Comparison of Air Emissions between Cordwood and Wax-Sawdust Firelogs Burned in Residential Fireplaces

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ABSTRACT

Air emissions from the use of wax-sawdust firelogs and cordwood in fireplaces were measured. The study was designed to operate the fireplaces during testing in a manner that simulated real-world use and to use the most common/typical appliance type, cordwood, and set-up. Standard air quality source testing and analysis methods were used. Results showed that emissions of key air pollutants associated with residential wood combustion were reduced in the range from 69% to 90% through the use of wax-sawdust firelogs in fireplaces. Particulate and carbon monoxide emission reductions documented in this study were consistent with previous studies. Emissions of the hazardous air pollutants of formaldehyde, benzene and polycyclic organic matter (POM), measured for the first time for firelogs in this study, were also significantly lower than for cordwood and their emission reductions were comparable in magnitude as seen for particles and carbon monoxide. The majority of the particulate emissions from both cordwood and firelogs were $PM_{2.5}$, however, the fraction of the total particles that were $PM_{2.5}$ were slightly less for firelogs than for cordwood,

AIR EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION

Residential wood combustion (RWC) has been identified as a significant source of air pollutants nationwide. The overwhelming majority of RWC air emissions are from two categories of appliances: woodstoves and fireplaces. About 72% of the cordwood used annually in the United States is burned in woodstoves and about 28% in fireplaces[1]. Emissions of both federal criteria pollutants (namely, particles and carbon monoxide) and hazardous air pollutants (HAP's) have been associated with RWC.

It has been estimated that RWC emitted 368,000 short tons of PM_{10} particles in 1997 which comprised 12% of the total PM_{10} particles attributed to the sum of all fuel combustion, industrial and transportation sources[2]. Unlike many sources, nearly all the PM_{10} particles from RWC are also $PM_{2.5}$ particles, consequently RWC will figure prominently in future air quality improvement programs. It has also been estimated that RWC emitted 2,778,000 short tons of carbon monoxide (CO) in 1997 which comprised about 3% of its total national inventory[2]. While significant in its own right, the 3% contribution is exacerbated by the fact that all of the CO inventory assigned to RWC occurs only during the heating season and much of that episodically, therefore RWC's relative contribution to peak short-term one-hour and eight-hour National Ambient Air Quality Standards (NAAQS) for CO ambient air concentrations is greater than the inventory numbers alone would suggest.

Besides the criteria pollutants of particles and carbon monoxide, RWC has been identified as a large source of several of the hazardous air pollutants (HAP's) listed in the Clean Air Act Amendments of 1990. For example, nationwide, RWC has been determined to be the single largest source of polycyclic organic matter (POM), and the second largest source of benzene after the various categories of mobile sources[3]. Similarly, while not tabulated in the EPA inventories, annual emissions of formaldehyde from RWC are significant and estimates of national emissions from RWC range from 2560 to 281,000 short tons per year[4].

The spatial and temporal characteristics of RWC emissions add to their effective impact on air quality. As noted for carbon monoxide, most emissions occur episodically during only a portion of the year which increases the potential magnitude of short-term impacts. Further, and perhaps more important, all air emissions enter the atmosphere from chimneys that are usually no taller than 15 to 25 feet in height causing local ground-level impacts in residential areas where human exposure is at a maximum.

FIREPLACES

Fireplaces are ubiquitous and popular. There are an estimated 27 million fireplaces currently in homes the United States[5,6]. About 20% of the fireplaces are site-built masonry fireplaces and 80% are manufactured metal fireplaces. Manufactured metal fireplaces are commonly referred to as zero-clearance fireplaces. Manufactured zero-clearance fireplaces are designed to last 40 years or more. Masonry fireplaces can last indefinitely. About 0.4 million manufactured fireplaces are installed annually with new home construction. About one-half of all single-family homes have a fireplace and fireplaces are the third most popular home amenity after air conditioning and a two-car garage[7]. Unlike woodstoves, fireplaces are not (and cannot be) certified for low emissions by the U.S. EPA New Source Performance Standards (NSPS) protocol and there appear to be only a few substantive design features or retrofit devices currently available to reduce air emissions from them.

In other words, the fireplaces currently in homes will be available for use well into the future and their number is steadily increasing. Potentially they represent a growing air pollution source. There are only a few available, but not widely employed, "hardware fixes" to reduce air emissions from them. The banning of fireplace use would be impractical, unpopular and contrary to the lifestyle of many North American families. One pragmatic air quality mitigation strategy is to replace traditional cordwood with an alternative fuel. Two alternate fuel options have proven successful: the conversion of the appliance to gas and the use of manufactured wax-sawdust firelogs.

