

# **The PM<sub>2.5</sub> Reduction Potential of New Technology Home Heating Appliances and Fuels**

**James E. Houck and Paul E. Tiegs**

OMNI Environmental Services, Inc.  
5465 SW Western Ave.  
Beaverton, OR, 97005

**John Crouch and Carter Keithley**

Hearth Products Association  
1601 North Kent St., Suite 1001  
Arlington, VA, 22204

## **ABSTRACT**

Reduction in PM<sub>2.5</sub> emissions from residential wood stoves and fireplaces by the replacement of existing units with new technology appliances and by using alternate fuels are discussed. Percentage emission reductions for each type of new technology and alternate fuel are presented. A description of each of the technology types and fuels are also provided. Predicted reductions in PM<sub>2.5</sub> emissions by appliance replacement and changes in fuel usage were calculated regionally by census division and by population increments in each of the census divisions. The reduction by population increments was calculated to provide insight into the magnitude of reductions that could reasonably be expected in a given city or nonattainment area in each of the census divisions.

## **INTRODUCTION**

Residential wood combustion (RWC) has been identified as the dominant source or as a major contributor of PM<sub>10</sub> in many PM<sub>10</sub> nonattainment areas. National PM<sub>10</sub> emissions from RWC in 1995 have been estimated as  $3.24 \times 10^8$  kg<sup>1</sup>. Well over 80% of particulate emissions from RWC are PM<sub>2.5</sub><sup>2</sup>. Consequently, unless emissions from RWC are reduced, RWC will be a significant source in many future PM<sub>2.5</sub> nonattainment areas.

In 1993, 9% of the 96.6 million households nationwide used a wood stove<sup>3</sup>. Also, in 1993, 46% of the 55.5 million single family detached homes had fireplaces<sup>4</sup>. Currently a fireplace is the number three most popular amenity for a single family detached home after a two-car garage and central air conditioning<sup>5</sup>. Almost two-thirds of new single family detached homes have a fireplace and about 5% have two or more fireplaces<sup>4</sup>. In 1993, about 9% of the nation's space heating energy demand was met by RWC<sup>3</sup>. PM<sub>2.5</sub> reduction solutions based on moratoriums or bans on the installation or use of RWC appliances are not responsible in terms of the national need for the utilization of renewable energy resources and they are contrary with the life styles of most American families.

It is estimated, based on commercial surveys, that there are currently 9.6 million wood stoves (including pellet stoves) and 7.1 million fireplace inserts (a total of 16.7 million appliances) used as significant heating appliances nationwide<sup>6</sup>. However, Hearth Products Association (HPA) manufacturer surveys show that only about 1.8 million of them are new technology appliances (1.0 million certified cordwood stoves + 0.3 million pellet stoves + 0.5 million certified fireplace inserts)<sup>7</sup>. In addition to the existing 7.1 million fireplaces with inserts, there are more than 20 million fireplaces without inserts (for a total of more than 27 million fireplaces)<sup>4,6</sup>. Most of the fireplaces without inserts are used for aesthetic enjoyment or as a minor secondary source of heat. (Only 60% to 70% of installed fireplaces are used in

any given year<sup>4, 8</sup>.) More than eight million cords of wood were burned in fireplaces in 1997 and about 0.8 million cord equivalents of that amount were manufactured wax logs. The wide gap between the total number of appliances and the number of low-emission, high technology units in homes, as well as, the difference in the amount of cordwood and manufactured wax logs burned in fireplaces provides the opportunity for reduction in atmospheric PM<sub>2.5</sub> levels by replacing older technology units with high technology ones or by changing fueling practices in fireplaces.

New technology appliances and fuels provide large reductions in PM<sub>2.5</sub> as compared with conventional wood stoves and traditional open radiant fireplaces burning cordwood. For the approximately 8.3 million old technology wood stoves currently in use, their replacements with certified catalytic stoves, certified non-catalytic stoves, pellet stoves, masonry heaters, or the use of manufactured densified fuel in place of cordwood all provide PM<sub>2.5</sub> reductions. For fireplaces used as significant heating sources, there is a wide range of options to reduce PM<sub>2.5</sub> emissions. Some of these options can be retrofitted into existing units while others are only practical during home construction or remodeling. Options include simple older measures such as installing glass doors, double shell convection design, the use of blowers, the use of convection tubes and masonry fireplaces with specially shaped fire chambers. Higher technology options include the use of certified cordwood, pellet or gas inserts; or the installation of certified wood stoves or gas appliances that have the fireplace look. For fireplaces used for aesthetic and minor heating purposes, the use of manufactured wax logs or decorative gas logs provides PM<sub>2.5</sub> emission reductions.

