

Air Emissions from Residential Wood Combustion



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Glossary of Air Quality Terms

Acid Equivalent	A standardized unit that is a measure of potential acid strength.
Carbon Equivalent	A standardized unit which allows for the greenhouse gas impact from various sources emitting different greenhouse gases to be compared.
Dioxin	A group of organic compounds, many of which are toxic, particularly those that contain the element chlorine. The most toxic is 2,3,7,8-tetrachlorodibenzo-p-dioxin.
Elemental Carbon	Uncombined carbon giving combustion emissions their black color, also referred to as soot or graphitic carbon.
HAPs	189 Hazardous Air Pollutants defined in Title III of the federal clean air act amendments of 1990.
Micron	One millionth (10^{-6}) of a meter. As an example of scale, a red blood cell is 7 microns in diameter.
NO_x	Nitrogen Oxides. There are several common forms of nitrogen oxides including: nitrous oxide (N ₂ O) which is a greenhouse gas, nitric oxide (NO) which is the most abundant nitrogen oxide formed by combustion, and nitrogen dioxide (NO ₂) which is formed by oxidation of NO in the atmosphere and to a lesser extent directly in the combustion process. NO ₂ is a federal criteria pollutant and a contributor to acid precipitation.

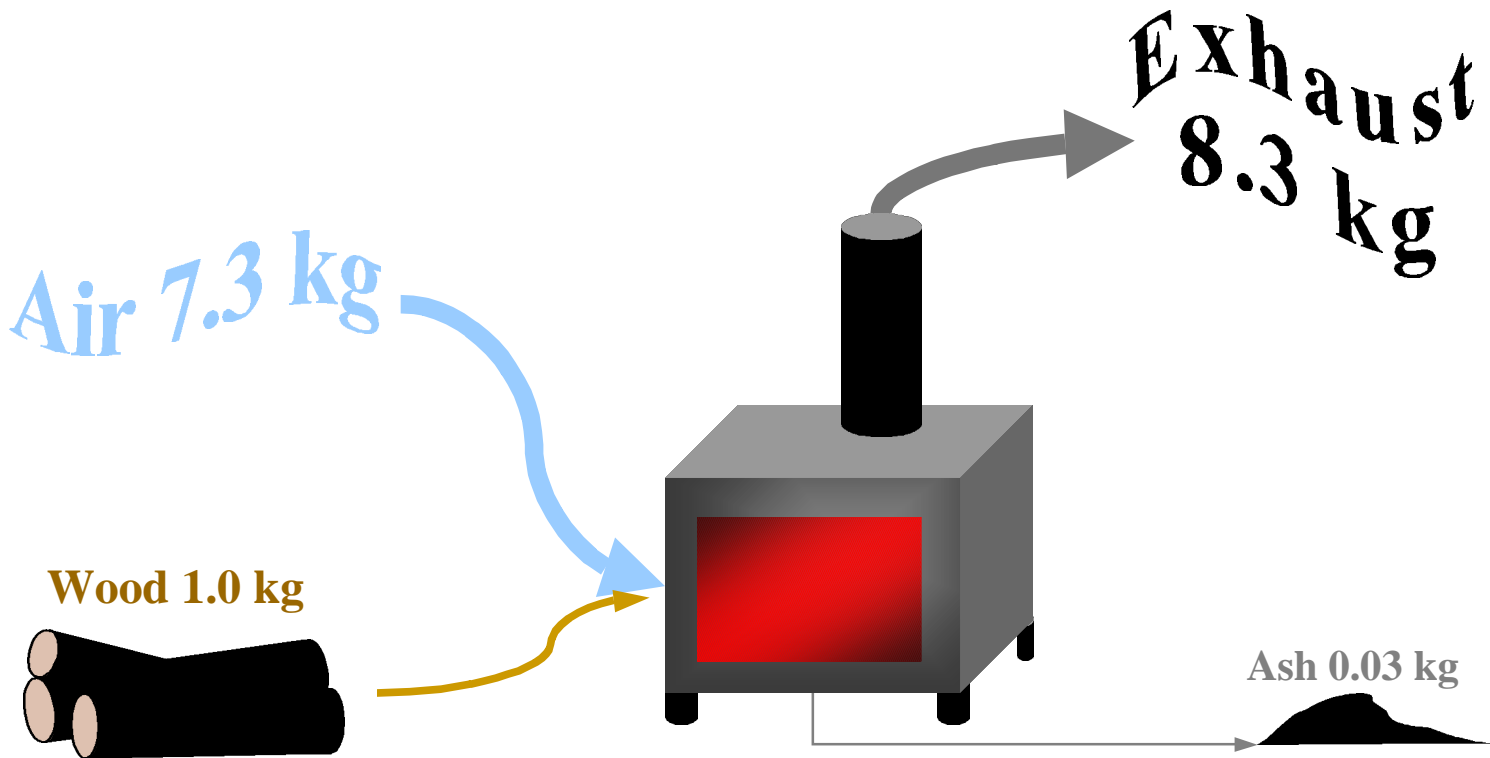
Glossary of Air Quality Terms (continued)

Organic Compounds	Compounds which are composed of carbon in combination with hydrogen, oxygen or nitrogen. Hydrocarbons are a type of organic compound composed of only carbon and hydrogen.
16-PAH	The sum of 16 specific individual Polycyclic Aromatic Hydrocarbons which are some of the literally millions of possible POM compounds. 16-PAH is used as a surrogate measure of POM.
PM	Particulate Matter. Solid or liquid particles suspended in the atmosphere
PM_{2.5}	Particulate Matter with an aerodynamic diameter less than 2.5 microns. Regulatory status in flux, often referred to as respirable particles.
PM₁₀	Particulate Matter with an aerodynamic diameter less than 10 microns. A federal criteria pollutant, often referred to as inhalable particles.
POM	Polycyclic Organic Matter. A group of complex organic compounds, including several which are carcinogenic.
Quad	One quadrillion (10^{15}) BTU
RWC	Residential Wood Combustion
SO₂	Sulfur Dioxide gas. A contributor to acid precipitation and a federal criteria pollutant. Produced by the combustion of fuels containing sulfur (e.g., coal).
VOC	Volatile Organic Compounds. Organic compounds that are in the vapor (gaseous) form.

