating and energy production

Air pollution impacts

65. There is a need for any renewable energy or climate change-related policies that support combustion of wood for residential heating to consider the local and global ambient air pollution impacts and to immediately promote only the use of lowest emission or best available combustion technologies.

Regulations for wood combustion efficiency

66. Legal regulations for improved efficiency of wood combustion in new heating appliances are urgently needed throughout the world both to slow down the current rapid speed of global warming (i.e., owing to BC in fine particles and VOCs that promote ozone formation) and to reduce the great burden of disease caused by wood combustion-derived particles (especially organics carried by BC). It is recommended that these regulations include tight, but technically achievable, limits for the primary emissions of especially particulate mass, gaseous hydrocarbons and CO from new boilers and heaters.

Education on energy efficiency

67. Improved efficiency of wood combustion in small-scale heating appliances greatly reduces emissions of major GHGs, such as CO_2 and methane (CH_4), per unit of energy required for heating purposes. There is an urgent need for education on this issue, including active outreach by air pollution, energy and health ministries.

Heater exchange regulations

68. As new wood heating devices become more energy efficient and emit less pollution (especially PM), there is a need for national Governments to prepare heater-exchange regulations or voluntary programmes. It is recommended that municipalities, counties and states consider requiring heater exchanges at the time of home remodels or sales. In many cases, these regulations will be most successful if financial compensation is offered to incentivize the replacement of old heaters with those meeting tight energy efficiency or emission limit regulations.

No-burn areas

69. There is also a true need, especially with current combustion technologies, to define urban areas with dense populations and/or geographical features (e.g., valleys between mountains), where residential heating or cooking with small-scale appliances burning solid fuels (wood, coal) is not permitted at all or is at least limited to registered models of low-emission wood combustion devices. There is a need for residential heating with coal burning in small-scale appliances to be permanently prohibited at least in communities of developed countries, as well as the use of log-wood burners for central heating without sufficiently large water tanks (otherwise this results in badly incomplete combustion and very large emissions).

No-burn days

70. There is a need to introduce regulatory use of "no wood burning" days or morning and evening hours during unfavourable meteorological conditions (low wind speed, temperature inversion) in vulnerable, densely populated areas and more generally in valleys of mountainous areas. This is one of the ways that can be rapidly introduced to alleviate local air pollution episodes in vulnerable areas with prevalent wood burning and, at the same time, reduce the risk of acute adverse health outcomes among the currently fast-growing susceptible population group of over-65-year-old subjects with chronic respiratory or cardiovascular disease. This would be favourable health-wise also to newborns and preschool children, who also spend much more time at home and are more susceptible than older children and adults to developing respiratory symptoms and infections.

Information campaigns

71. There is a need for local and regional authorities, together with patient organizations, to implement community-wide information campaigns to inform the residents about the climate and health benefits of locally emission-free alternatives for house heating (e.g., district heating by well-controlled combined heat and power plants, geothermal energy for single houses or as a larger local installation and heat pumps for single houses or apartments). Together with chimney sweepers, they could distribute information materials to residents regarding how to properly dry and store wood logs and how to properly use their current small-scale heater. An example of this is the information campaign implemented by chimney sweepers in Finland.[23] The most challenging task is to change the attitudes of those who are attached to the tradition of burning wood for house heating and comfort, and who often get their wood cheaply or without charge by harvesting small trees and chopping their own wood logs.

VIII. What are the co-benefits for health and climate of reducing residential heating emissions?

72. Co-benefits are health benefits that result from actions primarily motivated by an interest in mitigating climate change, or climate mitigation benefits produced by actions primarily motivated by an interest in improving public health. Reducing emissions of health-relevant air pollutants, especially those that are also climate-active pollutants (especially CH_4 and BC), can have short- and medium-term co-benefits for health; they can also immediately reduce exposure to associated particulate air pollution. Accounting for these health co-benefits can produce a more complete economic picture of the costs and benefits associated with efforts to reduce heating-related emissions, such as wood-stove change-out programmes.

73. Tightening restrictions on emissions from wood and coal heating throughout the world would both slow down the current rapid speed of global warming (i.e., owing to BC in fine particles and VOCs and CH_4 that promote ozone formation) and reduce the burden of disease caused by combustion-derived particles (especially organics carried by BC and contaminants in coal). There is a need to better educate the public that the improved efficiency of wood combustion in small-scale heating appliances greatly reduces emissions of major long-lived GHGs, such as CO_2, and short-lived climate forcers, such as BC and CH_4, and that coal heating should be discontinued for both health and climate reasons.

