Indoor air pollution in developing regions of the world

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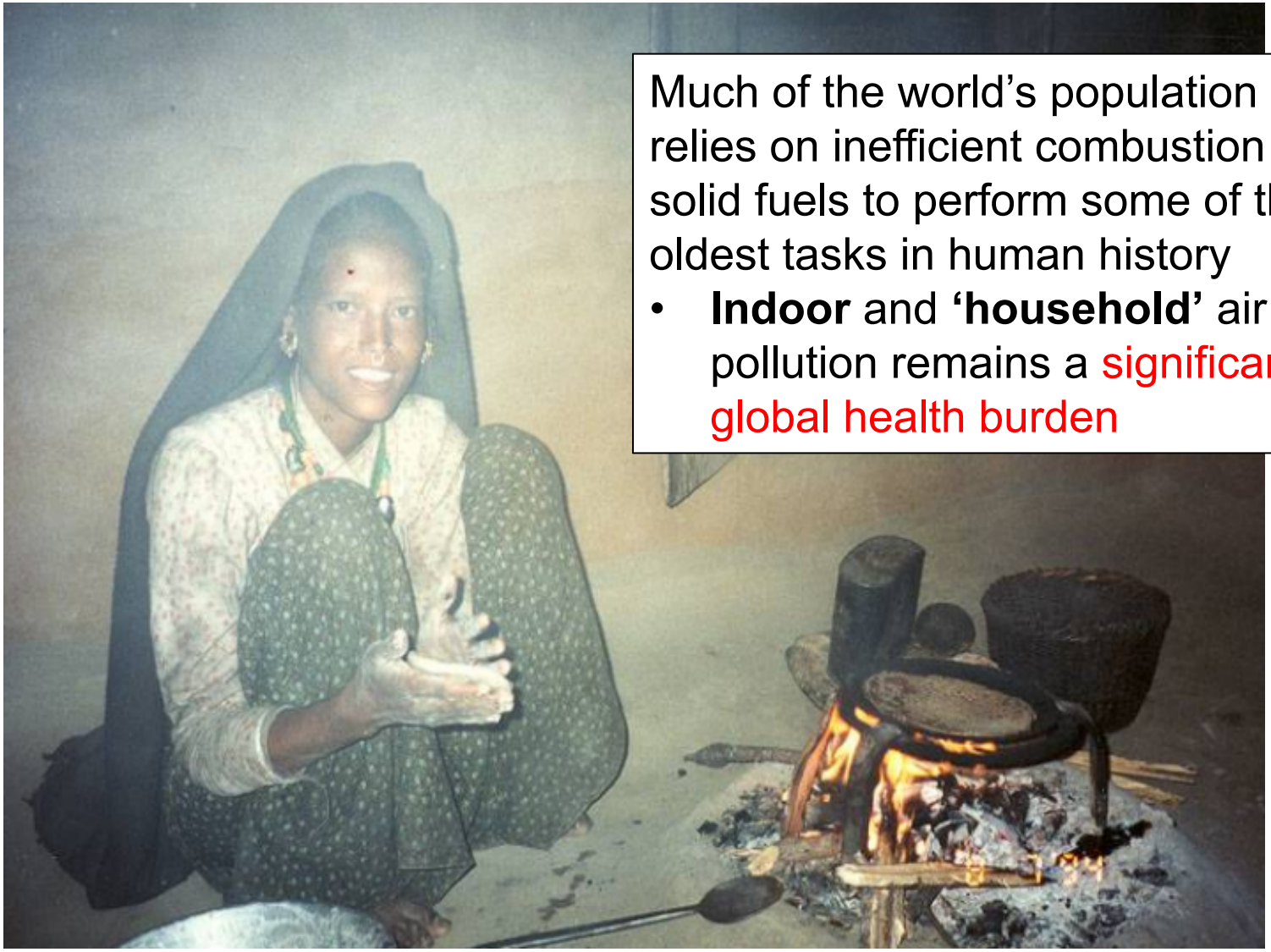
Indoor air pollution in developing regions of the world



Much of the world's population relies on inefficient combustion of solid fuels to perform some of the oldest tasks in human history

- **Indoor** and **'household'** air pollution remains a significant global health burden

Photo: Kirk Smith, UC-Berkeley

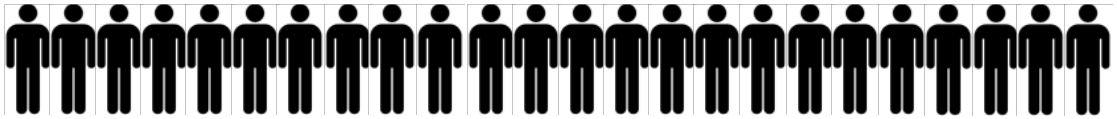
Biomass burning across the world

One-third of the world's population burns biomass for:

Cooking Heating Lighting

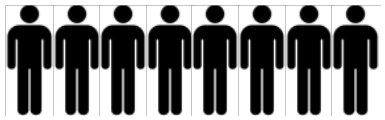
Fuels used include:

Wood, dung, crop residue



2.4 billion people

Coal



800 million people

= 100 million people

Fullerton et al., 2008 *Trans R Soc Trop Med Hyg*; Bruce et al., 2000 *WHO Bulletin*

Cooking and heating

- Poor ventilation (no flues or hoods)
- Low combustion efficiency
  - High levels of products of incomplete combustion

http://photos.state.gov/libraries/amgov/3234/Week_3/09222010_AP070911056524_300.jpg
http://images.angelpub.com/2010/37/5835/cookstove-2.jpg

Lighting

http://www.vleindia.com/images/thumb/1279793271_slide.jpg

- 1.6 billion people use fuel-based lighting after dark
  - Kerosene, diesel
- Indoor air pollution + substandard luminance + fire

Pollutants emitted from biomass burning

Particulate matter (UFPs, $PM_{2.5}$ and PM_{10})

Carbon monoxide (CO)

Nitrous oxides (NO_x)

Sulfur oxides (SO_x) (coal)

Metals (coal)

Hydrocarbons (HC; e.g. naphthalene)

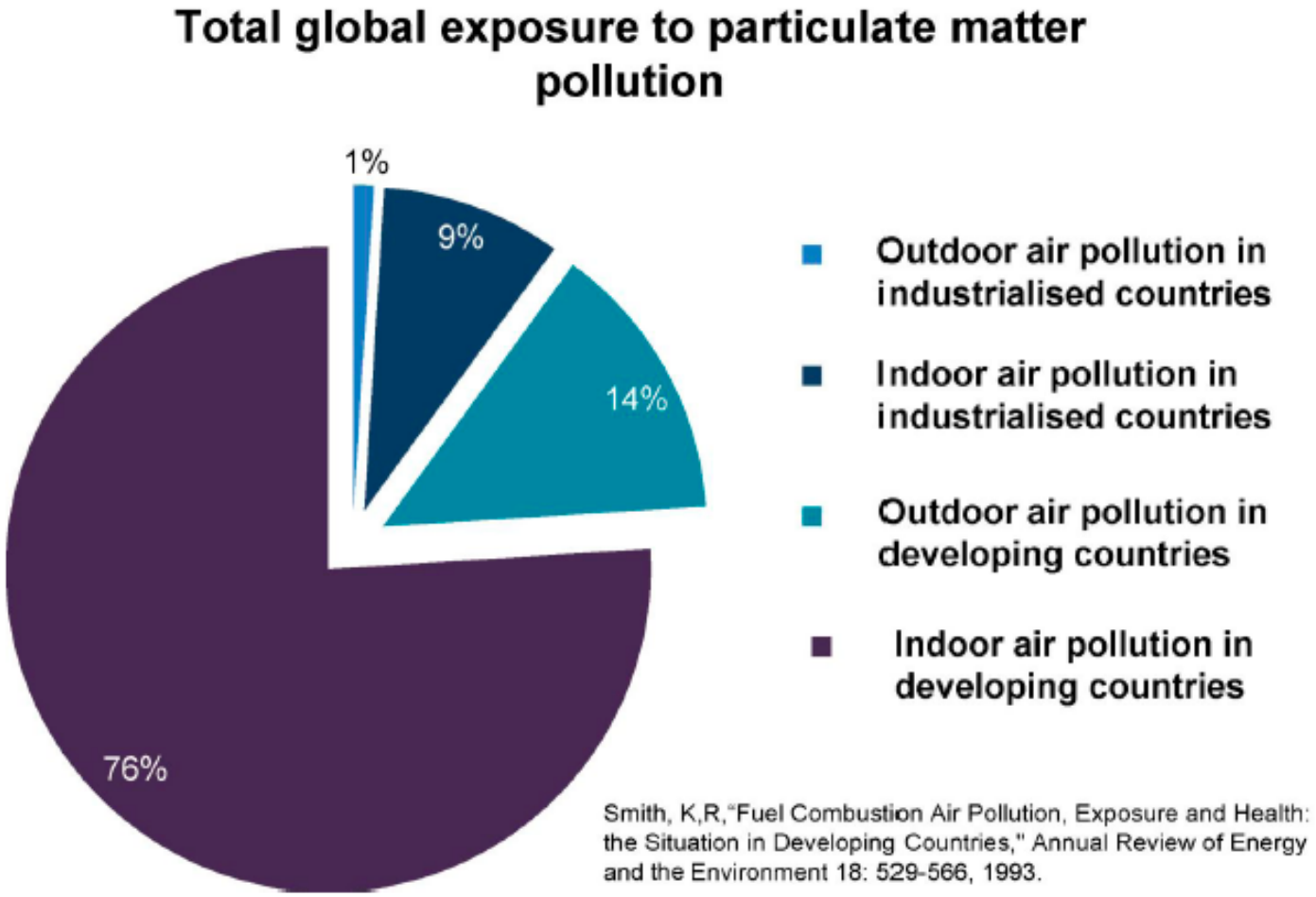
Polycyclic aromatic hydrocarbons (e.g. benzo[a]pyrene)

Oxygenated organics (e.g. formaldehyde) (wood)

