Household Cooking, Health, and Climate: Indoors Going Out

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UC Berkeley, July 14, 2010

the Lancet 374(9705):1917-29, 2009 (Dec).

Health and Climate Change 1

Public health benefits of strategies to reduce greenhouse-gas emissions: household energy

Paul Wilkinson, Kirk R Smith, Michael Davies, Heather Adair, Ben G Armstrong, Mark Barrett, Nigel Bruce, Andy Haines, Ian Hamilton, Tadj Oreszczyn, Ian Ridley, Cathryn Tonne, Zaid Chalabi

Energy for Sustainable Development 14 (2010) 63–72

The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion

C. Venkataraman [a], A.D. Sagar [b], G. Habib [b], N. Lam [c], K.R. Smith [c,*]

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_2O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%

Indian Cookstoves

Fuel	Nominal Combustion Efficiency	Approximate % of Households - 2001
• Gas: `	99% (98-99.5)	[18%]
• Kerosene:	97 (95-98)	[7]
Solid Fuels		
• Wood:	89 (81-92)	[53]
• Crop resid:	85 (78-91)	[10]
• Dung:	84 (81-89)	[10]
• Coal	(variable)	[2]

Source: Smith, et al, 2000
Census, 2001

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

Size Distribution of Biomass Smoke Particles

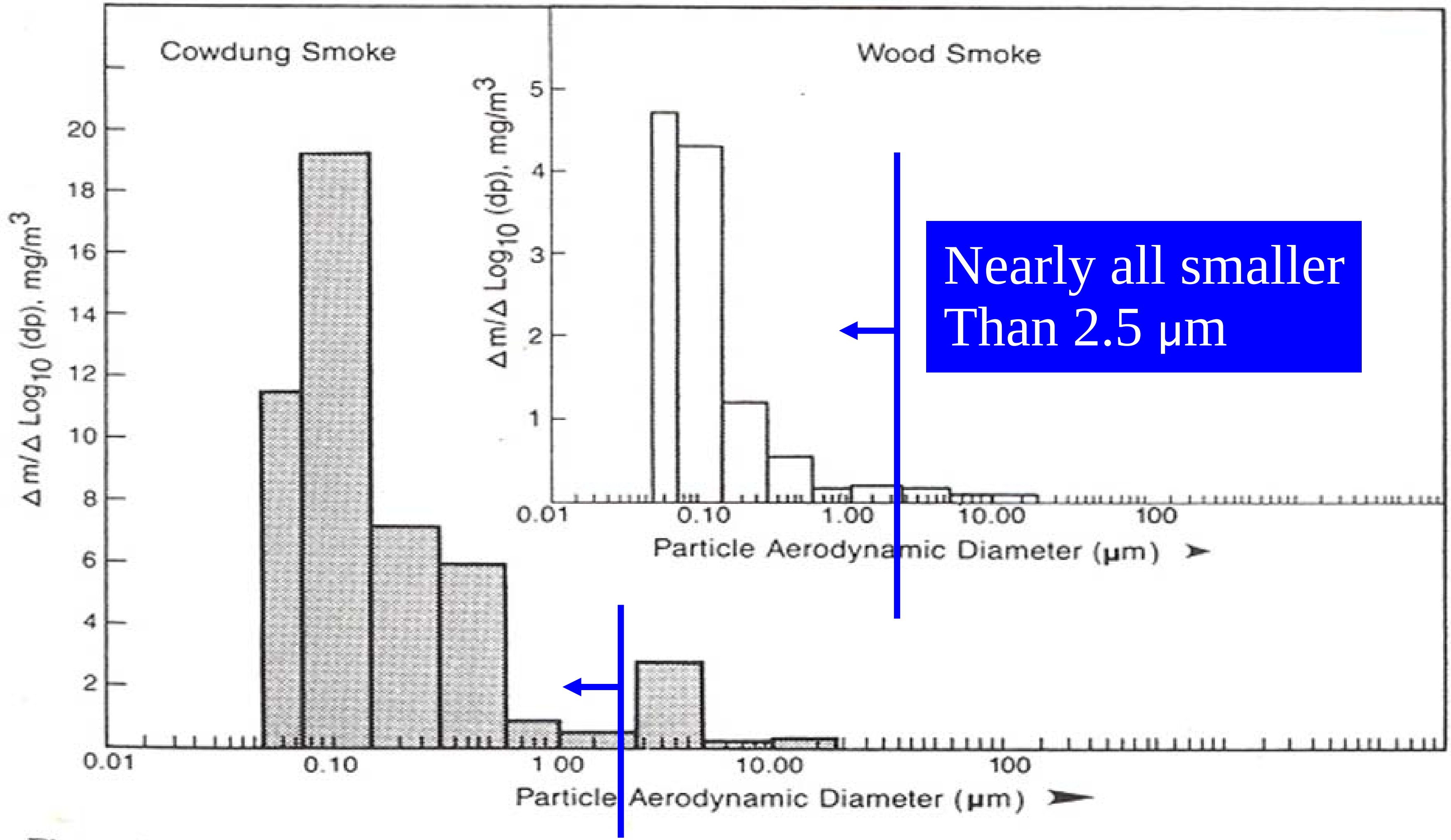


Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East–West Center simulated village house as reported in Smith *et al.* (1984b). (Figure prepared by Premlata Menon.)

Source: Smith, Apte et al. 1984

Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

Organics known to be mutagens, immune system suppressants, severe irritants, inflammation agents, central nervous system depressants, cilia toxins, endocrine disrupters, or neurotoxins.

Several chemicals firmly established as human carcinogens.

Other toxic inorganic chemicals.

- 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*

Source: Naeher et al, *J Inhal Tox*, 2007

Smoke Production

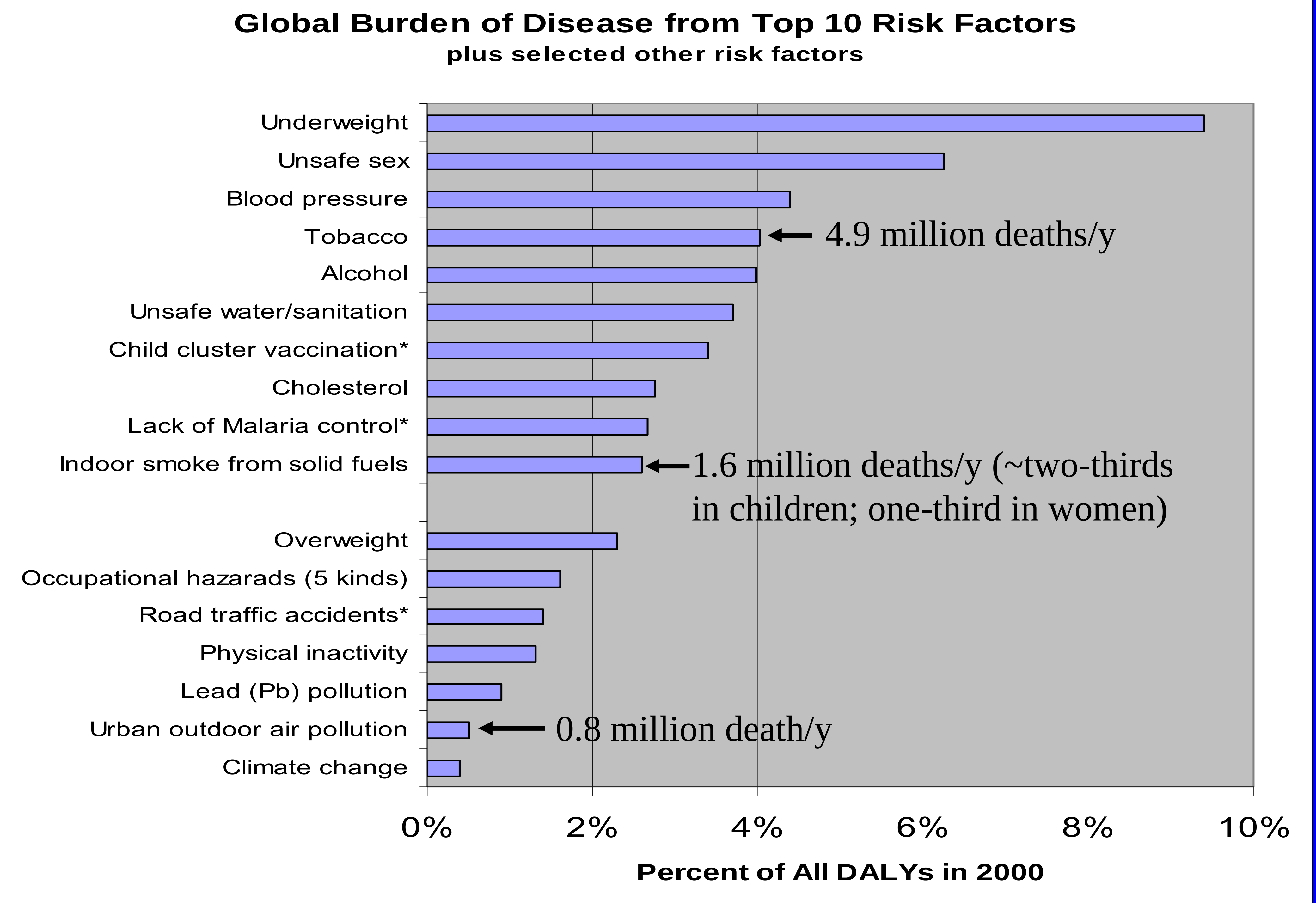
- Biomass has nearly no intrinsic contaminants, i.e., can be burned cleanly to CO_2 and water
- Poor combustion creates large volumes of products of incomplete combustion (PIC), nearly all of which are hazardous to health
- Main constituent (90%) is carbon monoxide (CO)
- Small particles also created
- Nearly all remainder is in the form of toxic organic gases
- But how many people exposed and what is impact?

International Comparative Risk Assessments – Second Assessment

- In progress – scheduled for 2011
- 40 major risk factors being compared including several combustion particle categories
- Only **<u>comparable</u>** risk assessment with

consistent

  - Population and background disease databases
  - Common rules of evidence
  - Standard methods for PAR and exposure modeling
  - Extensive cross-risk-factor peer review


Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
Underweight
Unsafe sex
Blood pressure
Tobacco
4.9 million deaths/y
Alcohol
Unsafe water/sanitation
Child cluster vaccination*
Cholesterol
Lack of Malaria control*
Indoor smoke from solid fuels
1.6 million deaths/y (~two-thirds in children; one-third in women)
Overweight
Occupational hazarads (5 kinds)
Road traffic accidents*
Physical inactivity
Lead (Pb) pollution
Urban outdoor air pollution
0.8 million death/y
Climate change
0%
2%
4%
6%
8%
10%
Percent of All DALYs in 2000

Framing for HAP

- Household air pollution (HAP) from cooking fuel – incomplete combustion
- Cooking only, although sometimes difficult to separate from space heating
- Uses long-term fine particle ($PM_{2.5}$) exposures as metric
- All combustion produces some pollution, but solid fuels produce much more
- Includes household contribution to outdoor air pollution and (potentially) climate change

Advances Since First Assessment

- Much more robust global modeling of fuel use
- Proportion of outdoor air pollution from HAP in Asia – 70% of solid fuel households worldwide
- Modeling of $PM_{2.5}$ exposures for 25% of world solid fuel households, those in India
- New SR/MAs for the previous 3 outcomes (ALRI, COPD, LC)
- RCT and exposure-response also available for ALRI
- Common exp-resp curve with outdoor air pollution
- New SR/MAs for 2 additional primary outcomes (LBW, cataracts)
- Better discrimination of male/female outcomes
- Assessment of consistency from trends in overall combustion particle literature (outdoor air, passive smoking, HAP, and active smoking)
- Interpolation of CVD outcomes from exposure-response relationship across combustion particle sources

485 Nationally Representative HH Surveys

GBD Region	Total Regional Population ('000)	Population Covered ('000) by HH Surveys	% of Population Covered by HH Surveys
Asia Pacific, High Income	215,171	47,870	**27%**
Asia, Central	76,815	76,815	100%
Asia, East	1,344,125	1,312,979	98%
Asia, South	1,498,563	1,498,563	100%
Asia, Southeast	574,410	572,558	100%
Australasia	24,407	0	**0%**
Caribbean	41,874	35,327	84%
Europe, Central	76,815	60,177	**50%**
Europe, Eastern	211,614	208,189	98%
Europe, Western	407,168	43,397	**11%**
Latin America, Andean	49,517	49,517	100%
Latin America, Central	215,171	188,445	88%
Latin America, Southern	58,368	42,073	72%
Latin America, Tropical	192,735	192,735	100%
North Africa/Middle East	410,800	380,815	93%
North America, High Income	332,117	0	**0%**
Oceania	8,637	8,213	95%
Sub-Saharan Africa, Central	84,412	83,928	99%
Sub-Saharan Africa, East	314,207	314,207	100%
Sub-Saharan Africa, Southern	68,019	68,019	100%
Sub-Saharan Africa, West	300,592	291,949	97%