[23] International Cryosphere Climate Initiative. 2013. *Legislation and Regulations in Nordic Countries to Control Emissions from Residential Wood Burning: An Examination of Past Experience*, International Cryosphere Climate Initiative.

Carbon balance of coal and biomass

74. Coal is an extremely GHG-intensive energy source. Coal produces 1.5 times the CO_2 emissions of oil combustion, and twice the CO_2 from burning natural gas (for an equal amount of energy produced). When burned in homes, rather than power plants, coal is a major source of BC and other $PM_{2.5}$ as well.

75. Wood and other forms of biomass are often considered renewable and climate-friendly fuels, because trees take up CO_2 as they grow and store it in the form of carbon; as wood is burned, this carbon is released back to the atmosphere, either as CO_2 or in the form of short-lived pollutants such as BC and CH_4.

76. For both climate and health purposes, the form that these fuels' carbon takes when it is released matters greatly, since BC and CH_4 are both strongly climate warming. BC is a climate-relevant component of fine particles, whether they are derived from tailpipe emissions of cars or residential heaters burning wood or other biomass. It is also harmful to health (see chapter III). Note that although the toxicity behind the health impacts is indirect, via organic and inorganic constituents attached to BC, the impact on climate change is more direct, via increased light absorption of BC in atmospheric aerosols and on snow and ice.

Co-benefits for health

77. The World Bank found that replacing current wood stoves and residential boilers used for heating with pellet stoves and boilers, and replacing chunk coal fuel with coal briquettes (mostly in Eastern Europe and China), could provide significant climate benefits and would save about 230,000 lives annually, with the majority of these health benefits occurring in Organization for Economic Cooperation and Development (OECD) nations.

78. Another study coordinated by the United Nations Environment Programme and the World Meteorological Organization found that widespread dissemination of pellet stoves (in industrialized countries) and coal briquettes (in China), for BC mitigation, could improve health, since these interventions lead to reductions in $PM_{2.5}$. Major reductions in annual premature deaths expected as a result of these interventions include about 22,000 less deaths in North America and Europe, 86,000 less deaths in East Asia, South-East Asia and the Pacific, and 22,000 less deaths in South, Western and Central Asia.

Co-benefits for the Arctic

79. If Arctic climate change becomes a focus of targeted mitigation action (e.g., because of threats from sea-level rise), widespread dissemination of pellet stoves and coal briquettes may warrant greater consideration, because of their disproportional benefit to mitigating warming from BC deposition in the Arctic. The World Bank found that replacement of wood logs with pellets in European stoves could lead to a 15% greater cooling in the Arctic (about 0.1°C). For Arctic nations, the modelling strongly indicates that the most effective BC reduction measures would target regional heating stoves, for both climate and health benefits.

IX. Conclusions

80. The results presented here indicate that it will be difficult to tackle outdoor air pollution problems, in many parts of the world, without addressing the combustion of biomass for heating at the household level along with other sources. To protect health, there is a need for policymakers in regions that have relatively high levels of outdoor air pollution from household heating-related combustion to provide incentives to switch from solid fuel combustion for heating to gas- or electricity-based heating.

81. Given that residential wood combustion for heating will continue in many parts of the world due to economic considerations and the unavailability of other fuels, there is an urgent need to develop and promote the use of lowest emission or best available combustion technologies.

82. There is also a need for renewable energy or climate change-related policies that support combustion of wood for residential heating to consider the local and global ambient air pollution impacts and to immediately promote only the use of lowest emission or best available combustion technologies.

83. Policymakers working in regions where the proportion of $PM_{2.5}$ emissions attributable to household space heating with biomass-based fuels is high might want to consider incentives to assist with a transition to more efficient technologies, which encourage more complete combustion and thus less $PM_{2.5}$ and other health-relevant emissions.

84. It may be preferable, in many cases, however, to focus on making biomass-based home heating more efficient and less polluting, rather than transitioning away from biomass to fossil fuels, given the climate change implications of using fossil fuel for heating.

85. A better understanding of the role of wood biomass heating as a major source of globally harmful outdoor air pollutants (especially fine particles) is needed both among the national, regional and local administrations, the politicians and the public at large.