While conversion to gas does reduce air emissions and it is a credible option, there are some draw backs that, in practice, limit the applicability and/or popularity of gas conversion. These are: initial conversion costs[8], the lack of availability of natural gas in some areas, and the fact that even in areas where natural gas is available many homes are not connected to a gas line or plumbed for its use. The use of liquified petroleum gas (LPG) in areas where natural gas is not available is considerably more costly than natural gas and less convenient due to fuel storage/delivery and, as with natural gas, many homes are not set up for LPG use. Perhaps the most unpopular aspect of gas conversion is that once a fireplace is converted, cordwood can no longer be burned in the appliance. Manufactured wax-sawdust firelogs have become very popular in part because they require no appliance conversion with associated costs, they are convenient, and they are relatively inexpensive at two to three dollars per fire. Another advantage is that either wax firelogs or cordwood can still be used in the fireplace since no hardware conversion is necessary for their use. During episodic air pollution events the use of wax firelogs could be required while still allowing the use of cordwood at other times.

MANUFACTURED WAX-SAWDUST FIRELOGS

It has been estimated that 100 million wax-sawdust firelogs or 0.8 million wood cord equivalents are burned each year[9]. Based on survey data, wax-sawdust firelogs were burned some of the time in 30% of fireplaces and exclusively in 12% of the fireplaces during the 1994-1995 heating season[10].

Wax-sawdust firelogs are composed of approximately 40% to 60% wax with the remaining portion sawdust. Waxes obtained from petroleum refineries are typically used. The heat content of wax-sawdust firelogs is much higher than that of cordwood (15,700 Btu/lb for wax-sawdust firelogs as compared to 8900 Btu/lb for Douglas fir) and their moisture content is much lower (3% as compared to 20% for well-seasoned cordwood). There are two types of manufactured firelogs, densified firelogs and wax-sawdust firelogs. Wax-sawdust firelogs, discussed here, are for use exclusively in fireplaces, require no kindling, and are designed for one-at-a-time use. While several sizes of firelogs are commercially available, those with a burn duration of about three to four hours, which is the typical fireplace usage period, are most popular.

There have been a number of studies that have evaluated the reduction in particulate and carbon monoxide emissions achievable with wax-sawdust firelogs as compared with cordwood[11-14]. The test parameters for these studies are summarized in Table 1. These studies used emission rates (g/hr) rather than emission factors (g/kg fuel) or emissions per unit of heat (g/Mj) to compare emissions. This was done since the heat content is different for wax-sawdust firelogs than for a cordwood and their prescribed usage (one log burned at a time without the use of kindling) is also different than for cordwood. That is the, average emission rates over a normal burn cycle for both cordwood and firelogs provide the best measure for comparison of the total amount of air pollutants that are released into the environment when a standard fireplace is used in a normal fashion with either fuel type. As summarized in Table 1, a variety of fireplace types, cordwood types, firelog brands and burn patterns/cycles were used in the studies. While the percent reduction in emissions were different for each test due to these variables, the results of all studies showed substantial reduction in particulate matter (PM) and carbon monoxide (CO) emissions. Figure 1 illustrates the reduction in particulate emissions by each study and Figure 2 illustrates the reduction in carbon monoxide by each study. The average reduction in particulate emissions for all previous studies was 69% and the average reduction in carbon monoxide emissions was 88%. Because virtually all particles emitted from cordwood and firelogs burned in fireplaces are submicron in diameter, reductions documented for total particulate matter (PM) emissions are also representative of reductions in PM_{10} and $PM_{2.5}$ particles.

FIRELOG EMISSION TESTING PROGRAM

Air emissions from regional cordwood and from standard commercially available firelogs burned in a fireplace were measured. Emissions of total particles (PM), PM_{10} particles, $PM_{2.5}$ particles, carbon monoxide, formaldehyde, benzene, and the polycyclic organic matter (POM) surrogate16-PAH were measured. Because wood from different tree species from different regions of the country have characteristically different moisture contents, resin contents, densities, and heat contents which all influence burning characteristics and commensurate emissions, three different regional cordwood types were burned for comparison of emissions with firelogs. These were: Douglas fir which is used in the Pacific Northwest, ponderosa pine which is used in the arid west, and oak which is used nationwide.