Free radicals

Combustion efficiency is far less than 100%

Global exposure to particulate matter

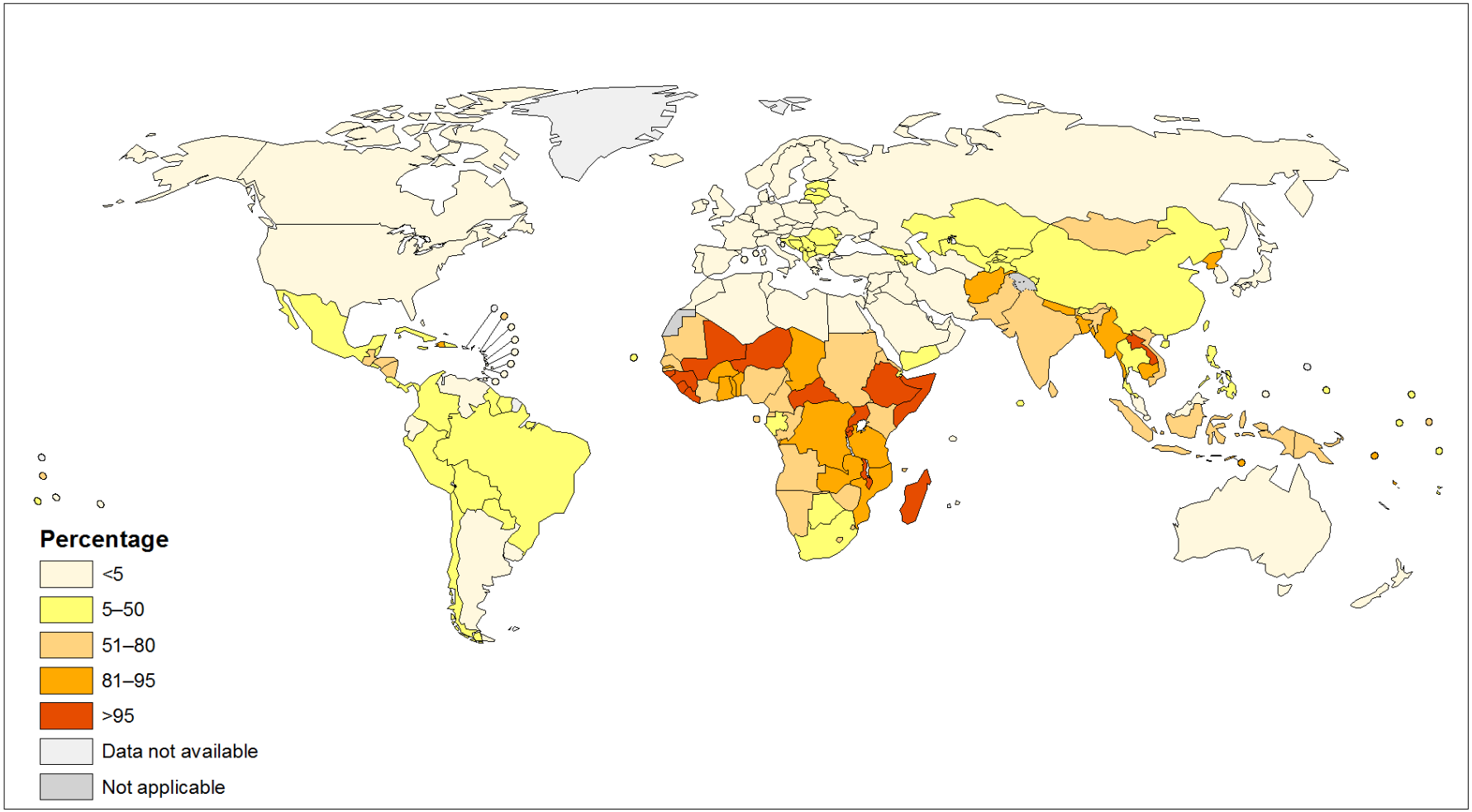


Fullerton et al., 2008 *Trans R Soc Trop Med Hyg*

GLOBAL HEALTH

and indoor air pollution

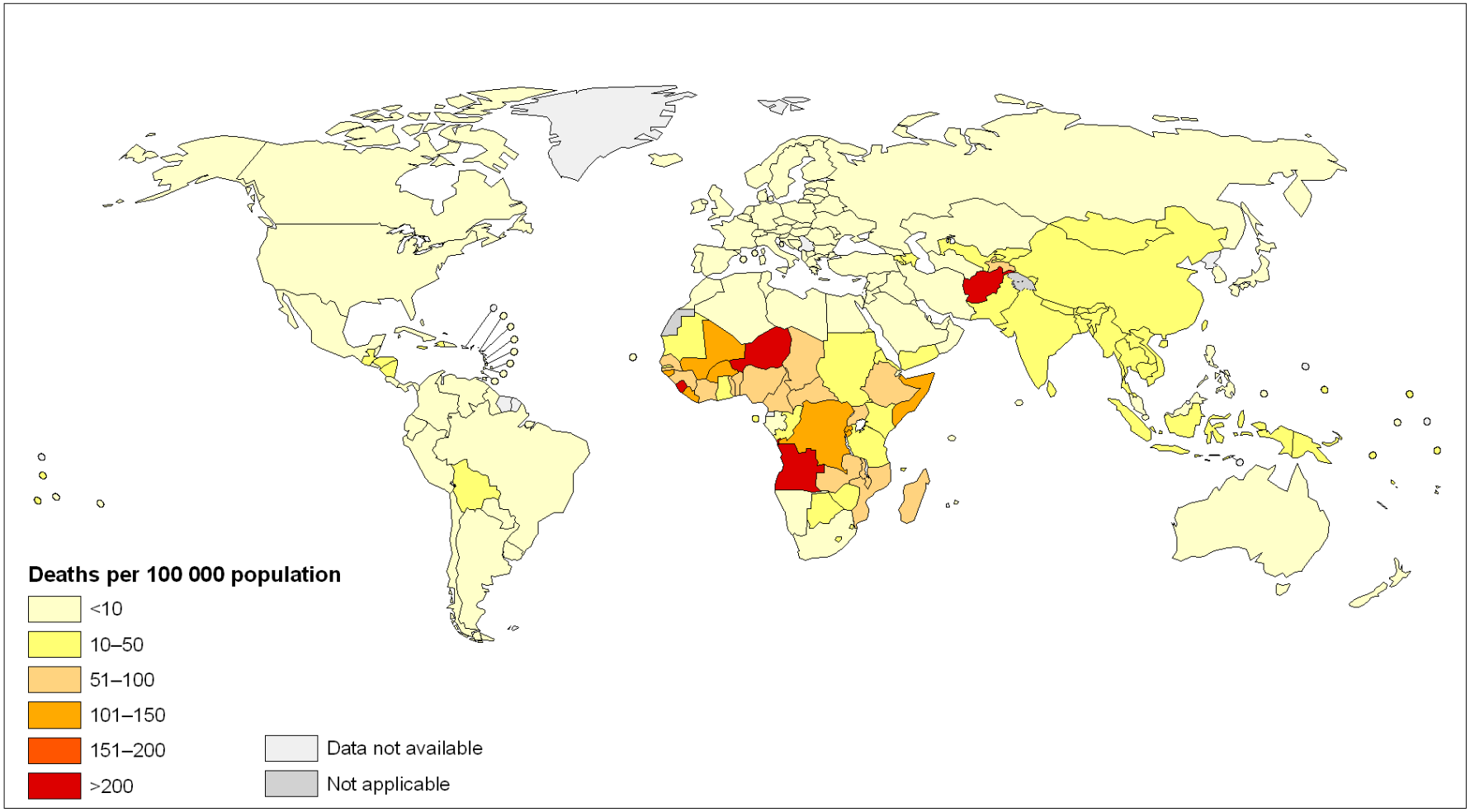
Population using solid fuels (%), 2010
Total



Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization

World Health Organization

Deaths attributable to household air pollution, 2004

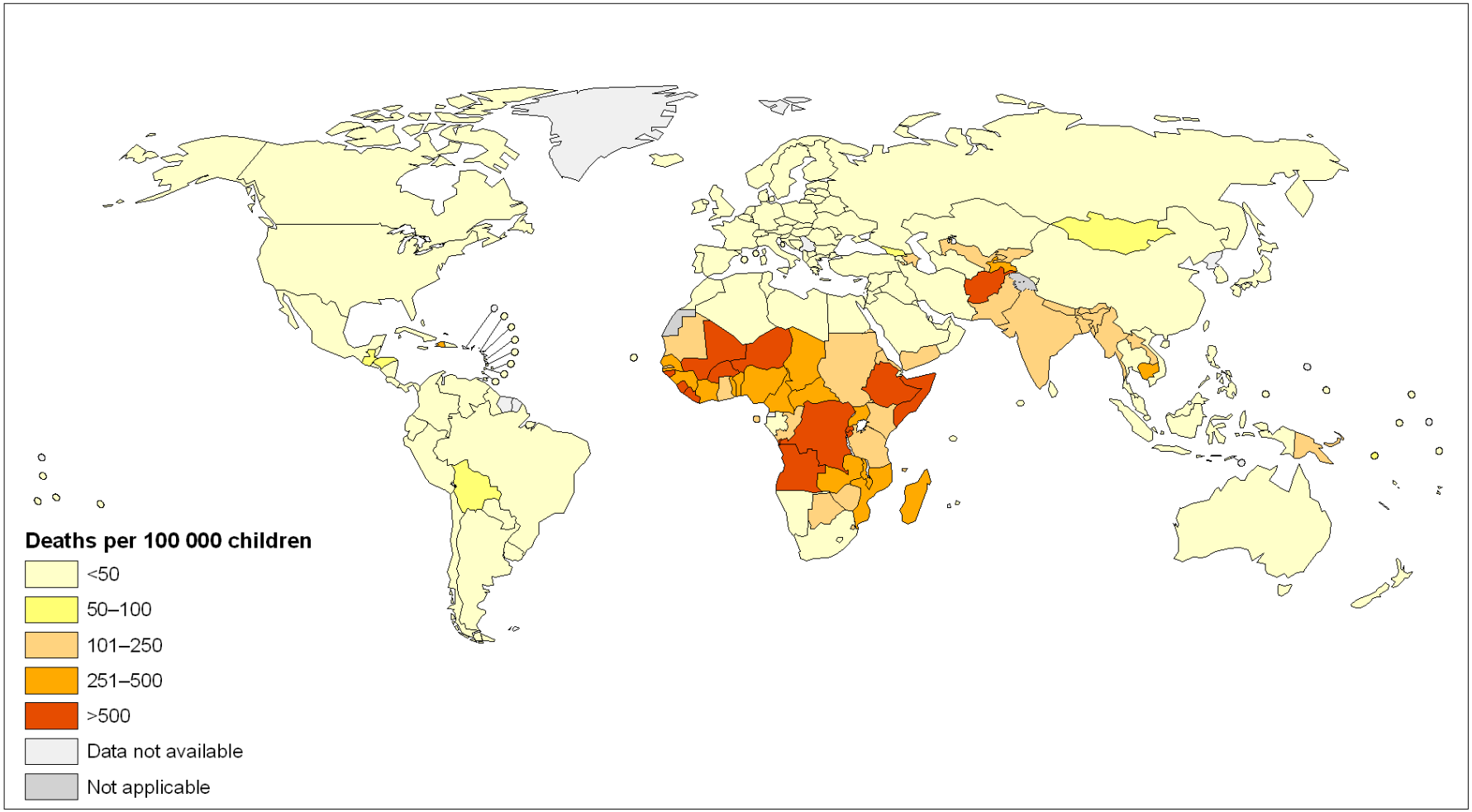


The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization

World Health Organization

Deaths attributable to household air pollution in children aged under 5 years, 2004



