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Impact of Residential Wood Stove Replacement on Air Emissions in Canada

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Note to readers:

Two types of stoves or wood combustion appliances are considered in this report. There are the state-of-the-art or advanced technology stoves, such as those compliant to the Canadian Standard Association (CSA) B415.1-00 Standard or the United States Environmental Protection Agency (EPA) Standard Performance for New Residential Wood Heaters (40 CFR Part 60, Subpart AAA). In the report, they are also referred to as certified stove or appliance. The other appliances of old technology or non-compliant appliances do not respect the CSA B415.1-00 standard or the EPA standard.

We refer to dioxins and furans with two toxic equivalent scales. Equivalency factors for the first scale (TEQ or I-TEQ) refers to those used by Environment Canada in the toxicity assessment while the second scale refers to those developed for the World Health Organization in 1998 (WHO_{98}-TEQ). Results differ slightly if they are presented according to one or the other scale.

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Summary

Residential wood combustion fulfills 1% of the energy demand but is responsible of 29% of the fine particulates ($PM_{2.5}$) and 48% of the polycyclic aromatic hydrocarbons (PAHs) emitted by all the Canadian sources put together (excluding forest fires and emissions from paved and unpaved roads). New technology fireplaces and wood stoves such as those compliant to CSA's Standard B415.1-00 or EPA's Standard emit much less pollutants than non compliant old technology appliances. The replacement, in part or all, of the old technology wood burning appliances by state-of-the-art technology appliances would result in a 30% to 55% emission reduction for $PM_{2.5}$, PAHs, volatile organic compounds (VOCs) and carbon monoxide (CO) emitted by the home heating sector and a 10% decrease in greenhouse gas (GHG) emissions. Considering the lifetime expectancy of wood stoves, the replacement of the appliances in use could take between 20 and 40 years.

Table of Content

List of Tables

List of Figure

Appendix

Introduction

Wood has been used for heating and cooking since the beginning of mankind. The arrival of other sources of energy that are easier to use, more efficient and requiring less time and effort for the end user have resulted in a decrease in the proportion of people using wood as a source of energy for heating and cooking. However, residential wood combustion is an important source of pollutants and its effects are more frequently observed in urban areas. The Canadian Council of Ministers of the Environment (CCME) have identified it among the sectors for which actions had to be taken to reduce particulate emissions (CCME, 2000). The CCME have tasked the federal/provincial/ territorial Joint Action Implementation Coordinating Committee (JAICC) for Canada-Wide Standards (CWS) for Particulate Matter (PM) and Ozone of coordinating the implementation of joint initial actions. Among these measures, there is the assessment of the option of a national wood stove upgrade or change-out program.

This report will compare emissions from residential wood combustion to those from the other sectors in Canada. It will also estimate the emission levels from several replacement scenarios of old technology wood stoves, fireplaces and fireplace inserts by advanced technology stoves or appliances such as those compliant to the B415.1-00 Standard of the Canadian Standard Association (CSA) or certified by the United States Environmental Protection Agency (U.S. EPA). It will also evaluate the potential impact of the replacement of all residential wood combustion by the other forms of energy used in Canada. These calculations should not be considered as an indication that a residential wood combustion ban is in preparation by the Government but only as an indication of the maximum emission reduction for this sector.

Energy demand and greenhouse gas emissions

According to Environment Canada (Olsen *et* al., 2002), the residential sector needs for energy represented 10% of the total demand for all the activity sectors of Canada while the energy production and the transportation sectors were almost equal with approximately 30% or 2 700 PJ each (Table 1). However, it should be noted that electrical energy used at the residential, commercial or industrial level is not directly accounted for within the values presented for these sectors in Table 1 but is included with the energy production value. Greenhouse gases (GHG) emitted by the use of energy represented almost 533 megatonnes of CO_2 equivalent (MT CO_2 eq.) while the total Canadian GHG emissions, including those from the industrial processes and from agriculture was estimated at 726 Mt of CO_2 eq. in 2000 (Olsen *et al*., 2002).

In 2000, the energy demand for the residential sector totalled 1 388 petajoules (PJ) when electricity needs were included (NRCan, 2002) and about 60% of this energy (831 PJ) was used for home heating (Table 2). This Table also shows the proportion filled by each of the fuel used at the Canadian residential level and the related GHG emissions. Natural gas represented the largest source with 55.5% of the energy used to heat Canadian homes, while wood provided 12% of the residential needs (equivalent to 1%

Table 1 Energy demand, greenhouse gas emissions related to the use of energy and the relative importance of each sector in Canada for 2000 (Olsen *et al.*, 2002)

