The Danger of Incomplete Combustion for Environment, Health, and Climate

The Impacts of Humanity’s Oldest Occupation

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美国国家科学院 院士 (1997)
300-400 thousand years ago, the hearth became a regular feature in human habitation

“On the earliest evidence for habitual use of fire”
Roebroeks and Villa, PNAS, 2011
Households using biomass or coal to cook today

Comparative Risk Assessment (CRA) 2011 - preliminary,
Biomass Cooking in History

• Only quite recently in human history did more than half of households use non-solid fuels for cooking – perhaps around 1980.

• Today, ~43% use solid fuels, about 3 billion people

• Although the percentage is dropping, the absolute number is still rising.

• Perhaps 20 million people a year are added to the total each year.

• Indeed, there are more people using solid fuels today for cooking than the total world population in 1950

• Or any year previously
A problem that has lasted one-third of a million years and is showing no sign of quickly going away by itself.
Rural Energy in China: 2004

Total

Crop wastes 33%
Coal 35%
Biogas 1%
Wood 21%
Electricity 7%
LPG 1%
Kerosene 2%

Households

Crop wastes 44.3%
Coal 12.9%
Biogas 1.2%
Wood 36.6%
Electricity 3.7%
LPG 1.2%
Kerosene 0.1%

70% of total

Ministry of Agriculture
National Bureau of Statistics
Household Energy in China

• ~60% of China’s population is rural.
• >70% of energy use in rural areas is simple solid biomass (wood, agricultural wastes)
• >15% as coal
• Thus, it is still true to say that in China most people rely on biomass fuels for most of their energy
• Substitution of biomass by coal is increasing – probably worse for health and climate
Rural energy situation is typically complex:
Road Map

• Why is there so much pollution?
• What are the major constituents of the smoke?
• What adverse health effects have been measured?
• What is the climate connection?
• What interventions have been evaluated in China?
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 Chinese 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: Zhang, et al., 2000
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

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

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

Typical Health-based Standards

- Carbon Monoxide: 150 mg/m³
  - Best single indicator
  - 10 mg/m³

- Particles: 3.3 mg/m³
  - 0.1 mg/m³

- Benzene: 0.8 mg/m³
  - 0.002 mg/m³

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

Typical Indoor Concentrations

- 1,3-Butadiene: 0.15 mg/m³
  - 0.0003 mg/m³

- Formaldehyde: 0.7 mg/m³
  - 0.1 mg/m³

IARC Group 1 Carcinogens
How much Ill-health?
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 the World Health Organization

First ever comprehensive risk assessment with consistent rules of evidence and common databases
Those diseases each causing more than 2% of total death in China are:

- Cancer
- Stroke
- COPD
- Ischemic Heart
- Acute Respiratory Infections
- Chronic Obstructive Lung Disease
- TB
- Suicide
- Road Traffic
- Hypertensive Heart
Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors

Percent of All DALYs

0.0%  2.0%  4.0%  6.0%  8.0%  10.0%

Underweight
Unsafe sex
Blood pressure
Tobacco
Alcohol
Unsafe water/sanitation
Child cluster vaccination*
Cholesterol
Lack of Malaria control*
Indoor smoke from solid fuels

Overweight
Occupational hazards (5 kinds)
Road traffic accidents*
Physical inactivity
Lead (Pb) pollution
Urban outdoor air pollution
Climate change
Chernobyl per month

1.6 million premature deaths/year
0.8 million premature deaths/year
0.12 million premature deaths/year
Global Burden of Disease Database and Comparative Risk Assessment World Health Organization

Being completely updated For 2011 release

For household air pollution:
New exposure assessment modeling
New outcome estimates based on meta-analyses
ALRI, COPD, Lung Cancer
Low birth weight, cataracts, cardiovascular
Diseases for which we have epidemiological studies - 2011

ALRI/Pneumonia
Low birth weight
Stillbirth

COPD
Lung cancer (coal)
Lung cancer (biomass)
Blindness (cataracts, opacity)
Heart disease
Blood pressure
ST-segment

These additional diseases will be included in the 2011 Comparative Risk Assessment

In addition, using evidence from other exposure sources, CVD will be included
Pollution and health effects of indoor fuel smoke exposure in China*

- Lung cancer
- Respiratory illnesses
- Lung function impairment
- Immune system weakening
- CO poisoning
- Endemic arsenism and fluorosis

*120+ publications from studies conducted in China
Coal stoves
### Household Coal Use and Lung Cancer

