Global Burden of Disease due to Household Air Pollution from Cooking Fuel

Kirk R. Smith, UC Berkeley
For the HAP Expert Group

NIH/Fogarty Training Workshop
on Household Air Pollution
NIH, October 10, 2012

HAP Expert Group

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2010 GBD Study

- The global burden of diseases, injuries, and risk factors 2010 (GBD) Study is a systematic scientific effort to quantify the comparative magnitude of health loss due to diseases, injuries and risk factors by age, sex, geographies for specific points in time.
- The GBD Study involves hundreds of experts working on epidemiology of specific diseases, injuries, and risk factors, as well a core group bringing the pieces together in common analytical frameworks.
- The GBD Study is coordinated by the Institute for Health Metrics and Evaluation at the University of Washington along with a steering committee consisting of several other organizations, including WHO.

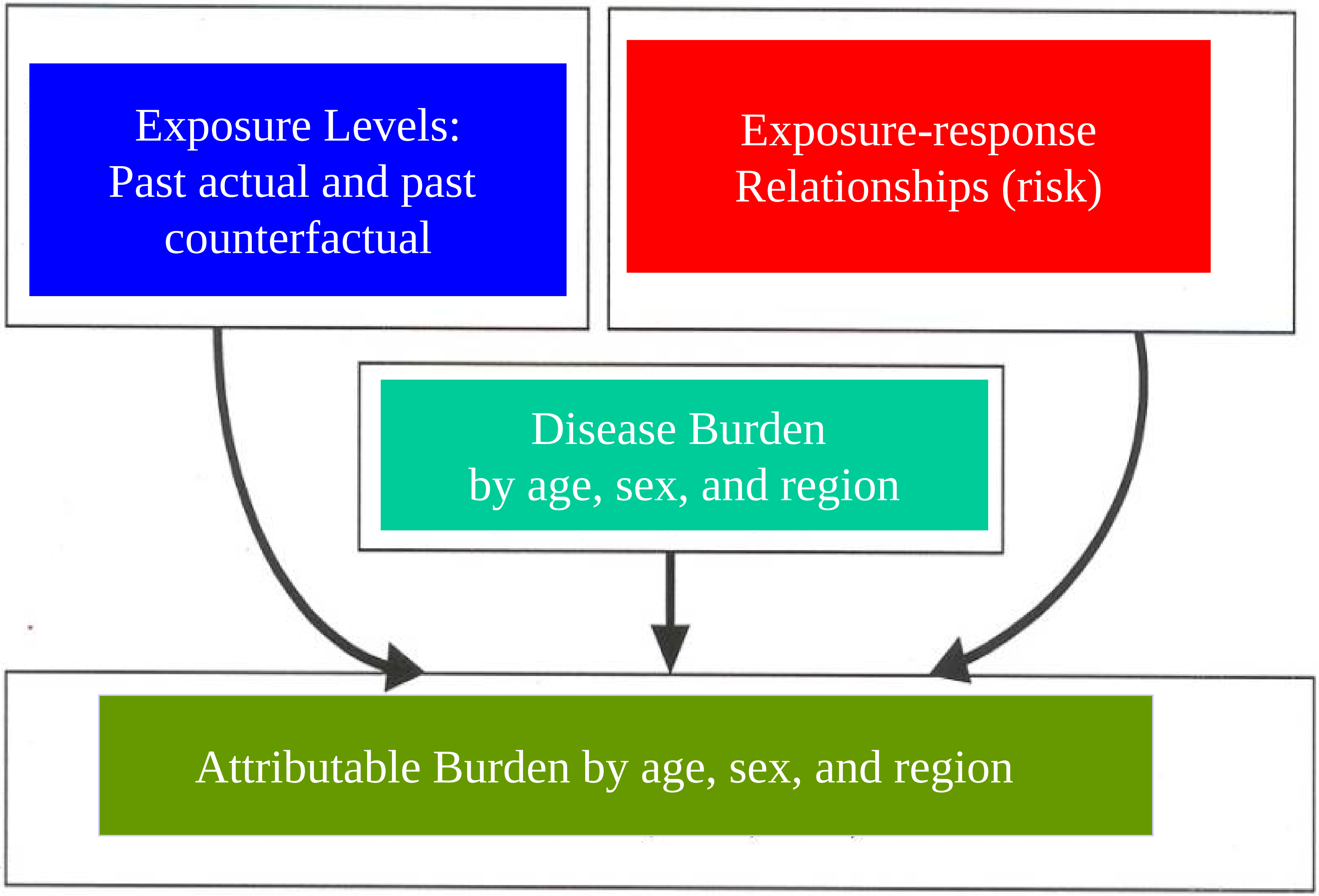
Brief history

- GBD 1990 initiated by the World Bank, WHO and Harvard University produced preliminary results in the *World Development Report 1993: Investing in Health*.
  - Final results for 1990 published in 1996 and 1997; with revisions compared to preliminary findings.
- GBD 2000, at WHO, advanced the methods used for mortality and cause of death estimation substantially.
- Risk factor analysis was expanded and standardized across different risk factor traditions (Comparative Risk Assessment), published in *World Health Report 2002: Reducing Risks, Promoting Health* and in 2-volume technical book in 2004.
- WHO released updates of the GBD for 2002 and 2004 with some revisions to methods and data.
- GBD 2010 initiated in 2007; summary papers submitted and expected to be published in late 2012.

Scope of GBD 2010 Study

- GBD cause list: 3 major groups (communicable diseases, noncommunicable diseases and injuries), 19 level-2 causes, 147-level 3 causes, 225-level 4 causes and 1045 specific outcomes/sequelae of the 225 diseases and injuries.
- Risk factors expanded from 26 to 50+ different exposures.
- Time periods: 1990, 2005 and 2010

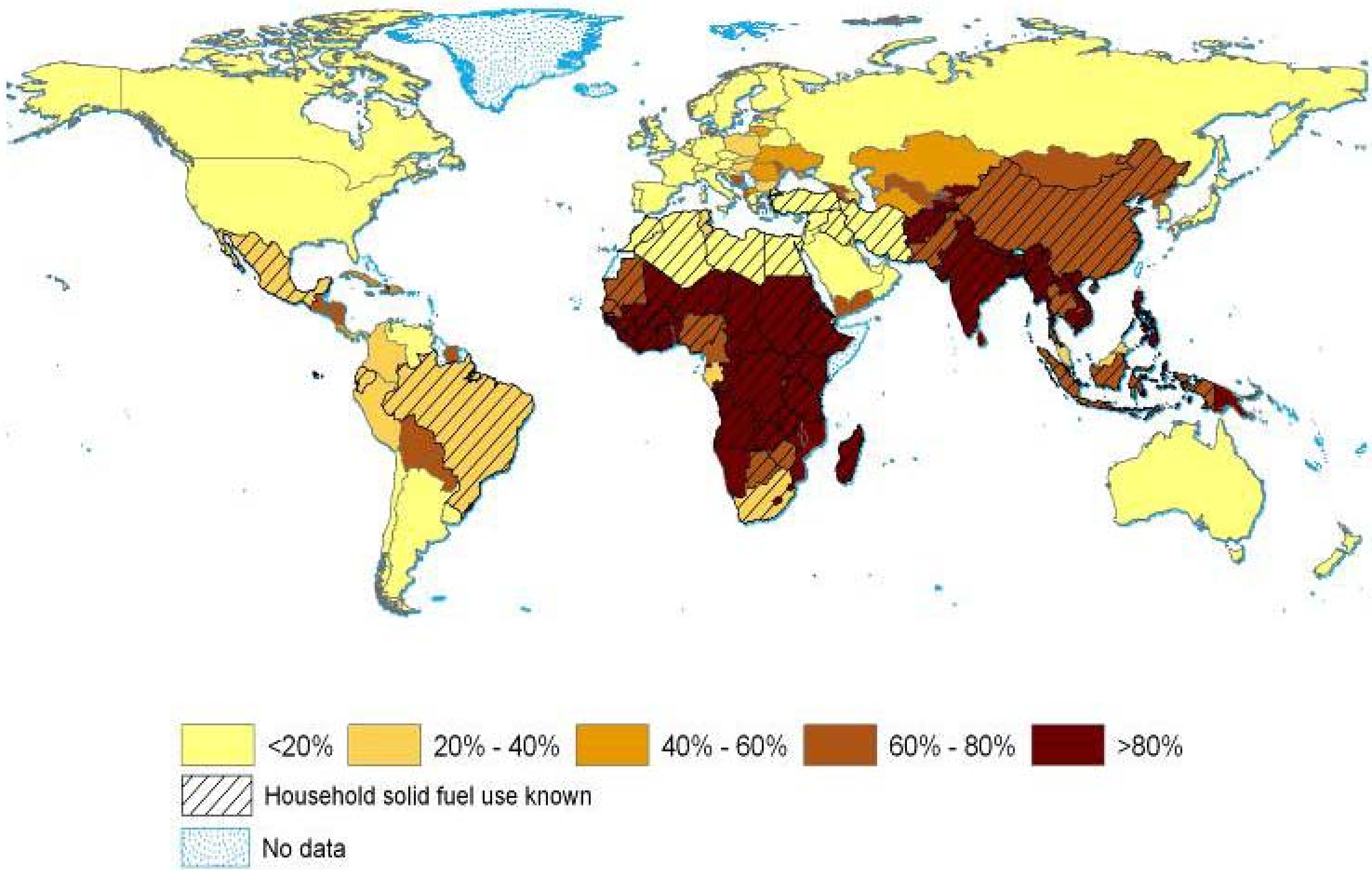
Comparative Risk Assessment Method



Road Map

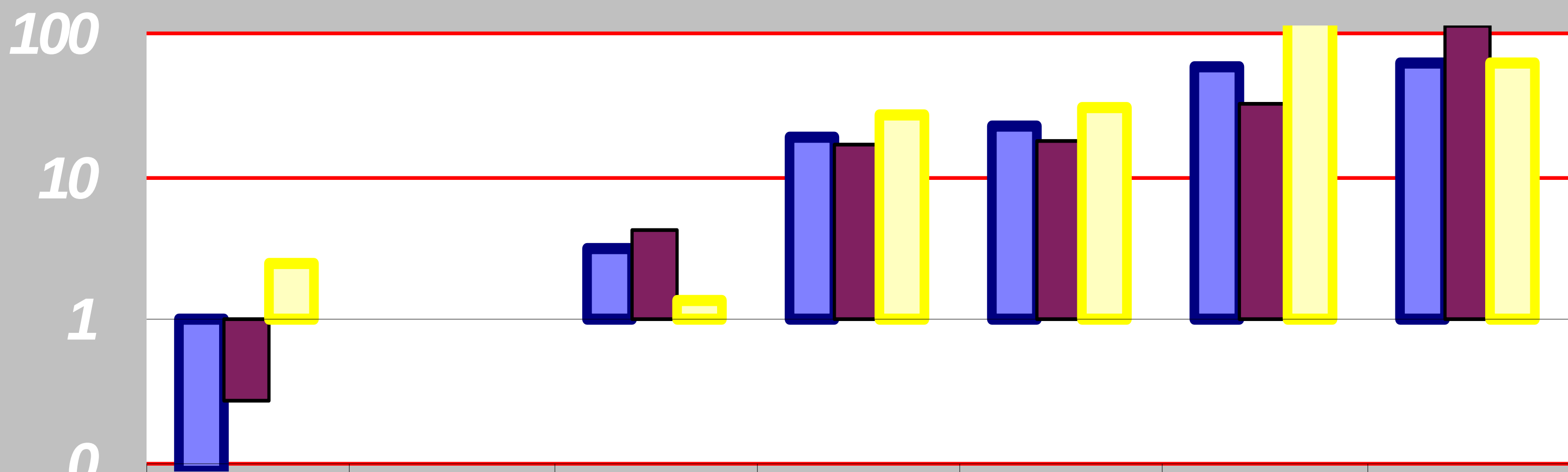
- Framing, counterfactuals, arguments for consistency
- Updated exposure assessment
- Updated outcome assessments
- Final burden estimates: in progress

