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Health Effects of Residential Wood Combustion: Survey of Knowledge and Research

September 1980

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Environment
Office of Environmental Assessments

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U.S. DEPARTMENT OF ENERGY
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Washington, D.C. 20545

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PREFACE

This document reviews and evaluates current and recently completed environmental and health effects research on residential wood combustion. Information from the research surveyed will assist decisionmakers to (1) identify major current environmental, health, and safety (EH&S) concerns, and define necessary research and related assessments; (2) develop the timing for a coordinated schedule of EH&S research and technology program development; and (3) determine whether regulatory action is necessary from a health and safety consideration.

Research and development activities are extensive in resolving the EH&S uncertainties of residential wood combustion. Subsequent resolution of these uncertainties may require adjustments in the technology development program. Involved agencies in research and development activities include the U.S. Department of Energy, Environmental Protection Agency, Tennessee Valley Authority, New England Regional Commission, Solar Energy Research Institute, and their contractors. In addition, industry, universities, and state and local governments are actively involved in EH&S research.

The Department of Energy Office of Environment is responsible for the development of environmentally acceptable energy technologies. This review will assist in planning, managing, and reviewing the EH&S aspects of residential wood combustion. Dr. K.E. Kawaoka of The Aerospace Corporation was responsible for systematically gathering and evaluating relevant EH&S research. Comments would be greatly appreciated and can be addressed to my office.

Dr. Gregory J. D'Alessio
Solar Technology Assessment
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I. INTRODUCTION

A. BACKGROUND

Throughout the history of the United States, residential woodburning was a major source of heat. With the advent of inexpensive oil and gas for use in central home heating systems, the use of wood declined. A few years ago, wood use in the home was more of a novelty or a decorating idea for rustic homes. However, wood energy is again becoming a serious means of home heating. Woodburning stoves, dual-fuel capacity furnaces, and, to a limited extent, conventional fireplaces are the most prevalent devices for residential application.

The popularity of home wood heating is increasing in several regions of the country. Figure 1 depicts the trend in recent years. In 1970, out of a total of 63 million occupied homes, 800,000 used wood as a primary fuel (Ref. 1). During 1970 to 1973, the use of wood heating declined, but it increased approximately 50 percent from 1973 to 1976. This represents a net increase of 15 percent from 1970 to 1976. Over 900,000 homes were reported as using wood in 1976; over half of this use was in the South. Other regions have also experienced renewed interest. In the New England area, wood energy use has grown sixfold since 1970, and in Maine, Vermont, and New Hampshire, 18 percent of all households rely on wood fuel as their primary heating source (Ref. 2). Some sources regard even this as a drastic underestimate of current wood use for space heating (Ref. 3).

The prospects for more home woodburning should expand greatly, considering the potential near-term wood fuel availability and the uncertain future availability of oil and natural gas. Noncommercial timber, which consists of small or defective living trees and salvable dead trees, represents a significant reservoir of the Nation's forest inventory for residential woodburning. The U.S. Forest Service estimates that approximately 1.7 billion dry tons or about 29 quads of wood fuel could be available from the noncommercial timber reservoir (Ref. 5). One-fifth of this total consists of salvable dead trees, nearly all of which are located in the West. Two-thirds of the total includes cull hardwood trees found primarily in the East (Ref. 4). Cull softwoods are distributed both in the East and West. Figure 2 presents an overall total of standing forest resource by region.

B. FOCUS OF REVIEW

This review will examine health and safety issues related to residential woodburning. Current research and findings will also be described, and research status will be assessed in terms of future health and safety requirements. Analytical and experimental studies have been gathered and reviewed in reports received. Ongoing and new research is also included.

The review is organized by major issues along with the research and development efforts accompanying each concern. Because much of the effort dealing with these concerns is still in its early stages, emphasis is placed on ongoing research.

Source: Annual Housing Survey, U.S. Department of Commerce, extracted from Ref. 4.

Figure 1. Residential Use of Wood as a Fuel

Figure 2. Distribution of the Standing Forest Resource - Quads by Region

II. RESEARCH SURVEYED

The following surveyed investigations of air pollution, safety, and related concerns are in various stages of research.

A. AIR POLLUTION

1. A Study of Wood Stove Particulate Emissions (Characterization)

- Objective: Characterize particulate emissions from wood stoves.
- Scope: Particulate emission factors for two wood stove models range from 1 g/kg (fuel) to 24 g/kg depending on wood fuel type and operating conditions. The emission factor model was applied to a total community and suggests that wood stoves may contribute particulate levels as high as 100 $\mu\text{g}/\text{m}^3$ in a worst-case 24-hr average ambient concentration.
- Status: Complete. S.S. Butcher and E.M. Sorenson, J. of Air Pollution Control Association, Vol. 29, No. 7, pp. 724-728, July 1979.

2. Source Assessment--Industrial Wood Combustion (Characterization)

- Objective: Characterize emissions from industrial wood combustion.
- Scope: Sampling and analysis of emissions from six small- to medium-sized industrial wood boilers was conducted. Polycyclic organic matter (POM) analysis was included.
- Status: Sampling completed, chemical analysis completed, report in preparation; report due (as part of industrial boiler report) in January 1980. Contractor is TRW for the Industrial Environmental Research Laboratory, Environmental Protection Agency (IERL/EPA).