<table>
<thead>
<tr>
<th>Region</th>
<th>Year Range</th>
<th>Cases</th>
<th>Controls</th>
<th>Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>1981-82</td>
<td>220</td>
<td>220</td>
<td>2.30 (1.00–5.50)</td>
</tr>
<tr>
<td>India</td>
<td>1995-97</td>
<td>265</td>
<td>525</td>
<td>1.52 (0.33–6.98)</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td></td>
<td></td>
<td>2.30 (1.00–5.50)</td>
</tr>
<tr>
<td>Mainland China and Taiwan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wu-Williams et al.</td>
<td>1985-87</td>
<td>965</td>
<td>959</td>
<td>1.30 (1.00–1.70)</td>
</tr>
<tr>
<td>Sun et al.</td>
<td>1985-87</td>
<td>418</td>
<td>398</td>
<td>2.26 (1.53–3.33)</td>
</tr>
<tr>
<td>Huang et al.</td>
<td>1990-91</td>
<td>135</td>
<td>135</td>
<td>1.59 (1.01–2.07)</td>
</tr>
<tr>
<td>Ger et al.</td>
<td>1990-91</td>
<td>131</td>
<td>524</td>
<td>1.44 (0.44–4.69)</td>
</tr>
<tr>
<td>Li et al.</td>
<td>1986-92</td>
<td>161</td>
<td>161</td>
<td>2.08 (0.85–5.08)</td>
</tr>
<tr>
<td>Dai et al.</td>
<td>1992-93</td>
<td>120</td>
<td>120</td>
<td>4.70 (1.28–17.18)</td>
</tr>
<tr>
<td>Lin et al.</td>
<td>1985-90</td>
<td>122</td>
<td>122</td>
<td>3.24 (1.05–9.94)</td>
</tr>
<tr>
<td>Luo et al.</td>
<td>1990-91</td>
<td>102</td>
<td>306</td>
<td>6.00 (5.07–7.10)</td>
</tr>
<tr>
<td>Ko et al.</td>
<td>1992-93</td>
<td>117</td>
<td>117</td>
<td>1.30 (0.83–2.04)</td>
</tr>
<tr>
<td>Hao et al.</td>
<td>1981-86</td>
<td>122</td>
<td>122</td>
<td>1.76 (1.27–2.42)</td>
</tr>
<tr>
<td>Huang et al.</td>
<td>1993-96</td>
<td>135</td>
<td>135</td>
<td>1.58 (0.89–2.80)</td>
</tr>
<tr>
<td>Wu et al.</td>
<td>1997</td>
<td>135</td>
<td>135</td>
<td>2.40 (1.30–4.40)</td>
</tr>
<tr>
<td>Lan et al.</td>
<td>1995-96</td>
<td>122</td>
<td>122</td>
<td>2.10 (1.20–3.70)</td>
</tr>
<tr>
<td>Lee et al.</td>
<td>1993-99</td>
<td>122</td>
<td>122</td>
<td>1.29 (1.03–1.61)</td>
</tr>
<tr>
<td>Kleinerman et al.</td>
<td>1994-98</td>
<td>135</td>
<td>135</td>
<td>2.22 (1.28–3.86)</td>
</tr>
<tr>
<td>Sun et al.</td>
<td>1996-99</td>
<td>135</td>
<td>135</td>
<td>3.44 (1.38–8.57)</td>
</tr>
<tr>
<td>Lu et al.</td>
<td>1998-2001</td>
<td>135</td>
<td>135</td>
<td>2.02 (1.20–3.39)</td>
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<tr>
<td>Liang et al.</td>
<td>2001-02</td>
<td>152</td>
<td>152</td>
<td>7.40 (4.91–13.10)</td>
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<tr>
<td>Galeone et al.</td>
<td>1987-90</td>
<td>218</td>
<td>436</td>
<td>2.27 (1.61–3.12)</td>
</tr>
<tr>
<td>Lan et al.</td>
<td>1985-90</td>
<td>498</td>
<td>498</td>
<td>2.10 (1.61–2.89)</td>
</tr>
</tbody>
</table>

Chinese households using coal have 2.27 times more lung cancer than those using cleaner fuels.

Hosgood, et al., 2011
Health Benefits of Fuel/stove Intervention

Best published studies in the world were done by examining introduction of improved coal stoves in China
Improved Stoves Brought to Xuanwei County in early 1980s

• The reduction in particle levels was ~a factor of about three.

