The Unfinished Agenda of Incomplete Combustion for Climate and Health

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US Department of State
April 29, 2009
A large part from PIC: products of incomplete combustion

Warming in 2005 from emissions since 1750
The climate change problem is caused not only by too much complete combustion of fossil fuels (CO2), but also by too much incomplete combustion of all fuels (PIC)
Where do these PIC come from?

From forest and savannah fires – not directly human caused in general

Where else?
Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 1.67 toe

World Energy – 2001

- Natural Gas: 21.7%
- Nuclear: 6.9%
- Hydro: 2.3%
- "Modern" Biomass Renewables: 1.4%
- Other Renewable: 0.8%
- Traditional Biomass: 9.3%
- Oil: 35.1%
- Coal: 22.6%

Also from solid household fuels: Biomass and coal

World Energy Assessment, 2004
Global Black Carbon Emissions

- Household Fuels, 55.9%
- Off-road Transport, 7.0%
- On-road Transport, 19.6%
- Ag Burning, 5.5%
- Industry, 12.1%
- Power, 0.2%

No forest fires

Total 6600 gigagrams in 2000

BC Campaign Data
More than 75% of households

2+ million tons methane per year of 300 Mt total global human emissions

50-74% of households

2000 Census
Household Solid Fuel Burning

- What are the PIC and why are they created?
- Where do they sit in the climate landscape?
- What are their health implications – current estimates?
- Results from the first randomized trial – RESPIRE in the Guatemalan Highlands
- Need and prospects for advanced stoves
- New capabilities for M&E
- Summary of where we are now
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%
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

Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.

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

**Typical Health-based Standards**
- Carbon Monoxide: 150 mg/m³
  - 10 mg/m³
- Particles: 3.3 mg/m³
  - 0.1 mg/m³

**Typical Indoor Concentrations**
- Benzene: 0.8 mg/m³
  - 0.002 mg/m³
- 1,3-Butadiene: 0.15 mg/m³
  - 0.0003 mg/m³
- Formaldehyde: 0.7 mg/m³
  - 0.1 mg/m³

**IARC Group 1 Carcinogens**
- Best single indicator
<table>
<thead>
<tr>
<th>Location</th>
<th>Region</th>
<th>Number of households</th>
<th>Range (24 hour average of PM 10)</th>
<th>Mean (µg/m3) (24 hr average of Kitchen &amp; Living Concentrations of PM10)</th>
<th>Other Determinants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamil Nadu</td>
<td>South</td>
<td>4</td>
<td>110-410</td>
<td>223</td>
<td>Fuel/Kitchen/Stove</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>South</td>
<td>3</td>
<td>115-980</td>
<td>485</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>Karnataka</td>
<td>South</td>
<td>3</td>
<td>608-1443</td>
<td>898</td>
<td>Fuel/Stove</td>
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<tr>
<td>Madhya Pradesh</td>
<td>West/Central</td>
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<td>280-3300</td>
<td>690</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>Gujarat</td>
<td>West</td>
<td>6</td>
<td>489-1530</td>
<td>780</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>Goa</td>
<td>West</td>
<td>1</td>
<td>450-978</td>
<td>635</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>West Bengal</td>
<td>East/North East</td>
<td>9</td>
<td>270-2240</td>
<td>795</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>Haryana</td>
<td>North</td>
<td>1</td>
<td></td>
<td>850</td>
<td>Fuel/Kitchen</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>North/Mountain</td>
<td>76</td>
<td>270-2240</td>
<td>620</td>
<td>Fuel/Kitchen</td>
</tr>
</tbody>
</table>

WHO Global Air Quality Guideline for Indoor/Outdoor particle Levels

- 20 µg/m³

Absolutely no population even in the poorest countries should be exposed to more than

- 70 µg/m³

Data compiled by SRU, Chennai
First person in human history to have her exposure measured doing one of the oldest tasks in human history

Exposures seem to be high in a large vulnerable population. But what are the health effects?

