Indoor Air Pollution and Child Health
What do we know, what should we know and what are some of the systems relationships?

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University of California, Berkeley

NICHD/NIEHS, Bethesda
September 26, 2008
Children in the poorest nations with 2.7 billion people: <$750/year-person (WHO databases)

Deaths per year if no change in risk ~200 million dead unnecessarily over 25 years

What more could be done?
Children in the poorest nations with 2.7 billion people: <$750/year-person (WHO databases)

What more could be done?

“Business as Usual”
If all goes as predicted, the actual deaths will be ~155 million

5.1 M/year
Children in the poorest nations with 2.7 billion people: <$750/year-person (WHO databases)

Children Mortality Wedges: 2005-2030

Avoidable Deaths Per Year

- Perinatal = 1.4 million/y
- ARI = 0.8 million/y
- Diarrhea = 0.7 million/y
- Vaccines = 0.5 million/y
- Malaria = 0.6 million/y
- Chronic Diseases = 0.4 million/y
- HIV = 90 thousand/y
- Unavoidable Deaths = 0.2 million/y

And, indirectly, all these diseases through malnutrition

What more could be done?

“Business as Usual” If all goes as predicted, the actual deaths will be ~155 million

Climate Change directly affects

Children in the poorest nations with 2.7 billion people: <$750/year-person (WHO databases)
Child Mortality Wedges: 2005-2030

However, we are doing something. If all goes well, the actual deaths will be ~155 million.

2+ million of these child deaths are due to Acute Respiratory Infections – ARI. These kill more children than any other condition today.

Children in the poorest nations with 2.7 billion people: <$750/year-person (WHO databases)
Also linked to low birthweight

ARI has strong links to inefficient energy use, which offers a great opportunity for “Co-benefits” -- achieving both climate mitigation and health protection with the same policies.

Children in the poorest nations with 2.7 billion people: < $750/year-person (WHO databases).
World Energy – 2001

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

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

World Energy Assessment, 2004
National Household Solid Fuel Use, 2000

- <20%
- 20% - 40%
- 40% - 60%
- 60% - 80%
- >80%

Household solid fuel use known
No data
More than 75% of households

50-74% of households

2000 Census
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 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 \textit{n-hexane}
  - 40+ unsaturated hydrocarbons such as \textit{1,3 butadiene}
  - 28+ mono-aromatics such as \textit{benzene & styrene}
  - 20+ polycyclic aromatics such as \textit{benzo(α)pyrene}
- Oxygenated organics
  - 20+ aldehydes including \textit{formaldehyde & acrolein}
  - 25+ alcohols and acids such as \textit{methanol}
  - 33+ phenols such as \textit{catechol & 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 India.

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

IARC Group 1 Carcinogens
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
Diseases for which we have epidemiological studies linking indoor air pollution to disease:

- ALRI/Pneumonia (meningitis)
- Low birth weight & stillbirth
- Asthma
- Early infant Death?
- Cognitive Effects?
- Chronic obstructive lung disease
- Interstitial LD
- Cancer (lung, NP, cervical, aero-digestive)
- Blindness (cataracts, trachoma)
- Tuberculosis
- Heart disease?
### New ALRI-IAP Systematic Review and Meta-Analysis

Dherani et al.  
Bull WHO, 2008

<table>
<thead>
<tr>
<th>Study design</th>
<th>N</th>
<th>OR</th>
<th>95% CI</th>
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<td>Cohort</td>
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<td>Case-control</td>
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<td>Cross-sectional</td>
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<td>All</td>
<td>26</td>
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<td>1.45, 2.18</td>
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### Odds Ratio (OR) and 95% Confidence Interval (CI)