Residential Wood Combustion Facts

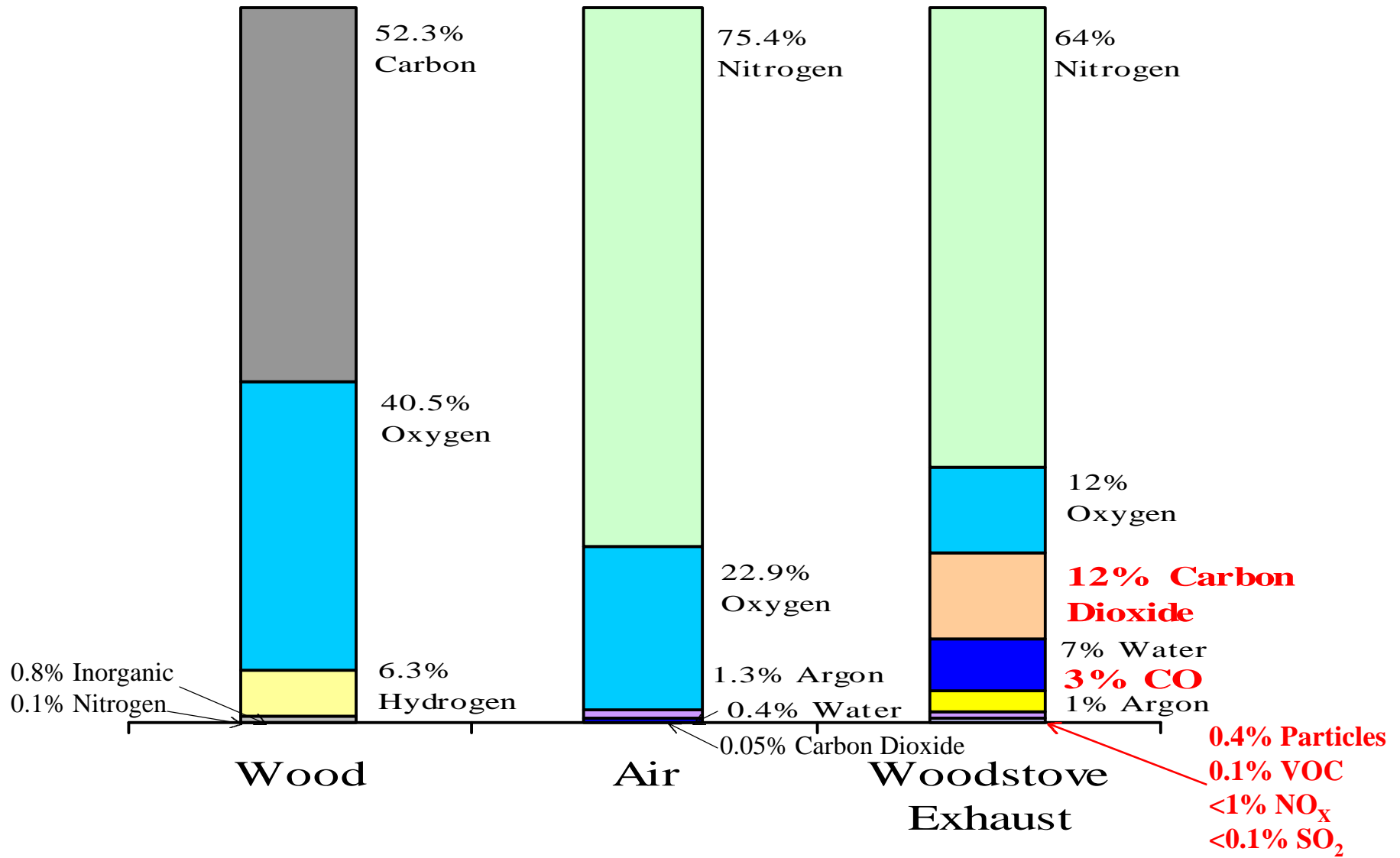
- About 28% of cordwood is burned in fireplaces and 72% in woodstoves
- Pellet stove, masonry heater, wood-fired cookstove and wood-fired furnace use is insignificant as compared to fireplace and woodstove use
- 9% of home space heat was from wood combustion in 1997
- 25.7 million cordwood fireplaces and 8.6 million woodstoves in the United States (1993)
- Many fireplaces are used infrequently

Mass Balance



- 20% Moisture, Douglas Fir Fuel
- Conventional Woodstove
- Low Burn Rate

Composition of Wood, Air and Woodstove Exhaust



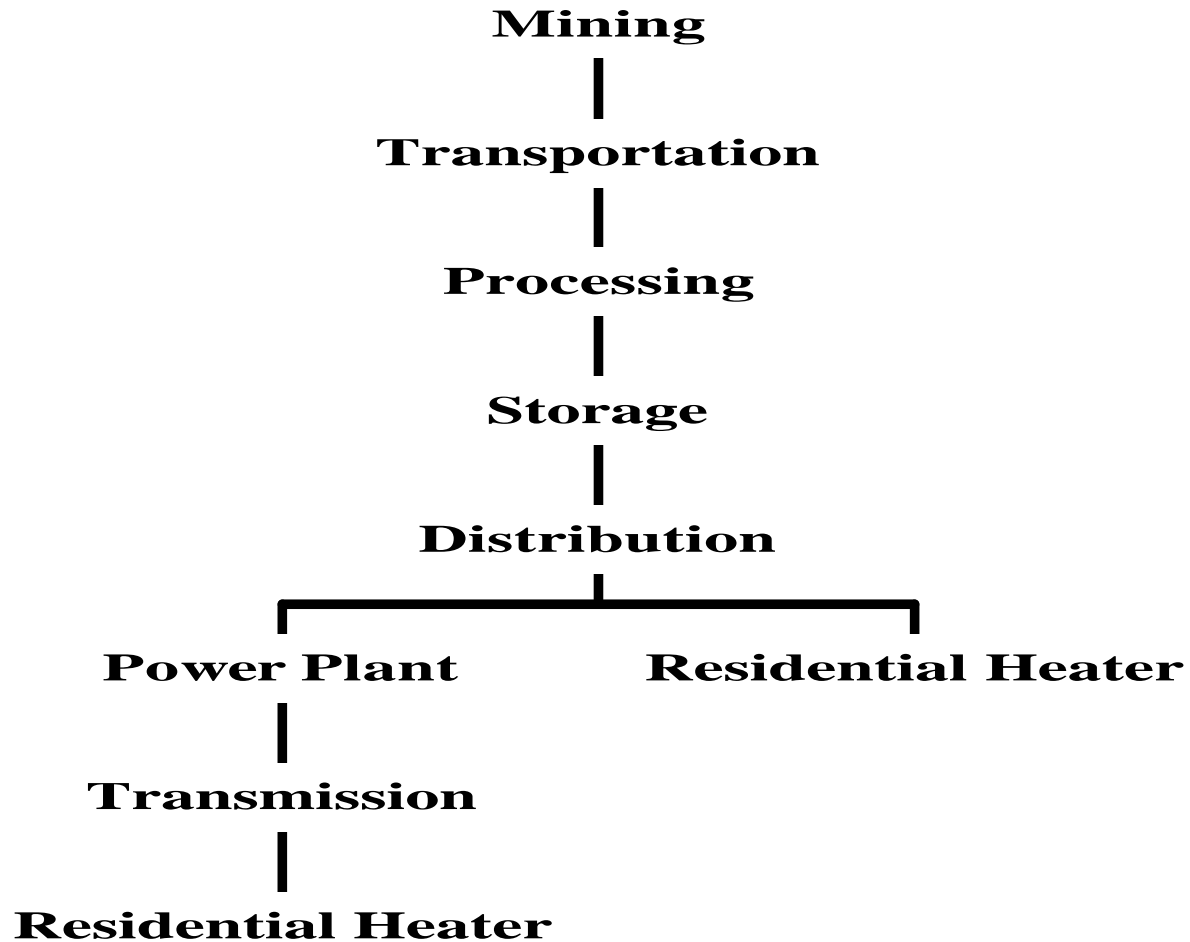
All values weight percent, dry Douglas fir, 20% relative humidity in air at 70°F, conventional woodstove