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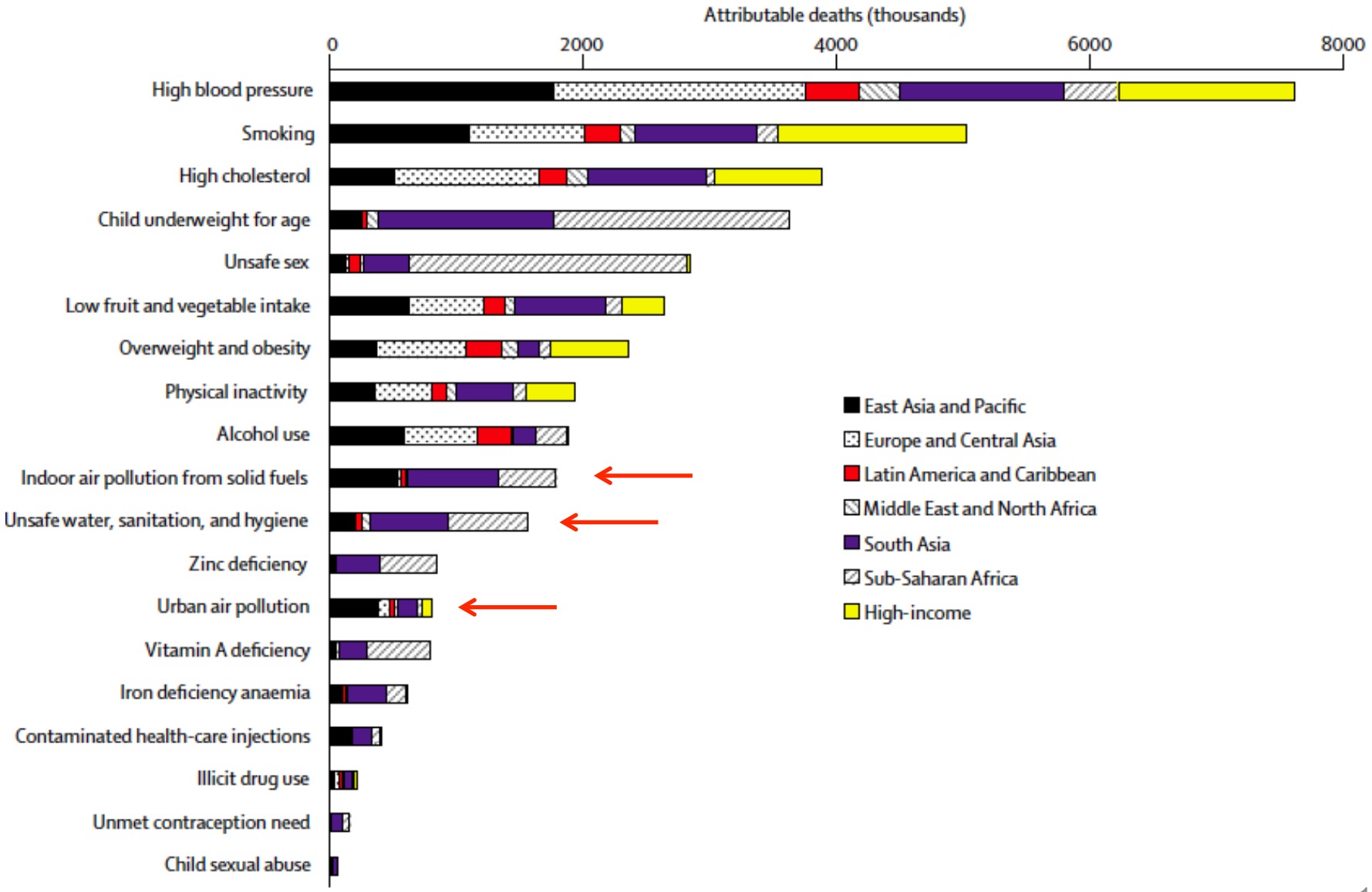
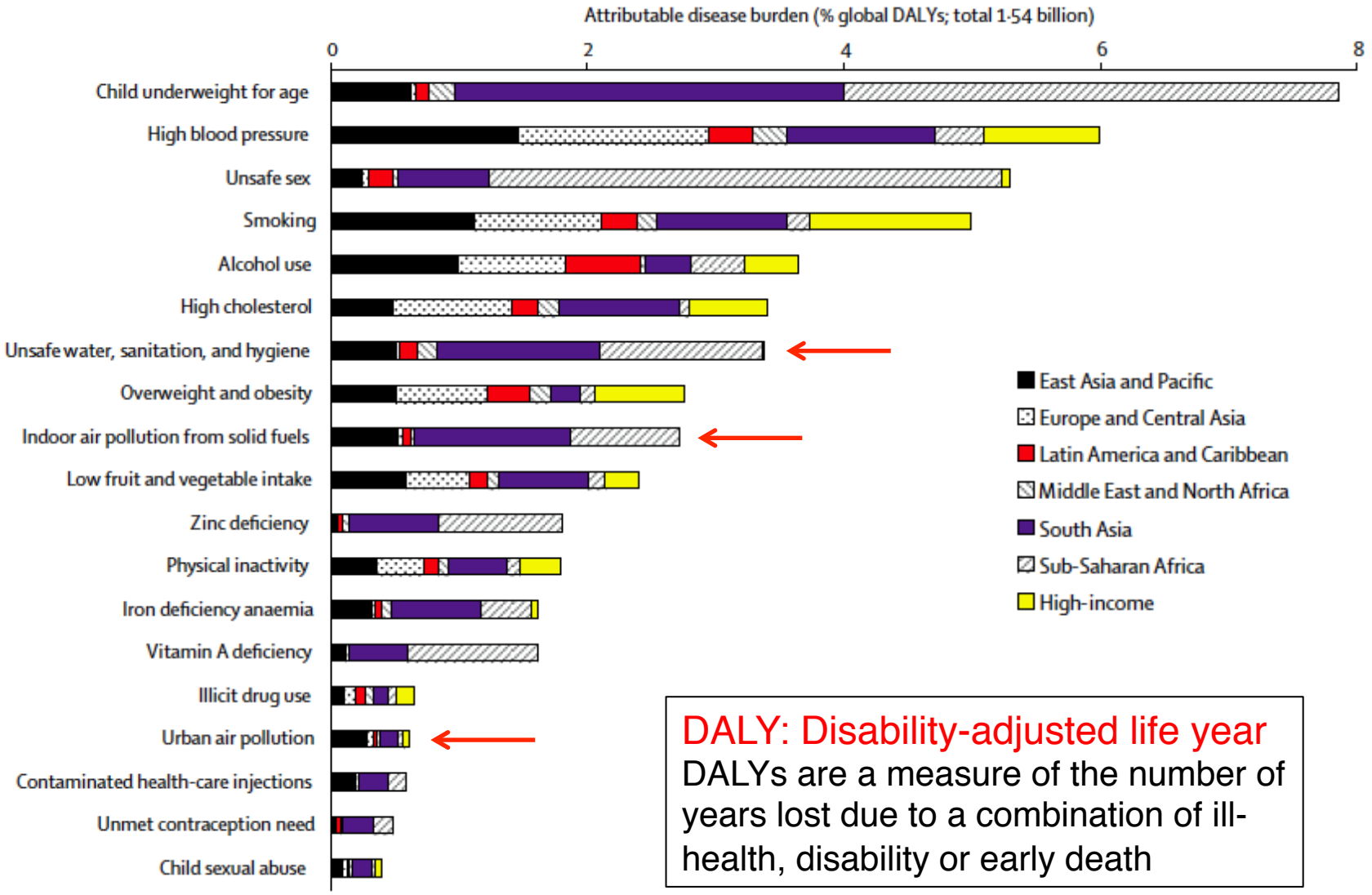
Global risk factors for mortality



