Biomass smoke and Health

Michael Brauer

Webinar
October 24, 2013

UBC
a place of mind
THE UNIVERSITY OF BRITISH COLUMBIA
Air pollution and health

• Air pollution (individual) **risk** is small...but large **exposed population = large population risk**
  – Smoking: Larger risk, smaller exposed population

• On **days** with worse air quality, more people die*

• In **more polluted cities**, people die earlier than in less polluted cities...

• ...and, in the **most polluted areas** of cities, there is an increased risk of dying

*out-of-hospital, >65 yrs
Wood biomass fuels in context

• Inexpensive, secure fuel
  – Increasing/fluctuating costs & taxes for fossil fuels
• Promoted as renewable, GHG-neutral fuel
• Relatively unregulated source
• Impact on winter air quality coinciding with stagnation
• Exposure proximity, high “intake fraction”
Issues raised in response:

• Is biomass really inexpensive?
• Sufficient supply?
• Emissions of current technologies > emissions of oil, natural gas
  • need cleanest fuels/emissions controls when burned in populated areas and with distributed sources
• Carbon neutrality
  • Stock replacement
  • Black Carbon
Wood biomass fuels in context

• Inexpensive, secure fuel
  – Increasing/fluctuating costs & taxes for fossil fuels
• Promoted as renewable, GHG-neutral fuel
• Relatively unregulated source
• Impact on winter air quality coinciding with stagnation
• Exposure proximity, high “intake fraction”

Biomass smoke and health: evidence

- Constituents/Composition (PM$_{2.5}$, aldehydes, PAHs)
- Toxicology
- High concentration, chronic exposures – developing countries
- High concentration acute/sub-chronic exposures – wildland firefighters
- Firesmoke, agricultural burning
- Controlled human exposures
- Residential woodsmoke epidemiology

- NOTE: very little direct research on health impacts of ICI-scale combustion
Do woodsmoke particles pose different levels of risk from other particles?

- Respiratory disease: No
- Cardiovascular disease: ?

Woodsmoke Particles

Bar = 1 µm = 1/1000 of 1mm

Woodsmoke Health Effects: A Review

Luke P. Naehler  
Department of Environmental Health Science, College of Public Health, University of Georgia, Athens, Georgia, USA

Michael Brauer  
School of Occupational and Environmental Hygiene, University of British Columbia, Vancouver, British Columbia, Canada

Michael Lipsett  
Department of Epidemiology and Biostatistics, School of Medicine, University of California, San Francisco, San Francisco, California, USA

Judith T. Zelikoff  
Department of Environmental Medicine, New York University School of Medicine, New York, New York, USA

Christopher D. Simpson and Jane Q. Koenig  
Department of Occupational and Environmental Health Sciences, University of Washington, Seattle, Washington, USA

Kirk R. Smith  
Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley, California, USA

PAH content: WS > Traffic PM  
Inflammatory potential: WS ≈ Traffic PM


PM composition

“conventional”

Wood smoke soot

Wood smoke organic particles (low-temp combustion)

from Kocbach et al, Science of the Total Environment, 2005)

“advanced”

“Good” wood pellet combustion PM (alkali salt particles)

<table>
<thead>
<tr>
<th>Combustion source</th>
<th>Emissions (mg/MJ)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open fireplace</td>
<td>160 – 910 (0.38-2.2 lb/mmBTU)</td>
<td><img src="image1" alt="Composition" /></td>
</tr>
<tr>
<td>Conventional woodstove</td>
<td>50 – 2100 (0.38-2.2 lb/mmBTU)</td>
<td><img src="image2" alt="Composition" /></td>
</tr>
<tr>
<td>Conventional log boilers</td>
<td>50 – 2000 (50 – 250)</td>
<td><img src="image3" alt="Composition" /></td>
</tr>
<tr>
<td>‘Modern” woodstoves log/chip boilers</td>
<td>34 – 330</td>
<td><img src="image4" alt="Composition" /></td>
</tr>
<tr>
<td>Pellet stoves/boilers</td>
<td>10 – 50 (0.04 – 0.21 lb/mmBTU)</td>
<td><img src="image5" alt="Composition" /></td>
</tr>
</tbody>
</table>

adapted from: Kocbach Bølling et al. 2009
Animal/Cellular Toxicology

Inflammation: Medium Temp > High Temp
Low oxygen > High oxygen

Soluble inorganic ash particles:
- inflammation in cell culture
- no inflammation in animal inhalation studies
  - soluble and cleared from lungs

