Air Quality Considerations in Designing Biomass-Fueled Heating Plants

Chris Schilling, Ph.D.
C. J. Strosacker Professor and Chair of Engineering
Saginaw Valley State University
University Center, Michigan

Corn Marketing Program of Michigan
Michigan Corn Growers Association

Saginaw Bay Watershed Initiative Network

U.S.D.A.

Michigan Agriculture Department

U.S. Department of Labor

Michigan Soybean Promotion Committee

Michigan Department of Labor & Economic Growth

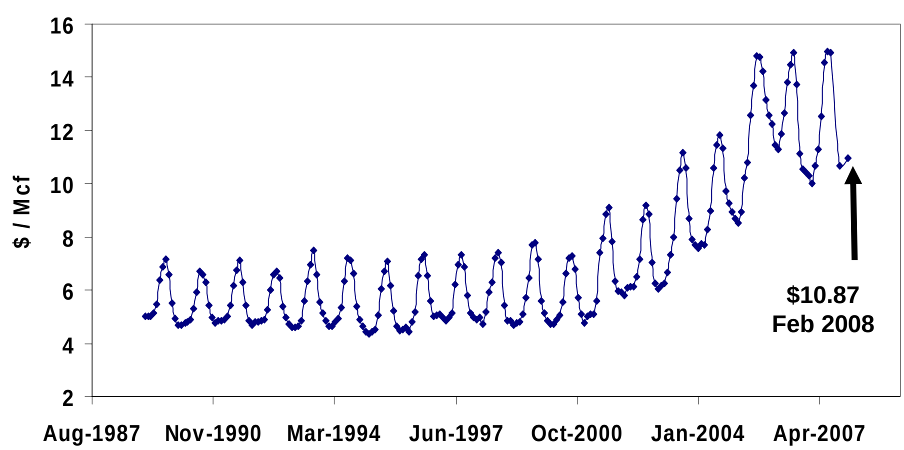
Outline

1. Brief review of energy prices

2. Pollution chemistry basics

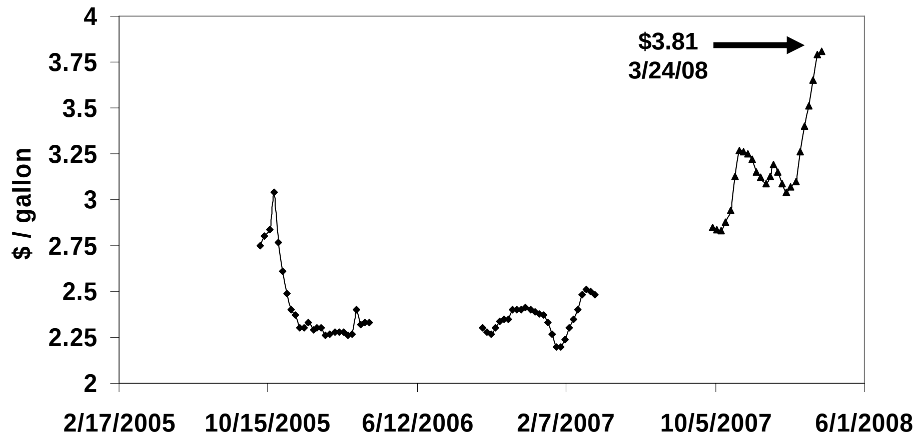
3. Basics of air quality permitting

Michigan Residential Natural Gas Prices



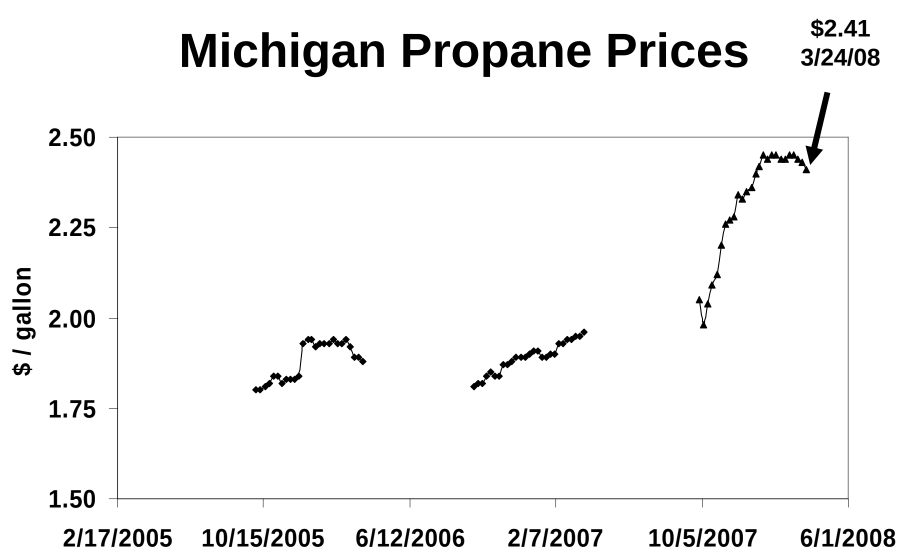
Source: U.S. Department of Energy

Michigan Heating Oil Prices



Source: MI Public Service Commission

