Households stoves: energy, health, and global warming

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

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>% of Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass/ twigs</td>
<td>2</td>
</tr>
<tr>
<td>Dung</td>
<td>4</td>
</tr>
<tr>
<td>Crop Residues</td>
<td>18</td>
</tr>
<tr>
<td>Wood</td>
<td>22</td>
</tr>
<tr>
<td>Charcoal</td>
<td>4</td>
</tr>
<tr>
<td>Coal</td>
<td>6</td>
</tr>
<tr>
<td>Kerosene</td>
<td>10</td>
</tr>
<tr>
<td>Gas</td>
<td>20</td>
</tr>
<tr>
<td>Electricity</td>
<td>14</td>
</tr>
</tbody>
</table>

1% = 60 million people

The diagram illustrates the typical household energy ladder, showing the progression from Dung, Crop Residues, Wood, Kerosene, Gas, and finally Electricity, with Coal in China.
Two Important Policy Questions about a Possible Intervention

- Does it address a significant proportion of global warming and/or other negative impacts?
- Is it a cost-effective way to address these negative impacts?
Global Carbon Cycle

What goes on here?
Triple Carbon-Balance Analysis of a combustion device

- Energy
- Health
- Global Warming
Carbon-balance Analysis: Combustion

- Follow the fuel carbon

\[ C_f = C_{CO_2} + PIC \]

- PIC =

\[ C_{CH_4} + C_{CO} + C_{TNMHC} + C_{TSP} \]
Triple Carbon Balance: Energy
Triple Carbon Balance: Health

Diagram shows a flow of carbon from a stove, with the following components:
- 1 kg wood with 500g carbon
- CO₂ (440 m³/c)
- CO, CH₄, TNMOC, RSP
- Dilution factor (m³/c):
  - CO: 230
  - CH₄: 0.1
  - TNMOC: 9400
  - RSP: 30,000
  - Total: 10,000

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Triple Carbon Balance: Warming
Carbon-balance: Efficiencies

- Establish carbon balance while measuring overall efficiency (OE)
- OE 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 = \(\frac{CO_2}{(CO_2 + PIC)}\) -- on a carbon basis
Nominal Combustion Efficiencies in Indian Stoves

- Gas: 99% (98-99.5)
- Kerosene: 97 (95-98)
- Wood: 89 (81-92)
- Crop residues: 85 (78-91)
- Dung: 84 (81-89)
Chinese Stove efficiencies HTE VS NCE

Nominal Combustion Efficiency

Heat Transfer Efficiency

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Calculation of global warming commitments

- 20-year GWP Smith et al 2000
  Molar basis (per carbon atom)
  \( \text{CO}_2 \) 1.0
  \( \text{CH}_4 \) 22.6
  \( \text{CO} \) 4.5
  TNMHC 12
- 20-year GWP IPCC 1990
  per kg relative to \( \text{CO}_2 \)
  \( \text{NO}_x \) 150
- Black carbon?
Tracing fuel carbon: Chinese improved wood

Fuel wood
0.286 kg (130 g C)

CO₂
106

GWC
60

BC

GWC 25.9 13.5 14.7
PIC 10.4
CO 7.4
CH₄ 0.6
TNMHC 1.3
TSPC 1.0

Ash

Carbon Balance Per MJ
Delivered for Improved Wood Stove - China

NCE  HTE  OE
0.92  0.26  0.24

NOₓ
0.1

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GWC of different household fuels in China:
$\text{CO}_2+\text{CH}_4$

Non-renewable

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>GWC CO2</th>
<th>GWC CH4</th>
<th>Non-renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved brick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved brick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved brick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat residues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brushwood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel wood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unprocessed coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular briquettes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NG (m3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GWC of different household fuels in China: \( \text{CO}_2 + \text{CH}_4 + \text{CO} + \text{TNMHC} + \text{NO}_x \)
Tracing fuel carbon: LPG

LPG
0.02 m³ (38.2 g C)