Sector	Energy		GHG	
	Demand	Relative importance	Emission	Relative importance
	PJ	%	Mt CO_2 eq.[a]	%
Residential	907[b]	10.3	45	8.4
Energy Production	2 740	31.4	195	36.6
Industrial	1 761[b]	20.2	69	12.9
Transportation	2 683	30.7	190	35.6
Commercial	595[b]	6.8	31	5.8
Agriculture	45[b]	0.5	2.6	0.5
Total [b]	8 731[c]	100	533[d]	100

a: megatonnes of CO_2 equivalent
b: values related to the use of energy included in the Energy Production sector
c: total energy used to heat or cool dwellings, working places or to operate equipments, vehicules and industries
d: values directly related to the use energy use; emissions related to fugitive emissions from fuel excluded

Table 2 Distribution of energy sources for residential uses, related GHG emissions and relative importance of each source for home heating in 2000 (NRCan, 2002; Olsen *et al.*, 2002)

Source	Energy use			GHG emissions		
	Total	Heating	Relative importance	Total.	Heating	Relative importance
	PJ		%	Mt CO_2 eq		%
Electricity	497.6	141.9	17.1	30	8.6	20.0
Natural gas	644.8	461	55.5	32.3	23.1	53.3
Oil	132.4	117.9	14.2	9.7	8.6	19.9
Wood	**100.3**	**99.3**	**12.0**	**2.2**[a]	**2.2**	**5.1**
Propane	11.4	9	1.1	0.7	0.6	1.4
Coal and others	1.6	1.5	0.2	0.2	0.2	0.5
Total	1 388.1	830.7	100	75.1[b]	43.3[b]	100

a: include methane and nitrous oxide emissions but not CO_2 emissions; data from Environment Canada (Olsen *et al.*, 2002)
b: take into account the value for residential wood combustion from Environment Canada

of all the activity sectors of Canada) (NRCan, 2002). Regarding GHG emissions, 53% came from natural gas and only 5% from wood combustion. Even if wood combustion for home heating emits CO_2 to the atmosphere, it is not accounted for in the energy sector of the GHG inventory, in accordance with the *United Nations Framework Convention on Climate Change* (UNFCCC). Instead, it is considered as a woody biomass loss in the *Land-Use Change and Forestry (LUCF)* section of the inventory (Olsen *et al.*, 2002). However, methane (CH_4) and nitrous oxide (N_2O) emitted by residential wood combustion are accounted for in the energy chapter of the inventory and are reported as CO_2 equivalent in Table 2.

Atmospheric Emissions from Residential Wood Combustion

To estimate the emissions from residential wood combustion, we had to use several sources of information including the 2000 version of the Criteria Air Contaminants (CAC) Emissions Inventory of the Residual Discharge Information System (RDIS) database (Niemi, 2003). There are approximately 3.6 million wood combustion appliances in Canada and the RDIS inventory provides information on the types of appliances and on the amount and type of wood burned by each Province and for the country as a whole (see Appendix).

Table 3 shows the estimated number for each type of appliances and the emission factors used in the 2000 Inventory to estimate the amount of CAC pollutants emitted by residential wood combustion. Polycyclic aromatic hydrocarbons (PAHs) emission factors were derived from the PAH Priority Substance List (PSL) Assessment inventory (LGL, 1993), from Fisher *et al*. (2000) and from Valenti and Clayton (1998). When wood is burned, naphthalene is one of the PAH compounds emitted in larger amount among all PAHs, but it was excluded from the Fisher *et al.* (2000) emission factors as the authors of the other studies do not mention it.

Table 4 provides some of the PAH emission factors available (excluding naphthalene) and those retained for calculation. For advanced technology stoves, such as the EPA-certified stoves, we have retained PAH emission factors (but excluding naphthalene) from Fisher *et al.* (2000) because they averaged on-site test results from 11 non-catalytic stoves (30 runs) and 5 catalytic stoves (13 runs) in use for 8 or 9 years in Klamath Falls and Portland in Oregon. In this study, chimneys were sampled with an automated wood emission sampler (AWES) developed for use while wood appliances were in normal in-home use. Each run was done over a one-week period and sampling was done for two minutes every 15 minutes over the week. The sampling was done only when the stoves were in operation. Results obtained in a study done for Environment Canada in 2000 were not used because they represent results from only two stoves and two species of wood tested in controlled conditions.