Lopez et al., 2006 *The Lancet*

Global disease burden

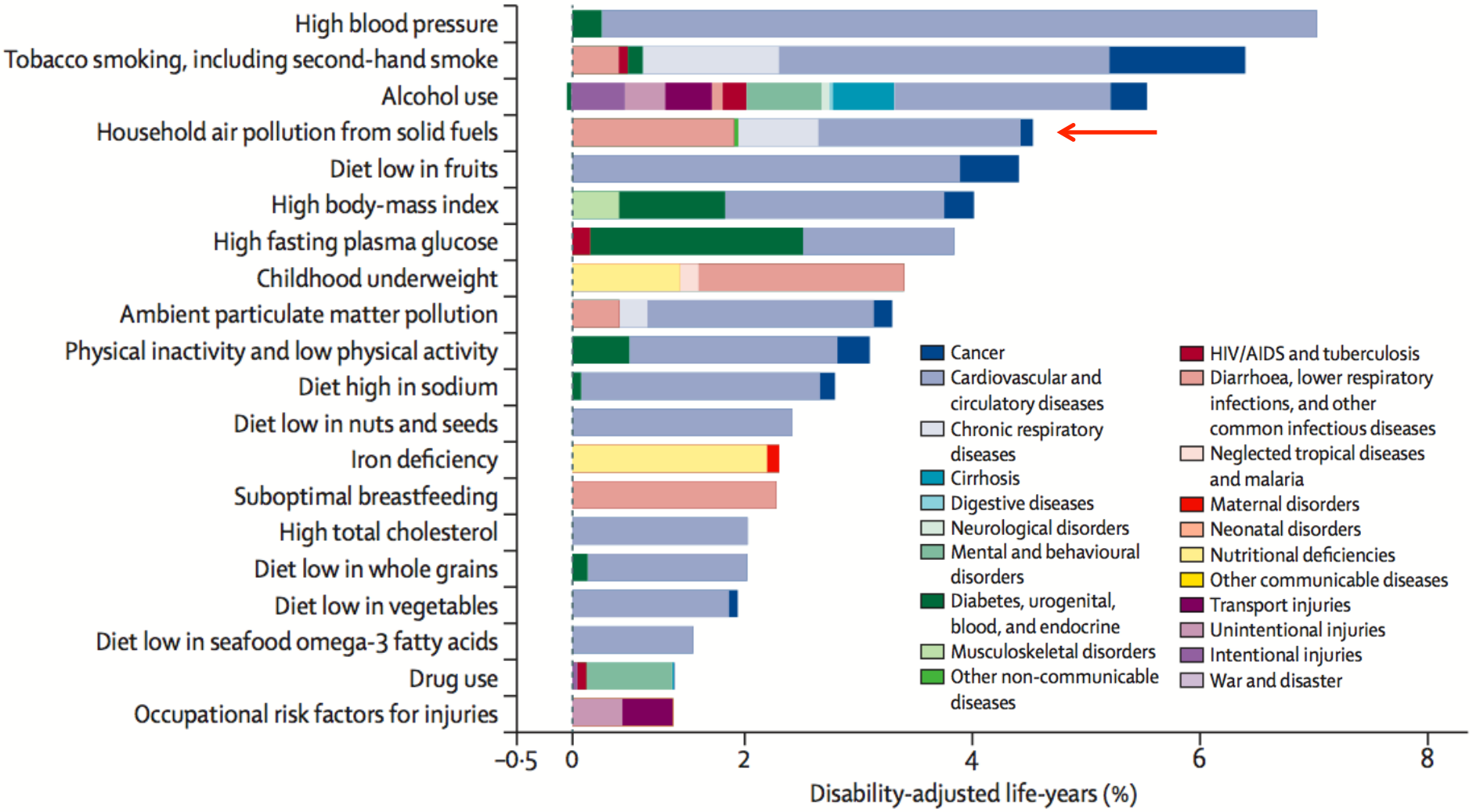


DALY: Disability-adjusted life year

DALYs are a measure of the number of years lost due to a combination of ill-health, disability or early death

Lopez et al., 2006 *The Lancet*

Global disease burden: 2010 update



Women and young children are especially at risk!

Lim et al., 2013 *The Lancet*

Adverse health effects

Exacerbations of inflammatory lung conditions

Respiratory tract infections

Low birth weight

Cardiac events

Stroke

Eye disease

Tuberculosis

Cancer

Developmental disorders

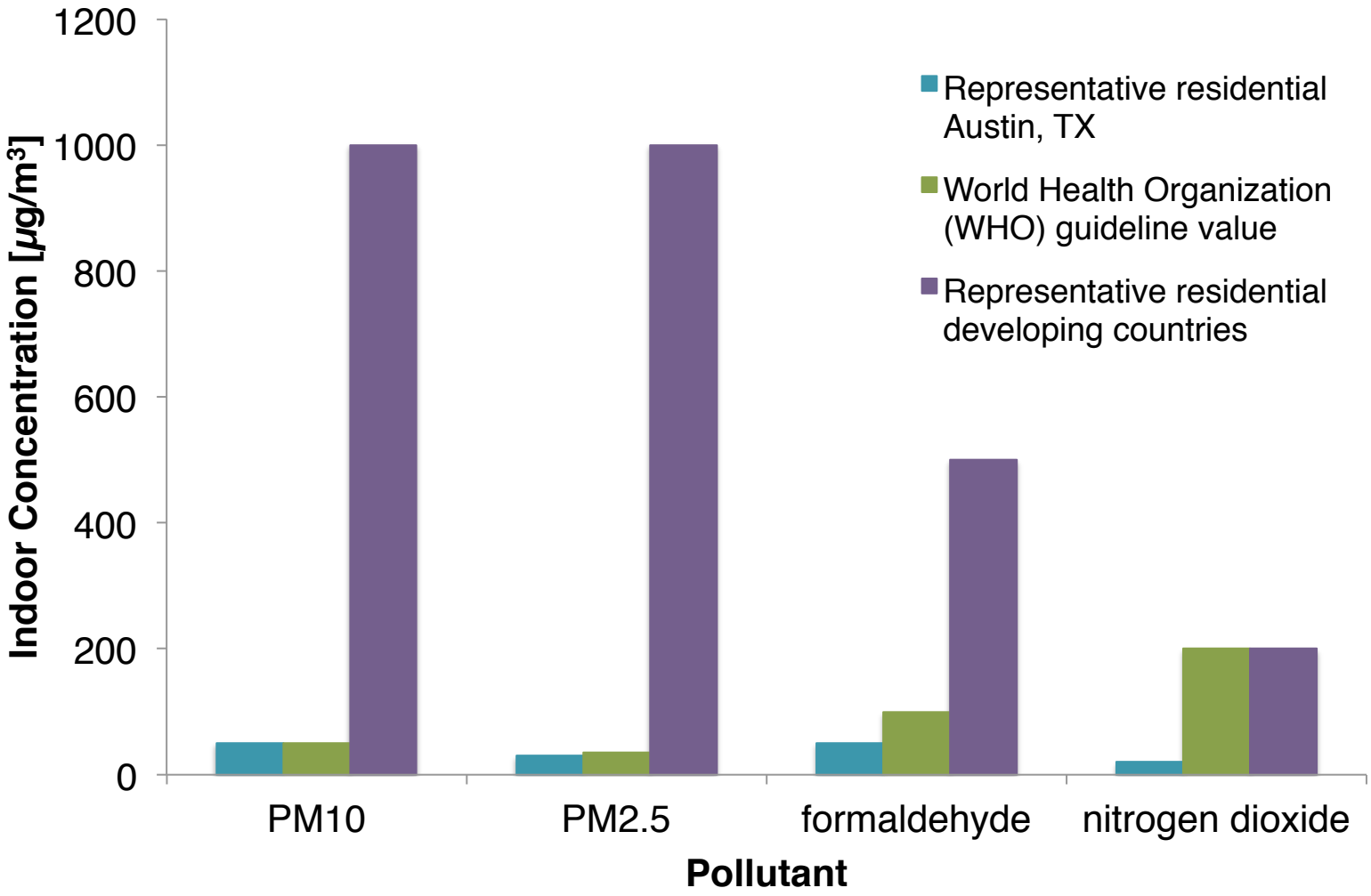
Pollutant-specific adverse health effects

Pollutant	Primary adverse health effects
particulate matter ($PM_{2.5}$, PM_{10})	acute lower respiratory infection, pneumonia, chronic obstructive pulmonary disorder (COPD)
carbon monoxide	fatigue, headache, vertigo, memory impairment, tinnitus and nausea
formaldehyde, naphthalene, polycyclic aromatic hydrocarbons (PAHs; e.g. benzo[a]pyrene), benzene, radon, trichloroethylene	carcinogenicity
nitrogen dioxide, formaldehyde	increased susceptibility to respiratory infection