Kheda District, Gujarat, India
1981
How Much Global Ill-Health can be Attributed to Household Indoor Air Pollution?
Comparative Quantification of Health Risks
Global and Regional Burden of Disease Attributable to Selected Major Risk Factors
Volume 1
Edited by Majid Ezzati, Alan D. Lopez, Anthony Rodgers and Christopher J.L. Murray

Published in late 2004, 2 vols, ~2500 pp
Available on World Health Organization website
Being completely revised Publication in 2010

http://www.who.int/publications/cra/en/
National Household Solid Fuel Use, 2000

Being updated – now more than 300 nationally representative household surveys available
## The Energy Ladder: Relative Pollutant Emissions Per Meal

### India Data

<table>
<thead>
<tr>
<th></th>
<th>Biogas</th>
<th>LPG</th>
<th>Kerosene</th>
<th>Wood</th>
<th>Roots</th>
<th>Crop Residues</th>
<th>Dung</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO</strong></td>
<td>0.1</td>
<td>1.0</td>
<td>3</td>
<td>19</td>
<td>22</td>
<td>60</td>
<td>64</td>
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<tr>
<td><strong>Hydrocarbons</strong></td>
<td>0.3</td>
<td>1.0</td>
<td>4.2</td>
<td>17</td>
<td>18</td>
<td>32</td>
<td>115</td>
</tr>
<tr>
<td><strong>PM</strong></td>
<td>2.5</td>
<td>1.0</td>
<td>1.3</td>
<td>26</td>
<td>30</td>
<td>124</td>
<td>63</td>
</tr>
</tbody>
</table>

Smith, et al., 2005

Legend:
- **CO**
- **Hydrocarbons**
- **PM**
Diseases for which we have studies showing links to household solid fuel use

ALRI/Pneumonia (meningitis)
Low birth weight & stillbirth
Asthma?
Early infant Death?
Cognitive Effects (lower IQ)?
Birth defects?; cleft

Chronic obstructive lung disease
Interstitial lung disease
Cancer (lung, NP, cervical, aero-digestive)
Blindness (cataracts, trachoma)
Tuberculosis
Heart disease?

Fire-related deaths and burns
Diseases for which we have studies showing links to household solid fuel use

ALRI/Pneumonia (meningitis)

Chronic obstructive lung disease

Only two qualified with sufficient evidence to be included in the original WHO Comparative Risk Assessment – 2004

More to be added in the update, slated for 2010
The Lancet, March 2, 2009

Fire-related deaths in India in 2001: a retrospective analysis of data

Prachi Sanghavi, Kavi Bhalla, Veena Das

Summary
Background Hospital-based studies have suggested that fire-related deaths might be a neglected public-health issue in India. However, no national estimates of these deaths exist and the only numbers reported in published literature come from the Indian police. We combined multiple health datasets to assess the extent of the problem.

Methods We computed age–sex-specific fire-related mortality fractions nationally using a death registration system based on medically certified causes of death in urban areas and a verbal autopsy based sample survey for rural populations. We combined these data with all-cause mortality estimates based on the sample registration system and the population census. We adjusted for ill-defined injury categories that might contain misclassified fire-related deaths, and estimated the proportion of suicides due to self-immolation when deaths were reported by external causes.

Findings We estimated over 163,000 fire-related deaths in 2001 in India, which is about 3% of all deaths. This number was six times that reported by police. About 106,000 of these deaths occurred in women, mostly between 15 and 34 years of age. This age–sex pattern was consistent across multiple local studies, and the average ratio of fire-related deaths of young women to young men was 3:1.

Interpretation The high frequency of fire-related deaths in young women suggests that these deaths share common causes, including kitchen accidents, self-immolation, and different forms of domestic violence. Identification of populations at risk and description of structural determinants from existing data sources are urgently needed so that interventions can be rapidly implemented.

Funding None.
Acute lower respiratory infections (ALRI)

Chief cause of death among the world’s children (>2 million per year). Thus, it is the chief global cause of lost healthy life years.

Child mortality occurs almost entirely in developing countries, and as pneumonia.

