Providing Clean Cooking in Developing Countries: What’s the Big Deal?

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The Environmental Health Pathway

SOURCE ➔ EMISSIONS ➔ CONCENTRATION ➔ EXPOSURE ➔ DOSE ➔ HEALTH EFFECTS
The three major solid fuels
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SOURCE ➔ EMISSIONS ➔ CONCENTRATION ➔ EXPOSURE ➔ DOSE ➔ HEALTH EFFECTS
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 cookstove

A Toxic Waste Factory!!

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

<table>
<thead>
<tr>
<th>Energy Flow</th>
<th>Value</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Into Pot</td>
<td>2.8 MJ</td>
<td>18%</td>
</tr>
<tr>
<td>In PIC</td>
<td>1.2 MJ</td>
<td>8%</td>
</tr>
<tr>
<td>Waste Heat</td>
<td>11.3 MJ</td>
<td>74%</td>
</tr>
</tbody>
</table>

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, NO$_2$
- 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*

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Health-Damaging Air Pollutants From Typical Wood-fired Cookstove.

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

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

Typical Indoor Concentrations
- Carbon Monoxide: 10 mg/m³
- Particles: 0.1 mg/m³
- Benzene: 0.002 mg/m³
- 1,3-Butadiene: 0.0003 mg/m³
- Formaldehyde: 0.1 mg/m³

Best single indicator

IARC Group 1 Carcinogens
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SOURCE ➔ EMISSIONS ➔ CONCENTRATION ➔ EXPOSURE ➔ DOSE ➔ HEALTH EFFECTS
First person in human history to have her exposure measured doing the oldest task in human history

~5000 ug/m³ during cooking
>500 ug/m³ 24-hour

Emissions and concentrations, yes, but what about exposures?

Kheda District, Gujarat, 1981
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R.I.P.
How much PM2.5 is unhealthy?

- **WHO Air Quality Guidelines**
  - 10 ug/m³ annual average
  - No public microenvironment, indoor or outdoor, should be more than 35 ug/m³

- **USEPA**
  - Was 15 ug/m³ until 2012: annual outdoors
  - Now 12 ug/m³
  - Same as California since ~2000

Metrics

- Mortality – important, but can be misleading as it does not take age into account or years of illness/injury
  - Death at 88 years counts same as at 18, which is not appropriate
- Disability-adjusted Life Years (DALYs) lost do account for age and illness.
- GBD 2010 compares deaths against best life expectancy in world – 86 years
Diseases for which we have many epidemiological studies:
- ALRI/Pneumonia
- COPD
- Lung cancer
- Blindness (cataracts, opacity)
- Stillbirth
- Low birth weight
- Heart disease
  - Blood pressure
  - ST-segment

These diseases are included in the 2010 Comparative Risk Assessment (released in 2012)
Global DALYs 2010: Top 20 Risk Factors

- High blood pressure
- Tobacco smoking, including second-hand smoke
- Alcohol use
- Household air pollution from solid fuels
- Diet low in fruits
- High body-mass index
- High fasting plasma glucose
- Childhood underweight
- Ambient particulate matter pollution
- Physical inactivity and low physical activity
- Diet high in sodium
- Diet low in nuts and seeds
- Iron deficiency
- Suboptimal breastfeeding
- High total cholesterol
- Diet low in whole grains
- Diet low in vegetables
- Diet low in seafood omega-3 fatty acids
- Drug use
- Occupational risk factors for injuries
Global DALYs 2010: Top 20 Risk Factors

Premature Deaths
HBP -9.3 million
Alcohol – 7.7
Tobacco – 5.7
SHS-T – 0.6
House AP – 3.5
SHS-C – 0.5
High BMI – 3.4
Phys Inactive – 3.2
Outdoor AP – 3.3
High Sodium – 3.1
### DALYS - South Asia by Risk Factor

<table>
<thead>
<tr>
<th>1990</th>
<th>2010</th>
</tr>
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<tbody>
<tr>
<td><strong>1 Childhood underweight</strong></td>
<td><strong>1 Household air pollution</strong></td>
</tr>
<tr>
<td><strong>2 Household air pollution</strong></td>
<td><strong>2 Smoking</strong></td>
</tr>
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HAP in India in 2010
~900 thousand annual premature deaths
About one-quarter of global total

Secondhand cooksmoke
~150 thousand more

About 10% of national mortality

About the same as tobacco
The framing

- Household air pollution from use of solid fuels for cooking
- Exposure based on percent of households using biomass or coal as their primary cooking fuel
- Country models informed now by ~600 nationally representative household surveys over 20+ years.
- Much less confusion with space heating, but not perfectly separated
Population Cooking with Solid Fuels in 2010 (%)
Percent of households cooking with solid fuels by region

Bonjour et al., GBD-2010
Total Population Cooking with Solid Fuels

Bonjour et al., CRA-2010
Framing, cont.

