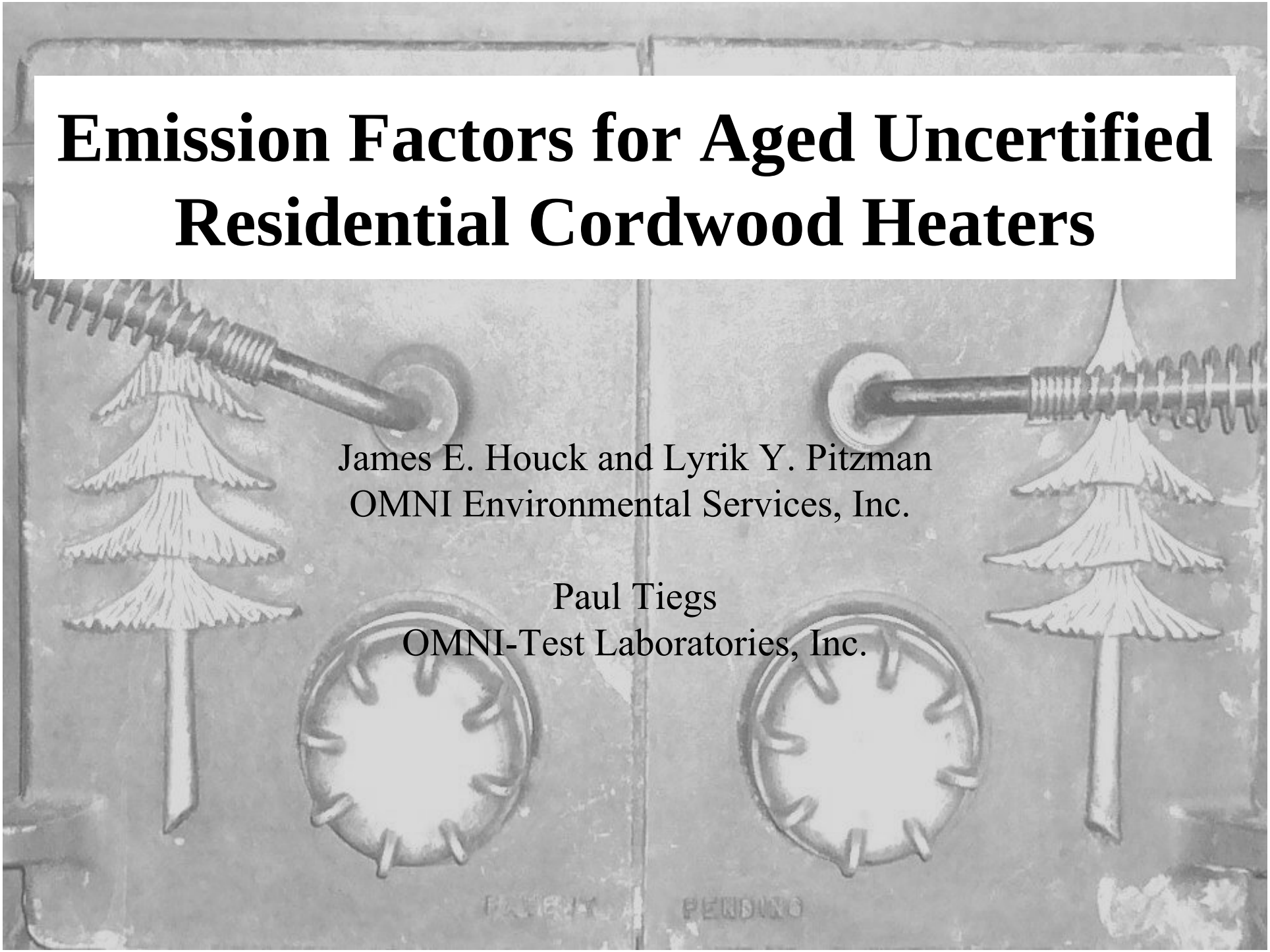
Emission Factors for Aged Uncertified Residential Cordwood Heaters



