The Unfinished Health and Research Agendas of Incomplete Combustion Particles

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Tyler Laureate 2012
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Environmental Mutagens in Human Populations,
International Conference
Doha, Qatar
March 29, 2012
300-400 thousand years ago, hearths became a regular feature in human habitation.

The skill that many anthropologists use for defining the point when humanity switched from pre-human to human conditions was learning to control fire (e.g., Levi-Strauss 1969).

By this definition, cooking is the oldest task in human history.

How long ago was this?

“On the earliest evidence for habitual use of fire” Roebroeks and Villa, PNAS, 2011
The three major solid fuels
Comparative Risk Assessment (CRA) 2012

Households using biomass or coal to cook

1990

2010

% of HH Exposed to HAP

- <5
- 51 - 75
- 6 - 20
- 76 - 94
- 21 - 50
- No Data

Comparative Risk Assessment (CRA) 2012
Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn’t it just change to CO₂ and H₂O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%
Energy flows in a well-operating traditional wood-fired Indian cooking stove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances

- Into Pot: 2.8 MJ (18%)
- In PIC: 1.2 MJ (8%)
- Waste Heat: 11.3 MJ (74%)

PIC = products of incomplete combustion = CO, HC, C, etc.

Source: Smith, et al., 2000
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO₂
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*
  - 40+ unsaturated hydrocarbons such as *1,3 butadiene*
  - 28+ mono-aromatics such as *benzene & styrene*
  - 20+ polycyclic aromatics such as *benzo(α)pyrene*
- Oxygenated organics
  - 20+ aldehydes including *formaldehyde & acrolein*
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as *catechol & cresol*
  - Many quinones such as *hydroquinone*
  - Semi-quinone-type and other radicals
- Chlorinated organics such as *methylene chloride and dioxin*

First person in human history to have her exposure measured doing the oldest task in human history

Emissions, yes, but what about exposures?

Kheda District, Gujarat, 1981
Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.

Typical Health-based Standards

- Carbon Monoxide: 150 mg/m³
- Particles: 3.3 mg/m³
- Benzene: 0.8 mg/m³
- 1,3-Butadiene: 0.15 mg/m³
- Formaldehyde: 0.7 mg/m³

10 mg/m³
0.1 mg/m³
0.002 mg/m³
0.0003 mg/m³
0.1 mg/m³

Wood: 1.0 kg Per Hour in 15 ACH 40 m³ kitchen

Best single indicator

Typical Indoor Concentrations

IARC Group 1 Carcinogens
Woodsmoke found to be 2A – probable human carcinogen (Not Group #1 due to weak epidemiological evidence)
Exposure Model for India based on measurements in ~1000 households

Estimated PM2.5 for only solid-fuel-using households

Household Air Pollution Comparative Risk Assessment, 2012

~350 ug/m³ mean WHO guidelines = 10-35 ug/m³
Diseases for which we have epidemiological studies:

- ALRI/Pneumonia
- COPD
- Lung cancer (coal)

These three diseases were included in the 2004 Comparative Risk Assessment managed and published by WHO.

First ever comprehensive risk assessment with consistent rules of evidence and common databases.
How much would 12 Chernobyl-size accidents per year add to the global burden of disease?

- 2 million premature deaths/year - <5% cancer
- 1 million premature deaths/year
- 0.1 million premature deaths/year
Global Burden of Disease Database
and Comparative Risk Assessment
World Health Organization

Being completely updated
For 2012 release

For household air pollution:
New outcome estimates based on meta-analyses
ALRI, COPD, Lung Cancer (from biomass also)
Cataracts, Cardiovascular
Diseases for which we now have epidemiological studies

ALRI/Pneumonia
COPD
Lung cancer (coal)
Lung cancer (biomass)
Blindness (cataracts, opacity)
CV disease
Blood pressure
ST-segment

Stillbirth
Low birth weight

These additional diseases will be included in the 2010 Comparative Risk Assessment – being published 2012

In addition, using evidence from other exposure sources, CVD will be included
There is epi evidence for these other diseases, but considered insufficient to include in the 2010 Comparative Risk Assessment.