Table 3 Number of residential wood combustion appliances and emission factors used to estimate the emissions

Wood combustion appliances	Estimated number of appliances ('000)	Emission factors			
		$PM_{2.5}$ g/kg	CO g/kg	VOCs g/kg	PAHs[a] g/kg
Wood Burning Fireplaces					
Fireplaces					
Without Glass Doors	846	18.4	77.7	6.5	0.0375
With Glass Doors	897	12.9	98.6	21	0.0375
Fireplaces With an Insert					
Conventional	129	13.6	115.4	21.3	0.215
Advanced Technology (catalytic)	22	4.8	70.4	7	0.064
Fireplaces Advanced Technology (any)	57	4.8	70.4	7	0.064
Wood Burning Stoves					
Conventional Stoves					
Not Air-Tight	445	23.2	100	35.5	0.215
Air-Tight	777	13.6	115.4	21.3	0.276
Advanced Technology Stoves	142	4.8	70.4	7	0.064
Central Furnaces/Boilers	278	13.3	68.5	21.3	0.288
Other Wood Burning Equipment	41	13.6	115.4	21.3	0.215
Pellet Stoves	13	1.1	8.8	1.5	0.0015

a: see Table 4 for PAH emission factor development

Many papers deal with PAH emissions from residential wood combustion but few report dioxin and furan (D/F) emissions. The U.S. EPA emission factor of 2 nanograms D/F toxic equivalent/kg of wood burned (ng-TEQ/kg) was derived from only two European studies and was considered as of low certainty (Gullett *et al*., 2003). In the study done with an EPA-certified, non-catalytic woodstove and a conventional fireplace, Gullett *et al.* (2003) reported that average D/F emission factors were 0.28 (standard deviation or SD of 0.17), 1.4 (1.7 SD) and 2.4 (0.29 SD) ng-TEQ/kg for oak, pine wood and artificial logs respectively. They found no statistical differences in emission factors from the different types of appliances. Environment Australia (2002) measured D/F emissions of 4.1 ng-WHO_{98}-TEQ/kg of wood in testing done with stoves compliant and non-compliant to the Australian A4013 standard. Launhardt *et al*. (1998) reported that contrary to PAH emissions, D/F emissions from a stove with old combustion technology ('70s) were nearly at the same low level as those from a state of the art (as of early '90s) stove. From the same report, burning of wastes, PVC or painted wood with clean wood resulted in an increase of D/F levels in the flue gas from 4 - 21 picogram I-TEQ/m^3 (pg I-TEQ/m^3) to 579, 900 and 952 pg I-TEQ/m^3, respectively.

Table 4 PAH emission factors considered and retained

Wood combustion appliances	LGL (1993)	Fisher *et al.* (2000)[a]	Valenti and Clayton 1998) (AP-42)	EC[c] (2000)	Factor retained
	g/kg	g/kg	g/kg	g/kg	g/kg
Fireplaces					
Conventional Fireplaces	0.0375	-[b]	-	-	0.0375
Fireplace with an insert (conventional)	-	-	-	-	0.215[d]
Wood burning stoves					
Conventional Stoves					
Not Air-Tight	0.121	0.215	0.754	-	0.215
Air-Tight	0.276	-	-	0.033	0.276
Advanced Technology Stoves					
with catalyser	-	0.064		-	0.064
no catalyser	-	0.065		0.014	0.064
Boilers	0.276	-	0.288	-	0.288
Pellet stoves	-	-	0.0015	-	0.0015

a: naphthalene values excluded b: no factor available
c: Environment Canada study d: no factor available, the conventional stove emission factor was used

Environment Canada (2002) reported D/F emissions of 0.74 and 0.26 ng-TEQ/kg for an EPA-certified wood stove and an old technology conventional stove respectively. In a preliminary test, the same EPA-certified stove burning maple emitted 0.29 ng-TEQ/kg of D/F, similar to the 0.30 ng-TEQ/kg emitted by the conventional stove while burning maple in the formal testing. The only noticeable difference between the two tests was the length of the chimney. In the preliminary test, its length was 4.6 m (15 feet) while the stack was 7.3 m (24 feet) in the formal testing to reflect the average chimney length of Canadian homes. According to Fisher *et al.* (2003), changes in fuel combustion conditions, fuel loading, orientation, air draft, fuel charge rate or other operating parameters can have an effect on D/F emissions. Considering the variation in the D/F emissions between preliminary and formal testing, and considering those observed in the few references available, D/F emission values were calculated with the average emission factor derived from the Environment Canada (2000) study, *e.g.* 0.5 ng TEQ/kg of wood, for both EPA-certified and uncertified stoves. This emission factor was also used to calculate the D/F emissions from residential wood combustion in the updated Canadian Dioxin and Furan Inventory (Environment Canada, 2001).

