Residential Use of Wood-Burning Appliances in Canada: Emissions, Health Effects, and Intervention Strategies

Final Report

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December 4, 2009

**Production of this report has been made possible through a financial contribution from the Public Health Agency of Canada through the National Collaborating Centre for Environmental Health. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the National Collaborating Centre for Environmental Health.*

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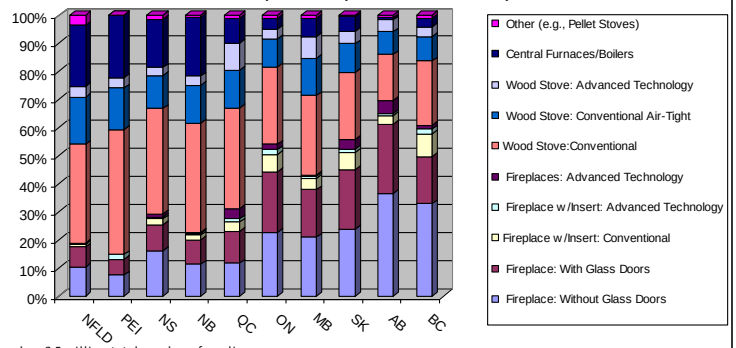
1.0 EXECUTIVE SUMMARY

In this report, we summarize the published literature and other sources of information with respect to (a) the residential use of wood-burning appliances in Canada, (b) woodsmoke emissions and health effects associated with woodsmoke exposures, and (c) wood-burning intervention strategies implemented in Canada. The purpose of this report is to better inform practitioners and policymakers about potential health risks or other concerns associated with residential wood-burning as well as useful mechanisms for addressing or mitigating these risks. However, because few programs to date have included an evaluation component, we were not able to review the efficacy of different wood-burning intervention strategies in Canada in a quantitative manner. Instead, we provide a qualitative indication of the potential effectiveness of different intervention strategies based on our review of the available information and interviews with Canadian health authorities.

Figure ES-1. Percentage of Wood-Burning Appliances Used in Canada by Province ***(source: adapted from Germain 2005)***



*Based on 3.5 million total number of appliances (number per Province not provided)

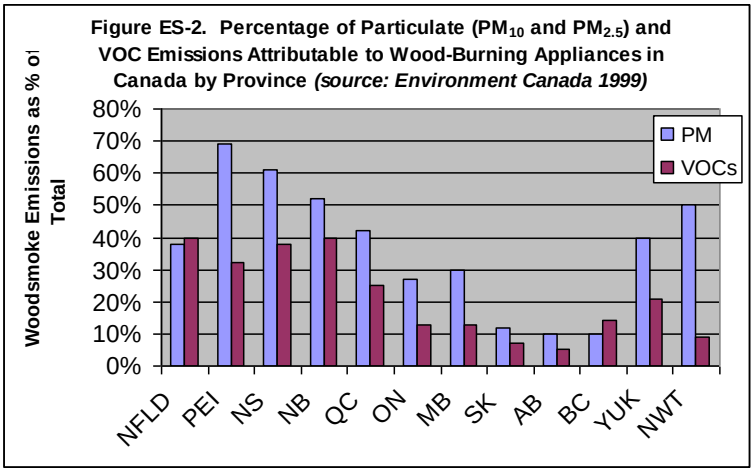
Overall, residential wood-burning is a common and accepted practice in many regions of Canada, and the use of wood as a primary or secondary heat source may be on the rise due to a variety of factors (e.g., increased heating costs, response to power outages, desire to promote renewable resources) (Ries et al. 2009; Bélanger et al. 2008; Snider 2006; Xue and Wakelin 2006; Germain 2005; Preto 2005; IWGRWC 2002; Lightowlers 2000). Although there are many different types of wood-burning appliances used by Canadian households in different geographic regions, conventional wood stoves and fireplaces (particularly those without inserts or glass doors) are projected to be used much more frequently than advanced wood-burning appliances (Xue and Wakelin 2006; Germain 2005; IWGRWC 2002) (see Figure ES-1).

Residential wood-burning is an important issue because the use of wood-burning appliances can have a negative impact on local air quality, which may limit the ability of individual provinces to meet air pollutant goals, such as the new Canada-wide standards for $PM_{2.5}$ (CCME 2000). Indeed, emissions of contaminants from wood-burning appliances are well-documented, and ambient levels of PM_{10}, $PM_{2.5}$, SOx, NOx, CO, PAHs, VOCs, and/or dioxins have been largely attributed to residential wood-burning in many areas of Canada (Jeong et al. 2008; Larson et al.

2007; Xue and Wakelin 2006; BC Ministry 2005; Germain 2005; Environment Canada 2004, 1999; IWGRWC 2002; Basrur 2002; Lightowlers 2000) (see Figure ES-2).

In general, newer advanced technologies (i.e., those in compliance with Canadian Standards Association [CSA] or U.S. Environmental Protection Agency [EPA] standards) produce lower emissions than older non-compliant technologies (Xue and Wakelin 2006; Germain 2005; Preto 2005; Basrur 2002; Environment Canada 1999). For example, EPA-certified woodstoves must meet a PM emission limit of 7.5 grams per hour for non-catalytic wood stoves and 4.5 grams per hour for catalytic wood stoves, and older uncertified stoves and fireplaces release 40-60 grams of smoke per hour compared to 2-5 grams of smoke per hour for new EPA-certified stoves (Ward and Noonan 2008). CSA-certified wood-heating appliances must currently meet the same standards, although newly proposed CSA-standards (expected to be promulgated in Spring 2010) must meet a PM emission limit of 4.5 grams per hour and 2.5 grams per hour for non-catalytic and catalytic appliances, respectively. The substitution of advanced or EPA/CSA-certified wood-burning appliances for conventional appliances is therefore expected to reduce ambient contaminant levels, but it is difficult to know the exact impact of the effect as this analysis has not been conducted.

Figure ES-2. Percentage of Particulate (PM_{10} and $PM_{2.5}$) and VOC Emissions Attributable to Wood-Burning Appliances in Canada by Province *(source: Environment Canada 1999)*



Additionally, less is known about the magnitude of public exposure to woodsmoke, particularly indoors where people spend the most time. Some studies show that indoor air quality is not affected by heat source (e.g., wood stove versus electric heating) or that infiltration from outdoor emissions is minimal, although infiltration is highly dependent on many factors and is difficult to generalize (Allen et al. 2009; Barn et al. 2008; Weichenthal et al. 2007; Lévesque et al. 2001; Sexton et al. 1986). On the other hand, some studies suggest that residential wood-burning can increase indoor contaminant concentrations, contribute significantly to personal exposures, and result in adverse health effects among household occupants (Gustafson 2009; Ries et al. 2009; Ward and Noonan 2008; Naeher et al. 2007; Zelikoff et al. 2002; Larson and Koenig 1994; Pierson et al. 1989; Sexton et al. 1986).

According to several recent reviews, many woodsmoke constituents have been shown to individually produce acute and/or chronic health effects in exposed humans (Naeher et al. 2007;

Boman et al. 2003; Zelikoff et al. 2002; Larson and Koenig 1994). Of the more than 200 chemicals and compound groups contained in woodsmoke, fine particles (which can penetrate deep into the lung) are generally considered to be the best indicator of the health impacts of wood combustion sources. PM_{10} and $PM_{2.5}$ are primarily associated with causing inflammation and oxidative stress and may be allergenic, while other woodsmoke constituents are known respiratory irritants and may have mutagenic and/or carcinogenic properties (see Table ES-1). Exposure to woodsmoke in developed countries has been associated with a variety of adverse respiratory health effects and symptoms (e.g., lung function decrements and shortness of breath; exacerbation of asthma; wheezing, coughing and congestion), particularly in children, with potential cardiovascular and cancer effects being less certain. A health effects study conducted in Canada reached similar conclusions, particularly if wood-burning appliances are not maintained and used properly (Lévesque et al. 2001). In developing countries, there is also some evidence linking biomass smoke under certain exposure conditions to chronic obstructive pulmonary disease (COPD) and perhaps lung cancer among women and acute lower respiratory infections among children due to cooking indoors with open unvented fire (Smith 2008; Straif et al. 2006; Hernández-Garduño et al. 2004; Zelikoff et al. 2002; Larson and Koenig 1994). Based on limited human evidence of lung cancer in humans (due to cooking indoors) and supporting animal and mechanistic data, the IARC recently categorized household biomass fuel (mainly wood) as Category 2A "probably carcinogenic to humans" (Straif et al. 2006).

Table ES-1: Air Contaminants Associated with Wood Smoke and their Mode of Toxicity *(adapted from Naeher et al. 2007)*

Class of Compound	Specific Contaminant	Mode of Toxicity
Inorganic gases	Carbon monoxide	Asphyxiant
	Ozone	Irritant
	Nitrogen dioxide	Irritant
Hydrocarbons	1,3-butadiene	Irritant, carcinogenic, mutagenic
	Benzene	Carcinogenic, mutagenic
	Polycyclic aromatic hydrocarbons	Mutagenic, carcinogenic
Oxygenated organics	Aldehydes (formaldehyde)	Irritant, carcinogenic, mutagenic
	Organic alcohols	Irritant, teratogenic
	Phenols	Irritant, carcinogenic, mutagenic, teratogenic
Particulate matter	Inhalable particles (PM_{10})	Inflammation and oxidative stress, may be allergenic
	Fine particles ($PM_{2.5}$)	Inflammation and oxidative stress, may be allergenic

Government agencies in Canada have taken a number of steps to address air quality and health concerns associated with residential wood-burning through a combination of public education programs and by supporting intervention strategies, generally in the form of municipal by-laws restricting the use of wood-burning appliances or through wood-burning appliance change-out programs (Environment Canada 2006; CCME 2004; IGWGRWC 2003, 2003). Similar types of public education programs and health intervention strategies have also been implemented in

other developed and developing countries (U.S. EPA 2005; CCME 2004; von Schirnding et al. 2000). General information, fact sheets, and/or guidelines on residential wood-burning and wood smoke are accessible to the public via various website links (see Table ES-2).

Most of these strategies have focused on increasing public awareness of proper wood-burning practices (e.g., using clean, dry, and untreated wood) and offering incentives for homeowners to replace older wood-burning appliances with more advanced units (i.e., change-out programs). However, public attitudes and perceptions can represent a significant barrier to change, given that wood-burning appliance users often perceive far fewer health risks from wood smoke and exhibited far less support for woodsmoke control policies or changing wood-heating practices than non-users (Bélanger et al. 2008; Hine et al. 2007; Xue and Wakelin). Additionally, in many regions in Canada, public health authorities report that woodsmoke from residential wood-burning is viewed by local municipalities or health agencies as a public nuisance issue, rather than being perceived as a threat to public health. Provincial, regional, and local health practitioners may also be unaware of the air quality impacts and potential health risks associated with residential wood-burning and/or have limited information on intervention strategies or few resources available to address these issues.

Table ES-2: Summary of Website Links Related to Informational Materials and Change-Out Programs in Canada

Program or Topic	Supporting Organization	Website URL
Burn it Smart!	Environment Canada (formerly NRCan)	http://www.environnement-canada.ca/cleanair-airpur/Campagne_chauffage_au_bois-WS69573E19-1_En.htm
Clean Air Online	Environment Canada	http://www.ec.gc.ca/cleanair-airpur/Home-WS8C3F7D55-1_En.htm
Healthy Living - Woodsmoke	Health Canada	http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/wood-bois-eng.php
Particulates and Woodsmoke	British Columbia Ministry of Environment	http://www.env.gov.bc.ca/air/particulates/index.html
Smart Burning Tips	British Columbia Lung Association	http://www.bc.lung.ca/airquality/wood_burning.html
Wood Burning Efficency and Safety	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/efficiently.html
Woodsmoke Health Effects	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/healtheffects.html
Residential Wood-Heating Guide	Wood Heat Organization Inc	http://www.woodheat.org/
Woodsmoke Pollution	Citizens for Environmental Health	http://02a17a1.netsolhost.com/sustainability_community.html
ecoEnergy Home Retrofit	Natural Resources Canada	http://oee.nrcan.gc.ca/residential/personal/retrofit-homes/retrofit-qualify-grant.cfm
Woodstove Changeout Campaigns	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/changeout.html#links
Hearth Changeout Programs	Hearth and Patio Builders Association	http://woodstovechangeout.org

The Intergovernmental Working Group on Residential Wood Combustion (IGWGRWC), which is comprised of representatives from municipal, provincial, territorial and federal governments, was formed in 1999 to promote and coordinate government actions on the sustainable development of residential wood combustion in Canada. In 2002, IGWGRWC led a stakeholder workshop to identify options for reducing emissions from residential wood-burning appliances, which represented Canada's first national consultation on residential wood-burning appliances. Since the initial IGWGRWC (2002) stakeholder workshop, the Canadian Council of Ministers of the Environment (CCME) commissioned a feasibility assessment of a national change-out/education program aimed at reducing emissions from residential wood combustion. As part of this effort, 12 wood stove change-out/education campaigns in different regions of Canada were examined (CCME 2004) (see Table ES-3). A key finding from this assessment was that while information campaigns serve to raise public awareness of the issue, they are not sufficient by themselves to lead to changes in behavior with respect to the use of wood-burning appliances. Significant barriers to effective wood-burning change-out programs were also identified due to the cost of advanced appliances and long service life of conventional appliances. Regulation was deemed to be the most effective approach to stopping the retail sale of conventional woodstoves.

A *Model Municipal Bylaw for Regulating Woodburning Appliances* was also published under the auspices of the IGWGRWC as a tool to assist communities in addressing air quality problems from residential wood combustion (Environment Canada 2006). This document provides supporting information on seven potential control strategies that are part of the model municipal by-law which either specify limits on total emissions or provide incentives (or impose disincentives) to limit emissions from wood-burning appliances (see Table ES-4). In addition to these efforts at the national level, limited information is available on recent public education and intervention efforts that have been implemented in specific provinces of Canada, such as an inventory of air quality by-laws for anti-idling, open-burning, and wood-burning appliances in British Columbia (BC Ministry of Environment 2009; UBC 2009; Alderson 2007). At the local level, available information suggests that a range of interventions have also been implemented by various municipalities throughout Canada (e.g., bans on residential wood-burning), but this information is not readily available from the published literature or public health authorities. A comprehensive summary of wood-burning interventions at the local level would require an in-depth survey of municipalities, which was outside the scope of the current review.