Cell cyotoxicity:

adapted from: Kocbach Bølling et al. 2009
<table>
<thead>
<tr>
<th>Combustion source</th>
<th>Emissions (mg/MJ)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open fireplace</td>
<td></td>
<td>MORE TOXIC</td>
</tr>
<tr>
<td>Conventional woodstove</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional log boilers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Modern” woodstoves log/chip boilers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pellet stoves/boilers</td>
<td></td>
<td>LESS TOXIC</td>
</tr>
</tbody>
</table>

adapted from: Kocbach Bølling et al. 2009
Controlled human exposure studies

- Subjects exposed to realistic (high) concentrations (~250 μg/m³) of woodsmoke for 4 hrs
  - Increases in measures of inflammation, oxidative stress post-exposure compared to clean air

- Pellet stove incomplete combustion
  - No inflammation
  - Early adaptive protective response


Biomass smoke epidemiology

” .....epidemiologic studies of indoor and community exposure to biomass smoke indicate a generally consistent relationship between exposure and increased respiratory symptoms, increased risk of respiratory illness, including hospital admissions and emergency room visits, and decreased lung function. Several studies suggest that asthmatics are a particularly susceptible subpopulation with respect to smoke exposure...The effects of community exposure to biomass air pollution (from wildfires) on mortality have not been sufficiently studied to support general conclusions.”

## Biomass combustion and CVD

<table>
<thead>
<tr>
<th>Country</th>
<th>Study</th>
<th>Exposure</th>
<th>Outcome</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Zealand</td>
<td>McGowan (2002)</td>
<td>Outdoor PM$_{10}$ (90% from biomass in winter)</td>
<td>CVD admissions</td>
<td>+</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Barnett (2006)</td>
<td>Outdoor PM$_{10}$</td>
<td>CVD admissions</td>
<td>-</td>
</tr>
<tr>
<td>Chile</td>
<td>Sanhueza (2009)</td>
<td>Outdoor PM$_{10}$ (90% from biomass in winter)</td>
<td>CVD admissions, CVD mortality</td>
<td>+ +</td>
</tr>
<tr>
<td>Canada</td>
<td>Allen (2011)</td>
<td>Indoor PM$_{2.5}$ intervention study</td>
<td>Markers of inflam &amp; endothelial function</td>
<td>+</td>
</tr>
<tr>
<td>India</td>
<td>Ray (2006)</td>
<td>Biomass vs non biomass fuel use</td>
<td>Markers of thrombosis risk</td>
<td>+</td>
</tr>
<tr>
<td>Turkey</td>
<td>Emiroglu (2010)</td>
<td>Biomass vs non biomass fuel users</td>
<td>Ventricular dysfunction</td>
<td>+</td>
</tr>
</tbody>
</table>
Woodsmoke & multiple health measures

• 32% increase in middle ear infections**
  – Top reason for children < 2 yrs to see physician, be prescribed antibiotics

• 8% increase in bronchiolitis*
  – Top reason for hospitalization of children < 1 yr

• 15% increase in COPD hospitalization*

• 15% increase in SGA birth*

• No associations with:
  – pre-term birth#
  – asthma incidence#
  – cardiovascular, COPD mortality#

• ~30% reduction in winter PM$_{2.5}$
• ↓ in childhood wheeze, itchy eyes, sore throat, cold, bronchitis, influenza, throat infections
• School absence associations inconsistent

• ~39% reduction in winter PM$_{10}$
• ↓ winter cardiovascular (-19.6%) and respiratory (-27.9%) mortality
• Similar decreases not observed in control community
Air filtration

- Portable HEPA filters 60% ↓ in indoor PM$_{2.5}$
- ↑ endothelial function, ↓ inflammatory markers

Towards healthier wood heat & energy

• Location matters!!
  – Distributed sources – high intake fraction

• Health impacts
  – Respiratory disease (+++)
  – Systemic inflammation (+)
  – Cardiovascular disease (+/-)
  – Pregnancy outcomes (?)