Table 5 presents some of the CAC, PAH, D/F and GHG emissions for different sectors of activity. For comparison, emissions from other sources of residential fuel combustion and total Canadian emissions (with and without open sources) are also presented. Fine particulate ($PM_{2.5}$), volatile organic compounds (VOCs) and carbon monoxide (CO) emission values were taken from Environment Canada's 2000 version of the CAC Inventory. The PAH emissions were mostly taken from the 1990 Inventory prepared for the toxicity assessment of PAHs (LGL, 1993), except for residential wood combustion and the industrial sector. For residential wood combustion, emissions were calculated using the amount of wood burned available in the 2000 CAC Inventory and emission factors presented in Table 3; for the industrial sector, PAH emissions from the 1990 inventory were updated to reflect the emission reduction in the aluminum sector up to year 2000. PAH emissions of 1,381 tonnes from residential wood combustion calculated here are greater than the 474 tonnes obtained by LGL (1993). Differences are explained by the smaller amount of wood burnt used by LGL (1993) compared to the 2000 CAC Inventory, *e.g.* 4.8 Mt vs 6.6 Mt and by the emission factor retained for the conventional stoves. Dioxin and furan values come from Environment Canada's D/F Inventory (2001) and GHG values come from the Canadian GHG Inventory for 2000 (Olsen *et* al., 2002). It should be noted that GHG emissions reported in Table 5 also take into account the emissions related to the processes of the industrial sector in addition of those from the use of energy.

Table 5 Air emissions from various sectors in Canada

Selected sectors	$PM_{2.5}$	VOCs	CO	PAHs	D/F	GHG
	kt	kt	kt	tonnes	TEQ grams	CO_2 eq. Mt
Year	2000	2000	2000	1990	1999	2000
Residential fuel combustion						
Natural gas, propane, oil, electricity and coal	3.6	2.3	14.0	32	7	42.7
Wood	101.3	147.4	662.0	1 381[a]	3	2.2
Total residential fuel combustion	**104.9**	**149.7**	**676.0**	**1,413**	**10**	**44.9**
Energy production	27.2	804.1	172.2	n.a.[f]	5	195
Industrial sources	133.5[b]	190.8[b]	1 132.0[b]	610[a,b]	26[b]	119[b]
Transportation	72.2	727.1	8 375.0	200	9	190
Commercial	3.1	6.5	8.1	n.a.	n.a.	31.9
Canada's total [c] without open sources	350	2 431	10 381	2 859	n.a.	n.a.
Canada's total emissions [c]	963	2 604	11 282	4 945	163	726
Proportion from Residential wood combustion (%)	**29.0**[d]	**6.1**[d]	**6.4**[d]	**48.3**[d]	**2.0**[d]	**0.3**[e]

a: year 2000 data for residential wood combustion and industrial sector (reflect the improvement by the aluminum sector)
b: industries related to the energy sector excluded
c: rounded to closest unit
d: proportion (%) vs Canada's total without open sources such as dust from roads and forest fires
e: proportion (%) vs Canada's total GHG emissions
f: n.a.: not available
Note: $PM_{2.5}$, VOCs, CO from the 2000 CAC Inventory; GHG from Olsen *et al.* (2002)

Table 5 shows that residential wood combustion is responsible of more than 95% of $PM_{2.5}$, VOC, CO and PAH emitted by residential fuel combustion even if it provides only 12% of the energy needs for this sector (Table 2). According to the Environment Canada's 2000 CAC Emissions Inventory, residential wood combustion is the fourth highest source of $PM_{2.5}$ (after forest fires and dust from unpaved and paved road). It is the seventh highest source of PM_{10} (also after forest fires and dust from unpaved and paved road, and tiling and wind erosion) and the sixth highest source of VOCs in Canada (behind forest fires, upstream oil and gas industry, light duty gasoline vehicles and trucks, general solvent use) (Environment Canada, 2002). Because it has air emission control equipment, the Pulp and Paper sector, included in the industrial sector, emits less $PM_{2.5}$, VOCs, CO, D/F and CO than residential wood combustion. This sector emits more SO_2 and NO_x, but these come mostly from the combustion of the other types of fuel used, not from wood.

In the *Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases* (UNEP, 2003), D/F emission factors for virgin wood, coal, oil and natural gas combustion at the residential level were 100 µg TEQ/TJ (terajoule), 70 µg TEQ/TJ, 10 µg TEQ/TJ and 1.5 µg TEQ/TJ respectively; for contaminated wood/biomass fired stoves, the emission factor was 1 500 µg TEQ/TJ. In Table 5, D/F emissions from the other forms of residential home heating (oil, gas, and coal) reflects the findings of the UNEP's toolkit.

Replacement of old technology wood burning appliances by certified appliances

We can expect a 40-year lifetime expectancy for good quality stoves (Houck and Tiegs (1998) while inexpensive models of lower quality degrade rapidly when used at their maximum capacity and have to be replaced every few years (Gulland Associates Ltd, 1997). In Australia, industry suggests that wood heaters have a working life of 15-20 years (Environment Australia, 2002). To calculate the impact of replacing non compliant old technology stoves, fireplaces or fireplace inserts by lower-emission certified appliances, consideration was given to the fact that certified appliances are more energy efficient. Even if the literature reports that certified wood stoves can burn 30% less wood than non compliant stove, it was assumed that the use of certified stoves or fireplace inserts only results in a 10% decrease in the amount of wood burned for the same heat output, to take into consideration people's habits. Table 6 shows the impact of residential wood burning appliance change-outs on air emissions, using 2000 as year of reference. It compares the emissions related to residential fuel combustion (excluding wood combustion) to those from residential wood combustion alone, and to different replacement scenarios. Emission values for scenario A to D are for residential wood combustion only.