The findings of the research conducted by OMNI Environmental Services, Inc. (OMNI) for the U.S. Environmental Protection Agency (U.S. EPA) and HPA are provided here. The establishment of the current state-of-the-art of RWC technology was a key objective of the research conducted for the U.S. EPA. It was accomplished by reviewing literature and reports published since the late 1970's and by formally interviewing recognized RWC experts in the appliance manufacturing industry, academia and wood stove testing laboratories. The establishment of the numbers and types of wood burning appliances in use and their characteristic emissions and efficiencies were the key objectives of the research conducted for the HPA. This research was accomplished by reviewing governmental surveys, HPA manufacturer surveys, other commercial surveys, emissions studies and by interviewing HPA members. By combining the results of the U.S. EPA and HPA research, the potential for reducing RWC PM<sub>2.5</sub> emissions by using the various new technology options was documented. A description of the new technologies available with their corresponding emissions and efficiencies are provided. Calculated PM<sub>2.5</sub> emission reductions as compared to either conventional wood stoves or open radiant fireplaces burning cordwood are also provided. In addition, the PM<sub>2.5</sub> reductions that would be achievable nationally, by census division and by 100,000 population increments in each census division from the use of new technology appliances and manufactured fuels were calculated. The later calculation was done to allow estimates to be made of the PM<sub>2.5</sub> reduction potentials in given cities or nonattainment areas based on population.

## **COMPARATIVE EMISSIONS UNITS**

Particulate emissions from RWC have traditionally been reported in three ways. These ways are: (1) emission factors, i.e., mass of emissions per mass of dry fuel burned (g/kg or lb/ton), (2) emission rates, i.e., mass of emissions per time of appliance operation (g/hr), and, (3) mass of emissions per unit of heat delivered (g/MJ or lb/million BTU). The use of mass of emissions per unit of heat delivered (g/MJ) allows for the comparison of emissions for heating appliances with different efficiencies. Emission factors (g/kg) do not take into account the fact that higher efficiency appliances will burn less wood to produce the same heat as lower efficiency appliances and therefore will have effectively lower emissions, even if their emission factors are comparable. Emission factors (g/kg) are, therefore, inappropriate for comparing emissions. Emission rates (g/hr) do not take into account the amount of heat produced by an appliance. To be useful they would need to be indexed to efficiency and the amount of fuel burned. Emission rates (g/hr) are, therefore, inappropriate for comparing emissions. Some

confusion over the use of emission rates (g/hr) has occurred from the use of emission rates in the U.S. EPA certification program for wood stoves. The U.S. EPA certification process is a method to evaluate the relative performance of wood stoves under specific burn rates and conditions using dimensional lumber and permits those with acceptable emissions performance to be sold. It is generally recognized that the certification emission rates (g/hr) are different (lower and not directly correlatable) than the emission rates that the same appliances will have in homes under Areal-world@ use. Certification numbers cannot be used in the development of emission inventories. Comparisons of emissions in terms of mass emissions per unit of heat delivered (g/MJ) are presented in Figure 1 for alternatives to conventional stoves burning cordwood and in Figure 2 for alternatives to conventional open radiant fireplaces burning cordwood.

Unlike the case of appliances used as significant sources of heat, the use of emissions per unit of heat (g/MJ) delivered for comparison of emissions for fireplaces, used primarily for aesthetic or minor heating purposes, is inappropriate. In this case, emission rates (g/hr) do provide for a better comparison. The burn rate of a fireplace used for aesthetic or minor heating purposes is mostly related to the size of a typical sustainable Awarm@ aesthetic fire characteristic of fireplaces (about 3 kg/hr). That is, the amount of wood burned and the corresponding emissions are not directly related to heat demand, but are more or less constant for a given appliance. In addition, one of the two alternatives to fireplaces burning cordwood, the use of manufactured wax logs, has a fixed burn rate associated with it. The manufacturers of wax logs generally recommend one-at-a-time usage with a specified burn duration per log. The other alternative, decorative gas log systems, have negligible particulate emissions at all heat output levels. Consequently, emission rates (g/hr) were used to compare emissions and emission reductions for fireplace alternatives for a fireplace used for aesthetic and minor heating purposes (Figure 3).

## **WOOD STOVE/HEATERS**

There are an estimated 8.3 million conventional wood burning stoves currently in use<sup>6,7</sup>. Wood stoves are designed for a lifetime of about 40 years. Consequently, without regulatory impetus the replacement of existing wood stoves with new technology devices will be a slow process. Estimates of the average efficiency and emissions of conventional wood stoves are 54% and 1.68 g/MJ, respectively (Figure 1). The efficiency and emissions estimates have been based on a number of field studies<sup>9-14</sup> and interviews with RWC experts. Average emissions for conventional wood stoves may be higher than the 1.68 g/MJ since most of the studies were conducted in cold climates with stoves operating at higher burn rates. High burn rates tend to produce lower emissions than low burn rates. The consequence of this is that the PM<sub>2.5</sub> reductions calculated for the various alternatives to conventional stoves burning cordwood may be conservative and the actual reduction achievable may be greater. While we report an average efficiency and emissions value, it is widely recognized that efficiencies and emissions are highly variable for conventional cordwood stoves. This is due to the facts that there are hundreds of wood stove models in use, many dozens of tree species are commonly used for fuel wood, draft characteristics (chimney conditions) vary from home to home, household altitude is variable, there are variations in fuel seasoning and storage practices (wood moisture) and there are wide variations in home owner operation of wood burning devices (e.g., burn rate, damper setting, kindling approach, etc.). To provide more accurate percent PM<sub>2.5</sub> reduction values in a specific airshed measurement of conventional stove efficiencies and emissions in that airshed would be appropriate to produce average values more reflective of local conventional wood stove usage.