• Reduction in lung cancer was ~40% in men and ~45% in women. (*Journal of the National Cancer Institute*)

• Reduction in COPD rates was also significant at about 50% in both men and women (*British Medical Journal*)

• Reduction in lung cancer and COPD took 10 years to fully develop after IAQ improvement.
One of the few stove intervention studies in the world with a health outcome. A “natural experiment” – retrospective study of COPD after introduction of chimney stoves in a Yunnan county in late 1970s

Coal is the primary fuel in these households

Chapman et al.
BMJ, 2005
Why We Know Now that Chimneys are not Enough

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

Factor of \(~10\) less

285 48-h measurements

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

1888 48-h measurements

Smith, et al, 2010
Children with chimney stove

Children with open fire

~ 50% reduction in exposure on average

Chimney stove did not protect all children

120 240
(ug/m³ PM_{2.5})
Kitchens down by 10x, but children exposure 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
Reduction in Kitchen 24-h PM$_{2.5}$ (ug/m$^3$)

<table>
<thead>
<tr>
<th>Location</th>
<th>Amount Reduced</th>
<th>PM$_{2.5}$ (ug/m$^3$)</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langzhong</td>
<td>101</td>
<td>161</td>
<td>-39%</td>
</tr>
<tr>
<td>YiLong</td>
<td>55</td>
<td>109</td>
<td>-34%</td>
</tr>
<tr>
<td>Nanbu</td>
<td>98</td>
<td>128</td>
<td>-43%</td>
</tr>
<tr>
<td>Enshi</td>
<td>83</td>
<td>122</td>
<td>-40%</td>
</tr>
<tr>
<td>Yongshun</td>
<td>91</td>
<td>86</td>
<td>-51%</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td></td>
<td><strong>121</strong></td>
<td><strong>-41%</strong></td>
</tr>
</tbody>
</table>

~National Standard
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
Sources of Primary PM$_{2.5}$: India and China

Source: GAINS-China and GAINS-South Asia (2010)

Chafe, 2010
China: PM2.5 mass by province (2005)

PM2.5 Emissions in China (2005)

Source: GAINS-China

Chafe, 2010; data from GAINS-China (2010) http://gains.iiasa.ac.at
NASA INTEX_B Database

Percent PM$_{2.5}$ emissions from households

Chafe, 2010; data from NASA INTEX_B 2006
China Primary PM2.5 Emissions

Source: GAINS-China 2010

Percent Anthropogenic PM2.5

Source: GAINS-China (2010) http://gains.iiasa.ac.at
Controllable Global Warming from Black Carbon Emissions
Net of OC, Forcings from IPCC, 2007: 0.25 W/m²
Inventory from T Bond Database, V 7.1.1 Feb 2009

~One-third of net black carbon and carbon monoxide emissions globally come from household fuels
~One-sixth of ozone causing pollutants
~One-twentieth of methane
A large part from PIC: products of incomplete combustion

Warming in 2005 from emissions since 1750

IPCC, 2007
Climate Warming in 2020 Under Present Trends

Household Biomass

Unger et al. 2010
Why we need really clean combustion

• Chimneys by themselves do nothing for outdoor air pollution or climate
• We now know they do not help very much with health – only a factor of two reduction in exposure
• This is not enough to either reach WHO or Chinese standards
• Or to obtain the health benefits needed
Heart Disease and Combustion Particle Doses

From “Mind the Gap,” Smith/Peel, 2010 and Pope et al., 2009
Heart Disease and Combustion Particle Doses

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


data given by

Heart Disease Impact

Household Air Pollution

Annual mean PM2.5 - ug/m3
MD-diagnosed Child Pneumonia

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

Where we Want to Be!

Open fire

Chimney stove

RESPIRE-Guatemala
After independence, China had special concerns for rural areas than were reflected in energy programs for decades

- China led the world in rural energy development in the 1970s and 80s
- It introduced ~180 million improved biomass stoves, for example – one of the largest rural development projects in world history
China’s National Improved Stove Program (NISP)

• More than 180 million improved stoves with chimneys were introduced from early 80s to mid 90s
• Evaluation showed that NISP improved energy efficiency and IAQ in rural households, but not sufficiently to meet current Chinese air pollution standards or WHO guidelines.
• It focused on biomass; the rising coal use in rural areas is threatening to erode the benefits unless action is taken soon. This is particularly a problem in the areas of “poisonous coals”.
Improved Stove in Shanxi
China’s National Improved Stove Program (NISP) 1981-1998

- Total Rural Households
- Total Improved Stoves

 Sources:
- Lu Y., 1993
- Smith et al., 1993
- Qiu et al., 1996
- MOE/DOE 1998
- CERS and CAREI 2000
- China Statistical Yearbook, 2001
New generation of Chinese stoves show low particle emissions. But can they be reliably achieved in the field?