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Key Issues

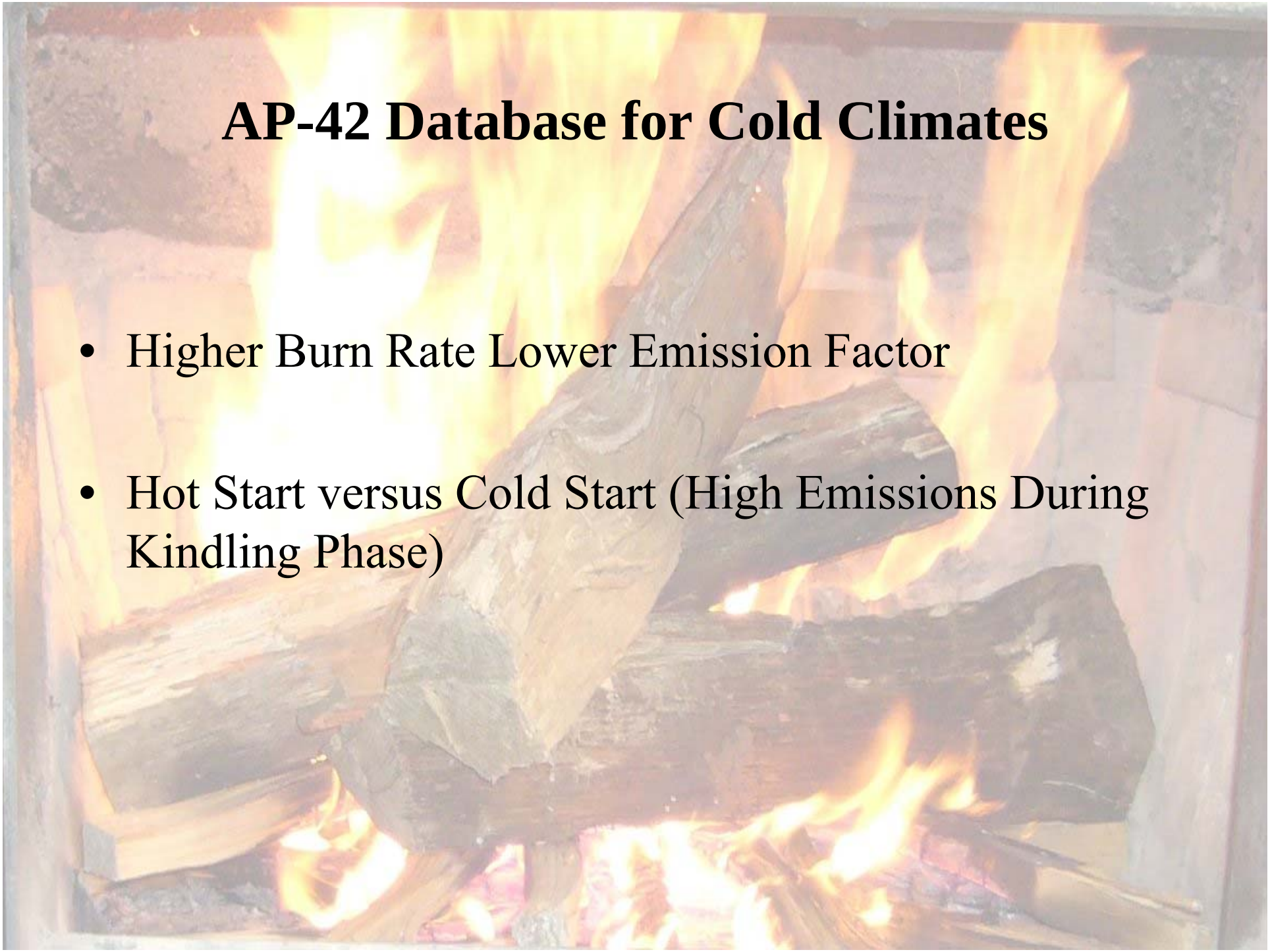
- 12 Million Still in Service
- AP-42 Emission Factors are Too Low Due to Non-representative Database
- Change in Performance Due to Degradation (Heaters ≥18 yrs Old, AP-42 Last Revised 1991)
- Regional Variation in Emission Factors
- Contribution of Secondary Organic Aerosols (SOA)
- Toxic Air Pollutants More Significant to Human Health and the Environment than PM

AP-42 Conventional Cordwood Database

Comparison of Yearly HDD the with the National Average

Location in-home tests	Number of in-home Heaters	Yearly HDD
Glens Falls, NY	3	7150
Waterbury, VT	3	7790
Klamath Falls, OR	7	6600
Crested Butte, CO	18	11,300
Portland, OR	2	4369
Whitehorse, Yukon	16	12,260
AP-42 average (heater weighted)		10,190
U.S. average (population weighted)		4540