Despite the different types of residential wood-burning intervention strategies that have been implemented in Canada, few attempts have been made to evaluate the efficacy of these strategies and most programs have not included an evaluation component. In the CCME (2004) review of 12 wood stove change-out programs in Canada, an attempt was made to evaluate the impact of these programs using different qualitative metrics (e.g., number of workshops held, number of attendees) and quantitative metrics (e.g., number of woodstove exchanges, estimated reductions

Table ES-3: Summary of Selected Wood Stove Change-out Efforts in Canada
(Adapted from CCME 2004)

Municipality	Approach	Duration	Budget per Community	Incentives offered	Program Impacts Qualitative	Quantitative
BC Changeout (1995)	Change-out	One season April 1 - May 15	$7463 per community	$50 - $200 cash discount; Enviroloan program	208 responses to 1 800 number	196 exchanges; estimated reduction of 11220 grams particulate per hour (calculated, not measured)
Nova Scotia (1997)	Change-out supported by education	One season Sept 3 - 10	$21950 cash and $27635 in kind over 100,000 households	$150 cash	1000 requests for information to 1 800 number	120 stoves traded in; 72 recycled; estimated reduction of 3960 gr/hr (calculated, not measured)
New Brunswick (1997)	Change-out supported by education	One season Sept 3 - Oct 15	Budget unknown	Under $250	200 participants in moisture testing clinics; 900 people phoned the 1 800 number	112 woodstoves exchanged; estimated reduction of 6160 gr/hr of PM (calculated, not measured)
ALAP Project Quebec (2001)	Change-out supported by education	One season three weeks in Autumn	$1097 per community	$210 - $300 rebate	175000 flyers; 2600 posters; 2000 user guides	68 wood stoves changed out; estimated reduction of 3855 gr/hr PM (calculated, not measured)
Great Eastern Ontario Woodstove Change-out Program	Change-out supported by education	Starting in January for eight weeks	$10875 per community	Trade-in rebate of $150	Eight public workshops with 500 total attendees	83 wood stove exchanges; 28 fireplace inserts; estimated reduction of 6365 gr/hr PM (calculated, not measured)
Renewing an Old Flame Campaign (2000)	Education campaign	One season in fall	$65000 cash	None	Point of sale purchase materials	unknown
Great Woodstove change-out and Education Program of Georgian Bay (2001)	Change-out supported by education	Starting in late February for nine weeks	$33267 per region	Trade in rebate of $125	12 workshops (1210 total participants)	85 woodstoves; estimated reduction of 4675 gr/hr PM (calculated, not measured)
First Nation Communities in Ontario (2002-2003)	Education campaign	Unknown	Unknown	None	14 workshops (171 total attendees)	Unknown
2003 Great Okanagan Woodstove Exchange Program	Change-out supported by education	Early February for six weeks	$13000 cash and $5000 in kind	15% trade-in allowance (up to $500)	3 workshops (214 total attendees)	190 wood stoves; estimated reduction of 7725 gr/hr PM (calculated, not measured)
Whitehorse Efficient Wood Heat Demonstration	Demonstration	Nine one week PM emissions sampling periods	Unknown	None	14 homeowners reduced emissions by adopting better burning practices	8 change-outs
Burn it Smart	Change-out supported by education	January - March 2002	$161548 cash and $381627 in kind	Various	reached 6940 participants (home visit or workshop)	223 change-outs

*Note that the Whitehorse Efficient Wood Heat Demonstration was excluded from analysis because it was determined that this was a scientific study rather than a change-out/education campaign.

in PM emissions). However, these metrics do not necessarily account for the ultimate outcomes of interest, such as a reduction in air contaminant levels, public exposures, or adverse health effects, and estimated emission reductions were based on simplified calculations rather than measured or verified data. Several recent and ongoing case studies in Canada that provide

measured air quality data "before and after" an intervention should provide more useful information for evaluating the effectiveness of wood-burning intervention strategies. For example, a source apportionment study conducted in Golden, British Columbia found that ambient PM levels decreased following the introduction of a number of wood stove change-out programs (Jeong et al. 2008), while another study in Smithers and Telkwa, British Columbia found a significant decrease in outdoor levels of levoglucosan after an exchange program, but no evidence of a significant change in indoor $PM_{2.5}$ levels (Allen et al. 2009).

Table ES-4: Selected Supporting Information for Model Municipal By-Law Control Strategies *(source: adapted from EC 2006)*

Strategy	Description	Advantages	Disadvantages	Use in Canada
Restrictions on Some Fuels	This by-law would prohibit the use of the following fuels in a wood-burning appliance: wet or unseasoned wood, garbage, treated wood, plastic products, rubber products, waste oil, paints, solvents, coal, glossy colored papers, particle board and salt driftwood	Encourages best practices regarding wood use and will reduce emissions, even in older appliances	Requires public education and enforcement of proper implementation	Prince George, BC; North Saanich, BC; Greater Vancouver Regional District, BC
Installation of Wood-Burning Appliances Option A) All Appliances (certified appliances with or without exceptions) Option B) New Construction (alternative form of space heating with or without exceptions) Option C) Total Ban	This by-law under Option A would prohibit the installation of wood-burning appliances that do not meet the CSA and/or U.S. EPA standard with possible exceptions (e.g., decorative fireplace), under Option B would require that for all new construction the structure contain an alternate form of space heating (e.g., natural gas, propane, electric, oil) with possible exceptions (e.g., systems that could demonstrate low emissions), and under Option C would prohibit the installation of all wood-burning appliances	Encourages manufacture and sale of advanced-technologies, easy to enforce/track through building permits, reduces future air quality concerns	Turnover of old appliances is slow, older appliances could still be used elsewhere, does not address current problem caused by old appliances	Option A only: Prince George, BC; Quesnel, BC; Whitehorse, YK; Greater Vancouver Regional District, BC; Comox, BC
Non-Certified Appliance Removal Option A) Removal Program (Change-Out) Option B) Time Limit Option C) Prior Sale or Transfer of Real Property	This by-law under Option A would entail establishing a voluntary removal program for non-certified wood-burning appliances that may incorporate incentives for energy conservation and air quality improvement, under Option B would require that all wood-burning appliances that are not certified be removed or rendered permanently inoperable by a certain date, and under Option C would require that all existing wood-burning appliances that are not certified be replaced, removed, or rendered permanently inoperable prior to the sale or transfer of real property	Could avoid further regulatory actions (Option A), will directly reduce emissions	Limited effectiveness because voluntary and resources needed to develop and administer program (Option A), and will result in substantial costs to homeowners and require extensive enforcement program (Options B & C)	Option A only: Central Okanagan, BC; Columbia-Kootenay, BC
No-Burn Days Option A) Voluntary Curtailment (non-certified and/or all wood-burning appliances) Option B) Mandatory Curtailment (non-certified and/or all wood-burning appliances)	This by-law under Option A would entail the voluntary curtailment of the use of non-certified and/or all wood-burning appliances whenever conditions within the region are projected to cause a certain level of air pollution, and under Option B would prohibit the use of non-certified and/or all wood-burning appliances during the poorest air quality periods	Minimal time and effort to implement (Option A) and gives strong message that certified appliances are better and can substantially reduce emissions on worst air quality days (Option B)	Limited effectiveness because voluntary (Option A) and will require monitoring and enforcement (Option B)	Option B only: Whitehorse, YK; Prince George, BC;
Nuisance	This by-law states that wood-burning appliance fires shall be maintained so as not to cause a nuisance for more than two minutes in succession (except during a thirty-minute period following the starting or re-fuelling of the appliance)	Can be used as an educational tool and provides recourse for affected neighbors	Requires implementation costs	Central Okanagan, BC.
Opacity	This by-law states that no person owning or operating a wood-burning appliance shall at any time cause, allow, or discharge emissions of an opacity greater than 20% (i.e., opacity is a measurement of the degree to which smoke obstructs the view of objects behind it)	Provides an objective measure of pollution	Measurements require certified personnel and can be time consuming	Whitehorse, YK; North Saanich, BC; Greater Vancouver Regional District, BC

Due to data limitations, we provide only a qualitative indication of the potential effectiveness of different intervention strategies in Canada based on our professional judgment after reviewing the available literature and interviewing Canadian health authorities (see Table ES-5). We conclude that the most effective strategies are likely to be those that mandate the removal of the highest emitting wood-burning appliances (e.g., older, non-certified units), while programs that are voluntary in nature or rely solely on public education campaigns are unlikely to result in significant improvements to public health. Overall, the literature suggests that change-out programs involving some combination of economic incentive (e.g., cash rebate) and education (e.g., that emphasize cost savings, nuisance issues, health effects) are likely to be the most effective. National or provincial legislative efforts may also result in more efficient policies than relying on disparate and non-uniform municipality by-laws.

Table ES-5: Potential Effectiveness of Residential Wood-Burning Intervention Strategies

Strategy[A]	Degree of Effectiveness	Rationale	Potential Barriers
Awareness, Education, and Communication	Low	May not result in any change in behavior	Requires commitment of public to participate in education efforts
Restrictions on Some Fuels	Low	Only acheives a small reduction in emissions and does not address older wood-burning appliances	Difficult to enforce and potential lack of availability of acceptable fuels
Nuisance	Low	Complaint driven and does not address older wood-burning appliances	Neighbors may not want to complain
No-Burn Days Option A) Voluntary Curtailment Option B) Mandatory Curtailment	Low to Moderate	Will reduce emissions at critical times (especially if mandatory), but does not address older wood-burning appliances	Difficult to enforce and potential lack of other available heating source
Opacity	Low to Moderate	Can provide quantitative measure of woodsmoke, but complaint driven and does not address older wood-burning appliances	Neighbors may not want to complain; requires formal testing
Installation of Wood-Burning Appliances Option A) All Appliances Option B) New Construction Option C) Total Ban	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Outdoor Solid-Fuel Combustion Appliances	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Non-Certified Appliance Removal Option A) Removal Program (Change-Out) Option B) Time Limit Option C) Prior Sale or Transfer of Real Property	High	Relatively easy to implement and removes the older, highest emitting wood burning appliances	May face public resistance and puts financial burden on public

[A]Based on strategies identified in the *Model Municipal Bylaws* document (EC 2006)

Note that an important finding of our research is that there appears to be a disconnect in knowledge and coordination among different levels of government in Canada with respect to the health hazards of residential wood-burning and the implementation of wood-burning intervention strategies. In particular, several key data and information gaps were identified based on our work, which if addressed, could result in an improved understanding of the potential health risks associated with residential wood-burning and the most effective ways to prevent or control such risks. These include (1) lack of a central clearinghouse of information related to woodsmoke

emissions, public exposures, and health effects as well as public education and intervention programs that have been implemented in Canada; (2) limited mechanisms for increased dialogues among professionals and the timely transfer and sharing of data or information on intervention strategies; (3) limited data on the effectiveness of different wood-burning intervention strategies and guidance on appropriate evaluation methods and metrics; (4) limited discussions about the feasibility, costs, and benefits of different wood-burning intervention strategies under alternative scenarios; and (5) limited consideration of broader environmental, social, and economic factors.

Given the current state of knowledge, we offer the following five recommendations to better inform health practitioners and policymakers in Canada about potential health risks or other concerns associated with residential wood-burning as well as useful mechanisms for addressing or mitigating these risks:

1. A central clearinghouse or repository of information related to residential wood-burning that is accessible to all levels of government (and the general public) should be developed and hosted under the auspices of a single entity in Canada (perhaps a national-level agency in coordination with other agencies). The repository would include general information on (a) best wood-burning practices and advanced wood-burning appliances; (b) wood-burning emissions, public exposures, and related health effects; and (c) public education campaigns and intervention strategies that have been implemented throughout Canada. This would provide health practitioners and policymakers at the national, provincial, regional, and municipal levels access to shared information to assist in designing their own policies and programs related to residential wood-burning. Although numerous web-based sources of information currently exist, these tend to contain limited and disparate types of information, and it is not clear that those regions and municipalities most impacted by residential wood-burning are aware of many of these resources.

2. An interactive, web-based, government-sponsored resource (i.e., on-line forum not accessible to the general public) should be developed where academic researchers, health practitioners, policymakers, and other professionals can post questions or provide feedback on ongoing or proposed public education programs and intervention strategies. This forum would allow for a relatively easy and timely transfer of information among professionals directly involved in designing and implementing such programs, and could be used to communicate up-to-date information on "lessons learned" regarding the effectiveness of different intervention programs (i.e., what programs are working/not working in different communities and why).

3. Before implementation, all future wood-burning education and intervention programs should include an evaluation component as part of the study design. As part of this effort, a guidance document should be developed that describes best practices and tools for evaluating the effectiveness of different intervention strategies, with an emphasis on meaningful evaluation metrics (e.g., change in behavior following education, improvement in ambient and indoor air quality, reduction in specific health outcomes). This document could also include details from existing or proposed case studies, where available.

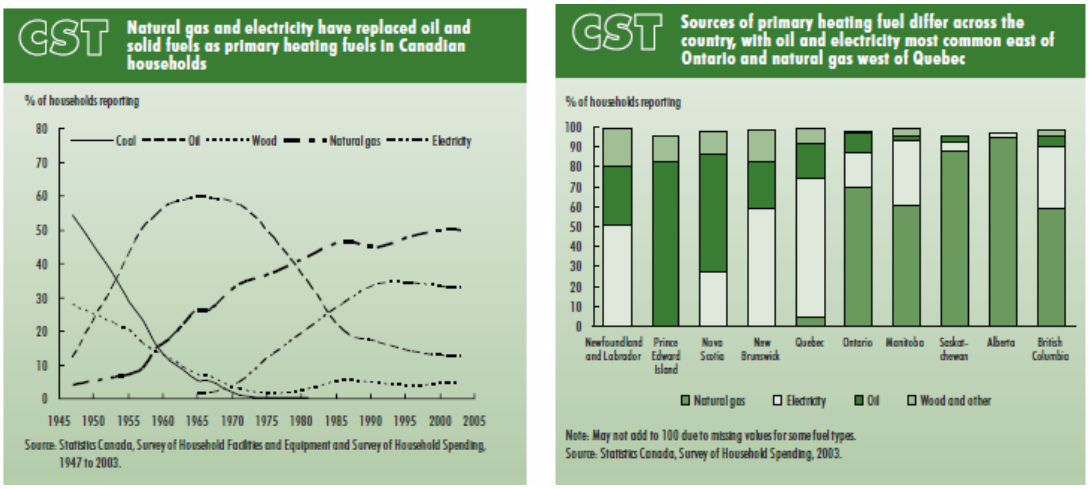
4. A scenario-specific decision analysis should be conducted to assist health practitioners and policymakers in assessing and choosing among various wood-burning intervention strategies for a particular region or municipality. Such an analysis could incorporate data and information on the feasibility, costs, and benefits (e.g., reduction in specific health outcomes) of different intervention strategies under a number of alternative scenarios. The results of this analysis would help ensure that informed decisions are made about the most appropriate and efficient wood-burning strategies for use in a particular area.. Decision analysis methods provide a transparent process for evaluating and informing policy and management decisions. Example applications of the use of these methods for informing decision making and evaluating alternative courses of action can be found in the literature (Belton and Stewart, 2001; Figueira et al., 2005). It should be recognized, however, that total emissions and related health impacts could increase or remain the same even with more efficient intervention strategies if wood-burning use increases in Canada.

