The smoke filled mountain valleys: Biomass combustion smoke exposures and health

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Goal of this Discussion

During this presentation we will describe how communities in our region are impacted by smoke inhalation exposures from biomass combustion via two distinct scenarios, residential wood heating during cold temperature season and wildland fires during dry, hot season. We will explore how these scenarios offer unique challenges with respect to understanding health risks and employing evidence-based exposure reduction intervention strategies.

Disclosures / Conflict of Interest

• None
Learning Objectives

1. Compare health-based guidelines to exposures associated with wildland fires or wood heating
2. Evaluate known intervention strategies to reduce exposure to smoke from biomass combustion
3. Make informed decisions and recommendations concerning health risks associated with smoke from nearby wildland fires.
Smoke PM Components

- Organic compounds
- Methoxy phenols
- 1,3 butadiene
- Benzene
- PAHs
- Metals
  - K, Ca, Zn


EPA Standards for PM (2012)

<table>
<thead>
<tr>
<th></th>
<th>Primary/Secondary</th>
<th>Averaging Time</th>
<th>Exposure recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM\textsubscript{2.5}</td>
<td>Primary</td>
<td>Annual</td>
<td>13 μg/m\textsuperscript{3}</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>Annual</td>
<td>15 μg/m\textsuperscript{3}</td>
</tr>
<tr>
<td></td>
<td>Primary and Secondary</td>
<td>24-hour</td>
<td>25 μg/m\textsuperscript{3}</td>
</tr>
<tr>
<td>PM\textsubscript{10}</td>
<td>Primary and Secondary</td>
<td>24-hour</td>
<td>50 μg/m\textsuperscript{3}</td>
</tr>
</tbody>
</table>

WHO Guidelines for 24 hour exposure*:
PM\textsubscript{10} = 50 μg/m\textsuperscript{3}
PM\textsubscript{2.5} = 25 μg/m\textsuperscript{3}


A. PM Exposure from Residential Wood Combustion

- Exposures relative to health based standards
- Associations with respiratory health effects
- Interventions
Contribution of wood smoke to ambient PM: selected communities

<table>
<thead>
<tr>
<th>Location</th>
<th>Year(s)</th>
<th>PM10</th>
<th>PM2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christchurch, NZ</td>
<td>2000</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Launceston, AUS</td>
<td>2000</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Libby, MT</td>
<td>2003-2004</td>
<td>84%</td>
<td></td>
</tr>
<tr>
<td>British Colombia</td>
<td>2008</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>Missoula, MT</td>
<td>2010</td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>2002</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>San Jose, CA</td>
<td>1990</td>
<td>45%</td>
<td></td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>1996-2001</td>
<td>34% - 49%</td>
<td></td>
</tr>
<tr>
<td>Allegheny Cty, PA</td>
<td>2008</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Vermont</td>
<td>2001</td>
<td>10% - 18%</td>
<td></td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>2001</td>
<td>11%</td>
<td></td>
</tr>
</tbody>
</table>
How does residential wood combustion translate to exposure risk?

- Ambient Exposure
- Seasonal
- Highly variable
- Occasional exceedance of NAAQS

For Context:
Primarily urban locations in the ACS study


What about indoor exposures?

<table>
<thead>
<tr>
<th>Study Area</th>
<th>No. Homes</th>
<th>Pre-change median PM$_{2.5}$ (ug/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Libby, MT$^1$</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>Nez Perce Reservation$^4$</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>Northern BC$^2$</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>MT, Idaho, Alaska$^3$</td>
<td>49</td>
<td>54</td>
</tr>
</tbody>
</table>

1 Noonan et al., Indoor Air 2012.
2 Allen et al., Atmos Environ 2009.
3 Semmens et al., ISEE 2011.

Respiratory health associations: Studies of effects on asthmatics in Seattle, WA (= 34% woodsmoke PM$_{2.5}$)