The objective of the testing was the realistic measurement and comparison of emissions from the use of cordwood and firelogs in a typical fireplace. All tests were performed in a standard 36 inch zero clearance radiant fireplace without glass doors. Thirty-six inch zero clearance radiant fireplaces are the most common type in home use. To simulate a home set-up, a typical 16.5 foot high chimney extended through the roof exhausting emissions through a chimney cap to the outside. A standard grate (about six inches spacing between bars) was used with the cordwood. Some firelog tests were with this same standard grate and some were with a grate with more closely spaced bars (less than two inches). A grate with closely spaced bars is recommended for firelog use and typically firelog wrappers instruct the home user to utilized such a grate with the firelog.

Cordwood was started with crumpled black print newspaper and kindling sticks, followed by small logs and finally normal size logs were added. Surveys have shown that the typical burn rate for most fireplaces is approximately 3 kg dry fuel per hour[15,16]. The burn rates achieved for the four cordwood tests that were part of this study ranged from 2.9 to 3.4 dry kg/hr.

Single firelogs were burned one at a time as per the package instructions. The firelogs were tapped with a fireplace poker in some tests when the flames started to flicker out as it is believed that most home users would follow this practice.

The experimental burn period for the cordwood and firelog tests were adjusted to be comparable to each other and to the real-world use of fireplaces to allow for the comparison of air pollutant emissions. Most fireplaces are used for less than six hours at a time in the evening[17]. A recent confidential survey for a firelog manufacturer showed that most fireplaces are used for less than four hours at a time. Two cordwood wood addition schedules were used in the study. For one, wood was added over a three-hour time period. For the other, wood was added over a four-time period. The corresponding burning period as defined from ignition to the time when the chimney temperature inside the chimney one foot above the fireplace dropped to 100°F ranged from 4.8 to 6.0 hours. For the most typical firelog burning scenario (grate with two inch bar spacing and tapped with a fireplace poker), the last flame flickered out at about five hours and the burn period, as defined as the time from ignition to when the concentration of carbon monoxide in the chimney dropped to 10 ppm, was 6.3 hours. All test parameters for this study are summarized in Table 2.

A dilution tunnel was used to cool and dilute the fireplace emissions prior to sample collection. A hood was placed over the chimney cap and the entire exhaust stream was captured and mixed with outdoor ambient air. Dilution tunnels have been used in a wide variety of source test applications because they permit the collection of air pollutants in a chemical and physical form similar to that which they will have once they exit the chimney and mix with ambient air[18]. This is particulary important for characterizing emissions from the combustion of biomass fuels because a large fraction of their air emissions are comprised of semi-volatile organic compounds. The relative partitioning of these compounds between the vapor phase and submicron particles is primarily dependent on temperature. The average temperature difference between the point where samples were collected in the dilution tunnel and outside air was less than 10°C for all tests and less than 5°C for the two most representative tests discussed later. Ambient temperatures varied somewhat with meteorological conditions over the course of the testing, however they were in all cases cold/cool Northwest temperatures characteristic of conditions under which fireplaces would normally be used.

Pollutant samples were collected from the dilution tunnel and analyzed following standard sampling and analytical methods. Particulate samples were collected isokinetically onto Gelman type A/E filters and processed following the protocols specified for wood heaters (40 CFR Pt. 60, App. A, Meth.5G) in OMNI's EPA accredited wood heater testing laboratory (certified under 40 CFR Subpart AAA, Pt. 60). The PM values were the sum of total particulate material collected on the filter and the material removed from the button hook nozzle and connecting hardware with acetone. The PM_{10} samples were collected using an Apex Instruments cyclone pre-separator developed for EPA method 201A (40 CFR Pt. 51, App. M). The $PM_{2.5}$ samples were collected using a impactor pre-separator developed for the California Air Resources Board[19]. Formaldehyde was collected and analyzed by EPA methods SW-846 0011/8315. Benzene was collected and analyzed by EPA method TO-14 (EPA/625/R-96/010b). The POM surrogate compounds (16 individual polycyclic aromatic hydrocarbons referred to as 16-PAH) were collected and analyzed by EPA methods SW-846 0010/8270. Carbon monoxide and carbon dioxide concentrations were measured with infrared gas analyzers. Oxygen concentration was measured with an electrochemical gas analyzer. All gas analyzers were calibrated with certified gas standards. Gas flow within the dilution tunnel was measured with a thermal anemometer. A platform scale was used to prepare pre-weighed bundles of wood and to provide accurate individual firelog weights. The heat content of the cordwood and of the firelogs was determined by proximate/ultimate analyses. The moisture content of the firelogs was also obtained by proximate/ultimate analyses. The moisture content of cordwood was determined by averaging two to five moisture readings made on each piece of fuel with a Delmhorst Instrument Company resistance wood moisture meter. The moisture content of gas within the chimney was measured by EPA method 4 (40 CFR, Pt. 60. App. A). Chimney draft was monitored with a Dwyer Instruments, Inc. Magnehelic gage. Chimney, dilution tunnel, outside and inside temperatures were measured with type-K thermocouples. For quality assurance 10% of the data reduction calculations were independently checked.