Spatial Scale of Air Quality Impacts

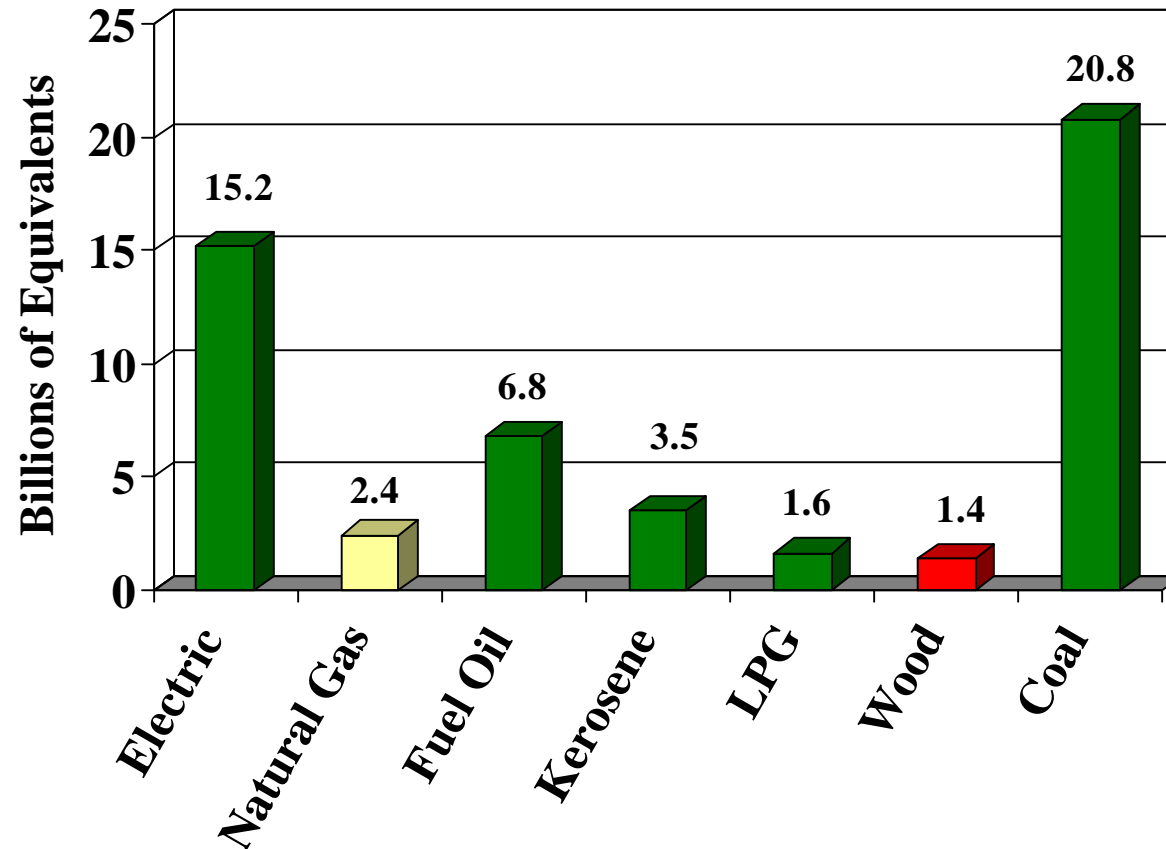
- **Regional / Global**
- Local

Example Energy Trajectory