National Household Solid Fuel Use, 2000



CRA-2000

Health-Damaging Pollutants per Unit Energy Delivered
Ratio of Emissions to LPG



	Biogas	LPG	Kerosene	Wood	Roots	Crop Residues	Dung
CO	0.1	1.0	3	19	22	60	64
Hydrocarbons	0.3	1.0	4.2	17	18	32	115
PM	2.5	1.0	1.3	26	30	124	63

CO Hydrocarbons PM

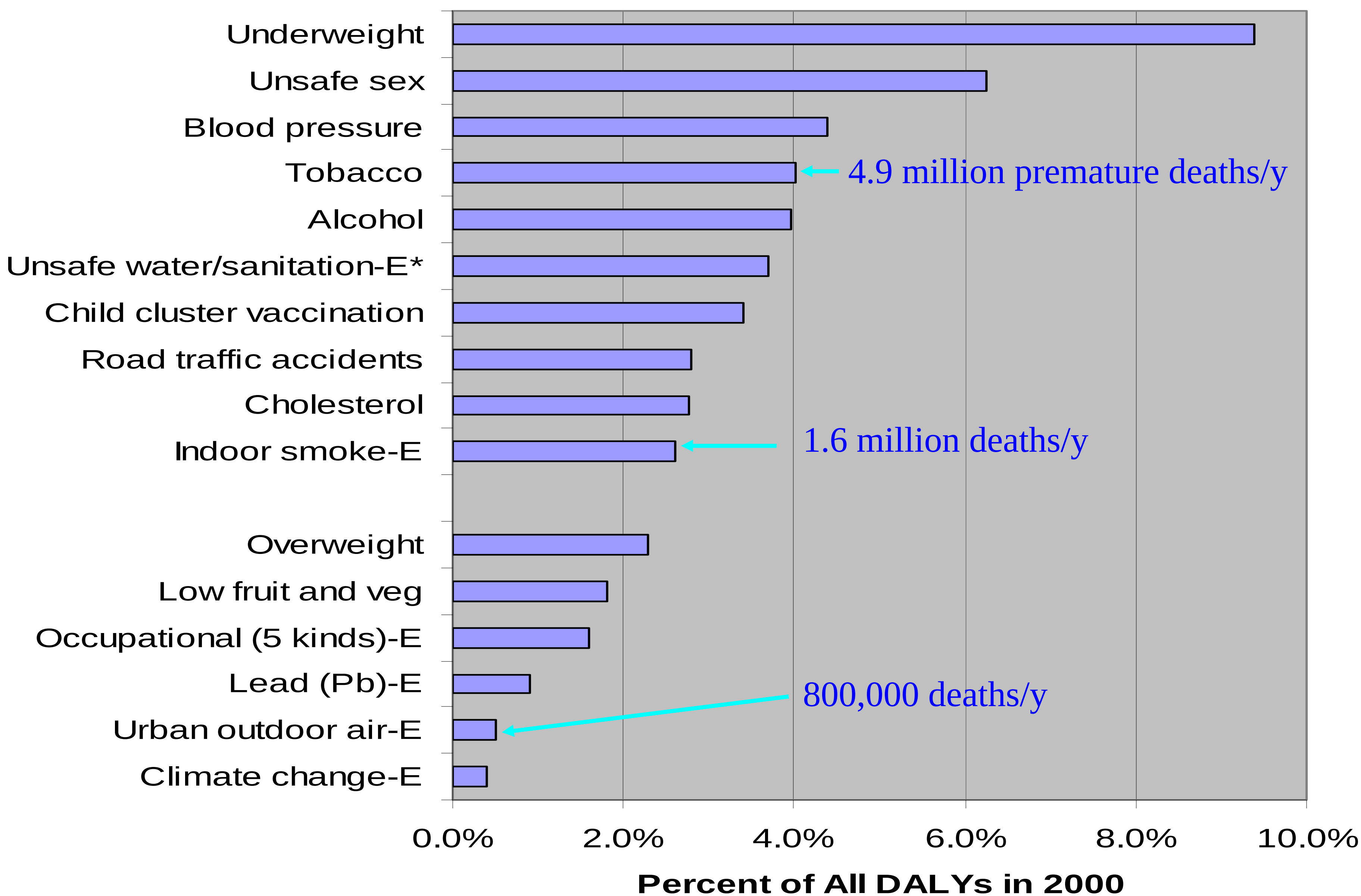
Indian measurements, Smith, et al., 2005

CRA-2000

- Indoor air pollution from household solid fuel use
- Counterfactual: non-solid fuel use
- Exposure: Solid fuel use from household surveys, separating biomass and coal, modeled globally
- Outcomes
  - ALRI in children
  - COPD
  - Lung cancer from coal use

Global Burden of Disease from Top 10 Risk Factors

plus selected other risk factors



Framing for CRA-2010: HAP

- Household air pollution (HAP) from cooking fuel – incomplete combustion
- Cooking fuels only, although sometimes difficult to separate from space heating
- Uses long-term fine particle ($PM_{2.5}$) exposures as metric, where possible,
- Otherwise solid fuel use
- Includes household contribution to outdoor air pollution

Potential HAP Counterfactuals

Potential CF	PM2.5 equivalent (ug/3)	How relates to epidemiology	Consistency with proposed outdoor air CF?	Currently achievable?	Useful target for medium term?
1.Dichotomous solid vs. 'low exposure' comparison	Unknown in almost all studies; perhaps 40-100, maybe more	Consistent, but poorly defined	Higher, uncertain, not consistent	Yes, although actual levels uncertain, and very mixed	Too poorly defined
2. WHO Air Quality Guideline	10 (annual)	Probably lower than 'low exposure group' in most or all studies	Higher, not consistent	Not globally, in short term	Yes, especially with AQG 'IT' phased approach concept

HAP Counterfactuals: cont.

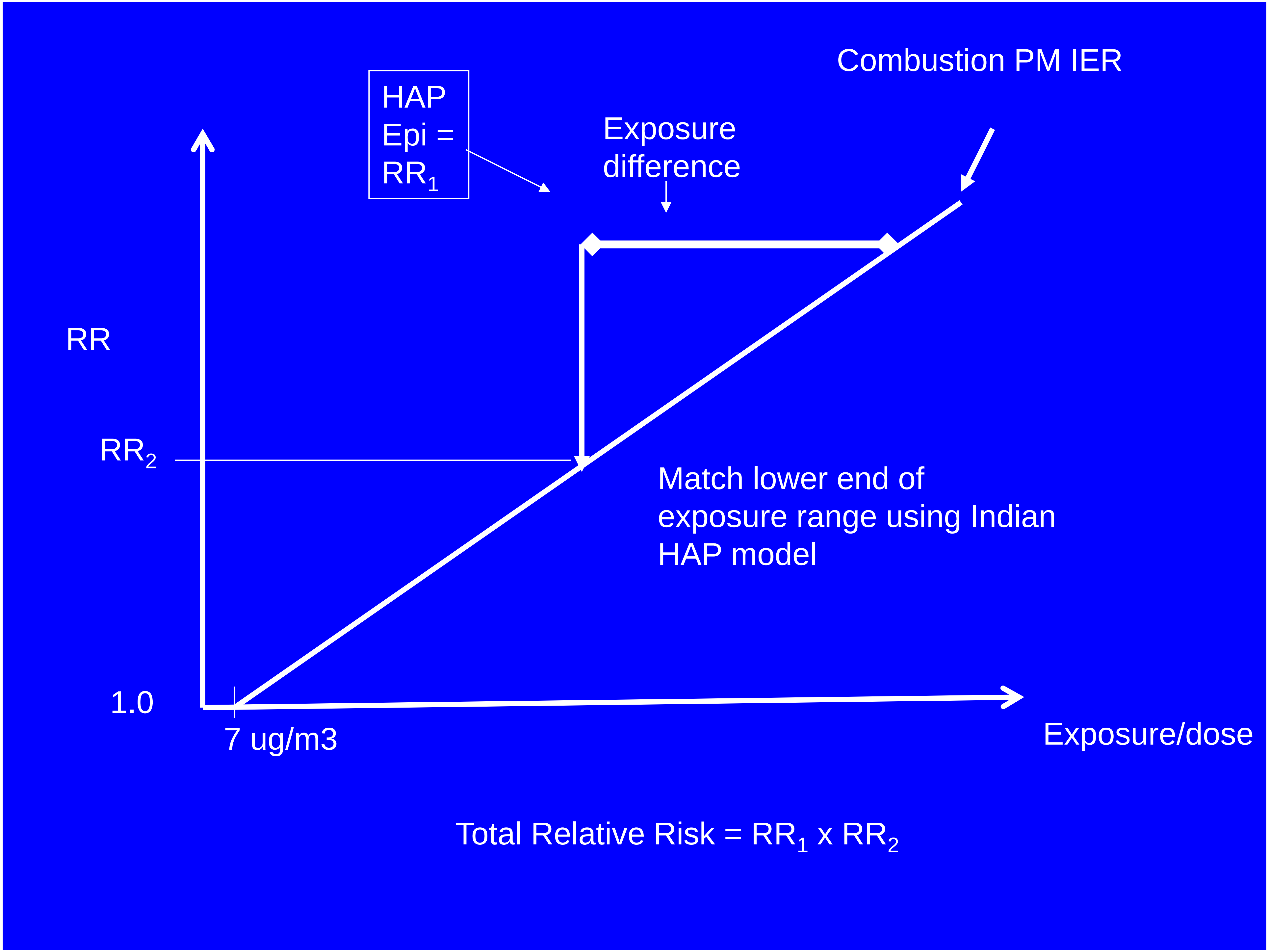
Potential CF	PM2.5 equivalent (ug/3)	How relates to HAP epidemiology	Consistency with outdoor air CF?	Currently achievable?	Useful target for medium term?
3. Proposed OAP CF	7 (annual)	Lower than 'low exposure group' in all studies	Same	Not in short to medium term	Probably unrealistic and not useful for policy
4. Gas cooking	5-20 ug/m3, lower with venting	May be similar to some clean fuel' comparisons	Reasonably consistent	~50% of world at this level	Similar to WHO AQG and matches Indian policy
5. Electric cooking	Zero emissions – no combustion	There is developed country epidemiology	Lower, but reasonably consistent	Potentially over time, but raises question of how to treat current gas use	Less so than with gas but still easily understood

Counterfactual Chosen

- 7 ug/m3 annual average $PM_{2.5}$ – same as OAP
- This can be achieved with electric cooking or gas cooking with ventilation
- Clearly feasible – gas and electricity now used by three-fifths of world population

How to estimate risk down to 7 ug/m3 with no direct epi?