HDD= Heating Degree Day



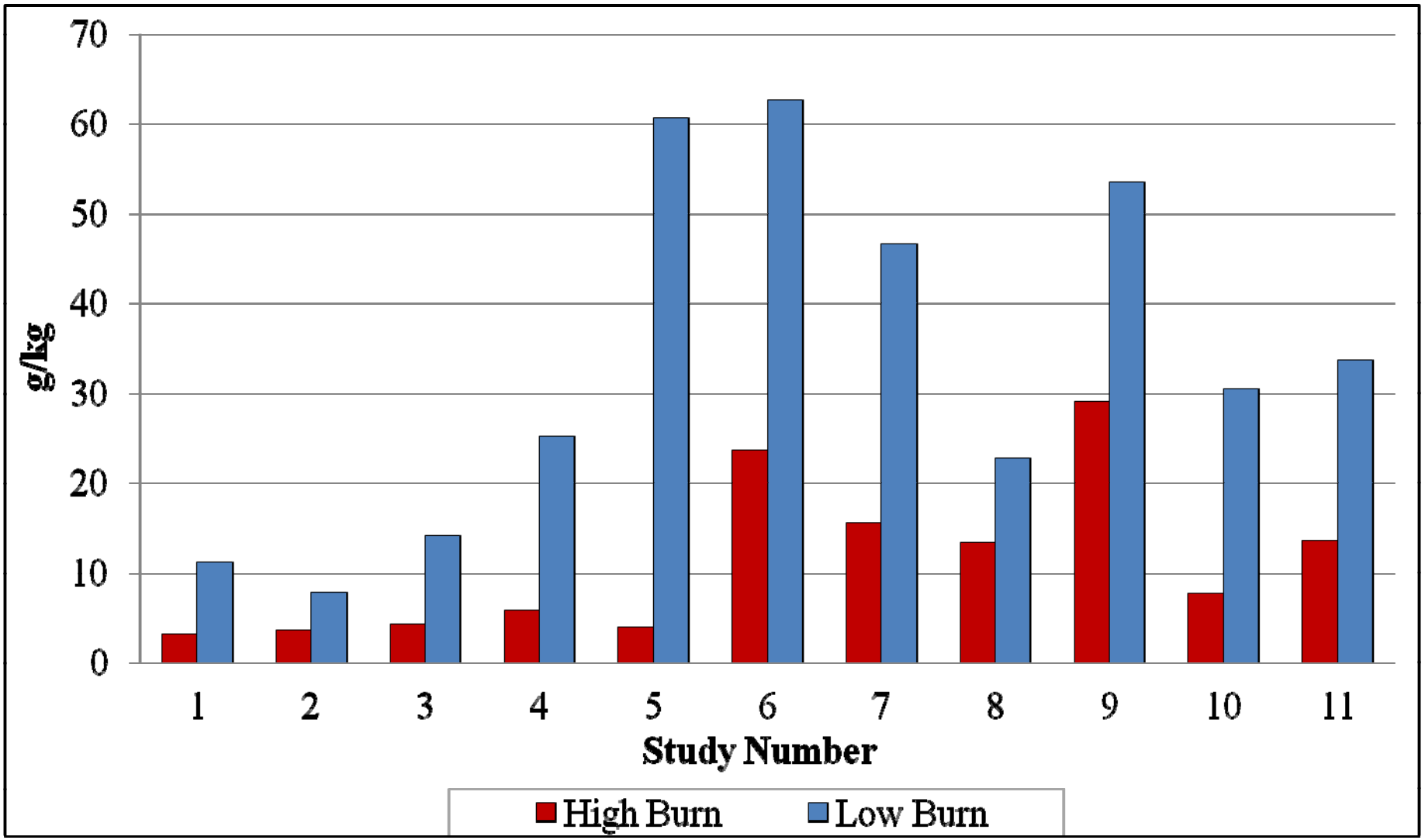
AP-42 Database for Cold Climates

- Higher Burn Rate Lower Emission Factor
- Hot Start versus Cold Start (High Emissions During Kindling Phase)