<table>
<thead>
<tr>
<th>Publications</th>
<th>Observed Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koenig et al 1993;</td>
<td>Decreased lung function (FEV1, FVC)</td>
</tr>
<tr>
<td>Trenga et al 1990;</td>
<td></td>
</tr>
<tr>
<td>Allen et al 2008</td>
<td>Decreased lung function (FEV1, PEF, MEF)</td>
</tr>
<tr>
<td>Allen et al 2008</td>
<td>Increased FeNO ? in uncontrolled asthmatics (perhaps not assoc. with WS component)</td>
</tr>
<tr>
<td>Slaughter et al 2003</td>
<td>Increased medication use</td>
</tr>
<tr>
<td>Schwartz et al 1993;</td>
<td>Increased asthma ER visits</td>
</tr>
<tr>
<td>Norris et al 1999</td>
<td></td>
</tr>
<tr>
<td>Sheppard et al 1999</td>
<td>Increased asthma hospitalizations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Exposure window</th>
<th>N (n cases)</th>
<th>Design</th>
<th>Mean Days exposed</th>
<th>Adjusted OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronchiolitis$^1$</td>
<td>2 – 12 months</td>
<td>86,337</td>
<td>Nested C-C</td>
<td>54 [45]</td>
<td>1.08 (1.04 - 1.11)</td>
</tr>
<tr>
<td>Otitis Media$^2$ (1 – 24 mos.)</td>
<td>1 month pre-diagnosis</td>
<td>45,113</td>
<td>Cohort</td>
<td>15 [16]</td>
<td>1.32 (1.27 - 1.36)</td>
</tr>
<tr>
<td>Asthma$^3$ (0 – 48 mos.)</td>
<td>All pregnancy</td>
<td>37,401</td>
<td>Nested C-C</td>
<td>60 [33]</td>
<td>1.00 (0.94 - 1.07)</td>
</tr>
<tr>
<td>COPD$^4$ Hospitalization</td>
<td>5 years</td>
<td>400,254</td>
<td>Cohort</td>
<td>15% Exposed</td>
<td>1.15 (1.02 – 1.29)</td>
</tr>
<tr>
<td>Mortality</td>
<td>5 years</td>
<td>400,254</td>
<td>Cohort</td>
<td>15% Exposed</td>
<td>0.81 (0.64 – 1.03)</td>
</tr>
</tbody>
</table>

References:

“...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...”
What are the possible interventions?

- Community-wide woodstove interventions and impact on ambient air quality
  - Legislation/enforcement
  - Fuel switching
  - Technology upgrades
- Residential interventions and impact on indoor air quality
  - Woodstove technology upgrade
  - Air filters
- Residential interventions and health outcomes

Community-wide interventions: Ambient Air Impacts (Select Examples)

- **Fuel switching:**
  - Missoula, Montana, United States
  - Launceston, Tasmania, Australia

- **Technology upgrades:**
  - Libby, Montana, United States
  - Seeley Lake, Montana, United States

Legislation/banning/enforcement: Missoula, MT

- **1983:** Air Pollution Control Board
  - New installs can only be “clean burning” wood stoves
  - Burning restriction on Stage 1 Air Alert days
  - Opacity: Restrictions on fuel materials

- **1987:** Fine for violations during Stage I Air Alert days ($20, increased to $50 in 1994)

- **1994:** More stringent rules
  - No new wood stoves installed
  - All wood stoves removed upon sale of property
Missoula wood burning trends

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Households</td>
<td>21,970</td>
<td>22,875</td>
<td>23,325</td>
<td>26,930</td>
<td>27,205</td>
</tr>
<tr>
<td>Tons Burned</td>
<td>54,120</td>
<td>40,296</td>
<td>33,174</td>
<td>22,297</td>
<td>15,153</td>
</tr>
<tr>
<td>Tons CO Emitted</td>
<td>5,141</td>
<td>6,362</td>
<td>6,316</td>
<td>3,595</td>
<td>1,569</td>
</tr>
<tr>
<td>Tons PM10 Emitted</td>
<td>1,208</td>
<td>1,316</td>
<td>1,079</td>
<td>608</td>
<td>206</td>
</tr>
</tbody>
</table>

Missoula County Environmental Health Division

Fuel Switching: Launceston, Tasmania, Australia

- Approach: funded program to promote replacement of wood heaters with electric heat.
- Marketing, education, enforcement.
- Pre-intervention: 1994-2000
- Post-intervention: 2001-2008

From 2001-04, reduction of wood heaters from 66% of homes to 30%.
Winter PM$_{10}$: 43.6 to 27.0 µm/m$^3$ (-38%).
Interventions in wood stove homes: Replacement of older technology devices

Old stove
40-60 g smoke/hr

EPA-certified stove
2.5 g smoke/hr

Woodstove technology: Libby, MT, US

- Approach: funded program to exchange old woodstoves to “EPA certified” stoves.
- Vouchers, registry, enforcement.

![Map of Libby, MT, US](image)

Ambient PM 2.5 ($\mu g/m^3$)
27.0 $\mu g/m^3$
19.7 $\mu g/m^3$


Annual Standard
Daily Standard

Graph showing PM 2.5 concentrations over time.
Residential Intervention Strategies: Indoor Air Impacts

- Technology upgrade
  - Nez Perce Reservation, Idaho, United States
  - Libby, Montana, United States
  - Northern British Colombia, Canada
  - ARTIS study – Montana, Idaho, Alaska
- Air filters
  - Southern British Colombia, Canada
  - Northern British Colombia, Canada
  - ARTIS study – Montana, Idaho, Alaska
- Other?

