Emission Factors for New Certified Residential Wood Heaters

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Presentation Outline

- Importance and Background
- Issues with:
  - Baseline Studies (AP-42)
  - Appliances in General
  - Standards and Reporting (NSPS)
- Recommendations

Importance of Certified Wood Heaters Emission Factors

- Emission Inventories – 4 Million Certified Wood Heaters
- Woodstove Change Outs Programs

Background of Certified Wood Heaters

- 705 models (March 12, 2008)
- Heaters = Freestanding Stoves + Fireplace Inserts
- Three appliance groups in NSPS (1988) :
  - Oregon “Grandfathered”
  - Phase 1
  - Phase 2 (July 1, 1992)
- Majority Phase 2 Cordwood
- Cordwood and Pellet

AP-42 Issues

- Particulate Data Prior to 1991
- NSPS Certification (Phase 2 after July 1, 1992)
- Reported as “5H Equivalent” (over prediction)
- Assumes Total PM is Equivalent to PM_{10} (no consideration for $PM_{2.5}$)
- Data from Field Sampling Methods (imperfect correlation to 5H equivalency)
- Studies Not Representatively Distributed (field studies from predominately cold climates only, upstate NY, VT, Crested Butte, CO, Klamath Falls, OR and a few in Portland, OR)
- Variability in Emissions among Models
- Emissions Have Become Lower with Newer Models

NSPS Issues

- Benchmark Method Not Predictive of Real-World Emissions
- Reports a Weighted Emission Rate (g/hr) Not an Emission Factor (g/kg)
- Hot Start Only (no start-up or kindling phase)
- Burn Rate Scenarios and Weighting Not Representative of Real-World
- Method 5H Equivalent Reporting (over prediction and high uncertainty)
- Softwood Only (no hardwood)
- Dimensional Lumber Cribs (reproducible but not representative and perhaps produce lower emissions)

Appliance Issues

- **Variability among Models More than a Factor of Ten**
  - -Low of 0.6 g/hr to emission limit of 7.5 g/hr

- **Heater Degradation – Increased Emissions**
  - -Both Cat. and Non-cat.
  - -Typical Catalyst Lifetime 5 Years
  - -Catalyst Bypass Moving Parts, Non-cat Baffle/Secondary Air System
  - -All Heaters Doors Warp, Gasket Deterioration

Newer Models Have Lower Emissions than Older Models

Time period	Woodstove type	Number of heaters	Average emission rate (g/h, 5H equivalent)	Percent reduction (%)
First five years of certification (1988-1992)	Non-catalytic	115	5.1	-
	Catalytic	110	2.9	-
Wood heaters certified or renewed between 2000 and 2005	Non-catalytic	137	4.1	19.6
	Catalytic	23	2.7	6.9

Standards and Reporting Issues

Particulate Size Distribution

- AP-42 – "PM-10 is defined as equivalent to total catch by EPA method 5H train"
- Certified non-cat. heater – 94% of PM is PM_{10} and 92% $PM_{2.5}$ (EPA study)
- Certified cat. heater – 88% of PM is PM_{10} and 80% $PM_{2.5}$ (EPA study)

Standards and Reporting Issues (cont.)

Particulate Sampling Methods

- In-Home Sampling Methods Converted to 5H Equivalency for AP-42, Two Exponential Equations, High Uncertainty
- NSPS Method 5H Over Predicts Real-World Emissions
- Uncertainty in converting Method 5G to Reporting Requirement of “5H Equivalent”, Method 5G used More Frequently than 5H

Comparison of 5H and 5G Emission Rates

5H (g/h)	Equivalent 5G (g/h) NSPS conversion*	Equivalent 5G (g/h) AP-42 conversion**
1	0.48	0.59
4.1 (cat. limit)	2.7	2.8
5	3.4	3.5
7.5 (non-cat. limit)	5.5	5.4
10	7.8	7.5
20	18.0	16.1

* $5H = (1.82) \times (5G)^{0.83}$

** $5H = (1.619) \times (5G)^{0.905}$

Emissions During Start-up

- Cold Start vs. Hot Start
- Emissions High During Kindling Phase and Initial Part of Fire
- Products of Incomplete Combustion High before Main (hot) Fire Achieved
- Catalyst By-passed
- Secondary Combustion not Initiated
- NSPS Uses Hot Start
- AP-42 Data from Cold Climates which Over Represents Hot-starts

HPBA 2004 National Survey

Length of use per occasion (hours)	Percent of total freestanding stoves owned (n = 539)
Never burned	10%
1 hour or less	3%
1 to 3 hours	12%
3 to 5 hours	15%
5 to 7 hours	16%
8 or more hours	44%

Cold vs. Hot Starts

- Heaters Used More than 8 Hours per Occasion
  - Possible Hot Start
- Heaters Used Less than 8 Hours per Occasion
  - Clearly Mostly Cold Start