RESULTS

The results of the individual emissions tests with cordwood and with commercial firelogs are summarized in Table 3. Average emission values for each of the two fuel categories are also shown in Table 3. Figure 3 illustrates the emissions for the most representative fireplace scenarios for both cordwood and commercially available firelogs. All methods of evaluating results show that substantial reductions in air emissions can be achieved through the use of firelogs.

The emission reductions for the most representative use scenarios provide the best assessment of the level of pollutant reductions that can be reasonably expected in an airshed through the use of firelogs. The most representative fireplace scenario for cordwood consists of seasoned oak fuel, 3-hour wood addition period, a standard factory-supplied grate and an approximately 3 kg/hr burn rate. The most representative firelog scenario consists of burning a “4-hour” firelog following manufacturer’s instructions (one at a time on a grate with bar spacing less than 3 inches) and tapping the log with a fireplace poker when visible flames start to flicker out. In both cases the most common/typical fireplace and chimney set-up which consisted of a 36- inch radiant fireplace, no glass doors, and a 16.5 ft chimney height was used.

Particulate size distribution was investigated. The results for cordwood and commercial firelogs show that for both the overwhelming majority of the particulate emissions are smaller than 2.5 microns in aerodynamic diameter, i.e., they are $PM_{2.5}$. The emission values for PM, PM_{10} and $PM_{2.5}$ are so close for some of the test runs that the uncertainty in the measurements are larger than the differences in emissions for the different sizes. Consequently to minimize the effect of the uncertainty, the average values for the fuel categories were used to assess the relative particulate size distribution. Using average values for all four cordwood tests and average values for the two firelog tests for which there is both PM and $PM_{2.5}$ data, it can be estimated that about 4% of the particulate matter emitted from cordwood burned in a fireplace is larger than $PM_{2.5}$ and slightly more (about 12%) of particulate matter from firelogs is larger than $PM_{2.5}$. The significance of this finding is that PM is a reasonable surrogate for PM_{10} and $PM_{2.5}$ and that the reduction seen in PM emissions in this study and in previous studies is a good indicator of the reduction that can be expected in PM_{10} and $PM_{2.5}$ with the use of firelogs. The fact that relatively slightly less of the PM from firelogs than from cordwood is $PM_{2.5}$ implies that if all else is equal (i.e., similar chemical composition), firelog particulate emissions are slightly less of an environmental and health issue than particulate emissions from cordwood for a given PM level.

The overall results of the study are summarized in Table 4 and can be simply stated. Emissions of key air pollutants associated with residential wood combustion were reduced in the range from 69% to 94% through the use of wax-sawdust firelogs in fireplaces. Particulate and carbon monoxide emission reductions documented in this study were consistent with previous studies. Emission reductions of the hazardous air pollutants of formaldehyde, benzene and polycyclic organic matter (POM), measured for the first time for firelogs in this study, were also significantly lower than for cordwood and their emission reductions were comparable in magnitude as seen for particles and carbon monoxide.

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Table 1. Parameters used in previous firelog studies

study	fireplace	cordwood, number of tests	firelogs, number of tests	cycle/test period
1993 DOE, ref. 11	zero-clearance & masonry	Douglas fir, n = 2	composite of 7 brands, n = 3	cold-to-cold
1991 CCRL, ref. 12	zero-clearance	spruce, wet maple, dry maple, n = 3	3 brands, n = 3	cold-to-cold
Shelton Res., ref. 13	zero-clearance	pine, oak, cedar, n = 6	3 brands, 2 sizes each, n = 6	cold-to-cold
1987 B.C. Res., ref. 14	zero-clearance	alder, fir, n = 2	1 firelog, n = 1	hot part of burn only