Scenario A, *e.g.* replacement of 25% of conventional wood stoves by certified models, would result in an emission reduction of approximately 10% for $PM_{2.5}$ and VOCs emitted by the residential wood combustion sector, and a 5% decrease for CO and PAH sbut changes would be negligible for D/F (same emission factor for all the equipments) and GHG (only a small decrease in the amount of wood burned). Scenario D, replacement

Table 6 Impact on air emissions of changing residential wood combustion appliances (reference year : 2000)

	$PM_{2.5}$ Kt	VOCs Kt	CO Kt	PAHs tonnes	D/F grams	GHG CO_2 eq. Mt
Residential home heating						
Total Residential home heating	**104.9**	**149.7**	**676.0**	**1 413**	**10**	**44.9**[a]
Natural gas, propane, oil, electricity and coal	3.6	2.3	14.0	32	7	42.7
Wood	101.3	147.4	662.0	1 381	3.28	2.2[a]
Air emissions from wood combustion when :						
Scenario A: 25% of conventional stoves replaced	91.7	133.3	625.9	1 303	3.24	2.2[a]
Scenario B: 25% of conventional stoves and conventional fireplaces replaced	88.0	130.3	615.9	1 223	3.23	2.2[a]
Scenario C: 50% of conventional stoves replaced	82.5	118.4	593.5	1 080	3.23	2.1[a]
Scenario D: All conventional stoves, conventional fireplaces and conventional fireplace's inserts replaced	46.4	72.3	466.5	751	3.06	2.0[a]
Air emissions from residential home heating when :						
Scenario E: All wood combustion replaced by oil, electricity, coal, natural gas or propane	4.1	2.6	15.9	36	8	48.7

a: CO_2 emissions from residential wood combustion are not included

of all conventional wood stoves, fireplaces and inserts (but keeping wood furnaces, boilers and pellet stoves) with certified stoves or inserts (for fireplaces), would result in a 45-55% decrease in $PM_{2.5}$, VOC and PAH emissions, a 30% reduction in CO emissions, a 10% decrease in GHG emissions and a 6% cut for D/F (Table 6). Scenario E, which assumes that ***all*** residential wood combustion appliances are replaced by the other forms of energy (such as oil, natural gas, electricity, coal) used to heat Canadian homes (and keeping the actual proportions), results in an emission reduction of greater than 95% for all the pollutants, except for D/F and GHG. For D/F, the overall emission reduction would be 20%. For GHG, since CO_2 emissions from residential wood heating are not accounted for, emissions would increase from 44.9 megatonnes (42.7 + 2.2) to 48.7 megatonnes of CO_2 equivalent (or + 8%) because of the increase in the amount of fossil fuel used. However, Scenario E is not realistic but is included to illustrate what could be the emissions from the residential home heating sector if all the residential wood combustion was replaced by the other forms of home heating.

Figure 1 illustrates the estimated emission reductions for $PM_{2.5}$, VOCs, CO and PAHs if change-outs were done according to scenarios A through D. Because of the uncertainty associated with the D/F emission factor, it was excluded from the chart.