Well-accepted risk factors (malnutrition, micro-nutrient deficiencies, other diseases, crowding, chilling) do not account for its scale.
Pneumonia Deaths in the United States

Not so long ago pneumonia was chief cause of death in developed countries

ALRI associated with use of solid fuels: analysis of ~10 observational studies

<table>
<thead>
<tr>
<th>Subgroup analyses</th>
<th>Odds ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All studies</td>
<td>2.3 (1.9-2.7)</td>
</tr>
<tr>
<td>Use of solid fuel</td>
<td>2.0 (1.4-2.8)</td>
</tr>
<tr>
<td>Duration of time child spent near the cooking fire</td>
<td>2.3 (1.8-2.9)</td>
</tr>
<tr>
<td>Studies adjusting for nutritional status</td>
<td>3.1 (1.8-5.3)</td>
</tr>
<tr>
<td>Studies not adjusting for nutritional status</td>
<td>2.2 (2.0-3.0)</td>
</tr>
<tr>
<td>Children aged &lt;2 years old</td>
<td>2.5 (2.0-3.0)</td>
</tr>
<tr>
<td>Children aged &lt;5 years old</td>
<td>1.8 (1.3-2.5)</td>
</tr>
</tbody>
</table>

Smith et al in WHO, Comparative quantification of health risks, 2004
Consistent with

- Controlled animal and human exposures showing effects on respiratory immune system
- Dozens of studies of the effect of environmental tobacco smoke exposures in children
- A few studies of outdoor air pollution
Global Burden of Disease from Top 10 Risk Factors plus selected other risk factors

- Underweight
- Unsafe sex
- Blood pressure
- Tobacco
- Alcohol
- Unsafe water/sanitation-E*
- Child cluster vaccination
- Road traffic accidents
- Cholesterol
- Indoor smoke-E
- Overweight
- Low fruit and veg
- Occupational (5 kinds)-E
- Lead (Pb)-E
- Urban outdoor air-E
- Climate change-E

Percent of All DALYs in 2000

- 4.9 million premature deaths/y
- 1.6 million premature deaths/y (~1 million in children under 5 y)
Indian Burden of Disease from Top 10 Risk Factors and Selected Other Risk Factors

- Underweight: 13.8%
- Unsafe water/sanitation: 8.1%
- Indoor smoke: 5.3%
- Unsafe sex: 4.5%
- Iron deficiency: 4.2%
- Tobacco: 4.1%
- Blood pressure: 4.1%
- Child cluster Vaccination: 3.9%
- Cholesterol: 3.5%
- Road traffic accidents: 3.3%
- Zn Deficiency: 3.0%
- Low fruit & veg: 2.3%
- Occupational (5 kinds): 2.0%
- Lead (Pb): 1.0%
- Climate change: 0.8%
- Urban outdoor air: 0.6%
- Unsafe sex: 760,000 deaths/year
- Tobacco: 420,000 deaths/year

Percent of All DALYs in 2000

KRS from data in World Health Reports – 2001, 02

420,000 deaths/year

760,000 deaths/year
Burden of Disease in Sub-Saharan Africa from Top 10 Risk Factors and Selected Other Risk Factors

- Unsafe sex
- Underweight
- Lack of Malaria control*
- Unsafe water/sanitation
- Childhood cluster*
- Vitamin A deficiency
- Zinc deficiency
- Indoor smoke from solid fuels
- Iron deficiency
- Alcohol
- Road traffic accidents*
- Blood pressure
- Tobacco
- Climate change
- Occupational hazards (5 types)
- Lead (Pb) pollution
- Urban outdoor air pollution

Percent of All DALYs in 2000

Poorest 20 countries only (~350 million people)

220,000 deaths per year

In Smith et al., 2005. Derived from WHO data
Problems with all Previous ALRI and IAP Studies

• Studies were all observational and thus not able to be sure the effect was not due just to poverty and not air pollution.
• Too much confusion with upper respiratory infections
• Little or no exposure assessment.
• Solution is a
  – Randomized control trial (RCT) in which half households receive improved stove on a random basis at the start, other keep open fires until end
  – Much better diagnosis of disease
  – Full exposure assessment
History of a RCT

- ~1980: Early studies of health effects in Nepal and elsewhere
- 1981: First measurements of pollution levels in India
- 1984: International meeting to decide on needed research
  - Chose randomized control trial (RCT) of ALRI
- 1986-89: Unfunded proposals to do RCT in Nepal
- 1990: WHO establishes committee to find best sites
- 1990-1992: Criteria established and site visits made
- 1992: Highland Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: Unfunded proposals
- 2001: NIEHS funding secured
- 2002-2005: Fieldwork completed
- 2007: First results published
- 23+ years from deciding to conduct RCT to results!
First Randomized Trial In Air Pollution History*