3. Source Assessment--Residential Wood Combustion (Characterization/Bioassay)

- Objective: Characterize emissions from residential wood combustion.
- Scope: Sampling and analysis of emissions from 12 residential wood combustion configurations (three combustor types -- two "air tight" wood stoves and one fireplace, two types of wood -- oak and pine, two moisture levels -- seasoned and green) was conducted. POM analysis and bioassay testing was included.
- Status: Sampling program completed, chemical analysis and bioassay testing underway, report due in early 1980. Monsanto Research Corporation is contractor for IERL/EPA.

4. Control of Emissions From Residential Woodburning by Combustion Modification (Control)

- Objective: Develop means for controlling emissions from wood-burning stoves through modification of the combustion process.
- Scope: The effect of combustor design parameters (e.g., grates, air-flow patterns); operating variables (e.g., fuel and air feed rates); and fuel properties (e.g., percent moisture, size distribution) will be studied with respect to emissions. Principles of combustion modification that will result in low emission performance will be developed.
- Status: Project was initiated May 15, 1979; target completion date is May 14, 1980. Contractor is Battelle Columbus Laboratories for IERL/EPA.

5. Residential Wood Combustion--Issue Paper (Characterization)

- Objective: Define potential problem.
- Scope: Review and analyze all available information on emissions from residential wood combustion. Determine the potential for adverse air quality impacts and the conditions affecting such impacts.
- Status: This issue paper will not be completed until all significant data from an associated Monsanto Research Corporation project have been received, reviewed, and analyzed. Contractor is MITRE for IERL/EPA.

6. Emission Factors for Industrial Wood Combustion (Characterization)

- Objective: Summarize existing data for emission factor development for industrial wood combustion processes.
- Status: Completed for NO_x emission factor; complete draft report includes emission factors for other criteria pollutants. Contractor is TRW for IERL/EPA.

7. Wood Stove Particulate Emissions Reduction Research (Control)

- Objective: Assess and evaluate wood stove design criteria.
- Status: Final report to be issued April 1, 1980. Contractor is TRW for EPA, Region X, and Oregon State Department of Environmental Quality.

8. Air Quality Impact Potential From Residential Woodburning Stoves (Ambient)

- Objective: Evaluate the regional air pollution impacts resulting from rural woodburning in Tennessee Valley Authority (TVA) areas.
- Scope: Determine the impacts in a high-density wood stove and fireplace area on ambient air quality and visibility standards.
- Status: Final report issued February 1979. Prepared by Tennessee Valley Authority, Division of National Resources Services.

9. Portland Airshed Studies (Ambient)

- Objective: Monitor ambient particulate matter emissions, particularly as contributed from woodburning stoves and fireplaces.
- Scope: Used a radiocarbon measurement technique to measure wood smoke impacts in the Portland and Eugene airsheds.
- Status: Studies complete. Contractors are the Oregon Graduate Center (Beaverton, Oregon) and the National Bureau of Standards for IERL/EPA and Oregon Department of Environmental Quality.

10. Air Pollutant Emissions and Stack Parameters for Woodburning Sources (Characterization)

- Objective: Determine factors that influence the characteristics and quantities of air pollutants from wood-fired boilers and stoves. Derive emission factors and stack parameters for various pollutants.
- Scope: Comprehensive review of all air emissions from wood-burning literature. Use of mass balance calculations for emission factor determination.
- Status: Draft report by R.G. Narender, "Characterization of Air Pollutant Emissions and Stack Parameters for Wood-Burning Stoves," prepared by Argonne National Laboratory for DOE, Conservation and Solar Energy (CS), Biomass Energy Systems Division (BESD), October 1979.

11. Residential Wood Combustion (Characterization/Bioassay)

- Objective: Determine and characterize stove emission factors as a function of wood type, operating conditions, and stove design. Evaluate biological activity of the emissions and determine potential air impacts from these emissions.
- Scope: Test various stove types and wood varieties. Determine source emissions and regional impacts.

- Status: Studies in progress through FY 1984. Work is by Argonne National Laboratory for DOE/CS/BESD.

12. Wood Stove Emission (Characterization)

- Objective: Characterize stove emission factors for various wood stove designs and wood fuel types.
- Scope: Laboratory test of stoves under different operating conditions.
- Status: Research nearing completion. Draft report due in April 1980. Work is by Battelle-Columbus Laboratories for TVA.

B. SAFETY

1. Review of Fire Incidents, Model Building Codes, and Standards Related to Woodburning Appliances

- Objective: Establish accident patterns and determine risk involved with woodburning equipment.
- Scope: Surveyed approximately 11,800 fire incidents associated with injuries or deaths from equipment burning solid fuel. Reviewed model building codes and test methods.
- Status: Study complete. Contractor is National Bureau of Standards for the Department of Energy (DOE).