Coverage: 84% of World's Population

Covariates considered

Covariate Data for Country & Year			
	Variable Definition	**Source**	**# of points**
gdp_pc	2000 international dollars	IHME	436
pop_den	people per sq. km	World Bank WDI	425
pct_rural	% of total population	World Bank WDI	425
pct_urban	% of total population	World Bank WDI	425
pct_ag	% of total land area	World Bank WDI	423
crude_bth	per 1,000	World Bank WDI	423
fertrate	births per woman	World Bank WDI	423
wsan_all	% of population with access	World Bank WDI	388
ttl_pop	'000	IHME	420
co2_sfu	(% of total)	World Bank WDI	416
co2_pc	CO2 emissions (metric tons per capita)	World Bank WDI	415
gdp_ppp_pc	PPP (current international $)	World Bank WDI	408
gni_pc_atlas	Atlas method (current US$)	World Bank WDI	408
gni_pc_ppp	PPP (current international $)	World Bank WDI	405
for_pct	% of total area	World Bank WDI	405
wsan_all	% of total population w/ access	World Bank WDI	388
wh20_all	% of population with access	World Bank WDI	388
wh20_rur	% of rural population with access	World Bank WDI	388
wd_gross	cubic metres ('000)	UN Energy Statistical Yearbook	390
wsan_rur	% of rural population with access	World Bank WDI	390
hh_expen	PPP (current international $)	World Bank WDI	374
wd_net	cubic metres ('000)	UN Energy Statistical Yearbook	360
prime_pct	% of relevant age group	World Bank WDI	353
crnw_pct	(% of total energy)	World Bank WDI	307
coal_pct_el	(% of total)	World Bank WDI	307
egy_pc	kg of oil equivalent per capita	World Bank WDI	306
fffuel_pct	% of total	World Bank WDI	306
elec_pc	(kWh per capita)	World Bank WDI	304
wd_hhco	cubic metres ('000)	UN Energy Statistical Yearbook	290
fem_litpct	% of females ages 15 and above	World Bank WDI	267
adult_litpct	% of people ages 15 and above	World Bank WDI	267
gini		World Bank WDI	249

Finalized Global Model

$\% \, HH_{exp} = \beta_0 + \beta_{gni}(x) + \beta_{ff}(x) + \beta_{san}(x) + \beta_{\%rur}(x) + \beta_{name}(x) + \text{i.year, cluster (country id)}$

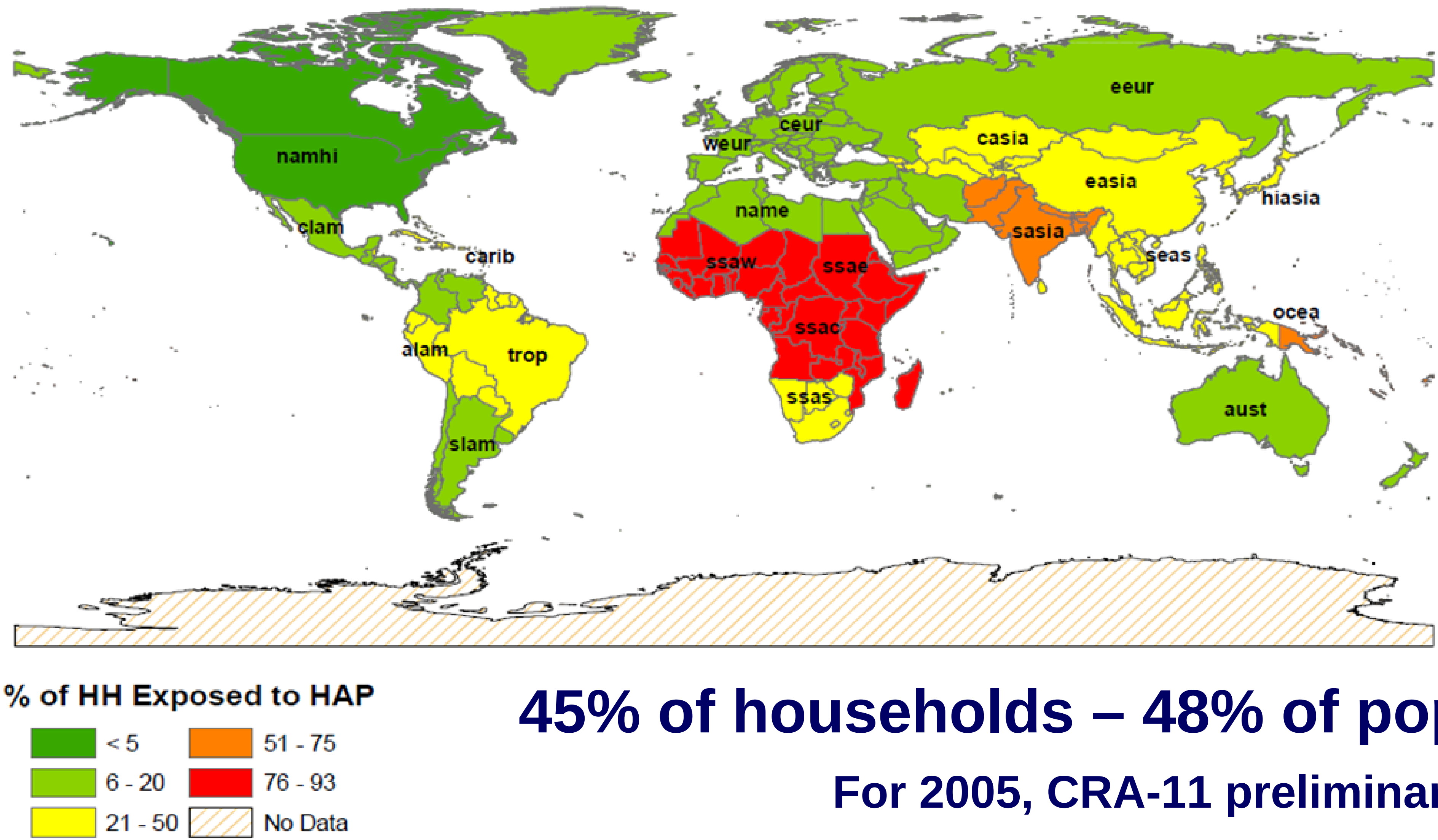
Where:	Coefficient	p-value	Std. error
β_0 = constant	1.616143	<0.0005	0.2270526
β_{gni} = GNI per capita (PPP)	-0.1248968	<0.0005	0.0263975
β_{ff} = % of total energy from fossil fuels	-0.0028653	<0.0005	0.0006432
β_{san} = % of total population with access to clean sanitation	-0.0023438	0.001	0.0007079
$\beta_{\%rur}$ = % of total population living in rural areas	0.0033154	0.002	.0010404
β_{name} = North Africa/Middle East Region (Y/N)	-0.1728939	0.000	0.0463104
i.year = indicator for year	0.028949 ('05) 0.077753 ('90)	0.52 0.363	0.0561452 .0850541

***(R^2= 0.8587)** *based on non-imputed regression*

Note: Oceania analysis conducted separately due to lack of covariate data:

$\% \, HH_{exp} = \beta_0 + \beta_{gdp}(x) + \beta_{pop\ density}(x)$

Households Using Solid Cooking Fuels

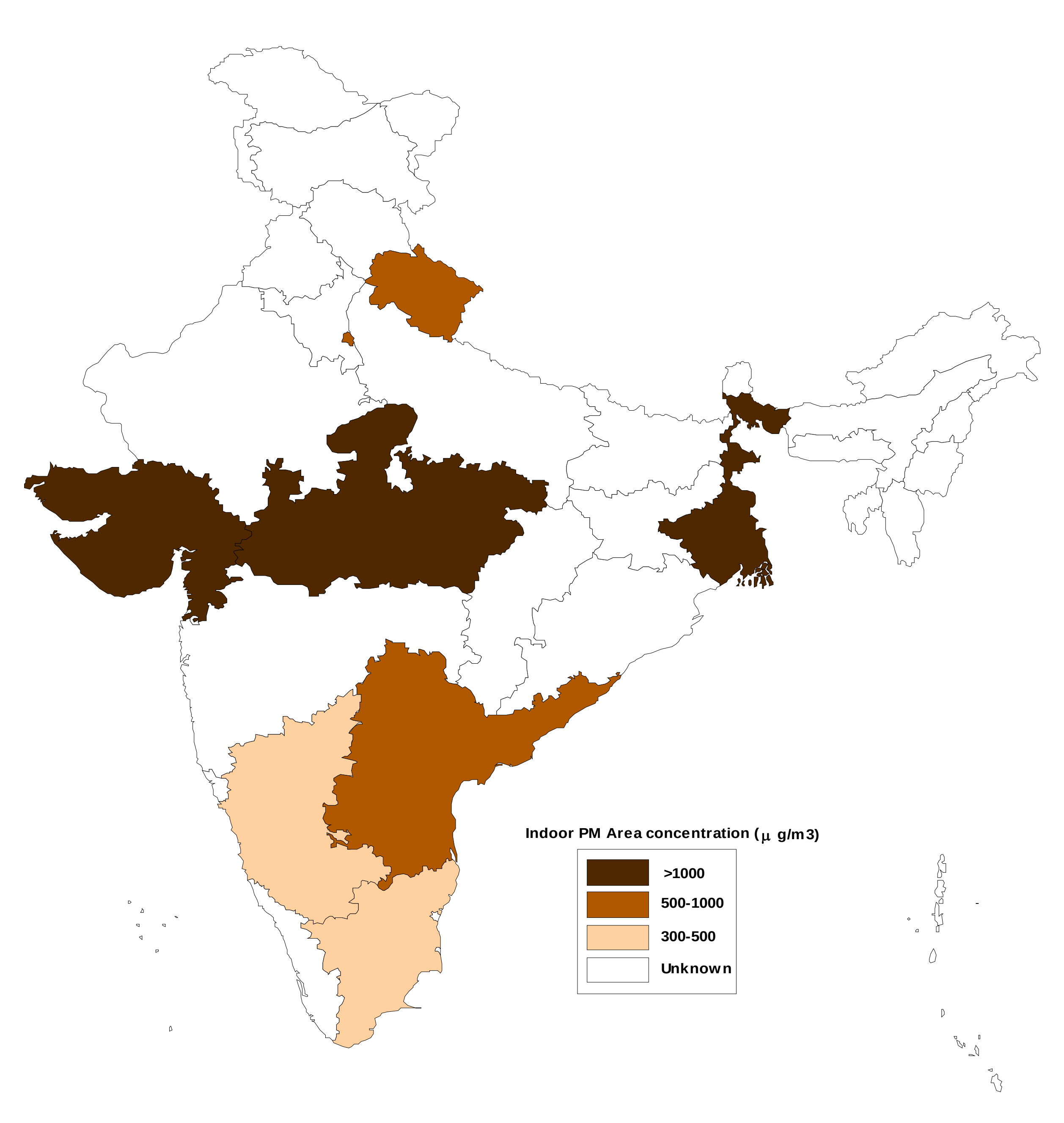


45% of households – 48% of pop

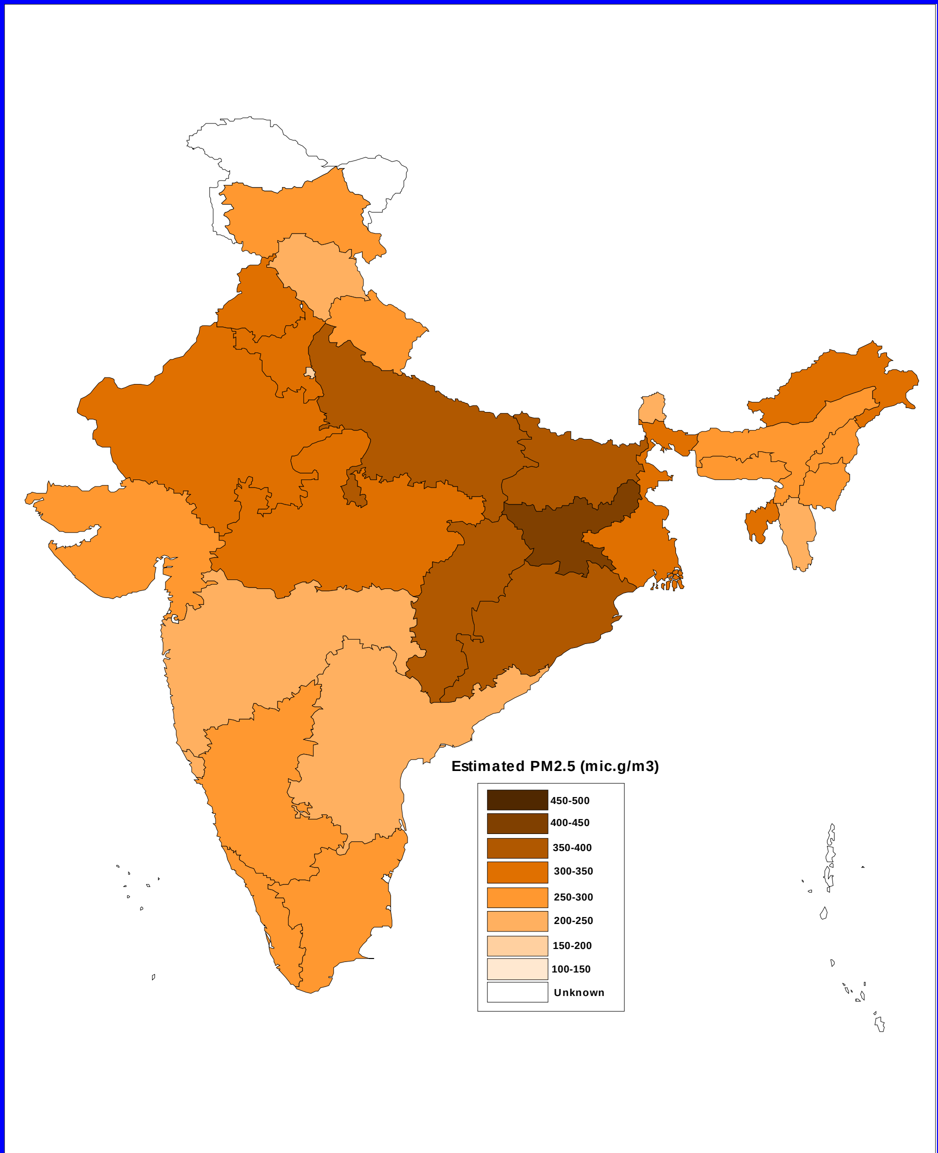
For 2005, CRA-11 preliminary

First person in human history to have her exposure measured doing the oldest task in human history