How clean do they need to be?
Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model

Michael Johnson\textsuperscript{a,\ast}, Nick Lam\textsuperscript{a,b}, Simone Brant\textsuperscript{a}, Christen Gray\textsuperscript{a}, David Pennise\textsuperscript{a}

\textsuperscript{a} Berkeley Air Monitoring Group, 2124 Kittredge St #57, Berkeley, CA 94704, USA
\textsuperscript{b} Environmental Health Sciences, University of California, 725 University Hall, Berkeley, CA 94720, USA
Box model for Indoor Pollution

\[ C_t = \frac{q f}{\alpha V} (1 - e^{-\alpha t}) + C_o (e^{-\alpha t}) \]

\( C_t \) = Concentration of pollutant (PM2.5 or CO) at time \( t \) (mg m\(^{-3}\))
\( q \) = emission rate (mg min\(^{-1}\))
\( \alpha \) = nominal air exchange rate (ventilation rate) (min\(^{-1}\))
\( V \) = kitchen volume (m\(^3\))
\( t \) = time (min)
\( C_o \) = concentration from preceding time unit (mg m\(^{-3}\))
\( f \) = fraction of emissions that enter kitchen

(Note: time and emissions rates are a function of thermal efficiency, emission factor, stove power, and daily cooking energy needs.)
## Top Performers in the Chinese National Cookstove Competition – 2007

<table>
<thead>
<tr>
<th>Location</th>
<th>CO/CO$_2$</th>
<th>Nominal Combustion Efficiency</th>
<th>PM$_{10}$ g/kg</th>
<th>Efficiency</th>
<th>PM$_{10}$/MJ delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daxu</td>
<td>0.020</td>
<td>98.1%</td>
<td>0.28</td>
<td>41.9%</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>(24%)**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luoyang*</td>
<td>0.019</td>
<td>98.1%</td>
<td>0.24</td>
<td>35.2%</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>(37%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xintai*</td>
<td>0.025</td>
<td>97.6%</td>
<td>0.36</td>
<td>32.6%</td>
<td>0.061</td>
</tr>
<tr>
<td></td>
<td>(43%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zhenghong</td>
<td>0.019</td>
<td>98.1%</td>
<td>0.24</td>
<td>35.9%</td>
<td>0.037</td>
</tr>
<tr>
<td></td>
<td>(19%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.021</td>
<td>98.0%</td>
<td>0.28</td>
<td>36.4%</td>
<td>0.043</td>
</tr>
</tbody>
</table>
How clean does the stove have to be to meet the WHO Guidelines to protect health?

<table>
<thead>
<tr>
<th>% meeting WHO Annual Interim Target-1 PM$_{2.5}$ (35 µg m$^{-3}$)</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>g MJ-delivered$^{-1}$</td>
<td>0.055</td>
<td>0.030</td>
<td>0.018</td>
</tr>
<tr>
<td>Mean Concentration (µg m$^{-3}$)</td>
<td>52</td>
<td>28</td>
<td>17</td>
</tr>
<tr>
<td>Median Concentration (µg m$^{-3}$)</td>
<td>35</td>
<td>19</td>
<td>11</td>
</tr>
</tbody>
</table>

Mean performance of 4 top stoves in the Chinese National Cookstove Contest was about 0.043 g/MJ-delivered.

Thus, if the fraction of particles entering the house from stove is less than 0.18/0.43 ~40%, 90% or more of households will meet the WHO Air Quality Guideline.
Conclusions: Intervention.

- Reductions in exposures through simple improvements, such as chimney stoves, are intrinsically limited because smoke from the solid fuel is still around the household.

- Future improvements should focus on stoves and fuels that reduce emissions, such as the biomass gasifier stoves being developed in the country.

- Advanced combustion stoves can lower pollution levels substantially, with 90+% reduction documented.

- Substituting cleaner fuels for the poisonous coals used in tens of millions of households should have an especially high priority.
SMALL, SMART, FAST, & CHEAP
monitoring devices for household energy & health

Stove Use Monitors Utilization

Time-of-use measuring devices allow more accurate estimations and objective definitions of usage patterns including cooking periods, meal times, and technology adoption rates.