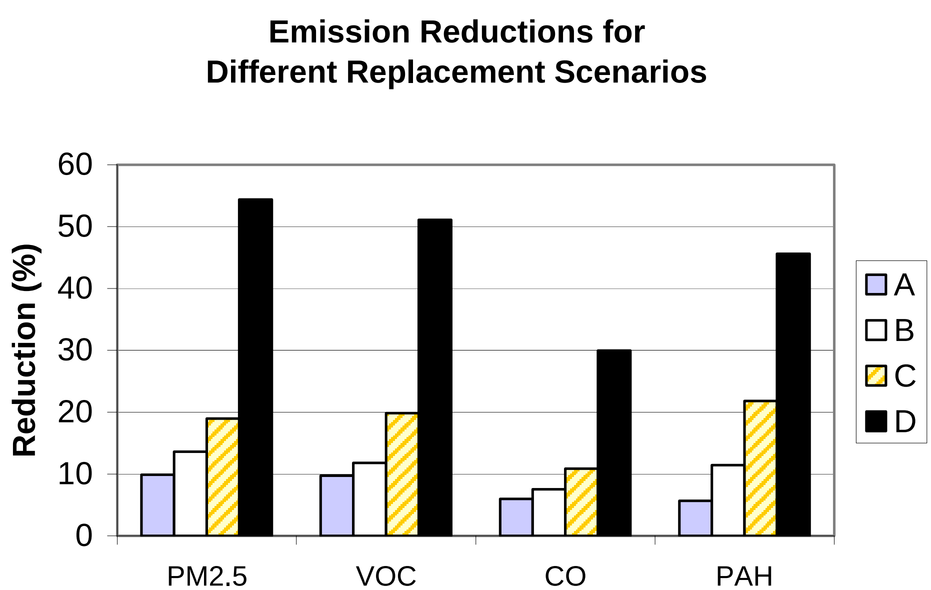

Figure 1 Emission reductions associated with change-outs Scenario A through D

Wood combustion does emit CO_2 to the atmosphere; in fact, each kilogram of wood burnt releases 1.5 kg of CO_2 (Olsen *et al.*, 2002). As mentioned at the beginning of the report, CO_2 emissions from biomass combustion are not included in the total emissions from energy use, as required by the UNFCCC. Instead, it is considered as a biomass loss in the Land-Use Change and Forestry (LUCF) section of the Canadian GHG Inventory. That Inventory reports that LUCF represented a CO_2 sink between 1990 and 2000 and that general trend showed a reduction in the net absorption from 59 Mt to 14 Mt during this 10-year period. This reduction resulted from the 18% increase in round-wood production over the same period of time. On the other hand, in a report presented in June 1999 to the Canadian Senate, the Senate Sub-committee on the Boreal Forest mentioned that (SSC, 1999) :

> *"The large number and extent of forest fires and other natural disturbances between 1970 and 1989 may have changed boreal forests of Canada from a carbon sink to a carbon source (37). However, they will probably revert back again to being a sink, over time. The length of time it takes will depend on future distrubance (*sic*) rates and a number of other factors".*

For their study done for the United States, Houck *et al.* (1998) mention that:

> *"While carefully managed wood fuel plantations could achieve a nearly "greenhouse gas neutral" condition, a reasonable estimate of the steady state condition produced by standard wood harvesting practices is that 40% of the carbon emitted by RWC is in the form of fixed carbon. "*

Because of the large gap between the different assumptions, it is difficult to make an informed decision on either it is beneficial or not to use wood as a heating source with respect to GHG. In the absence of data, it is estimated that the amount of CO_2 emitted by wood heating is offset by the amount absorbed by the forests when these are managed in a sustainable manner. It was hence decided not to calculate if there were CO_2 gains or losses by using wood instead of the other sources of energy in Canada. A life-cycle analysis that takes into consideration all the steps required to produce the fuels used at the residential level is required to better understand this issue.

Conclusion

Wood combustion accounts for only 12% of the energy needs of the residential sector but is a much greater source of pollution than all the other residential heating sources combined, and even more so if wastes, plastic or painted wood are burned along with properly seasoned wood. The replacement of all old technology stoves, inserts and fireplaces by state-of-the-art certified appliances would result in a 30-55% decrease of $PM_{2.5}$, VOCs, CO and PAHs emitted by residential home heating. For GHG and D/F, emissions would be reduced by 10% and 6% respectively. Assuming that a regulation prohibiting the sale of uncertified wood appliances was enacted and considering the 20 to 40-year lifetime expectancy of a wood stove, replacement of all uncertified appliances due to turn-over will take a long time without incentives. Replacement of appliances would take less time for lower quality stoves.

This report shows that if all the residential wood combustion was replaced by other sources of energy for home heating (a scenario that is not realistic), it would reduce the CAC and PAH emissions by at least 95% and D/F by 20%. For GHG, there would be an 8% emission increase when we consider that wood combustion is CO_2 neutral. The increase would be less if wood combustion was not considered as CO_2 neutral. A life-cycle analysis is required to better understand this issue.

References

Bremmer, H.J., L.M. Troost, G. Kuipers, J. de Koning and A.A. Sein (1994). Emissions of Dioxins in the Netherlands. Report 770501018 prepared for National Institute of Public Health and Environmental Protection (RIVM) and Netherlands Organization for Applied Scientific Research (TNO), Bilthoven and Apeldorn, 178 p.

CCME (2000) Joint Initial Actions to Reduce Pollutant Emissions That Contribute to Particulate Matter and Ground-level Ozone, 3p. available on the CCME web site http://www.ccme.ca/assets/pdf/pmozone_joint_actions_e.pdf

Environment Australia (2002). Technical Report No. 4: Review of Literature on Residential Firewood Use, Wood-Smoke and Air Toxics. 49 p. Report available on the Environment Australia web site htpp://ea.gov.au/atmosphere/airtoxics/report4/exec-summary.html

Environment Canada (2000). Characterization of Organic Compounds from Selected Wood Stoves and Fuels. Report 2000-0, Environmental Technology Center, Ottawa, 41 p.