- Cognitive Impairment
- Birth defects
- Asthma?
- Tuberculosis
- ALRI
- Other cancers (cervical, NP, upper airway)
- Burns and the health/safety impacts of fuel gathering
Systematic Review and Meta-analysis of lung cancer and household coal combustion

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Year</th>
<th>Cases</th>
<th>Controls</th>
<th>ES (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Africa</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Sasco (2002)</td>
<td>1996-1998</td>
<td>118</td>
<td>235</td>
<td>0.74 (0.17, 3.14)</td>
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<td>Subtotal</td>
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<td>0.74 (0.17, 3.14)</td>
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<td><strong>Europe</strong></td>
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<tr>
<td>Lissowska (2005)</td>
<td>1998-2001</td>
<td>2861</td>
<td>3118</td>
<td>1.13 (0.93, 1.38)</td>
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<td>Subtotal</td>
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<td>1.13 (0.93, 1.38)</td>
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<td><strong>North America</strong></td>
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<tr>
<td>Wu (1985)</td>
<td>1981-1982</td>
<td>220</td>
<td>220</td>
<td>2.30 (0.96, 5.50)</td>
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<tr>
<td>Subtotal</td>
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<td>2.30 (0.96, 5.50)</td>
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<td><strong>India</strong></td>
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<tr>
<td>Gupta (2001)</td>
<td>1995-1997</td>
<td>265</td>
<td>525</td>
<td>1.52 (0.33, 6.98)</td>
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<tr>
<td>Subtotal</td>
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<td>3.76 (1.64, 8.63)</td>
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<td><strong>Mainland China and Taiwan</strong></td>
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<td>Wu-Williams (1990)</td>
<td>1985-1987</td>
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<td>959</td>
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<td>Chengyu (1992)</td>
<td>1990-1991</td>
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<td>135</td>
<td>1.59 (1.22, 2.07)</td>
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<tr>
<td>Ger (1993)</td>
<td>1990-1991</td>
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<td>524</td>
<td>1.44 (0.44, 4.69)</td>
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<td>Li (1993)</td>
<td>1986-1992</td>
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<td>2.08 (0.85, 5.08)</td>
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<td>Lin (1996)</td>
<td>1985-1990</td>
<td>122</td>
<td>122</td>
<td>3.24 (1.05, 9.94)</td>
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<td>Dai (1996)</td>
<td>1992-1993</td>
<td>120</td>
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<td>4.70 (1.29, 17.18)</td>
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<td>Luo (1996)</td>
<td>1990-1991</td>
<td>102</td>
<td>306</td>
<td>6.00 (5.07, 7.10)</td>
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<td>Ko (1997)</td>
<td>1992-1993</td>
<td>117</td>
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<td>1.30 (0.29, 5.80)</td>
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<td>Huang (1999)</td>
<td>1993-1996</td>
<td>122</td>
<td>244</td>
<td>1.92 (1.40, 2.62)</td>
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<td>Wu (1999)</td>
<td>1997</td>
<td>258</td>
<td>258</td>
<td>1.58 (0.89, 2.80)</td>
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<td>Lee (2001)</td>
<td>1993-1999</td>
<td>527</td>
<td>805</td>
<td>2.10 (1.19, 3.70)</td>
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<tr>
<td>Kleinerman (2002)</td>
<td>1994-1998</td>
<td>832</td>
<td>1724</td>
<td>1.29 (1.03, 1.61)</td>
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<tr>
<td>Liang (2004)</td>
<td>2001-2002</td>
<td>152</td>
<td>152</td>
<td>2.02 (1.20, 3.39)</td>
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<tr>
<td>Galeone (2008)</td>
<td>1987-1990</td>
<td>218</td>
<td>436</td>
<td>2.19 (1.08, 4.46)</td>
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<tr>
<td>Subtotal</td>
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<td></td>
<td></td>
<td>2.28 (1.66, 3.13)</td>
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<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td>2.16 (1.62, 2.90)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Odds ratio</th>
<th>0.8</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>5</th>
<th>10</th>
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</thead>
</table>
Lung Cancer: Biomass vs. clean fuel