<table>
<thead>
<tr>
<th>Study or sub-category</th>
<th>Odds Ratio (random) 95% CI</th>
<th>Weight %</th>
<th>Odds Ratio (random) 95% CI</th>
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<tr>
<td>Intervention Studies</td>
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<tr>
<td>Smith (2007)a</td>
<td>5.53</td>
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<td>Smith (2007)b</td>
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<td>Cohort Studies</td>
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<td>0.50</td>
<td>0.26, 1.32</td>
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<td>Armstrong (1991)b</td>
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<td>Camilleri (1992)</td>
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<td>Ezzati (2001)</td>
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<td>Jin (1993)</td>
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<td>Pandey (1999)b</td>
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<td>Case-control Studies</td>
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<td>Aziz (1995)</td>
<td>3.97</td>
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<td>Broor (2001)</td>
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<td>Collings (1993)</td>
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<td>De Francisco (1993)</td>
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<td>5.23</td>
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<td>Forsecco (1996)</td>
<td>4.65</td>
<td>1.14</td>
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<td>Johnson (1999)a</td>
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<td>Kossow (1982)</td>
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<td>Kumar (2004)</td>
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<td>1.42, 10.57</td>
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<td>Mahalenkos (2002)</td>
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<td>Morris (1993)</td>
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<td>O'Dempsey (1996)</td>
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<td>Rolan (1998)a</td>
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<td>Victoria (1994)</td>
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<td>0.61, 1.90</td>
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<td>Waynes (2004)</td>
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<td>Wesley (1996)</td>
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<td>0.39, 4.63</td>
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<td>Subtotal (95% CI)</td>
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<td>40.15</td>
<td>1.97</td>
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<td>Test for heterogeneity: Chi² = 32.72, df = 14 (P = 0.003), I² = 57.2%</td>
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<td>Test for overall effect: Z = 4.53 (P &lt; 0.00001)</td>
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<td>Cross-sectional Studies</td>
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<td>Mishra (2003)</td>
<td>3.83</td>
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<td>Mishra (2005)</td>
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<td>1.28, 2.82</td>
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<td>Wichmann (2005)</td>
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<td>1.02, 1.47</td>
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<td>Subtotal (95% CI)</td>
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<td>16.48</td>
<td>1.18</td>
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<td>Test for overall effect: Z = 3.74 (P &lt; 0.0002)</td>
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<td>Total (95% CI)</td>
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<td>100.00</td>
<td>1.78</td>
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<tr>
<td>Test for heterogeneity: Chi² = 101.74, df = 26 (P &lt; 0.0001), I² = 74.4%</td>
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<tr>
<td>Test for overall effect: Z = 5.68 (P &lt; 0.00001)</td>
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</tbody>
</table>

### Forest Plot

The graph illustrates the odds ratios and 95% confidence intervals for each study, along with the combined effect size. The forest plot shows the risk of increased and decreased outcomes.
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
• 1992: Guatemala chosen
• 1991-1999: Pilot studies to establish data needed for proposal
• 1996-1999: unfunded proposals
• 2001: NIH funds first randomized control trial for air pollution in highland Guatemala
• 2002-2005: fieldwork completed
• 2007: first results published
• 23 years from deciding to conduct RCT to results!
First Randomized Control Trial in Air Pollution History

Highland Guatemala

Traditional 3-stone open fire

Plancha chimney wood stove

RESPIRE - Guatemala
RCT Study

October 2002 - Eligible homes: open fire; pregnant; child <4 months: n=777

Consent & baseline questionnaire: n=534 (69%)
Declined n=243 (31%)

Randomization

Intervention (n=271)
Control (n=263)

Plancha built: needs 5 weeks to ‘cure’

Child health surveillance starts: (n=518)
Continues until child 18 months, death, declined to continue, or cessation of surveillance in December 2004

6 losses: 1 miscarriage 2 stillbirths 3 deaths

27 losses: 4 refusals 16 migration 6 broke stove 1 other

10 losses: 4 miscarriages 2 stillbirths 4 deaths

19 losses: 10 refusals 8 migration 1 switch to plancha

14,756 child weekly visits
14,369 child weekly visits

Offered plancha
Guatemala RCT Results

[Unpublished results presented showing that with ITT analysis, all outcomes showed improvement, but only severe ALRI outcomes were significant. With exposure-response analysis using personal pollution monitoring, however, nearly all outcomes significant, including primary outcome: MD-diagnosed pneumonia]
Respiratory Disease - other

- Minor burden, but important economic impact
  - Otitis Media – 0.08% of global burden
  - AURI – 0.11%
- Compared to 3% and 6% for LBW and ALRI
Low birth weight
(associated with IAP)

- Large direct impact on child mortality
- Of which perhaps 25% is ALRI
- Barker-type effect has been found on chronic disease over life time, including COPD
Low Birth Weight

- Small number of studies conducted appearing to show results for IAP consistent with evidence from ETS and ambient air pollution.
- Pregnant women in countries with high rates of (a) solid fuel use, and (b) adverse pregnancy outcomes rarely able to avoid activities that expose them and their unborn children to IAP
- Hence, even modest increase in RR for these conditions can be expected to translate into a substantial population attributable risk.
- Systematic review carried out in order to:
  - summarise the extent and quality of the evidence for the relationship between IAP from solid fuel use and adverse pregnancy outcomes
  - quantify these associations by meta-analysis.
Results: IAP and LBW (<2500gms)