- Extrapolating from high to low doses – inverse of usual problem
- Link HAP epi with integrated exposure-response (IER) models
- Use Indian exposure modeling to determine ug/m3 equivalent of epi studies


Combustion PM IER
HAP
Epi =
RR1
Exposure
difference
RR
RR2
Match lower end of
exposure range using Indian
HAP model
1.0
7 ug/m3
Exposure/dose
Total Relative Risk = RR1 x RR2

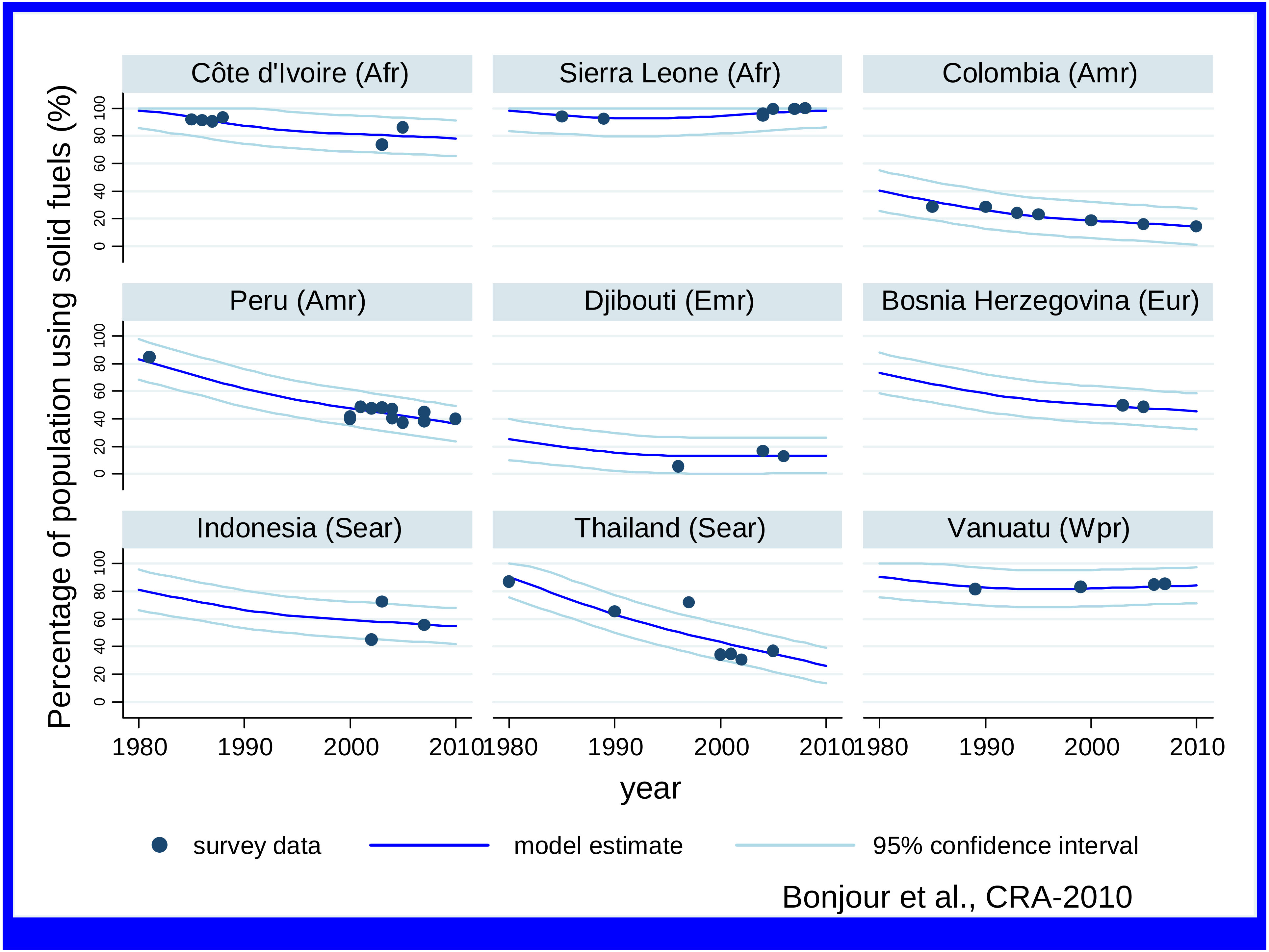
Advances in CRA-2010

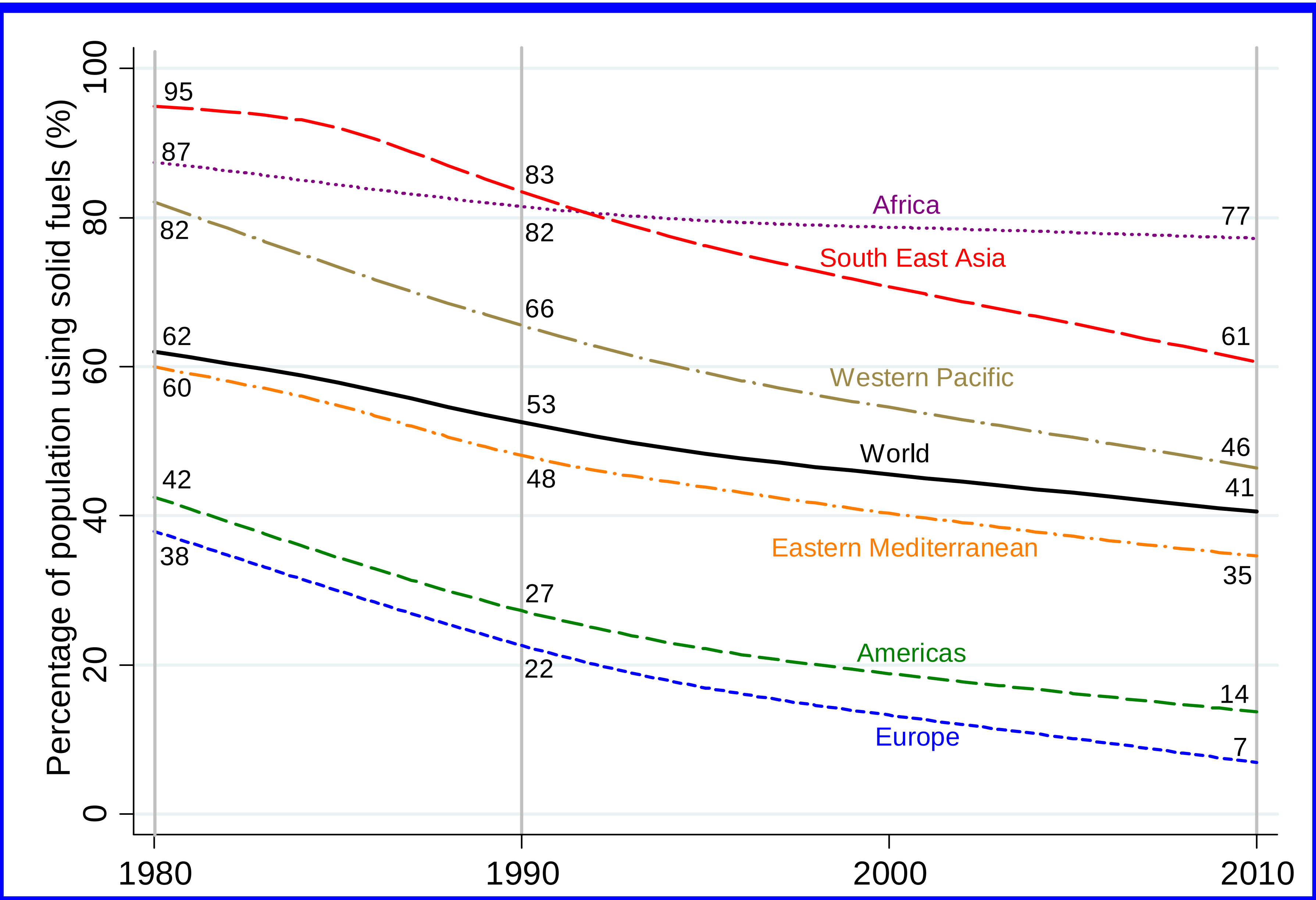
- Much more robust global modeling of fuel use
- Proportion of outdoor air pollution from HAP
- Modeling of $PM_{2.5}$ exposures for 25% of world solid fuel households, those in India
- New SR/MAs for the previous 3 outcomes (ALRI, COPD, LC from coal)
- RCT and exposure-response also available for ALRI
- New SR/MAs for 3 additional outcomes (LBW, cataracts, LC from biomass)
- Better discrimination of male/female outcomes/ exposures
- Consistency from IERs derived from outdoor air, passive smoking, HAP, and active smoking
- Interpolation of CVD outcomes from IERs

