Today’s Talk:
Characterizing Health Risks from Exposure to Wood Smoke (and other carbon-based combustion byproducts)...

What clinicians, public health practitioners and environmental health advocates should know.

Gillian Gawne-Mittelstaedt, MPA
Director, Tribal Healthy Homes Northwest
Top 5 Concepts to Know and Communicate:

1. **Physiochemical properties** of woodsmoke and lung/environment interface
2. **Respiratory** outcomes - Particulates
3. **Infectious** outcomes – PAHs and immune suppression
4. **Chronic** exposure outcomes - mutagenic and carcinogenic properties of woodsmoke
5. **Cumulative** risk
“Heating with wood ...is proving to be the workhorse of residential renewable energy production.”

- John Ackerly, Alliance for Green Heat
• The fluctuating and high cost of fossil fuels continues to put pressure on households.

August 27, 1990…

Fuel worries reviving sales of wood stoves

BOston (AP) — Sales of wood stoves are heating up again as people worry about the rising cost of fuel for the winter.

Wood stoves have been both maligned and romanticized as having a certain pioneer mystique. While oil price hikes and tensions in the Middle East fanned sales in the 1970s and early 1980s, wood stoves also were the target of pollution restrictions and the source of fatal house fires.

Industry officials say stoves today have more sophisticated designs to remedy the old problems. New wood stove makers and retailers are hoping to cash in on the growing interest in alternatives to oil and gas.

December 6, 2012…

Fighting winter with fire? Wood-burning on the rise.

The number of US homes relying on burning wood for heat is up 24 percent since 2006. But environmental concerns could quash further growth of wood-burning.

By David J. Ungar, Correspondent / December 6, 2012
• Wood heat largely an economic decision at the household scale.

• Wood heating practices, however, are based on intrinsic beliefs and attitudes about the relative harm or safety of wood smoke.

• Behaviors are difficult to modify in light of a thousand-year relationship with fire - food preparation, spiritual and cultural events, and basic survival.
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5. Cumulative risk
When we burn wood, the process is called “combustion”. If the fire isn’t hot enough, combustion “fails”, meaning unburnt material turns into fine ash, smoke and hazardous gases.
<table>
<thead>
<tr>
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<th>Range (ppm)</th>
<th>Compound</th>
<th>Range (ppm)</th>
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<td>carbon monoxide</td>
<td>80-370</td>
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<td>7-27</td>
<td>total particle mass</td>
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<td>aldehydes</td>
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<td>substituted furans</td>
<td>0.15-1.7</td>
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<tr>
<td><strong>benzene</strong></td>
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<td>Individual PAHs</td>
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<td>sulfur dioxide</td>
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<td>aluminum</td>
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<td>silicon</td>
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<tr>
<td>napthalene</td>
<td>0.24-1.6</td>
<td>sulfur</td>
<td>1x10⁻³-2.9x10⁻²</td>
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<td></td>
<td></td>
<td>chlorine</td>
<td>7x10⁻⁴-2.1x10⁻²</td>
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Chemical composition of woodsmoke

• Carbon constitutes up to 40% of total PM

• Classified as either Organic Carbon (OC) or Elemental Carbon (EC)

□ OC is generally the dominant constituent of PM$_{2.5}$ mass – usually present as a vapor – between 10 – 50% of the total mass concentration

• OC fraction varies - fuel being burned, combustion conditions.

• EC fraction - approximately 5-20% of woodsmoke particulate
Figure 1: Schematic illustration of the differential characteristics of mineral particles and carbon aggregates.
“The small diameters of the primary particles provide a large surface area per mass, which allows for adsorption of various compounds such as metals, organic compounds, allergens and endotoxins... Thus, carbon aggregates may act as carriers that transport toxic or biologically active compounds into the lung. (Dasch, 1982; Evans et al., 1981; Tesfaigzi et al., 2002). (Kocbach, 2008)
Over 90% of woodsmoke particles are smaller than 1 micron - behaving more like a gas than a particle.

Electron micrograph of wood smoke particles. Bar = 1 μm.
This network (our “Respiratory System”) is enormous... almost 1500 miles of airways. Stretched out, they would reach from Seattle to Anchorage.
At the end of the tubes, we have thousands of tiny air sacs....