Michigan Propane Prices



Source: MI Public Service Commission

On average…..

Heating a 2000 ft^2 Michigan home requires 85.3 million Btus each winter.

What's the annual heating bill?

$$A = \frac{B\ C}{D\ E} = \text{energy bill}$$

85.3

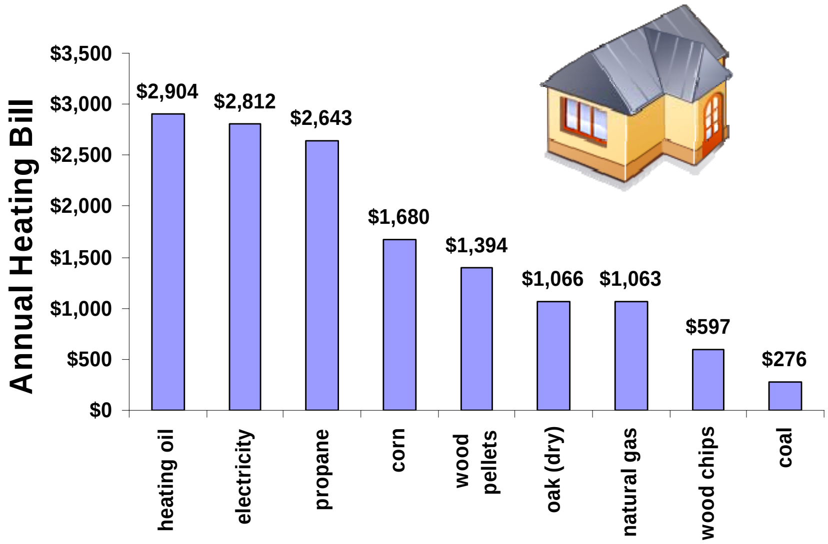
B = energy demand (MBtu / yr)

C = price of energy source

D = heat content of energy source

E = furnace efficiency

Cost to heat a 2000 ft^2 Michigan home



The conundrum

Biomass fuel costs are low….

…but capital & maintenance costs are high…

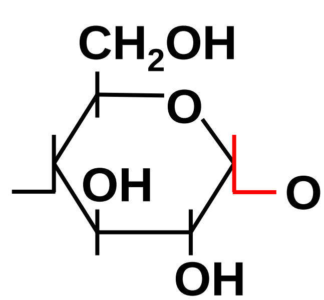
…and air pollution is a bigger problem…

…turn-key methods of reducing air pollution are proven but add cost.

Biomass Combustion Basics

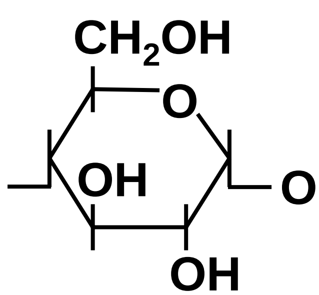
Polysaccharides (carbohydrates) make up the majority of the dry weight of nearly all plant matter.