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>IV, Random, 95% CI</th>
<th>IV, Random, 95% CI</th>
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</thead>
<tbody>
<tr>
<td><strong>2.7.1 Male</strong></td>
<td></td>
<td></td>
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<tr>
<td>Lissowska2005</td>
<td>1.24 [1.00, 1.54]</td>
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<tr>
<td>Sapkota2008</td>
<td>1.30 [0.90, 1.87]</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td>1.26 [1.04, 1.52]</td>
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</tr>
<tr>
<td>Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 0.05$, $df = 1$ ($P = 0.83$); $I^2 = 0%$</td>
<td></td>
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<tr>
<td>Test for overall effect: $Z = 2.37$ ($P = 0.02$)</td>
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<tr>
<td><strong>2.7.2 Female</strong></td>
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<tr>
<td>Sapkota2008</td>
<td>1.01 [0.42, 2.41]</td>
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<tr>
<td>Lissowska2005</td>
<td>1.07 [0.67, 1.71]</td>
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<tr>
<td>Ko1997</td>
<td>2.08 [1.06, 4.07]</td>
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</tr>
<tr>
<td>Lee2001</td>
<td>3.36 [1.62, 6.96]</td>
<td></td>
</tr>
<tr>
<td>Behera 2005</td>
<td>3.59 [1.08, 11.97]</td>
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</tr>
<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td>1.81 [1.07, 3.06]</td>
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<tr>
<td>Heterogeneity: $\tau^2 = 0.21$; $\chi^2 = 10.21$, $df = 4$ ($P = 0.04$); $I^2 = 61%$</td>
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<tr>
<td>Test for overall effect: $Z = 2.20$ ($P = 0.03$)</td>
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<td></td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td>1.48 [1.12, 1.97]</td>
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<tr>
<td>Heterogeneity: $\tau^2 = 0.06$; $\chi^2 = 12.14$, $df = 6$ ($P = 0.06$); $I^2 = 51%$</td>
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<tr>
<td>Test for overall effect: $Z = 2.75$ ($P = 0.006$)</td>
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<tr>
<td>Test for subgroup differences: $\chi^2 = 1.89$, $df = 1$ ($P = 0.17$), $I^2 = 47.1%$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CRA, Imran et al. submitted
Other outcomes

• Intriguing but with insufficient evidence to date to include as primary outcomes. Among them are:
  – Cognitive impacts in children
  – Cervical cancer
Neurodevelopmental performance among school age children in rural Guatemala is associated with prenatal and postnatal exposure to carbon monoxide, a marker for exposure to woodsmoke

Linda Dix-Cooper\textsuperscript{a}, Brenda Eskenazi\textsuperscript{b}, Carolina Romero\textsuperscript{c}, John Balmes\textsuperscript{a,d}, Kirk R. Smith\textsuperscript{a,*}

\textsuperscript{a} Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, CA 94720-7360, USA
\textsuperscript{b} Center for Environmental Research and Children’s Health (CERCH), School of Public Health, University of California, Berkeley, CA, USA
\textsuperscript{c} Centro de Estudios en Salud Universidad Del Valle, Guatemala
\textsuperscript{d} Division of Occupational and Environmental Medicine, Department of Medicine, University of California, San Francisco, CA, USA

(D) Reitan-Indiana Finger Tapping

\[ \beta = -0.6 \quad p = 0.004 \quad n = 37 \]

(B) Bender Gestalt-II Immediate Recall Figures Phase

\[ \beta = -0.3 \quad p = 0.03 \quad n = 39 \]
### Cervical Cancer and Household Air Pollution