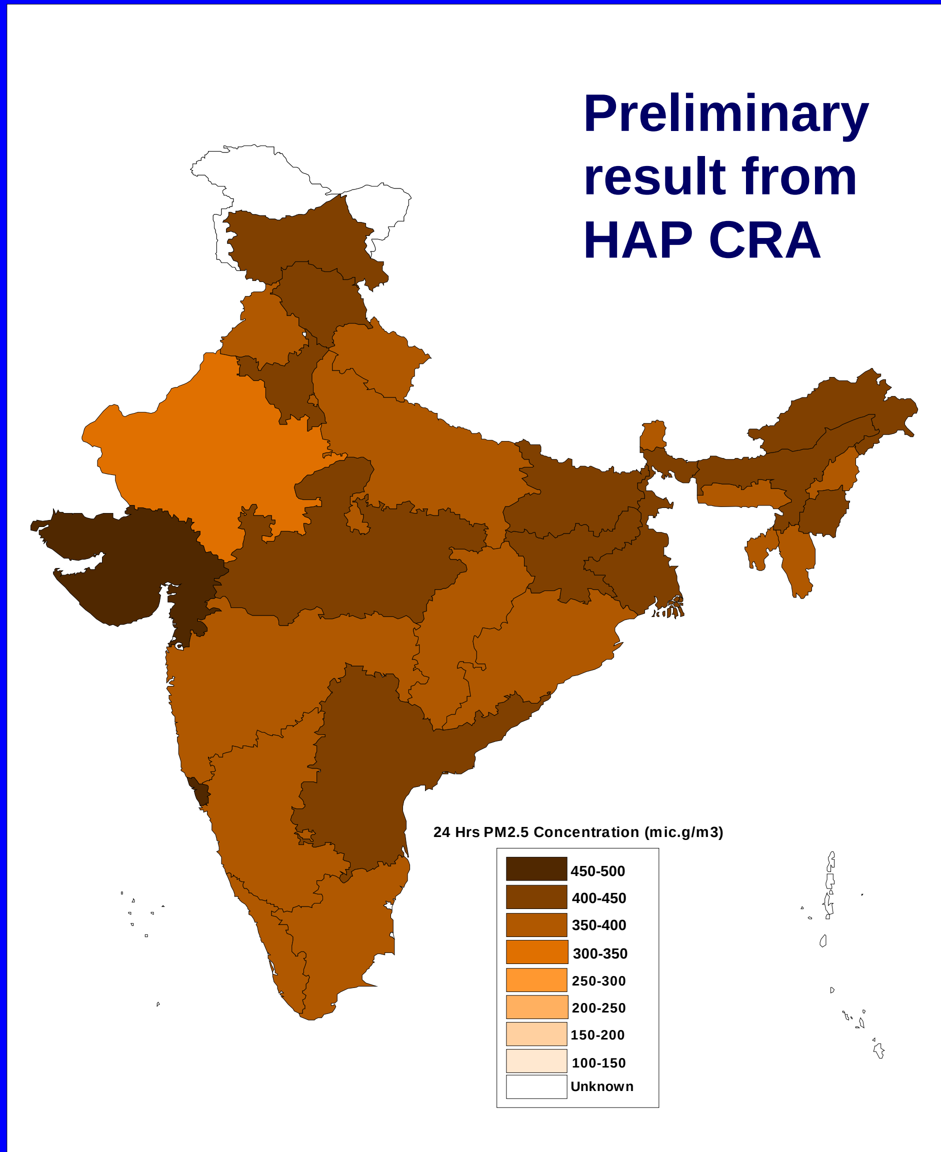
Ranges of pollutants (PM2.5) across the six states with systematic measurements



Estimated PM2.5 indoors for all HHs



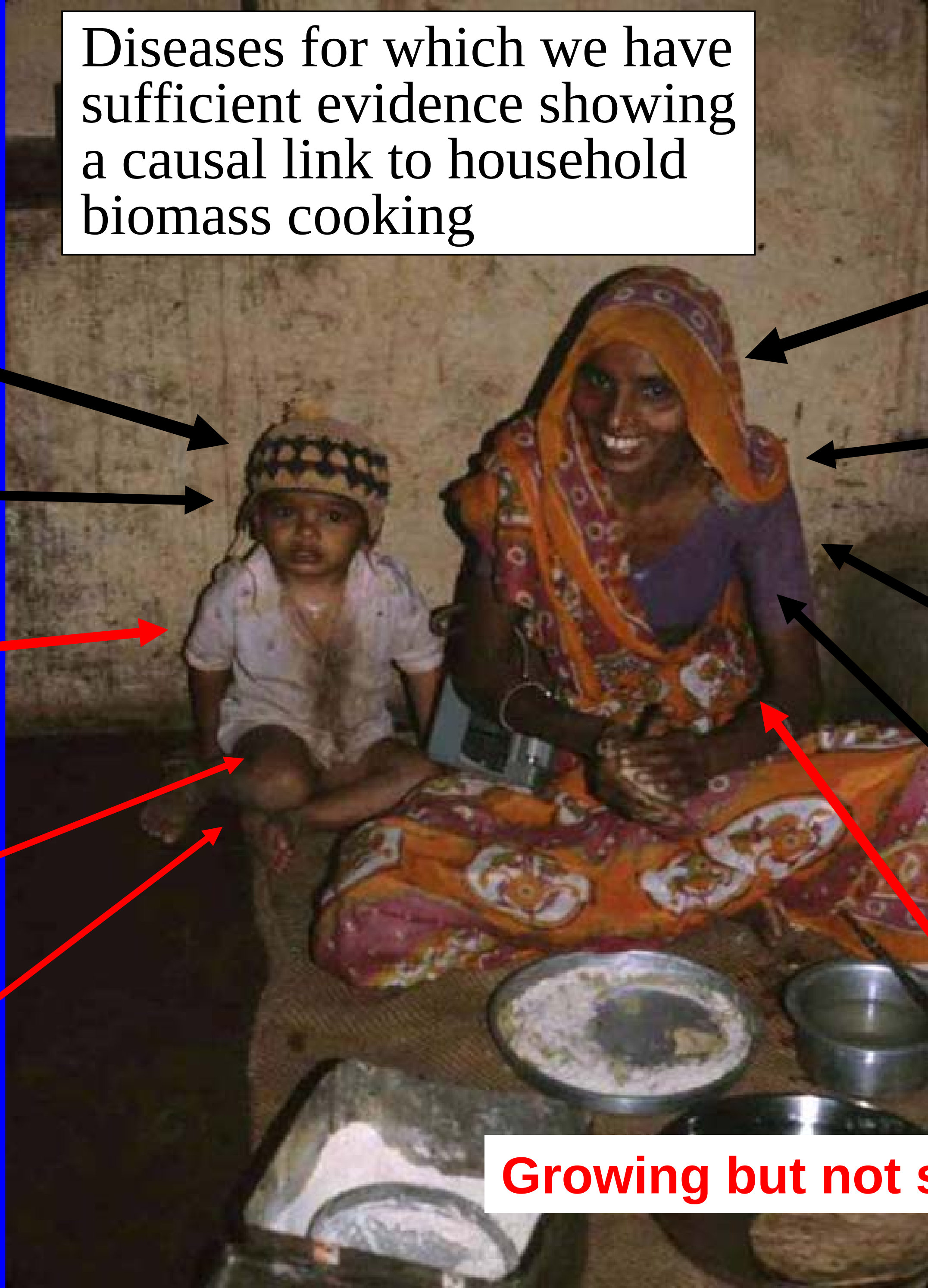
Estimated PM2.5 for only solid fuel using HHs



Household solid fuels and health

- About 45% of world’s households rely on these fuels - nearly half of world population
- Large source of ill-health worldwide in poorest populations ~ 2 million premature deaths annually in last comparative risk assessment – CRA-04. (tobacco = 5 million)
- These are all due to respiratory disease from indoor exposures – ALRI, COPD, and lung cancer
- Now sufficient evidence of heart disease, stroke, cataracts, and adverse pregnancy outcomes, which will also be included in new CRA-10 in progress

Diseases for which we have sufficient evidence showing a causal link to household biomass cooking



ALRI/ Pneumonia (meningitis)

Low birth weight

Asthma?

Birth defects?

Cognitive Impairment?

Chronic obstructive pulmonary disease

Cataracts

Cancer (lung, cervical, aero-digestive)

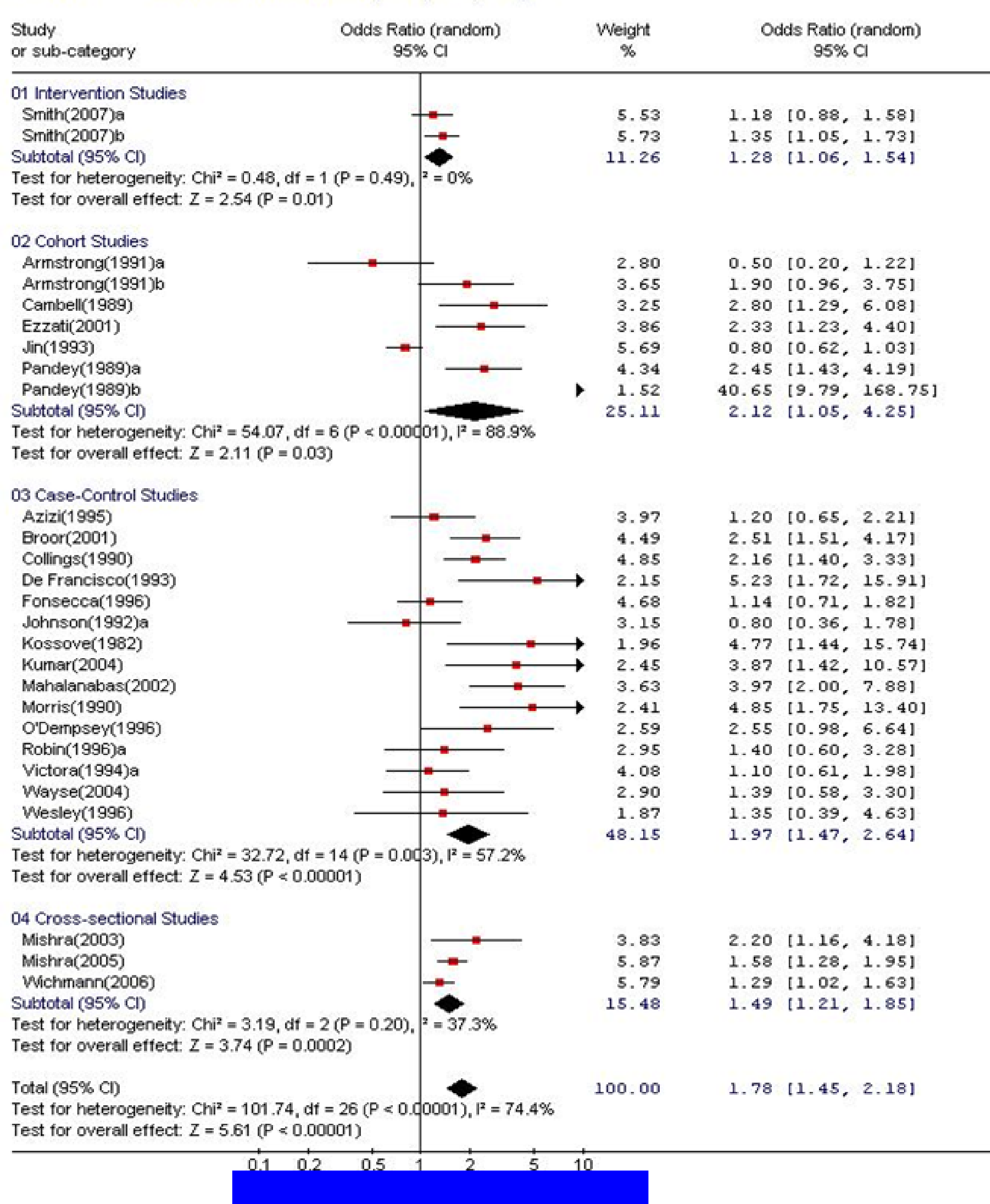
Heart disease and stroke

Tuberculosis?