- cellulose
- hemicellulose
- starch
- simple sugars



Polysaccharides

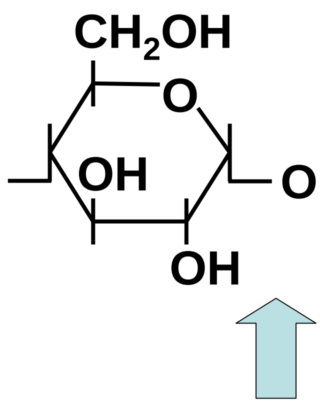
- Corn cobs
- Corn stover
- Distillers' grain
- Leaves
- Grasses
- Sawdust
- Sugar beet pulp
- Cotton gin residue
- Bakery waste
- Waste paper



$+ O_2$

$CO_2 + H_2O$

- Oxidizing combustion is clean combustion
- Inherent in corn-burning stoves & wood-pellet stoves but not ordinary wood stoves & fireplaces



$+ O_2$

$CO_2 + H_2O$

Photosynthesis is the reverse reaction

… nature's battery stores solar energy in chemical bonds of glucose.

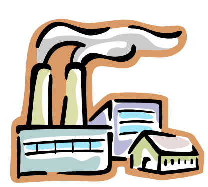
What if polysaccharides burn with insufficient oxygen?

…..smoke is no longer colorless

…..many organic compounds form

…..which have fuel value

…..and are toxic



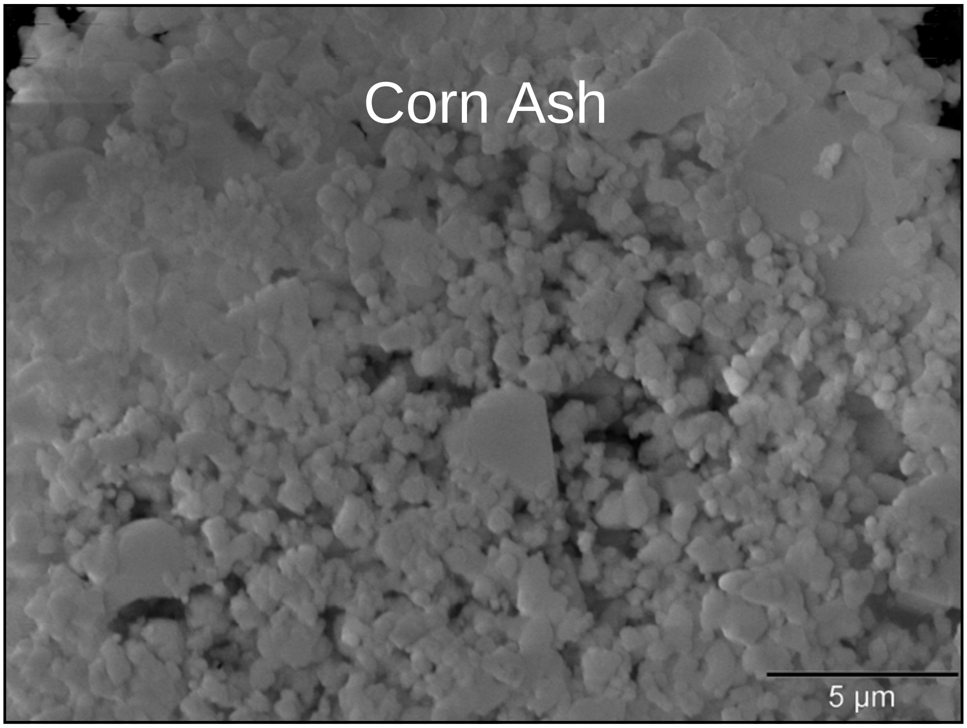
Chemistry of Wood Smoke (Part 1)

Species	g/kg wood
Carbon Monoxide	80-370
Methane	14-25
VOCs (C2-C7)	7-27
Aldehydes	0.6-5.4
Formaldehyde	0.1-0.7
Acrolein	0.02-0.1
Propionaldehyde	0.1-0.3
Butryaldehyde	0.01-1.7
Acetaldehyde	0.03-0.6
Furfural	0.2-1.6 1.6

1993 EPA Report, A Summary of the Emissions Characterization and Noncancer Respiratory Effects of Wood Smoke, EPA-453/R-93-036