Environment Canada (2001). Inventory of Releases of PCDDs and PCDFs (updated February 2001). Report prepared for Environment Canada and the Federal/Provincial Working Group on Dioxins and Furans for the for the Federal-Provincial Advisory Committee for the Canadian Environmental Protection Act (CEPA-FPAC) m.p.

Environment Canada (2002). Discussion Document. Options to Reduce Emissions from Residential Wood Burning Appliances. Prepared for Environment Canada, 33 p.

Fisher, L.H., J.E. Houck, P.E. Tiegs and J. McGaughey (2000). Long-Term Performance of EPA-Certified Phase 2 Woodstoves, Klamath Falls and Portland, Oregon: 1998-1999. Report prepared for U.S. EPA, EPA contract 68-D7-001, WA 2-04, Washington, DC, 64 p. available on the Omni Environmental Web site http://www.omni-test.com/Publications/Long-Term.pdf

Gulland Associates Ltd (1997). Scoping Study: Reducing Smoke Emissions From Home Heating With Wood. Report prepared for Environment Canada, Air pollution Directorate, EPS Manuscript Series # WM-22, 57 p + Appendices

Gullett, B.K., A. Touati and M.D. Hays (2003). PCDD/F, PCB, HxCBz, PAH, and PM Emission Factors for Fireplace and Woodstove Combustion in the San Franscisco Bay Region. *Environm. Sci. Technol.* 37: 1758-1765

Houck, J.E., J. Crouch and R.H. Huntley (2001). Review of Wood Heater and Fireplace Emission Factors *in* Proceedings U.S. Environmental Protection Agency Emission Inventory Conference, Denver, CO. Available on the web site http://www.omni-test.com/Publications/ei.pdf

Houck, J.E. and P.E. Tiegs (1998). Residential Wood Combustion - $PM_{2.5}$ Emissions outline of presentation prepared for WESTAR $PM_{2.5}$ Emission Inventory Workshop, Reno, Nevada, July 22-23 1998. Available on the web site: http://www.omni-test.com/Publications/westar.pdf

Houck, J.E., P.E. Tiegs, R.C. McCrillis, C. Keithley and J. Crouch (1998). Air Emissions from Residential Heating: The Wood Heating Option Put into Environmental Perspective *in* Proceedings of a U.S. EPA and Air Waste Management Association Conference: Emission Inventory: Living in a Global Environment, v. 1, pp 373-384, 1998

Launhardt, T., A. Strehler, R. Dumler-Gradl, H. Thoma and O. Vierle (1998). PCDD/F- and PAH-Emission from House Heating Systems. *Chemos*. 37:2013-2020

LGL (Lavalin-Girouard-Letendre) (1993) PAH Emissions into Canadian Environment - 1990. Supporting Document No. 1 for the National Evaluation Report on PAHs. Report prepared by M. Fabbri-Forget for Environment Canada, Conservation and Protection, Québec Region, Montreal (Qc), m.p.

Olsen, K., P. Collas, P. Boileau, D. Blain, C. Ha, L. Henderson, C. Liang, S. McKibbon and L. Morel-à-l'Huissier (2002). Canada's Greenhouse Gas Inventory 1990-1999. Greenhouse Gas Division, Environment Canada, Ottawa (Ont), 138 p.

Natural Resources of Canada (NRCan) (2002). End-Use Energy Data Handbook: 1990 to 2000. Office of Energy Efficiency (OEE) of Natural Resources Canada, 110 p.

Niemi (2002, 2003). Environment Canada, Pollution Data Branch, Personal communications

NRCan, (2002b). Energy Efficiency Trends in Canada 1990 to 2000. Office of Energy Efficiency (OEE) of Natural Resources Canada, 36 p.

Schatowitz, B.; G. Brandt, F. Gafner, E. Schlumpf, R. Biihler, P. Hasler, P. and T. Nussbaumer. (1993). Dioxin emissions from wood combustion. Organohalogen Compounds, 11:307-310 *in* U.S. EPA (2000). Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds Volume 2: Source of Dioxin-Like Compounds in the United States. Exposure Assessment and Risk Characterization Group, National Center for Environmental Assessment, U.S. EPA, Washington DC, m.p. draft report not to be cited but available on the EPA web site www.epa.gov/ncea/pdfs/dioxin/part1and2.htm (p. 4.19)

SSC (Senate Sub-Committee on the Boreal Forest) (1999). *COMPETING REALITIES: The Boreal Forest at Risk*. Report of the Sub-Committee on Boreal Forest of the Standing Senate Committee on Agriculture and Forestry. Chair of the Subcommittee : The Honourable Nicholas W. Taylor, Deputy Chair *:* The Honourable Mira Spivak