Exposure to Household Air Pollution from Cooking Fuel

Exposure Overview

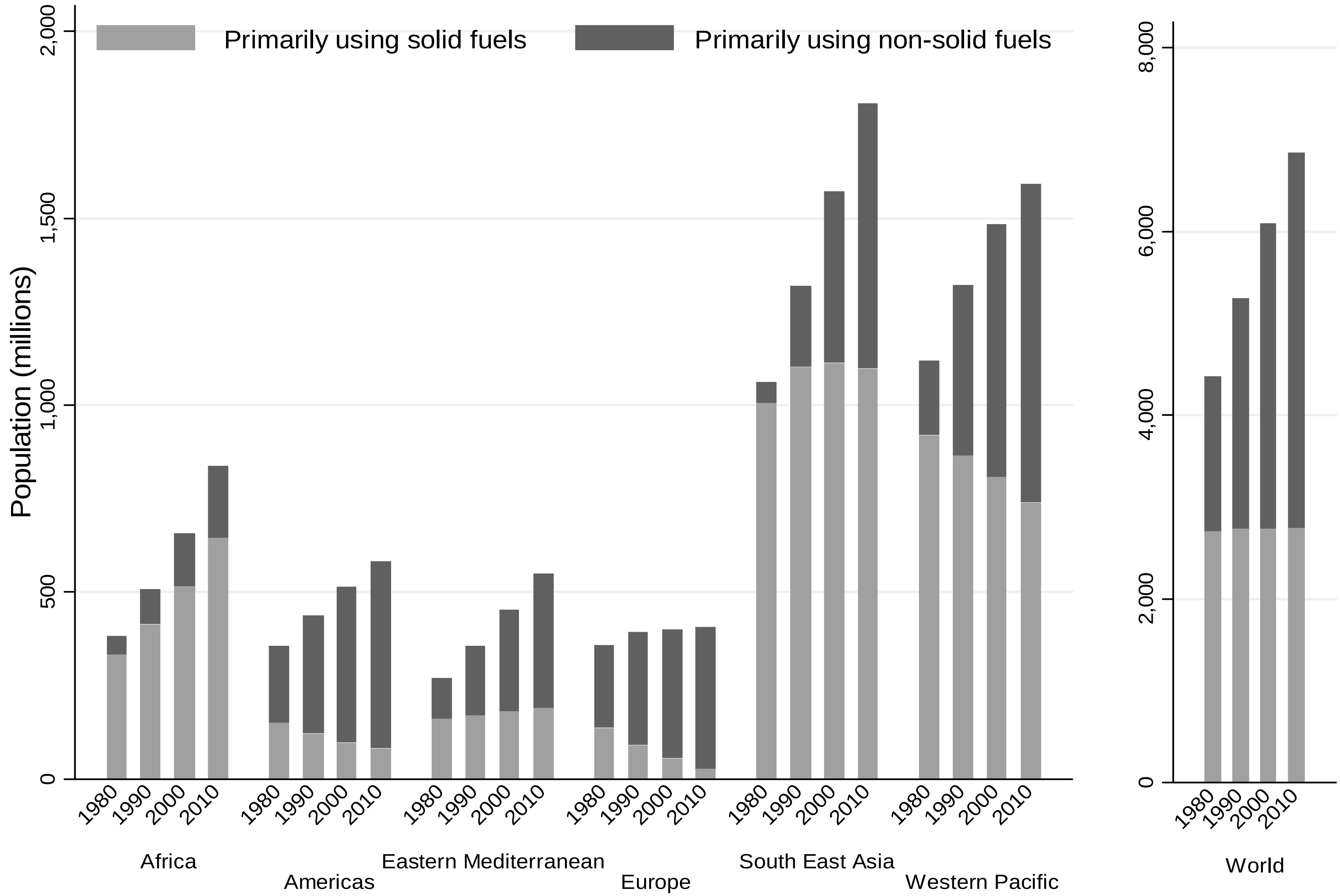
1. Estimating household cookfuel use – 1990, 2005, 2010
   - Update of global model to include the much larger set of nationally representative household surveys available, nearly 600 in total – 155 countries
2. Estimating the HAP contribution to ambient $PM_{2.5}$ concentrations – 1990, 2005, 2010
   - A portion of the exposure to outdoor air pollution and burden will thus be attributable also to HAP
3. Estimating household $PM_{2.5}$ exposures based on a model linking actual measurements to household parameters found in DHS surveys – India
   - Can link HAP with IER models


Côte d'Ivoire (Afr)
Sierra Leone (Afr)
Colombia (Amr)
Peru (Amr)
Djibouti (Emr)
Bosnia Herzegovina (Eur)
Indonesia (Sear)
Thailand (Sear)
Vanuatu (Wpr)
Percentage of population using solid fuels (%)
0
20
40
60
80
100
1980
1990
2000
2010
year
survey data
model estimate
95% confidence interval
Bonjour et al., CRA-2010



Percent of households cooking with solid fuels by region

Bonjour et al., CRA-2010

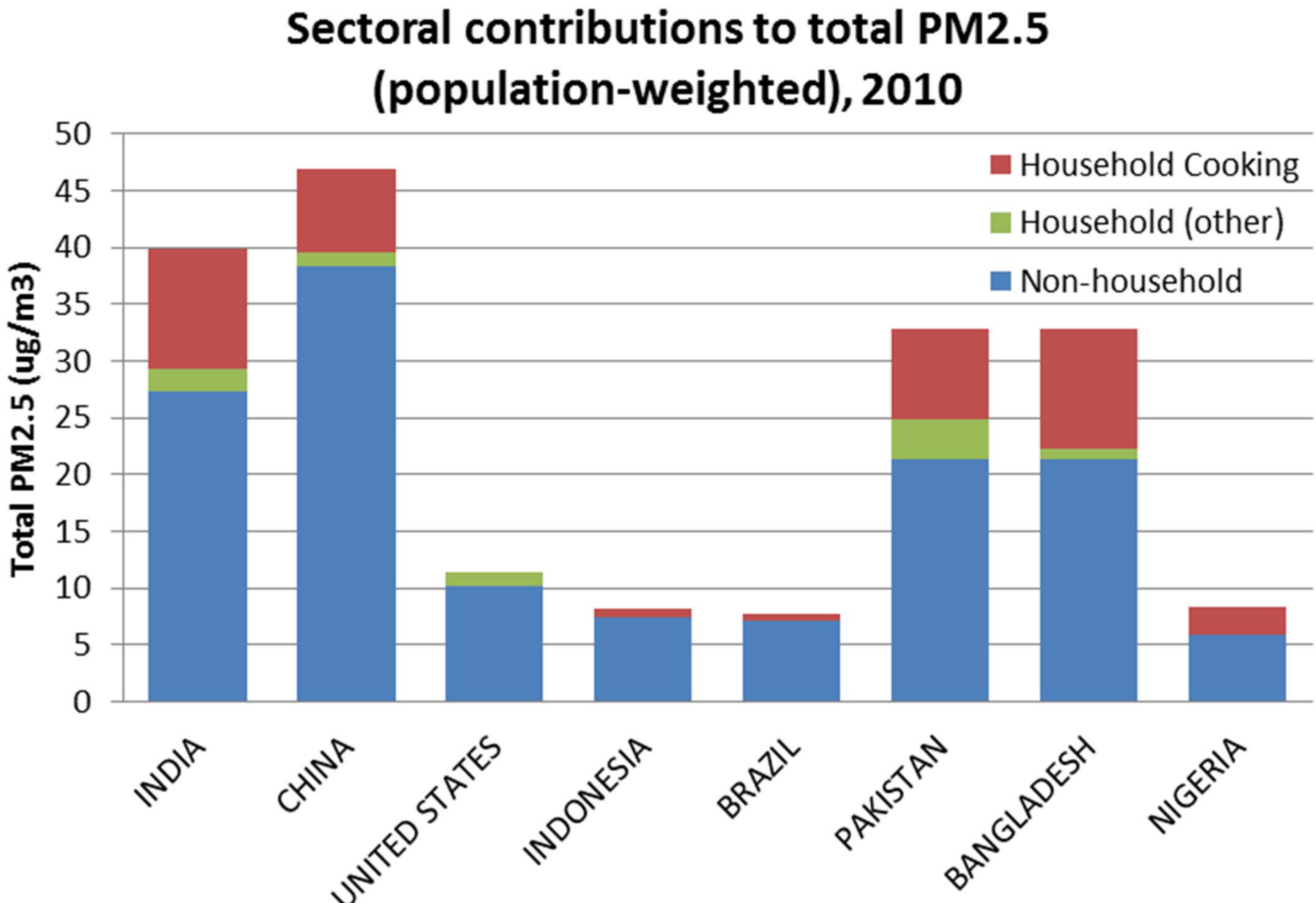


Total Population Cooking with Solid Fuels

Bonjour et al., CRA-2010

2. Estimating the HAP contribution to ambient $PM_{2.5}$ concentrations

- IIASA Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model gives the fraction of of total household PM2.5 emissions attributable to the combustion of solid fuels for household cooking, by country.
- TM5-FASST database of the European Joint Research Centre gives the fraction that total household emissions make of total PM2.5 emissions.
- Together they give the proportion of total PM2.5 attributable to household cooking.
- Do not deal directly with secondary PM formation, but estimated fractions reasonable given HH sources also include PM precursors.

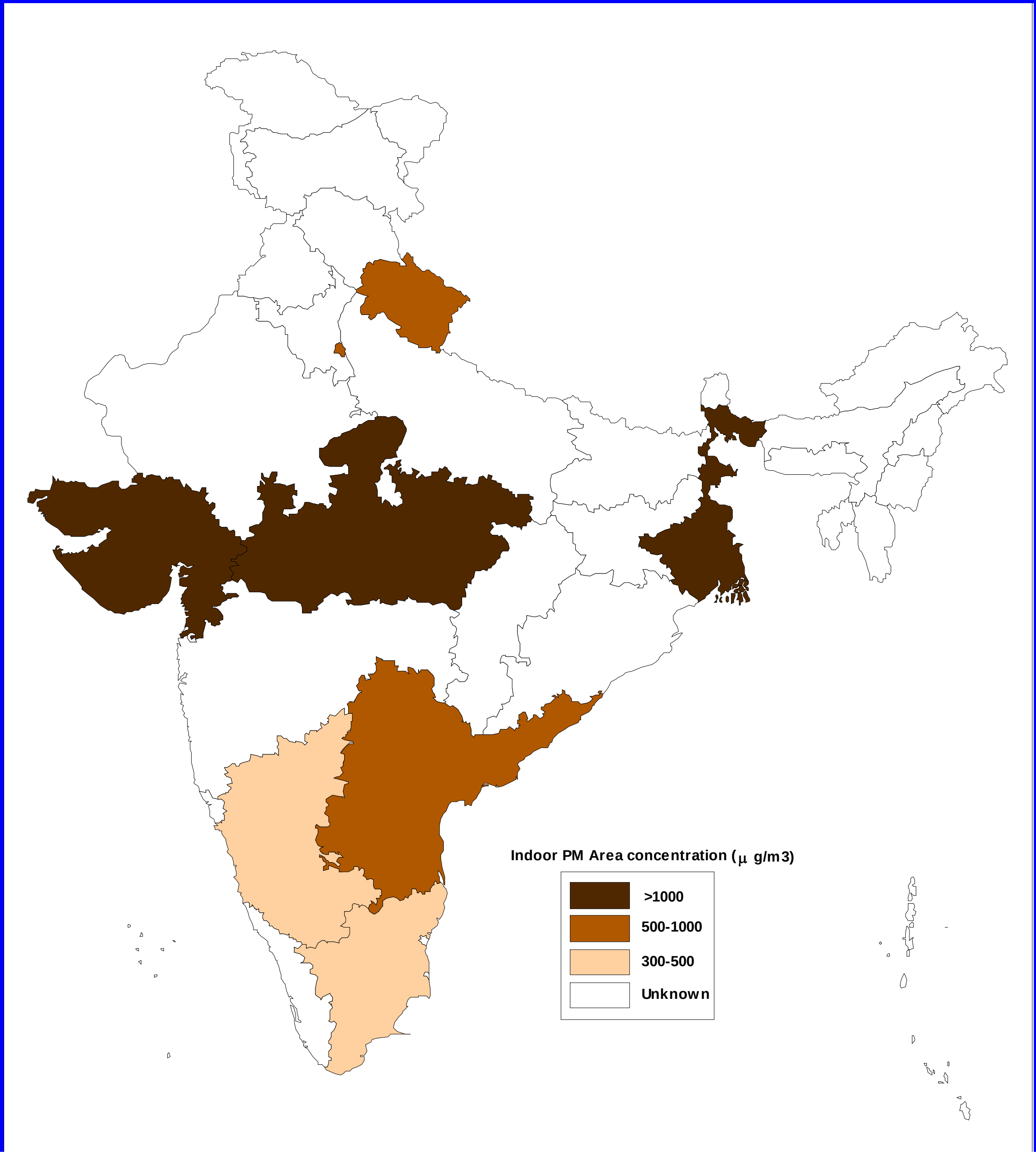


Chafe et al., CRA-2010

3. Estimating household $PM_{2.5}$ exposures in India

- Large-scale monitoring studies in six states modeled against household parameters commonly assessed in household surveys – fuel type, kitchen location, stove type, agro-climatic region
- National exposure estimates can thus be estimated without measurements in each state
- Distribution and trends can be assessed
- Exposure distributions will be derived for major combinations of fuel use and kitchen type in India
- Distribution of modeled exposures will enable use of continuous exposure-response functions