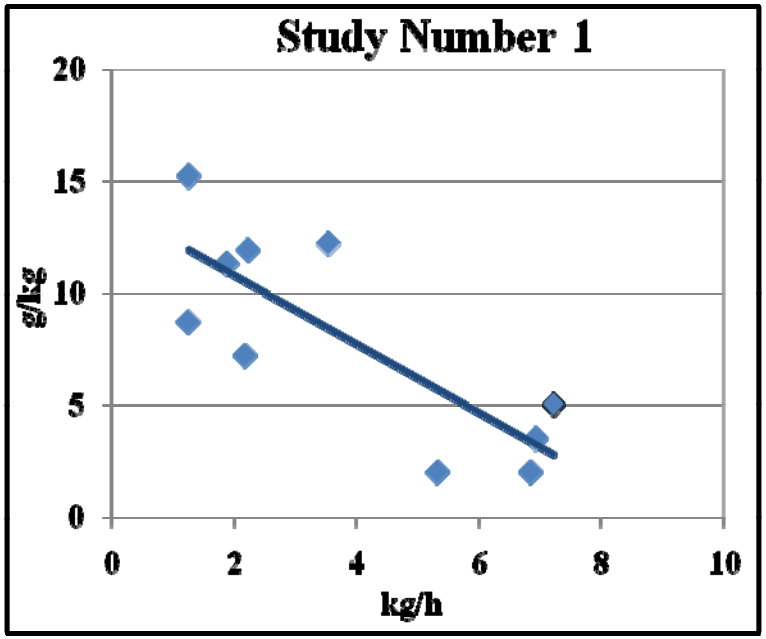
Creosote as a Surrogate for Particles

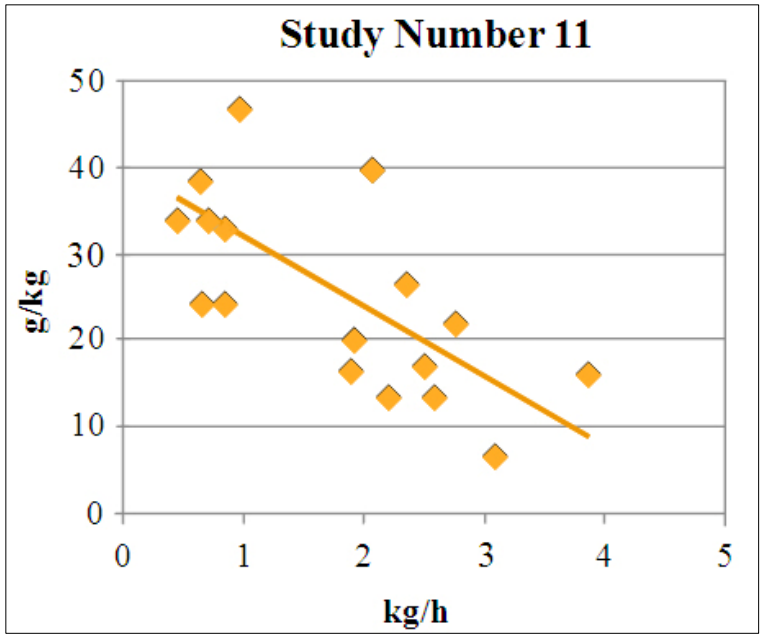
Burn rate	Fuel moisture (%)	Creosote accumulation, piñon pine (g/kg)	Creosote accumulation, oak (g/kg)
Low	5	9.2	16.5
	15	11.0	16.6
	25	9.5	19.4
Medium	5	9.8	4.1
	15	8.0	2.9
	25	5.4	2.3
High	5	6.4	2.7
	15	3.9	0.88
	25	2.2	0.40

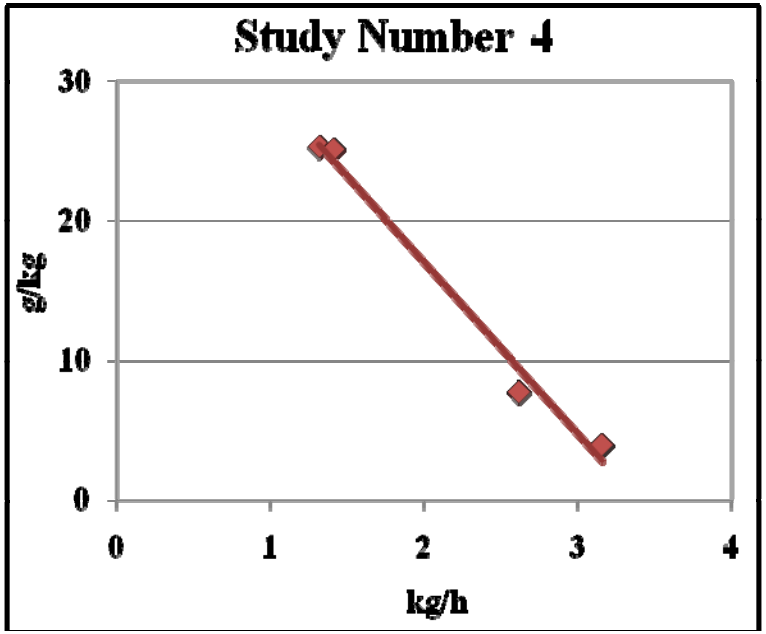
Eleven Studies Spanning from 1980 to 2005 Comparing Particulate Emission Factors at High Burn versus Low Burn Rates