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

* In normal populations
Setting

- Rural highlands of San Marcos, western Guatemala
- Population nearly all indigenous Mayan Indians
- Nearly all depend on wood for cooking and heating
- Traditional stove is the 3-stone fire – no venting to outside
- Very poor, high IMR, pneumonia, diarrhea and stunting common
- Poor health service uptake - culture, language, transport, time
- Intervention is a stove with chimney that is well-accepted by community
RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)

Highland Guatemala

Traditional 3-stone open fire

Plancha chimney wood stove
RESPIRE Teams

• 25-35 fulltime field staff
  – 17-25 locally hired bilingual (Mam-Spanish) fieldworkers
  – Field manager
  – 2 field supervisors
  – Data manager
  – 2-3 physicians
  – Environment engineer for air pollution monitoring
  – 4-6 office/data entry staff
  – All Guatemalan
• Investigators and students in Berkeley, Guatemala, Liverpool, Boston, Geneva, and Bergen
• International **Data Safety Management Board** for ongoing protection of human subjects
• NIH and several other funders
Overview of RESPIRE study design

- 530 eligible households: open fire, woman pregnant or child less than 4 months
- Baseline survey and exposure assessment

Randomize

Keep open fire

Plancha

Follow up till aged 18 months
- Surveillance for ALRI, diarrhoea, &c
- Detailed exposure monitoring

Compare incidence and exposure in 2 groups
Plancha offered to ‘controls’

Year 1
5500 Households total

Years
1-3

Years
3-4
## Randomisation: balance of groups at baseline

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Socio-demographic factors</strong></td>
<td></td>
<td></td>
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<tr>
<td>Mother’s Age (years)</td>
<td>27.0</td>
<td>26.4</td>
</tr>
<tr>
<td>Pregnant at recruitment (%)</td>
<td>48.3</td>
<td>51.3</td>
</tr>
<tr>
<td>Own home (%)</td>
<td>92.8</td>
<td>94.1</td>
</tr>
<tr>
<td>Migrates part of year (%)</td>
<td>17.7</td>
<td>17.1</td>
</tr>
<tr>
<td><strong>House structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separate enclosed cooking area (%)</td>
<td>76.2</td>
<td>74.3</td>
</tr>
<tr>
<td>Completely open eaves (%)</td>
<td>42.7</td>
<td>40.6</td>
</tr>
<tr>
<td>Walls – adobe (mud) (%)</td>
<td>88.7</td>
<td>90.7</td>
</tr>
<tr>
<td>Roof – metal (%)</td>
<td>77.4</td>
<td>74.3</td>
</tr>
<tr>
<td>Floor – earth (%)</td>
<td>92.5</td>
<td>88.8</td>
</tr>
<tr>
<td>Leaks in roof (water) (%)</td>
<td>24.5</td>
<td>33.3</td>
</tr>
<tr>
<td>Electricity (%)</td>
<td>70.8</td>
<td>69.3</td>
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<tr>
<td><strong>Other sources of smoke</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other fire near house (%)</td>
<td>14.6</td>
<td>14.4</td>
</tr>
<tr>
<td>Smoking (tobacco) indoors (%)</td>
<td>26.8</td>
<td>20.4</td>
</tr>
<tr>
<td>Use traditional sauna bath (%)</td>
<td>84.5</td>
<td>87.8</td>
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<tr>
<td><strong>Geographic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean altitude (metres)</td>
<td>2613</td>
<td>2601</td>
</tr>
</tbody>
</table>
Overview of child health outcomes assessment

**Home**
- Weekly visit
  - Well
  - Mild illness
  - Referral to study doctor

**Community centre**
- Study doctor examines
  - Pulse oximetry
  - If pneumonia, RSV* test and refer for CXR
  - Refer if very ill

**Hospital**
- Assessed by duty doctor
  - Study team obtain CXR and inpatient data and diagnosis

Follow-up at weekly visit

Health outcome definitions

* Respiratory syncitial virus
PHYSICIAN ASSESSMENT

- Clinical assessment is the key outcome
- Needed to standardise
- Six employed (four assessed 96.4% referrals)
- Use of agreed terms and signs
- Initial ‘calibration’ and ongoing (± monthly) clinical sessions
PULSE OXIMETRY