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>log(Odds Ratio)</th>
<th>SE</th>
<th>Weight</th>
<th>IV, Random, 95% CI</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrera 2000(a)</td>
<td>0.54232429</td>
<td>0.53624989</td>
<td>17.6%</td>
<td>1.72 [0.60, 4.92]</td>
<td></td>
</tr>
<tr>
<td>Ferrera 2000(b)</td>
<td>1.24990174</td>
<td>0.41614175</td>
<td>20.9%</td>
<td>3.49 [1.54, 7.89]</td>
<td></td>
</tr>
<tr>
<td>Velema 2002(a)</td>
<td>0.06765865</td>
<td>0.45514155</td>
<td>19.8%</td>
<td>1.07 [0.44, 2.61]</td>
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</tr>
<tr>
<td>Velema 2002(b)</td>
<td>1.75093748</td>
<td>0.36626585</td>
<td>22.4%</td>
<td>5.76 [2.81, 11.81]</td>
<td></td>
</tr>
<tr>
<td>Sierra Torres 2006</td>
<td>1.98787435</td>
<td>0.47618897</td>
<td>19.2%</td>
<td>7.30 [2.87, 18.56]</td>
<td></td>
</tr>
</tbody>
</table>

**Total (95% CI)**

100.0%  
3.14 [1.57, 6.30]

Heterogeneity: $\tau^2 = 0.43$; $\text{Chi}^2 = 12.71$, df = 4 ($P = 0.01$); $I^2 = 69$

Test for overall effect: $Z = 3.23$ ($P = 0.001$)

Three papers; two done in Honduras, one in Columbia
Issues with the Cervical Cancer Studies.

- **Problems**
  - Poor exposure assessment
  - Not all adjusted for smoking
  - Doubtful control selection
  - Interaction with HPV not clear

- **Strengths**
  - Large effects
  - Exposure-response shown
  - Known effects of tobacco smoke
Does a chimney reduce exposure enough?

Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial

Kirk R Smith, John P McCracken, Martin W Weber, Alan Hubbard, Alisa Jenny, Lisa M Thompson, John Balmes, Anaite Diaz, Byron Arana, Nigel Bruce

Published Nov 2011
First Randomized Trial In Air Pollution History*

After a worldwide search, chose a site in the Guatemalan Highlands.

* In normal populations
RESPIRE - Randomized trial (n=518)
Impact on pneumonia up to 18 months of age

Traditional open 3-stone fire: kitchen 48-hour PM$_{2.5}$ levels of 600 - 1200 μg/m$^3$

Chimney wood stove, locally made and popular with households
Guatemala RCT: Kitchen Concentrations

Effect of Chimney Stove on Kitchen CO Levels

- Control – open fire
- Intervention – Chimney Stove

Factor of ~10 less

285 48-h measurements

Smith, et al, 2010
Effect of Chimney Stove On Infant Exposures - 2x less

Smith, et al, 2010

1888 48-h measurements
Good chimney stove caused kitchen levels to go down by 10x, but child exposures were down by only 2x, because

--Time-activity: the kids do not spend their entire day in the kitchen
--Household (or “neighborhood”) pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less
--No significant difference in bedrooms
MD-diagnosed Acute Lower Respiratory Infection

Approximate Mean PM2.5 exposure in 100s of ug/m3

Where we want to be! Need clean fuel or very clean biomass burning

RESPIRE-Guatemala
You have heard of secondhand smoke – from tobacco burning

But there is another kind – from cookfires
20-month average ground-level PM2.5 from satellite data

Large areas of rural India and China have high ambient air pollution – much from household fuel
Percent PM$_{2.5}$ emissions from households

Chafe, 2010; data from NASA INTEX_B 2006
Combustion Particles

The Generalized Exposure Response (GER)
Heart Disease and Combustion Particle Doses

From “Mind the Gap,”
Smith/Peel, 2010 and Pope et al., 2009

Solid Fuel Zone
Table 2. Adjusted relative risk estimates for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

