Can Residential Biomass Pellet Stoves Meet a Significant Portion of Minnesota's Residential Heating Needs?

A Preliminary Investigation

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INTRODUCTION

Volatility in prices as well as environmental concerns of fossil fuels has resulted in increased attention to alternative fuels recently. This paper considers two issues that are likely to impact the extent to which biomass is able to displace fossil fuels within the residential home heating market: emissions and costs of pellet stoves. For home heating, wood furnaces, outdoor wood boilers, fireplaces and wood stoves are not considered viable for widespread adoption, because of their high emission rates. The widespread adoption of wood burning equipment could result in severe air pollution issues, such as occurred during the infamous "London fog" episodes of 1952 which resulted in thousands of premature deaths. However, biomass pellet stoves are often presented as a clean alternative to fireplaces and firewood stoves. Additionally, fireplaces and wood stoves only provide space heating and do not replace a whole house furnace. This paper presents existing data of relevance to considering the potential for increased utilization of biomass pellet stoves in the residential sector in Minnesota. Particular attention is paid to emissions, initial costs and operational considerations. Further information and analysis is necessary before reaching any conclusions, but it is hoped that the below information will represent a starting point for assessment of the potential of pellet stoves for widespread use.

FUELWOOD USERS IN MINNESOTA

In 2003 20.7% of households in Minnesota burned wood fuel as a heating source.[1] The study showed that the largest volume of fuelwood is consumed in rural areas, and it is used as primary or secondary source of heat.

Six categories of wood burning facilities and seven combination categories of two or more types of wood burning facilities are shown in Table 1. It is unclear where pellet stoves would fit in these categories, which were created before pellet stoves came into widespread popularity. There has been a substantial decrease in the proportion of wood stoves and wood furnaces, and an increase in regular and modified fireplace units, reflecting a strong shift toward burning wood for pleasure.

Table 1: Percent of Volume Burned by Type of Wood-burning Facility

Type of Wood-Burning Facility	Percent of Total		
	1988-1989	1995-1996	2002-2003
Wood Stove	46	44	15.4
Fireplace	17	9	20.9
Modified Fireplace	2	11	9.4
Wood Furnace	26	27	16.1
Wood Boiler	-	-	14.9
Fire Pit or Ring	-	-	0.5
Wood Stove/Fireplace	2	4	2.9
Wood Stove/Modified Fireplace	1	-	2.1
Wood Stove/Wood Furnace	-	3	2.0
Wood Stove or Fireplace/Wood Boiler	-	-	1.9
Fireplace/Wood Furnace	6	-	8.8
Fireplace/Modified Fireplace	-	-	1.4
Fireplace/Fire Pit	-	-	3.8
Total	100	100	100

Source: *Residential Fuelwood Assessment, State of Minnesota.*
2002 – 2003 Heating Season. Minnesota Department of Natural Resources.

The Minnesota's Forest Resources Report in 2006 indicates that Minnesota has become a large net importer of wood over the last several years, as mill demand and stumpage prices have increased, and offerings of timber from federal lands have been reduced. Mills have increasingly looked outside of Minnesota's borders in order to meet their raw material needs, especially for aspen and maple.

EMISSIONS

Wood stoves are a significant source of total particulate matter (PM) emissions in the U.S. and Minnesota (Appendix A). PM is responsible for a wide range of health impacts, including premature mortality. In addition to PM, the measurable emissions from commercial residential boilers fired with wood logs and wood pellets according to one study comprise carbon monoxide (CO), carbon dioxide (CO2), oxygen (O2), total organic

[1] Residential Fuelwood Assessment, State of Minnesota. 2002 – 2003 Heating Season. Minnesota Department of Natural Resources.

carbons (TOC), nitrogen oxides (NOx), polycyclic aromatic hydrocarbons (PAH), and 33 volatile organic compounds (VOC). L.S. Johansson et al. (Atmospheric Environment 38 (2004) 4183–4195) measured these emissions and compared them in the following table.