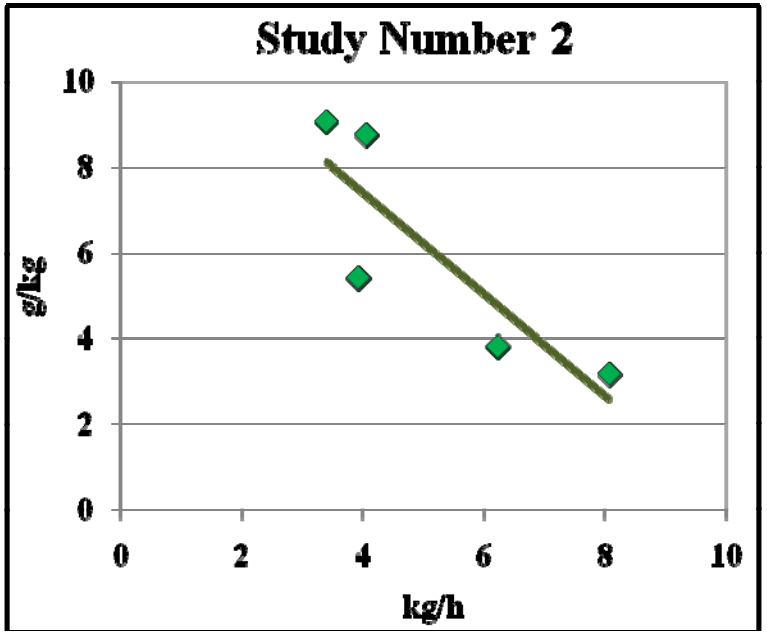


Four Studies Spanning from 1989 to 2005 Illustrating in Detail the Effect of Burn Rate on Particulate Emission Factors