<table>
<thead>
<tr>
<th>Source of risk estimate</th>
<th>Increments of Exposure</th>
<th>Lung Cancer</th>
<th>IHD (95% CI)</th>
<th>CVD (95% CI)</th>
<th>CPD (95% CI)</th>
<th>Estimated Daily Dose PM$_{2.5}$ (mg$^*$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS-present analysis</td>
<td>≥3 (1.5) cigs/day</td>
<td>10.44 (7.30-14.94)</td>
<td>1.61 (1.27-2.03)</td>
<td>1.58 (1.32-1.89)</td>
<td>1.72 (1.46-2.03)</td>
<td>18</td>
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<tr>
<td>ACS-present analysis</td>
<td>4-7 (5.5) cigs/day</td>
<td>8.03 (5.89-10.96)</td>
<td>1.64 (1.37-1.96)</td>
<td>1.73 (1.51-1.97)</td>
<td>1.84 (1.63-2.08)</td>
<td>66</td>
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<tr>
<td>ACS-present analysis</td>
<td>8-12 (10) cigs/day</td>
<td>11.63 (9.51-14.24)</td>
<td>2.07 (1.84-2.31)</td>
<td>2.01 (1.84-2.19)</td>
<td>2.10 (1.94-2.28)</td>
<td>120</td>
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<tr>
<td>ACS-present analysis</td>
<td>13-17 (15) cigs/day</td>
<td>13.93 (11.04-17.58)</td>
<td>2.18 (1.89-2.52)</td>
<td>1.99 (1.77-2.23)</td>
<td>2.08 (1.87-2.32)</td>
<td>180</td>
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<tr>
<td>ACS-present analysis</td>
<td>18-22 (20) cigs/day</td>
<td>19.88 (17.14-23.06)</td>
<td>2.36 (2.19-2.55)</td>
<td>2.42 (2.28-2.56)</td>
<td>2.52 (2.39-2.66)</td>
<td>240</td>
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<tr>
<td>ACS-present analysis</td>
<td>23-27 (25) cigs/day</td>
<td>23.81 (18.80-30.18)</td>
<td>2.59 (2.32-2.88)</td>
<td>2.66 (2.42-2.92)</td>
<td>2.77 (2.53-3.02)</td>
<td>300</td>
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<tr>
<td>ACS-present analysis</td>
<td>28-32 (30) cigs/day</td>
<td>26.82 (22.54-31.91)</td>
<td>2.69 (2.43-2.97)</td>
<td>2.76 (2.52-2.99)</td>
<td>2.86 (2.63-3.11)</td>
<td>360</td>
</tr>
<tr>
<td>ACS-present analysis</td>
<td>33-37 (35) cigs/day</td>
<td>26.72 (18.58-38.44)</td>
<td>2.78 (2.52-3.05)</td>
<td>2.85 (2.61-3.09)</td>
<td>2.95 (2.71-3.20)</td>
<td>420</td>
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<tr>
<td>ACS-present analysis</td>
<td>38-42 (40) cigs/day</td>
<td>30.63 (25.79-36.38)</td>
<td>2.90 (2.64-3.16)</td>
<td>3.07 (2.82-3.32)</td>
<td>3.17 (2.92-3.42)</td>
<td>480</td>
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<tr>
<td>ACS-present analysis</td>
<td>43+ (45) cigs/day</td>
<td>39.16 (31.13-49.26)</td>
<td>2.99 (2.73-3.27)</td>
<td>3.14 (2.89-3.40)</td>
<td>3.24 (3.00-3.50)</td>
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<td>ACS-air pol. original</td>
<td>24.5 µg/m$^3$ ambient PM$_{2.5}$</td>
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<td>-----</td>
<td>-----</td>
<td>1.31(1.17-1.46)</td>
<td>0.44</td>
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<tr>
<td>ACS-air pol. extend</td>
<td>10 µg/m$^3$ ambient PM$_{2.5}$</td>
<td>1.14(1.04-1.23)</td>
<td>1.18(1.14-1.23)</td>
<td>1.12(1.08-1.15)</td>
<td>1.09(1.03-1.16)</td>
<td>0.18</td>
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<tr>
<td>HSC-air pol. original</td>
<td>18.6 µg/m$^3$ ambient PM$_{2.5}$</td>
<td>1.20(0.92-1.69)</td>
<td>-----</td>
<td>-----</td>
<td>1.28(1.13-1.44)</td>
<td>0.18</td>
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<tr>
<td>HSC-air pol. extend</td>
<td>10 µg/m$^3$ ambient PM$_{2.5}$</td>
<td>1.21(0.92-1.69)</td>
<td>-----</td>
<td>1.24(1.19-1.41)</td>
<td>-----</td>
<td>0.18</td>
</tr>
<tr>
<td>WHI-air pol.</td>
<td>10 µg/m$^3$ ambient PM$_{2.5}$</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.18</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Low-moderate SHS exp.</td>
<td>-----</td>
<td>-----</td>
<td>1.16(1.03-1.32)</td>
<td>-----</td>
<td>0.36</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Moderate-high SHS exp.</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.90</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Live with smoking spouse</td>
<td>1.21(1.13-1.30)</td>
<td>-----</td>
<td>1.26(1.12-1.42)</td>
<td>-----</td>
<td>0.54</td>
</tr>
<tr>
<td>SGR-SHS</td>
<td>Work with SHS exposure</td>
<td>1.22(1.13-1.33)</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>0.72</td>
</tr>
<tr>
<td>INTERHEART</td>
<td>1-7 hrs/wk SHS exp.</td>
<td>-----</td>
<td>1.24(1.17-1.32)</td>
<td>-----</td>
<td>-----</td>
<td>0.36</td>
</tr>
<tr>
<td>INTERHEART</td>
<td>Live with smoking spouse</td>
<td>-----</td>
<td>1.28(1.12-1.47)</td>
<td>-----</td>
<td>-----</td>
<td>0.54</td>
</tr>
</tbody>
</table>
Lung Cancer

