# New Hampshire Biomass Boiler Workshop

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# Combustion 101

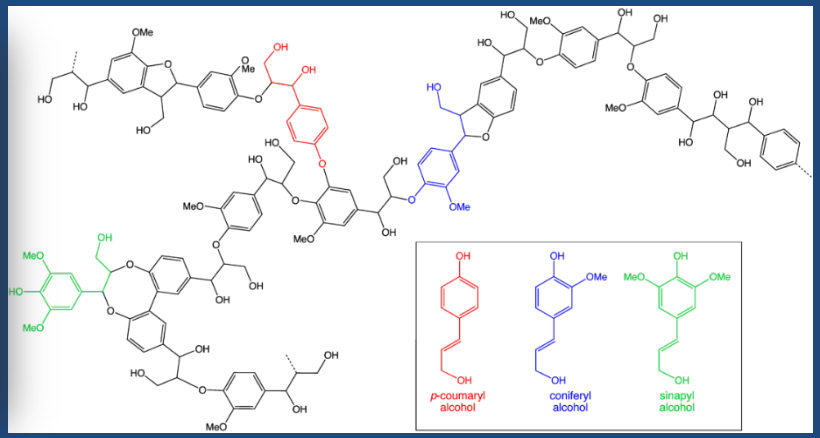
$H_2 + O_2 \rightarrow H_2O$

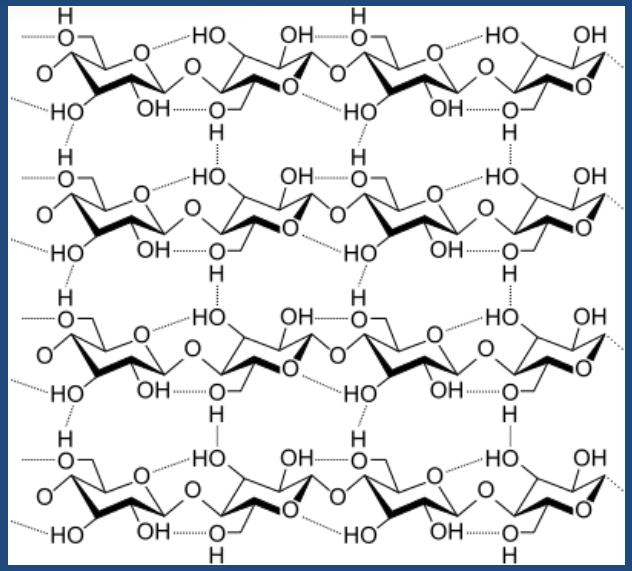
$C + O_2 \rightarrow CO_2$

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

$C_8H_{18} + O_2 \rightarrow CO_2 + H_2O$

$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$



+ [all sorts of other compounds] → ???

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# The Promise of Commercial Pellet Boilers

- Designed with 2-3 combustion stages, resulting in efficient burn
- Lambda controls to adjust burn conditions (dampering or combustion air, increasing fuel flow, etc) dramatically improve emissions.
- 60-85% thermal combustion efficiency is typical, but varies depending on load.

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# Comparing different wood boiler types

| Emission Species | Residential: Emission factors (Deangelis *et al.*, 1980) | | Commercial: Emission factors (EPA, 2008) | | This study: 517k BTU/hr | | This study: 517k BTU/hr | | This study: 1.7M BTU/hr | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Fireplace (g/kg) | Wood Stove (g/kg) | Wet Wood (lb/mmBTU) | Dry Wood (lb/mmBTU) | Wood Chips (g/kg) | Wood Chips (lb/mmBTU) | Wood Pellets (g/kg) | Wood Pellets (lb/mmBTU) | Wood Pellets (g/kg) | Wood Pellets (lb/mmBTU) |
| PM | 13• | 9.1• | 0.350♦ | 0.300♦ | 0.54* | 0.112* | 0.47 | 0.060* | 0.47 | 0.06* |
| $SO_2$ | 0.2 | 0.2 | 0.025 | 0.025 | 0.02 | 0.004 | 0.0065 | 0.001 | 0.005 | 0.001 |
| $NO_x$ | 2.0 | 0.49 | 0.220 | 0.490 | 1.84 | 0.302 | .35 | 0.040 | 0.42 | 0.07 |
| CO | 67 | 180 | 0.600 | 0.600 | 2.13 | 0.348 | 2.16 | 0.270 | 7.62 | 1.21 |