• Non-invasive and well-accepted (99%)
• Measure of severity (of respiratory illness):
  - mortality up to x5 in hypoxaemic
• Well children (n=55)
  - Mean (SD) 93.2% (3.0)
  - Hypoxaemic defined as mean - 2SD = 87%
• Bogota (5d – 24mo) altitude 2640m, mean (SD) 93.3% (2.1)
What a Well-Operating Chimney Does

McCracken, et al., 2009
Effect of Plancha on PM2.5

Log Scale

- Open fire: ~90% Reduction, sig.
- Plancha: ~20% reduction, ns

48-h ug/m³

Kitchen
Unpublished results from RESPIRE have been removed

Watch the website below where they will be posted as soon as they are published.

http://ehs.sph.berkeley.edu/krsmit

Regrets/KR Smith
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
Neighborhood Pollution

Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM
Neighborhood Pollution in an Indian Village

Smith, 1987
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
## China National Stove Contest - 2007

<table>
<thead>
<tr>
<th></th>
<th>Efficiency</th>
<th>CO/CO₂</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daxu</td>
<td>0.020</td>
<td>41.9</td>
<td>0.28</td>
</tr>
<tr>
<td>Jinqilin</td>
<td>0.014</td>
<td>41.4*</td>
<td>0.20</td>
</tr>
<tr>
<td>Xintai</td>
<td>0.025</td>
<td>32.6*</td>
<td>0.36</td>
</tr>
<tr>
<td>Zhenghong</td>
<td>0.019</td>
<td>35.9</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Compared to traditional biomass stove:

- 28.7 g to 1.2 g small particles/meal
- >20x less

# Zhang, et al., 2000

*Not including water heating function*
CO2 and methane only

Haigler and Smith, 2008

Carbon Cost Effectiveness ($/tCO2e)

Health Cost Effectiveness (Int$/DALY)

DALYs avoided Relative Values ($/Int)

- U.S.
- China
- India

China: Household coal to propane/LPG stoves
China: Wind
U.S.: Nuclear
U.S.: Hybrid vehicles
U.S.: Solar PV
China: Solar PV
India: Improved biomass stoves
China: Household coal to biomass gasifier stoves
Why M&E?
You don’t get what you expect, but what you inspect

Abandoned improved stove, Guatemala
Misplaced self-polluting chimney, Guatemala
Standard Methods are too slow, too imprecise, too labor intensive, and too expensive for use with millions of stoves.

**Fuel savings** estimation through KPT (kitchen performance test) and sales records.

**Tracking drop out rates** through surveys, visits and phone interviews.

**Monitoring** reductions in indoor air pollution and black carbon emissions.
What can be done?

Small, Smart, Fast, and Cheap monitors

Available or under testing

Where can we monitor what we do?

Smith, 1983

Smith, 1983

Figure 1.8. Categorization and flowchart of separate topics involved in investigating the extent and impact of air pollution exposures from combustion of biofuels in developing countries. Modified from Smith et al. (1983).
UCB-SUMS: The Stove Use Monitoring System

**Fuel savings** quantification using the SUMS system

Monitoring **drop out rates** and **patterns of use** with the SUMS system
Objective Monitoring with the UCB-SUMS System

Continental Information of Stove Use:

Sensor-data provide a complete record of how this improved stove was only used during the first 2 days of monitoring.

Ruiz et al., 2008
Measuring Adoption Dynamics with the UCB-SUMS

Population Level Information:
Each point is the average hours for a population of 40 households that a stove is used each day.

Data from the CRECER Guatemala Study

Ruiz et al., 2008
Transition from open fire to a new Plancha stove

Ruiz et al., 2008
Patterns of Stove Use from Around the World captured with the UCB-SUMS

ROCKET stove
Fuel: Biomass

TRADITIONAL stove
Fuel: Biomass

SEMI-GASIFIER stove
Fuel: Corn cobs

CHIMNEY stove
Fuel: Biomass

LP GAS Stove

breakfast lunch dinner

Tamil Nadu
INDIA

Shaanxi
CHINA

Michoacan
MEXICO

San Marcos
GUATEMALA
Laws of Carbon-thermodynamics

I. Keep all fossil and forest carbon out of the atmosphere

II. If you cannot do so, the least-damaging form to release is carbon dioxide because all other forms are worse for climate and health.