<table>
<thead>
<tr>
<th>Study or sub-category</th>
<th>Odds Ratio (fixed) 95% CI</th>
<th>Weight %</th>
<th>Odds Ratio (fixed) 95% CI</th>
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<tbody>
<tr>
<td>Thompson 2005</td>
<td>11.87</td>
<td>1.16 [0.84, 1.60]</td>
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</tr>
<tr>
<td>Siddiqui 2008</td>
<td>5.09</td>
<td>1.77 [1.09, 2.88]</td>
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<tr>
<td>Mavalankar 1992a</td>
<td>30.92</td>
<td>1.23 [1.01, 1.50]</td>
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<tr>
<td>Mavalankar 1992b</td>
<td>30.92</td>
<td>1.49 [1.22, 1.82]</td>
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<tr>
<td>Mishra 2004</td>
<td>10.91</td>
<td>1.12 [0.80, 1.56]</td>
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<tr>
<td>Boy 2002</td>
<td>10.30</td>
<td>1.30 [0.92, 1.83]</td>
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<tr>
<td>Total (95% CI)</td>
<td>100.00</td>
<td>1.31 [1.18, 1.47]</td>
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</table>

Test for heterogeneity: Chi$^2 = 4.89$, df = 5 (P = 0.43), $I^2 = 0$
Test for overall effect: Z = 4.87 (P < 0.00001)

Heterogeneity - ($I^2 = 0$%; Chi$^2$ (df=5) = 4.89, p=0.43)
Funnel plot asymmetry - Begg’s test (p = 0.566) Egger’s test (p=0.989)

Pope et al., in prep
Results: IAP and birth weight

<table>
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<tr>
<th>Study or sub-category</th>
<th>WMD (fixed) 95% CI</th>
<th>Weight %</th>
<th>WMD (fixed) 95% CI</th>
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<td>Thompson 2005</td>
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<td>14.89</td>
<td>47.00 [-69.69, 163.69]</td>
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<tr>
<td>Siddiqui 2008</td>
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<td>24.66</td>
<td>82.00 [-8.69, 172.69]</td>
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<tr>
<td>Mishra 2004</td>
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<td>12.98</td>
<td>175.00 [50.00, 300.00]</td>
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<tr>
<td>Boy 2002</td>
<td></td>
<td>47.47</td>
<td>63.00 [-2.36, 128.36]</td>
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<tr>
<td>Total (95% CI)</td>
<td></td>
<td>100.00</td>
<td>79.84 [34.81, 124.87]</td>
</tr>
</tbody>
</table>

Heterogeneity - ($I^2 = 0\%$; $\chi^2$ (df=3) = 2.79, $p=0.43$)

Funnel plot asymmetry - Begg’s test ($p = 0.308$) Egger’s test ($p=0.479$)

Pope et al., in prep
## Results: IAP and still birth

<table>
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<tr>
<th>Study or sub-category</th>
<th>Odds Ratio (fixed) 95% CI</th>
<th>Weight %</th>
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<td>Siddiqui 2005</td>
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<td>Mavalankar 1991</td>
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<td>35.28</td>
<td>1.50 [1.04, 2.17]</td>
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<td>Mishra 2005</td>
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<td>47.43</td>
<td>1.44 [1.05, 1.98]</td>
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<td>Total (95% CI)</td>
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<td>100.00</td>
<td>1.53 [1.23, 1.91]</td>
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</table>

Heterogeneity - ($I^2 = 0\%$; $\text{Chi}^2 (df=2) = 0.79, p=0.67$)

Funnel plot asymmetry - Begg’s test ($p = 0.296$) Egger’s test ($p=0.083$)

Pope et al., in prep
Discussion

• Paucity of studies, conducted using a variety of study designs and across a range of settings.
• Despite this, results remarkably consistent with little evidence of statistical heterogeneity.
• Possibility of residual confounding.
• Variation in exposure measurement (need direct measurement for exposure-response analysis).
• Lack of information on gestational age in some of LBW studies.
• Results consistent with literature on ETS, ambient air pollution and LBW.
• Mechanisms: (i) CO (ii) PM
• Few studies on ETS/ ambient air pollution and still birth.
Conclusions

- Population Attributable Risks (%):
  
  LBW = 17.8%
  Still birth = 27.1%
  (70% prevalence of solid fuel use)

- Primary or secondary outcome for CRA?
- Strong case for additional studies.
Interactions with IAP