* – measurements include only particles with diameters less than 2.5μm, cyclone used for PM control
♦ – multiclones used in series for PM control
• – no controls for PM

From NYSERDA, 2012 (No 13-01)

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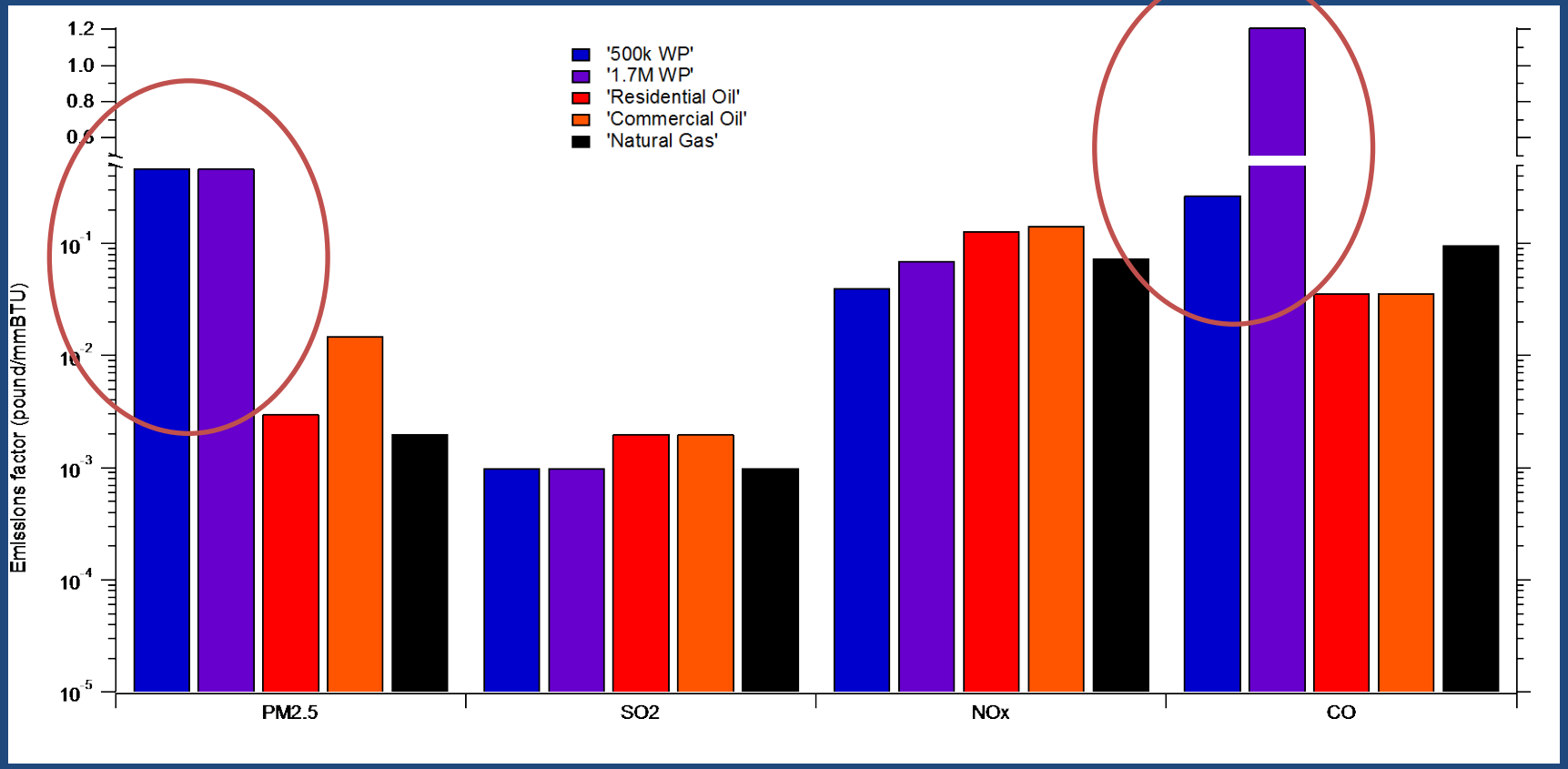
# How does this compare?