Table 2. Parameters used in this research

	Fuel Type	Fuel Moisture (% Dry Basis)	Heat Content (BTU/dry lb)	Burn Conditions[1]	Sample Duration (hrs)
Cordwood	Douglas Fir	21.2	8900	Standard grate, 4 hrs wood addition	5.5
	Ponderosa Pine	11.2	8750	Standard grate, 4 hrs wood addition	5.4
	Oak	18.8	8556	Standard grate, 4 hrs wood addition	6.0
	Oak	13.0	8556	Standard grate, 3 hrs wood addition[2]	4.8
Commercial Firelog	Firelog	2.9	15734	Standard grate, poker used	5.0
	Firelog	2.9	15734	Standard grate, poker used	7.6
	Firelog	2.8	15734	Firelog grate, poker not used	10.4
	Firelog	2.8	15734	Firelog grate, poker used[3]	6.3

[1] Most representative cordwood burning scenario.
[2] Most representative firelog burning scenario.
[3] Firelog grate refers to a grate with less than three inch spacing.

Table 3. Results

	Fuel Type	Emission Rates						
		PM (g/hr)	PM_{10} (g/hr)	$PM_{2.5}$ (g/hr)	CO (g/hr)	Formaldehyde (g/hr)	Benzene (g/hr)	16-PAH[1] (g/hr)
Cordwood	Douglas fir	80.2	84.3	87.6	242	5.8	1.69	1.05
	Ponderosa pine	41.1	34.4	34.6	199	4.0	1.05	0.40
	Oak	70.4	61.8	56.9	270	6.3	1.87	0.89
	Oak[2]	46.2	46.9	48.2	253	5.0	1.18	0.57
Average Cordwood		59.5	56.8	56.8	241	5.3	1.45	0.72
Commercial Firelogs	Firelog	-	-	-	39	-	-	-
	Firelog	17.7	-	14.1	41	0.53	0.589	0.032
	Firelog	17.8	-	-	26	-	-	-
	Firelog[3]	12.4	11.3	11.7	42	0.6	0.309	0.049
Average Commercial Firelog		16.0	11.3	12.9	37	0.57	0.449	0.0405

[1] 16-PAH is a surrogate for POM

[2] Most representative cordwood burning scenario.

[3] Most representative firelog burning scenario

Table 4. Reduction in air pollutant emissions through the use of wax/sawdust firelogs

Data Source	PM % Reduction	CO % Reduction	Formald. % Reduction	Benzene % Reduction	16-PAH % Reduction
Literature avg.	69	88	-	-	-
Avg. this study	73	85	89	69	94
Most representative scenarios this study	73	83	88	74	91