QUANTIFYING EXPOSURES

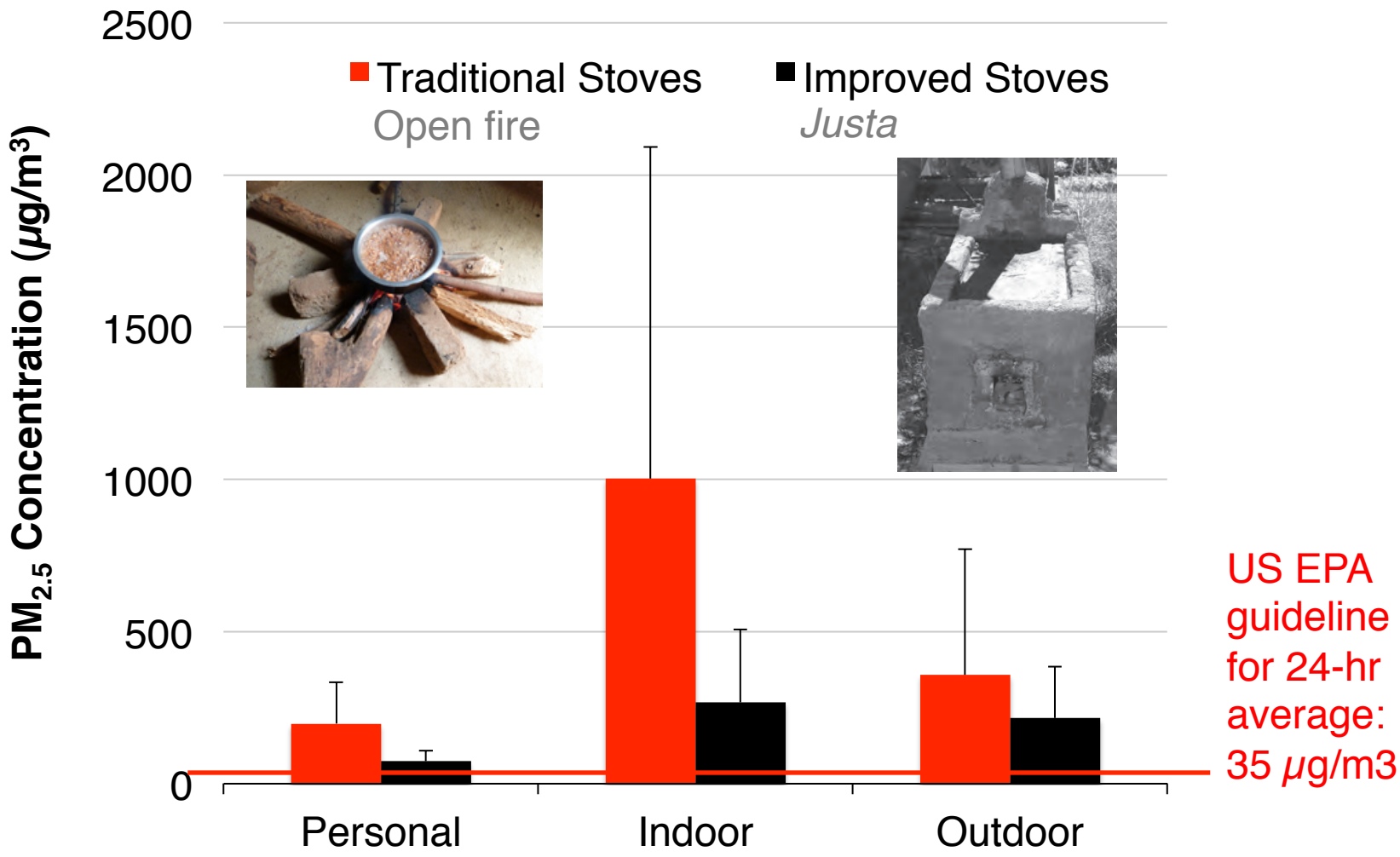
Indoor and household air pollution

Representative pollutant concentrations



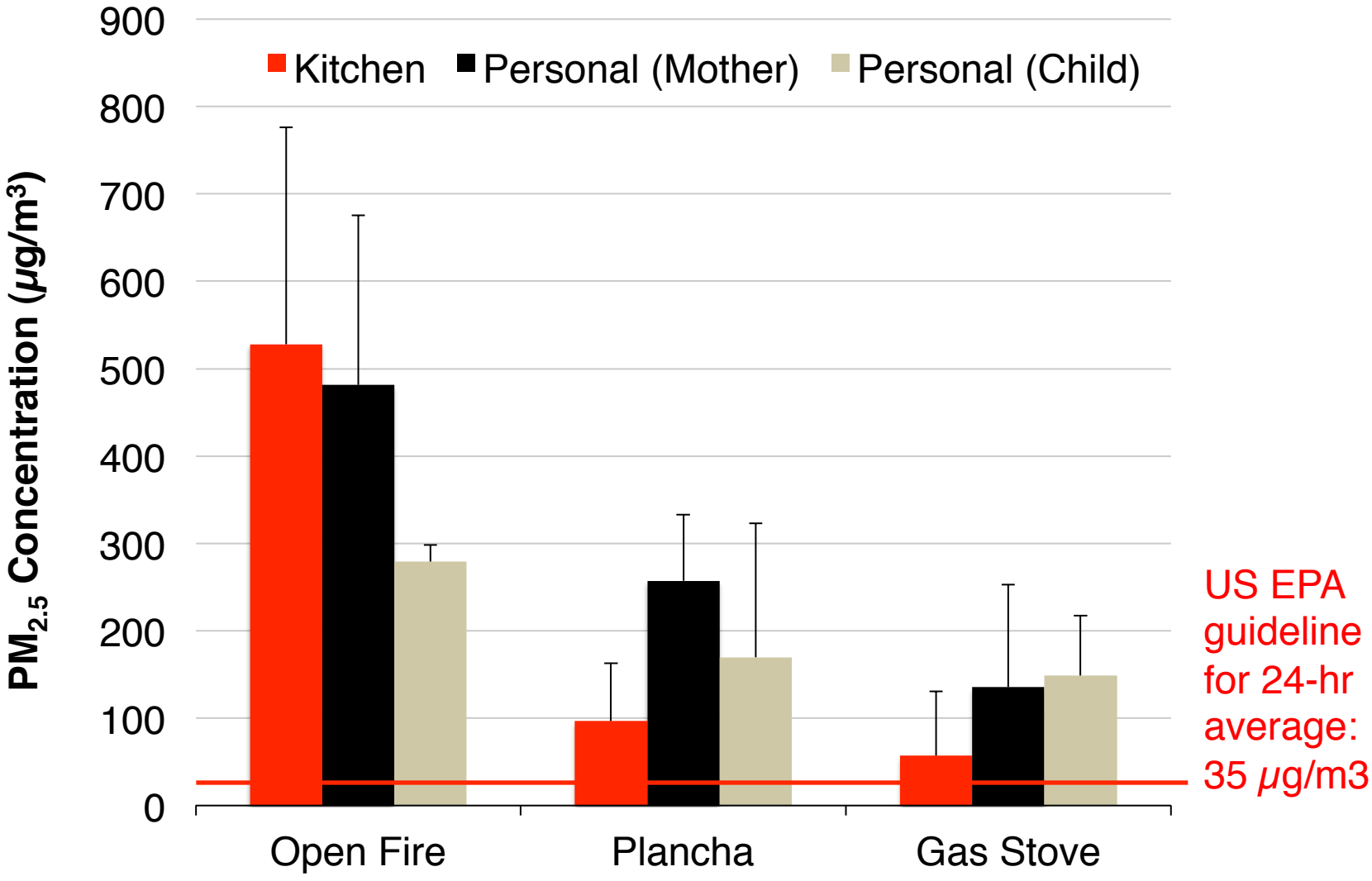
New and old stoves in Honduras: $PM_{2.5}$

~30 homes each group



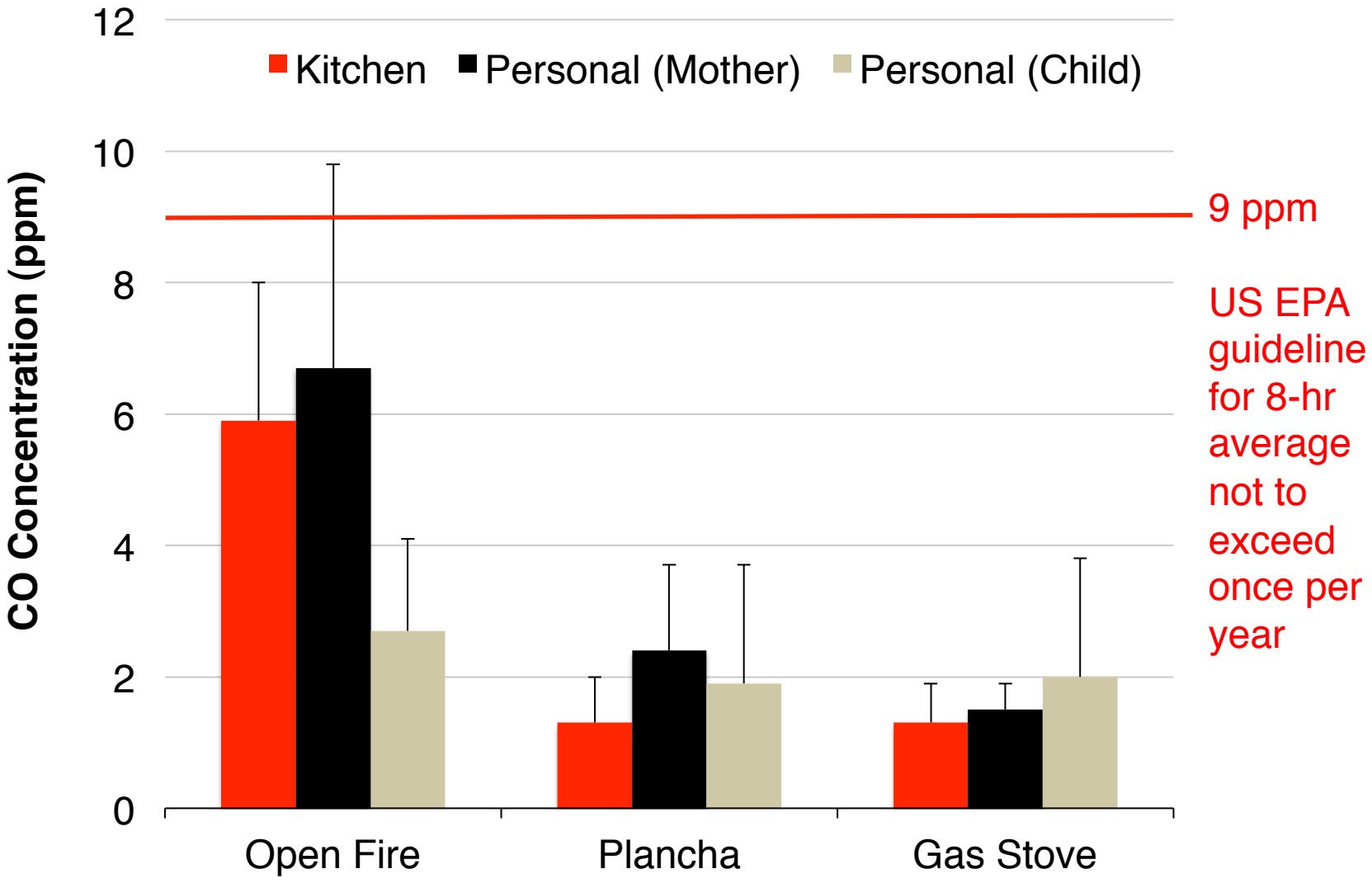
Clark et al., 2010 *Environmental Research*