2. Analysis of Fire Reports Associated With Woodburning and Coal Equipment

- Objective: Examine Massachusetts Fire Marshall's fire reports from local fire departments to determine specific causes of fires.
- Scope: Fires were attributed roughly to unsafe installation (three-fourths), unsafe operation/maintenance (one-fourth), and improper design or defects (2 percent).
- Status: Study complete. Study performed by Dr. J.W. Shelton.

3. Improving the Efficiency, Safety, and Utility of Woodburning Units

- Objective: Develop overall design and testing data on the efficiency, safety, and use of industrial and residential woodburning equipment.
- Scope: Laboratory testing of stoves, fireplaces, and other wood-burning appliances used to study combustion characteristics.

- Status: Interim reports have been published. No overall report is yet available. Study is by Auburn University for DOE/CS/Technology and Consumer Product Branch (TCPB).

C. OTHER RESEARCH AND DEVELOPMENT

1. DOE Wood Commercialization Program

- Objective: DOE is currently assessing the commercial readiness of the resources and technologies involved in the use of wood for steam, electricity, and heat. The purpose is to estimate how near wood combustion technologies are to commercial use and to identify specific barriers that must be overcome before wood will be widely used for energy. Future expansion of wood use is expected in industrial, utility, and residential sectors.
- Scope: If present trends continue, 3 to 4 quads of energy will be produced from wood in 1990. This would be over two times the present 1.5 quads/year of energy produced from wood and wood waste. Residential use of wood as a fuel is expected to double over the next 12 years to about 0.6 to 0.7 quad/year in 1990, or the equivalent of 5.5 to 6.4 million homes, with the increase mainly in rural areas (Ref. 5). The program will define DOE's role.
- Status: In preparation.

2. Residential Combustion of Coal and Wood: Equipment and Fuel Supply

- Objective: Survey and analyze (1) the distribution of residential coal and wood combustion equipment and (2) the distribution and use of coal and wood fuels as used for the purpose of residential space heating.
- Scope: Types of residential solid fuel combustion equipment characterized includes coal/wood furnaces, coal-fired stoves, and wood-fired stoves. Specific regional sales trends were surveyed and analyzed. The history of coal production and distribution for residential space heating was reviewed.
- Status: Final draft report is in preparation. Contractor is The Research Corporation of New England for IERL/EPA.

3. Assessment of Proposed Federal Tax Credit for Residential Woodburning Equipment (Including Safety and Environmental Impacts Considerations)

- Objective: Develop recommendations on the effect of tax credits for residential woodburning equipment in the National Energy Act.

- Scope: Examine pertinent woodburning issues, including sales and market trends, energy savings and tax revenue loss, safety and performance standards, environmental impacts and resource availability, and general economic impacts.
- Status: Draft report issued by D. Hartman and A. Hirshberg, "Assessment of Proposed Tax Credits for Residential Wood-Burning Equipment," prepared by Booz, Allen, and Hamilton, Inc., for DOE/CS/TCPB, March 1979.

4. Small-Scale Wood Combustion for Space Heating

- Objective: Develop and build a stock-wood furnace for residential use.
- Scope: Design will take into account efficiency, air pollution, and fire and safety hazards.
- Status: Completed. Richard Hill, "Small Scale Wood Combustion for Space Heating," prepared by the University of Maine for DOE, Conservation and Solar Energy, Technology and Consumer Product Branch, Consumer Products Division, 1978.

5. Circulating Fireplace Combustion Efficiency

- Objective: Determine fireplace efficiency and influencing efficiency factors.
- Scope: Used factory-built fireplace in laboratory calorimeter room.
- Status: Completed: William Bulpitt, "Circulating Fireplace Combustion Efficiency Studies," prepared by Georgia Institute of Technology for DOE/CS/TCPB, 1979.

6. Maine Firewood Study

- Objective: Assess demand for wood energy in Maine and determine effectiveness of market mechanisms in meeting the demand.
- Scope: Contacted both wood producers and consumers to assess the scale of operations and market activities.
- Status: Completed. Elizabeth Swain, "Maine Firewood Study," prepared by the Maine Audubon Society for DOE/CS/TCPB, 1979 and 1980 (draft).

III. MAJOR CONCERN ISSUES AND CURRENT ASSESSMENT

A. ENVIRONMENTAL AND HEALTH ISSUES

Air emissions affecting local air quality are a major environmental impact area associated with residential wood combustion. There are currently no Federal regulations for air emission sources less than 100 million Btu (heat output) per hour, far greater than the heat output for a residential heater. Further, large variations in emissions can be expected due to design characteristics, combustion efficiencies, fuel type, and operating conditions (Ref. 6).

Available source emission data from residential woodburning have been obtained through sampling techniques (Refs. 7, 8, 9, and 10). Other work is beginning or still in progress (Refs. 11, 12, and 13). In addition, there have been ambient air measurements in regions of high woodburning (Refs. 14 and 15). Although the research indicates several concerns related to air pollution, there is currently no definitive, quantitative assessment of the health effects resulting from residential woodburning air emissions.

Residential wood combustion equipment may emit substantial quantities of particulates, carbon monoxide, hydrocarbons, and polycyclic organic matter. Due to the low sulfur content of wood (0.01 to 0.05 percent), sulfur oxide emissions from woodburners are very small (Refs. 16 and 17).