Particulates in Smoke

- ✓ Flyash
- ✓ Carbonaceous particles
- ✓ All particles typically less than a micron (can be airborne for 3 weeks)
- ✓ They absorb toxic gases, bacteria, and viruses
- ✓ They embed deeply in the lungs where they pass into the bloodstream



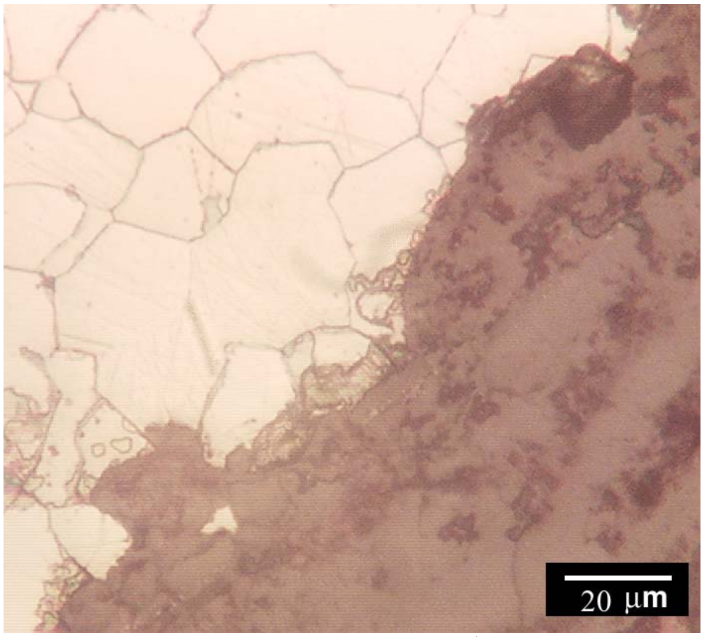
Silicon
Sodium
Potassium
Phosphorus
Calcium
Iron
Magnesium

- ✓ **They enter the plant as dissolved ions, salts, and acids in water.**
- ✓ **They deposit in the cells of the corn kernel, leaves, and stalks.**
- ✓ **Their concentrations depend on the corn plant variety and the soil type.**

During combustion, solid oxides form

$$P + 2O_2 \rightarrow PO_4$$
$$2\ Na + \tfrac{1}{2}\ O_2 \rightarrow Na_2O$$
$$2\ K + \tfrac{1}{2}\ O_2 \rightarrow K_2O$$
$$Mg + \tfrac{1}{2}\ O_2 \rightarrow MgO$$
$$Fe + O_2 \rightarrow Fe_xO_y$$

Furnace inner wall is made of steel →

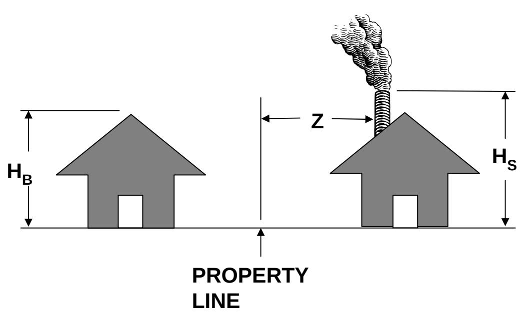


Phosphate glass chemically attacks furnace inner wall

Steps to Reduce Airborne Pollution

1. Clean fuel (no dust)
2. Furnace maintenance
3. Chimney size and location
4. Emission control devices

Air quality permitting is all about calculating ambient impact: the airborne pollutant concentration as a function of distance, Z



Critical Factors:

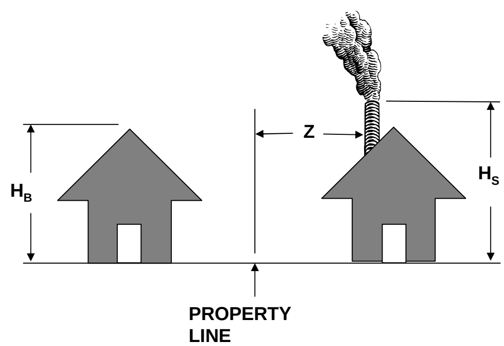
- H_s = stack height
- H_b = building height
- Z distance from building
- Furnace Size

Example: 1 MBTU/hr wood-burning furnace

Z = 100 feet

H_b = 10 feet

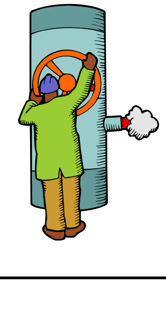
H_s = 12.5 feet



Step 1: Look up emission factors

…it's a number showing how fast the furnace emits each pollutant.