Low emission alternatives to conventional stoves burning cordwood are certified non-catalytic wood stoves, certified catalytic wood stoves, certified pellet stoves, exempt pellet stoves, masonry heaters and the use of manufactured densified fuel.

### **Certified non-catalytic wood stoves**

There are an estimated 0.6 million certified non-catalytic wood stoves currently in use<sup>7</sup>. There are 119 models listed as certified by the U.S. EPA as of August 12, 1997. All wood heaters manufactured after July 1, 1988 and sold after July 1, 1990 had to meet Phase I emission limits. All wood heaters manufactured after July 1, 1990 and sold after July 1, 1992 had to meet Phase II emission limits. Phase I and Phase II emission limits for non-catalytic wood stoves are 8.5 g/hr and 7.5 g/hr, respectively. Non-catalytic technology achieves the reduction in emissions primarily by using secondary combustion air and heat-retaining refractory materials that promote complete combustion. A substantial fraction of emissions from non-catalytic wood stoves occurs during fire start-up before efficient combustion is achieved. The average efficiency and emission values for certified non-catalytic wood stoves are based on a number of field studies<sup>9-12,14-16</sup> and interviews with RWC experts. The efficiencies and emissions are shown in Figure 1. It is estimated that certified non-catalytic wood stoves can reduce emissions by 71% as compared with conventional stoves.

### **Certified catalytic wood stoves**

There are an estimated 0.4 million certified catalytic wood stoves currently in use<sup>7</sup>. There are 83 models listed as certified by the U.S. EPA as of August 12, 1997. Phase I and Phase II emission limits had to be met for catalytic stoves in the same time frames as non-catalytic stoves. For catalytic stoves the Phase I and Phase II limits are 5.5 g/hr and 4.1 g/hr. The limits are lower for catalytic stoves than for non-catalytic stoves because their emissions increase with time as the catalyst performance becomes poorer. As with non-catalytic stoves, emissions are at their highest during start-up for catalytic stoves. Not only is combustion not efficient during the fire start-up period but the catalyst needs to be heated before it functions. The average efficiency and emission values for certified catalytic wood stoves are based on a number of field studies<sup>9, 10, 12, 14, 15</sup> and interviews with RWC experts. The efficiencies and emissions are shown in Figure 1. It is estimated that certified catalytic wood stoves with new catalysts can reduce emissions by 74% as compared with conventional stoves.

### **Pellet stoves**

There are an estimated 0.3 million pellet stoves currently in use<sup>7</sup>. During the 1995-1996 heating season 654,000 tons of pellets were sold<sup>17</sup>. Nearly all pellet stoves have been sold since 1989. There are two categories of pellet stoves C certified and exempt. There are five models listed as certified by the U.S. EPA as of August 12, 1997. Appliances with a greater than a 35 to 1 air-to-fuel ratio are exempt from certification. Early models with the high air-to-fuel ratio had lower efficiencies than certified models due to sensible heat loss out the exhaust. This is not the case with newer models since the high air-to-fuel ratio only needs to be demonstrated at low burn rates to obtain the exemption. At more normal burn rates the air-to-fuel ratio is much lower. Efficiency and emission values for pellet stoves are based on field studies<sup>18, 19</sup> and interviews with RWC experts. The efficiencies and emissions are shown in Figure 1. It is estimated that pellet stoves can reduce particulate emissions by 92% as compared with conventional cordwood stoves. Reduction in PM<sub>2.5</sub> is expected to be even greater than the reduction of total particulate since the PM<sub>2.5</sub> fraction of pellet stove particulate emissions is believed to be smaller than for cordwood stoves. Cordwood stove emissions are composed primarily of condensed organic products that are mostly submicron in size<sup>2</sup> whereas pellet stove emissions are believed to contain a higher fraction of entrained inorganic ash that is characteristically composed of larger particles.

### **Masonry heaters**

Masonry heaters are exempt from U.S. EPA certification and, in fact, the certification procedure is not applicable to their design or intended mode of operation. The state of Colorado does, however, have an emission limitation applicable to masonry heaters that is 6.0 g/kg. Masonry heaters are more costly than cordwood or pellet stoves and for that reason many fewer of them are in place. However, because of their aesthetic appeal many of them are the centerpieces of homes and are often installed in higher-end houses. They achieve their low emissions by burning a large mass of cordwood in a short time period. The high burn rate enhances complete high-temperature combustion and commensurate low emissions.