Burn Rates

- Higher Burn Rates Have Dramatically Lower Emission Factors
- AP-42 Data are from Predominantly Cold Climates Causing High Burn Rates to be Over Represented
- NSPS Burn Rate Categories and Weighting Scheme for Emissions Based on Burn Rates Are Seriously Flawed. "Apples and Oranges" between In-Home Data Base on which is was based and Method 28 Procedures

In-home data base	Burn over at 100º F
Example Method 28 non-cat. heater run, high burn rate (3.7 kg/h)	Temperature at end of burn 739º F
Example Method 28 non-cat. heater run, medium high burn rate (1.6 g/h)	Temperature at end of burn 418º F

Tree Species

- Hardwood and Softwood Burn Differently
- NSPS Uses Softwood (Douglas fir) Only
- Hardwood Dominate in East and Midwest
- Hardwood and Softwood both Common in West

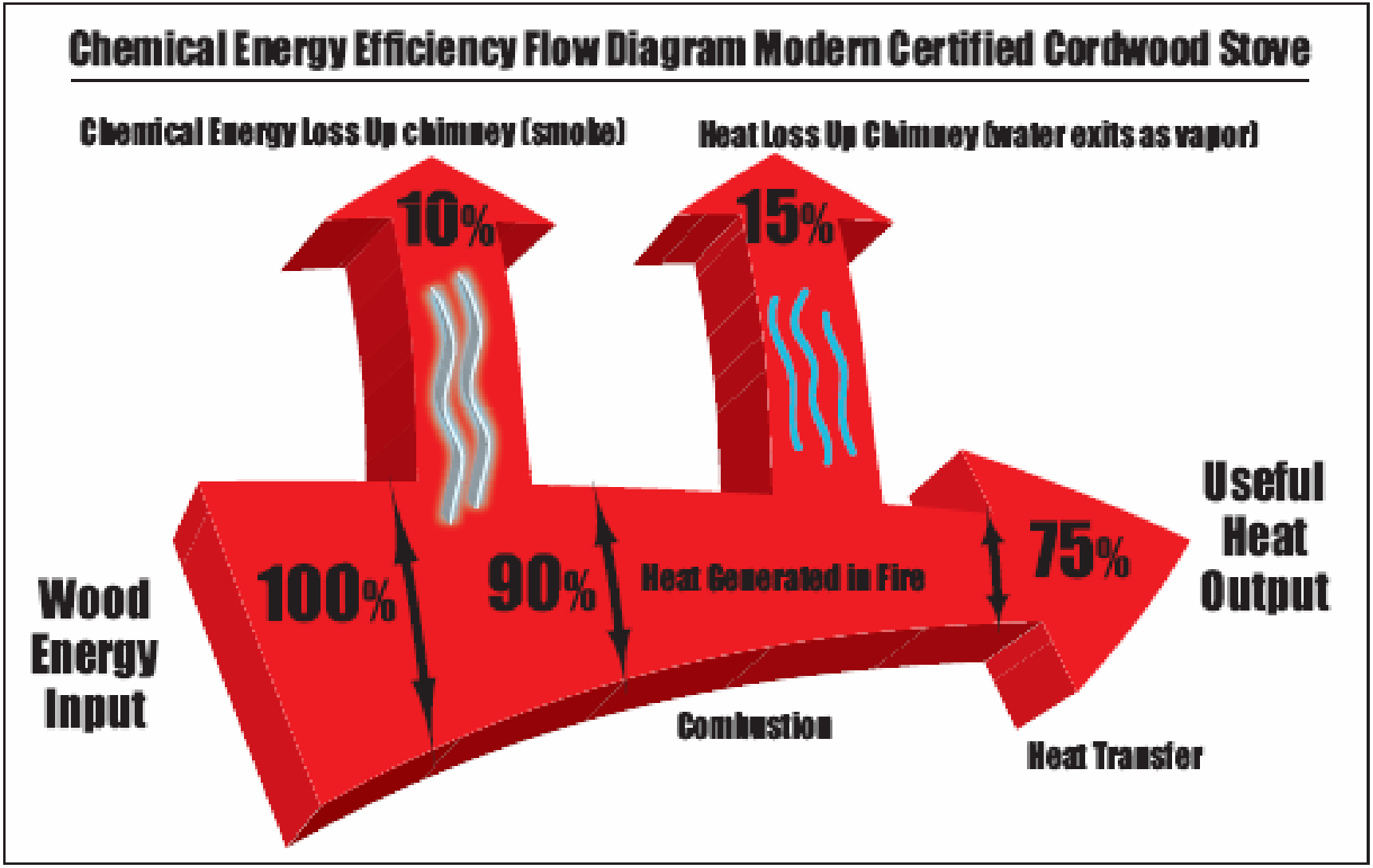
Hardwood	Softwood
Higher Density	Lower Density
Higher Energy per Unit Volume	Lower Energy per Unit Volume
Lower Energy per Unit Mass	Higher Energy per Unit Mass
Higher Moisture Content	Lower Moisture Content