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

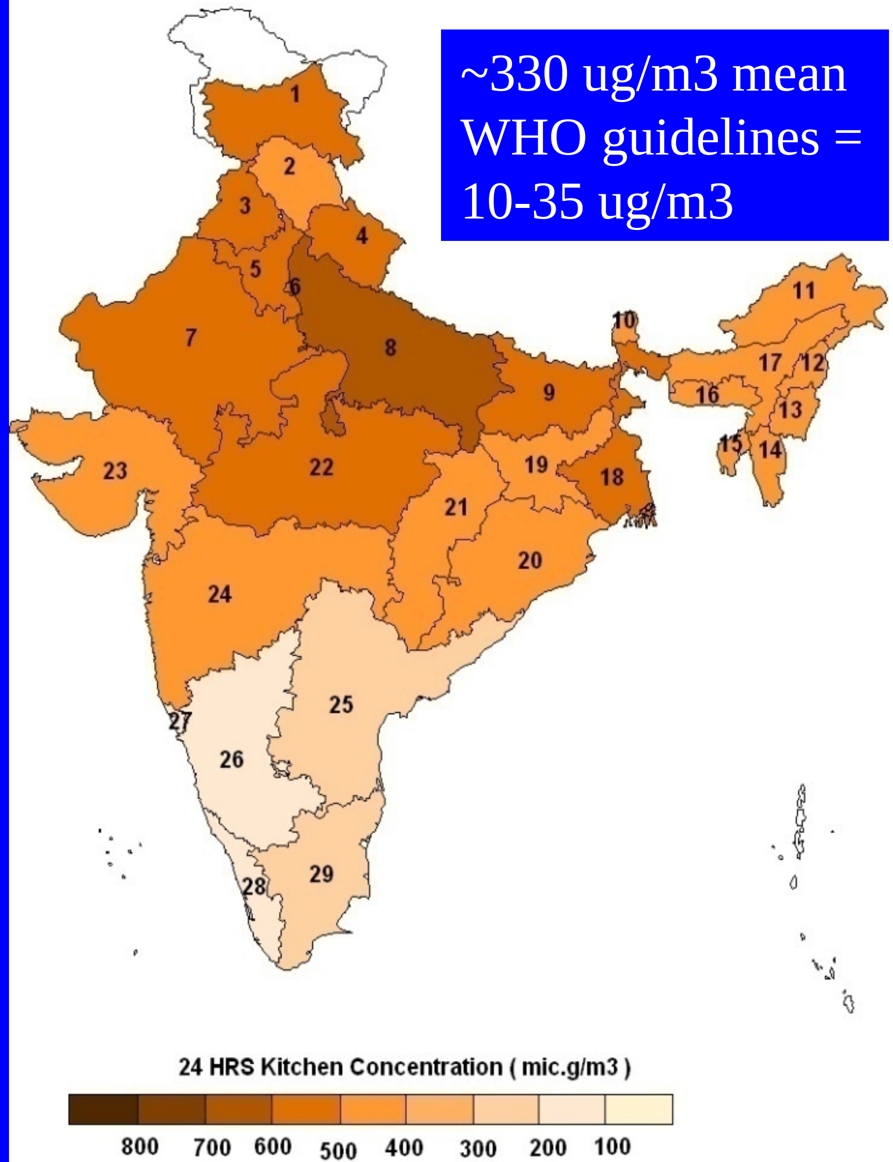


Balakrishnan, et al, -- CRA-2010

Exposure Model for India based on measurements in ~1000 households

Estimated PM2.5 exposure
For women in solid-fuel-using households

~330 ug/m3 mean
WHO guidelines =
10-35 ug/m3



Balakrishnan, et al. Household Air Pollution Comparative Risk Assessment-2010

Household air pollution (HAP)

Health outcomes

Evidence classes

- All evidence classes have plausible physiological mechanisms based on toxicology
- Class Ia: Quantified primary outcome
  - Multiple epi of good quality in LDC household settings sufficient for meta-analysis
  - Consistent results as well as significant and positive summary estimate
  - Supporting epi from other particle exposures
  - Fits RR trends for other particle exposure categories

Evidence classes

- Class Ib: Quantified primary outcome, cont.
  - Very strong epi from other particle exposure settings both at higher and lower exposure allowing interpolation for HAP

Evidence classes, cont.

- Class II: Quantified secondary outcome
  - Multiple epi LDC household settings sufficient for MA
  - Unconvincing adjustment for confounding and/or exposure assessment
  - Inconsistent results and/or non-significant positive result
  - Supporting epi from other particle exposures
  - Generally fits RR trends for other particle exposure categories

Evidence classes, cont.

- Class III: Unquantified secondary outcome
  - Still thought likely to be causal
  - Weak or insufficient epi from LDC households for meta-analysis
  - Less strong support from other particle exposure categories

Overview

Level	Outcomes	Planned reporting
I (a)	Child ALRI, Lung cancer, COPD, LBW, Cataract	Full description of review Effect estimate
I (b)	CVD (including stroke)	Full description of methods Effect estimate

Overview

Level	Outcomes	Planned reporting
I (a)	Child ALRI, Lung cancer, COPD, LBW, Cataract	Full description of review Effect estimate
I (b)	CVD (IHD and stroke)	Full description of methods Effect estimate
II	TB, Cancer of UADT	Briefer description of methods; forest plot
III	Ca cervix, adult ALRI, asthma, O/Media, cognitive effects	Briefer description of methods; forest plot

Only Level I included in GBD

Level	Outcomes	Planned reporting
I (a)	Child ALRI, Lung cancer, COPD, LBW, Cataract	Full description of review Effect estimate
I (b)	CVD (including stroke)	Full description of methods Effect estimate
II	TB, Cancer of UADT	Briefer description of methods; forest plot
III	Ca cervix, adult ALRI, asthma, O/Media, cognitive effects	Briefer description of methods;
Outside system	Burns, hygiene, time saving, climate and forests	Descriptive summary, with indication of evidence available
Benefit	Malaria	Summary of recent review

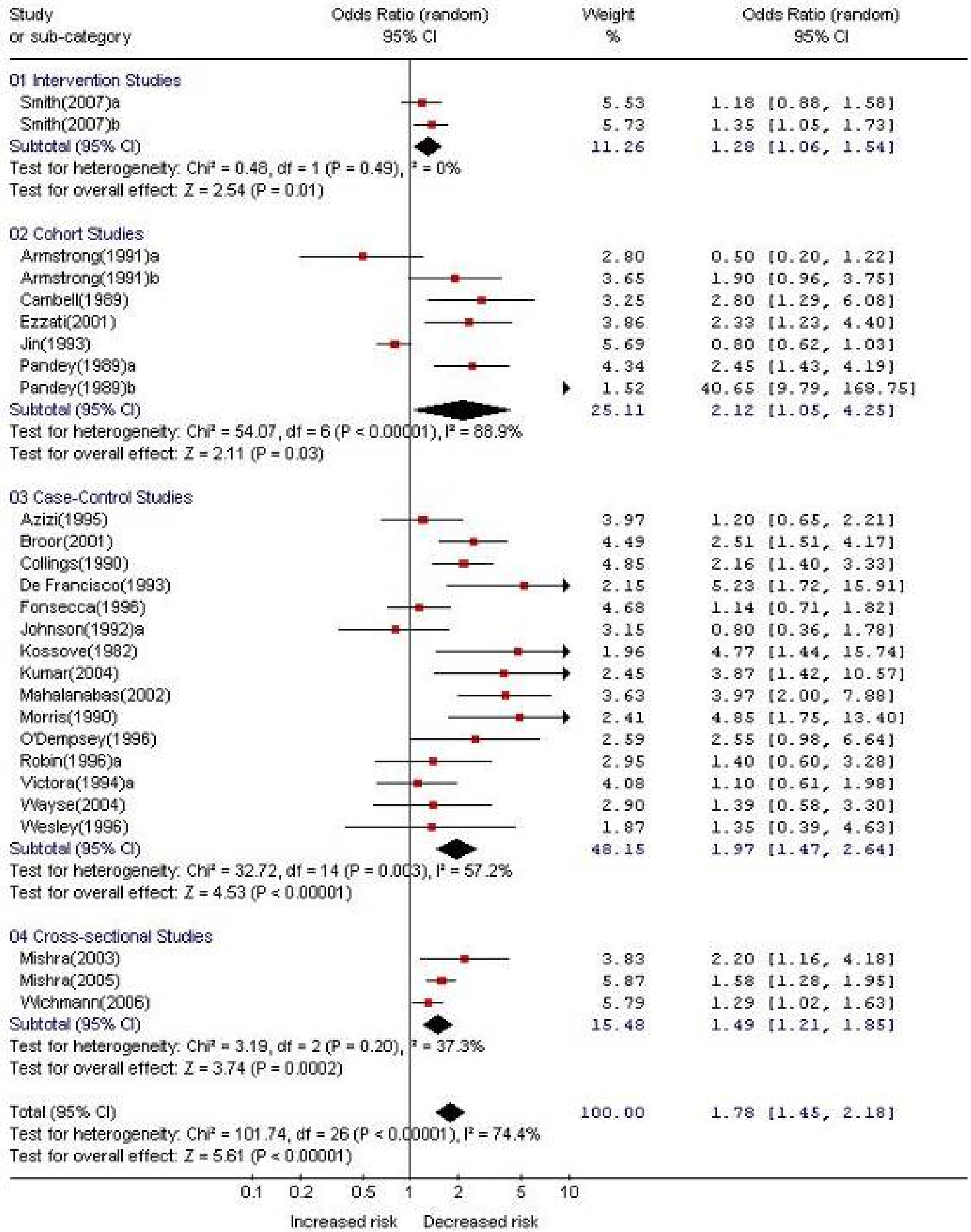
Child ALRI

Child ALRI: Evidence and approach

- Evidence available:
  - Published SR, mainly observational studies [Dherani (2008)]
  - RESPIRE (RCT) (a) Intention to treat (b) exposure response association [Smith (2011)]
- Approach taken:
  - Assess consistency of observational and RCT effects (ITT and exposure-response)
  - IER links RESPIRE exposure-response with OAP and SHS epidemiology for PM2.5
  - Derive OR for 'typical' PM2.5 child HAP exposure seen for homes using solid fuels vs. counterfactual