New and old stoves in Guatemala: $PM_{2.5}$



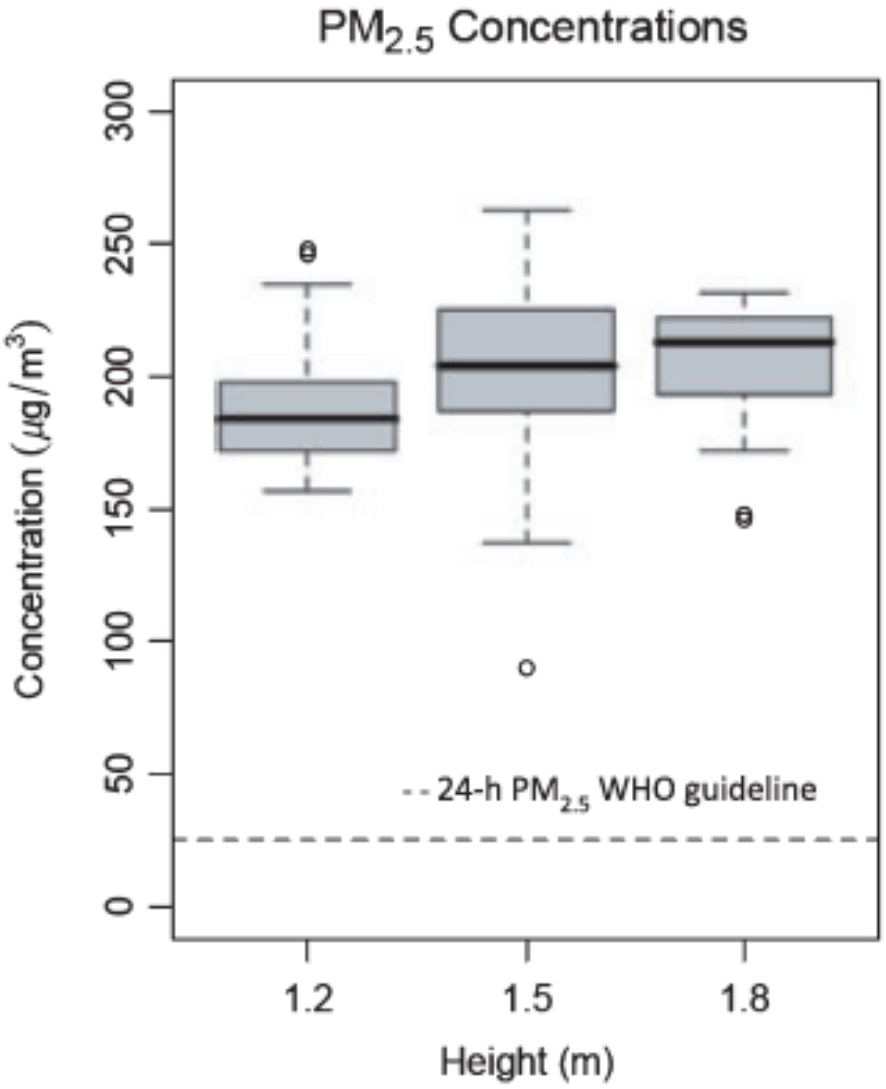
Naeher et al., 2000 *Indoor Air*

New and old stoves in Guatemala: CO



Naeher et al., 2000 *Indoor Air*

Kenya: Fuel-based lighting

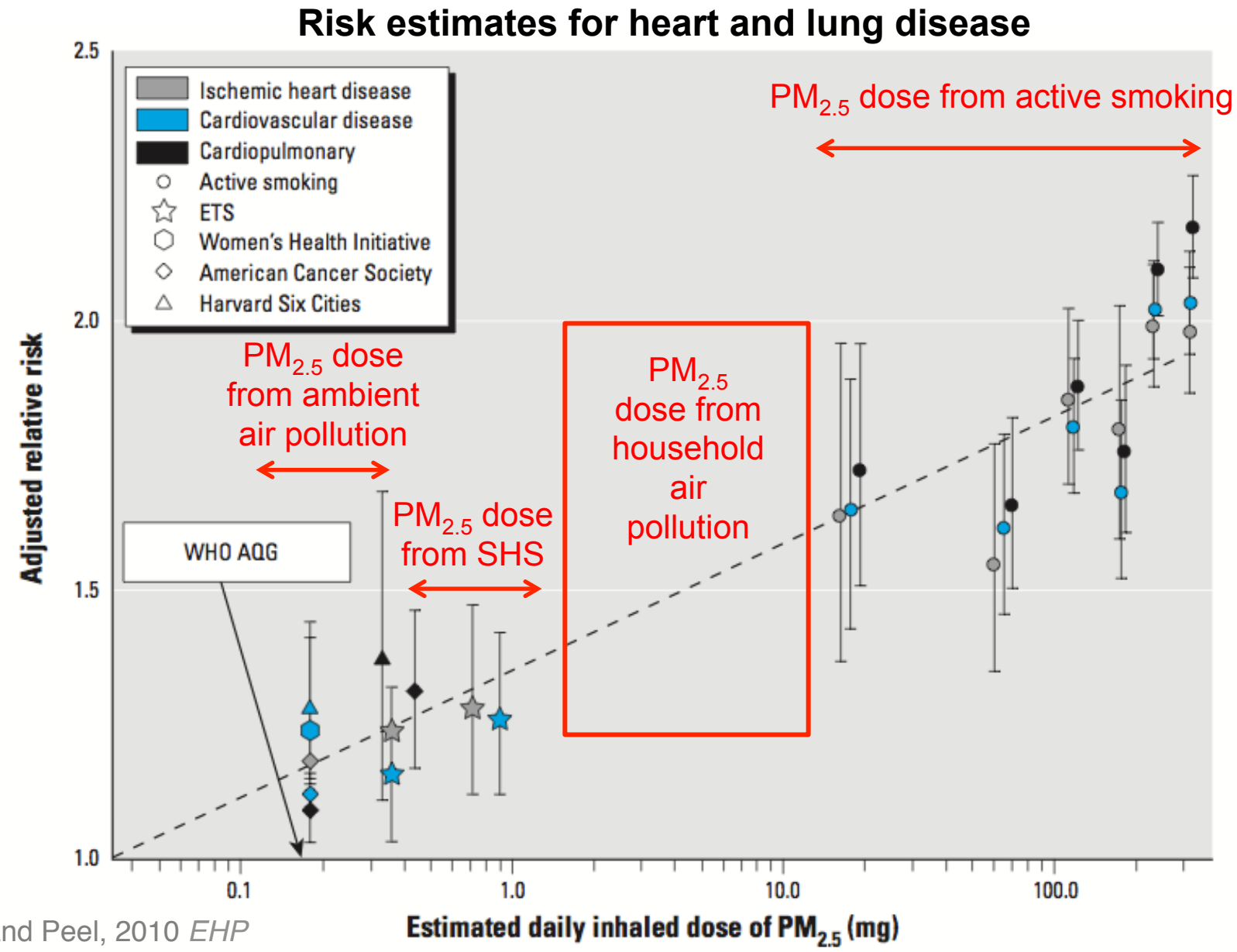


Simple wick lamps

Test kiosk

Apple et al., 2010 *Indoor Air*

What do these exposures mean for health effects?