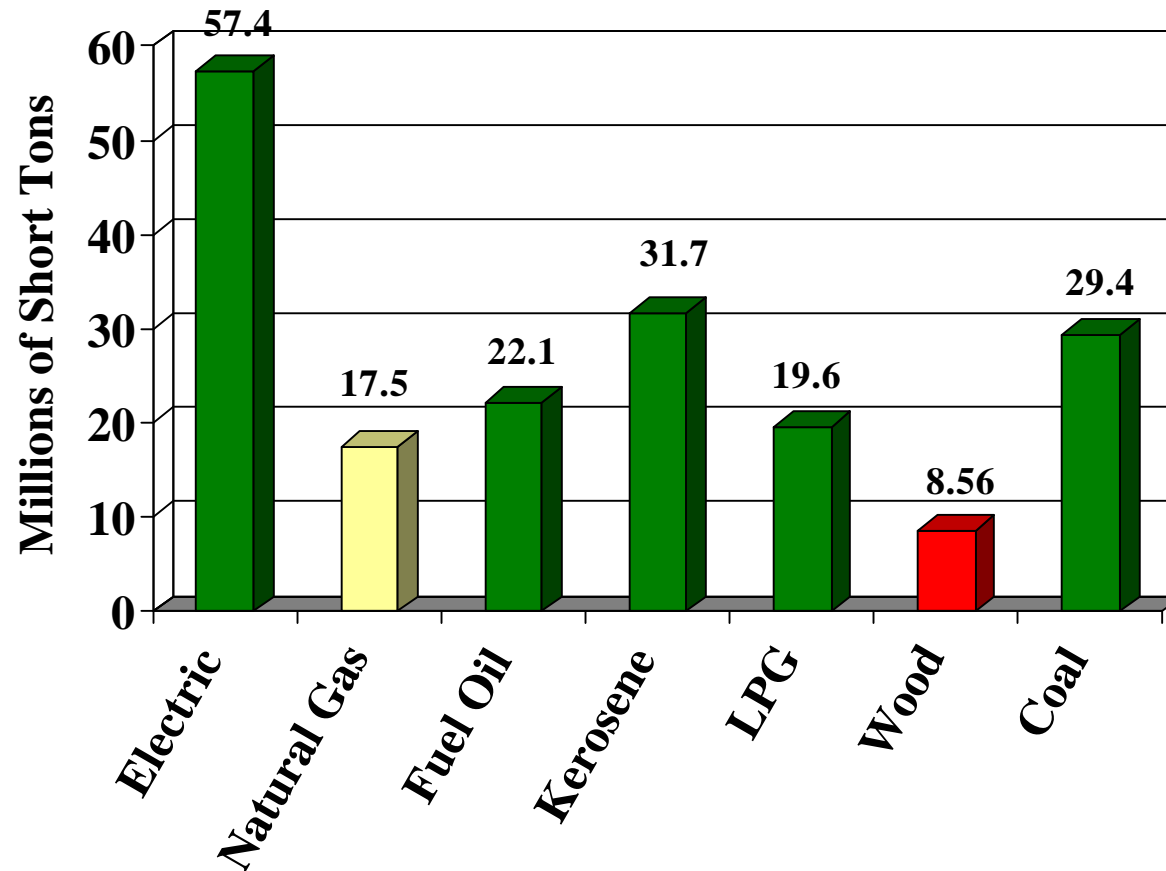
coal used for residential space heating



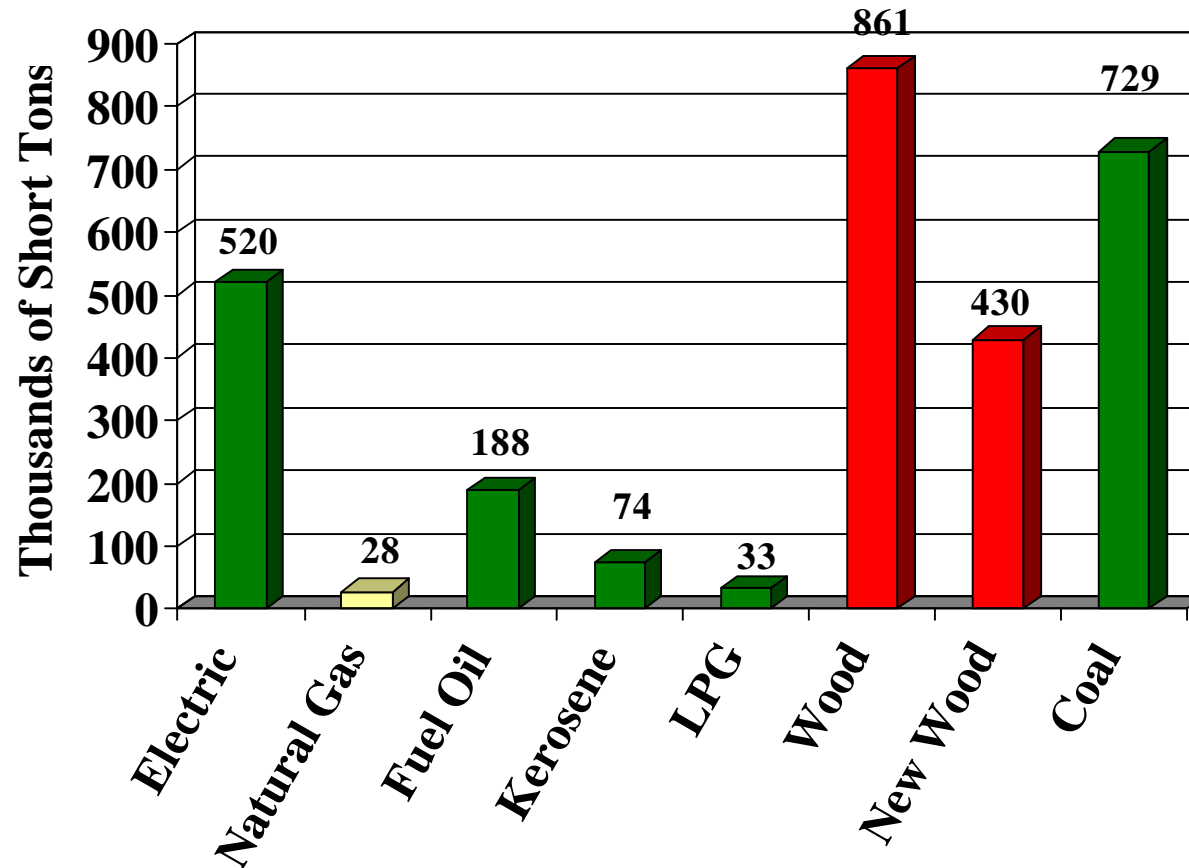
Acid Equivalents Emitted per Quad of Heat Delivered