Efficiency

Higher Efficiency Means an Effective Lower Emission Factor as Less Wood is Used to Provide the Same Heat Output

Cordwood Heater Type	AP-42 Efficiency (Lower Heating Value)	NSPS Efficiency (? Heating Value)	*OMNI* Efficiency* (Lower Heating Value)
Conventional	54%	-	54%
Non-catalytic	68%	63%	63%
Catalytic	68%	72%	63%

*Based on best professional judgment after review of all significant efficiency-related reports and publications


Chemical Energy Efficiency Flow Diagram Modern Certified Cordwood Stove
Chemical Energy Loss Up chimney (smoke)
Heat Loss Up Chimney (water exits as vapor)
10%
15%
Wood Energy Input
100%
90%
Heat Generated in Fire
75%
Useful Heat Output
Combustion
Heat Transfer

5G Emission Factors for Modern Certified Wood Heaters

- 5G Most Representative and Highest Precession Among Methods
- Credible Emission Factors Span Almost Two Orders of Magnitude

Start scenario	Burn rate (kg/h) † Avg. ± S.D.	Fuel	N	Description	5G emission factor (g/kg) Avg. ± S.D.	Reference
Hot	2.05 ± 1.35	Doug. fir dl	12	certified non-cat	3.41 ± 2.38	Tiegs & Houck 2000
Hot	0.75 ± 0.03	Doug. fir dl	3	certification tests on 26 non-cat. models	2.32 ± 0.50	OMNI-Test Lab. 3/06 to 1/08 tests
	0.99 ± 0.13		49		3.23 ± 2.32	
	1.50 ± 0.17		33		1.86 ± 1.19	
	2.51 ± 0.44		26		1.55 ± 0.84	

5G Emission Factors for Modern Certified Wood Heaters (Cont.)

Start scenario	Burn rate	Fuel	N	Description	5G E.F.	Reference
Cold	not provided, estimated as 1.1 to 2.2	one run oak cw, one run Doug. fir cw	2	certified cat.	1.7 (avg.)	Fine, et. al, 2004
Hot	3.52 ± 0.71	white gum cw	5	high tech. Australian stove similar in design to a U.S. certified heater	2.86 ± 1.60	Jordan & Seen, 2005
	2.15 ± 0.22		3		12.9 ± 7.3	
	1.42 ± 0.44		5		35.7 ± 9.6	

5G Emission Factors for Modern Certified Wood Heaters (Cont.)

Start scenario	Burn rate	Fuel	N	Desc.	5G E.F.	Reference
Hot	not provided, estimated as 2.4	3 runs spruce cw, 3 runs maple cw	6	certified non-cat	0.64 ± 0.17	Environment Canada, 2000, Intertek 2000
Cold	not provided, estimated as 2.3	oak cw	3	certified non-cat	8.2 (avg. estimated from data in publication)	Gullett et al., 2003, Crouch and Houck 2004
Cold (one run was hot start)	1.97 ± 0.68	oak cw	11	certified cat.	7.73 ± 5.95	U.S. EPA, 2000
	1.94 ± 0.99		7	certified non-cat	22.9 ± 10.7	

Recommendations:

- Revise Certification Method to Provide Emission Factors Representative of Real-World Usage and to Allow for Data to be Related to Different Regions of the Country with Different Climates and Sociodemographic Makeups

Specific Recommendations

- 5-G-like Dilution Tunnel with Tunnel and Filter Temperature Cooled to 65ºF
- Adjustment Factors for Other Temperatures Developed with an Independent Study so that Regional Emission Factors Can Be Estimated
- Emission Factors for Different Burn Rates Reported Separately to Accommodate Regional Differences Unlike the Single Weighted Value Now Reported
- Burn Rates for Different Regions Assessed with a Survey, Burn Rates Defined in the Certification Method Analogously as the Survey
- Certification Method Should Include Both Hot and Cold Starts
- Both Hardwood and Softwood Fuel Should be Used with an Option for Manufactured Biofuels

Specific Recommendations (Cont.)

- Emissions Reported as Emission Factors (g/kg) rather than Emission Rates (g/h)
- Efficiency Measurement and an Efficiency Rating as Part of the Certification Test
- An Independent Study of Typical Size Distribution of Particulate Emissions to Provide an Adjustment Factor to apply to PM for PM_{10} and $PM_{2.5}$ Emission Factors
- An Independent Study Relating Dimensional Lumber (Reproducible) Emission Factors to Real-World Cordwood Emission Factors to Provide Correction Factors
- An Independent Study of Real World Wood Moisture. Certification at Different Moisture Levels for Different Regions and/or Using Hardwood and Softwood at Different Moisture Levels May Be Appropriate

The Bottom Line

- The NSPS Needs Revision to Make Standards More Predictive of “Real-World” Emissions

As a Result:

- Emission Inventories Would Benefit by Providing a Realistic Emission Factor
- Manufactures Will Make Appliances which Reduce Emissions From Realistic Fires