…the bigger the furnace, the bigger the emission



Emission factors for wood

Pollutant	Emission Factor
particulate matter	0.4
oxides of nitrogen (NOx)	0.49
sulfur dioxide (SO_2)	0.025
carbon monoxide (CO)	0.6
volatile organic carbon (VOC)	0.017

Emission factor changes with fuel type

Source: Environmental Protection Agency, Section 1.6 of AP-42.

Example: 1 MBTU/hr furnace

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particulate matter	0.4
oxides of nitrogen (NOx)	0.49
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volatile organic carbon (VOC)	0.017

1 x 0.4 = 0.4 pounds particulate per hour

= particulate emission rate

……call this “B”

……the bigger the furnace the bigger the emission

$$A = \text{Ambient Impact} = \frac{B}{C}$$

$$A = \frac{B}{C} = \frac{\text{Rate of Emissions}}{\text{Design Factor}}$$

B = 0.4

C

C is a cloud dispersion factor

Finding C in the table

	H_B = 10 ft			H_B = 20 ft		
Distance Z (ft)	H_S = 12.5 ft	H_S = 17.5 ft	H_S = 25 ft	H_S = 25 ft	H_S = 35 ft	H_S = 50 ft
25	0.0085	0.022	0.159	0.032	0.084	0.679
50	0.0087	0.022	0.159	0.032	0.084	0.679
75	0.0096	0.022	0.159	0.032	0.084	0.679
100	0.011	0.023	0.159	0.033	0.084	0.679
200	0.020	0.040	0.159	0.042	0.084	0.679
300	0.030	0.053	0.178	0.059	0.113	0.679
400	0.040	0.065	0.171	0.077	0.140	0.679
500	0.051	0.077	0.189	0.094	0.164	0.679
600	0.063	0.091	0.222	0.112	0.188	0.746
700	0.075	0.104	0.241	0.130	0.211	0.812
800	0.089	0.119	0.257	0.148	0.235	0.768
900	0.103	0.134	0.264	0.167	0.258	0.770
1000	0.119	0.151	0.272	0.187	0.282	0.800
1500	0.209	0.245	0.318	0.290	0.406	1.080
2000	0.311	0.350	0.383	0.408	0.539	1.256

Table 2. *Annual Ambient Impact Ratios* (R) in units of (lb/hr) / (micrograms/m^3).

H_B = height of neighbor's building,

H_S = exhaust stack height.

Source: *Michigan Department of Environmental Quality Report: Air Pollution Control Rules, Part 2. Air Use Approval As Amended July 1, 2003.*