Wood pellet data from NYSERDA report (2012); all other data from AP42

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# What does this tell us?

- From a emissions standpoint, not really an impressive difference between different technologies.
- In general, pellet emission technology needs more study.
- Two pollutants are higher: particulates and carbon monoxide
  - Relatively simple control technology available for PM; not so much for CO.

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# Still much uncertainty


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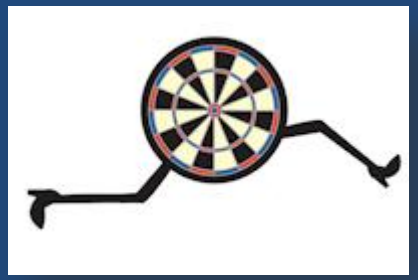
# Air Quality in New England

- Generally attaining standards everywhere.
- Important exception: Ozone still a problem.
  - Ozone usually a ‘summer’ problem.
  - Not enough to be listed as non-attainment (except Dukes County in Massachusetts)
- Wintertime inversion issues in W Mass, however.

# Clean Air Act and NAAQS



| Pollutant [links to historical tables of NAAQS reviews] | | Primary/ Secondary | Averaging Time | Level | Form |
|---|---|---|---|---|---|
| Carbon Monoxide (CO) | | primary | 8 hours | 9 ppm | Not to be exceeded more than once per year |
| | | | 1 hour | 35 ppm | |
| Lead (Pb) | | primary and secondary | Rolling 3 month average | 0.15 µg/$m^3$ (1) | Not to be exceeded |
| Nitrogen Dioxide ($NO_2$) | | primary | 1 hour | 100 ppb | 98th percentile of 1-hour daily maximum concentrations, averaged over 3 years |
| | | primary and secondary | 1 year | 53 ppb (2) | Annual Mean |
| Ozone ($O_3$) | | primary and secondary | 8 hours | 0.070 ppm (3) | Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years |
| Particle Pollution (PM) | $PM_{2.5}$ | primary | 1 year | 12.0 µg/$m^3$ | annual mean, averaged over 3 years |
| | | secondary | 1 year | 15.0 µg/$m^3$ | annual mean, averaged over 3 years |
| | | primary and secondary | 24 hours | 35 µg/$m^3$ | 98th percentile, averaged over 3 years |
| | $PM_{10}$ | primary and secondary | 24 hours | 150 µg/$m^3$ | Not to be exceeded more than once per year on average over 3 years |
| Sulfur Dioxide ($SO_2$) | | primary | 1 hour | 75 ppb (4) | 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years |
| | | secondary | 3 hours | 0.5 ppm | Not to be exceeded more than once per year |