Figure 1. Particulate emissions from cordwood and firelogs - previous studies

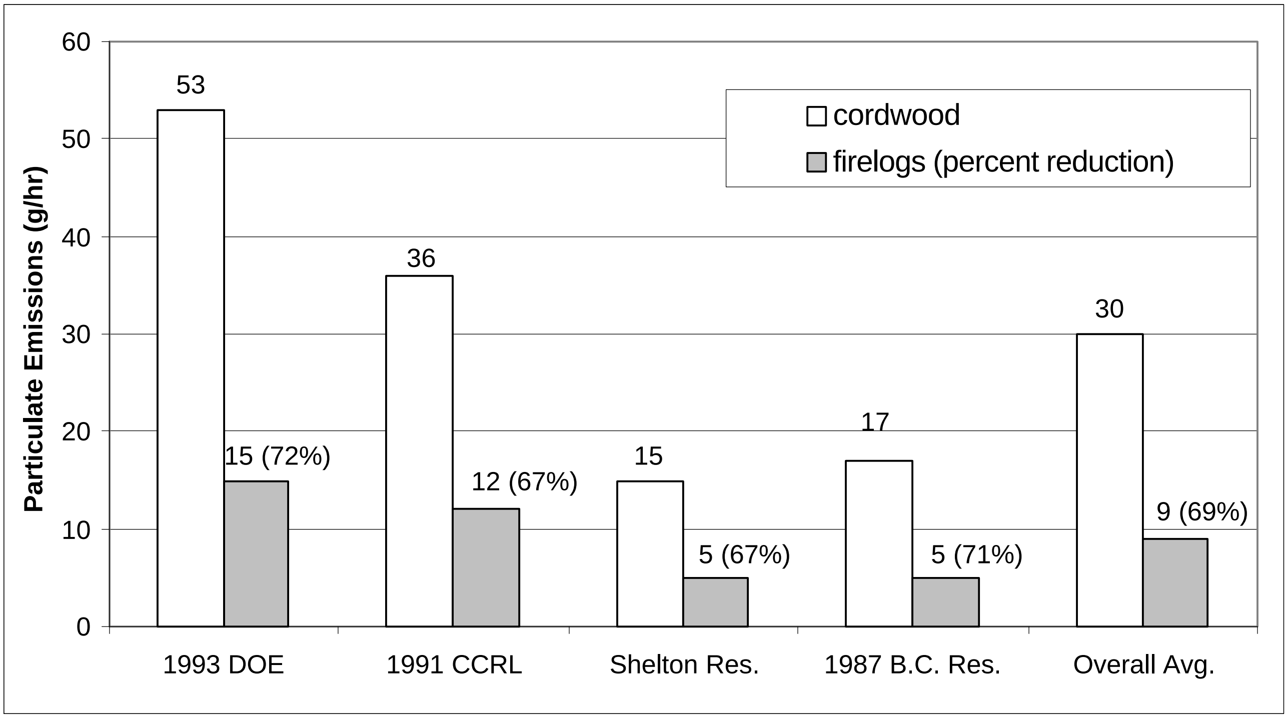

Figure 2. Carbon monoxide emissions from cordwood and firelogs - previous studies

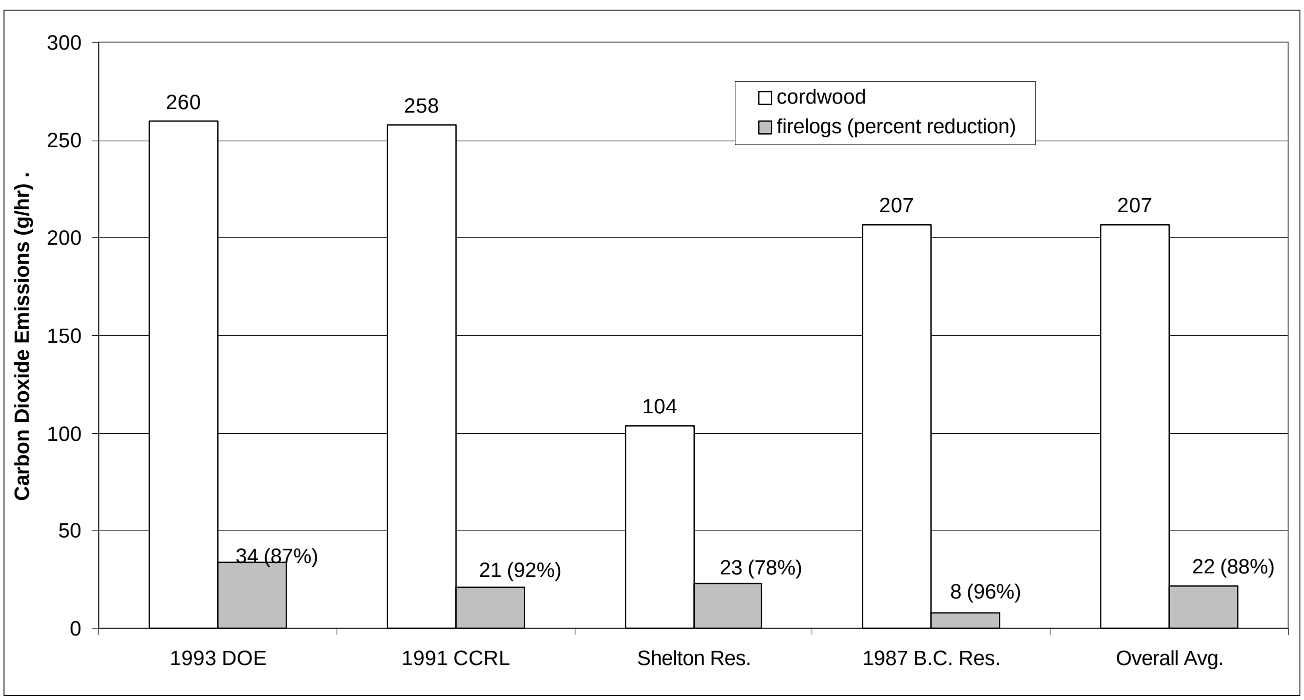

Figure 3. Comparison of air emission rates for representative cordwood and firelog use scenarios