5. A broader decision analytical framework should be developed that considers the positive and negative attributes of residential wood-burning in the larger context of other important environmental, social, and economic factors. For example, energy derived from renewable resources (e.g., woody biomass) could significantly reduce greenhouse gas emissions compared to non-renewable resources (e.g., natural gas, electricity) under certain situations when evaluated on a life-cycle basis. Alternatives to wood heat or switching to cleaner-burning appliances may also not be feasible for many households due to economic constraints, unless significant financial incentives or subsidies are available, or in rural areas where power outages are common. A conceptual framework that considers and weighs these types of factors and potential risk tradeoffs could help guide future policy decisions with respect to residential wood-burning in Canada.

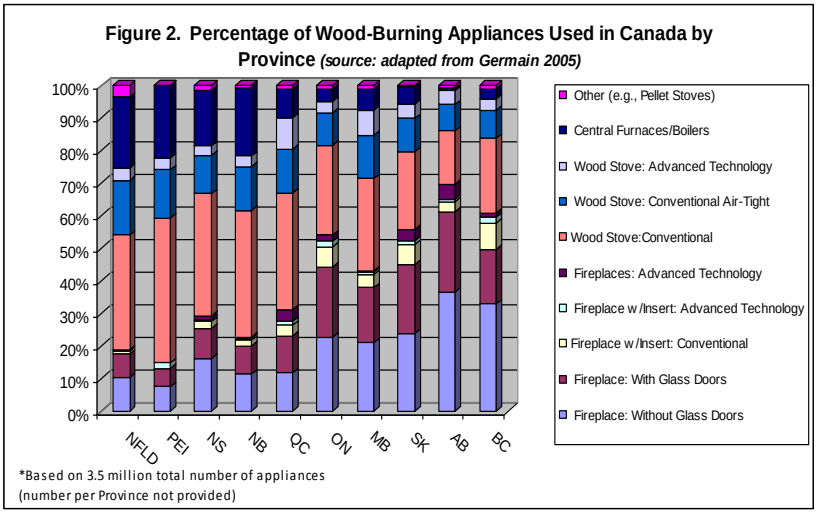
2.0 INTRODUCTION

Wood has been used as source of heat among Canadian households for many years (Snider 2006). In fact, data show that countries with ample wood supplies, such as Canada, burn more biomass fuel per capita than most other countries (Naeher et al. 2007). However, the use of wood as a primary heat source in Canada has declined more than 5-fold over the last 50 years, comprising about 28% of all household heating fuels in 1947 and 5% of all household heating fuels from the 1970s to 2003 (see Figure 1a). Note that this figure is likely to be higher today, given increases in global energy prices and expanded interest in renewable energy sources (Naeher et al. 2007; Xue and Wakelin 2006; Zelikoff et al. 2002; Lightowlers 2000). The Canadian government also encourages the use of wood as a primary or secondary source of heat for dealing with power outages brought on by extreme climatic events (Bélanger et al. 2008). The use of wood and other sources of heating fuels varies considerably by geographic location in Canada, with more wood being used in Quebec and the Atlantic provinces (e.g., New Brunswick, Newfoundland/Labrador) relative to other Canadian provinces in 2003 (see Figure 1b).

Figure 1. Percentage of Canadian Households Reporting the Use of Wood as a Primary Heating Fuel Relative to Other Heating Fuels Over Time (a) and by Province (b) (*source: Snider 2006*)



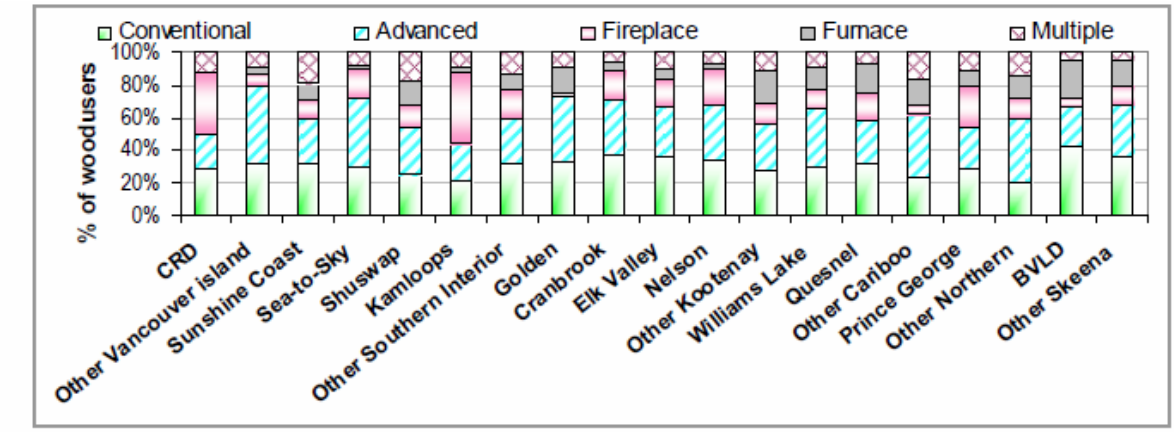
Despite the overall reduction in the use of wood in Canada, it is estimated that more than three million Canadians currently use wood-burning appliances (primarily stoves and fireplaces) as a primary or secondary heat source (Germain 2005; IWGRWC 2002). More specifically, approximately 5% of homes in Canada are estimated to use wood as the principle heating fuel, while 26% are estimated to use wood as a supplementary heating system (IWGRWC 2002). In regards to country-wide energy demand, wood-burning is projected to account for 15% of the biomass energy used, 12% of the energy used in the residential sector, and 1% of the energy used across all Canadian sectors (Germain 2005; Preto 2005). The prevalence of wood heating is often higher in peripheral or rural regions than more urban regions (Bélanger et al. 2008).



Additionally, there are many different types of wood-burning appliances used by Canadian households, and these can also vary by geographic location (see Figure 2). Overall, conventional wood stoves and fireplaces (particularly those without inserts or glass doors) are projected to be used much more frequently across Canada than advanced wood-burning appliances (Germain 2005; IWGRWC 2002). Conventional technology wood-burning appliances are defined as those that do not incorporate "advanced combustion technologies" that meet the Canadian Standards Association (CSA-B415.1-00) or U.S. Environmental Protection Agency emission standards (40 CFR Part 60) for wood heaters or stoves (Germain 2005; IWGRWC 2002). For example, EPA-certified woodstoves must meet a PM emission limit of 7.5 grams per hour for non-catalytic wood stoves and 4.5 grams per hour for catalytic wood stoves, and older uncertified stoves and fireplaces release 40-60 grams of smoke per hour compared to 2-5 grams of smoke per hour for new EPA-certified stoves (Ward and Noonan 2008). CSA-certified wood-heating appliances must currently meet the same standards, although newly proposed CSA-standards (expected to be promulgated in Spring 2010) must meet a PM emission limit of 4.5 grams per hour and 2.5 grams per hour for non-catalytic and catalytic appliances, respectively.

Note that previously reported province-wide estimates do not necessarily reflect the variability or recent change-outs in wood-burning appliances in different regions in Canada. For example, in a 2006 survey conducted in British Columbia (which excludes the Canadian Lower Fraser Valley and Okanagan Valley), advanced wood-burning stoves were found to be used more often than conventional units in many regions (see Figure 3).

Figure 3. Percentage of Wood-Burning Stoves (Conventional or Advanced), Fireplaces, and Other Heat Sources Used in British Columbia by Region (*source: Xue and Wakelin 2006*)



Although residential wood-burning appears to be a generally accepted and common practice in Canada, the combustion of wood can result in significant ambient air pollution at the local level, and potential indoor exposures due to appliance leakage or infiltration from outdoor emissions. Exposure to woodsmoke and/or its constituents has also been associated with various respiratory health effects, particularly in sensitive subgroups such as children. Additionally, as indicated by public health authorities throughout Canada, woodsmoke can pose a nuisance problem among neighbors, particularly in highly centralized urban areas. A range of public education and intervention programs are available and have been adopted in different regions of Canada to address woodsmoke-related issues, but little is known about the efficacy of these efforts. Public perceptions and attitudes can also pose a challenge because users of wood generally perceive fewer health risks from woodsmoke and exhibit less support for woodsmoke control policies than non-users (Hine et al. 2007; Xue and Wakelin 2006), and the perception of living in a region susceptible to winter smog or smog warnings was not found to influence wood-heating practices in Canada (Bélanger et al. 2008).

The purpose of the remainder of this report is to summarize the available literature and information with respect to some of the key issues related to residential wood-burning in Canada, with a particular emphasis on intervention strategies that have been implemented in different provinces and regions. Specifically, the primary objectives of this report are to:

1. Provide a general overview of air contaminant emissions and public exposures from residential wood-burning in Canada and the documented health effects associated with exposure to woodsmoke;

2. Provide a comprehensive summary of documented public education and intervention programs that have targeted residential wood-burning in Canada;

3. Identify key data gaps and research needs related to the design and effectiveness of wood-burning intervention strategies in Canada; and

4. Provide tangible recommendations to the National Collaborating Centre for Environmental Health (NCCEH) to assist in their efforts to better inform health practitioners and policymakers in Canada about potential health risks associated with woodsmoke exposures and useful mechanisms for addressing or mitigating these risks.

3.0 METHODS

Two steps were taken to achieve the objectives outlined above. First, a review of the published and white/grey literature was undertaken to identify relevant studies related to residential wood-burning and woodsmoke. Second, telephone interviews were conducted with representatives of national environmental and health agencies and a sample of health practitioners from different provincial and regional health offices in Canada. A more detailed description of the literature search and interview protocol is provided below.

3.1 Literature Review

We first conducted a literature search to identify existing reviews of contaminant emissions and public exposures from residential wood-burning in Canada and potential health effects associated with exposure to woodsmoke and/or its constituents in developed countries. In addition to summarizing these review articles, we included summaries of individual studies that were identified during our literature search but which were not captured in these reviews, especially if they were conducted in Canada. The summary information on contaminant emissions, public exposures, and health effects provides context and background for understanding the rationale behind the development and adoption of various wood-burning intervention strategies in Canada.

Next, we conducted a more systematic review of the literature to identify relevant studies and data related to residential wood-burning education and intervention programs that have been implemented in Canada. As part of this effort, we attempted to identify studies or recommendations related to the efficacy of different intervention strategies. However, because few programs to date have included an evaluation component, we were not able to review the efficacy of different wood-burning intervention strategies in Canada in a quantitative manner. Additionally, our summary focuses primarily on intervention strategies implemented or supported at the national and provincial/regional levels, as it was difficult to obtain published information on such efforts at the local (municipality) level.

Our literature search was based on the electronic resources available from the Harvard University library system. Specifically, our searches included the following types of terms: wood [and] smoke [and] intervention [and] health; wood [and] smoke [and] health [and] effect

[and] review; wood [and] smoke [and] exposure [and] review. We used all the major databases and search engines, including several proprietary databases, available from the Harvard University system. These included:

- Citation Index/Web of Science
- JSTOR
- National Library of Medicine/PUBMED
- MEDLINE (OvidSP)
- Google Scholar
- Google Books
- TRIP database
- Health-evidence.ca
- EBM (Evidence-Based Medicine) Reviews (OvidSP)
- Cochrane Database of Systematic Reviews (CDSR)
- EMBASE (OvidSP)
- Scirus
- Environmental Research (Harvard University resource)

We also conducted a rigorous search of various Canadian and U.S. government and other relevant websites, including those of Environment Canada, Health Canada, National Resource Canada, British Columbia Ministry of Environment, and the U.S. Environmental Protection Agency.

3.2 Interview Protocol

To learn more about health practitioners' knowledge and views with respect to residential wood-burning and intervention strategies in Canada, we conducted telephone interviews with representatives from a sample of provincial and regional health offices in Canada. Health practitioners were purposely targeted for these interviews, rather than professionals in environmental organizations, because these persons often serve as the primary source of information to the public regarding potential health hazards and risk reduction activities. An attempt was made to contact health practitioners (primarily office Directors or Managers) from approximately 35 provincial or regional health offices in Canada based on a list of initial contacts provided by NCCEH and a random selection of regional health offices. The sampling strategy was designed to target health organizations in all Canadian Provinces (N=10) and Territories (N=3), with a particular emphasis on oversampling those regions with the greatest population size (e.g., British Columbia, Ontario, Quebec). A total of 21 interviews were ultimately conducted with provincial or regional health practitioners, which included several representatives from environmental organizations who were recommended by the health

practitioners as potentially useful sources of information. Additional interviews were conducted with knowledgeable persons at national-level environmental and public health agencies, including Environment Canada, BC Ministry of Healthy Living and Sport, and Metro Vancouver. Appendix 1 provides a list of all the organizations that were contacted at the regional/provincial and national level in Canada.