Table 2: Emissions estimates from various types of wood burners

CO_2, CO, TOC, particles and NO_x emissions

	Case	CO_2 (%)	CO	TOC	CH_4	NMVOC	PAH	Particles	Particles (1/MJ)	NO_x
Old-type wood boilers	a	8.4	4100	660	—	—	—	87	—	65
	b	4.7	5200	1300	—	—	—	350	—	72
	c	6.8	4800	1100	610	270	14	89	17×10^{13}	71
	d	8.3	5900	1500	670	430	13	103	3.9×10^{13}	67
	e	6.9	16400	4800	4800	2000	64	2200	200×10^{13}	28
	f	5.6	8200	3000	—	—	15	—	2.8×10^{13}	64
Modern wood boilers	g	12.2	707	14	1	1.9	0.21	27	4.5×10^{13}	125
	h	11.5	507	33	0.8	1.3	0.14	25	2.4×10^{13}	111
	i	5.1	3781	690	73	43	3.0	89	8.5×10^{13}	101
	j	10.3	1300	89	14	14	1.1	32	3.6×10^{13}	72
	k	9.1	770	63	9.2	7.8	0.44	23	6.4×10^{13}	81
	l	10.2	880	28	4.3	3.9	0.33	18	2.0×10^{13}	60
Pellet burners and boilers	m	9.5	36	4	0.76	1.2	0.32	22	1.4×10^{13}	68
	n	6.0	350	78	2.7	3.3	0.26	—	1.7×10^{13}	71
	o	4.8	290	31	—	—	0.12	28	1.3×10^{13}	68
	p	3.7	960	250	14	23	0.27	65	7.4×10^{13}	66
	q	13.0	120	3	<0.55	0.95	0.06	16	0.8×10^{13}	70
	r	9.1	990	60	5.3	20	8.5	64	1.6×10^{13}	64
	s	8.6	120	10	<0.84	1.7	0.55	15	0.8×10^{13}	67
	t	11.7	30	1	—	—	—	13	—	—
	u	6.8	380	2	—	—	—	12	0.1×10^{13}	62
	v	3.8	1100	92	—	—	—	51	0.2×10^{13}	62
	w	10.6	730	42	1.8	4.8	1.1	—	—	180
Oil	x	12.2	2	1	0.46	0.64	0.17	12	0.01×10^{13}	37
	y	10.6	9	32	0.52	0.38	0.006	6	0.1×10^{13}	41

The measurement cases are explained in Appendix B. Emissions are in mg per MJ, where not other units (%, or number of particles per MJ). ***Source:*** *L.S. Johansson et al. / Atmospheric Environment 38 (2004) 4183–4195*

Johansson concluded that old-type wood boilers (water-cooled boiler, up-draught combustion) led to more emissions of particles and unoxidised compounds than modern wood boilers (ceramic wood boiler, downdraught combustion, and normally connected to storage tanks) and pellet burners. It was noted that the pellet and oil burners were more equal in performance than the wood boilers. The lowest emissions from wood boilers were as low as from pellet burners and were obtained from combustion of dry wood logs in modern boilers connected to storage tanks.

The highest emissions of unoxidised compounds occurred at the highest excess air ratio, and oxygen was not the limiting parameter for poor combustion. Instead, high excess air can be suspected to cool the combustion chamber, resulting in high CO emissions. They also observed very large differences in emissions between old-type and modern biofuel boilers. In particular, high emissions of the greenhouse gas methane were recorded for old-type wood boilers. However, Johansson suggests that the substitution of an old-type wood boiler with a modern wood boiler attached to a storage tank or with a pellet boiler, would reduce methane emissions by 8 to 9000 times and the efficiency would increase; and that most emissions can be reduced by charging small (in relation to the combustion chamber) batches of wood.

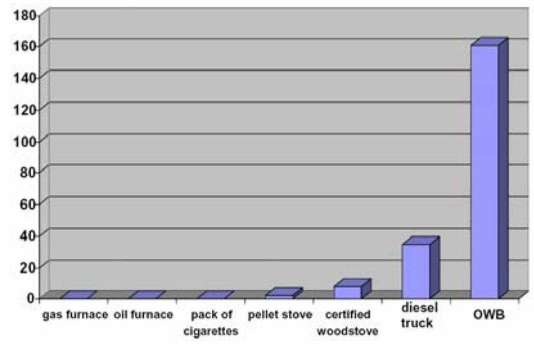
The *Low Emissions From Wood Burning In An Ecolabelled Residential Boiler* study indicates that large CO emissions are not necessarily linked to large emissions of organic compounds; and that relative to benzene, the concentrations of many of the aromatic compounds studied were higher in the glowing combustion phase, than in the flaming combustion phase.