Carbon Equivalents of Greenhouse Gases per Quad of Heat Delivered



Effective Fine Particulate Emissions per Quad of Heat Delivered



regional haze – summer problem

Spatial Scale of Air Quality Impacts

- Regional / Global
- **Local**

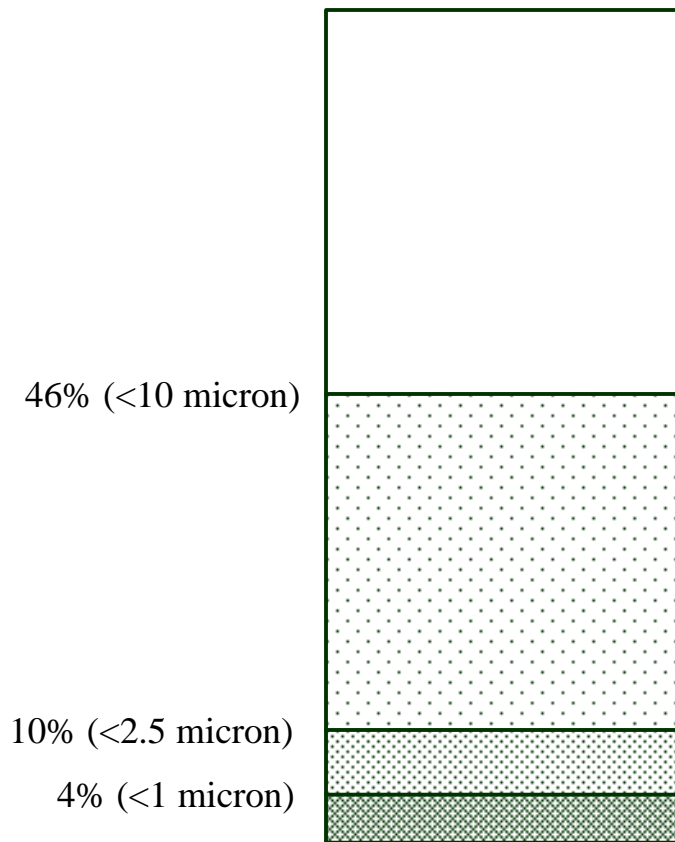
Residential Wood Combustion Air Pollutants with Localized Impacts

Pollutant	Characteristics	Regulatory Status	Magnitude of National Impact of RWC
Particles	<p style="text-align: center;">Solids and Liquids</p> <ul style="list-style-type: none"> • 90% organic compounds • 10% elemental carbon • <1% inorganic compounds • >90% less than one micron 	<ul style="list-style-type: none"> • PM₁₀ federal criteria pollutant • PM_{2.5} regulatory status in flux • Specific organic compounds in particles are HAPs (e.g., POM and dioxin) 	<ul style="list-style-type: none"> • RWC contributes 12% of the total PM₁₀ from fuel combustion, industrial and transportation sources nationally (1997) • Number one source of POM
VOC (Volatile Organic Compounds)	Gases (vapors)	<ul style="list-style-type: none"> • Specific organic compounds are HAPs (e.g., formaldehyde and benzene) 	<ul style="list-style-type: none"> • Number two source of benzene (after combined mobile sources)
Carbon Monoxide	Gas	<ul style="list-style-type: none"> • federal criteria pollutant 	<ul style="list-style-type: none"> • RWC contributes 3% of the total national inventory (1997)

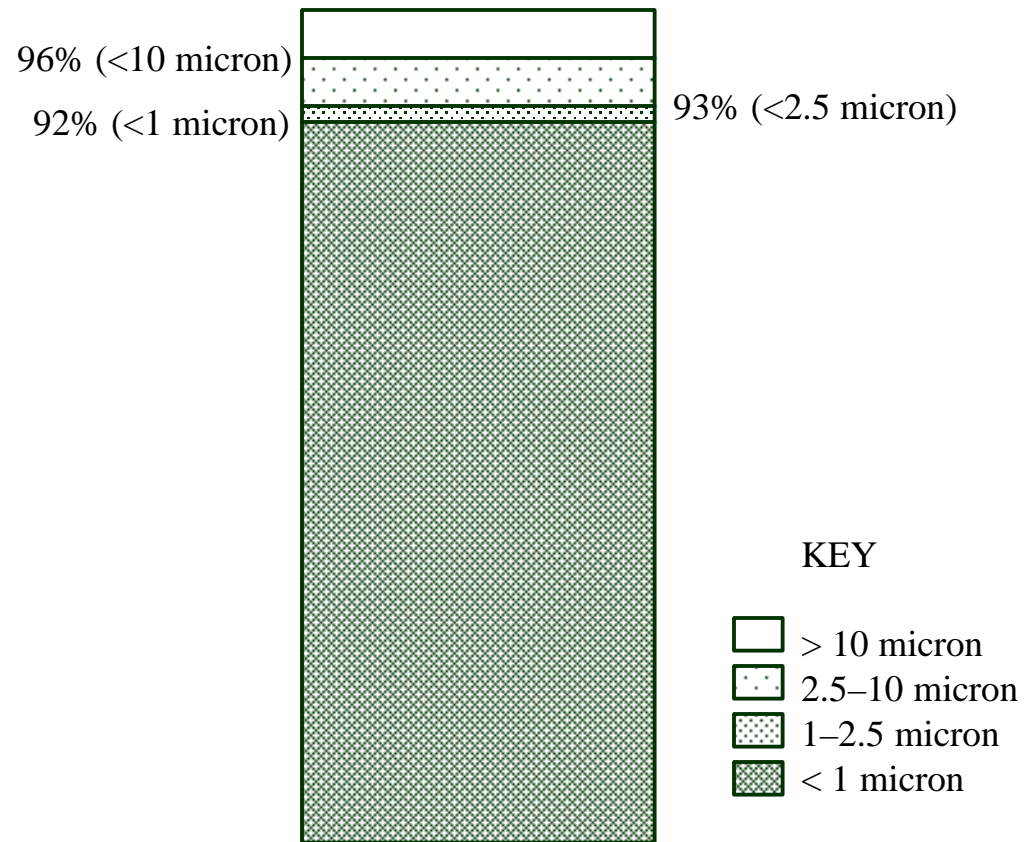
Note: Many organic compounds, and consequently HAPs, are partitioned between vapor and particulate phases, the relative amounts depending on pressure and temperature. RWC is a significant source of other HAPs in addition to the HAPs listed here.

Comparison of the Size Distribution of Particles Produced by Combustion and Physical Processes

Wind-Blown Agricultural Soil Dust



Residential Wood Combustion



KEY

- > 10 micron
- 2.5–10 micron
- 1–2.5 micron
- < 1 micron

Federal Clean Air Act Amendments of 1990

Title 3 Hazardous Air Pollutants

Acetaldehyde

Acetamide
Acetonitrile
Acetophenone
2-Acetylaminofluorene
Acrolein
Acrylamide
Acrylic acid
Acrylonitrile
Allyl chloride
4-Aminobiphenyl
Aniline
o-Anisidine
Asbestos
Benzene (including benzene from gasoline)
Benzidine
Benzotrichloride
Benzyl chloride
Biphenyl
Bis(2-ethylhexyl)phthalate (DEHP)
Bis(chloromethyl)ether
Bromoform
1,3-Butadiene
Calcium cyanamide
Caprolactam
Captan
Carbaryl
Carbon disulfide
Carbon tetrachloride
Carbonyl sulfide Catechol
Chloramben
Chlordane
Chlorine