Stove Use Monitors (SUMS) quantify utilization of cookstoves to improve estimates of personal exposure and environmental benefits related to household energy use. SUMS are based on commercially available, low-cost, small temperature loggers.

Particle and Temp Sensor Concentration

The ability to measure concentrations of small airborne particles is vital in understanding adverse health effects from combustion-derived air pollution. Available instrumentation to conduct such measurements is complex and expensive. Such devices are appropriate for developed countries and ambient air monitoring stations. However, their routine use in real-world household environments is expensive & cumbersome. Monitoring locations may also be remote, where security is questionable and electrical power not available, limiting the applicability of conventional instruments. In an effort to fulfill the needs for small, smart, fast, and cheap particle monitors that could be deployed easily in remote settings, a commercial smoke detector that uses optical scattering was identified and modified so that real-time signals could be logged continuously. This modified particle and temperature sensor is dubbed the UCB-PATS. Customized software handles data importing, graphing, and manipulation.

Time-Activity Monitoring Location

Measurement of exposure to pollutants is vital to the field of environmental health. The significance of a hazard depends on the amount of time a person is in contact with it. For instance, high indoor air pollution levels have been found in many homes globally. The risk of respiratory disease depends on the amount of time people spend in the presence of this pollution.

Time-Activity Monitoring System (TAMS) detects the presence or absence of individuals in an enclosed space. The system consists of one to five small ultrasonic emitting devices worn on an individual’s clothing. Each produces a distinct pattern that is emitted every few seconds. An ultrasonic receiver is mounted on the wall of a room and detects the unique pattern from the device worn by an individual.

If the identifying signal pattern emitted from a particular locator is received a certain number of times during a minute, that locator, and presumably the person wearing it, is recorded as being present in the room. Field trials show good results, with a 93% accuracy rate as measured against direct observation.

Device Software & Sample Output

Each device contains software to record environmental data, store, download and manipulate, and stream data to the DER data server. Data connect with the software a standard port or via USB to Serial connections.

For more information, google “Kirk R Smith” • To acquire devices, visit berkeleyair.com
Stove Use Monitors (SUMs) in Action

Ruiz et al., submitted
Percent of total Stove-days

Meals per day

Initial adoption 2008 2009 2010

Sustained use

Ruiz et al., submitted
Inter-instrument Comparison: 30 UCB-PATS
UCB Particle and Temperature Monitoring System
(custom PM monitor using smoke alarm technology)
How many hours should we measure to obtain a good estimate of the long-term mean? 

Kitchen PM$_{2.5}$ in household using open cookfire
Introduction of chimney stove
How Close to the True Mean With One Measurement?

Alnes, et al, in prep

Sampling duration

Percent Chance Of Being Within Bounds +/- of the Long-term mean

- Within 100%
- Within 75%
- Within 50%
- Within 25%
- Within 10%

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0 24 48 72 96 120 144 168 hours
The main reason household air pollution causes so much ill-health is

The **Intake Fraction** is large

IF is the fraction of material emitted that is actually breathed in by someone
IF = 1.0
Intake Fractions: these are rough calculations for typical examples of sources in each class.

<table>
<thead>
<tr>
<th>Source Category</th>
<th>Grams Inhaled per Ton Emitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles</td>
<td>10</td>
</tr>
<tr>
<td>Neighborhood Sources</td>
<td>100</td>
</tr>
<tr>
<td>US Coal Power Plant</td>
<td>0.1</td>
</tr>
<tr>
<td>LDC Power Plant</td>
<td>1000</td>
</tr>
<tr>
<td>Stove Vented Outdoors</td>
<td>10000</td>
</tr>
<tr>
<td>Stove Vented Indoors</td>
<td>100000</td>
</tr>
<tr>
<td>ETS</td>
<td>1000000</td>
</tr>
<tr>
<td>Cigarette - mainstream</td>
<td>10000000</td>
</tr>
</tbody>
</table>

Smith, 1993
Combustion Particles cause more health damage than any other environmental contaminant

- Worst thing to do is stick burning stuff in your mouth ~5 million deaths globally
- Not so great to have other people sticking in their mouths nearby ~ 300k deaths
- Bad even to have poorly burning stuff in your city ~ 1 million deaths
- The oldest of burning practice, however -- poorly combusted fuels in the home -- is still the cause of more ill-health than any other particle source except smoking ~ 1.6 million deaths
At a biogas stove exhibit in Wuhan on April 11, 1958, Mao Zhaledong instructed,

“This should be well promoted.”
Publications and presentations available at my website. Just “google” Kirk R. Smith

Thank You