Growing but not sufficient evidence

Study design	N*	OR	95% CI
Intervention	2	1.28	1.06, 1.54
Cohort	7	2.12	1.06, 4.25
Case-control	15	1.97	1.47, 2.64
Cross-sectional	3	1.49	1.21, 1.85
All	26	1.78	1.45, 2.18

Dherani et al Bull WHO (2008)



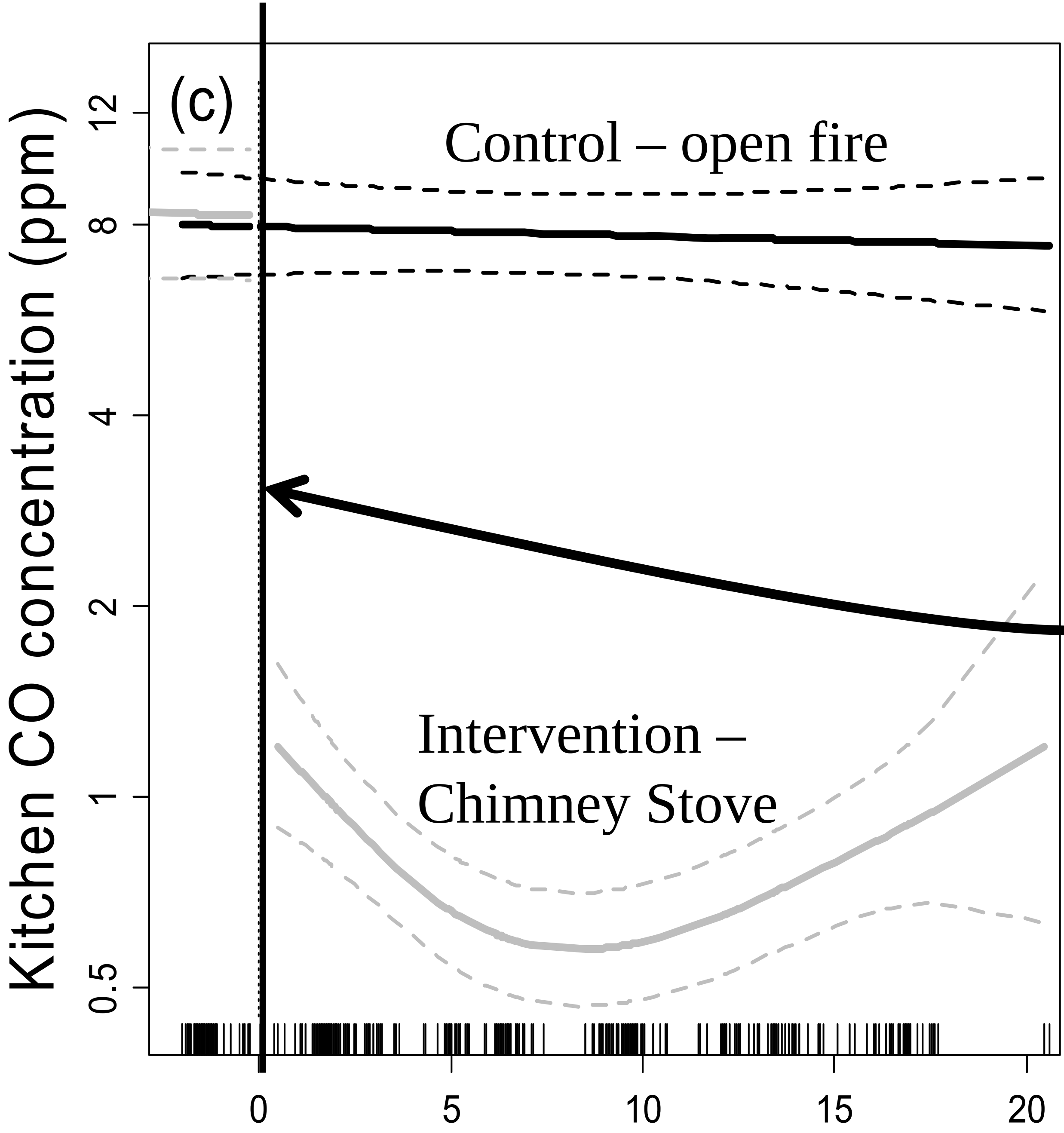
RESPIRE – Randomised trial (n=518)

Impact on pneumonia up to 18 months of age

Traditional open 3-stone fire: kitchen 48-hour $PM_{2.5}$ levels of 500 - 1000 $\mu g/m^3$

Chimney wood stove, locally made and popular with households

Guatemala Randomized Intervention Trial



Effect of Chimney Stove On Kitchen CO Levels

Factor of ~10 less

285 48-h measurements

Months

al, , 2020


Tubito
Tubito

Journal of Exposure Science and Environmental Epidemiology (2010) 20, 406–416

www.nature.com/jes

Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE)

KIRK R. SMITH[a], JOHN P. McCRACKEN[a], LISA THOMPSON[a], RUFUS EDWARDS[b], KYRA N. SHIELDS[a], EDUARDO CANUZ[c] AND NIGEL BRUCE[d]

PAPER www.rsc.org/jem | Journal of Environmental Monitoring

Estimating personal PM2.5 exposures using CO measurements in Guatemalan households cooking with wood fuel

Amanda Northcross,[a] Zohir Chowdhury,[b] John McCracken,[ac] Eduardo Canuz[c] and Kirk R. Smith*[d]

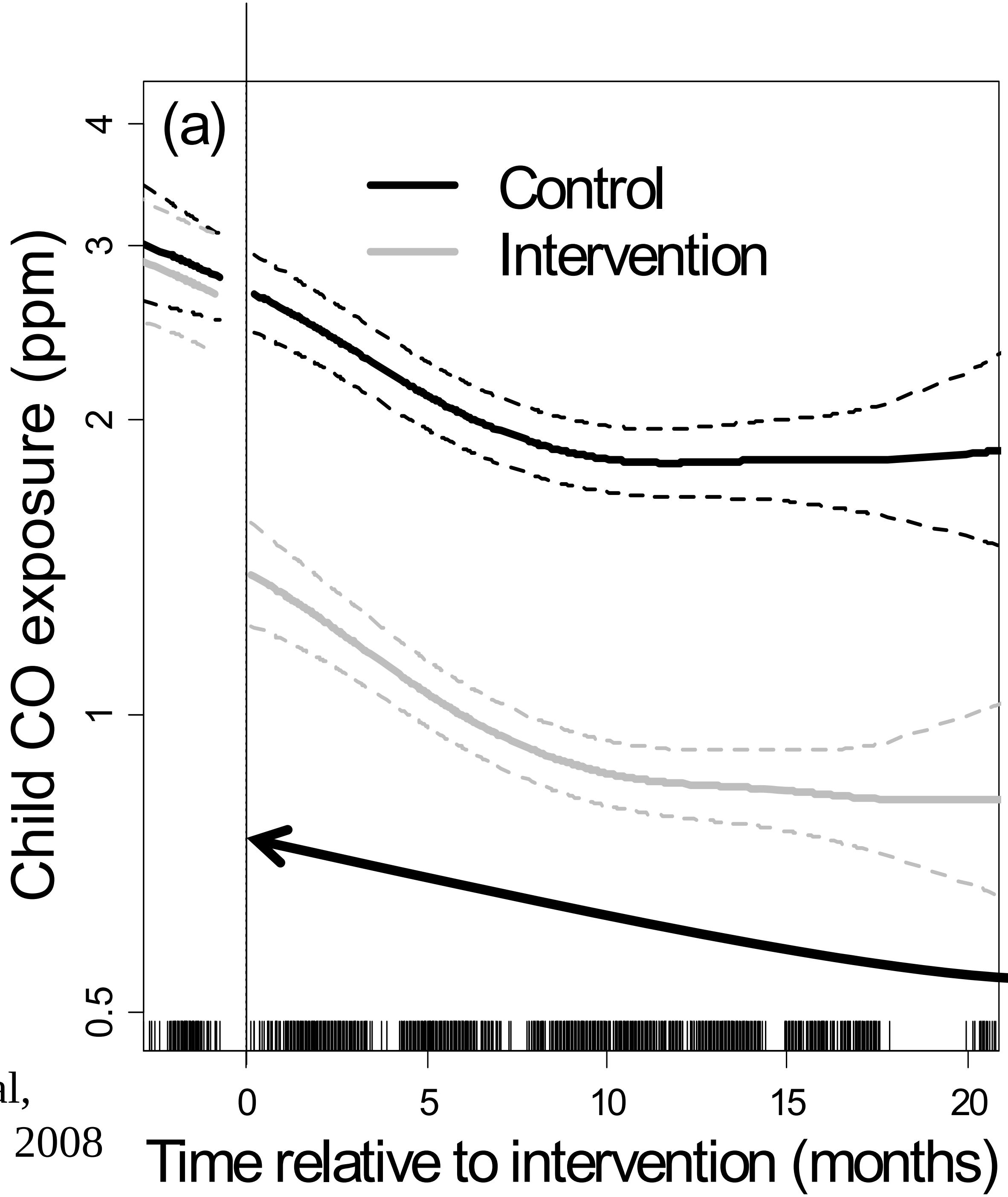
Received 5th August 2009, Accepted 6th January 2010
First published as an Advance Article on the web 15th February 2010

Combining Individual- and Group-Level Exposure Information

Child Carbon Monoxide in the Guatemala Woodstove Randomized Control Trial

John P. McCracken,[a,b] Joel Schwartz,[a,b] Nigel Bruce,[c] Murray Mittleman,[a] and Kirk R. Smith[f]

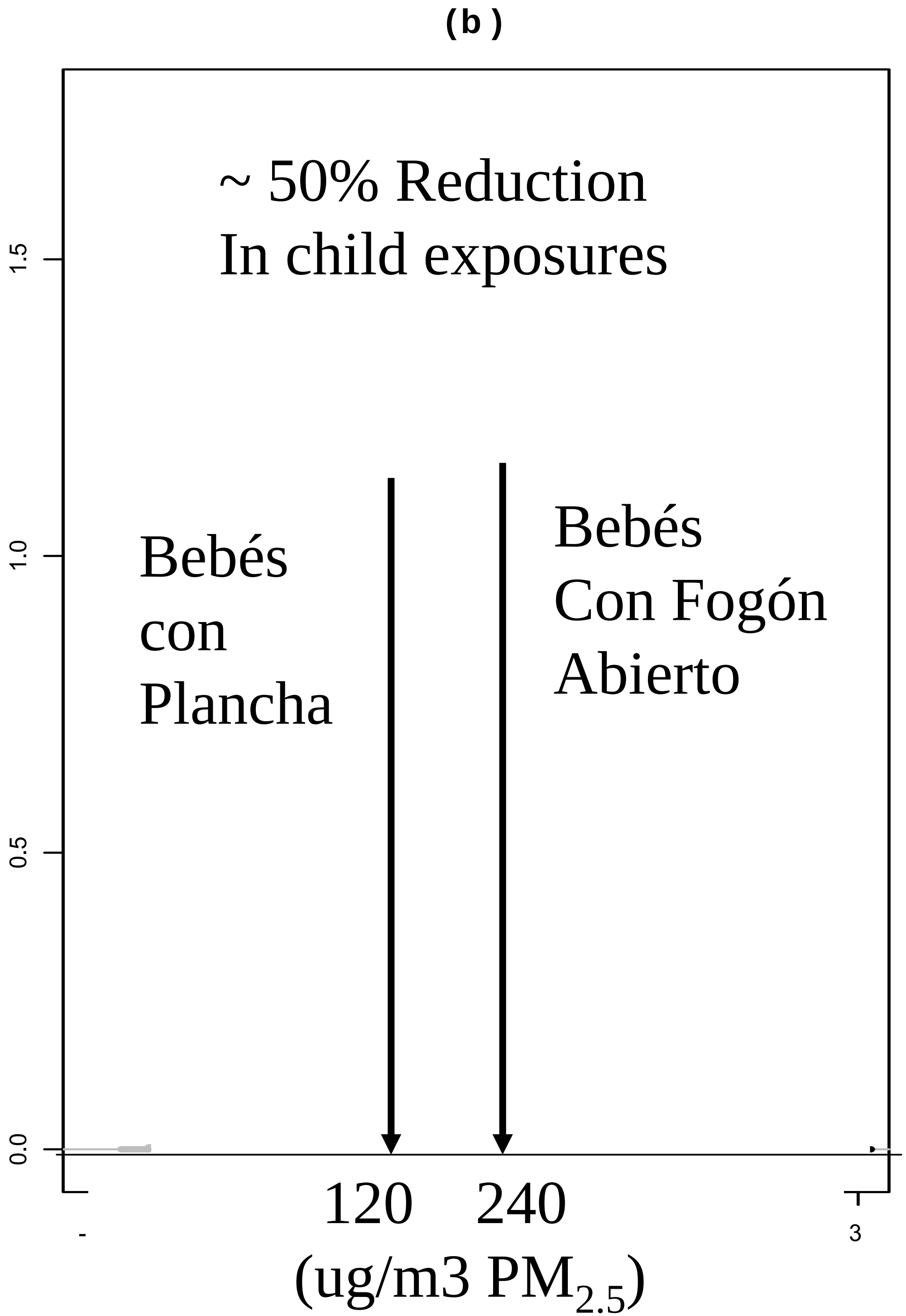
Epidemiology • Volume 20, Number 1, January 2009



1888 48-h measurements

Effect of
Chimney
Stove
On
Infant
Exposures
- 2x less

Smith, et al, submitted, 2008



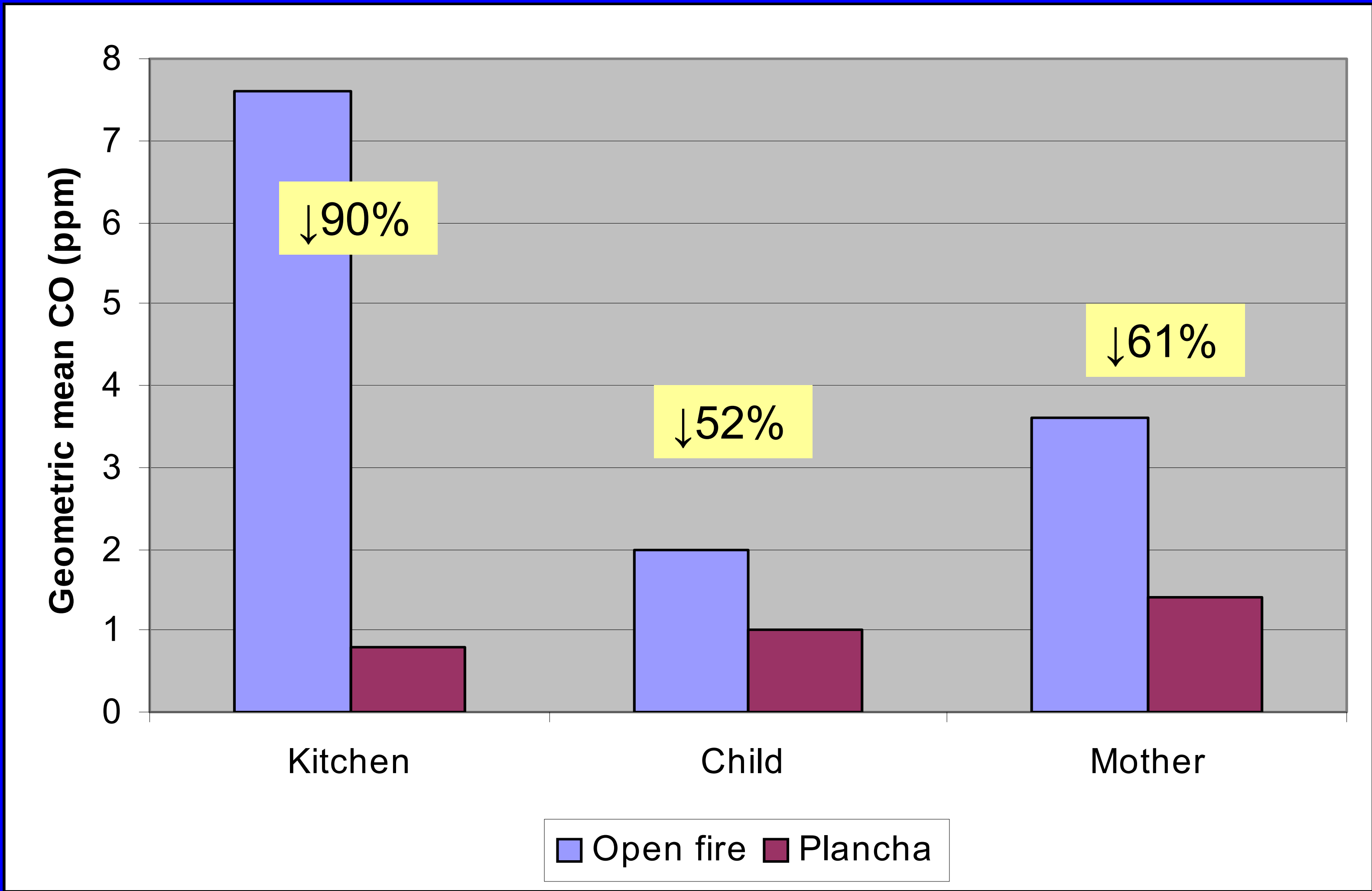
La plancha
Mejorada
No protegió
A todos los
bebes