A paper by Valenti and Clayton for EPA in 1998 regarding Outdoor Wood-Burnings indicates that these devices can emit between four and twenty times higher levels of fine particulate matter concentrations than certified wood stoves. Similarly, the authors concluded that OWBs emit between 0.5 and 196 times higher levels of PAHs. The Connecticut Department of Environmental Protection, according to NESCAUM's[2], completed a comparison of homes heated with natural gas, oil, and OWBs, and concluded that emissions from one OWB

[2] L. Rector et al. / NESCAUM Assessment of Outdoor Wood-fired Boilers (2006)

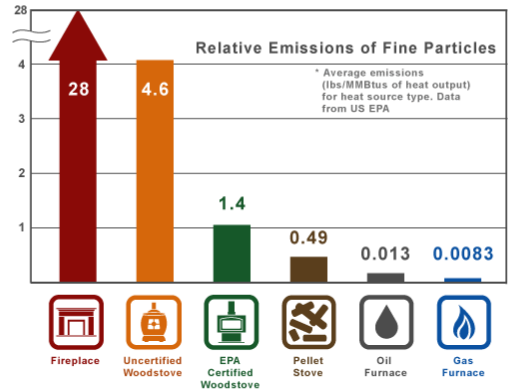
are equivalent to emissions from 4 non-certified wood stoves, 18 certified wood stoves, 205 oil furnaces or 3,000 to 8,000 natural gas furnaces. To put these emissions into perspective, one OWB can emit as much PM as four heavy duty diesel trucks. NESCAUM also reports that the operating efficiencies of OWBs are extremely low (OWBs heating efficiencies range from 28 to 55% while for woodstove efficiencies range from 60 to 80%).

Graph 1. PM Emission Comparison (g/hr)



Source: *Assessment of Outdoor Wood-fired Boilers*

Graph 2. Relative Emissions of Fine Particles (PM2.5)



Source: *Fuel comparison, EPA*

Valenti and Clayton concluded from table 3 that it is evident that all wood-burning home heating combustion equipment, including wood stoves, boilers, or fireplaces, has much higher particulate matter emissions than gas or oil fired home heating furnaces. This can also be seen in table 2.

Table 3: Overall comparison of wood, oil and natural gas combustion emissions (Valenti and Clayton)

Combustion Device	M5H Particulate mg/MJ input	PAHs mg/MJ input	Mutagenicity[b] krev/MJ input
Natural gas furnace			
Conventional	0.44	0.000124	0.007[c]
High Efficiency	0.43	0.000028	ND[c,d]
Oil furnace			
Retention head	3.2	—[e]	6
Conventional	15.1	—	20
Conventional wood stove	786	40	600
Certified wood stove			
Non-catalytic	383	28	100
Catalytic	425	24	—
Pellet (certified)	110	0.082	—
Pellet (exempt)	176	0.014	—
Fireplace 907 41	—		
Wood furnace			
Cordwood - Swedish lab tests			
Intermittent firing	1862	—	—
Continuous firing	182	15.3	148[f]
Chips (dry)	45.3	<0.02	0.48[f]
US EPA lab tests			
Furnace A[g]	*1048*	*15.6*	—
Furnace B	*681*	*16.1*	—

[a] All data except that in italics taken from: McCrillis, R.C., "Review and Analysis of Emissions Data for Residential Wood-Fired Central Furnaces," In Proceedings of the 88th Annual Meeting of the AWMA, Air & Waste Management Association, San Antonio, TX, June 1995, Paper No. 95-RP137.04.
[b] Microsuspension assay, TA98+S9 unless otherwise noted.
[c] Ames plate incorporation assay, TA98+S9.
[d] ND means not detected.
[e] No data available for this parameter.
[f] Ames plate incorporation assay, TA100+S9.
[g] Only includes comparison data.

Houck and Tiegs, in the Residential Wood Combustion Technology Review, report that Masonry heaters produce low particulate emissions through high-temperature, short-duration combustion of cordwood that transfers heat to a high masonry mass. The masonry mass radiates heat after the fire is out. Masonry heaters are exempt from certification and few are in use due to their high cost.

REGULATIONS

The internal design of wood stoves has changed entirely since the EPA issued standards of performance for new wood stoves in 1988. EPA's mandatory smoke emission limit for wood stoves is 7.5 grams of smoke per hour (g/h) for non-catalytic stoves, and 4.1 g/h for catalytic stoves[3].