The short-duration, high-burn heats a large masonry mass that radiates heat to the living space well after the fire is out. To enhance transfer of the heat to the masonry material, the exhaust gas is routed through a folded pathway through the appliance. The appliance is generally installed in the center of the home rather than along an exterior wall to facilitate radiant heating. The average efficiency and emission values for masonry heaters are based on field studies<sup>20</sup> and interviews with RWC experts. The efficiencies and emissions are shown in Figure 1. It is estimated that masonry heaters can reduce emissions by 85% as compared with conventional stoves.

### **Densified fuel**

Manufactured densified fuel is commonly used in cordwood stoves due to its convenience and good burning characteristics. It is typically composed of compressed sawdust. Its density ranges from 1.1 to 1.3 g/cm<sup>3</sup> as compared to wood, which typically ranges from 0.3 to 0.8 g/cm<sup>3</sup> depending on the species, and its moisture content is in the 6% to 10% range compared with quality cordwood that has a moisture content of around 20%<sup>13, 21</sup>. The dense, clean, low moisture fuel produces lower emissions than cordwood when burned in conventional stoves. Its cost during the 1991-1992 heating season in the Pacific Northwest averaged about 1.4 times that of cordwood<sup>13</sup>. The average efficiency and emission values for conventional stoves burning densified fuel are based on field and laboratory studies<sup>13, 21</sup> and interviews with RWC experts. The efficiencies and emission values are shown in Figure 1. It is estimated that the use of densified fuel in conventional stoves can reduce emissions by 27% as compared with conventional stoves using cordwood. Not surprisingly, when densified fuel was burned in certified stoves further reductions in emissions were achieved over the certified stove burning cordwood alone (Figure 1)<sup>13, 21</sup>. It should be noted that quality densified fuel has been made from a variety of other biomass materials besides sawdust. These include straw, rice hulls, waste paper, cardboard, nut shells, palm boughs, and peat. The emissions from these products vary but are generally lower than from cordwood.

### **FIREPLACES USED AS A HEAT SOURCE**

There are an estimated 27 million fireplaces currently in homes<sup>4</sup>. There are two structural types of fireplaces C manufactured metal fireplaces referred to as zero-clearance fireplaces and masonry fireplaces. Zero-clearance fireplaces are designed to last to 40 years or more. Masonry fireplaces can last indefinitely. Consequently, the 27 million fireplaces currently in homes will be available for use well into the future.

A large number of fireplaces are used as significant supplemental heat sources since fireplace inserts are designed for increase efficiency and there are 7.1 million fireplaces with inserts in them<sup>7</sup>. A small number of fireplaces are even used as primary heat sources. In 1993, 0.4 million households used wood burning fireplaces as their main source of heat<sup>3</sup>. Many existing fireplaces are more efficient than the simple open radiant fireplaces due to well established older technological improvements. It has often been stated that fireplaces are only used for aesthetic purposes due to their low efficiencies (around 7% for open radiant fireplaces). However, some fireplaces utilizing older technology can reach efficiency levels in the 40% range<sup>22</sup>. Older technologies that increase efficiencies and effectively reduce emissions by requiring less wood to provide the same heat include, double shell convection designs, convection tubes, the use of blowers to transfer heat, glass doors, and masonry fireplaces with shaped fire chambers (e.g., Rumford and Rosin fireplaces). Efficiency and emission values for open radiant fireplaces and various older technologies are shown in Figure 2. They are based on field and laboratory studies<sup>20, 22</sup> and interviews with RWC experts. Some older technologies, such as glass doors and convection tubes, can be added to existing open radiant fireplaces to reduce effective emissions. The open radiant fireplace with an efficiency value of 7% and emission value 8.55 g/MJ was used for comparison purposes in Figure 2 since it is the simplest fundamental unit.

There is no federal protocol for testing fireplace emissions. There is, however, a state of Washington testing protocol for non-masonry fireplaces (7.3 g/kg emission limit) and there is a Northern Sonoma County, California testing protocol currently in the process of development for masonry fireplaces.

### **Certified cordwood and pellet inserts**

Certified non-catalytic, certified catalytic and pellet inserts can be placed in existing zero-clearance and masonry fireplaces. They are essentially stoves modified to fit into a fireplace. If properly installed, their performance is similar to their stove counterparts, albeit their efficiencies are slightly poorer since convection and radiation of heat is more restricted by their placement into the fireplace cavity. There are an estimated 0.5 million certified cordwood inserts and 0.2 million pellet inserts in use<sup>7</sup>. As of August, 12, 1997, the U.S. EPA listed four catalytic and six non-catalytic insert models as certified. The emission reductions they provide over the use of a simple open radiant fireplace ranges from 94% to 98% (Figure 2).

### **Gas units**

There are three types of gas units that have the Afireplace-look@. They are gas fireplace inserts, decorative gas fireplaces and gas fireplace heaters. All have negligible PM<sub>2.5</sub> emissions as compared with cordwood fireplaces. Therefore, particulate reductions are near 100%. They can utilize either natural gas or liquid petroleum gas (LPG) which are, of course, fossil fuels, not renewable biomass fuels. Gas fireplace inserts like certified cordwood and pellet inserts can be put into existing fireplaces. Decorative gas fireplaces and gas fireplace heaters are designed for new construction. Gas fireplace heaters are more sophisticated than decorative gas fireplaces as they are designed more for efficiency whereas decorative gas fireplaces are designed more for flame presentation.