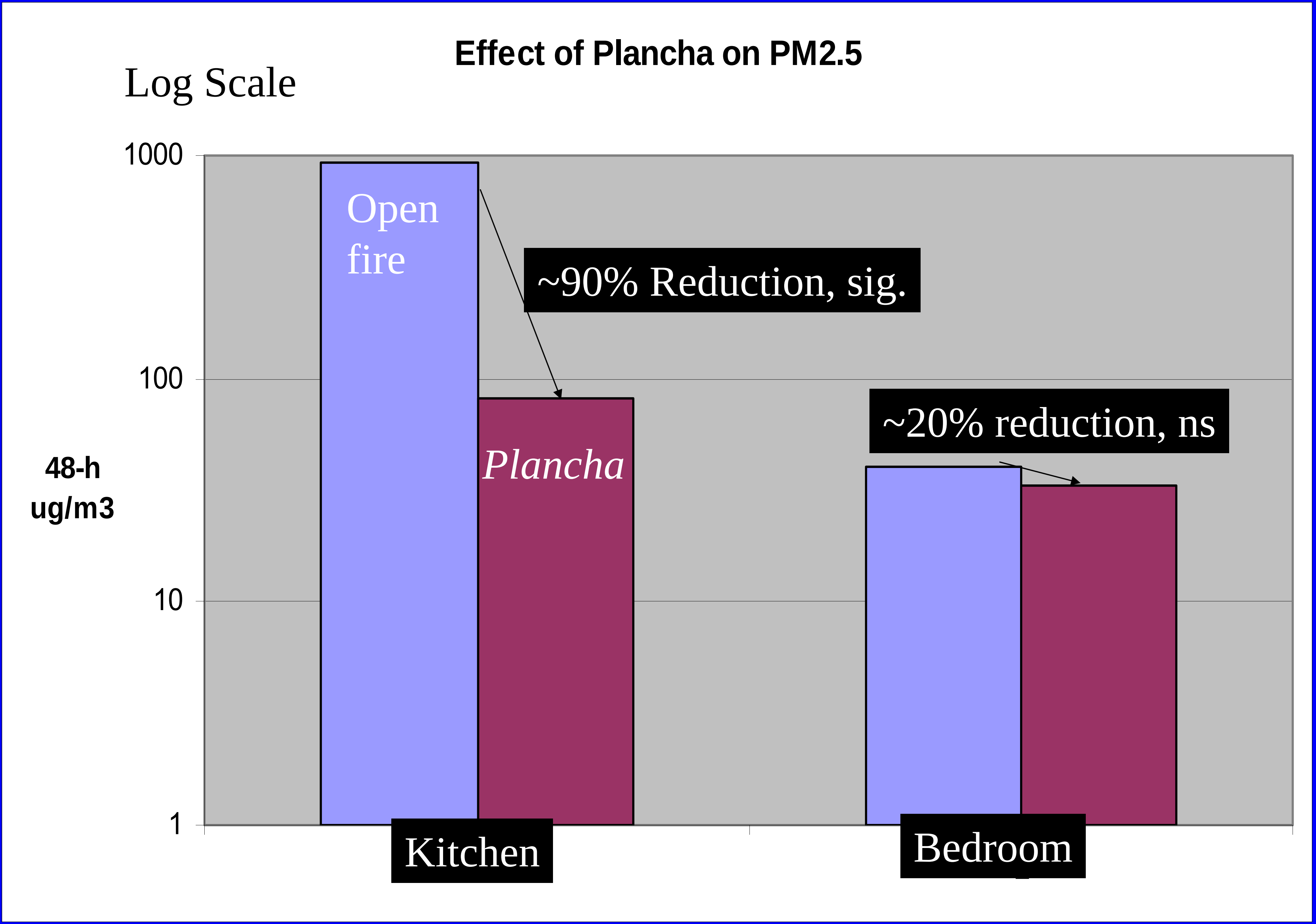
Unpublished results from RESPIRE have been removed

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

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

RESPIRE: effect of intervention on (i) kitchen IAP and (ii) personal exposure




Effect of Plancha on PM2.5
Log Scale
1000
100
10
1
48-h
ug/m3
Open
fire
~90% Reduction, sig.
Plancha
~20% reduction, ns
Kitchen
Bedroom

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

What Counterfactual to Use?

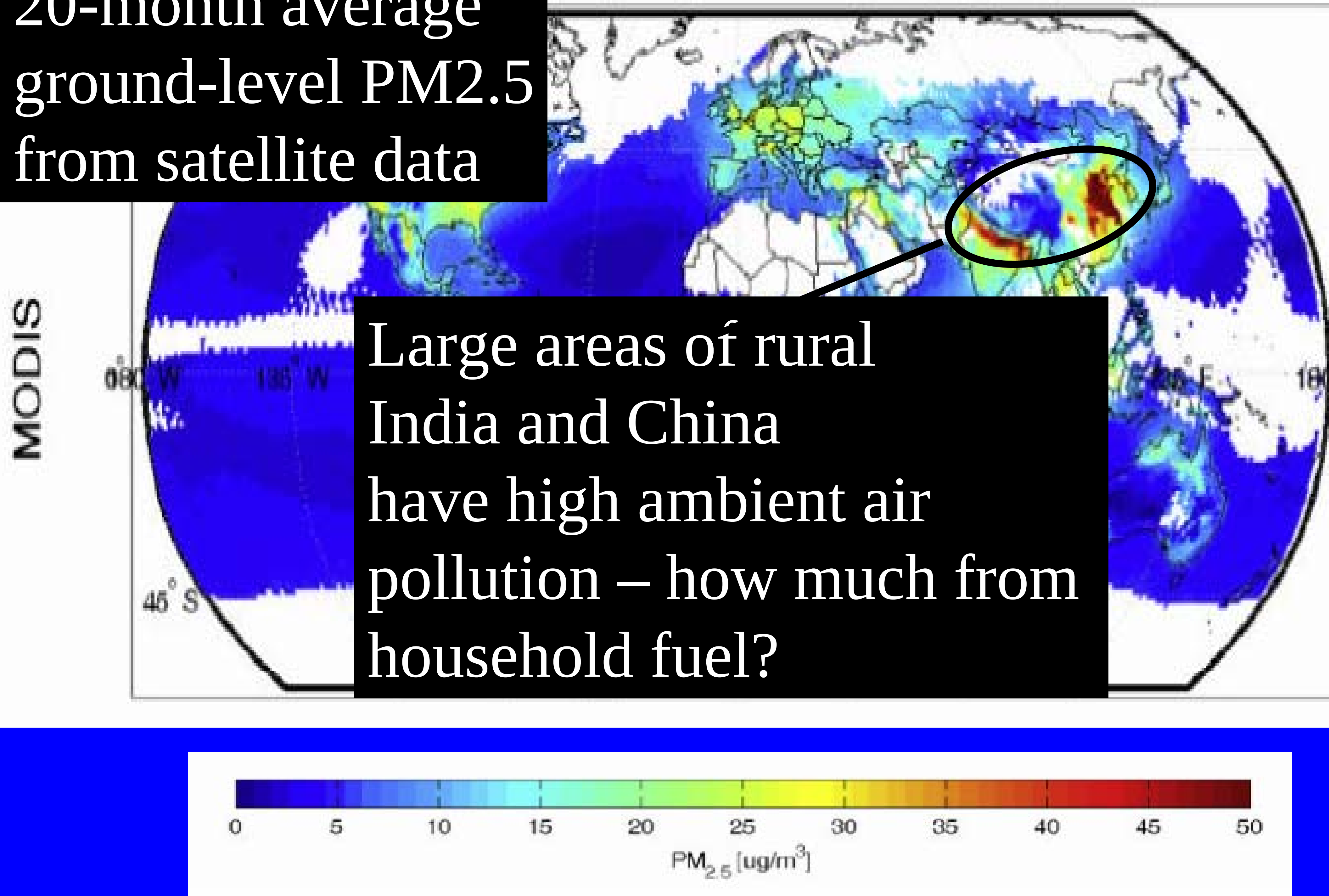
- Zero exposure
- Low end of epi results?
- WHO or other AQGs?
- LPG cooking?
- Equivalent to what OAP group is doing, i.e., 4 ug/m3

Preliminary effect estimates – CRA

Health Outcome	Sex	Age	Level of Outcome	Risk Estimate
ALRI	M & F	< 60 mo	Ia	1.78 (1.45 to 2.18)
ALRI: exposure/re sponse	M&F	< 60 mo	Ib	2.3 (95% CI ?)
COPD	F	>15 yr	Ia	2.7 (1.95 to 3.75)
COPD	M	>15 yo	Ia	1.9 (1.15 to 3.13)
Lung Cancer (coal)	F	> 15 yr	Ia	1.98 (1.16 to 3.36)
Lung Cancer (coal)	M	> 15 yr	Ia*	1.38
Cataract	F	> 30 yr	Ia	2.45 (1.61 to 3.73)
Cataract	M	> 30 yr	Ia	?
LBW (OR)	M & F	Perinatal	Ia	1.52 (1.25 to 1.80)
LBW (mean weight)	M & F	Perinatal	Ia	93.1g (64.6, 121.6)
Lung Cancer (biomass)	F	> 15 yr	Ia	1.81 (1.07 to 3.06)
Lung Cancer (biomass)	M	> 15 yr	Ia	1.26 (1.04 to 1.52)
CVD	F	> 30 yr	Ib	1.3 to 1.4 (95% CI)
CVD	M	> 30 yr	Ib*	1.16