The Residential Wood Combustion Technology Review indicates that most wood stoves are designed out of necessity to pass the EPA certification test. The EPA certification procedure implies a successful low burn rate condition and coal bed preparation particularly challenging, which do not simulate the way that a stove is used in a home. Consequently, emission results obtained from certification tests are only roughly predictive of how a wood stove will perform under actual in-home use. However, the general perception is that stoves that show low emissions in the certification testing will also do well in homes. On the other hand, the Assessment of Outdoor Wood-fired Boilers by L. Rector et al., informs that there are no federal standards for OWB's.

Due to indoor woodstoves manufactured prior to 1990 contained inadequate combustion design or lacked emissions controls, and given that there is a 2% annual change-out rate of pre-EPA-certified woodstoves, 80% of the current woodstove fleet was manufactured without efficient combustion designs or pollution control devices, according to Johnson PRS[4]. Johnson also makes reference to a study that suggests that about 12 million of woodstoves and fireplaces in the U.S are used for either primary (~20%) or supplemental (~80%) heating.

COSTS / OPERATIONAL CONSIDERATIONS

According to the Encyclopedia of Alternative Energy and Sustainable Living, pellet stoves typically range in price from $1,700 to $3,300, depending on the quality and features of the appliance. Installation costs are fairly low, usually from $350 to $550, because a pellet stove does not require a chimney but only a straightforward 3"-4" venting system. Many stoves can be vented horizontally, directly through an outside wall, and no special materials on the surrounding walls are required. Most current pellet stoves on the market are not whole-house furnaces, but rather room heaters that can offset heating needs in occupied rooms allowing homeowners to lower the thermostat in other rooms. Thus it should be noted that these stoves do not obviate the need or capital cost expenditures for a whole-house furnace when used in a typical residential setting.

Also it is important to consider that a pellet stove needs electricity to run its exhaust fan, circulating blower, and auger motor. Not only does this add over $100 per year in power usage for the average pellet burner, but replacement expenses must be factored in as well, as these motors wear out and eventually break down. Conventional wood stoves may lack some of the convenience features of pellet stoves but they run on ordinary fuel wood, which will always be much cheaper than pellets.

Cost and availability varies seasonally and from region to region. Local stores such as Home Depot, Wal-mart, Lowes, Ace, Agway, etc. may carry wood pellets. Prices per bag vary greatly in the $5 to $10 range, depending on location and grade[5]. "Poor fuel quality yields high emissions also from new boilers"[6]. It is important to keep in mind that wood is a sustainable fuel only when the harvesting is done in a sustainable manner.

NESCAUM (Rector, L. et al. / Asessment of Outdoor Wood-fired Boilers, 2006) has identified twenty-seven manufacturers of OWBs, eight of them are located in Minnesota. Information contented in that study, indicates that the total cost to purchase and install the smallest OWB can range from $8,000-$10,000 ($5,000 of which belong to the OWB itself), with costs increasing with the size of the unit. Installation usually includes laying a concrete foundation, putting in a power source, installing underground piping from the unit to the house, and other additional piping. New construction uses OWBs as primary furnaces and OWBs are also replacing conventional certified indoor wood stoves and oil or gas-fired furnaces. See EPA website for a list of EPA certified stoves (epa_certified_stoves.pdf)

CONCLUSIONS

[3] http://www.epa.gov/woodstoves/technical.html
[4] Johnson PRS, 2006 / In press – Journal of Human and Ecological Risk Assessment.
[5] The Encyclopedia of Alternative Energy and Sustainable Living
[6] L.S. Johansson et al. / Atmospheric Environment 38 (2004) 4183–4195

A review of the literature suggests that biomass pellet stoves can have significantly less emissions than older outdoor wood boilers and even less than certified woodstoves but significantly higher than natural gas furnaces (the predominate heating fuel in Minnesota). Because emissions of PM for biomass pellet stoves are still higher than natural gas, large scale adoption of biomass pellet stoves would likely still result in a net increase of PM emissions. Since current pellet stoves on the market can only provide space heating needs, they can not replace whole-house furnaces. However pellet stoves, could reduce overall PM emissions if they replace existing wood stoves or fireplaces due to their lower PM emissions. When compared with other wood burning space heating alternatives, pellet stoves should have higher operational costs. The economic data presented indicates the operational cost of a pellet stove will be higher than a wood stove or fireplace due to electrical motors and higher cost of fuel. Further information and analysis is necessary before reaching any conclusions, but it is hoped that this information will represent a starting point for assessment of the potential of pellet stoves for widespread use.