All interviews were conducted via telephone from March until June 2009. To ensure a baseline level of consistency across the interviews, a standard list of questions was developed in consultation with NCCEH and used to facilitate discussions with each health practitioner. Specific questions related to the practitioner's general knowledge about the extent of wood-burning stoves or fireplaces used by households in their province or region, the type of wood-burning appliances most commonly used (e.g., conventional or advanced), the frequency and duration of wood-burning appliance use, and the primary purpose and reason for the use of wood-burning appliances. Other questions related to whether individual health authorities were involved in tracking, monitoring, or analyzing air contaminant levels or adverse health effects due to residential wood-burning or had observed any impacts to local air quality or public health from woodsmoke exposures. Additional questions related to the development and adoption of public education programs and intervention strategies in different provinces or regions and their degree of effectiveness. Finally, each health practitioner was asked to identify any perceived data gaps or information needs in regards to the residential use of wood-burning appliances.

Because most of the responses to the interview questions were open-ended and based on the subjective judgments of the health practitioners (i.e., most persons contacted did not have specific data to support their general observations), the key findings from these interviews are synthesized and discussed in a more qualitative manner in this report.

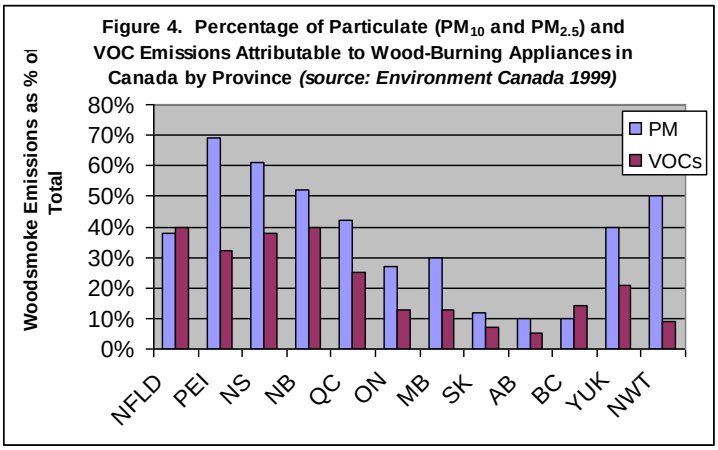
4.0 WOODSMOKE EMISSIONS AND HEALTH EFFECTS

The residential use of wood-burning appliances can impact local air quality and result in potential public exposures to a variety of air pollutants in indoor or outdoor settings. Specifically, emissions from wood-burning stoves and fireplaces consist of a complex mixture of gases and particles including respirable particulate matter (PM) with diameters ≤10 microns (PM_{10}) and fine PM with diameters ≤2.5 microns ($PM_{2.5}$); contaminants that contribute to poor air quality and smog formation such as sulfur oxides (SOx), nitrogen oxides (NOx), and carbon monoxide (CO); and potentially carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs), benzene, aldehydes, and dioxins (Naeher et al. 2007; Basrur 2002; Zelikoff et al. 2002; Larson and Koenig 1994). Exposure to woodsmoke and/or its constituents have also been associated with a number of respiratory-related and other health effects in developedcountries. The following section provides an overview of what is known about

contaminant emissions and public exposures to woodsmoke in Canada and summarizes the most recent health effects literature related to woodsmoke exposures in developed countries.

4.1 Woodsmoke Emissions and Exposures

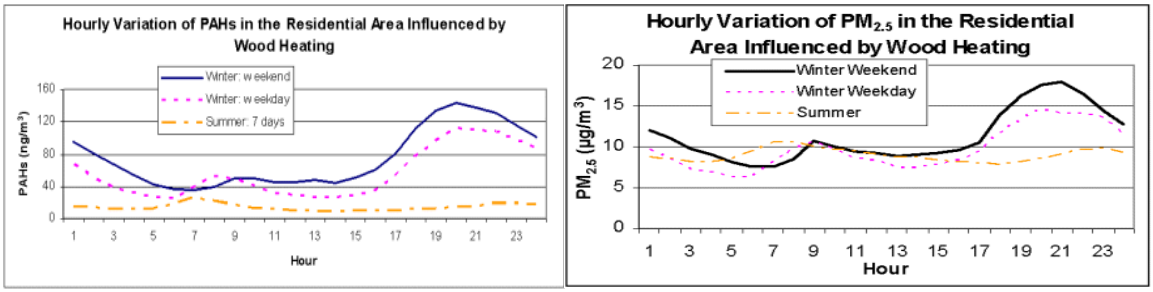
According to the available literature, emissions from residential fuel wood combustion contribute significantly to air pollution in Canada. At the national level, and excluding open sources such as forest fires and dust unpaved roads, it is estimated that residential fuel wood combustion is responsible for approximately 48% of PAH emissions, 25 to 29% of $PM_{2.5}$ emissions, 17% of PM_{10} emissions, 6 to 15% of VOC emissions, 6 to 10% of CO emissions, and 2% of dioxin and furan emissions in Canada (Germain 2005; IWGRWC 2002; Environment Canada 1999). However, the nature and extent of air contaminant emissions attributed to residential wood combustion differs among Canada's provinces and territories. For example, according to some estimates, wood-burning appliances account for approximately 50 to 70% of all $PM_{2.5}/PM_{10}$ emissions in the Northwest Territories, Nova Scotia, and Prince Edward Island and 30 to 40% of all VOC emissions in Newfoundland, Prince Edward Island, Nova Scotia, and New Brunswick (see Figure 4). By comparison, only 5 to 15% of $PM_{2.5}/PM_{10}$ and VOC emissions are attributed to wood-burning appliances in Alberta, British Columbia, and Saskatchewan in this study (see Figure 4).



Specific regions in Canadian may also experience local air pollution problems greater or less than that observed at the broader provincial level. For example, residential wood-heating was identified as one of the main sources of air pollution in the Greater Montreal area of Quebec, and ambient air monitoring conducted from 1998 to 2002 showed that concentrations of PAHs, dioxins/furans, and $PM_{2.5}$ were higher in a residential area northeast of Montreal (where residential wood combustion is popular) compared to downtown Montreal (Environment Canada 2004). Additionally, PAH concentrations and to a lesser extent $PM_{2.5}$ concentrations were higher during the winter than summer and during the night and on weekends in the winter in this study area (see Figures 5a and 5b). Conversely, it is anticipated that residential wood-burning in the City of Toronto results in a smaller contribution to $PM_{2.5}$ and VOC emissions than the estimated provincial annual average of 11% and 15%, respectively, because residential wood-

burning is more prevalent in rural than urban areas (although these emissions are still projected to have a significant impact on air quality and public health in Toronto) (Basrur 2002).

Figure 5. Hourly Ambient Air Concentrations of PAHs (a) and $PM_{2.5}$ (b) in Residential District Influenced by Wood-Heating in Montreal (*source: Environment Canada 2004*)



Air pollution from residential wood-burning is also a concern in many urban areas of the country where usage is more concentrated (Environment Canada 1999). For example, residential wood-burning is believed to be one of the largest cumulative sources of particulate matter in British Columbia, accounting for approximately 15% of all $PM_{2.5}$ emissions or an estimated 10,623 tonnes/year $PM_{2.5}$ emissions province-wide (Xue and Wakelin 2006; BC Ministry 2005; Lightowlers 2000). In an effort to identify high woodsmoke regions within urban airsheds in British Columbia, spatial models have been developed to predict $PM_{2.5}$ ambient concentrations attributable to residential wood-burning in Vancouver and Victoria based on fixed and mobile air monitoring (UBC 2009; Larson et al. 2007; Lightowlers 2000).

A recent source apportionment study was also conducted in a rural valley site (Golden) in British Columbia, in which wood burning and winter heating sources (of which wood-burning is one component) were found to account for approximately 31% and 43% of the total ambient $PM_{2.5}$ mass, respectively (see Figure 6) and these factors were positively correlated with gaseous contaminant and VOC (e.g., benzene, 1,3-butadiene) concentrations (Jeong et al. 2008). Weather patterns, such as those

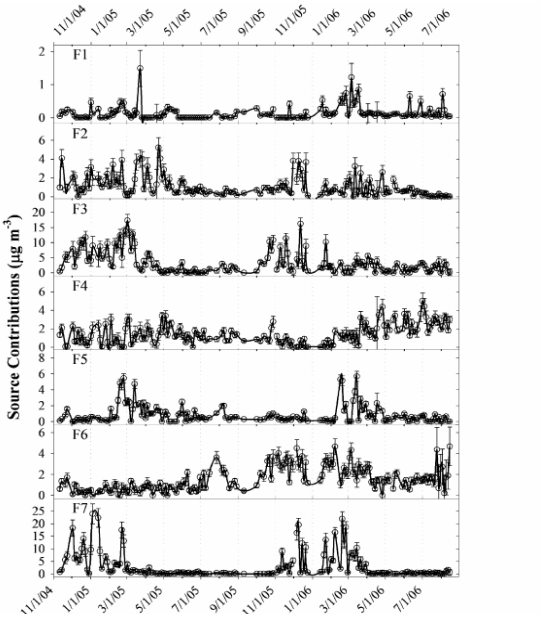


Figure 6. Source Contributions to $PM_{2.5}$ Concentrations in Golden, British Columbia Based on Positive Matrix Factorization (PMF) for Seven Factors; F1: Na-rich, F2: sulfate, F3: wood burning, F4: wood processing, F5: crustal material, F6: traffic, and F7: winter heating (*source: Jeong et al. 2008*)

experienced in the mountainous regions of British Columbia, can also exacerbate air pollution problems by trapping smoke near ground-level in populated valleys for extended periods of time (Jeong et al. 2008; Zelikoff et al. 2002; Lightowlers 2000; Environment Canada 1999). As documented in other reviews, wood-burning is a major source of $PM_{2.5}$ emissions in various cities within the United States too (Naeher et al. 2007; Boman et al. 2003; Zelikoff et al. 2002; Larson and Koenig 1994). For example, in a recent study of a highly populated, urban-scale neighborhood in Seattle, Washington, 24 to 31% of ambient $PM_{2.5}$ levels were attributed to residential wood-burning (Wu et al. 2007).

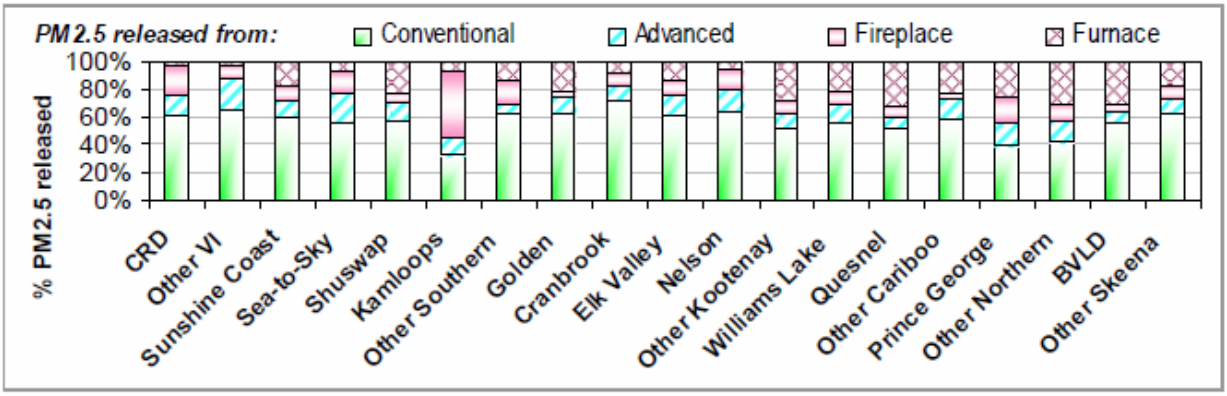
Importantly, the magnitude of air pollutants that are emitted from wood-burning appliances depends largely on the type of combustion unit that is used (as well as the fuel source), with advanced technology appliances producing substantially less emissions than conventional appliances (Germain 2005; Preto 2005; Basrur 2002; Environment Canada 1999). For example, estimated emission factors indicate that conventional wood-burning stoves and fireplaces, particularly those that that are not air tight or do not have glass doors, release approximately 2 to 5 times more emissions of $PM_{2.5}$, CO, VOCs, and PAHs per kg of dry wood burned than advanced combustion technologies as shown in Table 1.

Table 1: Estimated Emission Factors for $PM_{2.5}$, CO, VOCs, and PAHs by Residential Wood-Burning Appliance *(source: Germain 2005)*

Wood combustion appliances	Emission Factors (g/kg) $PM_{2.5}$	CO	VOCs	PAHs
Wood-Burning Fireplaces				
Fireplaces				
Without Glass Doors	18.4	77.7	6.5	0.0375
With Glass Doors	12.9	98.6	21	0.0375
Fireplaces With an Insert				
Conventional	13.6	115.4	21.3	0.215
Advanced Technology (catalytic)	4.8	70.4	7	0.064
Fireplaces Advanced Technology (any)	4.8	70.4	7	0.064
Wood-Burning Stoves				
Conventional Stoves				
Not Air-Tight	23.2	100	35.5	0.215
Air-Tight	13.6	115.4	21.3	0.276
Advanced Technology Stoves	4.8	70.4	7	0.064
Central Furnaces/Boilers	13.3	68.5	21.3	0.288
Other Wood-Burning Equipment *	13.6	115.4	21.3	0.215
Pellet Stoves	1.1	8.8	1.5	0.0015
*Includes outdoor wood boilers				

$PM_{2.5}$ emissions from conventional wood-burning stoves were also found to be much greater than those from advanced wood-burning stoves in a study of different regions in British Columbia (see Figure 7). The complete or partial replacement of old technology wood-burning appliances with state-of-the-art technology appliances is therefore expected to result in substantial reductions (e.g., 30 to 55%) in $PM_{2.5}$, PAH, VOC, and CO emissions attributed to the home heating sector (Xue and Wakelin 2006; Germain 2005; Basrur 2002). Environment Canada provides summaries of annual trends in emissions, but these statistics do not directly address the contribution of wood-burning appliance emissions to ambient air concentrations before and after implementation of CSA standards. In addition, CSA standards only apply to new purchases, consequently, the resulting impact on ambient air concentrations requires removal of older, less-efficient units, and this must be taken into account when evaluating the impact of CSA on ambient air quality.