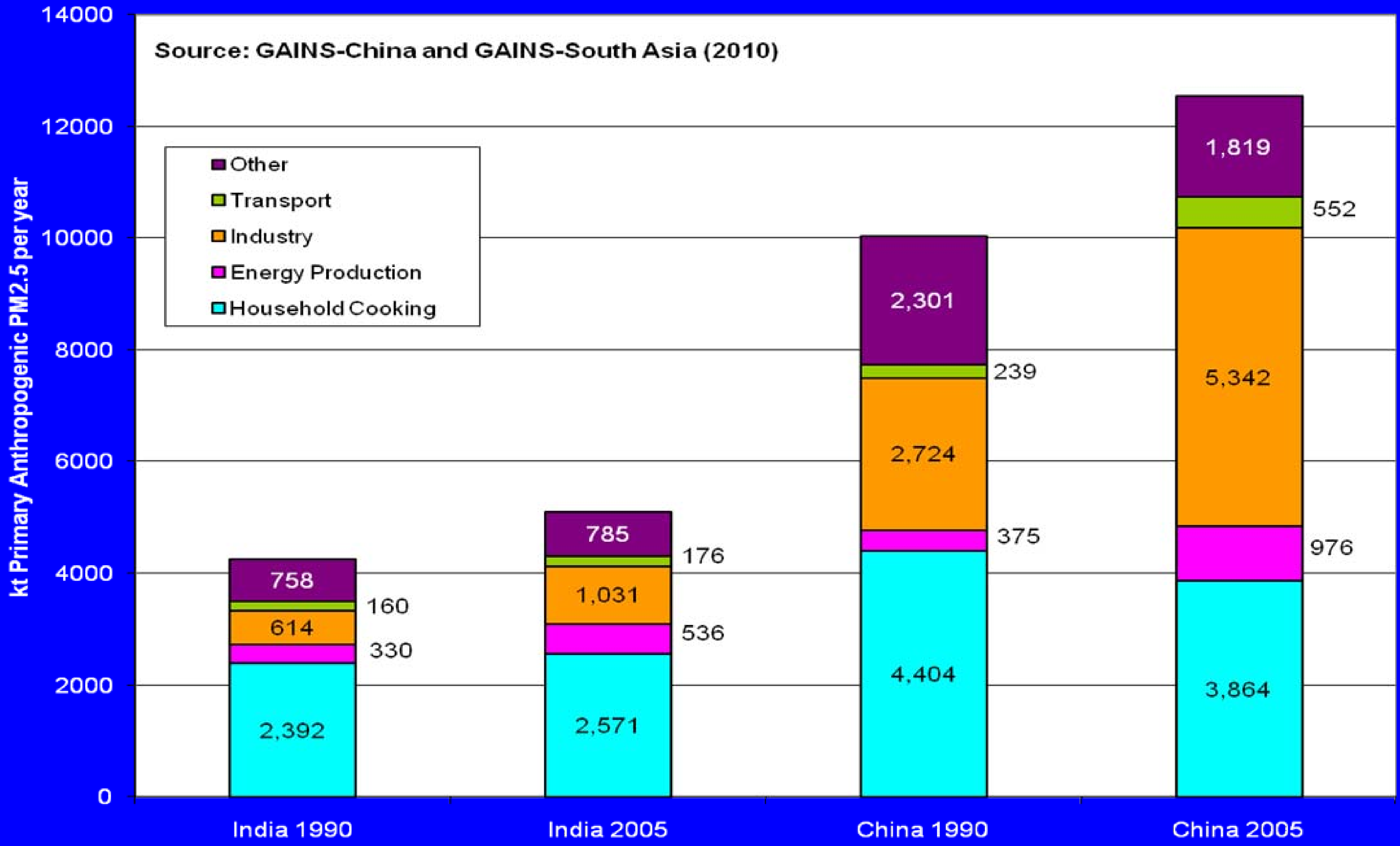

Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM

20-month average ground-level PM2.5 from satellite data



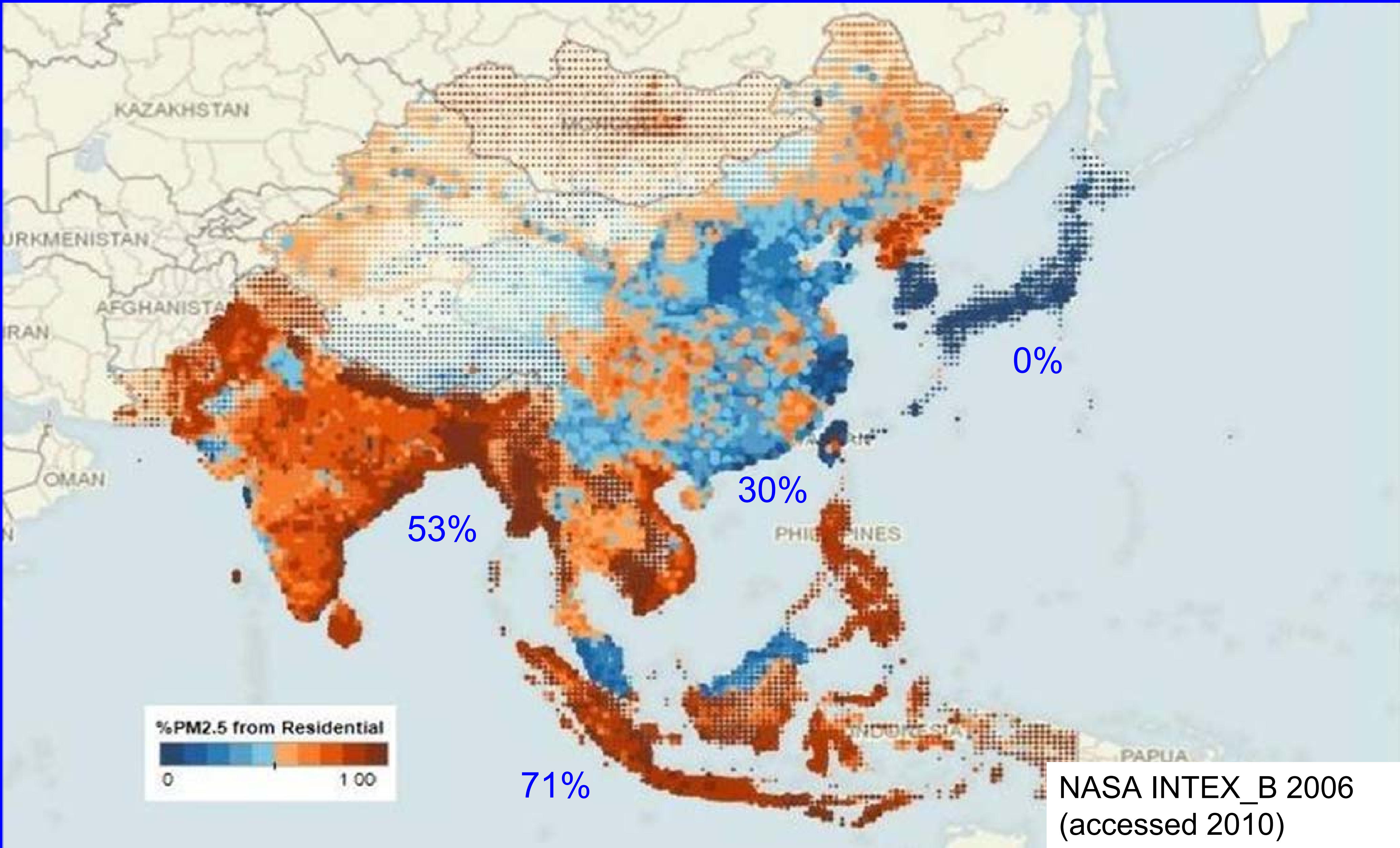
Large areas of rural India and China have high ambient air pollution – how much from household fuel?

Sources of Primary $PM_{2.5}$: India and China



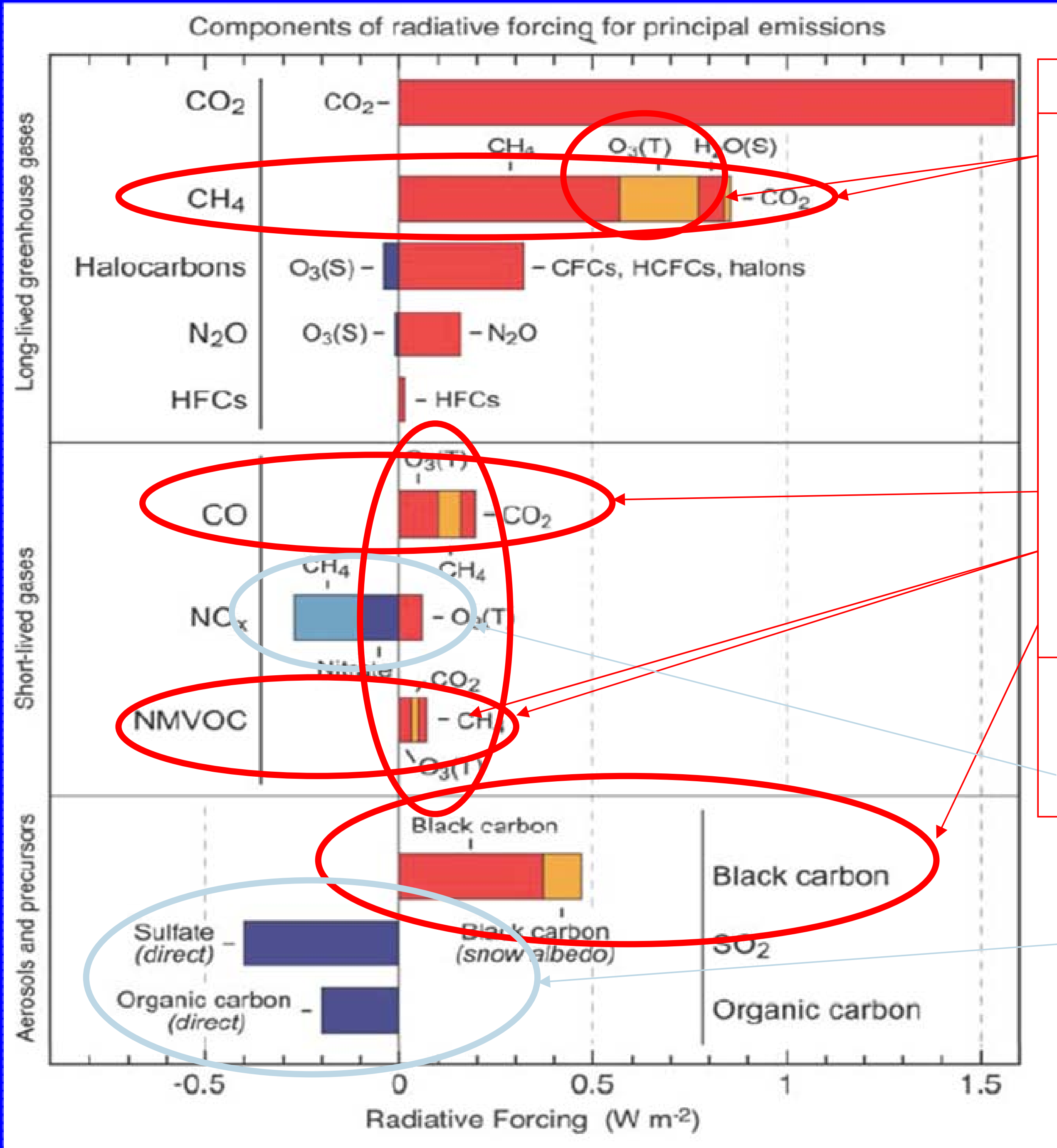
IIASA, 2010

NASA INTEX_B Database
Percent $PM_{2.5}$ emissions from households



NASA INTEX_B 2006
(accessed 2010)

Global warming in 2005 due to all human emissions since 1750



CO_2 is important for climate, but so are many other greenhouse gases including a good proportion of both their climate forcing and health damage through the secondary pollutant, tropospheric ozone

Several of the non-CO_2 pollutants, including the ones circled that, unlike CO_2, also have significant health as well as climate impacts

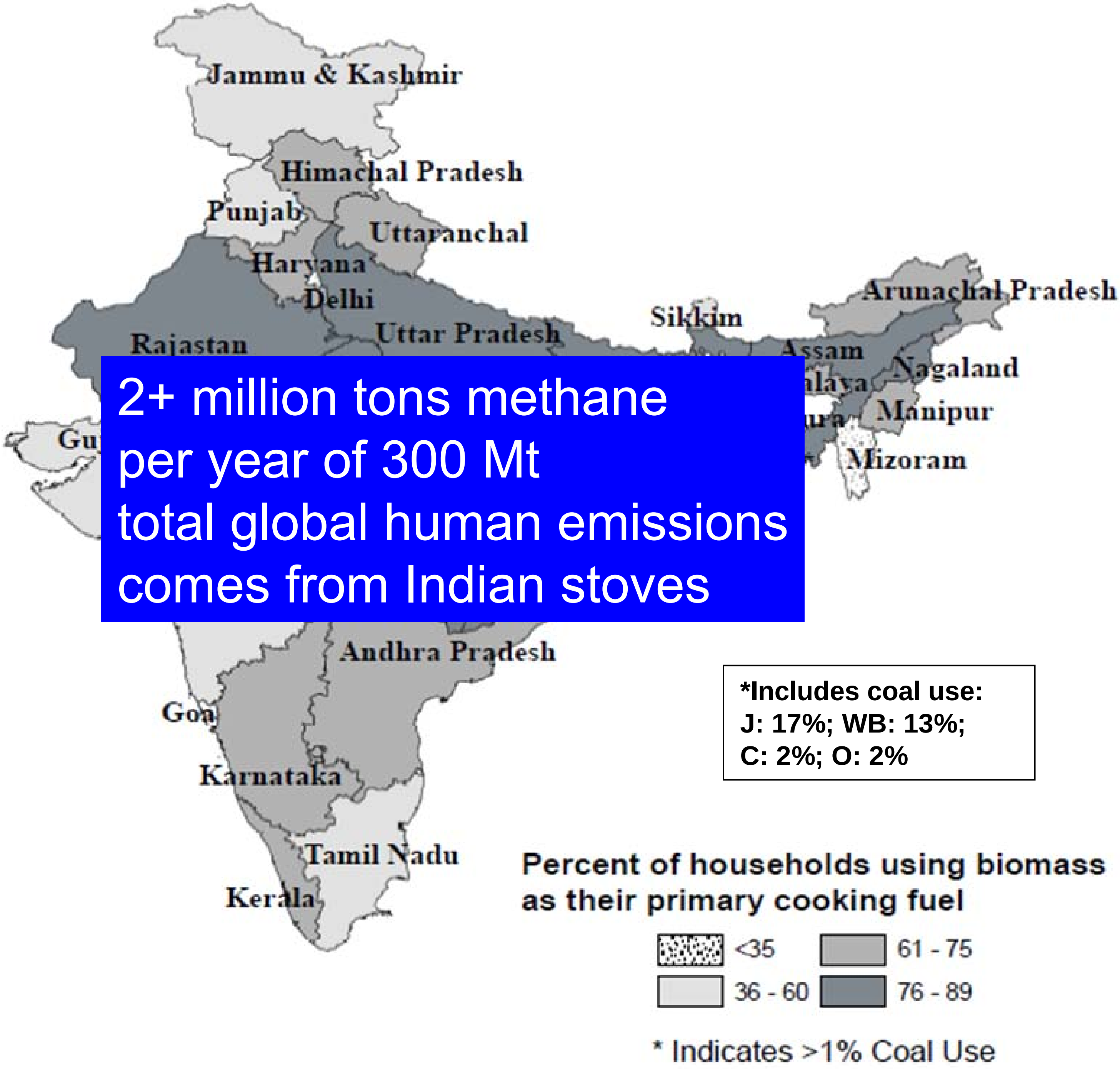
Nitrate, sulphate, and organic carbon particles however, have cooling impacts on climate but are still health damaging

IPCC, 2007

Household Fuels and Climate

- Climate impacts come from non-renewable biomass and coal, i.e., from net CO_2 emissions
- Poor combustion also leads to other emissions such as the relatively well-understood GHGs – methane and nitrous oxide – which are "Kyoto" GHGs
- In addition, a wide range of less well-understood short-lived GH-related emissions are emitted including
  - CO and black carbon – warming agents (one-third from HAP)
  - Ozone precursors – warming (one-sixth from HAP)
  - But also cooling agents such as sulfates and organic carbon particles
- There are also indirect climate impacts of these pollutants including
  - Reducing carbon capture of forests by ozone damage
  - Darkening of snow/ice by black carbon