Catechol

Chloramben
Chlordane
Chlorine
Chloroacetic acid
2-Chloroacetophenone
Chlorobenzene
Chlorobenzilate
Chloroform
Chloromethyl methyl ether
Chloroprene
Cresols/Cresylic acid (isomers and mixture)
o-Cresol
m-Cresol
p-Cresol
Cumene
2,4-D, salts and esters
DDE
Diazomethane
Dibenzofurans
1,2-Dibromo-3-chloropropane
Dibutylphthalate
1,4-Dichlorobenzene(p)
3,3-Dichlorobenzidene
Dichloroethyl ether (Bis(2-chloroethyl)ether)
1,3-Dichloropropene
Dichlorvos
Diethanolamine
N,N-Diethyl aniline (N,N-Dimethylaniline)
Diethyl sulfate
3,3-Dimethoxybenzidine
Dimethyl aminoazobenzene
3,3'-Dimethyl benzidine

Dimethyl carbamoyl chloride
Dimethyl formamide
1,1-Dimethyl hydrazine
Dimethyl phthalate
Dimethyl sulfate
4,6-Dinitro-o-cresol, and salts
2,4-Dinitrophenol
2,4-Dinitrotoluene
1,4-Dioxane (1,4-Diethyleneoxide)
1,2-Diphenylhydrazine
Epichlorohydrin (1-Chloro-2,3-epoxypropane)
1,2-Epoxybutane
Ethyl acrylate
Ethyl benzene
Ethyl carbamate (Urethane)
Ethyl chloride (Chloroethane)
Ethylene dibromide (Dibromoethane)
Ethylene dichloride (1,2-Dichloroethane)
Ethylene glycol
Ethylene imine (Aziridine)
Ethylene oxide
Ethylene thiourea
Ethylidene dichloride (1,1-Dichloroethane)
Formaldehyde
Heptachlor
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Hexamethylene-1,6-diisocyanate
Hexamethylphosphoramide
Hexane
Hydrazine

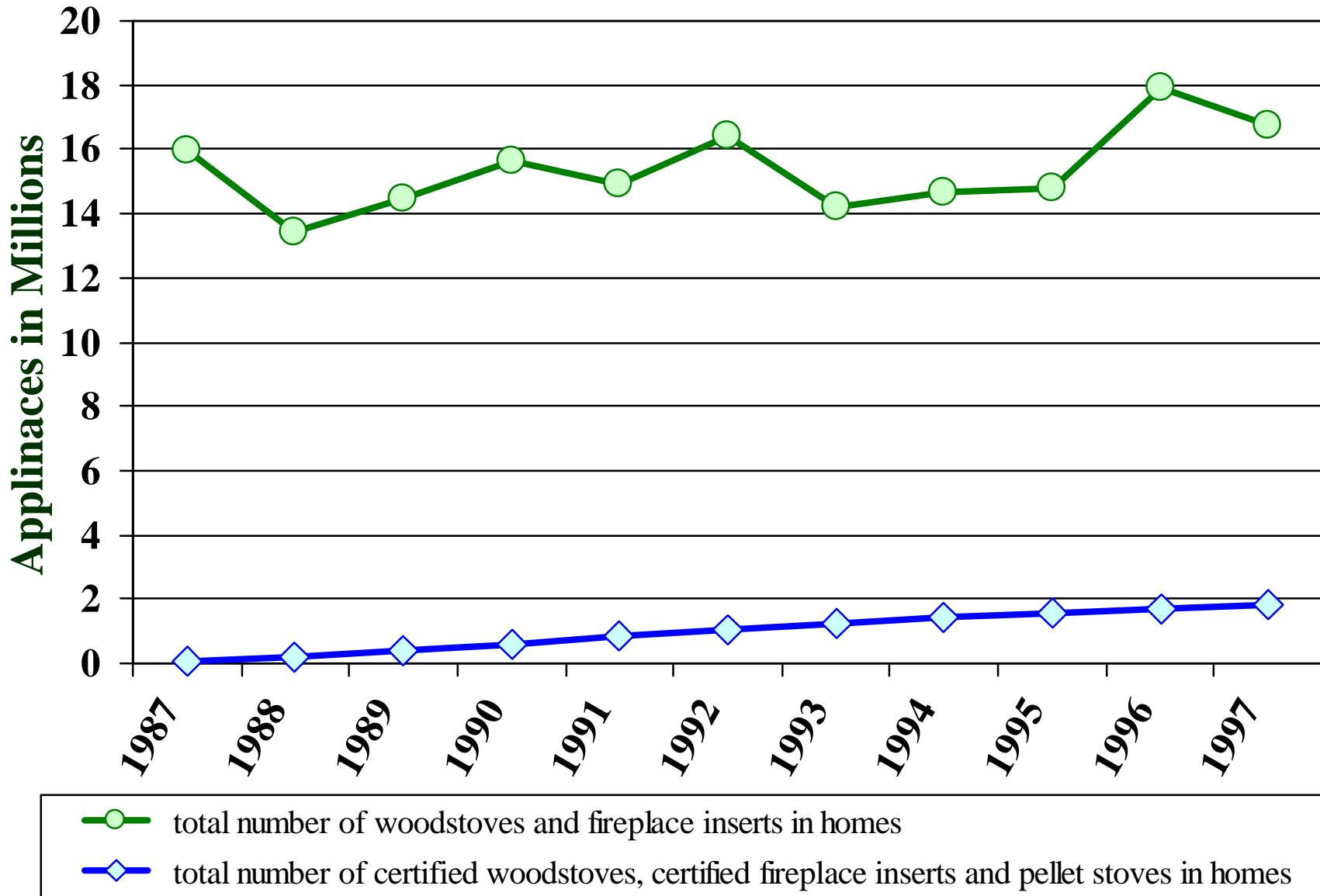
Federal Clean Air Act Amendments of 1990

Title 3 Hazardous Air Pollutants (continued)