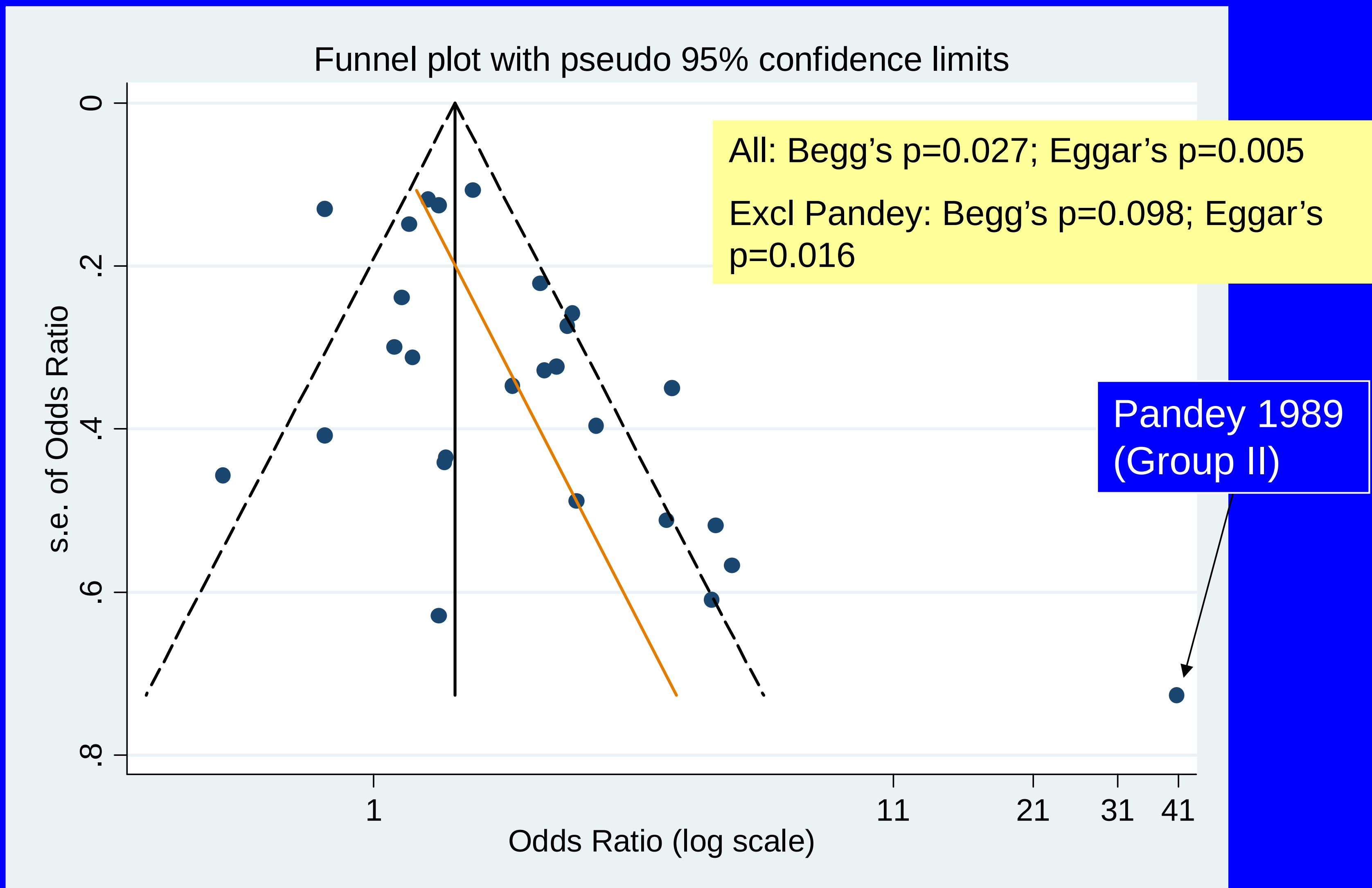
Study design	N*	OR	95% CI
Intervention	2	1.28	1.06, 1.54
Cohort	7	2.12	1.06, 4.25
Case-control	15	1.97	1.47, 2.64
Cross-sectional	3	1.49	1.21, 1.85
All	26	1.78	1.45, 2.18

Dherani et al Bull WHO (2008)



Funnel plot - all studies:

Assessment for evidence of publication bias

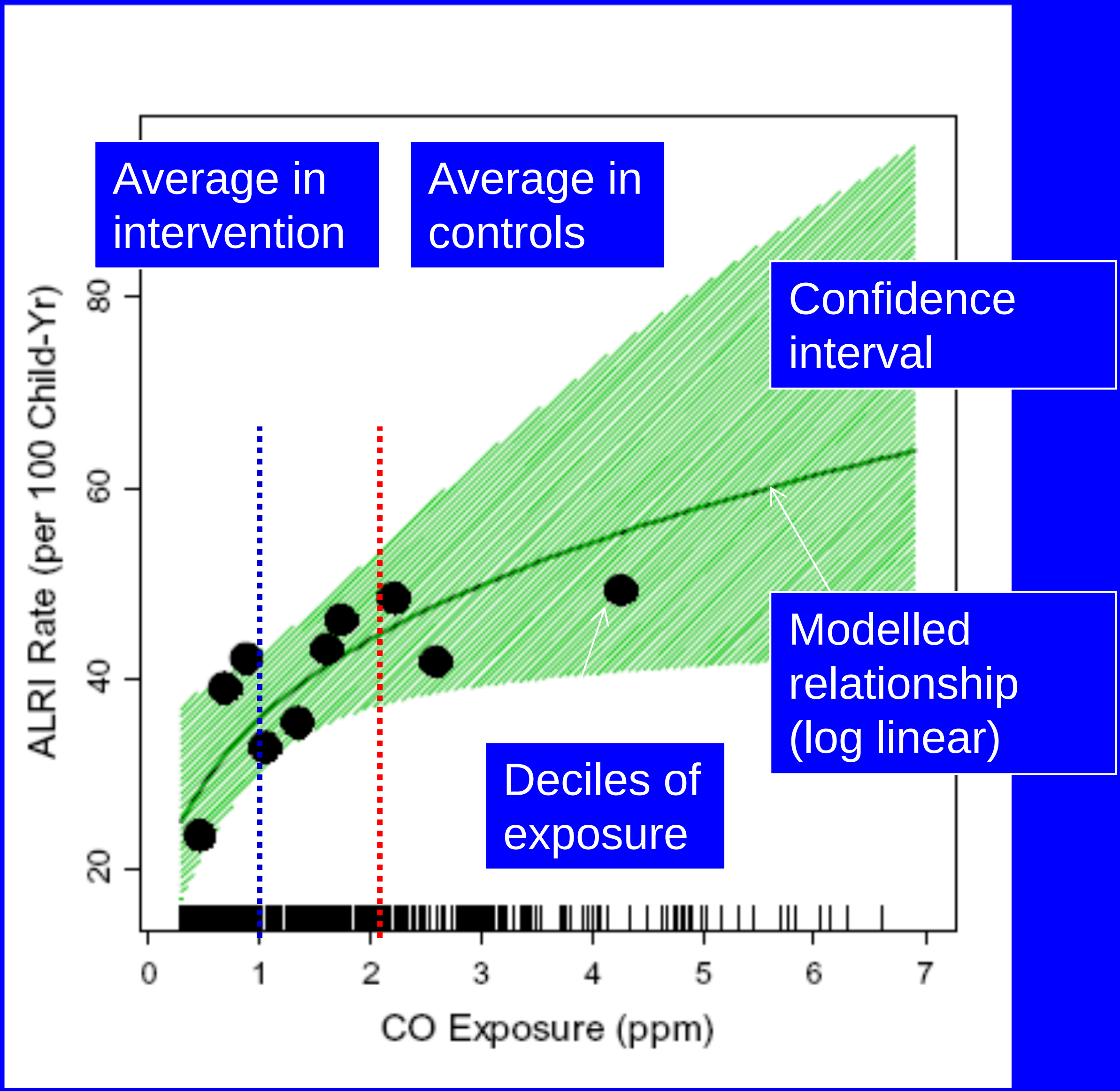


Sensitivity analysis

Group	Detail	Random effects estimates		
		N	**OR**	**95% CI**
All studies	All	27	1.78	1.45, 2.18
	Excl. Pandey (outlier)	26	1.67	1.39, 2.01
	+ excl. Low prevalence	22	1.79	1.46, 2.21
Controls	Unbiased selection	9	1.50	1.05, 2.14
Confounding	Good adjustment	16	1.77	1.43, 2.18
Exposure	Good categorisation	16	1.67	1.33, 2.09
	Solid vs. clean fuel	14	1.69	1.29, 2.20
Outcome measure	Excluding DHS	23	1.72	1.37, 2.17
	MD diagnosis/CXR	20	1.65	1.26, 2.15
Age group	< 60 months < 36 months < 24 months	11 4 12	1.62 2.05 1.96	1.21, 2.15 1.38, 3.07 1.36, 2.82
Adjustment for publication bias		[-3 studies]* 1.64 (1.34, 2.01) [-5 studies]** 1.54 (1.25, 1.89)		

* Manual trim ** Metatrim (Stata)