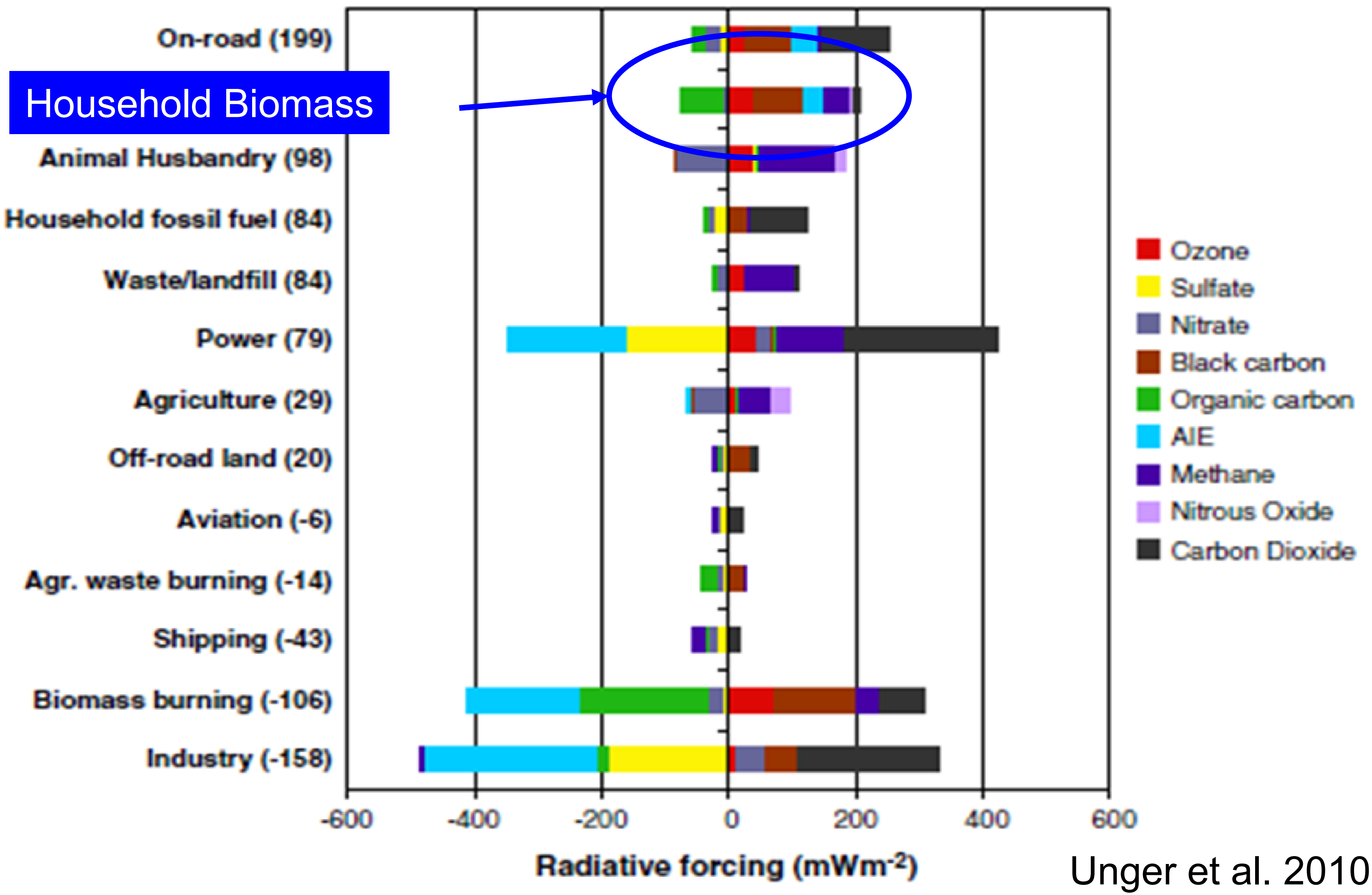
India in 2005



2+ million tons methane per year of 300 Mt total global human emissions comes from Indian stoves

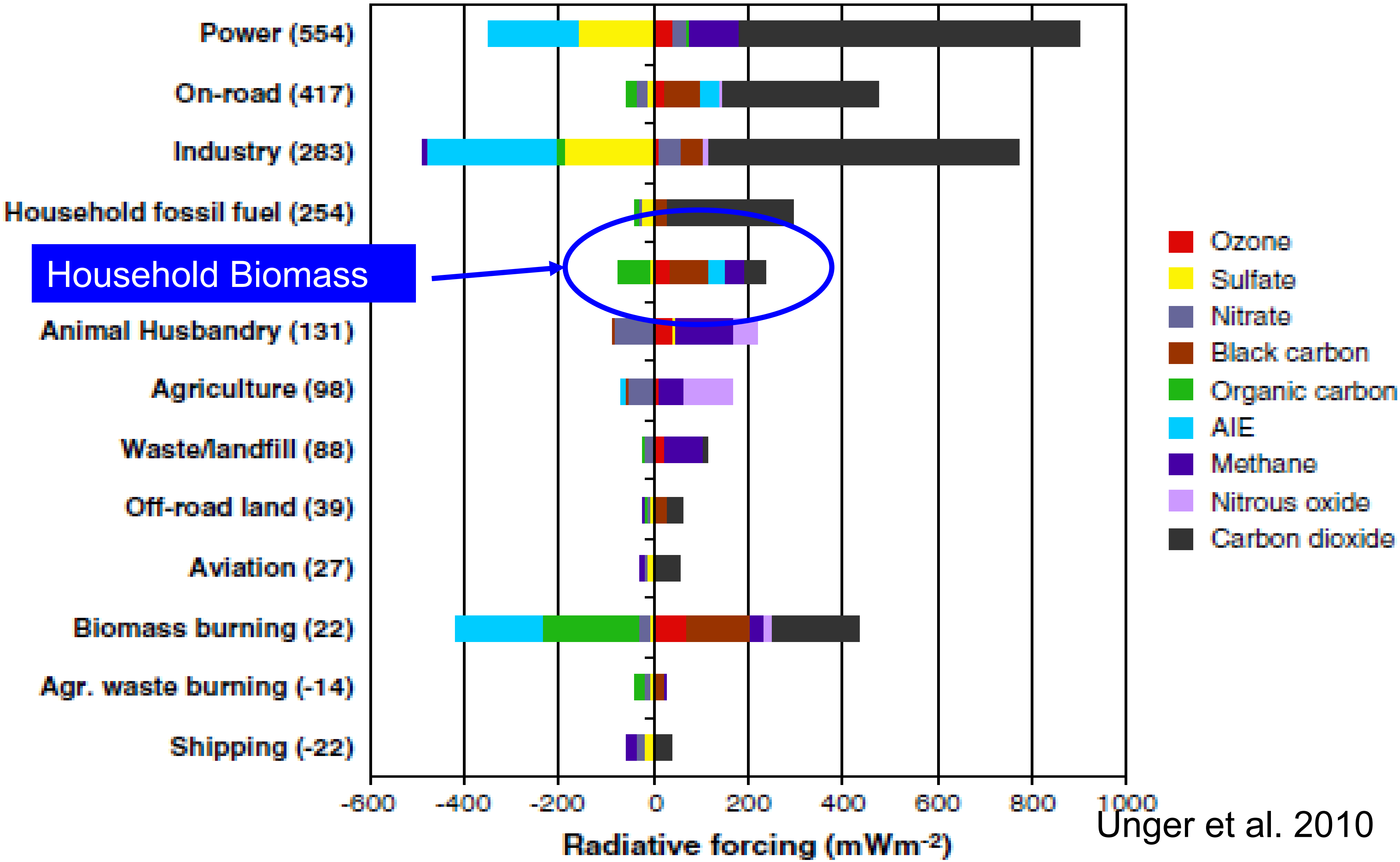
Venkataraman et al. 2010

Climate Warming in 2020 Under Present Trends



Unger et al. 2010

Climate Warming in 2100 Under Present Trends



Unger et al. 2010

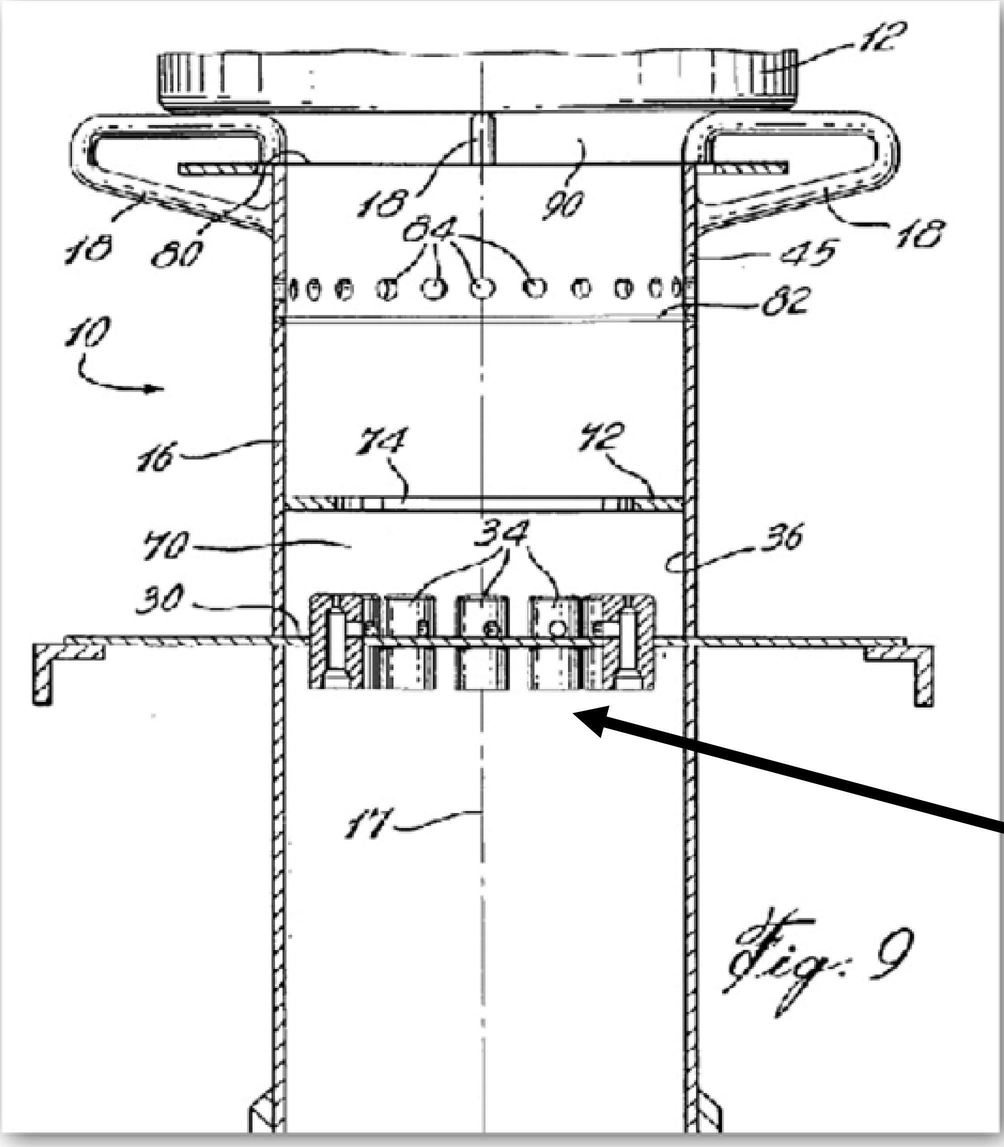
Can Anything be Done?

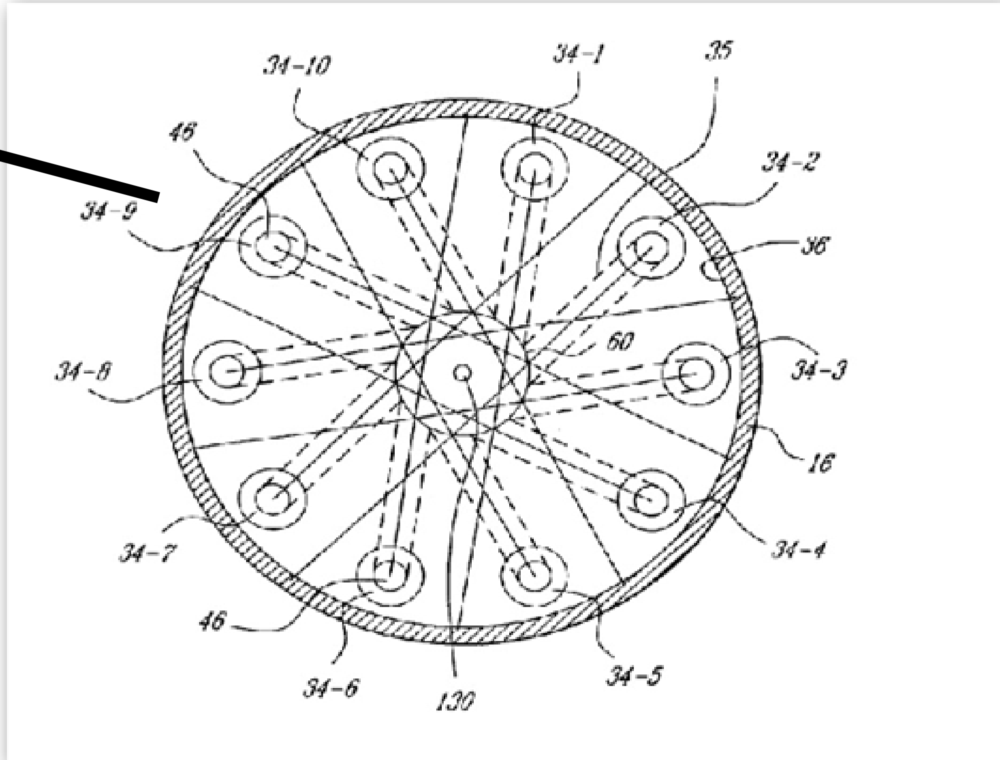
- Chimneys do not work well for health and do nothing for outdoor air pollution and climate
- Energy efficiency *per se* is not closely related to emissions, although it is most important for households
- Cl
- Only way to deal with all needs is not to generate the pollution in the first place, i.e., greatly increase combustion efficiency
- Can be done with gaseous or liquid fuels, but these are expensive and create other problems

El Salvador

Turbococina

US patent for Turbococina





Reduction in emissions for homes and schools using Turbococinas

	Stove	N	CO_2 (kg yr^{-1})	CH_4 (kg yr^{-1})	CO (kg yr^{-1})	TNMHC (kg yr^{-1})	PM (kg yr^{-1})
Homes	Traditional	25	5608	53	292	59	61
	Turbococina	15	689	0.93	4.00	1.03	0.51
	Difference*		88%	98%	99%	98%	99%
Schools	Traditional	25	7339	81	380	58	58
	Turbococina	25	341	0.49	3.78	0.69	0.53
	Difference*		95%	99%	99%	99%	99%

± represents 1 standard deviation.