Hydrochloric acid	Pentachlorophenol	Triethylamine
Hydrogen fluoride (Hydrofluoric acid)	Phenol	Trifluralin
Hydrogen sulfide	p-Phenylenediamine	2,2,4-Trimethylpentane
Hydroquinone	Phosgene	Vinyl acetate
Isophorone	Phosphine	Vinyl bromide
Lindane (all isomers)	Phosphorus	Vinyl chloride
Maleic anhydride	Phthalic anhydride	Vinylidene chloride (1,1-Dichloroethylene)
Methanol	Polychlorinated biphenyls (Aroclors)	Xylenes (isomers and mixture)
Methoxychlor	1,3-Propane sultone	o-Xylenes
Methyl bromide (Bromomethane)	beta-Propiolactone	m-Xylenes
Methyl chloride (Chloromethane)	Propionaldehyde	p-Xylenes
Methyl chloroform (1,1,1-Trichloroethane)	Propoxur (Baygon)	Antimony Compounds
Methyl ethyl ketone (2-Butanone)	Propylene dichloride (1,2-Dichloropropane)	Arsenic Compounds (inorganic including arsine)
Methyl hydrazine	Propylene oxide	Beryllium Compounds
Methyl iodide (Iodomethane)	1,2-Propylenimine (2-Methyl aziridine)	Cadmium Compounds
Methyl isobutyl ketone (Hexone)	Quinoline	Chromium Compounds
Methyl isocyanate	Quinone	Cobalt Compounds
Methyl methacrylate	Styrene	Coke Oven Emissions
Methyl tert butyl ether	Styrene oxide	Cyanide Compounds
4,4-Methylene bis(2-chloroaniline)	2,3,7,8-Tetrachlorodibenzo-p-dioxin	Glycol ethers
Methylene chloride (Dichloromethane)	1,1,2,2-Tetrachloroethane	Lead Compounds
Methylene diphenyl diisocyanate (MDI)	Tetrachloroethylene (Perchloroethylene)	Manganese Compounds
4,4-Methylenedianiline	Titanium tetrachloride	Mercury Compounds
Naphthalene	Toluene	Fine mineral fibers
Nitrobenzene	2,4-Toluene diamine	Nickel Compounds
4-Nitrobiphenyl	2,4-Toluene diisocyanate	Polycyclic Organic Matter
4-Nitrophenol	o-Toluidine	Radionuclides (including radon)
2-Nitropropane	Toxaphene (chlorinated camphene)	Selenium Compounds
N-Nitroso-N-methylurea	1,2,4-Trichlorobenzene	
N-Nitrosodimethylamine	1,1,2-Trichloroethane	
N-Nitrosomorpholine	Trichloroethylene	
Parathion	2,4,5-Trichlorophenol	
Pentachloronitrobenzene (Quintobenzene)	2,4,6-Trichlorophenol	

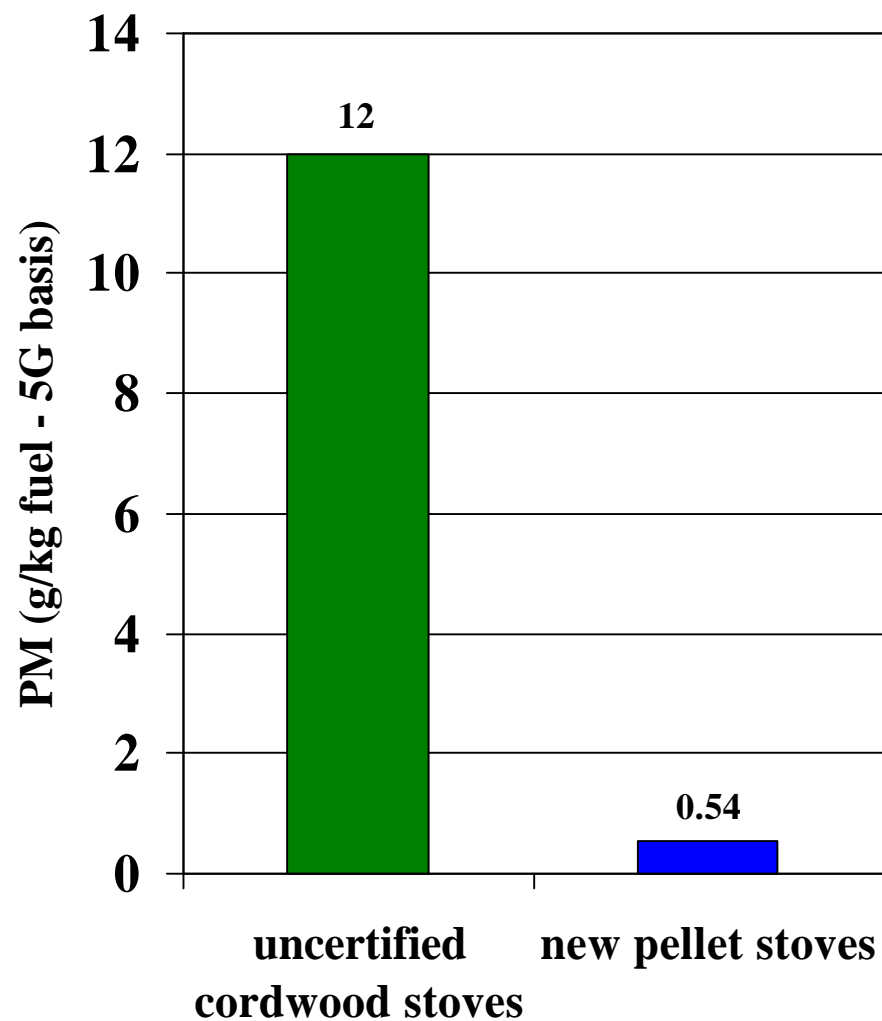
Residential Wood Combustion Additional Air Quality Issues

- Short-term impacts (e.g., night-time inversions or short air stagnation events)
- Near-ground level source
- Residential settings
- Annual inventory represents seasonal use only