If you laid them out flat, they would cover an entire tennis court, or about 750 square feet.
Surface area of the lungs is 80 times greater than the surface area of an average-sized adult’s skin.
The air sacs are very thin.
This picture shows how these sacs look — and act like — a “gateway”...
Chemical composition

- The adverse health effects of inhaled particles are highly dependent on the deposition and retention of particles in the lung.
• Fine particles efficiently evade the mucociliary defense system and are deposited in the peripheral airways where they may exert toxic effects. (Kirk et al, Berkley study, 2005)
ALVEOLUS

Pro-inflammatory cytokines: TNF-α, IL-1β, IL-6, IL-8

Recruitment of neutrophils

T1

PM

MØ

CAPILLARY

TNF-α, IL-1β, IL-6, IL-8

Local inflammation

Systemic inflammation

ASTHMA
COPD
FIBROSIS
CANCER

ATHEROSCLEROSIS
HEART ATTACK
STROKE
Woodsmoke is present in our bloodstream within **60 seconds** of inhaling it...

Minutes later, **carbon monoxide** can be detected in our blood and **benzene** is in our exhaled breathe.
Blood Pressure and Heart Rate Were Increased After CAPs Exposures
Top 5 Concepts to Know and Communicate:

1. Physiochemical properties of woodsmoke and lung/environment interface
2. Respiratory outcomes - Particulates
3. Infectious outcomes – PAHs and immune suppression
4. Chronic exposure outcomes - mutagenic and carcinogenic properties of woodsmoke
5. Cumulative risk
• Literature: Well established association between woodsmoke and asthma exacerbations.

• Epidemiological studies have associated exposure to particles less than 10 μm in diameter with increased pulmonary and cardiovascular morbidity and mortality (Franklin et al., 2007; Katsouyanni et al., 2001; Metzger et al., 2004; Ostro et al., 2006; Pope III et al., 2002; Zanobetti et al., 2000)
A range of pulmonary effects are documented and associated with PM exposure, including: decreased lung development and function, exacerbation of asthma, allergy, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis and increased risk of lung cancer (Alfaro-Moreno et al., 2007b; Borm and Donaldson, 2007; Kappos et al., 2004).
Daily PM2.5 and PM10 AQI Values in 2011
Yakima, WA

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Generated: July 30, 2013
Daily PM2.5 and PM10 AQI Values in 2011
Port Angeles, WA

Plot of m1 by sasdate

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
Daily PM2.5 and PM10 AQI Values in 2011
Bellingham, WA

Source: U.S. EPA AirData <http://www.epa.gov/airdata>
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• Benzene...traditionally studied as carcinogen
• First relationship between asthma and benzene studied in Anchorage (Gordian et al)
• Respiratory morbidity and mortality associated with exposure to biomass combustion (in developing countries) – primary health outcome is infectious
• *Could benzene and its metabolites be a contributing but unexamined factor in the high rates of asthma in AI/AN populations?*
– “Our findings indicate that hospital admissions for childhood respiratory diseases, especially pneumonia, are associated with exposure to woodsmoke, PM$_{2.5}$ and its constituents.” *Naehrer et al, 2007*

– “Despite the direct causes of pneumonia and other respiratory infections being biologic in nature, the effect of air pollution on the development of severe cases requiring hospitalization is especially plausible in children, because particulates likely hamper the ability of an already immature immune system to clear bacteria and other pathogens from the lung.” *Deitert et al, 2002*
It would take 16,667 cigarettes to emit the same amount of benz(a)anthracene as burning 1 kg of wood. You would have to smoke 16,000 - 222,000 cigarettes to produce the equivalent amount of PAH as burning 1 kg firewood in a correctly-operated heater. “- Australian Air Toxics analysis
“Both in vitro and in vivo studies indicate that benzene metabolites alter biochemical and functional activities of other immunocompetent cells and may impair immune responses in the lung. These inhibitory effects of benzene metabolites are primarily mediated by interference with early transduction signals such as PI3 kinase. Together, currently available studies indicate that benzene metabolites interfere by multiple mechanisms with the role of basophils and mast cells in innate immunity and in chronic inflammation in the lung.”
Benzene from Residential Wood Burning


The emissions from a traditional tiled stove consisted mainly of lignin-related methoxyphenols with antioxidant properties, and 1,6-anhydroglucose from cellulose degradation. A wood stove of presently introduced energy-efficient design for residential heating and hot-water supply was shown to emit small amounts of methoxyphenols and anhydrosugars from primary wood pyrolysis. **Secondary harmful components like benzene and polycyclic aromatic hydrocarbons constituted a major portion of the organic emissions.** It is concluded that differences in smoke composition are essential to consider in recommendations and rules for proper choices of wood burning devices.
Benzene/PAH Exposure and LRTIs in Children


Study indicates that “short-term exposures to PAHs may represent a significant public health threat to children...”