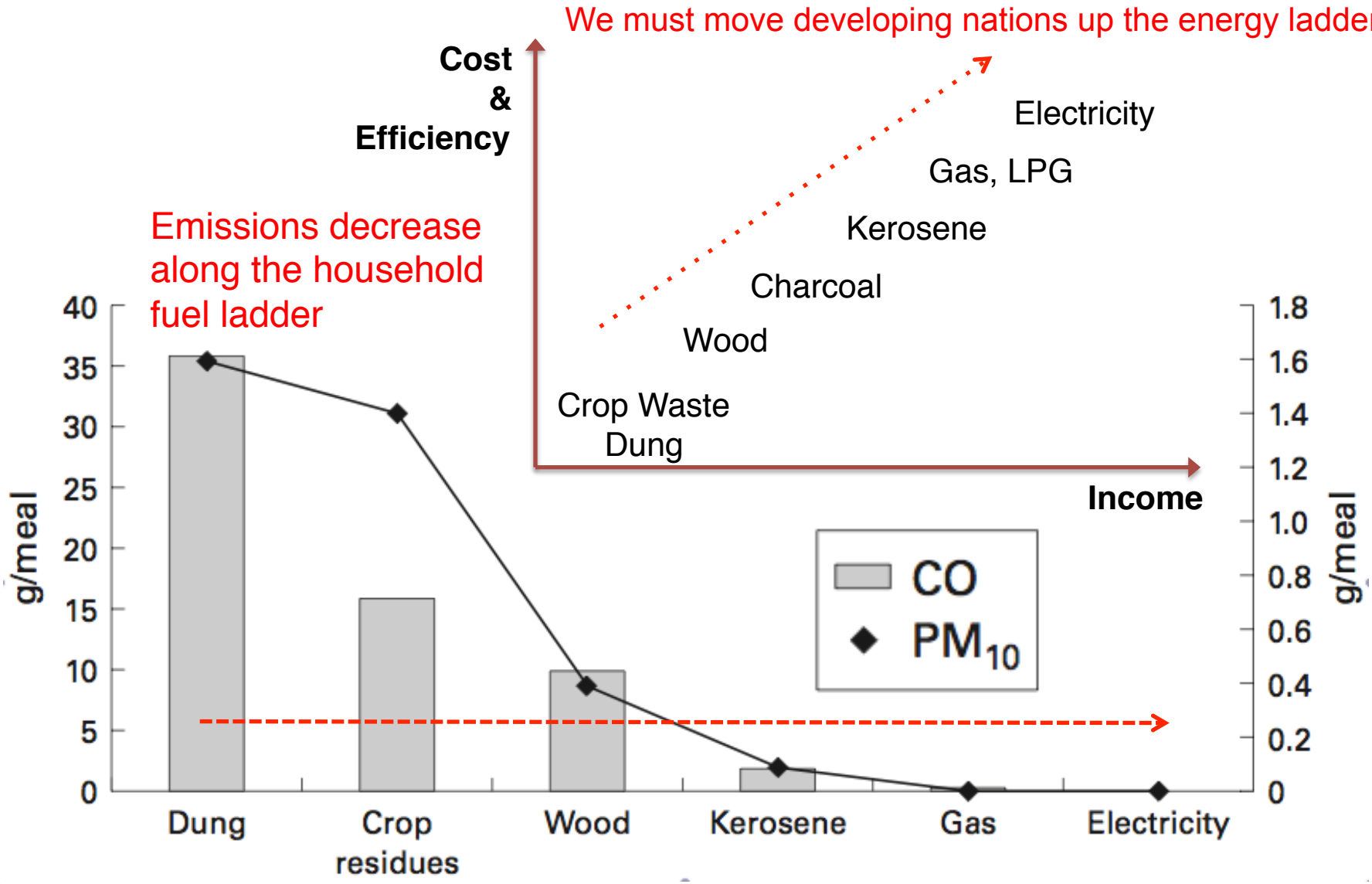


Smith and Peel, 2010 *EHP*

INTERVENTIONS

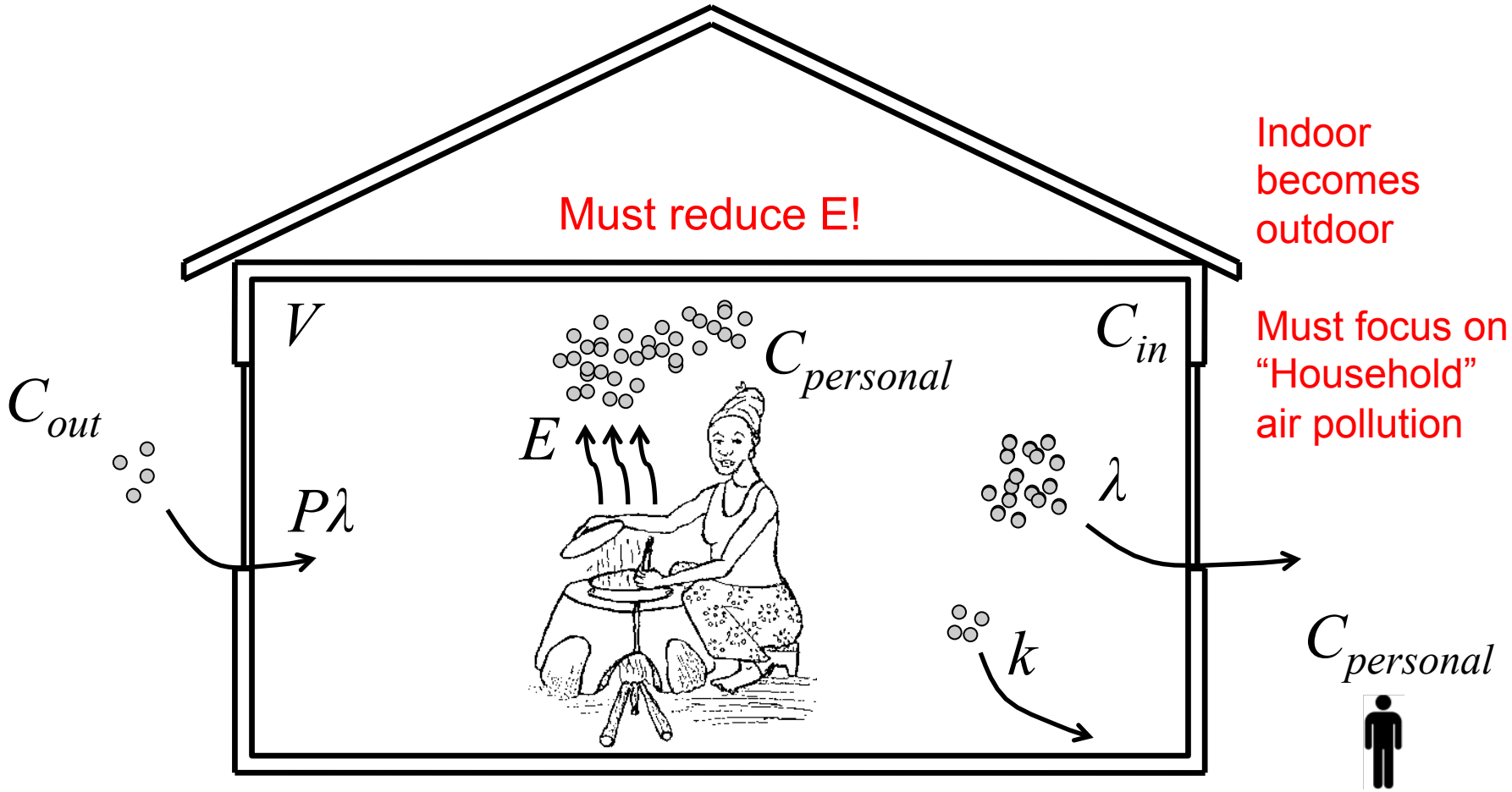
Clean cook stove campaigns

The energy ladder



Smith et al., 1999, US Environmental Protection Agency

Fundamental parameters driving exposures



C_{in} = Indoor concentration of pollutant C_{out} = Outdoor concentration of pollutant P = Penetration factor (-)
λ = Air exchange rate (hr^{-1}) k = Indoor loss rate (hr^{-1}) V = Volume of home (m^3) E = Emission rate (mg hr^{-1})

Cook stove emissions

$$Emission\ Rate,\ E = \frac{Emission\ Factor}{Energy\ Density} \times Stove\ Power$$

$$Stove\ Power = \frac{Cooking\ Energy\ Needed}{Cooking\ Time \times \eta}$$

Emission Rate, E = mg pollutant per hour
Emission Factor = mg pollutant per kg of fuel
Energy Density = MJ per kg of fuel
Stove Power = MJ per hour
Efficiency = MJ delivered per MJ burned

Johnson et al. (2011) *Atmos Environ*

Calculating emission rates

$$Emission\ Rate, E = \frac{Emission\ Factor}{Energy\ Density} \times Stove\ Power$$

$$Stove\ Power = \frac{Cooking\ Energy\ Needed}{Cooking\ Time \times \eta}$$

Typical values | Traditional Stove

- $EF_{PM2.5}$ = 5.2 g kg^{-1}
- Energy density of wood 18 MJ kg^{-1}
- Stove power = 4.9 kJ s^{-1}
  - Cooking energy needed = 11 MJ
  - Thermal efficiency = 14%
  - Cooking time = 4.5 hours

$$E = \frac{5.2\ g\ PM_{2.5}}{kg\ fuel} \times \frac{kg\ fuel}{18\ MJ} \times 4.9 \frac{kJ}{s} \times \frac{3600\ s}{hr} \times \frac{MJ}{1000\ kJ} = 5 \frac{g}{hr}$$

Johnson et al. (2011) *Atmos Environ*

Indoor concentrations

$$C_{ss} = PC_{out} + \frac{E/V}{\lambda + k} = \frac{E}{\lambda V}$$

- AER, λ = 25 hr^{-1}
- Kitchen volume, V = 30 m^3
- $E_{PM2.5}$ = 5 g hr^{-1}
- C_{ss} = 0.0067 g m^{-3} ≈ 7 mg m^{-3} ≈ 7000 μg m^{-3}
- WHO $PM_{2.5}$ standard = 35 μg m^{-3}
- 200 times higher

Johnson et al. (2011) *Atmos Environ*

Cookstoves: What has to change?

- Everything!

$$\downarrow \quad Emission\ Rate, E = \frac{Emission\ Factor}{Energy\ Density} \times Stove\ Power \quad \downarrow$$

$$\downarrow \quad Stove\ Power = \frac{Cooking\ Energy\ Needed}{Cooking\ Time \times \eta} \quad \uparrow$$

Stoves must get better
Fuels must get better

Can't just add a chimney

Cookstoves are major sources of outdoor pollution

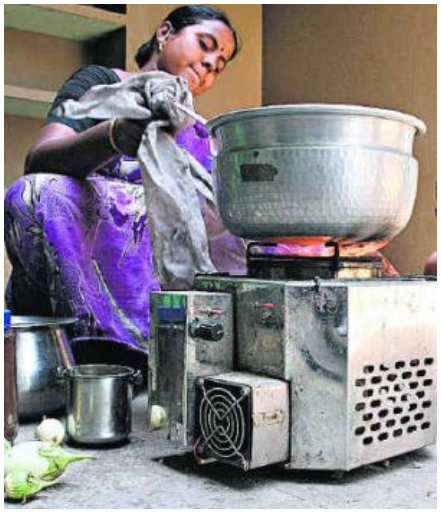
31-44% of primary $PM_{2.5}$ emissions in China
50-56% in India

Chafe et al., 2011 Indoor Air, Austin, TX

Enter: clean cook stoves

What is a clean cook stove?

1. Meets social, resource, income, and behavior needs
2. Improved performance relative to baseline conditions
   Pollutant emissions and energy efficiency
3. Scalable through markets or other mechanisms

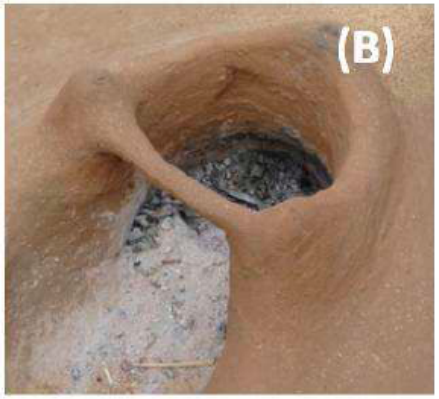


http://cleancookstoves.org/overview/what-is-a-clean-cookstove/

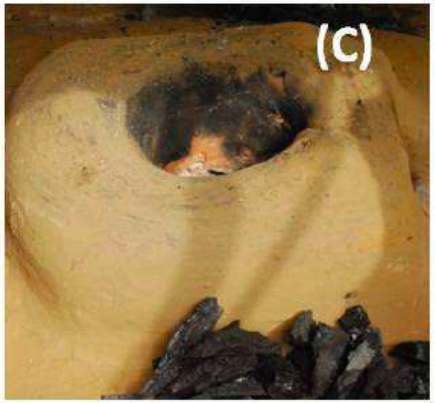
Example stoves

Traditional biomass *chulha*

Traditional coal *chulha*



Improved *chulha*



Kerosene

Biogas

Commercial biomass *bhati*

Commercial coal *bhati*

LPG stove

Sahu et al., 2011, ES&T

Example stoves

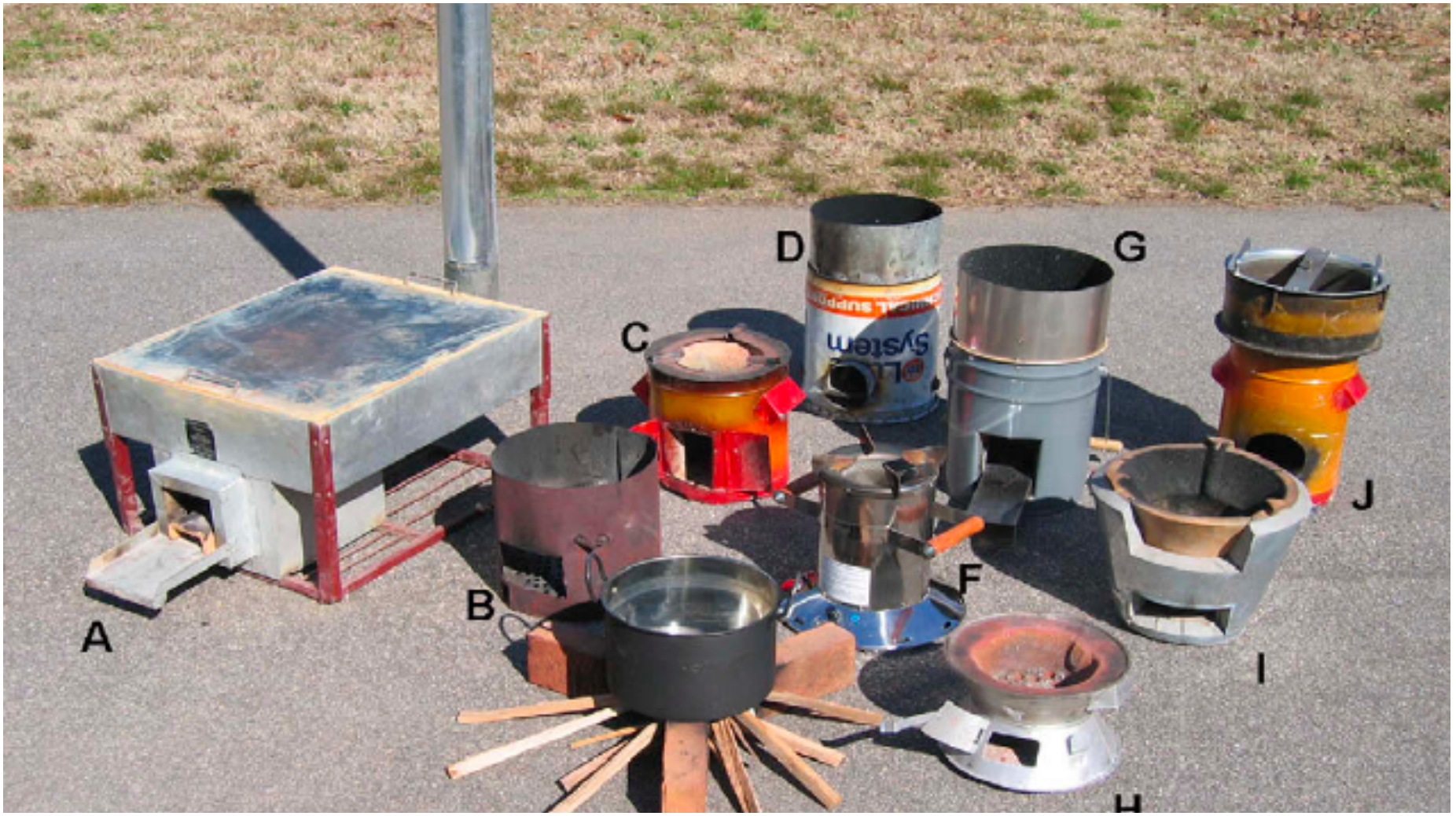


Fig. 1 – Stoves tested: A. Ecostove, B. VITA, C. UCODEA charcoal, D. WFP rocket, E. 3-stone fire, F. Philips, G. 6-brick rocket, H. Lakech charcoal, I. NLS, J. UCODEA rocket.