Appendix A: Particulate Matter emitting sources

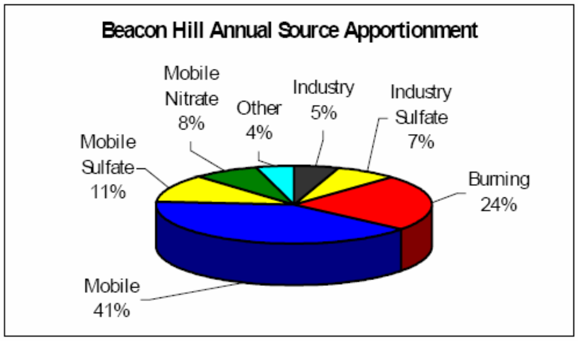
Data from the Puget Sound Clean Air Agency[7] indicate that the major PM2.5 emitting sources include industry, indoor burning, outdoor burning, on-road mobile, off-road mobile and other sources (e.g., dust). According to this study, there is a seasonal difference among the emission contributions of the various source categories. Overall, 10,647 tons/90 days were emitted during winter months, predominantly by residential wood burning; and 6,225 tons/90 days during summer months, predominantly by open burning and mobile sources (see table 1 for details).

Table 1

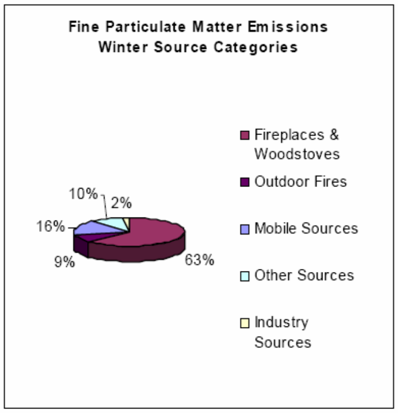
Source	% Contribution to Annual Primary $PM_{2.5}$ Emissions	% Contribution to Winter Primary $PM_{2.5}$ Emissions	% Contribution to Summer Primary $PM_{2.5}$ Emissions	Tons of Emissions Per Year
Industry	3%	2%	4%	1,036
Indoor Burning	38%	63%	2%	12,966
Outdoor Burning	23%	9%	39%	7,798
On-road Mobile	12%	9%	17%	4,128
Off-road Mobile	12%	7%	22%	4,033
Other (e.g., dust)	12%	10%	16%	4,109
TOTAL	**100%**	**100%**	**100%**	**34,070**

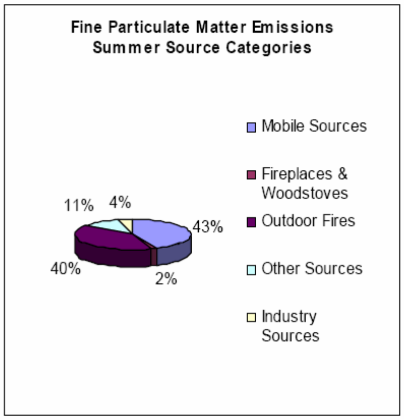
Source: Final Report of the PM2.5 Stakeholder Group. Puget Sound Clean Air Agency

In addition, Ross, B., and Duffy M. indicate that PM2.5 can also be formed in the atmosphere from sulfur oxides (SOx) and nitrogen oxides (NOx); being sulfates about 21% of the annual PM2.5 and nitrates about 10%. They state that these percentages increase in the summer months (sulfates 28%, nitrates 13%). Considering several uncertainties, and following the Beacon Hill model, the source apportionment of the annual PM2.5 can be graphed as follows:



The following data were obtained from the Next Ten Years Fact Sheet: Fine Particulate Matter, developed by the Puget Sound Clean Air Agency (pscleanair.org). The graphs below reinforce the seasonal differences in PM2.5 sources in the Puget Sound area, where mobile sources, are important year-round sources.