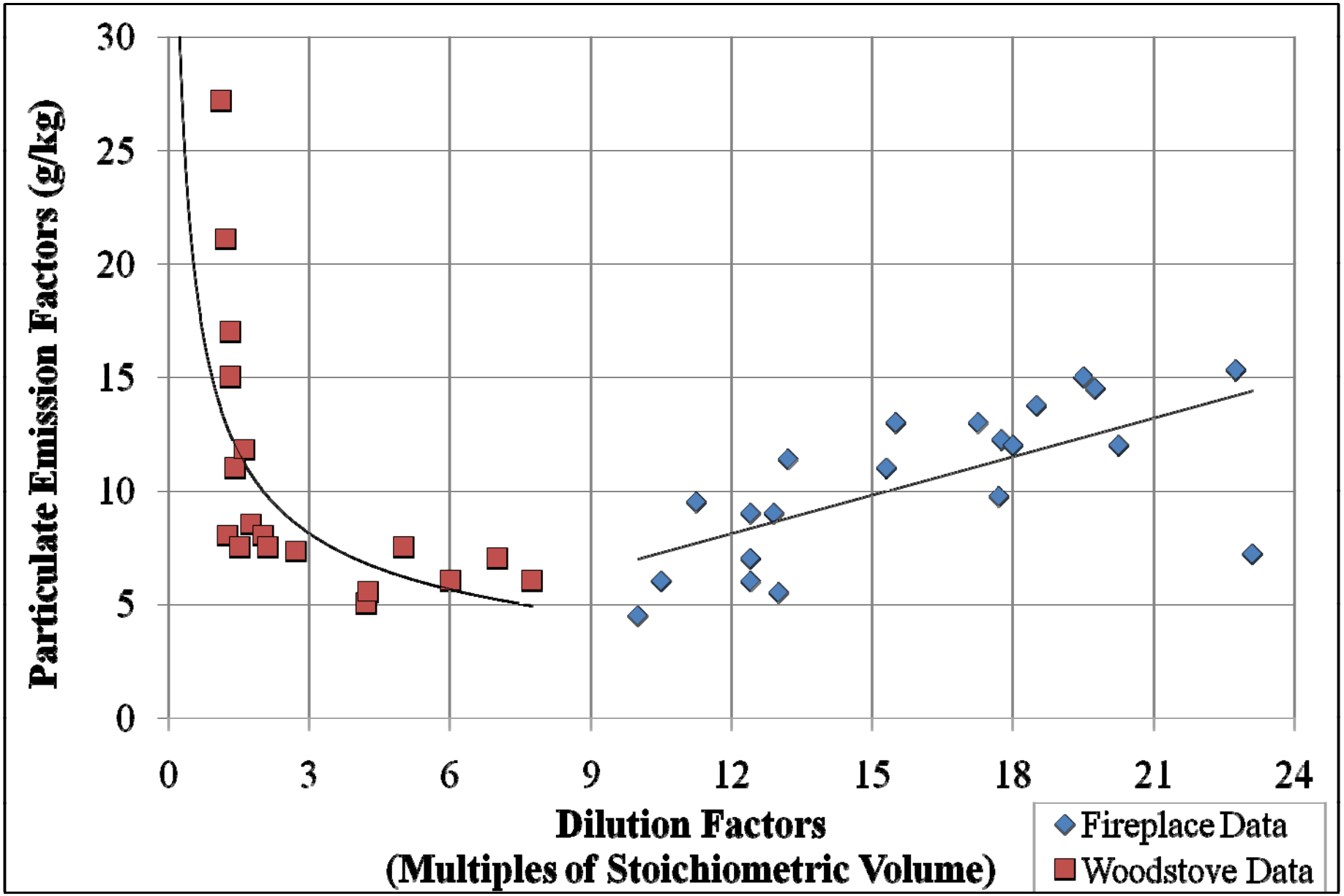




Degradation with Use

- Increase Air Flow
- Higher Burn Rates (Less Burn Control with Air Controller)
- Lower Emission Factors
- Lower Efficiencies (More Fuel for the Same Heat Demand)
- Gasket Material Degraded, Doors Warped (Not Sealing), Breaches in Unit Due to Corrosion and Rust, Air Control Systems Damaged

The Effect of Excess Air on Emission Factors



Efficiencies by Appliance Type

Study	Appliance type	Efficiency*
1	Conventional cordwood heater	54%
2	Conventional cordwood heater	40%-65%
3	Cordwood fireplaces (n = 14)	12%-32%
4	Cordwood fireplaces	5%-15%

*Heater efficiencies were calculated using lower heating values (LHV) rather than higher heating values (HHV), as the energy associated with water condensation is not available for heating because the water is carried up and out of the stack in the vapor phase.

Emission Factors for Conventional Wood Heaters

- Current Studies Span More than an Order of Magnitude
- Multiple Variables – Characteristics of Heater, Characteristics of Chimney System (Draft), Tree Species Used for Fuel, Fuel Shape and Size, Fuel Moisture, Burn Rate, Starting Scenario, Excess Air, Etc.
- Differences in Measurement Methods and Differences between Laboratories

Particulate Emission Factors (5G Equivalent) for Aged Uncertified Heaters

Start scenario	Burn rate (kg/h) avg. ± s.d.	Fuel	n	Description	5G Emission factor (g/kg) avg. ± s.d.	Reference
Hot	Not provided, estimated as 2.4	Maple cordwood	3	Single heater, "typical light burning fires"	2.95 ± 2.05	Environment 2000 and Intertek 2000
	Not provided, estimates as 2.5	Spruce cordwood	3		18.2 ± 5.7	
Cold	2.60 ± 0.70 2.39 ± 0.422 1.81 ± 0.273 (same burn rates, end point defined differently	Oak cordwood	5	Average of 5 different conventional heaters, "middle range burning scenarios"	7.5 ± 8.7	Pitzman et al. 2006
Hot	2.70 ± 0.64	White gum cordwood	7	Single heater, burn rates controlled with air inlet	13.5 ± 4.1	Jordan and Seen 2003
	1.58 ± 0.70		5		30.6 ± 7.6	
	0.72 ± 0.20		5		33.6 ± 9.6	
Hot	4.60± 1.08	Mixed hardwood and oak cordwood	6	Single heater	4.35 ± 1.97	McDonald et al. 2000
Cold	4.04 ± 0.42	Oak cordwood	3	Single exempt heater	4.87 ± 0.91	McCrillis 2000