<table>
<thead>
<tr>
<th>Study Area</th>
<th>No. Homes</th>
<th>Percent Reduction from Baseline</th>
<th>Mean Difference (95% CI)</th>
<th>Proportion of Homes with No Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nez Perce Reservation</td>
<td>15</td>
<td>13.3</td>
<td>-6 (-36, +24)</td>
<td>33%</td>
</tr>
<tr>
<td>Libby, MT</td>
<td>21</td>
<td>53.3</td>
<td>-24 (-41, -7)</td>
<td>33%</td>
</tr>
<tr>
<td>Northern BC</td>
<td>15</td>
<td>7.1</td>
<td>-1 (-6, +4)</td>
<td>40%</td>
</tr>
<tr>
<td>ARTIS–MT, ID, AK</td>
<td>16</td>
<td>[1.5]</td>
<td>0 (-12, +13)</td>
<td>45%</td>
</tr>
</tbody>
</table>

Summary: Inconsistent impact of woodstove upgrade on indoor PM$_{2.5}$

Interventions and Health: RCT Example

• PM exposure linked to increases in severe asthma attacks, asthma symptoms, asthma medication usage, and hospital visits for asthma and respiratory infections in children.

• Increased frequency of respiratory symptoms and lung function decrement observed in children living in homes with a wood stove.

• Estimated 11.6 million homes, in which ~3 million children reside (Noonan et al. 2015), use wood as a primary or secondary heating fuel in the U.S. (U.S. Department of Energy 2009).

No RCTs in the U.S. have targeted indoor residential wood smoke-derived PM exposures.

ARTIS overview and objectives

• The Asthma Randomized Trial of Indoor Wood Smoke (ARTIS) was set in rural areas of the U.S. where residential wood combustion is:
  • a major source of PM2.5
  • the primary source of home heating

• Included: children (7-18 yrs), with asthma living in a home using an older model wood stove as primary heating source.

• Three-armed RCT (NCT00807183) designed to evaluate the efficacy of in-home interventions in improving indoor air quality and respiratory health in children with asthma (Noonan and Ward 2012).
  • Sham filter
  • Air filter
  • Wood stove change out

ARTIS study communities and timeline

Two exposure assessment and health measures visits in each winter.
### Primary health measures and exposure assessment

**Primary health measures:**
1. Pediatric asthma quality of life instrument (PAQLQ, Juniper et al. 1996)
   - 23-item asthma-specific questionnaire
   - Domain scores for symptoms, activity limitation, and emotional function
   - Retrospective assessment

2. PiKo-1 meter (Ferraris), morning and evening for two weeks
   - % predicted peak expiratory flow (PEF)
   - % predicted forced expiratory volume in first second (FEV₁)
   - Diurnal peak flow variability (dPFV)

\[ \text{dPFV} = \frac{\text{previous night PEF} - \text{morning PEF}}{\text{mean of the two measures}} \]

**Exposure assessment:**
1. Indoor PM₂.⁵ mass (DustTrak, TSI)
2. Particle counts of several size fractions (Lighthouse)

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### PM reductions, by intervention arm

![Graph showing PM reductions by intervention arm]

* Wood stove change out arm eliminated prior to last cohort of homes enrolled due to lack of efficacy in reducing PM₂.⁵.

* Overall reduction in indoor PM₂.⁵ concentrations (-67%, 95% CI: -77% to -50%) for the air filter group relative to the placebo (Ward et al. 2015).

* Strong reductions in PMc in both the filter (72%) and placebo (57%) intervention arms (Ward et al. 2015).

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### Air Filter Impact on Children’s Quality of Life and Self Monitored Peak Flow

- No changes to Quality of Life metrics
- No changes to FEV₁ % predicted
- No changes to PEF % predicted

- Significant percentage point improvement in dPFV:
  - 4.2 (-7.9 to 0.5) for air filter group relative to placebo group
  - Equivalent to a 11% improvement in dPFV
  - Improvements strongest for those with more severe asthma
Air Filter: Efficacy to Effectiveness?

- Issues of noise, cost
- But robust to modest departure from compliance
- Energy

B. PM Exposure from Wildland Fires

- Exposures relative to health based standards
- Studies of respiratory health effects
- Interventions

Biomass Smoke Sources of PM$_{2.5}$: Wildland Fires

Photo: Paul Smith
Fraction of PM$_{2.5}$ attributable to wildfires during fire seasons 2004–2009.