- Not called “indoor” because stove smoke enters atmosphere to become part of general outdoor air pollution (OAP)
- HAP contributes about 16% to OAP globally, but much more in some countries
- Thus, part of the burden of disease due to OAP is attributable to cooking fuels in households ~500,000 premature deaths.
25-30% of primary particle pollution in India is from household fuels.
Delhi Jan 14, 2013
24h mean PM$_{2.5}$: 316.5 µg/m$^3$
Rural India
24h mean $\text{PM}_{2.5}$: 195 $\mu g/m^3$
Urban Beijing
24-hr PM$_{2.5}$ (Jan 18-19): 334 $\mu$g/m$^3$

Source: PM data from US Embassy monitors in Beijing - [https://twitter.com/BeijingAir](https://twitter.com/BeijingAir)
Rural Site outside Beijing

24-hr PM$_{2.5}$ (Jan 18-19): 695 µg/m$^3$

Source: Mean PM concentration from 2 gravimetrically calibrated DustTrak monitors on rooftops in ErHeZhuang Village, 40 km SW from central Beijing. Photos & measurements in village from Anna Zimmermann (Smith research group).
Framing, cont.

• Much effort made to make estimates consistent across the four combustion particle groups in the new GBD/CRA

• Active tobacco smoking, household air pollution, secondhand tobacco smoking, and outdoor air pollution

• HAP and OAP use the same counterfactual level for nearly all diseases: \( \sim 7 \, \text{ug/m}^3 \) annual mean PM2.5 concentration

• Roughly equivalent to cooking with a vented gas stove or electricity
Integrated Exposure-Response: Outdoor Air, SHS, and Smoking and Heart Disease

CRA, 2011
• One of the top risk factors in the world for ill-health.
• Most important environmental risk factor among all examined
• Biggest impact in adults --3 million premature deaths (two-thirds the DALYs)
• Still important for children ~500,000 deaths (one-third the DALYs)
• Important source of outdoor air pollution
• Impact going down slowly because background health conditions improving
• Actual number of people affected is not going down
Not all diseases included

• Many with evidence not included yet
  – Low birth weight
  – TB
  – Other cancers – cervical, upper respiratory, etc
  – Cognitive effects
  – Pneumonia in adults

• Can expect that HAP effects, over time, will be found for nearly all the many dozen diseases found for smoking.

• But at lower risk levels
Important!

• Implied health benefit from HAP reduction only potentially achieved by shifting to clean cooking – gas & electricity
Integrated Exposure-Response: Outdoor Air, SHS, and HAP

Pneumonia from combustion particles
Annual average PM2.5 in ug/m³

Annual Incidence

Outdoor Air Pollution
Secondhand Tobacco Smoke
HAP Zone

CRA, 2010
What is to be done?

A fresh look
World cooking in Pictograms –

One billion people each

With apologies to Hans Rosling at Gapminder*

*”Magic Washing Machine”

And thanks to Ajay Pillarisetti
What do the richest one billion people cook with?

Gas or electric stoves

Plus...
~4 billion worldwide cook with liquified petroleum gas, natural gas, and electricity.
What about the other 3 billion?

SMOKING SECTION

NON-SMOKING
NON-SMOKING

LPG
Natural Gas
Electricity

MARKET BASED OPTIONS
Around half have some access to electricity.
Incentives to move to new cooking technologies?  
Subsidized fuel / capital cost?  
Access to infrastructure and improved markets?

Market-ready advanced stoves + fuels

UNPURCHASED NO MARKET ACCESS

UNPURCHASED WILLING TO USE THE MARKET
Newborn Stove (NBS) Project

SOMAARTH Surveillance Site – Haryana ~200,000 people

Berkeley, Columbia INCLEN, SRU
NBS Project
Introducing advanced combustion stoves to pregnant women through the official ante-natal care system in India

Monitoring air pollution, usage, birth outcomes, and infant pneumonia.
Bottom Line

You don’t get what you expect, but what you inspect
Many thanks

Funders for HAP CRA
USEPA
Shell Foundation
For NBS Project
World Bank
CDC/GACC
World Lung
Foundation