There are a variety of criteria and noncriteria emissions from woodburning stoves. Two recent studies (Refs. 10 and 13) assessed by Cooper measured over 100 different classes and species of chemicals in emissions from burning wood and woodburning stoves (Ref. 18). The results from these studies showed smoke from wood and woodburning stoves and fireplaces contained 17 priority pollutants, up to 14 carcinogens, 4 cocarcinogens,* and 6 cilia toxic and mucus coagulating agents (see Tables A-1, A-2, A-3, and A-4 in Appendix A). Additional problem compounds may be expected to be found in the future because 85 percent of the condensable emissions were not characterized in the DeAngelis et al. study (Ref. 13). Table 1, from the Tennessee Valley Authority (TVA), presents potential emissions that can be expected per cord** of wood burned. Air quality impacts are ranked by TVA on a scale of 1 to 10, 10 being the most severe. Table 2, from EPA data, also lists a range of emission factors for residential wood combustion. Table 3, derived from a paper by Cooper (Ref. 18), combines the results of two other studies (Ref. 10 and 13). Comparison of the three tables indicates that the current range of emission factor estimates is very broad.

* Cancer-initiating or promoting agents.

** A cord is a common measure of firewood and pulpwood, equal to the amount of wood in a carefully stacked (parallel) pile of wood, 4 feet high, 8 feet wide, and 4 feet deep. The amount of solid wood in this 128-cubic-foot pile is usually estimated to be between 80 and 90 cubic feet (Ref. 16).

Table 1. Emissions From Residential Wood-Fired Stoves

Emission Parameter	Emission Range (lb/cord)	Average Emission Factor ^a (lb/cord)	Impact Severity ^b	Reference
<u>Criteria</u>				
Particulates	15-75	28.1	6	7-9, 19, 20
SO _x	0-1.5	0.7	1	19
NO _x	5-35	6.3	3	7, 9, 19
Hydrocarbons	10-90	29.7	4	7, 9, 19, 20
CO	50-450	188.1	2	7, 9, 19, 20
<u>Noncriteria</u>				
Organic species:				
Polycyclic organic materials	0.05-0.13	0.1	10	9, 20
Formaldehyde	0.5-17	5.3	6	20, 8
Acetaldehyde	0.5-4	2.3	5	20, 8
Phenols	0.3-8	3.3	2	20, 8
Acetic acid	5-48	21.1	4	20, 8
Elements:				
Aluminum		1.3	2	20, 16
Calcium		10.2	6	20, 16
Chlorine		0.1	2	20, 16
Iron		0.7	2	20, 16
Magnesium		2.0	2	20, 16
Manganese		1.6	3	20, 16
Phosphorus		1.0	5	20, 16
Potassium		3.6	6	20, 16
Silicon		1.6	2	20, 16
Sodium		0.7	3	20, 16
Titanium		0.02	-	20, 16

^a Conversion factor of g/kg to lb/cord based on Ref. 13.

^b Impact severity is based on a scale of 1 to 10 with 10 being most severe. Rank was established by comparing the following ratios:

For criteria pollutants: Ratio of a time-average minimum ground-level concentration to primary NAAQS.

For noncriteria pollutants: Ratio of a time-average minimum ground-level concentration to 24-hour occupational TLV (reduced by a factor of 100).

Source: Duncan, TVA, Ref. 14

Table 2. Emission Factors for Residential Wood Combustion Processes

	Emissions g/Kg ^a	Emissions lb/cord ^b	Reference
Particulate ^c	2-15	8-60	19
Carbon monoxide	60-130	240-520	19, 20
Hydrocarbons	2-9	8-40	19, 20
SO _x	0.2	0.8	20
NO _x	2	8	20
Formaldehyde	1.6	6.4	20
Acetaldehyde	0.7	3	20
Phenols	1	4	20
Acetic acid	6.4	26	20
Polycyclic organic matter	0.0005-0.2	0.002-0.8	9, 21
Elemental metals	7	30	20

^a Units are grams of species emitted per kg of wood burned. Wood moisture is not specified in the reference cited.

^b Alternate units are lb of species emitted per cord of wood burned. One cord is assumed to equal 4000 lb.

^c Particulate includes inorganic ash, condensable organics, and carbon char in aerosol (finely divided, nongaseous) form. Note that other entries in the table, e.g., polycyclic organic matter and elemental metals, are somewhat redundant in that they are subcomponents of particulate matter and are not separate species.

Source: Milliken, EPA, Ref. 6.