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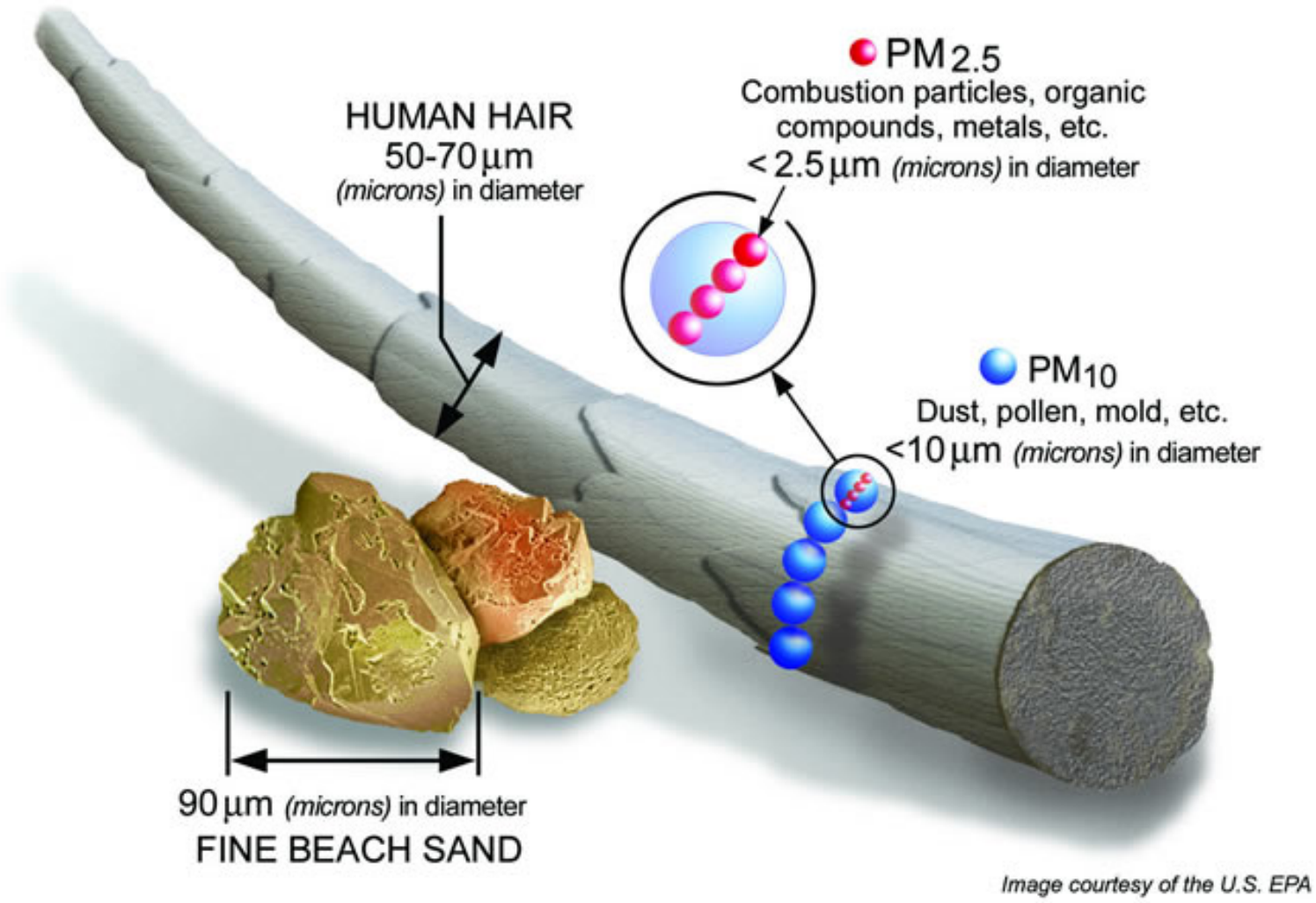


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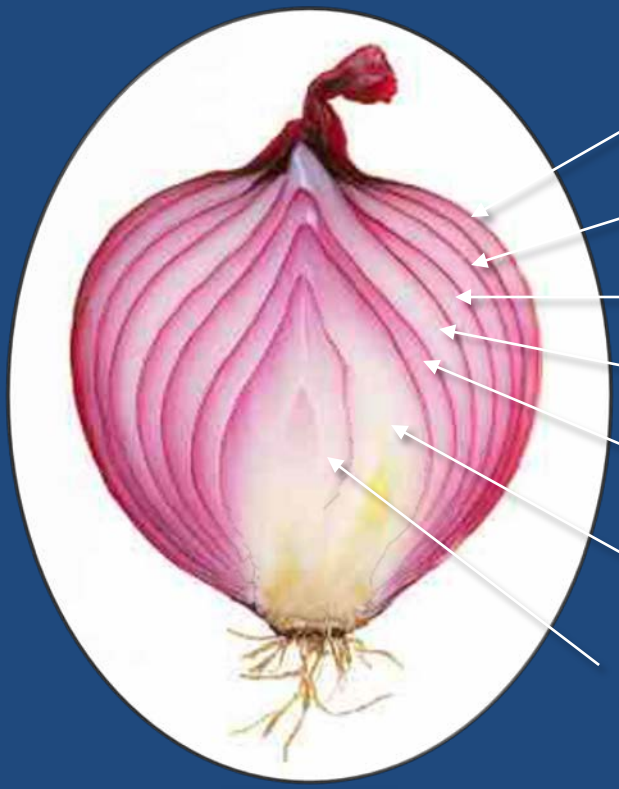
# A closer look:



- Inorganic Ions
  - Sulfate
  - Nitrate
  - Ammonium
  - Other Salts
- Trace metals
  - Alkali
  - Alkaline
  - Metalloids
  - Transition metals
- Unclassified
  - Inert materials
  - Trapped noble gases
  - Other???
- Biological components
  - Pollen
  - Bacteria
  - Viruses
  - Cell fragments
  - Proteins
- Elemental Carbon
- Adsorbed vapors
  - Acidic or basic vapors
  - Semi volatile organic vapors
  - Water vapor
  - Condensed metal vapors
- Organic Carbon
  - Hydrophobic
  - Hydrophilic
  - Oxidized
  - Organic acids
  - Alkane/alkene/ketone/aldehyde/…
  - Straight chain or ring structure

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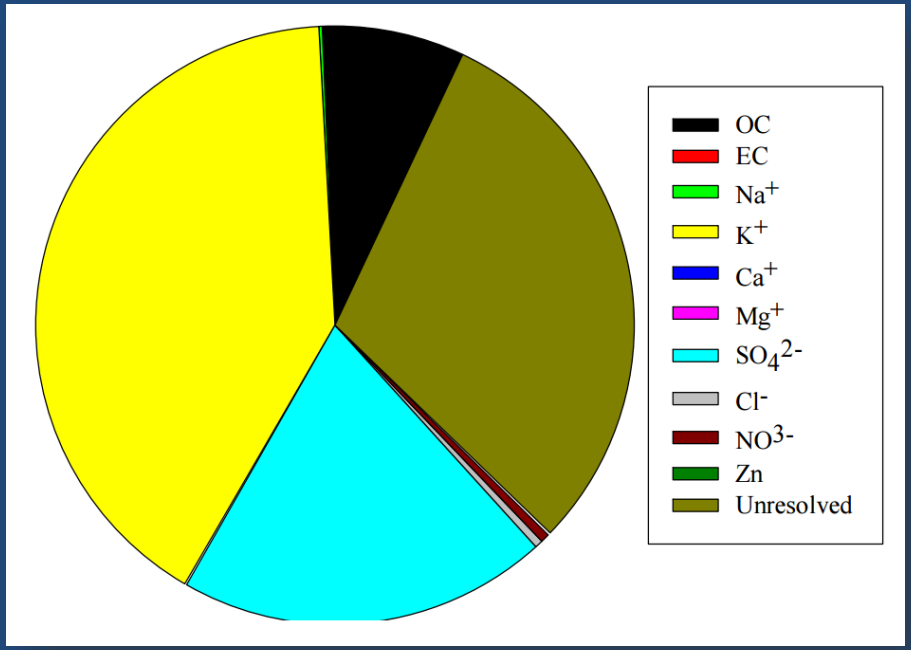
# Still much unknown in pellets

- Emphasizes importance of known fuel source.
- Hard vs softwood probably irrelevant (similar thermal content).
- Burner design and pellet source is essential for protecting health.