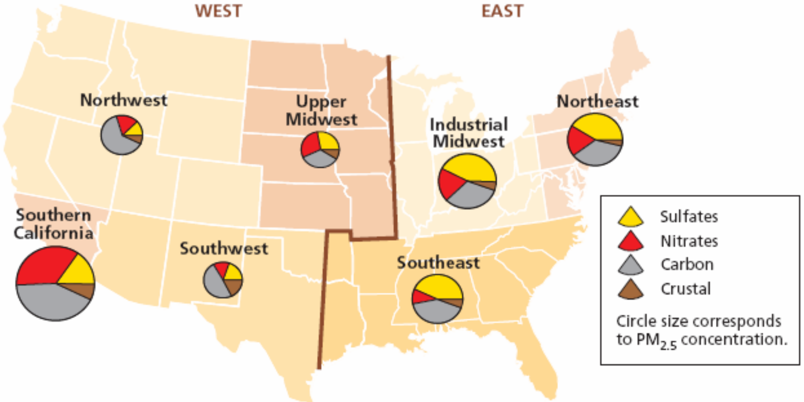




[7] Ross, B., Duffy, M., 1999. Final Report of the PM2.5 Stakeholder Group. Puget Sound Clean Air Agency

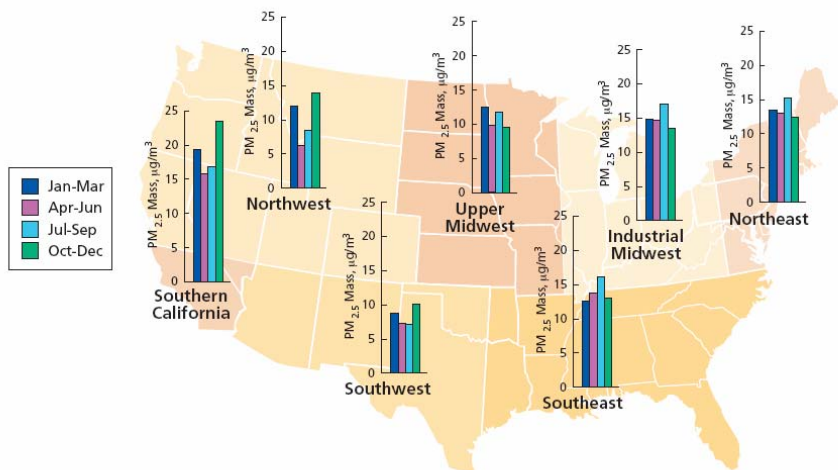
The Particle Pollution Report edited in 2004 by the EPA[8], shows the PM variation within the U.S. through the following figures:

Figure 2. Average $PM_{2.5}$ composition in urban areas by region, 2003.

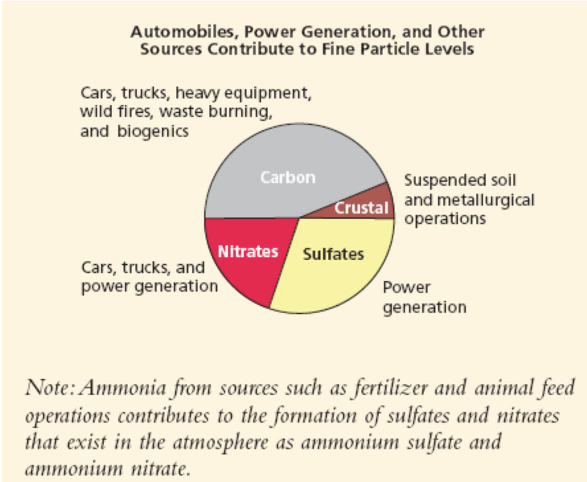


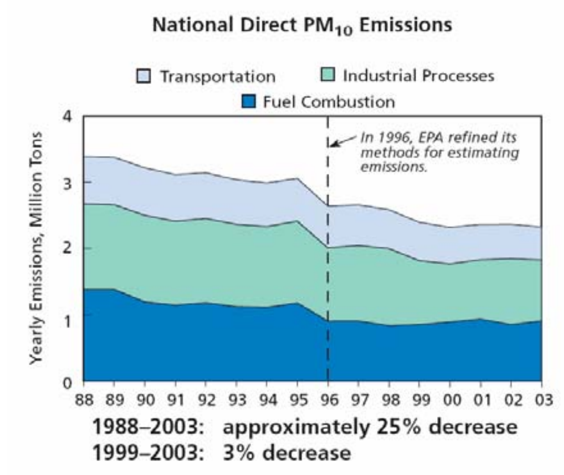
"Sulfates" refers to ammonium sulfate and "nitrates" refers to ammonium nitrate.
"Carbon" refers to total carbonaceous mass, which is the sum of estimated organic carbon mass and elemental carbon.
"Crustal" is estimated using the IMPROVE equation for fine soil at vista.cira.colostate.edu/improve.