### **Fireplace-like wood stoves**

Wood stoves have been designed to have the appearance of fireplaces, are Azero-clearance@ units and can be installed at the time of construction. The emission reductions they offer over simple open radiant fireplaces are in the 95% range (Figure 2).

## **FIREPLACES USED FOR AESTHETIC AND MINOR HEATING PURPOSES**

Among the 20.4 million households that burned wood in 1993, 9.6 million burned less than one-half of a cord per year and 5.6 million reported burning wood on the average of less than one hour per week<sup>3</sup>. During the 1994-1995 heating season 17% of fireplace owners reporting burning wood 1-2 times per season, 13% reported 1-2 times per month, and 18% 1-2 times per week<sup>8</sup>. The sum of these three categories during the 1994-1995 heating season corresponds to about 13 million fireplaces. While none of these statistics provides a clear picture of the number of fireplaces used for aesthetic and minor heating purposes, they do illustrate its magnitude. Figure 3 lists the typical emission rate (60 g/hr) of a simple open radiant fireplace obtained from field and laboratory studies<sup>20, 21</sup> and interviews with RWC experts. The emission rates from open radiant fireplaces were used to compare the emission reductions possible with manufactured wax logs and decorative gas logs. It should be noted, that there have been some general improvements in the design of fireplaces that minimize the under-fire air supply and maximize combustion conditions with the introduction of secondary air. Therefore some new fireplaces have emission rates lower than the Atypical@ 60 g/hr value.

### **Manufactured wax logs**

Manufactured wax logs are widely used in fireplaces nationwide. It has been estimated that 100 million manufactured logs are burned each year (0.8 million wood cord equivalents)<sup>5</sup>. Manufactured logs were burned some of the time in 30% of fireplaces and exclusively in 12% of the fireplaces during the 1994-1995 heating season<sup>8</sup>. They are composed of approximately 60% wax and 40% sawdust. Paraffin or microcrystalline waxes are used. The heat content of wax logs is much higher than that of wood. (34.8 MJ/kg for wax logs as compared to 21.0 MJ/kg for Douglas fir) and their moisture content is much lower as compared with cordwood (3% as compared to 20% for good quality cordwood)<sup>21</sup>. They are

exclusively for use in fireplaces (not wood stoves), they require no kindling, and are designed for one-at-a-time use. The emissions rate of 19 grams/hour shown in Figure 3 for wax logs is based on laboratory tests<sup>21, 23, 24</sup>. The PM<sub>2.5</sub> reduction achievable with wax logs as compared to cordwood when a fireplace is used for aesthetic or minor heating purposes is calculated as 68% (Figure 3).

### **Decorative gas logs**

The use of decorative gas logs has become popular. During the 1994-1995 heating season 17% of fireplaces used gas as fuel<sup>8</sup>. (While the majority of the gas units are decorative gas logs, this percentage also includes gas fireplace inserts, decorative gas fireplaces and gas fireplace heaters as well.) Decorative gas logs are designed to be used in existing masonry or factory-built zero-clearance fireplaces. Gas log sets consist of a valve and burner assembly, a grate, and imitation logs made of cast refractory or cement. Their functions are strictly for aesthetics with flame appearance being the primary design criteria. The flame appearance is achieved by a high volume of gas ideas without consideration for efficiency. Decorative gas logs have negligible PM<sub>2.5</sub> emissions as compared with cordwood fireplaces. Therefore, particulate reductions are near 100% compared with fireplaces burning cordwood. As with gas fireplaces and inserts, either natural gas or LPG can be used with decorative gas logs.

### **REGIONAL AND AIRSHED PM<sub>2.5</sub> EMISSION REDUCTION**

The magnitude of potential PM<sub>2.5</sub> reductions obtainable by the replacement of old technology wood stoves and fireplaces inserts with newer, higher efficiency, lower emission units is graphically illustrated in Figure 4. Similarly the magnitude of potential PM<sub>2.5</sub> reductions from fireplaces used for aesthetic and minor heating purposes can be appreciated when the total number of fireplaces in use for those purposes is considered. While it is difficult to draw the exact line between aesthetic/minor heating usage of fireplaces and significant heating usage there appears to be between 10 and 15 million fireplaces in the former category. Based on the data for individual appliances obtained from field and laboratory measurements and interviews with industry experts, an overall PM<sub>2.5</sub> reduction of 70% for wood stoves and 50% for fireplaces were used to calculate PM<sub>2.5</sub> reductions on a national basis, by census division and by 100,000 population increments in each census division (Figure 5). As can be seen by reviewing the data in Figures 1-3, the 70% and 50% values were conservative and even greater reductions may be achievable. The reductions per 100,000 population increments were calculated to allow estimates to be made of the PM<sub>2.5</sub> reduction potentials in given cities or nonattainment areas based on population. The reductions shown in Figure 5 need to be Afined- tuned@ for the ratio of fuel usage in fireplaces and wood stoves characteristic of a given area. Nationally, the ratio is estimated as 72% in wood stoves and 28% in fireplaces<sup>25</sup>. This ratio was used for the calculation of data shown in Figure 5. The reductions also need to be Afine-tuned@ for the local conventional wood stove usage and age distribution (e.g. heating degree days, typical age of homes, etc.). Although the data presented in Figure 5 are approximate and meant to be illustrative only, they do show the large reduction in PM<sub>2.5</sub> levels that can be expected with appliance replacement and fuel usage changes.