Table 3. Emissions of Major Pollutants From Residential Wood Combustion Sources^a

Chemical Species	Woodburning Stoves			Fireplaces		
	g/Kg wood	lbs/10 ⁶ Btu ^e	Percent Particulates	g/Kg wood	lbs/10 ⁶ Btu ^e	Percent Particulates
Carbon Monoxide	160.0 (83-370)	22.0	---	22.0 (11-40)	3.0	---
Volatile Hydrocarbons	2.0 (0.3-3.6)	.28	---	19.0	2.6	---
NO _x as NO ₂	0.5	.07	---	1.8	.25	---
SO _x as SO ₂	0.2	.03	---	---	---	---
Aldehydes	1.1	.15	---	1.3	.18	---
Condensable Organics	4.9 (2.2-14)	.67	58	6.7 (5.4-9.1)	.92	74
Particulates	3.6 (0.6-8.1)	.50	42	2.4 (1.8-2.9)	.33	26
Total Particulates	8.5 (1-24) ^b	1.2	100	9.1 (7.2-12)	1.3	100
Polycyclic Organic Mat.	0.3	.04	3.5	0.03	.004	0.3
Benzo (a) Pyrene ^c	0.0025	.0003	.03	0.00073	.0001	0.008
Carcinogens	.038	.005	.45	.0059	.0008	0.06
Priority Pollutants	0.41	.06	4.8	0.063	.009	0.7
Na ^d	.005	.0007	.06	.004	.0006	.04
Al ^d	.004	.0006	.05	.002	.0003	.02
Si ^d	.003	.0004	.04	.002	.0003	.02
S ^d	.03	.004	.4	.004	.0006	.04
Cl ^d	.05	.007	.6	.05	.007	.6
K ^d	.07	.01	.8	.05	.007	.5
Cad	.004	.0006	.05	.005	.0007	.05
Organic Carbon ^d	4.2	.58	49	4.2	.58	46
Elemental Carbon ^d	.7	.1	8	1.2	.16	13

^a Values noted are from DeAngelis et al., Ref. 13, except where noted.

^b Range is from Butcher and Sorenson, Ref. 17, which extends beyond those noted in Ref. 22.

C Ref. 23: for fireplace - .0009 g/Kg or about 0.01%
Ref. 21: for pine needles - .003 to .03% particulates
Ref. 24: for leaves, grass, branches - .004%
Ref. 13: Benzopyrenes/perylene: fireplace - .0015 g/Kg or about .016%
 stove - .009 g/Kg or about .1%
Assume 1/3 of above is B(a)P and averaging fireplace values
yield 0.008% for fireplace and 0.03% for stove

^d Values listed are based on average percentages reported by Cooper et al., Ref. 15. g/Kg values were calculated on the basis of the g/Kg values for total particulates listed above which are from DeAngelis et al., Ref. 13.

e 16,000 Btu/Kg.

Source: Cooper, Oregon Graduate Center, Ref. 18.

In addition to source emission studies, recent regional-scale air impact analyses have been implemented. TVA (Ref. 14) and Portland (Refs. 15 and 25) studies have indicated that a high concentration of woodburning stoves could contribute significantly to particulate air pollution in a region of high woodburning. Of particular concern are the fine respirable air particulates that could pose a significant health hazard. Butcher shows that for small wood stoves, the emission factor for particulate matter was inversely related to the heat release rate (Ref. 26). Hence, for inefficient residential woodburning, condensable organics can represent about 70 percent of the particulate matter (Ref. 9).

These same emissions from woodburning may also affect regional visibility and Prevention of Significant Deterioration (PSD) provisions of the Clean Air Act Amendments of 1977, thereby impacting economic and industrial growth. Under adverse meteorological conditions, wood stove particulate emissions may exceed ambient air quality standards in an area with 400 to 500 residences/km² spread over 4 km² or more using wood heat (Ref. 22).

Indoor air pollution from residential wood combustion is another major concern. For example, the buildup of carbon monoxide levels inside the home from the improper installation or improper use of a wood stove can be fatal. It is unclear at this stage what impact such emissions as NO_x and POM have in the indoor environment. No indepth investigations have been initiated in this area to ascertain whether indoor air pollution problems may be more significant than outdoor ambient air pollution (Refs. 27 and 28). More research on woodburning impacts is needed, particularly in indoor pollution monitoring and health effects evaluation.

1. Potential Adverse Health Effects

Source severity values in Table 1 roughly attempt to rank the potential environmental effects of pollutant emissions from wood-fired combustion systems. The severity value is expressed as a ratio of a time-average maximum ground-level concentration to some "hazard" factor (Ref. 14). For criteria emissions, the hazard factor is the primary (public health protection) National Ambient Air Quality Standards; for noncriteria pollutants, it is the applicable threshold limit value for occupational exposure converted into 24-hour values and reduced by an arbitrary factor of 100 for general population exposure (Ref. 14).

• Fine Particulates

Fine particulates (inorganic ash, carbon char, and condensable organic matter) appear to be the most significant health hazard among criteria emissions (Ref. 14). About 70 percent of particulates from wood combustion may be less than 5 μ m diameter, and 50 percent may be less than 2.5 μ m diameter (respirable particulates) (Ref. 14). Rate of emissions is dependent on factors such as combustion method, wood moisture content, and fuel type (Ref. 6 and 26). Clearly, the impacts on both general population and populations at risk (elderly, very young, asthmatics, emphysema patients, etc.) need to be assessed.