• Burn in most controlled manner → derive max energy
  – Wildfires → prescribed fires → Advanced Residential Combustion → Advanced Cogeneration

• Advanced technology
  – Lower mass emissions
  – Different composition → suggestions of lower toxicity
(Some) Key Knowledge Gaps

• Cardiovascular (mortality) impacts?
• Health impacts of short-term peak exposures
• Magnitude of population exposure
• Epidemiological and exposure studies of “advanced” combustion technologies
Thank you!

More questions?

michael.brauer@ubc.ca
EXTRA SLIDES
Combustion of biomass

• There is *limited evidence* in humans for the carcinogenicity of household combustion of biomass fuel (primarily wood). Household combustion of biomass fuel (primarily wood) is associated with cancer of the lung.

• There is *limited evidence* in experimental animals for the carcinogenicity of emissions from combustion of wood.

• There is *sufficient evidence* in experimental animals for the carcinogenicity of wood smoke extracts.

• **Overall evaluation:** Indoor emissions from household combustion of biomass fuel (primarily wood) are *probably carcinogenic to humans* (*Group 2A*).
**Pellet stove exposure**

- N=19 healthy adults
- 3 hrs (w/exercise) PM$_{2.5}$ = 224 μg/m$^3$
- ”Incomplete” combustion: emissions dominated by organic carbon
- Mild symptoms. No impact on lung function, FENO
- • Bronchoscopy 24 hrs post-exposure
  - GSH ↑ in BAL
  - No impact on cell counts, airway inflammatory markers
- No inflammation/cardiovascular effects
- Early adaptive protective response.

Cardiovascular effects

- Community wildfire exposure (+/-):
  - mixed results for CVD association (mortality, cardiac arrest)
  - high bushfire exposures in Australia: (+)
- Wildland firefighters (+):
  - systemic inflammation
- Controlled exposures: (+/-): systemic inflammation

For typical drainage wind speed (1 m/s) maintained over a 3 hour period, upslope influence \(\sim 10 \text{ km}\)

Catchment modeling\(^1,2\) suggests upslope influence of \(4 - 8 \text{ km}\)

Semivariogram analysis\(^3\) suggests spatial extent of \(2.7 \text{ km}\)

---


\(^3\)Lightowlers, C et al. Determining the spatial scale for analysing mobile measurements of air pollution. Atmospheric Environment 42 (2008)
PM 2.5 emissions input basis

Acknowledgements
Lisa Rector, NESCAUM
Phil Hopke, Clarkson University
Tom Butcher, BNL

Source: Ellen Burkhard
Firesmoke and CVD?