### **CONCLUSIONS**

Whether based on direct measurements or predicted from emission inventories, particulate levels attributed to RWC have been from emissions primarily from old technology appliances burning cordwood. Because most PM<sub>10</sub> from RWC is also PM<sub>2.5</sub>, RWC will become relatively more important in the future. RWC utilizes a renewable energy source and represents an important part of the nation=s space heating budget. The use of fireplaces is a valued household activity for many Americans. New appliances and fuels can reduce PM<sub>2.5</sub> emissions from RWC appliances dramatically. The replacement of existing appliances with new technology units or the use of alternative fuels can reduce atmospheric PM<sub>2.5</sub> levels, as well as, preserve renewable energy use and traditional household practices. The implications for emission reduction credits, emission trading, state implementation plan options and wood burning appliance trade-out programs are significant.

## REFERENCES

1. U.S. Environmental Protection Agency. *National Air Quality and Emissions Trends Report, 1995*; Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1996; EPA 454/R-96-005.
2. Houck, J.E.; Chow, J.C.; Watson, J.G.; Simons, C.A.; Pritchett, L.C.; Goulet, J.M.; Frazier, C.A. *Determination of Particle Size Distribution and Chemical Composition of Particulate Matter from Selected Sources in California*; Report prepared for the California Air Resources Board, by OMNI Environmental Services, Inc., Beaverton, OR, 1989; NTIS PB89 232805.
3. U.S. Department of Energy. *Household Energy Consumption and Expenditures 1993*; Energy Information Administration, Washington, D.C.; 1995, DOE/EIA-0321(93).
4. Kochera, A. Residential Use of Fireplaces, *Housing Economics*, March 1997, pp.10-11.
5. Buckley, J.T. Steadily Burning Passion C Gas Fireplaces Stoke Love of Hearth, *USA Today*, January 5, 1988, pp. 1D and 2D.
6. James G. Elliott Company; Summary of Wood Heating Portion of Simmons Market Research Bureau, Inc. Annual Studies of Media and Markets, 1987 C 1997, Prepared for OMNI Environmental Services, Inc., Beaverton, OR, 1998.
7. Smith, Bucklin & Associates, Inc., annual surveys of, Cordwood Burning Appliances Sales and Pelletized Fuel Burning Appliances Sales, 1989-1996, reports to the Heath Products Association, Arlington, VA, 1990-1997.
8. Vista Marketing Research. *Fireplace Owner Survey Usage and Attitude Report*; March, 1996.
9. Burnet, P. *The Northeast Cooperative Woodstove Study*; U.S. Environmental Protection Agency, Research Triangle Park, NC, 1987; EPA-600/7-87-026a, NTIS PB88-140769.
10. Simons, C.A.; Christiansen, P.D. *Whitehorse Efficient Woodheat Demonstration*; Report prepared for The City of Whitehorse, by OMNI Environmental Services, Inc., Beaverton, OR, 1987.
11. Simons, C.A.; Christiansen, P.D.; Houck, J.E.; Pritchett, L.C. *Woodstove Emission Sampling Methods Comparability Analysis and In-Situ Evaluation of New Technology Woodstoves*; U.S. Department of Energy, Bonneville Power Administration, Portland, OR, 1988; DOE/BP-18508-6, NTIS DE89001551/LP.
12. Dernbach, S. *Woodstove Field Performance in Klamath Falls, Oregon*; Report prepared for the Wood Heating Alliance, by Elements Unlimited, Portland, OR, 1990.
13. Barnett, S.G.; Bighouse, R.D. *In-Home Demonstration of the Reduction of Woodstove Emissions from the Use of Densified Logs*; U.S. Department of Energy, Bonneville Power Administration, Portland, OR, 1992; DOE/BP-35836-1.
14. Correll, R.; Jaasma, D.R.; Mukkamala, Y. *Field Performance of Woodburning Stoves in Colorado during the 1995-96 Heating Season*; U.S. Environmental Protection Agency, Research Triangle Park, NC, 1997; EPA-600/R-97-112.



