How can simple cookfires cause so much ill-health?

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Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors

- Underweight: 4.9 million deaths/y
- Unsafe sex: 1.6 million deaths/y (~two-thirds in children; one-third in women)
- Blood pressure: 0.8 million death/y

WHO, 2004

Percent of All DALYs in 2000
Oldest Pollution Source in Human History

Why does it still cause so much ill-health?

---Physical reasons
---Physiological reasons
---Political/economic/social reasons
#1 Widely used
Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 1.67 toe
Índice de Prioridad por uso de Leña (IPL)

- **Alto**: 322 municipios
- **Medio**: 329 municipios
- **Bajo**: 713 municipios
- **Sin Datos**: 33 municipios

Áreas prioritarias por uso residencial de leña en México - 2000

Áreas accesibles de 10km de radio alrededor de localidades y 3km al costado de caminos

Productividad media de madera para energía por hectárea por año.


Creado en ArcGIS 9.2 utilizando ArcMap.

More than half the world’s population relies on biomass for most of its energy, a situation that has not changed since the mastery of fire, one million years ago.
#2 Highly polluting
Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn’t it just change to CO$_2$ and H$_2$O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%
Heat

Products of Incomplete Combustion

PIC

PIC

Heat

SOLID FUEL

CHAR RESIDUE

FLAME

THERMAL FEEDBACK

VOLATILES

AIR

PRODUCTS OF COMBUSTION
Carbon Balance:

A Toxic Waste Factory!!

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

CO₂ Carbon: 295.8 g
PIC Carbon: CO: 18.5 g
CH₄: 2.8 g
TNMOC: 5.2 g
Char/Ash: 161 g
130 g Carbon
TSP Carbon: 1.7 g

Nominal Combustion Efficiency = 1/(1+k) = 89%
<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Nominal Combustion Efficiency</th>
<th>Approximate % of Households - 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>99% (98-99.5)</td>
<td>[18%]</td>
</tr>
<tr>
<td>Kerosene</td>
<td>97 (95-98)</td>
<td>[7]</td>
</tr>
<tr>
<td><strong>Solid Fuels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>89 (81-92)</td>
<td>[53]</td>
</tr>
<tr>
<td>Crop resid</td>
<td>85 (78-91)</td>
<td>[10]</td>
</tr>
<tr>
<td>Dung</td>
<td>84 (81-89)</td>
<td>[10]</td>
</tr>
<tr>
<td>Coal</td>
<td>(variable)</td>
<td>[2]</td>
</tr>
</tbody>
</table>

Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles: Best measure of risk
  - 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*

- Hydrocarbons
  - 20+ aldehydes including formaldehyde & acrolein
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as catechol & cresol
  - Many quinones such as hydroquinone
  - Semi-quinonone-type and other radicals

- Oxygenated organics such as *methylen chloride* and *dioxin*

- Chlorinated organics such as *methylene chloride* and *dioxin*

Best measure of risk ~ 0.1-0.4% of fuel weight

Naehler et al. 2007, JIT
Nearly all smaller than 2.5 µm

Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East-West Center simulated village house as reported in Smith et al. (1984b). (Figure prepared by Premlata Menon.)

Source: Smith, Apte et al. 1984
20-month average ground-level PM2.5 from satellite data
#3 High Intake Fraction
**Intake Fraction (IF)**

- *IF* is the fraction of material emitted that crosses some person’s physiological barriers (skin, GI tract, Resp. tract, etc.)
- For air pollution, *IF* is the fraction breathed in by the exposed population.
Defining “Intake Fraction”

For an inhaled pollutant:

\[
\text{Intake Fraction (iF)} = \frac{\text{Total Intake}}{\text{Total Emissions}} = \frac{\sum_t \sum_P C(P, t) \cdot Q_B(P, t)}{\sum_t E(t)}
\]

- \( C \) = Concentration (g/m\(^3\))
- \( Q_B \) = Breathing Rate (m\(^3\)/s)
- \( E \) = Emissions (g/s)
- \( P \) = Population
- \( t \) = time

Marshall et al., 2001
IF = 1.0
Intake Fraction Varies as Much as Toxicity (these are rough calculations for typical examples of sources in each class)

- **Cigarette - mainstream**
- **ETS**
- **Stove Vented Indoors**
- **Stove Vented Outdoors**
- **Neighborhood Sources**
- **Vehicles**
- **LDC Power Plant**
- **US Coal Power Plant**

Smith, 1993

**Grams Inhaled per Tonne Emitted**
What Does iF (Inhalation) Depend On?

1. **Proximity** (Source type)
   - indoor / outdoor
   - stack / ground-level

2. **Persistence** (Pollutant dynamics)
   - reaction kinetics
   - removal mechanisms

3. **Population**

4. **Breathing rate**

... and temporal and spatial variability of these factors
Power of Intake Fraction

• “Rule of One Thousand” = Pollutants released indoors are 1000 times more likely to reach someone’s lungs than if released outdoors.