Figure 3. Seasonal averages of $PM_{2.5}$ concentration by region, 1999–2003.



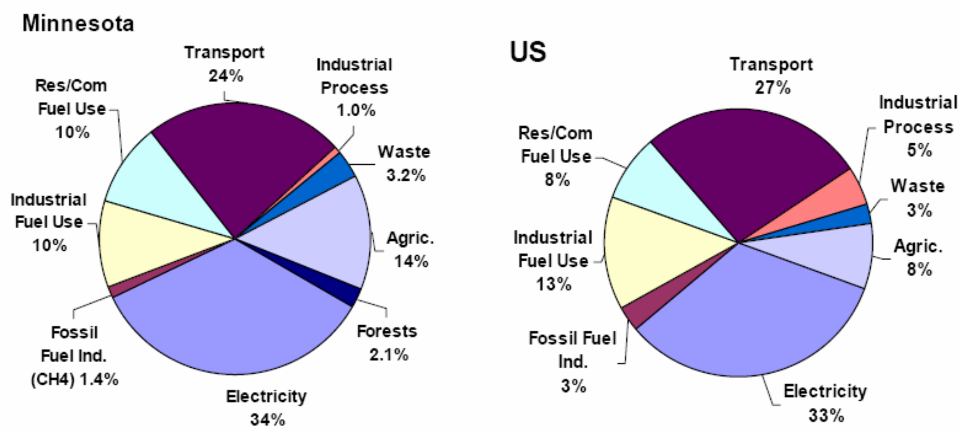
8 Ref: EPA 454-R-04-002





The Final Minnesota Greenhouse Gas Inventory and Reference Case Projections 1990-2025[9] provides the following charts:

Figure ES-2. Gross GHG Emissions by Sector, 2005: Minnesota and US



Note: At a national level, forests act as a net sink of CO_2; therefore, they do not show up in the above graph of gross US emissions sources.

[9] Strait, R., Dougherty, B., Mullen, M., Roe, S., and Lindquist, S. FINAL Minnesota Greenhouse Gas Inventory Inventory and Reference Case Projections 1990-2025. Center for Climate Strategies, March 2008.

APPENDIX B: Further information from Table 2

Measurement cases used in Table 2

Boiler/burner		Operation conditions, Power (kW)	Fuel type	Case
Old-type wood boilers	Water-cooled multi-fuel boiler, up-draught combustion	Heat storage tank, 10 (100%)	Dry wood	a
		Large wood batches, 6	Dry wood	b
		Small wood batches, 6	Dry wood	c
	Water-cooled wood boiler, up-draught combustion	Heat storage tank, 24 (100%)	Dry wood	d
		Large wood batches, 7	Dry wood	e
		Small wood batches, 6	Dry wood	f
Modern wood boilers	Ceramic wood boiler with flue gas fan, down-draught combustion	Heat storage tank, 34 (100%)	Dry wood	g
		Heat storage tank, 30 (100%)	26% moisture	h
		Heat storage tank, 12 (100%)	38% moisture	i
	Ceramic wood boiler with natural draught, down-draught combustion	Heat storage tank, 28 (100%)	Dry wood	j
		Heat storage tank, 24 (100%)	26% moisture	k
	Ceramic wood boiler with flue gas fan, down-draught combustion	Heat storage tank, 23 (100%)	Briquettes	l
Pellet burners and boilers	Pellet burner with pilot flame	Nominal, 11 (100% load)	Wood pellets	m
		Intermittent, 6	Wood pellets	n
		Intermittent, 6 high draught	Wood pellets	o
		Intermittent, 3	Wood pellets	p
	Pellet burner with electrical ignition	Nominal, 22 (100% load)	Wood pellets	q
		Intermittent, 6	Wood pellets	r
		Intermittent, 3	Wood pellets	s
	Pellet boiler	Nominal, 16 (100% load)	Wood pellets	t
		Intermittent, 6	Wood pellets	u
		Intermittent, 3	Wood pellets	v
	Pellet burner with electrical ignition	Intermittent, 6	Bark pellets	w
Oil burners	Environmental branded oil boiler	Nominal, 18 (100% load)	Oil	x
	Multi-fuel boiler with oil burner	Nominal, 21 (100% load)	Oil	y

Source: *L.S. Johansson et al. / Atmospheric Environment 38 (2004) 4183–4195*

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