- Carbon Monoxide

Carbon monoxide, which has a relatively high emission rate of 60 to 370 grams per kilogram of wood burned, is a well-known criteria pollutant (Refs. 6 and 18). Both acute and chronic effects of CO poisoning can be expected from exposure to various concentrations. Body reactions include headache, mental confusion and dizziness, vision and hearing impairment, and asphyxia, as well as cerebral congestion, edema, and death.

- Hydrocarbons

Volatile hydrocarbons from woodburning are other emissions that, when combined with other stationary and mobile sources, could contribute to the local photochemical smog inventory. Carbon monoxide and hydrocarbons tend to increase the background ozone levels in rural areas. Hydrocarbons are chemically active species and may produce photochemical oxidants.

- Aldehydes

Aldehydes have been identified in animal experiments as the poisonous agent in wood smoke causing pulmonary edema and death (Ref. 29). High emission factors for formaldehyde, isobutyraldehyde, and other aldehyde compounds were found in many of the studies surveyed (Refs. 13, 18, and 35). Formaldehyde, a mucous-membrane irritant, is formed and consumed in the atmosphere through photochemical actions.

- Sulfur Oxides and Nitrogen Oxides

Emission data on nitrogen oxides and sulfur oxides (mainly SO₂) are not well established for wood combustion processes. However, because sulfur is a minor constituent in wood, it is not expected to be significant health problems. Also, because combustion temperatures in residential wood stoves are lower than those in coal and oil burners, relatively lower levels of NO_x are expected.

- Polycyclic Organic Matter

The group of organic compounds known as polycyclic organic matter is the most significant group among the noncriteria emissions. POM compounds have three classes of known organic carcinogenics: polynuclear aromatic hydrocarbons, polynuclear heterocyclic and oxygenated compounds, and alkylating agents. Past research has indicated that POM is produced from virtually all types of combustion processes (Ref. 28) and is associated with particulates of less than 5 μ m diameter (smoke) (Ref. 30). Although only about 1 percent of the total condensable organic fraction of total ambient concentrations is believed to be contributed from residential wood combustion, research is currently being done on this issue (Ref. 6).

Benzo(a)pyrene (BaP) emissions (a known carcinogen) were estimated to be 50 times greater from wood combustion compared to oil combustion by the National Academy of Sciences in 1972 (Ref. 28). Further, the largest sources of BaP in the United States in 1972 were the inefficient combustion of coal in hand-fired residential furnaces (420 tons/year) and wood (40 tons/year). An emission factor of about 50,000 μg BaP per million Btu was used to estimate the contribution of woodburning residential units (Ref. 28). The carcinogenicity of BaP is increased in the presence of carbon particulates and SO_2 (Ref. 18).

- Summary

On the basis of similar considerations, Cooper (Ref. 18) concludes that "... emissions from RWC (residential wood combustion) sources must be considered a potential major threat to public health because of their highly respirable nature, the hazardous chemicals they contain, the available information relating these emissions, chemicals, etc. to health related problems, the fact that they are emitted in residential areas, and that the emissions are increasing."

2. Other Environmental Concerns

There are other environmental concerns associated with residential wood combustion. As with larger industrial technology processes, potential environmental and health issues are prevalent in the harvest, transportation, handling, combustion, and disposal phases. Although concerns have been identified by the Department of Energy (Environmental Readiness Document on Wood Combustion), there are no active research programs in these areas at present to examine the health and environmental effects of air emissions due to residential wood combustion. Among the more notable environmental concerns not directly related to air emissions in these areas are the ecological impacts of production and harvesting of forests for wood fuel, soil erosion from forest lands and stream sedimentation, changes in water yield from forest watersheds, emissions from wood handling systems and leachate from wood storage, and the regional solid residue impact (Ref. 31). DOE does have studies underway at Oak Ridge National Laboratory to examine the environmental effects of different methods of wood harvesting.

B. SAFETY ISSUES

An increased safety risk is apparent to the home dweller due to accidental fires and burns from woodburning units. Accidental fires are mainly due to spontaneous combustion of flammable materials from hot surfaces or sparks and to chimney fires from creosote ignition or sparks.

The National Bureau of Standards reviewed over 11,700 accidental fires reported by the National Fire Protection Association, U.S. Fire Administration (National Fire Incidence Reporting System (NFIRS)), and the Consumer

Product Safety Commission (Ref. 32). Most accidents reported are caused by improper installation of the woodburning system and carelessness during use. Accidents involved the woodburning unit in 55 percent of the fires, followed by chimneys, 35 percent, and chimney connectors in 10 percent of the fires. Of the 11,534 fires reported in the NFIRS data, injuries were reported in only 125 fires and deaths in 40 (Ref. 32). Table 4 lists the conditions attributed to accidental fires from woodburning units.

Another National Bureau of Standards study examined solid-fuel-related fire reports by local fire departments to the Massachusetts State Fire Marshall's office from late 1977 through June 1978 (Ref. 33). Specific causes were attributed roughly to unsafe installations (75 percent) and unsafe operation and maintenance (25 percent). Less than 2 percent of the fires were due to defects or poor design in the heating appliance itself. Hence, proper attention should be focused on installation, operation, and maintenance in preventing accidental woodburning appliance fires.