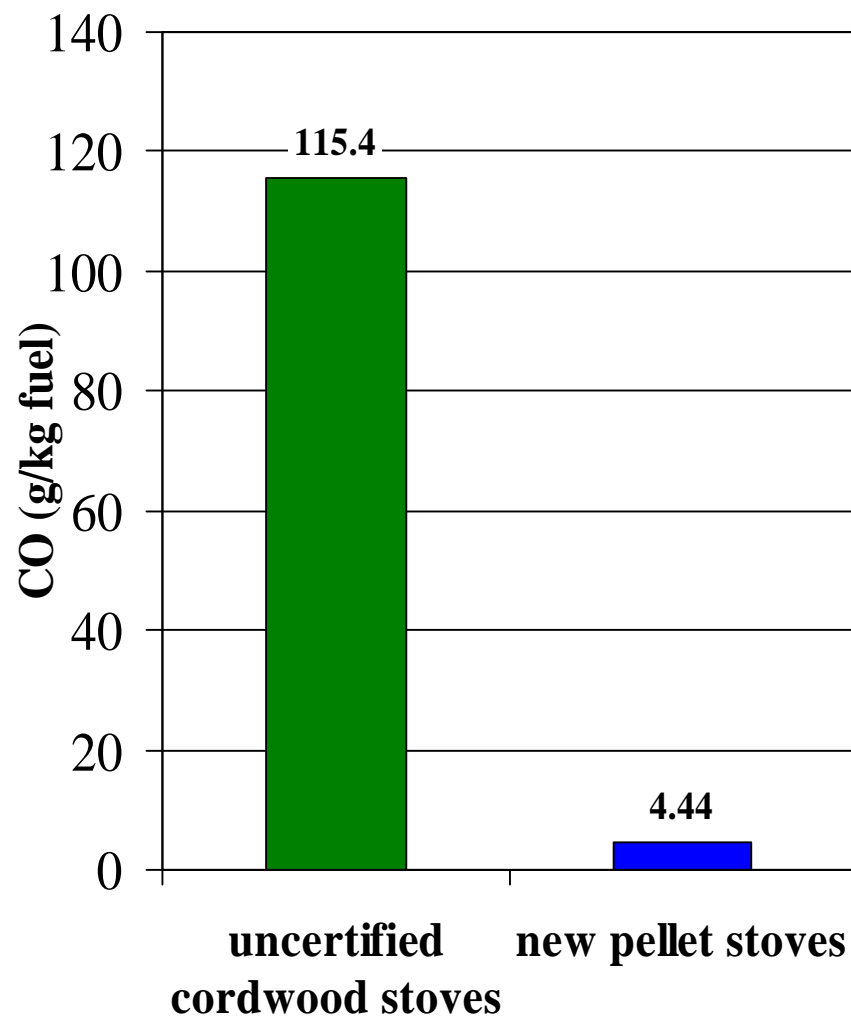


Old versus new wood burning appliances in use by year

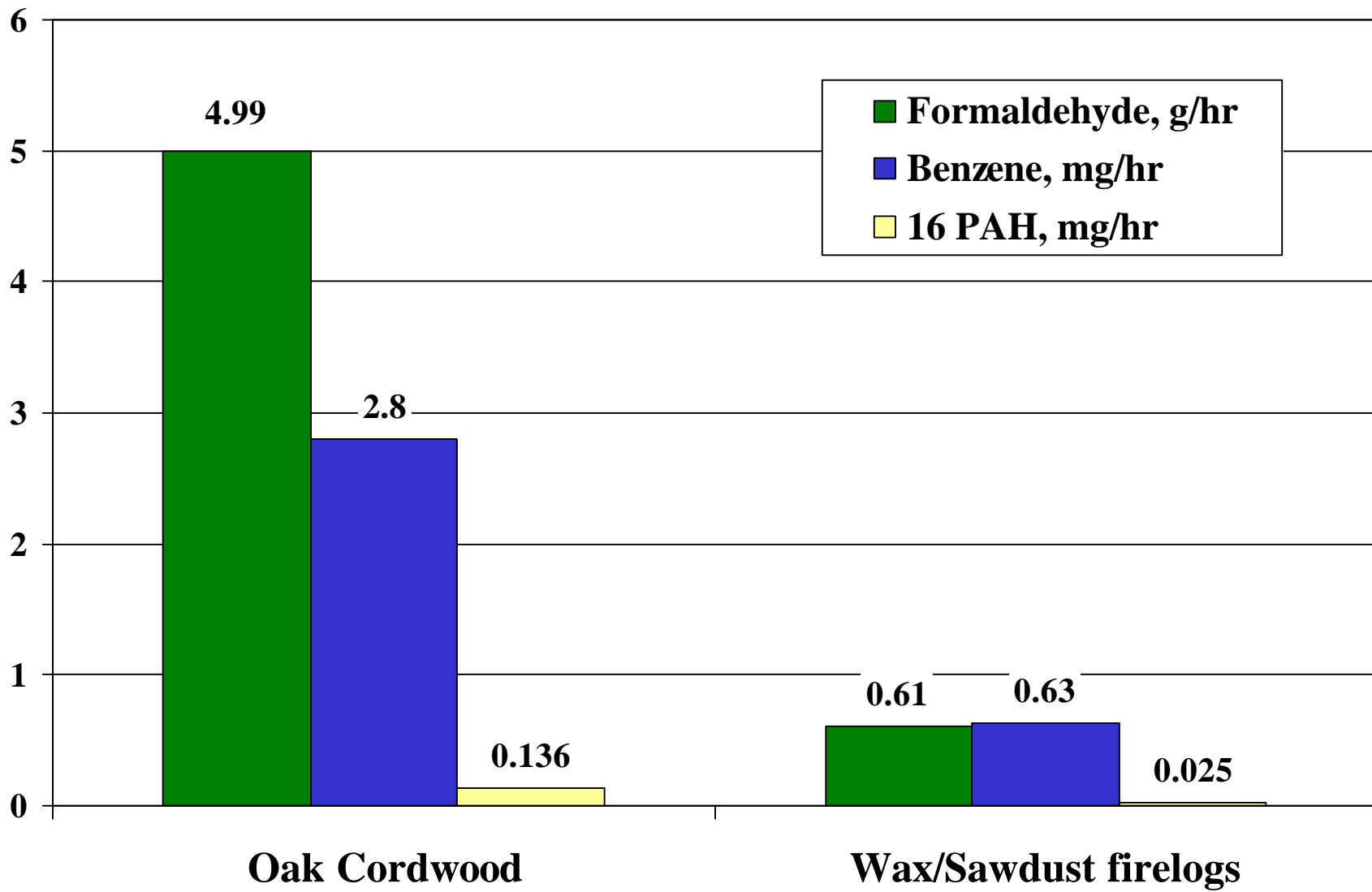
Particulate Matter



Carbon Monoxide



Reduction in particulate and carbon monoxide emissions from pellet stoves as compared to uncertified cordwood stoves



Reduction in HAP emissions in fireplaces from the use of wax/sawdust firelogs as compared to oak cordwood

Conclusions

- On a regional / global scale RWC is clearly one of the best space heating options and uses a renewable resource
- Old technology appliances produce elevated local impacts of particles, carbon monoxide and HAPs
- New technology appliances and fuel options reduce local impacts substantially
- Most appliances / fuels in use today are still old technology
- Most perceptions, regulations and emission estimates are based on old technology appliances and frequently on little hard data