• Sample comparison: U.S. power plant versus cigarettes
  – Source:
    • 1 ton coal = 1 million cigarettes (1 g each)
  – Emissions of particles
    • 1 ton coal = 24,000 cigarettes
  – Approximate particle intake equivalence
    • 1 ton coal = 24 cigarettes (ETS)

• Thus, even though there are more than 40 times more primary particles released from coal power plants in the US than from cigarettes, less than a 2-5% reduction in passive smoking (ETS exposures) would be equivalent to eliminating all the power plants in the country in terms of particle exposure.

Smith, 1988
First person in human history to have her exposure measured doing one of the oldest tasks in human history

What kind of exposures?
Indoor pollution concentrations from typical woodfired cookstove during cooking

- **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

**Indoor Levels**

- **Typical standards to protect health**
- **International Agency for Research on Cancer (IARC) Group I Carcinogens**

10 mg/m³
0.1 mg/m³
0.002 mg/m³
0.0003 mg/m³
0.1 mg/m³
#4 Not easy to fix - ventilation
RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)

- Traditional 3-stone open fire
- "Plancha" chimney wood stove

Highland Guatemala
Effect of Plancha on PM2.5

~90% Reduction, sig.

Log Scale

48-h ug/m³

Open fire

Plancha

Kitchen

1,000

100

10

1

Effect of Plancha on PM2.5

~90% Reduction, sig.
Tubito

Tubito

Tubito
(a) Log of 48-hour CO (ppm)

(b) Child Average of Log of CO (ppm)

~ 50% reduction in child exposures
Reasons that child personal exposures did not lower as much as kitchen levels:

--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

--Other burning around house not different
Effect of Plancha on PM2.5

Log Scale

Open fire

~90% Reduction, sig.

Plancha

Kitchen

48-h ug/m³

1000

100

10

1
Neighborhood Pollution

Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM
Neighborhood Pollution in an Indian Village
#5 Not easy to fix--combustion
Internal Stove Efficiencies (carbon balance method)

• Overall efficiency is function of two internal efficiencies: \( OE = NCE \times HTE \)
• Nominal Combustion Efficiency (NCE) = percent of fuel carbon released as \( CO_2 \)
• Heat transfer efficiency (HTE) = \( OE/NCE \)
• NCE = \( CO_2/(CO_2 + PIC) \) -- on a carbon basis
Energy flows in well-operating traditional woodfired cookstove

PIC = products of incomplete combustion.

Wood: 1 kg
15.33 MJ
Traditional Stove

Into Pot
2.76 MJ
18%

In PIC
1.23 MJ
8%

Waste Heat
11.34 MJ
74%
Increasing Fuel Efficiency Does not Always Decrease Emissions Per Meal
**How can less fuel mean more pollution?**

<table>
<thead>
<tr>
<th>Stove</th>
<th>Overall Efficiency</th>
<th>Heat Transfer Efficiency</th>
<th>Nominal Combustion Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>14</td>
<td>15</td>
<td>97</td>
</tr>
<tr>
<td>“Improved”</td>
<td>27</td>
<td>30</td>
<td>90</td>
</tr>
</tbody>
</table>

Change = 73% more pollution per meal!

\[
\begin{align*}
\text{27/14} &= 1.93 \times \text{fewer kg fuel per meal} \\
(1-0.90)/ (1/0.97) &= 3.33 \times \text{more PIC per kg fuel}
\end{align*}
\]
Biomass smoke – a global concern

• A significant contribution to PM2.5 emissions around the world – more than half in many developed countries (Canada, Denmark, much of USA, etc.)
  – Ag burning a function of ag production, not income - California
  – Wood heating and fireplace use common in many developed countries – Silicon Valley

• Growing because of energy prices
• And climate change
% Biomass Energy Use & GNP

Source: RWEDP
Energy Use in Thailand by Source

Source: RWEDP
Asia Pacific shares of 2.31 Gtoe

- Geothermal, Solar, etc.: 0.5%
- Hydro: 1.7%
- Combustible Renewables & Waste: 24.8%
- Coal: 39%
- Crude Oil: 24.5%
- Gas: 7.3%
- Nuclear: 0.8%

OECD shares of 5.33 Gtoe

- Combustible Renewables & Waste: 3.3%
- Coal: 20.8%
- Crude Oil: 40.4%
- Gas: 21.3%
- Nuclear: 11.2%
- Petroleum Products: 0.5%
- Hydro: 2.0%
- Geothermal, Solar, etc.: 0.7%

Approximately equal per capita consumption!

WEA, 2004
California’s 2005 Combustion PM$_{2.5}$ Emissions

Biomass: 62% of total

~450 t/day

From CARB database
Most the papers and other publications from which these data were taken are available at http://ehs.sph.berkeley.edu/krsmith

Thank you
Physiological Reason #1

- Smoke’s main impact is not by causing new diseases
- But by exacerbating risk of existing diseases
- Thus, populations with high background disease rates are most vulnerable
- Women and children in rural areas of poor countries are the most vulnerable in the world
Almost all Women & Children

World Lost Healthy Life Years (DALYs)