<table>
<thead>
<tr>
<th>Country</th>
<th>Study</th>
<th>Exposure</th>
<th>Outcome</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>LFS project</td>
<td>Bushfire smoke (PM$<em>{10}$ PM$</em>{2.5}$ event)</td>
<td>CVD admissions CVD mortality</td>
<td>- inconclusive</td>
</tr>
<tr>
<td>Australia</td>
<td>Morgan 2010</td>
<td>Bushfire smoke (PM$_{10}$)</td>
<td>CVD admissions IHD admissions</td>
<td>- inconclusive</td>
</tr>
<tr>
<td>Australia</td>
<td>Dennekamp 2010</td>
<td>Bushfire smoke (PM$<em>{10}$ PM$</em>{2.5}$ event)</td>
<td>Out of hospital cardiac arrest</td>
<td>+</td>
</tr>
<tr>
<td>Brazil</td>
<td>Arbex 2010</td>
<td>Sugar cane burning (TSP harvest vs non-harvest periods)</td>
<td>Admissions for hypertension</td>
<td>+</td>
</tr>
<tr>
<td>Canada</td>
<td>Henderson 2011</td>
<td>Forest fire smoke</td>
<td>CVD physician and hospital visits</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>Moore 2006</td>
<td>Forest fire smoke episode</td>
<td>CVD physician billing</td>
<td>-</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Mott 2005</td>
<td>Forest fire smoke episode</td>
<td>CVD admissions</td>
<td>-</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Sastry 2002</td>
<td>PM$_{10}$/visibility</td>
<td>Daily (all-cause/CVD) mortality</td>
<td>+</td>
</tr>
<tr>
<td>USA</td>
<td>Delfino 2009</td>
<td>Forest fire smoke (PM$_{2.5}$)</td>
<td>CVD admissions</td>
<td>inconclusive</td>
</tr>
</tbody>
</table>
Cautionary tales – the impact of the economic context

(Bulkley Valley) **Woodstove Exchange STudy**
<table>
<thead>
<tr>
<th></th>
<th>Spherical organic carbon particles</th>
<th>Soot (elemental carbon aggregates)</th>
<th>Inorganic ash particles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Schematic drawing</strong></td>
<td><img src="image1" alt="Schematic Drawing" /></td>
<td><img src="image2" alt="Schematic Drawing" /></td>
<td><img src="image3" alt="Schematic Drawing" /></td>
</tr>
<tr>
<td><strong>Diameter measured by electron microscopy</strong></td>
<td>50–600 nm$^{52, 53}$</td>
<td>20–50 nm$^{52, 73}$</td>
<td>50–125 nm$^{97}$</td>
</tr>
<tr>
<td><strong>Mobility diameter</strong></td>
<td>100–300 nm$^{58-70}$</td>
<td>50–300 nm$^{68, 76}$</td>
<td>50–125 nm$^{69, 98, 99}$</td>
</tr>
<tr>
<td><strong>Internal turbostratic microstructure</strong></td>
<td>No$^{61}$</td>
<td>Yes / No$^{81-83}$</td>
<td>No</td>
</tr>
<tr>
<td><strong>Solubility (H$_2$O)</strong></td>
<td>Depends on ageing$^{61}$</td>
<td>Insoluble</td>
<td>Soluble</td>
</tr>
<tr>
<td><strong>Main chemical characteristic</strong></td>
<td>Organic carbon$^{62, 64, 67}$ (Most abundant organic compounds: metoxyphenols and monosaccaride anhydrides)$^{57-60}$</td>
<td>Elemental carbon with variable amounts of organics condensed on the surface$^{12, 62, 81}$ (Most abundant organic compounds: hydrocarbons and polycyclic aromatic hydrocarbons)$^{84, 85}$</td>
<td>Alkali salts (mainly KCl and K$_2$SO$_4$ with small amounts of trace elements (e.g. Zn))$^{78, 92}$</td>
</tr>
<tr>
<td><strong>Combustion conditions</strong></td>
<td>Low-temperature, incomplete combustion$^{11, 52-56}$</td>
<td>High-temperature, incomplete combustion$^{52}$</td>
<td>High-temperature, complete combustion$^{120}$</td>
</tr>
<tr>
<td><strong>Possible sources</strong></td>
<td>Air starved combustion or start-up phase of batch wise combustion in conventional stoves, open fireplaces$^{58, 62, 64, 67}$</td>
<td>Combustion in conventional stoves, open fireplaces, boilers for wood, wood chips and pellets$^{14, 52, 75-79}$</td>
<td>Combustion in pellets stoves, boilers for wood, wood chips and pellets$^{69, 120}$</td>
</tr>
</tbody>
</table>
For equal mass: 16X lower (by number), 3x lower (by surface area) dose/hr, biomass particles relative to traffic exhaust PM

(lower deposition probability and lower number/surface area concentration per unit mass)

Biomass particles largely water soluble

...may impact toxicity