The creosote problem is receiving increasing attention as a safety concern. Creosote is a tar-like substance containing many complex compounds found in wood smoke, including acetic and formic acids, creosol, and cresol.* Creosote can ignite and burn intensely if enough heat is generated. Creosote deposition on flue surfaces depends on the density of smoke and fumes from the fire and the temperature of the surface on which it is condensing (Ref. 16). High smoke densities result when a large amount of wood in relatively small pieces is added to a hot bed of coal and the air inlet damper is closed. The wood is pyrolyzed but with little combustion and little air to dilute the smoke. Generally, creosote formation is inevitable because every kind of wood burned produces creosote. Hence, for a relatively air-tight woodburning unit, closing of the unit's air inlet dampers should suppress a creosote fire. Chimneys of leaky stoves or fireplaces will have a greater tendency to build up creosote and will thus have a higher potential for creosote fires. Proper design and installation of chimney or flue and regular maintenance and cleaning are the most effective methods of preventing creosote fires (Ref. 34).

* Creosol and cresol are two distinct compounds.

Table 4. Conditions Leading to Fires Attributed to Woodburning Equipment

Condition	Number of Fires	Percent
Ignition of Combustibles	1,895	18
Exterior Fire from Sparks	963	9
Chimney Fires	623	6
Improper Fueling Technique	578	5
Equipment Malfunction	457	4
Use of Flammable Liquids	126	1
Other	28	2
Improper Maintenance	2,875	27
Improper Equipment Design	1,050	10
Improper Operation	787	8
Ignition of Structure	702	7
Improper Installation	248	2
Improper Chimney	138	1
	10,470	100

Source: Ref. 32

IV. CURRENT INFORMATION UNCERTAINTIES AND FUTURE RESEARCH NEEDS

Development and installation of more efficient wood combustion units will alleviate many of the current environmental, health, and safety concerns. However, the expected expansion of residential wood heating in regions where fuel is abundant necessitates an accurate environmental characterization and assessment of potential impacts, such as present particulate levels and constituents in those regions. This should be coupled with toxicological and health studies of woodburning-related pollutants and their specific constituents to determine the severity and magnitude of health impacts on normal population and those at risk. Current environmental data assessment and future research needs are shown in Table 5.

Table 5. Residential Wood Combustion - Current Air Pollution and Safety Assessment and Future Research Needs

Research Activity Area	Adequacy of Current Data	Additional Research Requirements
<u>AIR POLLUTION</u>		
1. Woodburning source characterization, measurement, and monitoring	Characterization partially adequate; inadequate for measurement and monitoring	<ul style="list-style-type: none"> • Characterization, measurement, and monitoring of unburned combustible particulates (fine breathable), hydrocarbons, carbon monoxide, sulfur oxides, nitrogen oxides, aldehydes, and POM (for both current and advanced burners) • Analysis of design and construction criteria to lower combustion emissions • Development of improved operation criteria • Overall assessment of wood fuel chemical characterization and relationship to emissions • Evaluation of influence on photochemical oxidant/ozone formation • Determine the number of woodstoves/acre or amount of fuel burned/acre
2. Measurement of indoor pollution	Inadequate	<ul style="list-style-type: none"> • Characterization and health impact assessment of wood combustion emissions in indoor environment in combination with other indoor emissions
3. Measurement of ambient regional pollution	Inadequate; few regional assessments have been made (Portland and TVA)	<ul style="list-style-type: none"> • Characterization, modeling of transportation and dispersion, and assessment in regions where high density residential woodburning is occurring and will occur, include National Ambient Air Quality Standards, visibility, PSD, etc., impacts • Health assessment studies of wood combustion pollutants in regions that are in nonattainment status especially due to particulate violations • Development of ambient fine particulate, aldehyde, and POM measurements to determine actual population exposure

Table 5. Residential Wood Combustion - Current Air Pollution and Safety Assessment and Future Research Needs (Continued)

Research Activity Area	Adequacy of Current Data	Additional Research Requirements
<u>HEALTH AND SAFETY</u>		
1. Residential	Data available for accidents and deaths from woodburning units	<ul style="list-style-type: none"> • Evaluation of accident and death information from fires and burns and development of improved design, production, installation, and operational criteria for woodburning systems
	No data available for health impacts of indoor or areawide pollution	<ul style="list-style-type: none"> • Evaluation of acute and chronic adverse effects, such as morbidity and mortality from accidental burns and fires • Identification and assessment of causative agents, for example, health impacts from POM in wood emissions • Development of methods to reduce or eliminate harm when exposed to causative agents
2. General population	Inadequate	<ul style="list-style-type: none"> • Determination of the range of exposure that increased woodburning will produce, due to specific causative agents • Epidemiological studies of the incidence and distribution of diseases associated with increased air pollution in regions emphasizing residential woodburning
<u>OVERALL INFORMATION AND DATA ANALYSIS</u>		
1. Risk Analysis	Inadequate	<ul style="list-style-type: none"> • Economic and environmental analyses of using wood for residential applications • Determine relative risks of alternative residential heating options

APPENDIX A. NONCRITERIA AIR POLLUTANTS FROM RESIDENTIAL WOOD COMBUSTION

The following tables were developed by Cooper (Ref. 18) in reviewing several studies to date.