Heart Disease

Pope et al.
Environmental Health Perspectives
2011
Pneumonia from combustion particles
Annual average PM2.5 in ug/m3

Solid Fuel Zone

CRA, 2011
What we can expect based on ATS epidemiological evidence?

- “Traditional” ATS cancers: lung, oral cavity, pharynx, larynx, oesophagus, pancreas, urinary bladder and renal pelvis
- “New” ATS cancers: nasal, sinus, nasopharynx, stomach, liver, kidney, uterine cervix, oesophagus, and leukaemia

Review of Epi Evidence: Lung Cancer, 2004
ETS/SHS and Cancer?

- Causes lung cancer in nonsmoking adults. …living with a smoker increases a nonsmoker’s chances of developing lung cancer by 20 to 30 percent.
- Some research suggests that SHS/ETS may increase the risk of breast cancer, nasal sinus cavity cancer, and nasopharyngeal cancer in adults and the risk of leukemia, lymphoma, and brain tumors in children.

NCI Factsheet, 2012
The cancer research challenge

- **Hypothesis #1**: Most if not all the same cancers found for ATS can also be found for ETS/SHS and HAP, albeit at appropriately lower risks.

- **Hypothesis #2**: They have not yet all been confirmed for ETS/SHS because lower exposures and resultant risk levels make detection difficult compared to ATS studies.

- Living with substantially higher exposures than SHS/ETS, even if lower than ATS, HAP-exposed populations offer excellent opportunities for pinning down a range of cancer risks and associated mutagenicity and genetic associations.

- Considering that the HAP-population is larger and younger than those for ATS or ETS/SHS, the total cancer global burden of cancer is likely to be substantial.
Two policy dilemmas

- How to think about protection when some major impacts are linear, e.g. lung cancer, and others highly non-linear, e.g., heart disease?
- How to think about protection when the major reductions in risk occur only at relatively low levels, or put differently, there is relatively little benefit by changing from high to moderate levels of exposure?
IHD risks from combustion particles
Annual average PM2.5 in ug/m³

Generalized Exposure-Response: Outdoor Air, SHS, and Smoking

CRA, 2011
Many thanks

Publications and presentations on website – easiest to just “google” Kirk R. Smith