Figure 7. Percentage of $PM_{2.5}$ Released from Wood-Burning Stoves (Conventional or Advanced), Fireplaces, and Other Heat Sources used in British Columbia by Region (*source: Xue and Wakelin 2006*)



It is also important to recognize that most of the available literature focuses on contaminant emissions or ambient contaminant concentrations associated with residential wood-burning rather than human exposures. These data may therefore not accurately reflect daily personal exposures to woodsmoke, particularly indoors where people spend the most time. Indoor woodsmoke emissions are driven by two factors: appliance leakage (indoor emissions) and infiltration (outdoor emissions), the latter of which is dependent on many factors (e.g., home air exchange, climatology). Some studies show that indoor air quality is not affected by heat source or that infiltration due to wood-burning is minimal. For example, in a study of wood-burning appliances and indoor air quality in the Quebec City region, in which the sources of all combustion products were controlled, measured indoor air concentrations in 49 homes of formaldehyde, NO_2, PM_{10}, and CO were not significantly different in homes with a wood-burning appliance compared to homes with exclusive electric heating (Lévesque et al. 2001). Additionally, in a cross-sectional survey of 36 homes in Montreal, Quebec and Pembroke,

Ontario during the winter months, home heating systems (including wood stoves) were not found to be important determinants of indoor ultrafine particle exposures (Weichenthal et al. 2007). A study conducted in two communities (Smithers and Telkwa) in the Bulkley Valley and Lakes District of British Columbia also found that there was no consistent relationship between stove technology and outdoor or indoor concentrations of $PM_{2.5}$ or levoglucosan following a wood stove exchange program (Allen et al. 2009). Another study conducted in Prince George, British Columbia found that the mean infiltration of $PM_{2.5}$ (i.e., the fraction of outdoor particles that penetrate and remain suspended in indoor air) due to residential wood-burning in the wintertime was only 0.28, which indicated a substantial reduction in the concentration of outdoor generated particles indoors relative to outdoors (Barn et al. 2008). In the United States, a residential wood-burning study conducted during a relatively severe winter in Waterbury, Vermont showed that although one of the major outdoor sources of fine fraction particles was residential wood combustion, measured indoor particle concentrations were not significantly different between homes that burned wood and those that did not (Sexton et al. 1986).

On the other hand, some studies suggest that residential wood-burning can increase indoor contaminant concentrations either from indoor (leakage) or outdoor (infiltration) emissions, or contribute significantly to personal contaminant exposures. For example, in an exposure study in a small town in Sweden (Hagfors) where wood-burning for domestic heating is common, significantly higher indoor levels of 1,3-butadiene, benzene, and several PAHs were found in homes using wood-burning appliances compared to homes without in the same residential area and high correlations were found between measured personal exposures and indoor levels of these pollutants (Gustafson 2009). In another study of a Rocky Mountain valley community (Libby, Montana) in the United States, average and maximum indoor $PM_{2.5}$ concentrations were found to be significantly lower following a woodstove change-out program where new EPA-certified woodstoves were installed (Ward and Noonan 2008). However, it is not clear from either of these studies to what extent the measured indoor contaminant concentrations were driven by indoor versus infiltration emissions. Several other research and review papers have also concluded that wood-burning stoves and fireplaces can create high indoor pollution (especially if non-airtight or improperly operated wood stoves are used) and that ambient particles can readily penetrate inside residences in some woodsmoke-impacted communities (Naeher et al. 2007; Zelikoff et al. 2002; Larson and Koenig 1994; Sexton et al. 1986). For example, one study (based on unpublished data) found that approximately 70% of woodsmoke from chimneys can re-enter the home and neighboring residences (i.e., infiltration factor of 0.7) (Pierson et al. 1989). Additionally, in a study of the intake fraction of urban woodsmoke (i.e., proportion of emissions inhaled by an exposed population), urban woodsmoke was found to be an important source of $PM_{2.5}$ exposures, with intake fractions for woodsmoke comparable to or slightly larger than that for urban vehicle emissions (Ries et al. 2009).

4.2 Health Effects Associated with Woodsmoke

Several relatively recent review papers were identified from the published literature that summarize the health effects associated with woodsmoke or its constituents from residential wood combustion in developed countries (Naeher et al. 2007; Boman et al. 2003; Zelikoff et al. 2002; Larson and Koenig 1994). According to the available literature, many woodsmoke constituents have been shown individually to produce acute and/or chronic health effects in exposed humans. Of the more than 200 chemicals and compound groups contained in woodsmoke, fine particles (which can penetrate deep into the lung) are generally considered to be the best indicator of the health impacts of combustion sources, although the composition of woodsmoke particles is different from that of particles from fossil fuel combustion from which most health effects studies are based. PM_{10} and $PM_{2.5}$ are primarily associated with causing inflammation and oxidative stress and may be allergenic, while other woodsmoke constituents are known respiratory irritants and may have mutagenic and/or carcinogenic properties (see Table 2).

The three types of studies that have been used to assess potential health effects attributable to woodsmoke include: (1) a very limited number of controlled human exposure studies, (2) human epidemiology studies, and (3) animal toxicology studies. Based on the overall weight-of-evidence, exposure to woodsmoke in developed countries has been associated with a variety of adverse respiratory health effects and symptoms (e.g., lung function decrements and shortness of breath; exacerbation of asthma; wheezing, coughing and congestion), particularly in children, with potential cardiovascular and cancer effects being less certain. In developing countries, there is also some evidence linking biomass smoke under certain exposure conditions to chronic obstructive pulmonary disease (COPD) and perhaps lung cancer among women and acute lower respiratory infections among children due to cooking indoors with open unvented fire (Smith 2008; Hernández-Garduño et al. 2004; Zelikoff et al. 2002; Larson and Koenig 1994). Based on limited human evidence of lung cancer in humans (due to cooking indoors) and supporting animal and mechanistic data, the International Agency for Research on Cancer (IARC) recently categorized household biomass fuel (mainly wood) as Category 2A "probably carcinogenic to humans" (Straif et al. 2006)

In the most recent review by Naeher et al. (2007), the authors attempt to address whether woodsmoke should be regulated and/or managed separately from its constituents and whether woodsmoke particles pose different levels of risk than other ambient particles of similar size. This review covers the chemical and physical nature of woodsmoke as well as the exposure and health effects literature for different combustion sources (e.g., wildland fires, agricultural.

Table 2: Air Contaminants Associated with Wood Smoke and their Mode of Toxicity *(adapted from Naeher et al. 2007)*

Class of Compound	Specific Contaminant	Mode of Toxicity
Inorganic gases	Carbon monoxide	Asphyxiant
	Ozone	Irritant
	Nitrogen dioxide	Irritant
Hydrocarbons	1,3-butadiene	Irritant, carcinogenic, mutagenic
	Benzene	Carcinogenic, mutagenic
	Polycyclic aromatic hydrocarbons	Mutagenic, carcinogenic
Oxygenated organics	Aldehydes (formaldehyde)	Irritant, carcinogenic, mutagenic
	Organic alcohols	Irritant, teratogenic
	Phenols	Irritant, carcinogenic, mutagenic, teratogenic
Particulate matter	Inhalable particles (PM_{10})	Inflammation and oxidative stress, may be allergenic
	Fine particles ($PM_{2.5}$)	Inflammation and oxidative stress, may be allergenic

burning, residential wood-burning) in developed and developing countries, including Canada. In regards to residential wood-burning in developed countries, the authors identify only one controlled human exposure study involving woodsmoke itself, in which suggestive evidence of woodsmoke-associated systemic inflammatory effects was observed. The authors state that the majority of information regarding direct human health effects associated with woodsmoke exposure is derived from a relatively large number of epidemiologic studies (primarily conducted in the United States), in which respiratory effects and symptoms are often observed in residents of homes utilizing wood-burning, especially in children. For example, extensive health effects research conducted in Seattle, Washington show associations between $PM_{2.5}$ and lung function decrements in children, increases in asthma symptoms in children, and increased visits to emergency departments and hospitalizations for asthma. The authors also find that the majority of animal toxicology studies provide biological plausibility for the epidemiologic evidence suggesting that exposure to woodsmoke emissions adversely affects human health, particularly in regards to impacts on the respiratory immune system, and that woodsmoke is mutagenic and possibly carcinogenic in laboratory and field studies. Based on their review of the available literature, Naeher et al. (2007) conclude that woodsmoke associated with residential wood-burning is likely to cause a variety of adverse respiratory health effects, but there is only limited evidence for cardiovascular or cancer effects in developed countries. Additionally, the authors do not believe that there is currently sufficient evidence to regulate woodsmoke separately from its constituents (especially $PM_{2.5}$) or to conclude that woodsmoke particles pose different levels of risk than general ambient fine particles.

In another review article, Boman et al. (2003) identified nine relevant epidemiological studies (conducted in the United States, New Zealand, and Canada) that focus on adverse health effects from short-term exposure to ambient air pollutants in which residential wood combustion was identified as a major source of pollution. A number of health effects were assessed in these studies (e.g., daily mortality; asthma symptoms, hospital emissions, and emergency room visits;

lung function and respiratory symptoms) across different contaminant indicators (e.g., PM_{10}, $PM_{2.5}$, SO_2, CO, NO_2, O_3). However, the authors conclude that significant information was only found for a relationship between acute asthma and PM_{10} exposure (note that PM_{10} was the most commonly used indicator for ambient particulate matter), although CO also showed significant positive associations with the worsening of asthma in the Seattle, Washington area. The authors also conclude that there seems to be no reason to assume that the health effects associated with PM in areas polluted with woodsmoke are weaker than elsewhere.

In a self-described "mini-review" article, Zelikoff et al. (2002) summarize many of the human and animal studies performed over the last three decades regarding the toxicological impact of inhaled woodsmoke on exposed children and adults, with particular attention given to immune system effects. The authors state that a variety of acute and chronic health ailments have been associated with exposure to individual woodsmoke constituents (e.g., upper airway irritation, exacerbation of bronchial asthma, increased airway resistance, decreased vital capacity, increased respiratory symptoms, infections), and in particular, that there is a considerable body of epidemiologic evidence linking short-term exposure to PM with respiratory symptoms and other health outcomes. According to the study authors, a number of adverse effects have also been associated with exposure to woodsmoke itself based on limited laboratory animal and human epidemiology studies, and these effects appear to be related to the host age at the time of woodsmoke exposure. For adults, prolonged inhalation of woodsmoke was found to contribute to chronic bronchitis, chronic interstitial lung disease, and pulmonary arterial hypertension. For children, who appear to be a greatest risk, woodsmoke exposure was found to result in decreased pulmonary lung function in young asthmatics; increased incidence of acute bronchitis and severity/frequency of wheezing and coughing; and increased incidence, duration, and possibly severity of acute respiratory infections. Woodsmoke and many of its individual constituents were also found to alter pulmonary immune defense mechanisms in a persistent and often progressive manner in animal toxicology studies. The authors conclude that despite the limited studies on this topic, exposure to woodsmoke represents a potential health hazard, particularly for children.

In an earlier review, Larson and Koenig (1994) summarize the adverse noncancer respiratory effects associated with woodsmoke exposures based on animal toxicity and human epidemiological studies. The authors find that few data are available on acute effects (and none on chronic effects) of inhalation of woodsmoke based on animal studies, but indicate that existing toxicological studies show that woodsmoke exposure can disrupt cellular membranes, depress macrophage activity, destroy ciliated and secretory respiratory epithelial cells, and cause aberrations in biochemical enzyme levels. However, the authors note that none of the available animal studies evaluate relevant endpoints such as pulmonary function or symptoms of respiratory illness, and caution that extrapolation of these result to human populations living in

areas with elevated woodsmoke concentrations is very difficult. The authors also state that, at the time of their review, no controlled laboratory studies of human subjects exposed to woodsmoke were reported. In regards to human epidemiological studies, the authors reference eight studies that have found associations between respiratory symptoms, lower respiratory infection, and decreased pulmonary function as a result of exposure to woodsmoke (primarily in children with asthma), and one study linking emergency room visits for asthma and $PM_{2.5}$. The authors conclude that the preponderance of the data suggest a causal relationship between elevated woodsmoke levels and adverse respiratory health outcomes in young children.

Note that only one health effects study cited in the review article by Boman et al. (2003) was conducted in Canada, and it is questionable whether the results of this study are actually attributed to woodsmoke versus other sources of air pollution. Specifically, a study by Vedal et al. (1998) compared the acute effects of ambient PM_{10} in asthmatic and nonasthmatic children living in a pulp mill community (Port Alberni) on the west coast of Vancouver Island. However, the findings from this study are of limited use in assessing health effects attributable to residential wood-burning since both the pulp mill boilers and wood-burning were identified as the main sources of ambient particulate pollution in this town, and no attempt was made to apportion measured ambient PM_{10} concentrations to these sources.

One additional study was also identified from the published literature (which was not cited in the prior reviews) that specifically assessed the extent of indoor air contamination and frequency of respiratory symptoms and illnesses among occupants of wood-heated homes in the Quebec City region of Canada (Lévesque et al. 2001). In this study, which consisted of 89 child-adult pairs in three municipalities, indoor air samples were collected in 49 homes heated by wood or electricity (while the appliance was in use) and the frequency of respiratory symptoms and diseases among participants was documented using a daily symptom diary. Respiratory illnesses were classified by their medical symptoms or diagnoses and were categorized as either upper, lower, or complicated lower respiratory tract illnesses. Study results showed relatively low indoor air concentrations of all pollutants measured with no significant association observed between respiratory problems and PM_{10} levels above 20 $\mu g/m^3$. No significant findings were observed between respiratory symptoms and a combustion appliance for children, but a statistically significant relationship was obtained between having a wood-burning stove or fireplace and complicated lower pathologies for adults (a somewhat counterintuitive finding). Adult residents who claimed to have been exposed to fumes during the use of a wood-burning appliance also reported more respiratory illnesses and symptoms. Other factors that were associated with respiratory problems in either children or adults included the presence of animals or molds and keeping the windows closed in the winter. Although the authors conclude that residential wood-burning appears to be a respiratory health risk for occupants if the appliance is

not maintained and used properly, they acknowledge that the existing literature provides inconsistent results for the effects of wood-heating on respirable air and human health.