Table A-1. Priority Pollutants Measured in Smoke From
Residential Wood Combustion Sources

	Reference	Emission Factors (g/Kg) ^a	
		Stoves	Fireplace
Acenaphthylene	10, 3	0.064	0.010
Fluorene	10, 3	0.020	0.0047
Anthracene/phenanthrene	10, 3	0.096	0.0088
Phenol	3	0.1	0.02
Fluoranthene	10, 3	0.022	0.0016
Pyrene	10, 3	0.019	0.0016
Benz(a)anthracene	10, 3	0.0177	0.0019
Chrysene	10, 3	---	---
Benzofluoranthenes	10, 3	0.0135	.0019
Benzo(a)pyrene ^b	10, 3	0.0025	.00073
Indeno(1,2,3-ed)pyrene	10, 3	---	---
Benzo(ghi)perylene	10, 3	0.0059	0.0014
Dibenzanthracenes	10, 3	.001	.00018
Acenaphthene	3	.0064	.0012
Ethyl benzene	3	0.041	.0091 ^c
Phenanthrene	10, 3	d	d
Dibenz (a,h) anthracene	10	---	---
TOTAL		0.41	0.063

^a Grams emissions per kilogram wood, DeAngelis et al. (Ref. 13).

^b See Table 3, Note C.

^c May include xylenes.

^d Included in anthracene category.

Source: Cooper, Oregon Graduate Center, Ref. 18.

Table A-2. Carcinogenic Compounds Observed in Smoke From Residential Wood Combustion Sources^{a, b}

Compound	Carcinogenic Activity ^c	Reference Observed	Emission Factor (g/Kg) ^{a, d}	
			Stove	Fireplace
Dimethylbenzanthracene	++++	a		
Benz(a)anthracene	+	a, b	.0177	.0019
Dibenzanthracene		a	.0010	.00018
Dibenz(a, h)anthracene	+++	b	*	*
Dibenz(a, c)anthracene	+	b	*	*
Benzo(c)phenanthrene	+++	a	.0025	.008
Benzofluoranthene		a	.0135	.0019
Benzo(b)fluoranthene	++	*	*	*
Benzo(j)fluoranthene	++	*	*	*
Methylcholanthene		a	---	---
3-methylcholanthene	++++	*	*	*
Benzopyrenes		a	.009	.0015
Benzo(a)pyrene	+++	b	.0025 ^e	.00073 ^e
Indeno (1,2,3-ed)pyrene	+	a, b	---	---
Chrysene	+	a, b	f	f
Dibenzopyrenes		a	.0007	.0004
Dibenzo(a, l)pyrene	high	*	*	*
Dibenzo(a, h)pyrene	+++	*	*	*
Dibenzo(a, e)pyrene	+++	*	*	*
Dibenzocarbazoles		a	---	---
Dibenzo(a, g)carbazole	+	*	*	*
Dibenzo(c, g)carbazole	+++	*	*	*
Dibenzo(a, i)carbazole	+	*	*	*
TOTAL			.0389	.00599

^a DeAngelis et al., grams emissions per kilogram of wood, Ref. 13.

^b Lee et al., Ref. 10.

^c Based on classification in Ref. 23; + uncertain or weakly carcinogenic; + carcinogenic; ++, +++, ++++ strongly carcinogenic.

^d Average of results from Tables 20 and 22 of Ref. 13 excluding SASS train results for green pine in stove.

^e Not to be exceeded more than once per year.

^f Included in the benz(a)anthracene number.

^g Total will be upper limit because of the inclusion of some noncarcinogenic isomers included in the general classes measured. The benzopyrene class value was not used, only the benzo(a)pyrene value.

* These compounds were not specifically identified except as a group.

Source: Cooper, Oregon Graduate Center, Ref. 18.

Table A-3. Emission Factors for Cilia Toxic and Mucus Coagulating Agents Observed in Smoke and Flue Gas From Residential Wood Combustion Sources^{a, b}

Compound	Stoves	Fireplaces
Formaldehyde	0.2	0.4
Propionaldehyde	0.2	---
Acetaldehyde	0.1	---
Isobutyraldehyde	0.3	0.5
Phenol	0.1	0.02
Cresols	0.2	.06

^a DeAngelis, et al., Ref. 13. (grams emissions per kilogram wood)

^b Hoffman and Wynder, Ref. 35, page 339

Source: Cooper, Oregon Graduate Center, Ref. 18.

Table A-4. Initiating or Cancer-Promoting Agents and Co-Carcinogenic Compounds in Smoke From Residential Wood Combustion Sources^{a, b}

Compound	Emission Factors (g/Kg)	
	Stoves	Fireplaces
Catechol	0.01	.014
Phenols	0.1	0.02
Pyrene	0.019	0.0016
Fluoranthene	0.022	.0016

^a DeAngelis, et al., Ref. 13. (grams emissions per kilogram wood)

^b Van Duuren, Ref. 36.

Source: Cooper, Oregon Graduate Center, Ref. 18.

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