*All differences between stoves were significant at the $p<0.001$ level using a Student’s T test.

Edwards & Masera, 2010

Perfect Storm for Health Impacts

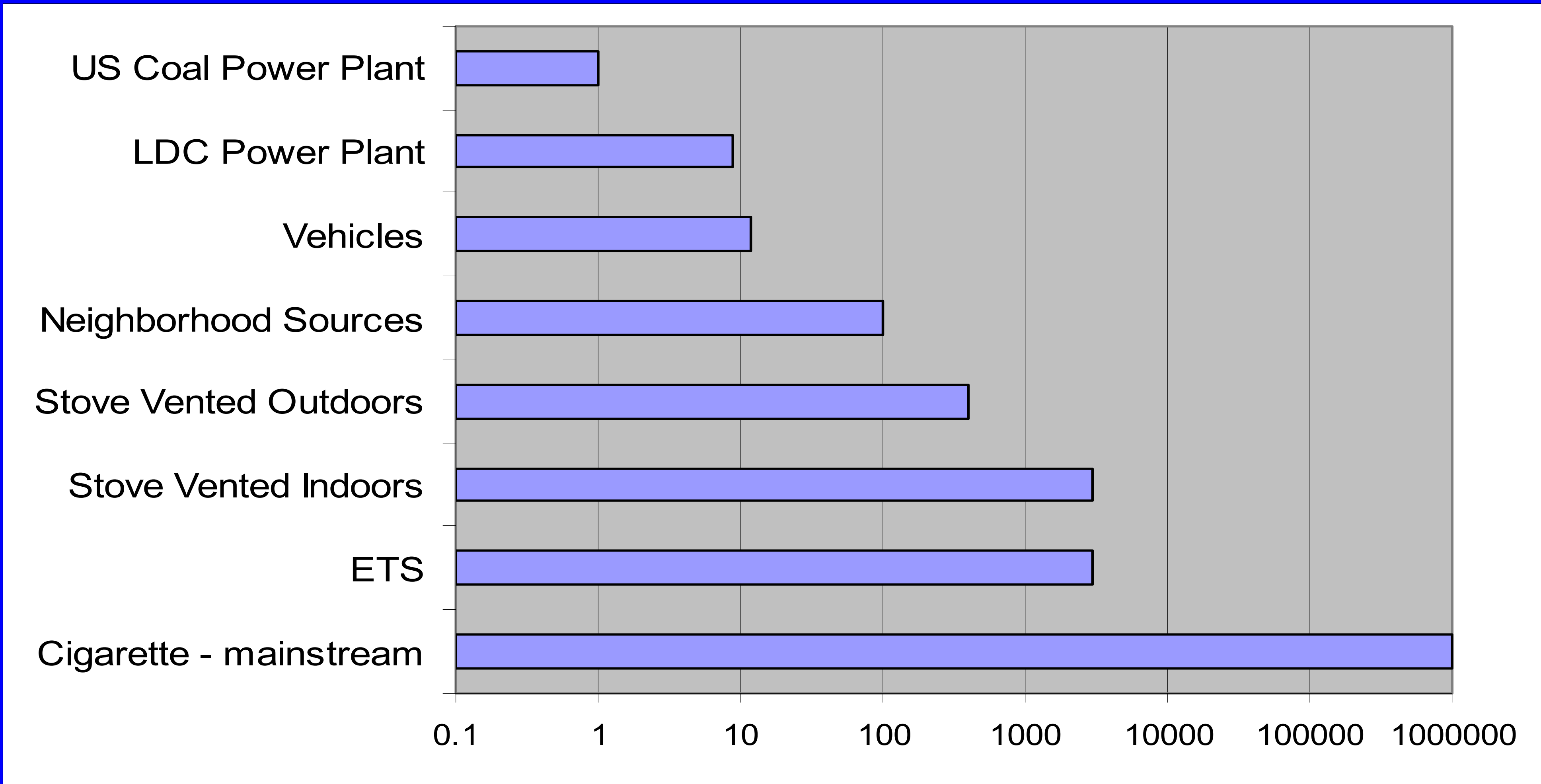
- Highly polluting activity
- Half of world households
- Several times a day
- Just when people are present
- Most vulnerable (women and young children) most likely to be there

In other words, the Intake Fraction is extremely large

IF is the fraction of material emitted that is actually breathed in by someone

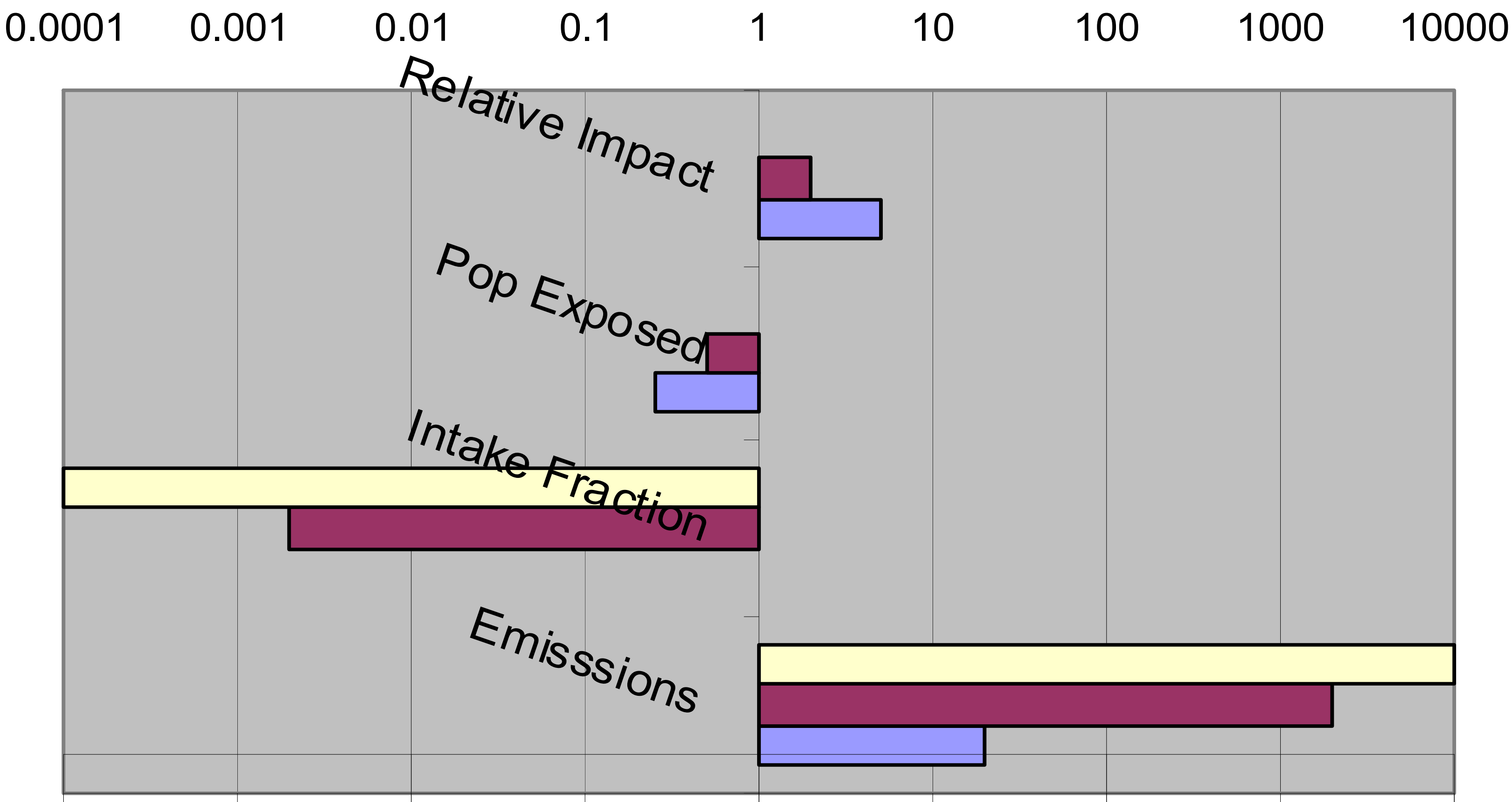
IF = 1.0

Intake Fractions : these are rough calculations for typical examples of sources in each class



Smith, 1993

Grams Inhaled per Ton Emitted

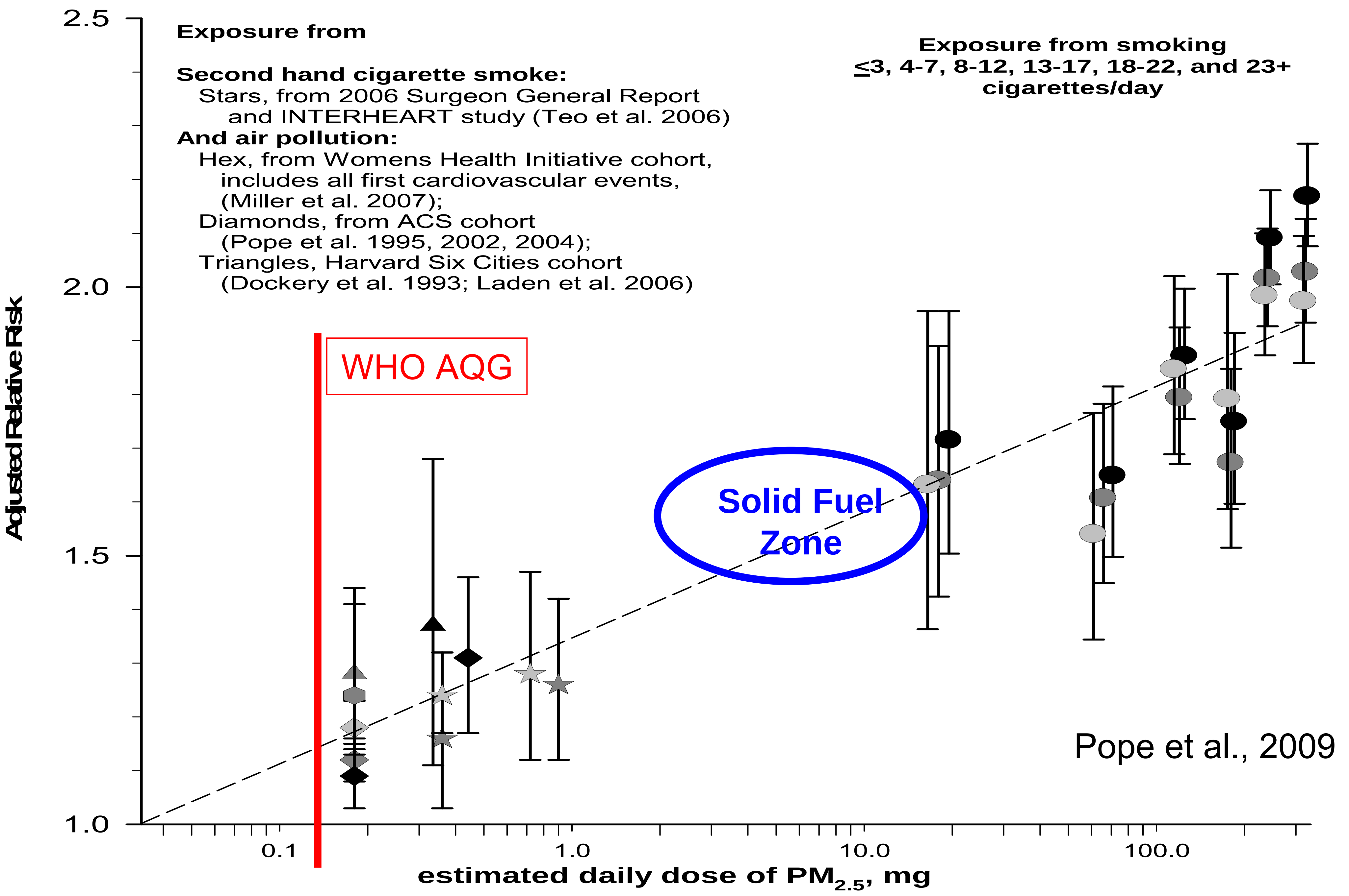


	Emisssions	Intake Fraction	Pop Exposed	Relative Impact
OAP	10000	1.00E-04	1	1
HAP	2000	2.00E-03	0.5	2
Smoking	20	1	0.25	5

Argument from consistency across combustion particle exposure settings

- Assumes fine combustion particles are best measure of risk in each setting and have similar effects per unit mass across the four source types
  - Three are mainly biomass
  - OAP contains significant biomass particles
  - Probably difference by outcome, however – e.g., LBW and lung cancer may be related to other components as well
- Remarkable consistency across 3 orders of magnitude of dose measured in mg/day of $PM_{2.5}$

IHD, CVD, CPD and Combustion Particle Doses



Publications and presentations at
http://ehs.sph.berkeley.edu/krsmith/

Or just google "Kirk R. Smith"

Thanks to **Shell Foundation, Gates Foundation,** and **USEPA** for funding in support of the expert group on household fuel use in the the updated CRA.

Thank you