15. Barnett, S.G.; Fesperman, J. *Field Performance of Advanced Technology Woodstoves in their Second Season of Use in Glens Falls, New York*; Report prepared for Canada Centre for Mineral and Energy Technology, by OMNI Environmental Services, Inc, Beaverton, OR, 1990.
16. Barnett, S.G. *In-Home Evaluation of Emission Characteristics of EPA-Certified High Technology Non-Catalytic Woodstoves in Klamath Falls, Oregon, 1990*; Report prepared for Canada Centre for Mineral and Energy Technology, by OMNI Environmental Services, Inc., Beaverton, OR, 1990.
17. Pellet Fuels Institute. *Pellet Sales Survey C 1995-1996*; Pellet Fuels Institute, Arlington, VA, 1996.
18. Barnett, S.G.; Roholt; R.B. *In-Home Performance of Certified Pellet Stoves in Medford and Klamath Falls, Oregon*; U.S. Department of Energy, Bonneville Power Administration, Portland, OR, 1990; DOE/BP004143-1.
19. Barnett, S.G.; Fields, P.G. *In-Home Performance of Exempt Pellet Stoves in Medford, Oregon*; U.S. Department of Energy, Bonneville Power Administration, Portland, OR, 1991; DOE/BP-041143-2, NTIS DE 92000993XSP.
20. Barnett, S.G. *In-Home Evaluation of Emissions from Masonry Fireplaces and Heaters*; Report prepared for the Western States Clay Products Association, by OMNI Environmental Services, Inc., Beaverton, OR, 1991.
21. Bighouse, R.D.; Houck J.E. *Evaluation of Emissions and Energy Efficiencies of Residential Wood Combustion Devices Using Manufactured Fuels*; Oregon Department of Energy, Salem, OR., 1993.
22. Modera, M.P.; Sonderegger R.C. *Determination of In-Situ Performance of Fireplaces*; Lawrence Berkeley Laboratory, Berkeley, CA, 1980; LBL-10701.
23. Shelton, J. *Testing of Sawdust-Wax Firelogs in an Open Fireplace*; Report prepared for Conros Corporation, Duraflame, Inc. and Pine Mountain Corporation, by Shelton Research, Inc., Santa Fe, NM, 1988.
24. Hayden, A.C.S.; Braaten, R.W. *A Reduction of Fireplace and Woodstove Pollutant Emissions through the Use of Manufactured Firelogs*, Presented at the 84<sup>th</sup> Annual Meeting of the Air & Waste Management Association, Vancouver, BC, June 1991; paper 91-129.1.
25. U.S. Environmental Protection Agency. *Emission Inventory of Section 112(c)(6) Pollutants*; draft report, Emissions, Monitoring and Analysis Division and Air Quality Strategies and Standards Division, Research Triangle Park, NC, September 1996.

**Figure 1.** Particulate emission reduction from alternatives to conventional stoves burning cordwood.

Appliance/Fuel	Efficiency (%)	Mass particulate emissions per delivered heat (g/Mj) <sup>a</sup>	Reduction (%)
Conventional	54	1.68	-
Certified non-catalytic	68	0.49	71
Certified catalytic <sup>b</sup>	72	0.44	74
Pellet stove	78	0.13 <sup>c</sup>	92
Masonry heater	58	0.25	85
Conventional/densified fuel	57	1.20	27
Certified non-catalytic/densified fuel	70	0.21	88

a. g/Mj = grams/megajoule

b. stoves with new catalyst

c. a smaller fraction of pellet stove particulate emissions are less than PM<sub>2.5</sub> than for other categories

Data from references 9-16 and 18-21. Adjustments have been made in the values based on interviews with RWC experts to reflect the current state-of-the art of wood heater technology and understanding of combustion parameters.

**Figure 2.** Particulate emission reduction from alternatives to conventional open radiant fireplaces burning cordwood for space heating.

	(%)	per delivered heat (g/Mj) <sup>a</sup>	(%)
Double shell convection, natural draft	13	4.60	46
Convection tube, "C" shaped, glass door	15	3.99	53
Double shell convection, blower, glass doors	32	1.87	78
Certified non-catalytic insert	66	0.50	94
Certified catalytic insert <sup>b</sup>	70	0.45	95
Pellet stove insert	76	0.13 <sup>c</sup>	98
Gas insert	75	Negligible	~100
Gas fireplace	50	Negligible	~100
Certified catalytic "fireplace-like" woodstove <sup>b</sup>	70	0.45	95
Masonry fireplace with shaped fire chambers and glass doors	42	1.22	86

a. g/Mj = grams/megajoule

b. unit with new catalyst

c. a smaller fraction of pellet insert emissions are less than PM<sub>2.5</sub> than for other categories