5.0 WOOD-BURNING INTERVENTION STRATEGIES

Because residential wood-burning has been found to cause significant air pollution problems throughout Canada, and has been identified by public health authorities as a nuisance issue or potential health hazard in some areas, various efforts have been undertaken by governmental agencies in Canada to try to educate the public regarding safe burning practices and to restrict the use of wood-burning appliances by households. Similar types of public education programs and health intervention strategies have also been implemented in other developed and developing countries (U.S. EPA 2005; von Schirnding et al. 2000), and global wood-burning appliance change-out programs are considered to be similar in magnitude, scope, and relevance to Canadian wood stove change-out programs (CCME 2004). The following section summarizes the nature, type, and potential effectiveness of wood-burning intervention strategies that have been implemented in Canada at the national, provincial, regional, and/or municipality level. The key findings from telephone interviews with a sample of Canadian health authorities and representatives from national environmental and health organizations are also summarized.

5.1 Published Literature on Intervention Strategies in Canada

A number of public education and intervention programs have been developed and adopted in Canada to address air quality impacts associated with residential wood-burning and potential adverse health effects from woodsmoke exposures. General information, fact sheets, and/or guidelines on residential wood-burning and woodsmoke are accessible to the public via various website links (see Table 3).

In regards to national public education efforts, perhaps the most notable is the *Burn it Smart!* program, which was launched in 2002-2003 by Natural Resources Canada (NRCan) in partnership with Health Canada and Environment Canada to increase public awareness related to health and safety issues and good practices when heating with wood. A series of promotional publications and videos were developed under this program which address air contaminant emissions and health impacts from wood-burning, advanced wood-burning technologies, and best burning practices. Note that NRCan's *Burn it Smart!* website is no longer active, but its promotional materials as well as educational materials on good wood-burning practices are available through Environment Canada's *Clean Air On-Line* website, which describes a range of air pollution issues, sources, and impacts (including residential wood-heating). Similarly, the British Columbia Ministry of the Environment and the British Columbia Lung Association provide online information on fine particulate emissions and health effects from wood-fired combustion as well as "smart burning" tips and brochures on ways to reduce exposures to

Table 3: Summary of Website Links Related to Informational Materials and Change-Out Programs in Canada

Program or Topic	Supporting Organization	Website URL
Burn it Smart!	Environment Canada (formerly NRCan)	http://www.environnement-canada.ca/cleanair-airpur/Campagne_chauffage_au_bois-WS69573E19-1_En.htm
Clean Air Online	Environment Canada	http://www.ec.gc.ca/cleanair-airpur/Home-WS8C3F7D55-1_En.htm
Healthy Living - Woodsmoke	Health Canada	http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/wood-bois-eng.php
Particulates and Woodsmoke	British Columbia Ministry of Environment	http://www.env.gov.bc.ca/air/particulates/index.html
Smart Burning Tips	British Columbia Lung Association	http://www.bc.lung.ca/airquality/wood_burning.html
Wood Burning Efficency and Safety	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/efficiently.html
Woodsmoke Health Effects	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/healtheffects.html
Residential Wood-Heating Guide	Wood Heat Organization Inc	http://www.woodheat.org/
Woodsmoke Pollution	Citizens for Environmental Health	http://02a17a1.netsolhost.com/sustainability_community.html
ecoEnergy Home Retrofit	Natural Resources Canada	http://oee.nrcan.gc.ca/residential/personal/retrofit-homes/retrofit-qualify-grant.cfm
Woodstove Changeout Campaigns	U.S. Environmental Protection Agency	http://www.epa.gov/woodstoves/changeout.html#links
Hearth Changeout Programs	Hearth and Patio Builders Association	http://woodstovechangeout.org

woodsmoke. Additionally, as part of its *Healthy Living* website, Health Canada provides public information on the health effects associated with woodsmoke and ways to minimize risks associated with woodsmoke exposure. The U.S. EPA website also provides general information on residential wood-burning efficiency and safety and health effects associated with woodsmoke. Additional educational information and fact sheets on woodsmoke pollution and residential wood-heating guides are available from nonprofit, nongovernmental agencies such as Wood Heat Organization Inc., and public citizen groups such as Citizens for Environmental Health.

Because advanced technology wood-burning appliances emit less pollutants than conventional technology appliances, most of the intervention strategies implemented in Canada relate to providing incentives for changing-out old heating units for newer ones. For example, through its *ecoEnergy Home Retrofit* program, NRCan provides financial support of $375 (1st system) and $190 (2nd system) for single-family homes to encourage Canadians to replace their conventional wood-burning appliance with a certified wood-burning or indoor wood pellet-burning appliance. Websites for the U.S. EPA and Hearth and Patio Builders Association (HPBA) also provide

information on woodstove change-out campaigns and programs that have been undertaken or are currently underway in the United States, and to a lesser extent, Canada.

In 2000, the Canadian Council of Ministers of the Environment endorsed Canada-wide standards for $PM_{2.5}$ and ozone (CCME 2000). Under the Canada-wide standards, residential wood-burning has been identified as a priority sector for the reduction of contaminant emissions. As part of this process, CCME has committed to a list of Joint Initial Actions that include: (1) an update of the CSA standards for new wood-burning appliances, (2) continuation of national public education programs and campaigns, (3) an assessment of a national wood stove upgrade or change-out program, and (4) development of a national regulation for new clean-burning residential wood-heating appliances. An updated standard from the Canadian Standards Association for wood-heating appliances (CSA B415.1, *Performance Testing of Solid-Fuel Burning Heating Appliances*), is expected to be promulgated in Spring 2010 and the public comment period ended in August, 2009. The proposed revised standard lowers the PM emission rate to 4.5 gr/hr for non-catalytic wood-heating appliances and to 2.5 gr/hr for catalytic wood-heating appliances.

The Intergovernmental Working Group on Residential Wood Combustion (IGWGRWC), which is comprised of representatives from municipal, provincial, territorial and federal governments, was formed in 1999 to promote and coordinate government actions on the sustainable development of residential wood combustion (IGWGRWC 2002). The first priority of this working group was to address the four components related to residential wood combustion under the Canada-wide standards. In 2002, IGWGRWC led a stakeholder workshop to identify options for reducing emissions from residential wood-burning appliances, which represented Canada's first national consultation on residential wood-burning appliances (IGWGRWC 2003). During the workshop, there was a general acceptance among participants that a public education campaign goes hand-in-hand with a change-out program (i.e., one informs and supports the other), and that these efforts would have greater impact if implemented together with a regulation (although there were different views on the legislative authority that should be used to develop a regulation). Regarding next steps, the workshop participants generally agreed that the IGWGRWC should create multi-stakeholder task groups to address these components and a Core Advisory Group to provide strategic direction and advice on the consultation process.

Since the initial IGWGRWC stakeholder workshop, CCME commissioned a feasibility assessment of a national change-out/education program aimed at reducing emissions from residential wood combustion. The purpose of this assessment was two-fold: (1) to evaluate whether change-out programs or education campaigns alone or in combination would be more effective in achieving reductions in $PM_{2.5}$ emissions from the residential wood sector; and (2) to assess the feasibility of a national wood stove change-out/education campaign (CCME 2004).

As part of this effort, 12 wood stove change-out/education campaigns in different regions of Canada were examined (see Table 4). A key findings from this assessment was that while information campaigns serve to raise public awareness of the issue, they are not sufficient by themselves to lead to changes in behavior with respect to the use of wood-burning appliances. Significant barriers to effective wood-burning change-out programs were also identified due to the cost of advanced appliances and long service life of conventional appliances. Successful change-out strategies were defined as those that combine tactics that target individual motivations, remove barriers to and provide incentives for behavior change, and are supported by an education program. Regulation was deemed to be the most effective approach to stopping the retail sale of conventional woodstoves, and without such a mandate, it was recommended that a national change-out program not be undertaken.

In another effort to address one of the key components related to the Canada-wide Standards, a *Model Municipal Bylaw for Regulating Woodburning Appliances* was published under the auspices of the IGWGRWC as a tool to assist communities in addressing air quality problems from residential wood combustion (Environment Canada 2006). Specifically, this document was intended for use by a municipality wishing to develop and put in place a municipal by-law to regulate wood-burning appliances. The document provides supporting information on seven potential control strategies that are part of the model municipal by-law which either specify limits on total emissions or provide incentives (or impose disincentives) to limit emissions from wood-burning appliances (see Table 5). The IGWGRWC document also provides a non-exhaustive list of jurisdictions in Canada (and the United States) that have implemented these strategies. Additional supporting information is provided for strategies that do not yield quantifiable emissions reductions, such as those related to public education and outreach. One or a combination of these strategies can be used to address local air quality problems, depending on the level of authority delegated by the province or territory where a municipality is located.

Besides these efforts at the national level, limited information is available on recent public education and intervention efforts that have been implemented in specific provinces of Canada. For example, from March 1, 2009 through April 30, 2009, British Columbia offered a provincial wood stove exchange program to encourage residents to exchange older wood stoves for low emission appliances, including gas, pellet, and U.S. EPA-certified clean-burning wood stoves or inserts (BC Ministry of Environment 2009). This program offered discounts and rebates to promote exchanges and provided education materials to assist residents in operating wood-burning appliances efficiently and reducing their emissions. The British Columbia Ministry of Environment also recently initiated a wood stove exchange study (called *WEST*) in the Bulkley Valley Lakes District as part of the air quality management plan for this airshed, with the goal of replacing all non-certified stoves in five specific communities (Terrace, Telkwa, Smithers,

Table 4: Summary of Selected Wood Stove Change-out Efforts in Canada
(Adapted from CCME 2004)

Municipality	Approach	Duration	Budget per Community	Incentives offered	Program Impacts	
					Qualitative	Quantitative
BC Changeout (1995)	Change-out	One season April 1 - May 15	$7463 per community	$50 - $200 cash discount; Enviroloan program	208 responses to 1 800 number	196 exchanges; estimated reduction of 11220 grams particulate per hour (calculated, not measured)
Nova Scotia (1997)	Change-out supported by education	One season Sept 3 - 10	$21950 cash and $27635 in kind over 100,000 households	$150 cash	1000 requests for information to 1 800 number	120 stoves traded in; 72 recycled; estimated reduction of 3960 gr/hr (calculated, not measured)
New Brunswick (1997)	Change-out supported by education	One season Sept 3 - Oct 15	Budget unknown	Under $250	200 participants in moisture testing clinics; 900 people phoned the 1 800 number	112 woodstoves exchanged; estimated reduction of 6160 gr/hr of PM (calculated, not measured)
ALAP Project Quebec (2001)	Change-out supported by education	One season three weeks in Autumn	$1097 per community	$210 - $300 rebate	175000 flyers; 2600 posters; 2000 user guides	68 wood stoves changed out; estimated reduction of 3855 gr/hr PM (calculated, not measured)
Great Eastern Ontario Woodstove Change-out Program	Change-out supported by education	Starting in January for eight weeks	$10875 per community	Trade-in rebate of $150	Eight public workshops with 500 total attendees	83 wood stove exchanges; 28 fireplace inserts; estimated reduction of 6365 gr/hr PM (calculated, not measured)
Renewing an Old Flame Campaign (2000)	Education campaign	One season in fall	$65000 cash	None	Point of sale purchase materials	unknown
Great Woodstove change-out and Education Program of Georgian Bay (2001)	Change-out supported by education	Starting in late February for nine weeks	$33267 per region	Trade in rebate of $125	12 workshops (1210 total participants)	85 woodstoves; estimated reduction of 4675 gr/hr PM (calculated, not measured)
First Nation Communities in Ontario (2002-2003)	Education campaign	Unknown	Unknown	None	14 workshops (171 total attendees)	Unknown
2003 Great Okanagan Woodstove Exchange Program	Change-out supported by education	Early February for six weeks	$13000 cash and $5000 in kind	15% trade-in allowance (up to $500)	3 workshops (214 total attendees)	190 wood stoves; estimated reduction of 7725 gr/hr PM (calculated, not measured)
Whitehorse Efficient Wood Heat Demonstration	Demonstration	Nine one week PM emissions sampling periods	Unknown	None	14 homeowners reduced emissions by adopting better burning practices	8 change-outs
Burn it Smart	Change-out supported by education	January - March 2002	$161548 cash and $381627 in kind	Various	reached 6940 participants (home visit or workshop)	223 change-outs

*Note that the Whitehorse Efficient Wood Heat Demonstration was excluded from analysis because it was determined that this was a scientific study rather than a change-out/education campaign.

Table 5: Selected Supporting Information for Model Municipal By-Law Control Strategies *(source: adapted from EC 2006)*

Strategy	Description	Advantages	Disadvantages	Use in Canada
Restrictions on Some Fuels	This by-law would prohibit the use of the following fuels in a wood-burning appliance: wet or unseasoned wood, garbage, treated wood, plastic products, rubber products, waste oil, paints, solvents, coal, glossy colored papers, particle board and salt driftwood	Encourages best practices regarding wood use and will reduce emissions, even in older appliances	Requires public education and enforcement of proper implementation	Prince George, BC; North Saanich, BC; Greater Vancouver Regional District, BC
Installation of Wood-Burning Appliances Option A) All Appliances (certified appliances with or without exceptions) Option B) New Construction (alternative form of space heating with or without exceptions) Option C) Total Ban	This by-law under Option A would prohibit the installation of wood-burning appliances that do not meet the CSA and/or U.S. EPA standard with possible exceptions (e.g., decorative fireplace), under Option B would require that for all new construction the structure contain an alternate form of space heating (e.g., natural gas, propane, electric, oil) with possible exceptions (e.g., systems that could demonstrate low emissions), and under Option C would prohibit the installation of all wood-burning appliances	Encourages manufacture and sale of advanced-technologies, easy to enforce/track through building permits, reduces future air quality concerns	Turnover of old appliances is slow, older appliances could still be used elsewhere, does not address current problem caused by old appliances	Option A only: Prince George, BC; Quesnel, BC; Whitehorse, YK; Greater Vancouver Regional District, BC; Comox, BC
Non-Certified Appliance Removal Option A) Removal Program (Change-Out) Option B) Time Limit Option C) Prior Sale or Transfer of Real Property	This by-law under Option A would entail establishing a voluntary removal program for non-certified wood-burning appliances that may incorporate incentives for energy conservation and air quality improvement, under Option B would require that all wood-burning appliances that are not certified be removed or rendered permanently inoperable by a certain date, and under Option C would require that all existing wood-burning appliances that are not certified be replaced, removed, or rendered permanently inoperable prior to the sale or transfer of real property	Could avoid further regulatory actions (Option A), will directly reduce emissions	Limited effectiveness because voluntary and resources needed to develop and administer program (Option A), and will result in substantial costs to homeowners and require extensive enforcement program (Options B & C)	Option A only: Central Okanagan, BC; Columbia-Kootenay, BC
No-Burn Days Option A) Voluntary Curtailment (non-certified and/or all wood-burning appliances) Option B) Mandatory Curtailment (non-certified and/or all wood-burning appliances)	This by-law under Option A would entail the voluntary curtailment of the use of non-certified and/or all wood-burning appliances whenever conditions within the region are projected to cause a certain level of air pollution, and under Option B would prohibit the use of non-certified and/or all wood-burning appliances during the poorest air quality periods	Minimal time and effort to implement (Option A) and gives strong message that certified appliances are better and can substantially reduce emissions on worst air quality days (Option B)	Limited effectiveness because voluntary (Option A) and will require monitoring and enforcement (Option B)	Option B only: Whitehorse, YK; Prince George, BC;
Nuisance	This by-law states that wood-burning appliance fires shall be maintained so as not to cause a nuisance for more than two minutes in succession (except during a thirty-minute period following the starting or re-fuelling of the appliance)	Can be used as an educational tool and provides recourse for affected neighbors	Requires implementation costs	Central Okanagan, BC.
Opacity	This by-law states that no person owning or operating a wood-burning appliance shall at any time cause, allow, or discharge emissions of an opacity greater than 20% (i.e., opacity is a measurement of the degree to which smoke obstructs the view of objects behind it)	Provides an objective measure of pollution	Measurements require certified personnel and can be time consuming	Whitehorse, YK; North Saanich, BC; Greater Vancouver Regional District, BC

Houston, and Burns Lake) by 2010 (UBC 2009). This study will involve evaluating temporal trends in exposures using monitoring network data, fixed site monitors, mobile monitoring, and spatial monitoring in relation to administrative health data (e.g., outpatient visits, hospitalizations, school absences).