Accessed on Internet, June 2, 2003 at the following address:
http://www.parl.gc.ca/36/1/parlbus/commbus/senate/Com-e/BORE-E/rep-e/rep09jun99part2-e.htm

Statistics Canada (2002). Year 2000 Data available on the web site accessed July 19, 2002. Year 2001 available when site accessed on December 30, 2002
http://www.statcan.ca/english/Pgdb/manuf27.htm

United Nation Environment Programme (UNEP, 2003). Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. 1rst version. Report prepared by UNEP Chemicals, Geneva, Switzerland. 216 p. available on the web site
http://www.chem.unep.ch/pops/pdf/toolkit/toolkit.pdf

Valenti, J.C. and R.K. Clayton (1998). Project Summary Emissions from Outdoor Wood-Burning Residential Hot Water Furnaces. Report EPA/600/SR-98/017 National Risk Management Research Laboratory, Research and Development, U.S. EPA, Cincinnati, OH, 4 p. available on the web site http://www.epa.gov/ttn/atw/burn/woodburn1.pdf

Appendix

A-1: Provincial and national distribution of wood burned (tons) by each category of appliances in Canada (Adapted from Niemi, 2003)

	NFLD	PEI	NS	NB	QC	ON	MB	SK	AB	BC	YT	NT	Canada
Conventional Fireplaces													
Without Glass Doors	3 592	1 995	16 863	16 012	141 544	165 927	10 366	5 304	66 273	88 108	129	282	515 984
With Glass Doors	4 316	3 106	14 310	16 231	208 844	191 404	12 021	11 160	59 896	63 829	201	439	585 118
Fireplaces With an Insert													
Conventional	712	894	8 449	8 619	29 113	78 202	3 247	1 496	6 658	39 498	58	126	176 887
Advanced Technology	1 559	1 236	4 967	4 852	57 913	32 136	927	1 375	11 344	11 148	80	175	127 457
Fireplaces Advanced Technology	0	1120	4 967	4 852	42 611	14 402	927	1 375	6 211	6 013	73	158	82 478
Wood Stoves													
Conventional Not Air Tight	72 504	15 484	59 897	81 325	266 869	219 647	27 985	10 118	40 107	116 627	1 004	2 187	910 561
Conventional Air-Tight	106 780	37 451	189 908	245 778	749 209	594 426	37 677	24 338	45 893	174 309	2 428	5 289	2 205 769
Advanced Technology	17 205	5 069	13 727	21 203	213 148	78 853	9 226	6 030	19 228	31 630	329	716	415 318
Central Furnaces/Boilers	173 713	46 800	191 024	254 715	455 418	279 918	35 054	17 557	5 804	59 270	3 034	6 609	1 519 273
Others[1]	0	1 148	6 985	4 304	17 700	30 431	2 460	389	5 323	16 981	74	162	85 722
Total	380 381	113 183	506 129	653 039	2 139 756	1 670 944	138 964	77 768	260 527	601 399	7 338	15 983	6 542 089

1: Includes pellet stoves

A-2: Provincial and national distribution of wood burning appliances (in percentage) (Adapted from Niemi, 2003)

	NFLD	PEI	NS	NB	QC	ON	MB	SK	AB	BC	Canada[1]
Conventional Fireplaces											
Without Glass Doors	12.2	8.2	18.0	12.6	13.1	24.5	24.3	25.3	39.1	34.9	22.9
With Glass Doors	8.5	6.1	10.1	9.7	12.7	23.0	19.6	22.3	26.6	17.8	18.1
Fireplaces With an Insert											
Conventional	1.1	0.0	2,4	1.8	3.5	6.7	4.7	6.6	3.2	8.6	5.2
Advanced Technology	0.5	2.0	0.6	0.7	1.3	1.9	0.9	1.2	0.7	1.9	1.5
Fireplaces, advanced technology	0.0	0.0	1.2	0.4	4.0	2.1	0.5	3.6	5.0	1.5	2.6
Wood Stoves											
Conventional Not Air Tight	41.5	49.0	41.7	43.2	39.9	29.7	32.7	25.3	17.6	24.3	32.2
Conventional Air-Tight	19.7	16.3	13.0	14.8	15.1	10.5	15.4	10.8	8.7	9.1	12.1
Advanced Technology	4.8	4.1	3.2	3.6	10.6	3.8	8.9	4.8	4.5	3.8	5.8
Central Furnaces/Boilers	25.5	24.5	18.9	23.4	10.1	4.2	7.5	5.4	0.8	3.2	7.5
Others	4.3	0,0	1.8	0.7	1.1	1.2	1.4	0.6	1.0	1.2	1.2
Total	100	100	100	100	100	100	100	100	100	100	100

1: includes YT and NT