$$A = \frac{B}{C} = \text{Ambient Impact}$$

B = 0.4

$$A = \frac{\text{Rate of Emissions}}{\text{Design Factor}}$$

C = 0.011

Answer = 36.4 micrograms per cubic meter

Ambient impact

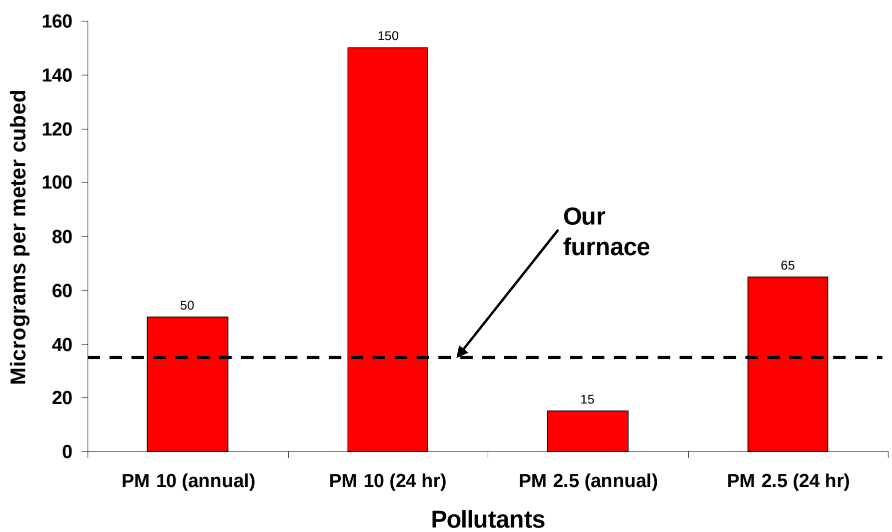
= 36.4 $\mu g / m^3$

Is the furnace safe?

EPA Safe Limits

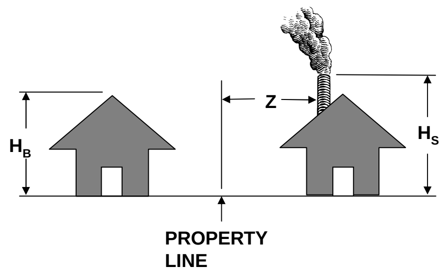
Pollutant	Maximum Permissible Concentration
PM_{10} (annual)	50 μg/m^3
PM_{10} (24 hr)	150 μg/m^3
$PM_{2.5}$ (annual)	15 μg/m^3
$PM_{2.5}$ (24 hr)	65 μg/m^3
NO_2 (annual)	100 μg/m^3
SO_2 (annual)	80 μg/m^3
SO_2 (24 hr)	365 μg/m^3
CO (8 hr)	10 μg/m^3

Source: National Ambient Air Quality Standards for Wood, Michigan 2005 Annual Air Quality Report, August 2006.



Design Choices

1. Reduce furnace size?
2. Increase the horizontal distance from chimney?
3. Raise the chimney height?
4. Install an emissions control device?



The answer is buried in the table

	H_B = 10 ft			H_B = 20 ft		
Distance Z (ft)	H_S = 12.5 ft	H_S = 17.5 ft	H_S = 25 ft	H_S = 25 ft	H_S = 35 ft	H_S = 50 ft
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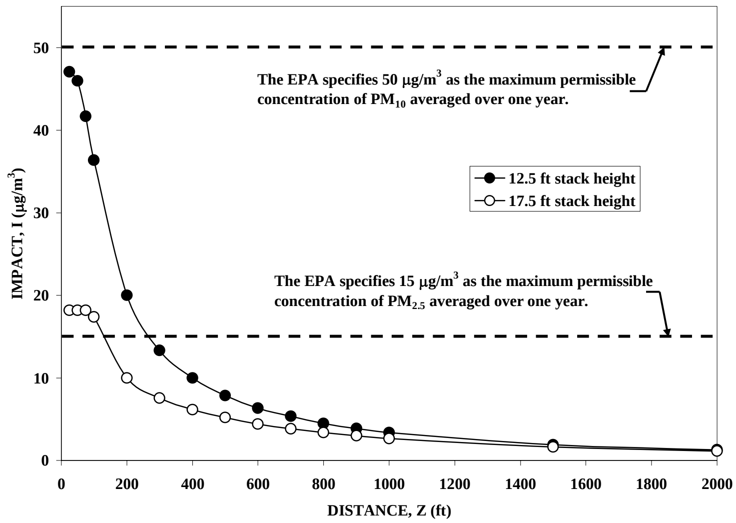

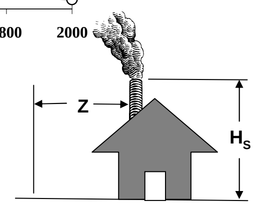

Safe installation with a taller chimney
located at a greater distance Z

Heating Buildings and Business Operations with Biomass Fuel: A Planning Guide

C. Schilling
Saginaw Valley State University

L. Jacobs, M. Seamon, and T. Dudek
Michigan State University Extension

Questions?

email: schillin@svsu.edu