Secondary Organic Aerosols (SOA)

These Are (often overlooked) Contributors to Particle Emissions

- C1-C6 NMVOC – Indirect Contributor, by Interaction with Other Compounds and Providing Oxidizing Free Radicals
- C7-C15 – Direct Precursors of SOA
- Acidic Compounds – Increase SOA Formation

Pollutant	Representative emission factors (g/kg)
Major pollutant categories	
primary particles (5H equivalent)	17
methane	32
carbon monoxide	78
NMVOC (appx 1/3 not identified)	18
Selected C1-C6 NMVOC potentially providing free radicals for SOA	
ethyne (acetylene)	1.1
C2-C6 alkanes	1.7
C2-C6 alkenes	3.7
acetone	0.4
methanal (formaldehyde)	0.2
ethanal (acetaldehyde)	0.4
methanol	3.2
benzene	1.2
C7-C15 VOC potential reactants	
toluene	0.2
xylenes (o, m and p)	0.07
total gaseous PAH	0.05
total semi-volatile XAD catch	~2
Selected acid compounds in particles enhancing SOA formation	
acetic acid	0.4
propionic acid	0.2
lactic acid	0.5

SOA <10% of Primary Particles

- Semi-volatile XAD Catch Surrogate for C7-C15 VOC. Semi-volatile Compounds b.p. > 100º C
- VOC from RWC only 4.5% of Total VOC Nationwide (2002)
- Heating Season Emissions – Not Summer During Time of Maximum SOA Formation

Toxic Air Pollutants

- Focus Has Been on PM Due to Non-attainment
- Toxic Air Pollutants More Significant Human Health and Environmental Impacts
- Mostly Volatile and Semi-Volatile Organic Compounds (and Carbon Monoxide)
- Hundreds of Organic Compounds Possible – Partial Oxidation and Rearrangement of Complex Organic Compounds in Wood (Cellulose, Hemicelluloses, Lignin and Polymeric Resins)
- Nitrogen Oxides Due to Amino Acids in Biomass

Title III Hazardous Air Pollutants Present in NMVOC Emitted from Residential Wood Combustion