Exposure – response relationship

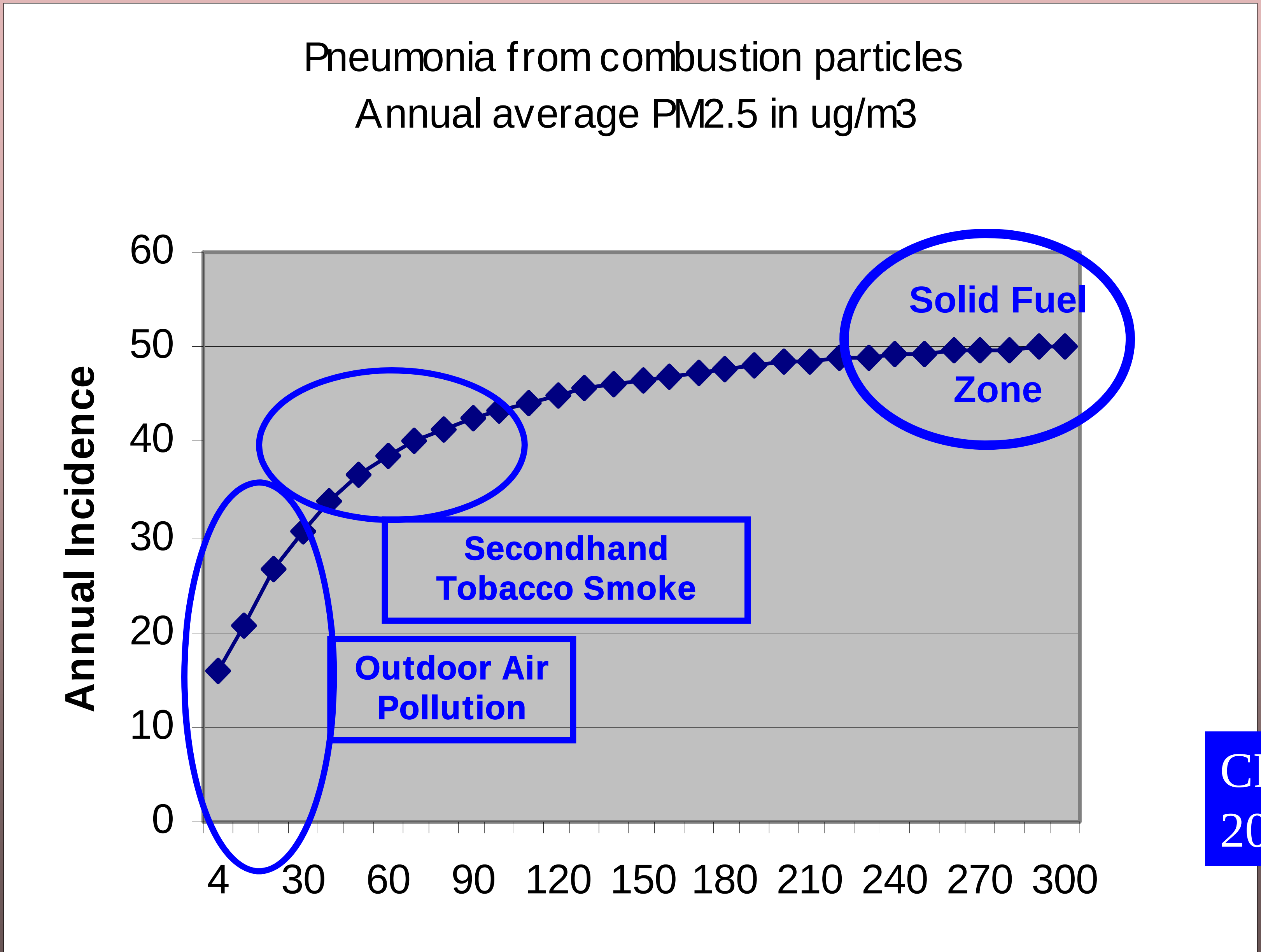


Physician-diagnosed pneumonia

From the

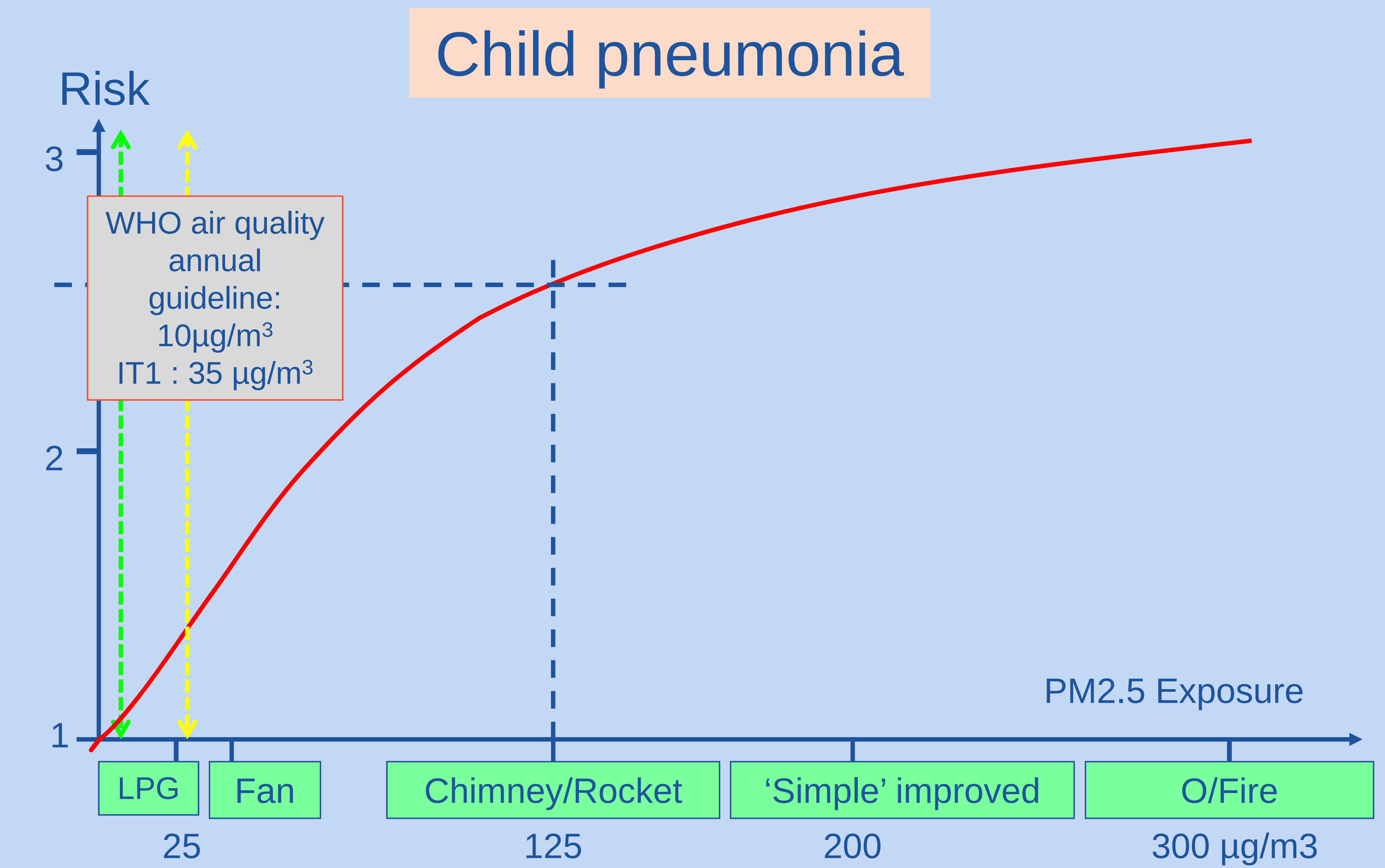
RESPIRE Studies in Guatemala

Generalized Exposure-Response: Outdoor Air, SHS, and HAP



CRA, 2010

Exposure-response relationship

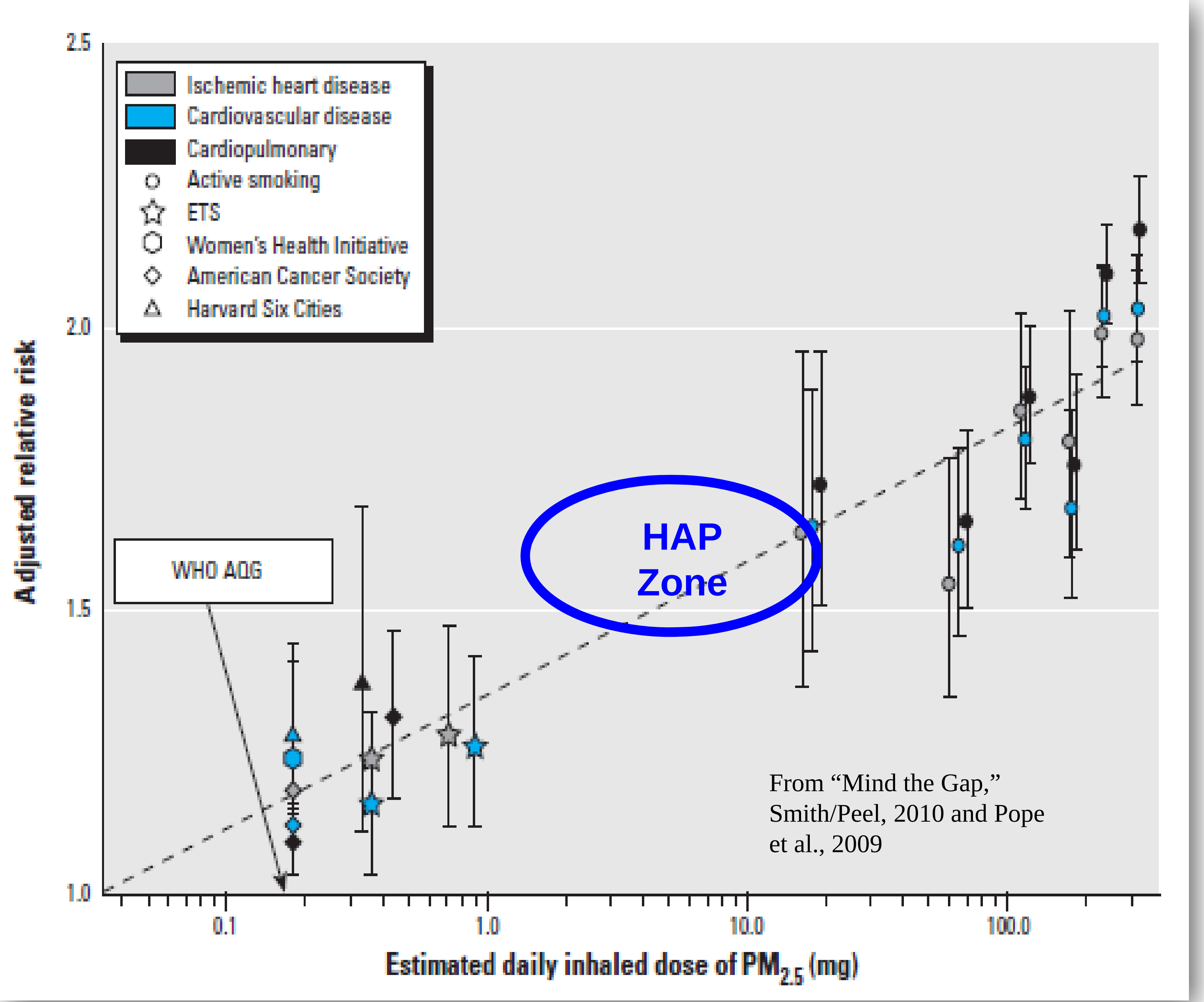


Cardiovascular Disease

Evidence and approach

- No studies of CVD and HAP
  - But studies showing effects on blood pressure and ST-segment, important disease signs
- Epidemiologic evidence shows clear, consistent evidence of increasing risk
  - at higher exposures – ATS
  - and lower exposures – OAP and SHS
- Interpolation indicates that HAP would also increase risk

Heart Disease and Combustion Particle Doses



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

Chimney Stove Intervention to Reduce Long-term Wood Smoke Exposure Lowers Blood Pressure among Guatemalan Women

John P. McCracken,[1,2] Kirk R. Smith,[3] Anaité Díaz,[4] Murray A. Mittleman,[1,5] and Joel Schwartz[1,2]

EHP, 2007

Table 3. Crude and adjusted between-group differences in SBP and DBP (mm Hg) associated with *plancha* compared with open fire use during the trial period.