In addition, British Columbia created an inventory of air quality by-laws for anti-idling, open-burning, and wood-burning appliances based on a survey of all regional districts and incorporated municipalities (N=185) conducted between January and April of 2007 (Alderson 2007). According to this survey, various communities in British Columbia had a total of 30 wood-burning appliance by-laws and 12 building code by-laws with wood-burning appliances terms (see Table 6). The survey found that a common approach to regulating wood-burning appliances in this region was to ensure that new stoves were certified by the CSA or U.S. EPA, and that some communities (e.g., Burns Lake, Houston, Smithers) had set removal dates on non-certified wood stoves. Survey results also showed that significantly more open-burning by-laws have been adopted in British Columbia than wood-burning appliance or anti-idling by-laws, perhaps because these former by-laws have traditionally been passed for fire prevention rather than air quality measures. Note that the terms of each by-law are attached as an Appendix to the original report (and are not summarized here). At the local level, available information also suggests that a range of interventions have been implemented by various municipalities throughout Canada (e.g., bans on residential wood-burning). However, this information is not readily available from the published literature or public health authorities, and a comprehensive summary of wood-burning interventions at the local level would require an in-depth survey of municipalities.

Table 6. Summary of Wood-Burning Appliance and Building Code By-Laws in British Columbia (*source: Alderson 2007*)

Community	Total # of Communities	# Wood-Burning Appliance By-laws	# Building Code By-laws	Percent with By-laws
Cities	48	16	2	38%
Districts	52	3	2	10%
Towns	15	5	5	67%
Villages	42	3	1	10%
Regional districts	28	3	2	18%
Total	185	30	12	23%

Despite the different types of residential wood-burning intervention strategies that have been implemented in Canada, few attempts have been made to evaluate the efficacy of these strategies and most programs have not included an evaluation component. For example, in the CCME (2004) review of 12 wood stove change-out programs in Canada, none of the public education campaigns were found to include any follow-up, making it impossible to gauge the effectiveness of these campaigns on changing public behavior. Efforts by CCME (2004) to evaluate other change-out/education programs also consisted of qualitative or potentially uninformative metrics, such as the number of people reached via phone, the number of materials distributed, the number of workshop participants, or the total number of appliance exchanges. Although the CCME (2004) review attempted to quantify the reduction in emissions expected from each change-out program, these estimates were based on a simple calculation (i.e., number of change-outs multiplied by estimated emissions assuming older appliances release 60 grams/hour PM and newer certified appliances release 5 grams/hour PM) and these estimates have not been verified

using actual data or field measurements. Additionally, these metrics do not necessarily account for the ultimate outcomes of interest, such as a reduction in air contaminant levels, public exposures, or adverse health effects. In the recent survey of air quality by-laws in British Columbia, it was recommended that future studies should evaluate the effectiveness of these by-laws, given that a few municipalities have never enforced their regulations due to the small size of the community and a lack of available resources (Alderson 2007).

Only a few studies were identified that have specifically evaluated (or are in the process of evaluating) the effectiveness of residential wood-burning interventions in Canada using different metrics. For example, a source apportionment study conducted in Golden, British Columbia found that the contribution of the wood-burning factor to ambient PM levels decreased 4-fold in 2006 compared to prior year, which the study authors hypothesized might be due to the introduction of a number of wood stove change-out programs during this time (Jeong et al. 2008). Specifically, the authors note that reports for residential wood-burning in British Columbia showed that the percentage of households using fireplaces decreased from 15% in 2003 to 2% in 2006, while the use of advanced stoves and conventional wood stoves increased from 25% and 29% to 41% and 32%, respectively, in the area of Golden. However, this study did not measure indoor air pollution levels over this time, so it not possible to assess how actual indoor contaminant concentrations or personal exposures changed over time based these data. In an indoor infiltration study conducted in Prince George, British Columbia, remaining indoors combined with the use of an air cleaner (i.e., HEPA filter) was found to reduce $PM_{2.5}$ exposures from woodsmoke associated with residential wood-burning (Barn et al. 2008). Additionally, as part of the WEST study which consists of a series of linked projects in British Columbia, air contaminant measurements were collected in selected homes in Smithers and Telkwa before and after a change-out of appliances to assess the impact of stove exchanges on indoor air quality (Allen et al. 2009). Preliminary results for this study show a significant decrease in outdoor levels of levoglucosan (i.e., product of cellulose combustion that is often used as a tracer for woodsmoke), but do not show any evidence of a significant change in indoor $PM_{2.5}$ levels as a result of the exchange program. The authors of this study have concluded that although outdoor $PM_{2.5}$ is driven by woodsmoke, infiltration is relatively low and indoor $PM_{2.5}$ is largely due to other sources.

Note that one of the most comprehensive evaluation programs completed to date identified in the literature relates to a study conducted in the United States by the University of Montana (HPBA 2008). Specifically, woodsmoke was found to contribute approximately 80% of ambient $PM_{2.5}$ levels in Libby, Montana in the winter of 2003-2004, but following an extensive two-phase change-out program coupled with before and after air quality monitoring, significant reductions in $PM_{2.5}$ were measured in both indoor and outdoor air. By 2007, average wintertime $PM_{2.5}$ levels decreased by nearly 30% in outdoor air and more than 70% in indoor air in homes with

new EPA-certified wood stoves (Ward and Noonan 2008). It is noteworthy that these findings are in contrast to those above by Allen et al. (2009), in which reductions in ambient $PM_{2.5}$ levels did not result in a corresponding reduction in indoor $PM_{2.5}$ levels, perhaps due to differences in indoor infiltration rates, number of woodstove exchanges, differences in stove installation or operation procedures, or other factors. Although somewhat outdated, the U.S. EPA (1989) also provides guidance to state and local officials regarding the most effective residential wood combustion emission control measures. In general, measures that can be readily enforced and result in long-term emission reductions are recommended over those that rely on the good will of the community or only offer a temporary solution. Specifically, the guidance document recommends the following hierarchy of control measures: (1) measures that result in fuel switching and/or conservation; (2) measures that result in improved combustion performance from advanced technologies; (3) measures that achieve temporary emission reductions, such as during episodic curtailments; and (4) measures that rely on public awareness and voluntary cooperation (least desirable).

5.2 Interviews With Canadian Health Authorities

To learn more about health practitioners' knowledge and views with respect to residential wood-burning issues and intervention strategies in Canada, telephone interviews were conducted with representatives from 21 different provincial and regional health offices in Canada, including several environmental organizations (see Appendix 1). With the exception of Novia Scotia and Nunavut, at least one health practitioner from all Canadian provinces and territories was interviewed. Consistent with the interview protocol, geographic areas with the largest population size (e.g., British Columbia, Ontario, Quebec) were over-sampled relative to areas with smaller populations. Because most persons contacted did not have specific data to support their general observations, the key findings from these interviews are discussed in a more qualitative manner.

Most of the practitioners interviewed only had a general sense of the nature and extent of the use of wood-burning appliances in their province or region, as the collection of this type of information is not considered to be within the mandate of public health agencies. In general, residential wood-burning is believed to occur much more frequently in rural areas (where wood is often used as a primary and/or secondary heat source) than urban areas (where wood is often used only for aesthetic or decorative purposes). Not surprising, residential wood-burning is believed to be the most common during the winter months, which typically span from November to March, but could be even longer in colder regions. Households are expected to use a wood-burning appliance only when someone is home, including during the day and in the evenings, and their use is estimated to range anywhere from once per week (e.g., if used only for aesthetic purposes) to every day in the winter (e.g., if used as a primary heat source).

The practitioners interviewed had little knowledge about the type of wood-burning appliances currently used by residents in their province or region, but most believed that these are likely to be older conventional units rather than advanced or CSA/EPA-certified ones, particularly in rural areas or older homes (whereas new housing was believed to have certified appliances or alternative heat sources due to building codes). The most frequently cited reasons why Canadian households use wood as a heat source included perceptions about cost-savings (particularly in rural areas), reliability (often driven by fears regarding utility disruptions), availability (due to abundant forests or wood from declining forest health such as Mountain Pine Beetle wood), and aesthetics.With the exception of two public health agencies, none of the agencies contacted were involved in the actual monitoring of ambient contaminant levels in their province or region (it was believed that this was in the domain of the Department of the Environment). However, a number of health practitioners indicated that they analyze and rely on such monitoring data as part of their overall assessments of air quality, although they did not think it was possible to apportion the monitoring data to different sources such as residential wood-burning. One health agency indicated that it has recently started using large mobile monitors to assess whether residential wood-burning is having an impact on ambient $PM_{2.5}$ levels in particular areas, while another health agency recently conducted a pilot study to analyze $PM_{2.5}$ levels during active wood-burning in a particular community. These data have thus far not shown significant detriments to air quality attributable to wood-burning, possibly owing to mild weather patterns (i.e., few inversions).

When queried about whether their particular agency has observed any air quality impacts due to residential wood-burning, many practitioners noted that wood-burning only poses a very localized problem (e.g., specific areas prone to inversions) and does not affect the overall ambient air quality or pose a problem from a broader airshed perspective. With that context, a number of practitioners indicated that residential wood-burning has affected the local air quality in their province or region based on a small number of "nuisance" complaints received from residents about woodsmoke emitted from neighboring homes. Several practitioners noted that such complaints were more notable a few years ago when gas prices were high and weather inversions were common, but that these have declined in recent years (others noted an increase in complaints in recent years). When an agency receives such a complaint, they usually either direct the caller to a local municipality (i.e., to assess whether a unit was installed in accordance with existing codes and bylaws) or they may send a health inspector to investigate whether a public health problem exists. The health inspectors typically try to diffuse the situation by encouraging neighbors to adopt better wood-burning practices or to switch to a certified appliance. None of the health agencies contacted have attempted to link potential health outcomes (e.g., hospital admissions) to woodsmoke exposure, and most health practitioners indicated that they have not received many complaints about health effects due to woodsmoke

from residential wood-burning. Nearly all of health practitioners contacted indicated that residential wood-burning is "low on their radar" and is not considered to be a high priority issue for their agency (and any attention given to this topic is largely nuisance-related or "complaint-driven"). Only a few of the health practitioners indicated that they thought residential wood-burning poses a public health problem in their province or region and that their agency needed to (or was in the process of) getting more involved on this topic. Overall, relatively few health practitioners have ever been involved with or are aware of public education programs or intervention strategies that have been implemented in their particular province or region (or in other provinces/regions) related to wood-burning. Of those health agencies that had been involved in such efforts, these typically consisted of providing support for education campaigns (e.g., distributing pamphlets, hosting informational sessions, co-sponsoring trade shows) or wood stove exchange programs, and assisting municipal governments in implementing local by-laws. There does not appear to have been any attempts to try to evaluate the effectiveness of these programs, however, and several health practitioners did not think that passive educational approaches (e.g., distributing leaflets) are very effective by themselves.

Most health practitioners indicated that they do not currently have any plans to implement education or intervention programs related to wood-burning in the future, unless this becomes a higher priority issue for their agency and budgets are available (although a couple of agencies indicated that they did plan to become more involved in this issue). In particular, many practitioners indicated that they did not have much authority to regulate or ban the use of wood-burning appliances unless they could prove that this posed a "nuisance" or "health hazard" under existing provincial legislation (e.g., Public Health Act), but that this would require evidence of loss of enjoyment or health effects. Some practitioners also indicated that wood-burning restrictions should only be done at the municipality level, while others thought that such restrictions are not politically feasible or are tougher to implement in rural areas where wood-burning is a part of life.

In regards to perceived data gaps or information needs, several practitioners indicated that since this topic is not considered to be a high priority by their agency, they did not have any data needs. However, the majority of health practitioners indicated that they would like to have more information on the following: (1) statistics on the use of wood-burning appliances (conventional vs. advanced) in different provinces and regions and practical tips on "best practices"; (2) air monitoring data (ambient and indoors) and meaningful parameters for evaluating what these measurements mean from a health perspective; (3) data on health effects associated with woodsmoke exposure and information on whether wood-burning has been identified as a public health issue in other provinces or regions; (4) information on what actions other agencies in Canada have taken to address residential-wood burning and which of these have been the most effective; and (5) summary of existing legislation (e.g., by-laws) in different provinces and

regions related to wood-burning. Several practitioners indicated that if they had more information or scientific data on specific issues related to wood smoke (e.g., health effects, efficient intervention programs) or specific provincial guidelines, then they would consider developing intervention strategies for use in their own regions.