Carbon Balance Per MJ Delivered for LPG traditional burner - China

NCE  HTE  OE
0.99  0.45  0.45

PIC 0.23

* CO₂
38

GWC
57

Production emissions
10.7

GWC
0.19  0.39  1.81  6.04

NOₓ
0.148

CO
0.053

CH₄
0.017

TNMHC
0.151

TSPC
0.005

D. Pennise 2002
GWC of residential stoves/fuels in China per 1MJ delivered

- GWC (CO2 + CH4)
- GWC (CO2, CH4, CO)
- GWC (CO2, CH4, CO, NOx)
- Non-renewable (CO2 + CH4)

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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!

\[
\begin{align*}
\text{27/14} &= 1.93x \text{ fewer kg fuel per meal} \\
(1-0.90)/ (1/0.97) &= 3.33x \text{ more PIC per kg fuel}
\end{align*}
\]
Dissemination of improved stoves in rural China and number of rural households

- China Statistical Yearbook, 2001
- CERS and CAREI 2000
- MOE/DOE 1998
- Qiu et al., 1996
- Smith et al., 1993
- Lu Y., 1993

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Chinese Improved Stove Program

- Probably the largest development project in history ~200 million households
- Major improvement in energy use
- Major reduction of human exposure to air pollution
- But
- Probably an increase in outdoor pollution and global warming
PIC vs NCE of biomass

nominal combustion efficiency

FUEL
- Wheat residues
- Brush wood
- Fuel wood
- Maize residues

Total Population

Rsq = 0.7869
TSP vs NCE for biomass

![Graph showing TSP vs nominal combustion efficiency with FUEL categories WR, WO2, WO1, and MR, and a Total Population line with Rsq = 0.6548.](image-url)
PIC vs NCE of coal

 nomial combustion efficiency

FUEL

- UNCW
- UNC
- HBC
- CB

Total Population
Rsq = 0.7796
Model estimation of GWC

$R^2 = 0.4-0.9$
Figure 3.4. GWC per MJ Delivered
Weighted by Stove Distribution in India
Average Stove Energy Efficiency Shown by Fuel

Warming from all GHGs emitted: CO2, CH4, CO, NMHC, N2O

GWC = Global Warming Commitment
Tracing fuel carbon: biogas

Biogas
0.02m³ (38.9 g C)

CO₂
38.73

GWC
2.8

PIC
0.19

CO
CH₄
TNMHC
TSPC
0.082
0.074
0.015
0.02

N₂O
0.009

Carbon Balance Per MJ Delivered for Biogas traditional burner - India

NCE HTE OE
0.99 0.58 0.57
Health and Greenhouse Gas Benefits of Biomass Stove Options

- Dung Stove
- Biogas Stove
- Traditional Woodstove
- Improved Ceramic Woodstove

India

PM10 Level (ug/m³)

Global Warming Per Meal

< $100/life-year

< $20/t-carbon

Grams CO₂
Limitations

- these studies do not, of course, cover all fuel/stove combinations in use by the 2.4 billion people in China and India.

- many other variations: local cooking practices, variations in construction techniques, differences in fuel quality, wind speed, dampening patterns, and indoor/outdoor temperature differences.

- many cooking stoves are also heating stoves in the winter, and emissions factors per MJ delivered will be smaller if the stove is preheated. Current surveys try to assess this parameter.
Global Importance of Biomass Fuel Cycles

Energy:

- Biomass makes up 10-15% of all direct human energy use
- Much larger proportion of carbon emissions from energy use
- It is 30-35% of energy use in developing countries
- It is 70-85% energy use in rural areas of developing countries
- It is probably still the most important fuel for the majority of humanity
Health:

- Cause of well more than half human exposure to respirable particulates
- Significant cause of ill-health worldwide
Global Warming:

- 2-5% of CH$_4$ emissions
- 6-15% of CO emissions
- 8-25% of hydrocarbon emissions
- 4-8% of all human-generated global warming from gases
- Significant contributor of BC
“Wood is the fuel that warms you twice” - true?

- Once when you chop it: 20 kJ
- Once when you burn it: 20 MJ
- but also
- When it warms you through radiative forcing in the atmosphere: 20 GJ +
- Indeed, biomass is the fuel that can warm you four times: breaking, burning, forcing, and fever.