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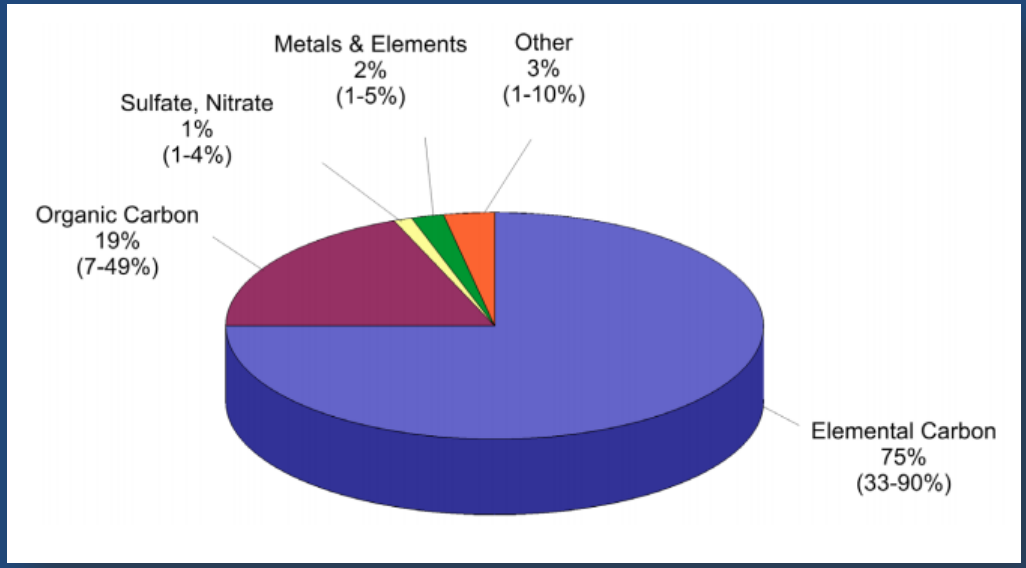
# More known about fuel oil

- Known carcinogen (G1, IARC, 2012).
- Hundreds-to-thousands of volatile gases.
- Short-lived climate pollutants (BC)




U.S. EPA (2002b) Health assessment document for diesel engine exhaust. Report by the National Center for Environmental Assessment Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C., EPA/600/8-90/057F. Available on the Internet at http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=36319

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# Outside of the lamppost

| PAH | Commercial Wood Pellets (ng/BTU)[1] | AP42 Wood residue (ng/BTU) | AP42 Fuel oil Burner (ng/BTU) |
|---|---|---|---|
| benzo(a)anthracene | 0.38 | n/a | 0.004 |
| benzo(b)fluoranthene | 0.57 | n/a | 0.013 |
| benzo(a)pyrene | 0.86 | 0.12 | n/a |
| dibenz(a,h)anthracene | mdl | 0.001 | n/a |
| indeno(1,2,3-c,d)pyrene | 3.42 | 0.004 | n/a |
| benzo(k)fluoranthene | 0.75 | 0.002 | 0.005 |

Carcinogens

[1]517kBTU/hr pellet boiler, NYSERDA (2012)

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# Simplifying the story (a little)

- Recent work in Finland compares PAH emissions from large scale wood chip and oil boilers, as well as small scale pellet and oil boilers.
- Of all measured PAHs, fuel oil (large and small) >>> wood >> pellet
- For most worrisome PAHs, the same results are observed

Kaivosoja et al, Atmospheric Environment 193-201:77, 2013

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# So where do we stand?

- Natural gas: lowest combustion emissions; important distribution concerns
- Fuel oil: relatively efficient (heat yield and pollutants), non-renewable fuel source.
- Pellets: not completely tested (but looking promising), somewhat higher emissions for certain pollutants, variable combustion efficiency.

# From a Public Health Perspective

- Natural gas emissions are the lowest.
- Not an impressive difference between oil and pellet emissions (at least the ones we have measured).
  - But we are particularly concerned with fuel oil combustion emissions.
- Federal emissions guidance (e.g. AP42) somewhat helpful, but not the complete story.

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# Consider Exposure

- Many strategies in exposure reduction
  - thoughtful siting
  - point of emissions controls (ESP, wet deposition)
  - effective stack heights (particularly important where atmospheric trapping occurs)
  - operation conditions (if pellet, consider heat reservoir technologies)
- Be cognizant of your population; children demand careful attention to your choice.

# Solutions to assessing impact

- Consider measurements
  - EPA-quality not likely viable ($10k + each)
  - Modest price sensors available (<$1000)
  - DIY approaches – even student/citizen-led initiatives can work at almost no cost.
- Measurements do not have to measure everything.
- Important to obtain baseline data – facility perimeter, downwind, upwind, inside.