“Ambient PAHs and fine particles were associated with early-life susceptibility to bronchitis. Associations were stronger for longer pollutant-averaging periods and, among children > 2 years of age, for PAHs compared with fine particles. Preschool-age children may be particularly vulnerable to air pollution–induced illnesses.”
Lower Respiratory Tract Infections (LRTI)

- High rates of RSV and LRTIs in AI/AN children < 1 yr/age
- RSV accounted for 14.4 percent of all American Indians/Alaska Native infant hospitalizations.

*Source: Washington State Department of Health, 2012*
LRTIs in Alaska Native Children

• 1 in 4 AN babies hospitalized each year
• Over 50% of children have Reactive Airway Disease
• Bronchiectasis still common
• High rates of invasive pneumococcal disease

Data and Photo Source: Yukon-Kuskokwim Delta. T. Ritter, Alaska Native Tribal Health Consortium

G. Gawne-Mittelstaedt, Tribal Healthy Homes Northwest
LRTIs in Native Children

• 58 Navajo children under 2 years with diagnosed pneumonia or bronchiolitis were compared with matched control children. Use of a wood burning stove was associated with a 4 times higher risk of lower respiratory tract infection (P<.001). *Hogg JC Apr 1997*
Asthma hospitalization by age: American Indian & Alaskan Native vs. All WA State children

<table>
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<tr>
<th>Age, y</th>
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<tr>
<td>Total</td>
<td>146.0</td>
<td>163.7</td>
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<tr>
<td>10-17</td>
<td>76.0</td>
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<tr>
<td>5-9</td>
<td>108.9</td>
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<td>1-4</td>
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<tr>
<td>&lt;1</td>
<td>232.5</td>
<td>528.0</td>
</tr>
</tbody>
</table>

Asthma Hospitalization Rate per 100,000 Population

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Compared to other pollution sources, woodsmoke contains very high levels of DNA-damaging free radicals.

Forchhammer et al, 2012

Relative amount of free radicals present in various effluent

Forchhammer et al, 2012
“...wood smoke particulates were found to be more powerful than other kinds of air pollution in causing potentially cancerous changes to DNA and “activating genes linked to inflammation and oxidative stress, which is a possible mechanism for atherosclerosis, asthma and other diseases.” Journal of Chemical Research in Toxicology Steffen Loft, researcher at the University of Copenhagen.

The white area shows where cancer-causing woodsmoke chemicals altered and damaged the DNA in lung cells.
Older woodstoves give off over 350 grams of fine particles an hour, or 20lbs/day...
An EPA study found that breathing woodsmoke during a high pollution day is the same as smoking 4 to 16 cigarettes.
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Cumulative Risk

- Complex mix of course, fine and ultrafine particles from combustion of fossil fuels (diesel) and woodsmoke.
- Near-roadway – *strong association with lung impairment*
- Residential and School
- Transportation
- Rural and urban
Those with impaired lung function become **highly susceptible to infection**, including **chronic bronchitis, pneumonia, and lung cancer**.

Those with “hyper-reactive” airways can be irritated by toxins, but also have greater susceptibility to permanently remodeled airways - **affecting long-term health and life span**.
Local Exposures: Living within 300m of major roadways affects lung function

(Brunekreef et al 1997, Netherlands)
Investigators conducting a study of 756 inner city children determined that exposure to heavy traffic is associated with the ability to achieve and maintain asthma control.

Peter N. Huynh, M.D., San Marino, Calif., et al
Best Practices to Reduce Risk:

• Drying the Fuel
• Maintaining the Woodstoves
• Ventilating the Homes
• Educating Residents on Effective Burning Practices
Two Questions to Consider for Cumulative Risk and Future Policy Reform:

1. Are we accurately measuring risk through our current air quality data collection methodology and infrastructure? – (Speciation and composition of PM)

2. Are we reasonably regulating for risk? “Ambient” vs “Household”
Recommended Reading...

- Breaking Patterns of Environmentally Influenced Disease for Health Risk Reduction: Immune Perspectives Rodney R. Dietert, Jamie C. DeWitt, Dori R. Germolec, and Judith T. Zelikoff

“The recent identification of major immune-based disease patterns beginning in childhood suggests that the immune system may play an even more important role in determining health status and health care needs across a lifetime than was previously understood.”
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