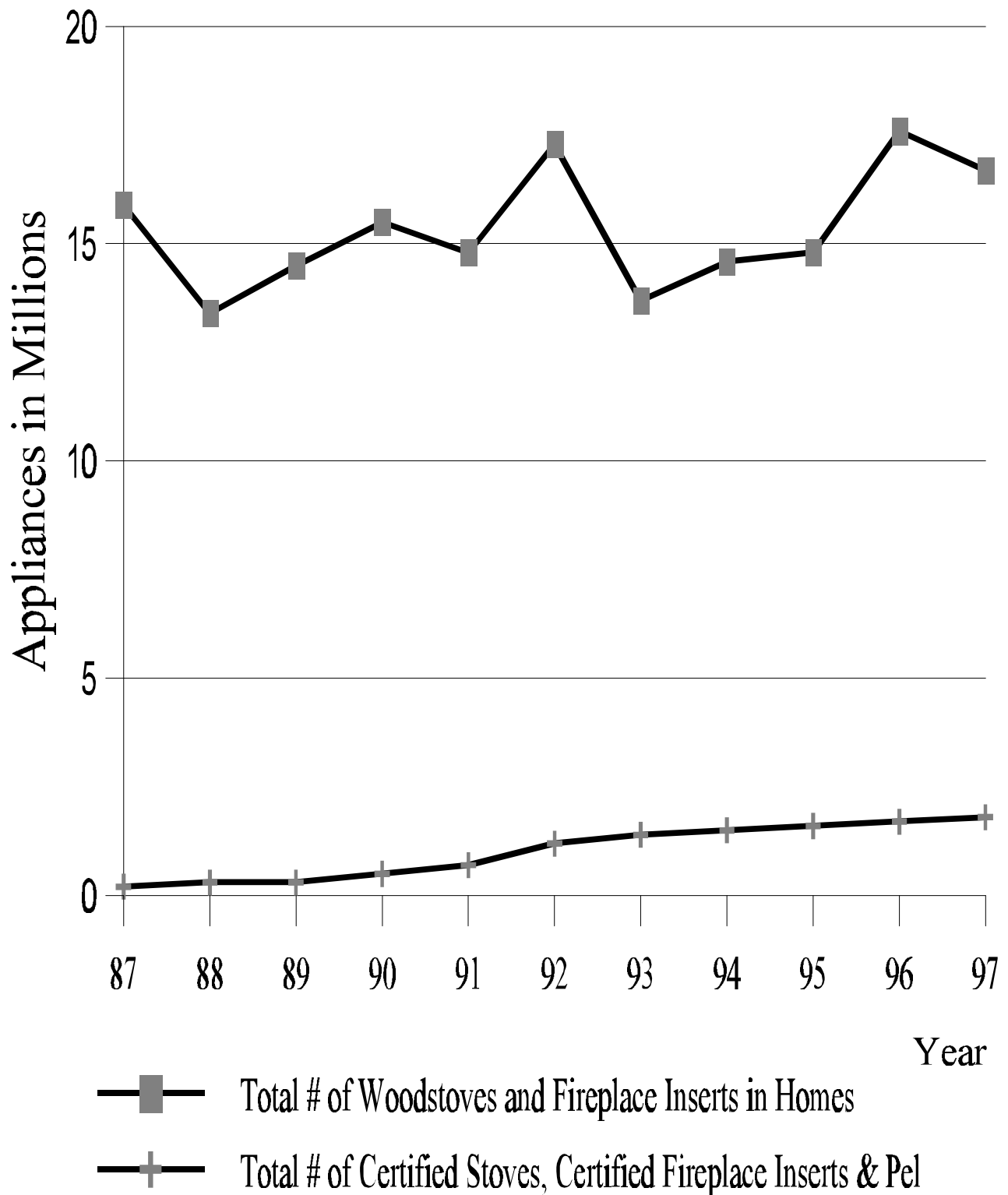
Data from references 20-22. Adjustments have been made in the values based on interviews with RWC experts to reflect the current state-of-the art of fireplace technology and understanding combustion parameters.

**Figure 3.** Particulate emission reduction from alternatives to conventional open radiant fireplaces burning cordwood for aesthetic and minor heat purposes.

Appliance/Fuel	Mass particulate emissions per unit time (g/hr)	Reduction (%)
Conventional open radiant fireplace	60	-
Manufactured wax logs	19	68
Decorative gas logs	Negligible	~100

Data from references 21, 23 and 24.

**Figure 4.** Replacement opportunity for low-emission units.



**Figure 5.** Approximate PM<sub>2.5</sub> emission reduction by census division and per 100,000 population increments by replacement of conventional woodstoves (at least 70% reduction in emissions), and by reduction of fireplace emissions by 50% through the use of new technology inserts and alternate fuels.

Census Division	Population x106	Total Households x106	RWC Households x106	Cords x106	PM2.5 Reduction			
					by division		per typical 100,000 population	
					lbs x 106	g x 109	lbs x 103	g x 106
New England	14	5.1	1.1	2.3	61	28	433	196
Middle Atlantic	38	14.4	2.4	4.8	125	57	325	148
East North Central	44	16.4	2.6	3.4	91	41	209	95
West North Central	18	6.9	1.5	2.1	54	24	302	137
South Atlantic	46	17.4	3.9	4.7	123	56	271	123
East South Central	16	6.0	1.3	2.4	64	29	397	180
West South Central	27	10.1	2.0	1.7	46	21	170	77
Mountain	14	5.4	1.3	1.5	39	18	277	126
Pacific	40	15.0	4.4	4.5	116	53	290	132
National	258	96.6	20.4	27.4	713	324	278	126

U.S. EPA trends report - National RWC PM<sub>10</sub> 956x10<sup>6</sup> lbs

1993 data