Jetter and Kariher, 2009 Biomass and Bioenergy

Ongoing research

- Emissions tests continue to be improved and conducted on more stoves
  - Often stark contrasts between laboratory and field test results
  - Some have turned to modeling efforts in stove design

- Exposure measurement studies continue to be conducted
  - Often coupled with health outcome studies
  - These take time, effort, and $$$ to do it right (i.e., randomized trials)

- The elephant in the room: cook stove adoption

Barriers to widespread adoption

- Previous reports have shown that stove implementation campaigns have been costly
  - And often result in poor adoption

- People often prefer their old inefficient stoves
  - Tradition or cooking preference
- People often use a mix of old and new stoves
  - “Stove stacking”
- People often alter their new stoves, diminishing effectiveness
- New stoves have had excessive costs
- Failures to integrate women in the stove design process

Social and behavioral aspects

- Stove adoption in El Fortin, Nicaragua
  - Problems with “culturally unfamiliar” stoves
  - Unfamiliar fuel types
- Surveyed 124 cooks in semi-rural Nicaragua
  - 1 year after introduction of improved cookstoves
- 48% still used their traditional open fire stoves
  - Often mixed
- Almost all preferred the new stove overall
- Many made adjustments to new stoves
  - Removing the plancha (griddle surface)
  - Leaving edges unsealed

For more information

Indoor Air Pollution in Developing Countries: Research and Implementation Needs for Improvements in Global Public Health

Elliott T. Gall, MSE, Ellison M. Carter, MSE, C. Matt Earnest, MSE, and Brent Stephens, PhD

American Journal of PUBLIC HEALTH

Barriers and research and implementation needs

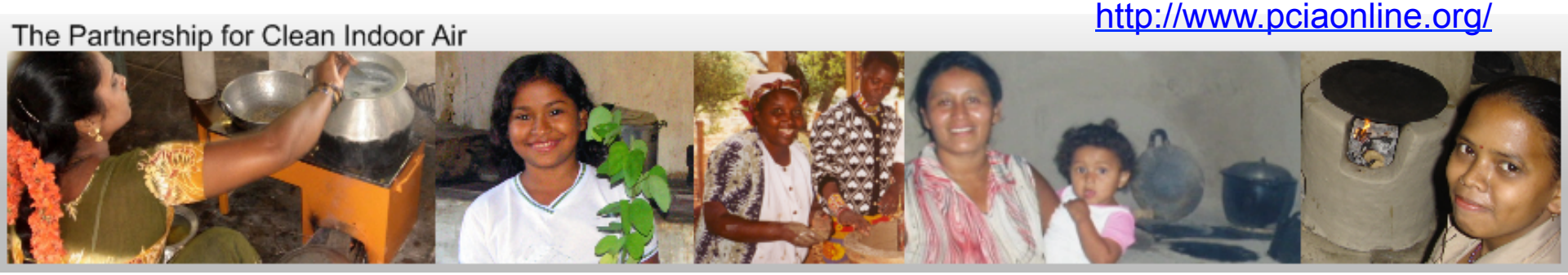
- Costs of improved cook stove programs have been too high
  - Costs must come down
- Research and implementation agencies need to integrate
  - Lab testing, field testing, and implementation together
- Mixed successes with stove adoption
  - Wide array of researchers need to work to understand adoption
- Indoor (and household) concentrations are still too high after new stoves
  - Engineers need to continue to develop cleaner and more efficient stoves
- Health assessments remain limited to draw robust conclusions
  - Need to standardize measurements/metrics to conduct larger scale intervention studies
- Instrumentation is a significant barrier to exposure studies
  - Need to develop low-cost reliable sensors

http://built-envi.com/wp-content/uploads/2013/03/gall_etal_ajph_2013.pdf

GET INVOLVED

Partnership for Clean Indoor Air

http://www.pciaonline.org/



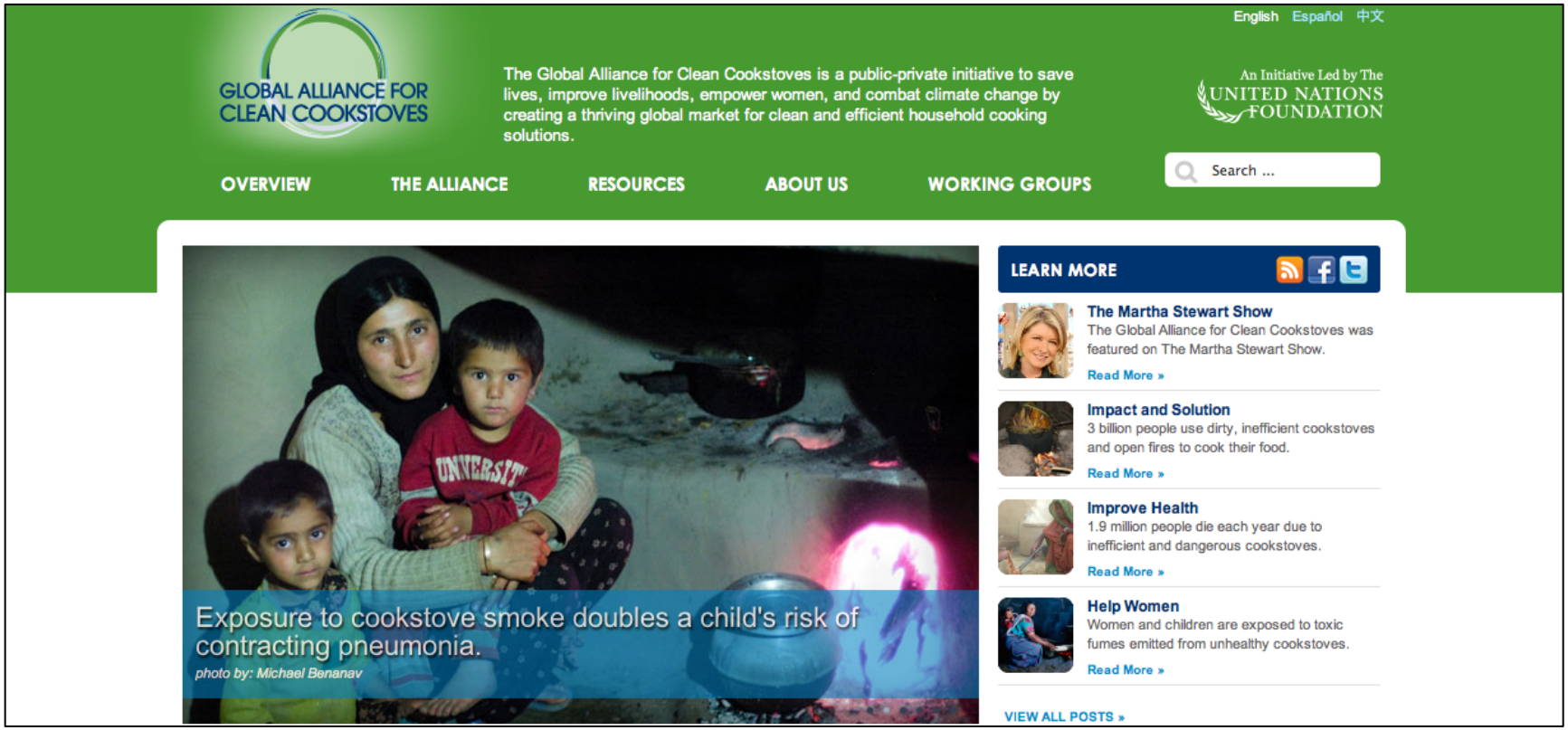
537 partner organizations contributing resources and expertise to reduce pollutant exposure from cooking and heating practices in households around the world.

Essential elements of effective, sustainable household energy and health programs:

1. Meeting the needs of local communities for clean, efficient, affordable and safe cooking and heating options
2. Improved cooking technologies, fuels and practices for reducing indoor air pollution
3. Developing commercial markets for clean and efficient technologies and fuels
4. Monitoring and evaluating the health, social, economic and environmental impact of household energy interventions

Global Alliance for Clean Cookstoves

The Global Alliance for Clean Cookstoves is a new public-private partnership to save lives, improve livelihoods, empower women, and combat climate change by creating a thriving global market for clean and efficient household cooking solutions. The Alliance's 100 by '20 goal calls for 100 million homes to adopt clean and efficient stoves and fuels by 2020.



http://cleancookstoves.org/

Resources for getting involved

- Some EWB resources
  - GA Tech: http://ewb-gt.org/?page_id=1568
  - Michigan Tech: http://ewb.students.mtu.edu/
- Some important academic groups in this field
  - Kirk Smith, UC-Berkeley: http://ehs.sph.berkeley.edu/krsmith/
  - Ashok Gadgil, LBL: http://cookstoves.lbl.gov/
  - Tami bond, UIUC: http://www.hiwater.org/
  - CSU Engines Lab: http://www.eecl.colostate.edu/research/household.php
  - Modi group, Columbia: http://modi.mech.columbia.edu/
  - Duke: http://sites.duke.edu/cookstove/
- Other important groups
  - Berkeley Air Monitoring Group: http://www.berkeleyair.com/
  - Trees, Water, People: http://www.treeswaterpeople.org/
  - Aprovecho: http://www.aprovecho.org
  - Bioenergylists: http://www.stoves.bioenergylists.org/