III. Even renewable (non-fossil) carbon is damaging for climate and health if not released as carbon dioxide.
Ranking of Carbon Emissions: The Pharmaceutical Index

• Carbon dioxide is bad if fossil or forest derived, but benign if from renewable sources
• Products of incomplete combustion (PIC) such as carbon monoxide and hydrocarbons are like CO$_2$ on caffeine – several times worse
• Methane from any source (fossil, biologic, or incomplete combustion) is like CO$_2$ on steroids – dozens of times worse.
• Black carbon in particles from incomplete combustion is like CO$_2$ on crack – hundreds of times worse.
Combustion Mismanagement and Health

• Sticking burning stuff in your mouth
• In your home
• In your workplace
• In your community
• On your planet
<table>
<thead>
<tr>
<th>Combustion Risk Factor</th>
<th>Million Deaths</th>
<th>Percent of Global Deaths</th>
<th>Percent of Disease Burden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tobacco</td>
<td>4.9</td>
<td>8.7%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Indoor smoke from household solid fuel</td>
<td>1.6</td>
<td>2.9</td>
<td>2.6</td>
</tr>
<tr>
<td>ETS and Workplace</td>
<td>0.5</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Urban outdoor air pollution</td>
<td>0.80</td>
<td>1.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Climate change</td>
<td>0.15</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Adjusted totals</strong></td>
<td><strong>~ 8</strong></td>
<td><strong>~ 14%</strong></td>
<td><strong>~ 10%</strong></td>
</tr>
</tbody>
</table>
The Unfinished Agenda

Products of Incomplete Combustion, an ancient but still large risk to health and climate

One out of seven deaths each year occurs prematurely because of combustion mismanagement - PIC

As PIC, a major reason for global warming – nearly half that from CO2

Short-lived – fix today and many impacts stop in a few months – all in a few years

Time to move on
Warming from Carbon Emissions Since 1750

- **CO2**
  - Decades to centuries

- **CH4**
  - Years

- **CO+NMVOC**
  - Months

- **BC-OC**
  - Weeks

Tropospheric Ozone Portion

Addition beyond IPCC models indicated by more recent work

2005 W/m²
**Stove Dissemination Lessons**

- Need to start in places/populations where success is easier and quicker
- Need to create a modest range of models for different fuels, foods, and incomes – perhaps designed to be phased (model for bride, for the first child, etc)
- Need to have sophisticated supply chains to assure quality and availability
- Need to consider innovative financing approaches to lower perceived cost to households (micro-finance, smart subsidies, etc.)
- Need to consider dissemination in conjunction with other widespread programs, e.g., pre-natal care
- Need to create incentives for purchase and proper use: marketing and service contracts
Technical Lessons

- Extremely low emissions are possible with good designs, particularly “semi-gasifier” stoves
- Better to have low emissions than rely on chimney, but reliability of low emissions an issue particularly with fuel variability
- Best to have both: chimneys will last longer with lower emissions
- Hybrid designs (with electric blowers) may have sufficiently reliable low emissions to be promoted without chimneys
- Need to have robust devices that require as little operator thinking as possible
- Need to move to manufactured units made with ceramic and/or metal to maintain performance
Joint Lessons

- Need to incorporate both lab and field-based M&E for determining impact and providing mid-course corrections
- Need to have government certification/benchmarking as with other household appliances
- Protection of IPR will be important at some stage
- Only government and private business probably have sufficient capabilities for the sustained effort to deal with the hundreds of millions needed
- As a purely market-based approach will probably not be able to disseminate technology of sufficient performance, a hybrid approach is needed until rural incomes grow.
Bottom lines

• Health effects information is growing – more diseases and age groups

• RESPIRE provides first serious exposure-response data for one major endpoint – child pneumonia (ALRI)
  – Consistent with outdoor air pollution studies
  – Non-linear at higher levels

• Chimneys alone do not seem to reduce exposures down to levels sufficient to fully protect health

• Need to move to low-emission stoves ASAP

• M&E is vital, but new methods needed for interventions measured in 10s of millions of households
Worldwide population of households using primarily coal and/or biomass stoves: ~500 million (half world population)
On behalf of all my colleagues and students

Thanks to funders for RESPIRE

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Kresge Foundation

And to all our participants and fieldworkers

Publications available at http://ehs.sph.berkeley.edu/krsmith/