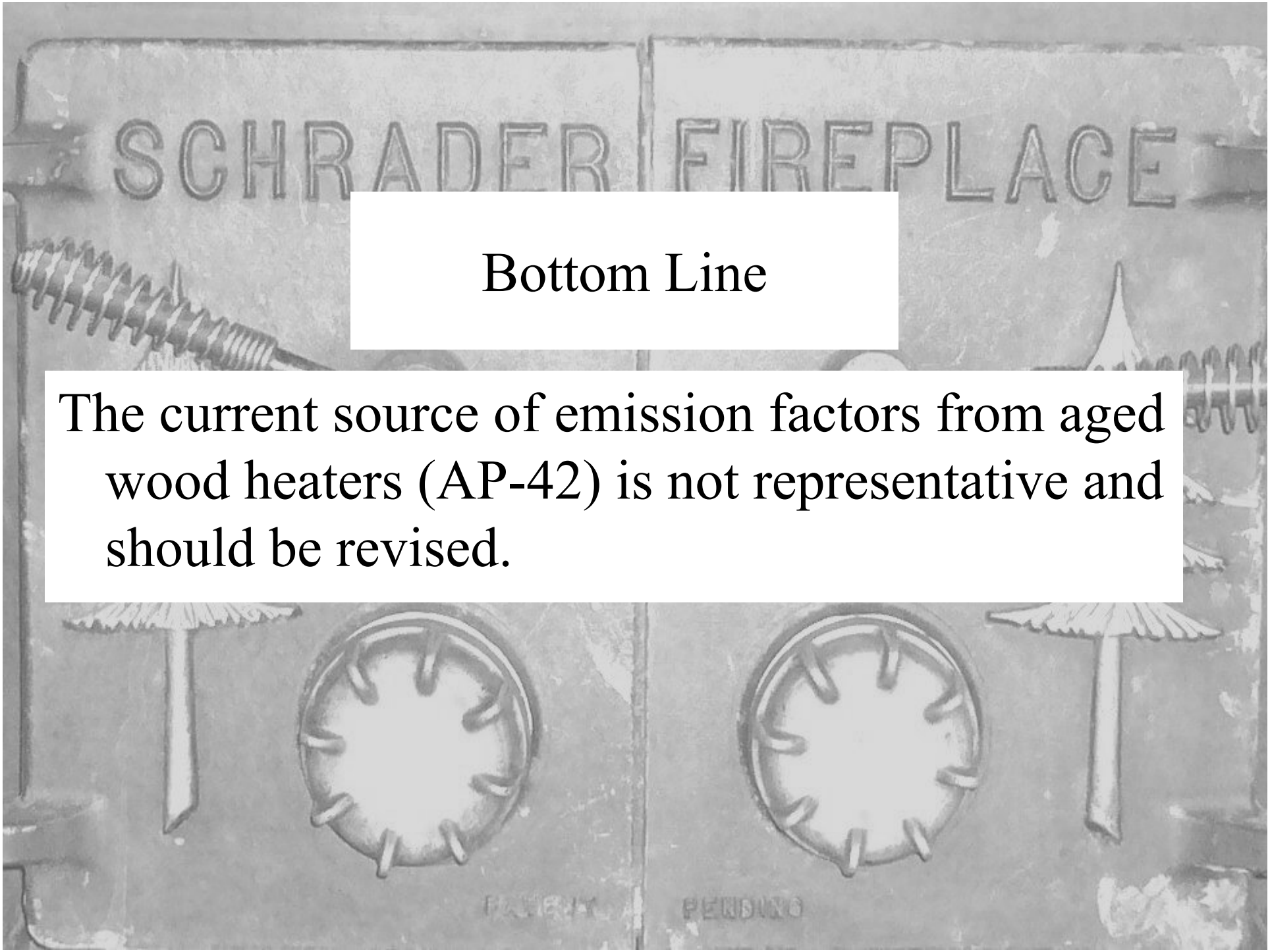
Pollutant	Emission Factor	Predominately vapor phase (V) or semi-volatile (SV)
Acetaldehyde	0.308 g/kg	V
Acetophenone	0.010 g/kg	SV
Acrolein	0.046 g/kg	V
Benzene	1.08 g/kg	V
Biphenyl	2.43 mg/kg	SV
1,3-Butadiene	0.197 g/kg	V
Catechol	0.331 g/kg	SV
o, m and p-Creosols	0.080 g/kg	SV
Dibenzofurans	1.9 mg/kg	SV
Ethyl benzene	ND	SV
Formaldehyde	0.727 g/kg	V
Hexachlorbenzene	13 ng/kg (certified non-cat heater)	SV

Title III Hazardous Air Pollutants Present in NMVOC Emitted from Residential Wood Combustion (Cont.)

Pollutant	Emission Factor	Predominately vapor phase (V) or semi-volatile (SV)
Hexane	0.012 g/kg (n-hexane)	V
Methanol	3.24 g/kg	V
Naphthalene	0.091 g/kg	SV
Phenol	0.147 g/kg	SV
Polychlorinated biphenyls	0.50 pg/kg (PCB_{TEQ})	SV
Propionaldehyde	0.096 g/kg	V
Styrene	0.117 g/kg	SV
2,3,7,8-Tetrachlordibenzo-p-dioxin	2.30 ng/kg ($Dioxin_{TEQ}$)	SV
Toluene	0.320 g/kg	SV
o, m and p-Xylenes	0.099 g/kg	SV
Polycylic Organic Matter	0.315 g/kg (16-PAH)	SV

Summary

- PM Emission Factors In AP-42 are Lower than the National Average and There Are Regional Differences
- Conventional Wood Heaters Have Degraded over 18+ years of Use Causing Counter Opposing Effects of Lower Emission Factors and Lower Efficiency
- PM Emission Factors Variable Among Heaters and Operating Parameters
- SOA Formation is Small, Compared to Primary Particle Emissions
- Toxic Air Pollutants are More Significant in Terms of Human Health and Environmental Impacts than Particles
- Benefit of The Replacement of Conventional Wood Heaters with Certified Heaters is Greater than Particulate Reduction Alone Due to the Greater Effectiveness of the Combustion of Vapors (Including Many Toxic Compounds) by Certified Heaters as Compared to Particles



Bottom Line

The current source of emission factors from aged wood heaters (AP-42) is not representative and should be revised.