- Arsenic in water – “largest poisoning in human history”
  - Causes COPD, lung cancer, and ALRI
  - Much common exposure with IAP
- High occupational exposures to various dusts including silica, asbestos,
- Malnutrition
- Smoking
Large Global Exposures to some surprising pollutants – perhaps largest

- Ultrafine particles – fresh and combustion-generated
- Formaldehyde
- Benzene
- PAH
- Dioxin
- Etc.
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
- Not clear whether effects across all major health outcomes are the same as those found in urban studies of PM
  - Chronic and Acute Respiratory
  - Cardiovascular
  - Cancer
- Households in LDCs perhaps only widespread exposure to nearly pure biomass smoke
Large areas of rural India have high ambient air pollution.
Climate Change – Co-benefits

- Products of incomplete combustion are both health damaging and climate warming
- Efforts to reduce them in household combustion can be highly effective for both goals – co-benefits
Current Cost-effective Region In India

Smith & Haigler, 2008
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

- Business As Usual Projected Child Deaths in Low Income Countries

Child Deaths Averted over 25 years

Unavoidable Deaths Using HI Rates

Avoidable child deaths (x100,000)

- 2005
- 2007
- 2009
- 2011
- 2013
- 2015
- 2017
- 2019
- 2021
- 2023
- 2025
- 2027
- 2029

Child Deaths Averted over 25 years

- 0.00E+00
- 5.00E+05
- 1.00E+07
- 1.50E+07
- 2.00E+07
- 2.50E+07
- 3.00E+07
- 3.50E+07
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years

- Improved stoves - ARI - full coverage

- 4.71E+06
Potential Impacts of Health Interventions

Child Deaths Averted over 25 years

- **Improved stoves - ARI - full coverage**
- **treated nets - Malaria - 50% coverage**

![Graph showing the potential impacts of health interventions over 25 years.](image-url)
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years

- Improved stoves - ARI - full coverage
- Treated nets - Malaria - 50% coverage
- Oral Zinc - Diarrhea

Avoidable child deaths (x100,000)
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years

- Improved stoves - ARI - full coverage
- Treated nets - Malaria - 50% coverage
- Oral Zinc - Diarrhea
- Malnutrition - ARI

Avoidable child deaths (x100,000)
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years

- Improved stoves - ARI - full coverage
- treated nets - Malaria - 50% coverage
- Oral Zinc - Diarrhea
- Malnutrition - ARI
- Malnutrition - Malaria
- Malnutrition - Diarrhea
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Child Deaths Averted over 25 years

- Improved stoves - ARI - full coverage
- Treated nets - Malaria - 50% coverage
- Oral Zinc - Diarrhea
- Malnutrition - ARI
- Malnutrition - Malaria
- Malnutrition - Diarrhea
- Malnutrition - Perinatal

Avoidable child deaths (x100,000)

Year:
- 2005
- 2007
- 2009
- 2011
- 2013
- 2015
- 2017
- 2019
- 2021
- 2023
- 2025
- 2027
- 2029

Total averted child deaths: 2.70E+07
Potential Impacts of Health Interventions on Child Mortality in Low Income Countries

Based mainly on *Lancet* Child Mortality Series

Child Deaths Averted over 25 years

![Graph showing potential impacts of health interventions on child mortality in low income countries.](image-url)
Potential Impacts of Climate Change on Child Mortality in Low Income Countries

550ppm

Avoidable Child Deaths (x10,000)

Diarrhea

Averted Deaths

446,828

Deaths
Potential Impacts of Climate Change on Child Mortality in Low Income Countries

550ppm

Avoidable Child Deaths (x10,000)

Malaria

Diarrhea

Deaths


446,828

564,672

8.0E+05 7.0E+05 6.0E+05 5.0E+05 4.0E+05 3.0E+05 2.0E+05 1.0E+05 0.0

4.0E+05 3.0E+05 2.0E+05 1.0E+05 0.0
Potential Impacts of Climate Change on Child Mortality in Low Income Countries

550ppm

Malnutrition
Malaria
Diarrhea

Av. Additional Child Deaths (x10,000)

Deaths

446,828
564,672
766,902

4.E+05
5.E+05
6.E+05
7.E+05
8.E+05
Potential Impacts of Climate Change on Child Mortality in Low Income Countries

750ppm

McMichael et al., Climate Change CRA
Thank you.
The Unhealthy Mother Effect

Solid Fuel Use → Smoke → Child ARI ↔ Child Health

Fuel Harvesting → Maternal Health → Maternal Time and Energy
Mark Twain on Casual Pathways

“Soap and education are not as sudden as a massacre, but they are more deadly in the long run”

- Facts Concerning the Recent Resignation, 1867