Left:

Subset of days with PM$_{2.5}>35$ μg/m$^3$ (NAAQS threshold).


How does Wildfire Smoke translate to exposure risk?

Liu et al., Epidemiology • Volume 28, Number 1, January 2017.
Findings from Liu et al., 2017

• Smoke Wave = 2 or more consecutive days with daily calibrated wildfire-specific PM2.5 > 50 μg/m3 (near the 98th percentile of all county days across all 561 counties).
• 65% of Western United States counties (369 of 561) experienced at least one smoke wave during the 6-year period.
• Total 10,080 smoke-wave days in all counties in 6 years.
• Among the 369 counties with at least one smoke wave, on average a county had 4.6 smoke-wave days/year.
• 46 million people of all ages were exposed to at least one smoke wave during 2004 to 2009 in the Western United States.
• 5 million Medicare enrollees (≥65 years).
• Respiratory effects from wildfire-specific PM2.5 may be stronger than that of PM2.5 from other sources.
• Note: “...assumed that all persons residing in a given county have the same exposure to wildfire-specific PM2.5 on a given day.”
• Note: Study only conducted among elderly.
• Note: Modeled on limited lag periods (0-5 days).

Liu et al., Epidemiology • Volume 28, Number 1, January 2017
Health Effects Associated with Wildfires: Summary of observational studies

<table>
<thead>
<tr>
<th>Reviews</th>
<th>All Cause Mortality</th>
<th>Respiratory Morbidity</th>
<th>Cardiovascular Morbidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naeher et al 2007</td>
<td>++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finlay et al 2012</td>
<td>+++</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Youssouf 2014</td>
<td>++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Liu 2015</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Reid 2016</td>
<td>++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Adetona 2016</td>
<td>+++</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>


Asthma outcomes in fire-exposed populations

<table>
<thead>
<tr>
<th>Author, year, Location, Study Population</th>
<th>Outcome</th>
<th>Risk estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caamano-Izorna et al. 2011, Galicia, Spain</td>
<td>2 M, Drugs, airway obstructive disease</td>
<td>&lt;18 doses/1000</td>
</tr>
<tr>
<td>Delfino et al. 2009, Southern CA, USA</td>
<td>20.5 M, Asthma hosp. admissions</td>
<td>1.05*</td>
</tr>
<tr>
<td>Henderson et al. 2011, BC, Canada</td>
<td>282 K, Asthma MD visit</td>
<td>1.16*</td>
</tr>
<tr>
<td>Kolbe &amp; Gilchrist, 2000, Albury, AUS</td>
<td>389, Symptoms, shortness of breath</td>
<td>44% of asthmatics</td>
</tr>
<tr>
<td>Rappold et al. 2011, South Carolina, USA</td>
<td>2.7 M, Asthma ER visit</td>
<td>1.65*</td>
</tr>
</tbody>
</table>
Population-based cohort: N = 281,711


Kelowna 2003 Asthma


1.06 (1.04 – 1.07) per 10 µg/m³ PM$_{2.5}$

Summertime Blues: Are there interventions to protect public health?
Hoopa Valley Indian Reservation, 1999
- Trinity River Valley, northern California
- 770 tribal households

Sample Participation Rates For Interventions Implemented by K’ima:w Medical Center

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Number Participating</th>
<th>Percent Participating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wore a Mask</td>
<td>100/286</td>
<td>35%</td>
</tr>
<tr>
<td>Evacuated Reservation</td>
<td>140/287</td>
<td>48%</td>
</tr>
<tr>
<td>Ran HEPA Cleaner at Home</td>
<td>98/287</td>
<td>34%</td>
</tr>
<tr>
<td>Recalled and Recited a PSA</td>
<td>223/289</td>
<td>77%</td>
</tr>
</tbody>
</table>

Conclusions from Hoopa Indian Reservation
- Mask Use: Ineffective
- PSA’s: Effective, but mechanism unclear
- HEPA Cleaners: Effective, need validation
- Evacuation: Ineffective, not feasible
Possibly the worst wildfire smoke event in U.S., both in duration and intensity

35 mornings of Hazardous air quality

Efforts to Protect Public Health

• Messaging. But what messages?
  • Stay indoors?
  • Go to clean spaces?
  • Masks?

• Evacuation declaration!

• Filter distribution

• Rapid Response Health Screen

Rapid Response Screening at Seeley Lake

Contacted by MCC-DEQ
Aug. 30th Sept. 3rd
Initial “Seeley group” meeting
Multiple email/phone/meetings to finalize procedures, surveys, and IRB
Sept. 18th Sept. 20th
Student training
The Event

Sept. 5th

Sept. 18th
Sept. 5th