Several additional interviews were also conducted with representatives from national-level health or environmental organizations who are familiar with issues related to wood-burning appliances in Canada (i.e., Environment Canada, BC Ministry of Healthy Living and Sport, and Metro Vancouver). According to one or more of these individuals, emissions from wood-burning appliances are primarily an issue in densely populated areas where community members complain about the woodsmoke affecting their breathing or asthma. Education and change-out programs can also be difficult to implement because the general public is often not aware of or does not believe there are any health implications of woodsmoke emissions (mainly because wood-burning is such a common and long-standing practice and there is distrust of the message being given by the health officers). Some municipalities are therefore shifting away from emphasizing health concerns to encouraging residents to be "good neighbors" and emphasizing potential financial benefits. Local by-laws can help to restrict the use of wood-burning appliances, particularly opacity by-laws where smoke levels can be easily measured and enforced, but the effectiveness of most by-laws is difficult to evaluate because they tend to relate only to whether an appliance is of a certain type or is installed properly.

6.0 CONCLUSIONS

Based on our review of the available literature and interviews with selected Canadian health authorities, residential wood-burning appears to be a common and accepted practice in many regions of Canada, and the use of wood as a primary or secondary heat source may be on the rise due to a variety of factors (e.g., increased heating costs, mechanism for dealing with power outages, desire to promote renewable resources). However, the continued use of wood-burning appliances can have a negative impact on local air quality, which may limit the ability of individual provinces to meet air quality goals, such as the new Canada-wide standards for $PM_{2.5}$. Although newer advanced technologies produce lower emissions than older non-compliant technologies and their use is expected to reduce ambient contaminant levels, less is known about the magnitude of public exposure to woodsmoke, particularly indoors where people spend the most time. Based on the overall weight-of-evidence, exposure to woodsmoke and/or its constituents is associated with a range of respiratory health effects and symptoms, particularly in children.

Government agencies in Canada have taken a number of steps to address air quality and health concerns associated with residential wood-burning through a combination of public education and intervention programs. Most of these intervention strategies have focused on increasing

public awareness of proper wood-burning practices (e.g., using clean, dry, and untreated wood) and offering incentives for homeowners to replace older wood-burning appliances with more advanced units (i.e., change-out programs). However, public attitudes and perceptions can represent a significant barrier to change, given that the users of wood often perceive far fewer health risks from wood smoke and exhibited far less support for wood smoke control policies or changing wood-heating practices than non-users. Additionally, in many regions in Canada, health officials report that woodsmoke from residential wood-burning is primarily viewed as a public nuisance issue, rather than being perceived as a potential threat to public health. Provincial, regional, and local health practitioners may also be unaware of the air quality impacts and potential health risks associated with residential wood-burning and/or have limited information on intervention strategies or few resources available to address these issues.

Despite the different types of residential wood-burning intervention strategies that have been implemented in Canada, few attempts have been made to evaluate the efficacy of these strategies and most programs have not included an evaluation component (although several case studies are currently underway). Additionally, in those instances where limited evaluations have been performed, the metrics used do not necessarily account for the ultimate outcomes of interest, such as a reduction in air contaminant levels, public exposures, or adverse health effects. Because of these data limitations, it is not possible to quantitatively assess or rank order the different intervention strategies that have been implemented in Canada.

However, we provide a qualitative indication of the potential effectiveness of different intervention strategies in Canada based on our review of the available literature and interviews with selected Canadian health authorities (see Table 7). These strategies were identified and described in detail in the *Model Municipal Bylaw for Regulating Woodburning Appliances* (Environment Canada 2006). The qualitative rankings reported here reflect our best judgment based on the likelihood of each strategy to reduce woodsmoke emissions or public exposures, but additional data are ultimately needed to support these rankings. We conclude that the most effective strategies are likely to be those that mandate the removal of the highest emitting wood-burning appliances (e.g., older, non-certified units), while programs that are voluntary in nature or rely solely on public education campaigns are unlikely to result in significant improvements to public health. Overall, the literature suggests that change-out programs involving some combination of economic incentive (e.g., cash rebate) and education (e.g., that emphasize cost savings, nuisance issues, health effects) are likely to be the most effective. National or provincial legislative efforts may also result in more efficient policies than relying on disparate and non-uniform municipality by-laws.

Table 7. Potential Effectiveness of Residential Wood-Burning Intervention Strategies

Strategy[A]	Degree of Effectiveness	Rationale	Potential Barriers
Awareness, Education, and Communication	Low	May not result in any change in behavior	Requires commitment of public to participate in education efforts
Restrictions on Some Fuels	Low	Only acheives a small reduction in emissions and does not address older wood-burning appliances	Difficult to enforce and potential lack of availability of acceptable fuels
Nuisance	Low	Complaint driven and does not address older wood-burning appliances	Neighbors may not want to complain
No-Burn Days Option A) Voluntary Curtailment Option B) Mandatory Curtailment	Low to Moderate	Will reduce emissions at critical times (especially if mandatory), but does not address older wood-burning appliances	Difficult to enforce and potential lack of other available heating source
Opacity	Low to Moderate	Can provide quantitative measure of woodsmoke, but complaint driven and does not address older wood-burning appliances	Neighbors may not want to complain; requires formal testing
Installation of Wood-Burning Appliances Option A) All Appliances Option B) New Construction Option C) Total Ban	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Outdoor Solid-Fuel Combustion Appliances	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Non-Certified Appliance Removal Option A) Removal Program (Change-Out) Option B) Time Limit Option C) Prior Sale or Transfer of Real Property	High	Relatively easy to implement and removes the older, highest emitting wood-burning appliances	May face public resistance and puts financial burden on public

[A]Based on strategies identified in *Model Municipal Bylaws* document (EC 2006)

6.1 Data Gaps and Research Needs

An important finding of our research is that there appears to be a disconnect in knowledge and coordination among different levels of government in Canada with respect to the health hazards of residential wood-burning and the implementation of wood-burning intervention strategies. It is clear from the published literature and selected interviews that national-level environmental and health agencies in Canada believe that residential wood-burning has a negative impact on air quality and public health and that greater public education and intervention programs are needed to address these issues. A number of municipalities also appear to have instituted air quality by-laws directed at the use of wood-burning appliances, although these bylaws may be driven more by nuisance-related rather than health concerns. However, interviews with health practitioners from a sample of provincial and regional health offices across Canada suggest that many of the practitioners who are often responsible for public education and outreach are neither aware of the potential health hazards associated with residential wood-burning, nor are they involved in the

development or implementation of different intervention strategies. In fact, several health practitioners indicated that they would like to know more about public exposures and health effects from woodsmoke and would consider developing intervention strategies for use in their own region if they had more information or scientific data on specific issues related to woodsmoke or specific provincial guidelines. This apparent disconnect in knowledge and coordination among different levels of government in Canada with respect to residential wood-burning may hinder the success of widespread public outreach and intervention efforts and should be reconciled.

In particular, several data and information gaps were identified based on our review of the available literature and interviews with Canadian health authorities, which if addressed, could result in an improved understanding among health practitioners and policymakers of the potential health risks associated with residential wood-burning and the most effective ways to prevent or control such risks. First, while there have been some efforts to summarize what is known about woodsmoke emissions and related health effects as well as recent or ongoing public education and intervention strategies in Canada, this information is largely fragmented and is contained in various publications, government reports, and websites. Because there is no central database or clearinghouse that contains all relevant (past and current) information on this topic, individual health authorities would need to devote their own time and resources to compile and summarize this information in a useful fashion. A centralized system that contained a comprehensive docket of reliable data and information would allow potential users of this information to easily assess the current state-of-the-science with respect to wood-burning emissions and health effects and assess what educational materials or interventions have been developed or implemented in different provinces or regions in the past.

Second, there does not appear to be any mechanisms in place for health practitioners or policymakers at different levels of government to share, discuss, or have ready access to data or information in "real time" with respect to ongoing public outreach and intervention programs. That is, although many of the findings or "lessons learned" from these efforts are eventually published in the peer-reviewed literature or government reports, it may take months or years before these publications are publicly available. Putting mechanisms in place that allow for greater dialogue among professionals and a more timely transfer of information could provide valuable assistance to health practitioners and policymakers as they consider or develop their own wood-burning intervention strategies.

Third, aside from several recent efforts, there have been few attempts to evaluate the efficacy of different types of residential wood-burning intervention strategies and most programs do not contain an evaluation component. This lack of data on program effectiveness makes it difficult to determine where scarce resources should be spent to yield the greatest health benefits.

Additionally, past evaluations of different intervention strategies (e.g., woodstove change-outs) do not always rely on metrics that account for the ultimate outcomes of interest, such as a reduction in air contaminant levels, public exposures, or adverse health effects. More specific guidance on evaluation methods and metrics for assessing the effectiveness of wood-burning intervention strategies is therefore needed.

Fourth, there has been little discussion in the published literature with respect to weighing the feasibility, costs, and benefits of different wood-burning intervention strategies under alternative scenarios. That is, it is likely that no single approach will fare the best in all situations and that different wood-burning intervention strategies will be needed for different geographic locations in Canada or under certain conditions. Greater consideration of these factors is needed to ensure that the most optimal wood-burning intervention strategies are selected for a particular region or municipality.

Fifth, discussions about residential wood-burning interventions in Canada generally do consider broader potential tradeoffs associated with these interventions. For example, woody biomass is often touted as a sustainable and renewable resource for meeting energy demands, and restrictions on its use could affect other public policies that have been implemented or are under consideration in Canada (e.g., greenhouse gas emission reduction efforts). Future decision-making with respect to residential wood-burning would benefit from greater consideration of these broader environmental, social, and economic factors.

6.2 Recommendations

Given the current state of knowledge, we offer the following five recommendations to better inform health practitioners and policymakers in Canada about potential health risks or other concerns associated with residential wood-burning as well as potentially useful mechanisms for addressing or mitigating these risks:

1. A central clearinghouse or repository of information related to residential wood-burning that is accessible to all levels of government (and the general public) should be developed and hosted under the auspices of a single entity in Canada (perhaps a national-level agency in coordination with other agencies). The repository would include general information on (a) best wood-burning practices and advanced wood-burning appliances; (b) wood-burning emissions, public exposures, and related health effects; and (c) public education campaigns and intervention strategies that have been implemented throughout Canada. This would provide health practitioners and policymakers at the national, provincial, regional, and municipal levels access to shared information to assist in designing their own policies and programs related to residential wood-burning. Although numerous web-based sources of information currently exist, these tend to contain limited

and disparate types of information, and it is not clear that those regions and municipalities most impacted by residential wood-burning are aware of many of these resources.

2. An interactive, web-based, government-sponsored resource (i.e., on-line forum not accessible to the general public) should be developed where academic researchers, health practitioners, policymakers, and other professionals can post questions or provide feedback on ongoing or proposed public education programs and intervention strategies. This forum would allow for a relatively easy and timely transfer of information among professionals directly involved in designing and implementing such programs, and could be used to communicate up-to-date information on "lessons learned" regarding the effectiveness of different intervention programs (i.e., what programs are working/not working in different communities and why).

3. Before implementation, all future wood-burning education and intervention programs should include an evaluation component as part of the study design. As part of this effort, a guidance document should be developed that describes best practices and tools for evaluating the effectiveness of different intervention strategies, with an emphasis on meaningful evaluation metrics (e.g., change in behavior following education, improvement in ambient and indoor air quality, reduction in specific health outcomes). This document could also include details from existing or proposed case studies, where available.

4. A scenario-specific decision analysis should be conducted to assist health practitioners and policymakers in assessing and choosing among various wood-burning intervention strategies for a particular region or municipality. Such an analysis could incorporate data and information on the feasibility, costs, and benefits (e.g., reduction in specific health outcomes) of different intervention strategies under a number of alternative scenarios. The results of this analysis would help ensure that informed decisions are made about the most appropriate and efficient wood-burning strategies for use in a particular area. Decision analysis methods provide a transparent process for evaluating and informing policy and management decisions. Example applications of the use of these methods for informing decision making and evaluating alternative courses of action can be found in the literature (Belton and Stewart, 2001; Figueira et al., 2005). It should be recognized, however, that total emissions and related health impacts could increase or remain the same even with more efficient intervention strategies if wood-burning use increases in Canada.

5. A broader decision analytical framework should be developed that considers the positive and negative attributes of residential wood-burning in the larger context of other important environmental, social, and economic factors. For example, energy derived from renewable resources (e.g., woody biomass) could significantly reduce greenhouse gas emissions compared to non-renewable resources (e.g., natural gas, electricity) under certain situations when evaluated on a life-cycle basis. Alternatives to wood heat or switching to cleaner-burning appliances may also not be feasible for many households due to economic constraints, unless significant financial incentives or subsidies are available, or in rural areas where power outages are common. A conceptual framework that considers and weighs these types of factors and potential risk tradeoffs could help guide future policy decisions with respect to residential wood-burning in Canada.

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APPENDIX 1. INTERVIEWS CONDUCTED WITH ENVIRONMENTAL AND HEALTH ORGANIZATIONS IN CANADA (APRIL - JUNE 2009)

Alberta

- Alberta Health Services (Edmonton)

British Columbia

- Interior Health Authority
- Fraser Health Authority
- Northern Health Authority
- Vancouver Coastal Health Authority
- Vancouver Island Health Authority

Manitoba

- Manitoba Health (Winnipeg)
- City of Winnipeg

New Brunswick

- Central Region (Fredericton)

Newfoundland/Labrador

- Government Services Centre (St. John's)
- Environment & Conservation, Pollution Prevention

Northwest Territories

- Health Promotion & Protection (Stanton Territorial HA)

Ontario

- Ministry of Health (Toronto)
- Sudbury & District HU

- Ministry of Environment (Sudbury)
- Thunder Bay District HU

Prince Edward Island

- Ministry of Health & Social Services (Charlottetown)

Saskatchewan

- Disease Prevention & Health Protectiion (Regina)

Quebec

- Règion de la Capitale-Nationale (Quebec City)
- Region de la Laval

Yukon Territory

- Yukon Health & Social Services (Whitehorse)

National-Level Organizations

- Environment Canada
- BC Ministry of Healthy Living and Sport
- Metro Vancouver