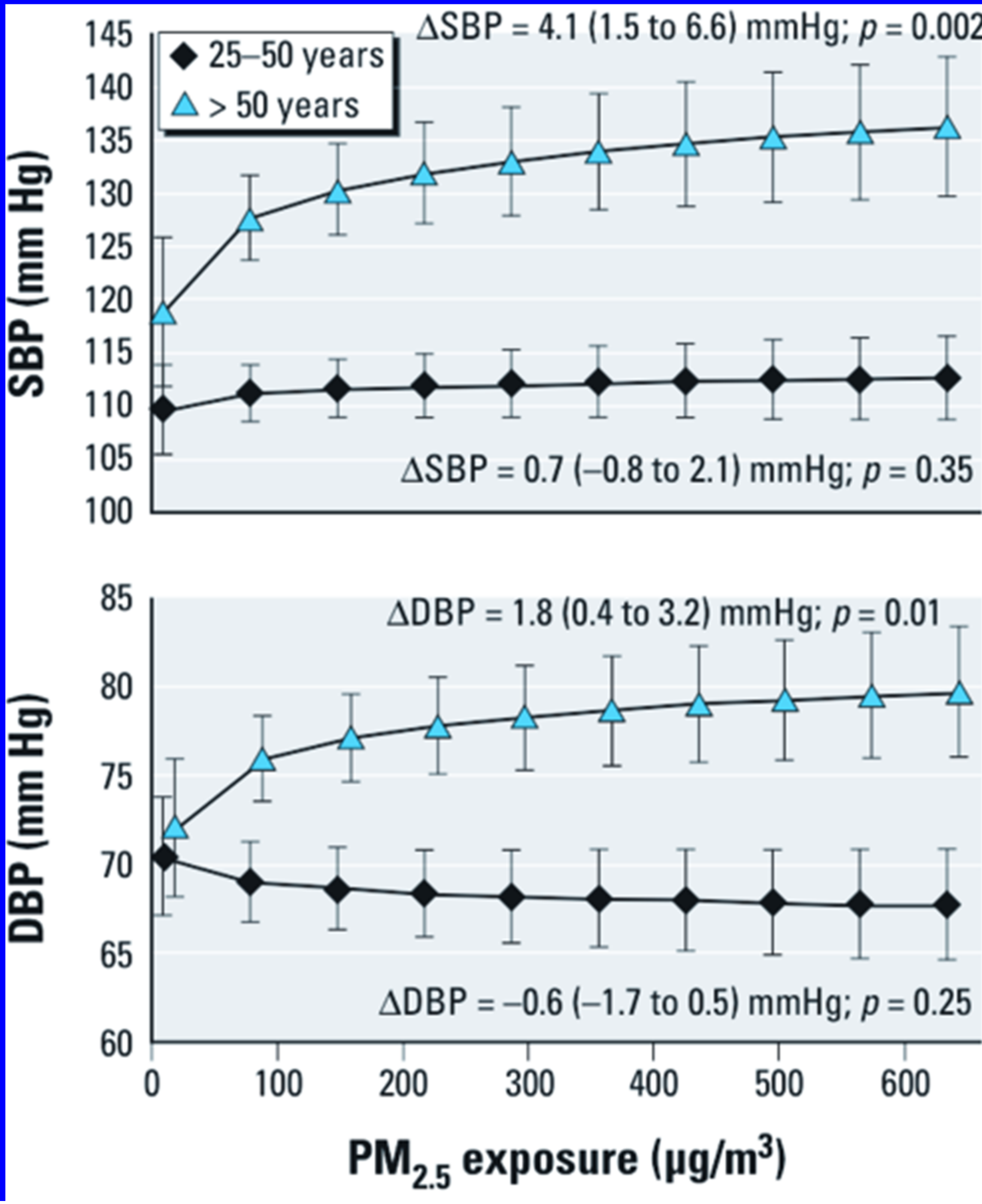
	No. of subjects (measures)		Crude mean difference			Adjusted mean difference[a]		
	Control group	Intervention group	Estimate	95% CI	*p*-Value	Estimate	95% CI	*p*-Value
SBP	71 (111)	49 (115)	–2.3	–6.6 to 2.0	0.30	–3.7	–8.1 to 0.6	0.10
DBP	71 (111)	49 (115)	–2.2	–4.7 to 0.3	0.09	–3.0	–5.7 to –0.4	0.02

Between group analysis

Table 4. Crude and adjusted within-subject differences in SBP and DBP (mm Hg) after the *plancha* echo-intervention compared with before.

	No. of subjects (measures)		Crude mean difference			Adjusted mean difference[a]		
	Trial period	Echo-intervention	Estimate	95% CI	*p*-Value	Estimate	95% CI	*p*-Value
SBP	55 (88)	55 (65)	–3.7	–6.0 to –1.4	0.002	–3.1	–5.3 to –0.8	0.01
DBP	55 (88)	55 (65)	–2.3	–3.8 to 0.9	0.003	–1.9	–3.5 to –0.4	0.01

Before and after analysis



Household
Air
Pollution
and
Blood Pressure

In Yunnan, China

Baumgartner et al.
EHP 2011

Intervention to Lower Household Wood Smoke Exposure in Guatemala Reduces ST-Segment Depression on Electrocardiograms

John McCracken,[1,2] Kirk R. Smith,[2] Peter Stone,[3] Anaité Díaz,[4] Byron Arana,[4] and Joel Schwartz[1]

[1]Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, USA; [2]Environmental Sciences Division, University of California, Berkeley, California, USA; [3]Brigham and Women's Hospital, Boston, Massachusetts, USA; [4]Center for Health Studies, Universidad del Valle, Guatemala City, Guatemala

EHP Nov, 2011

Table 3. Odds ratios (ORs) for nonspecific ST-segment depression (30-min average ≤ –1 mm, regardless of slope) associated with chimney-stove intervention compared with open fire from two study designs: between-groups and before-and-after analyses.

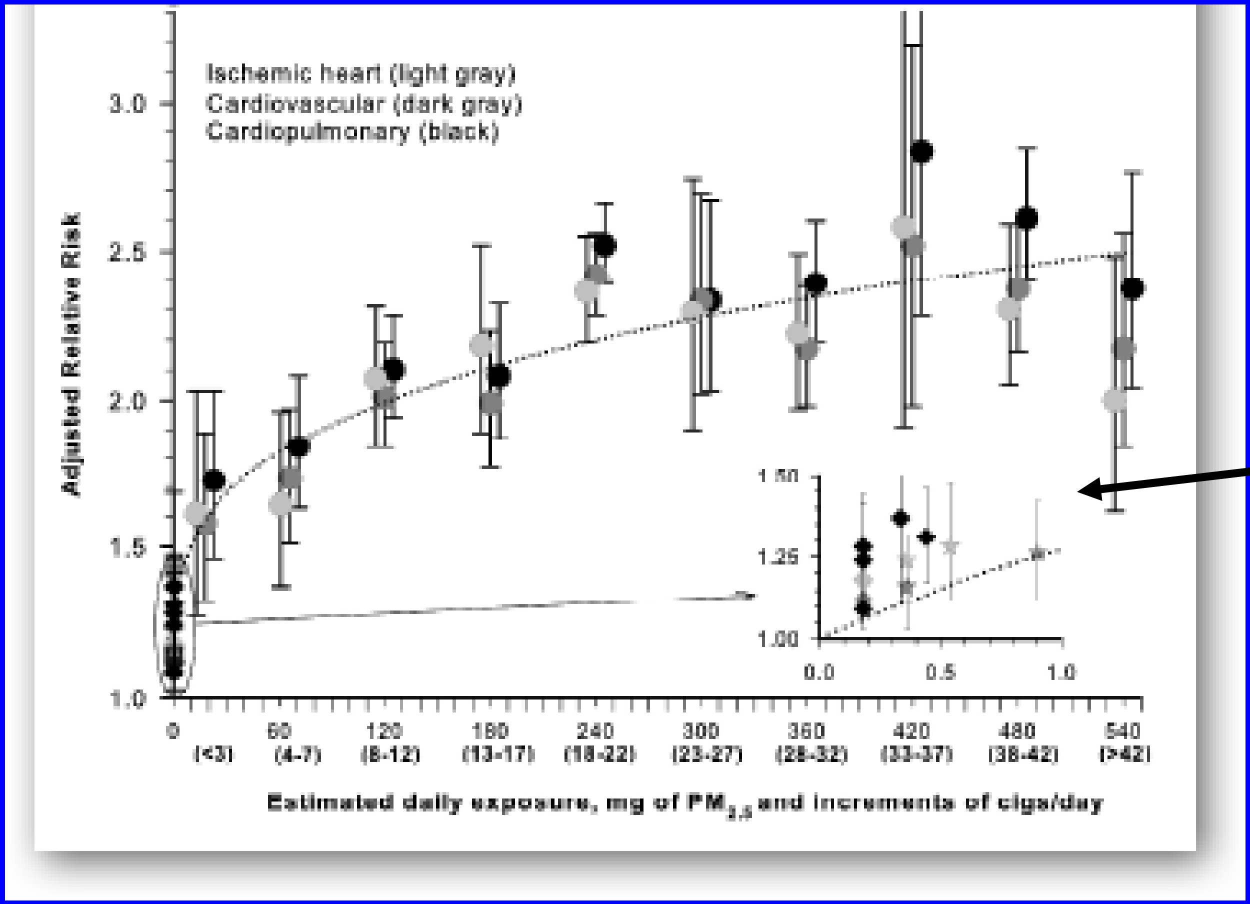
	Crude		Adjusted	
Comparison	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Between-groups	0.34 (0.15, 0.81)	0.015	0.26 (0.08, 0.90)[a]	0.033
Before-and-after (only control group)	0.41 (0.24, 0.70)	0.001	0.28 (0.12, 0.63)[b]	0.002

[a]Adjusted for age (quadratic), BMI (quadratic), asset index category, ever smoking, SHS, owning a wood-fired sauna, recent use of wood-fired sauna, and time of day (natural spline with 5 degrees of freedom). [b]Adjusted for age (quadratic), day of week, season (wet/dry), daily average temperature and relative humidity, daily rainfall, interactions of weather variables with season, recent use of wood-fired sauna, and time of day (natural spline with 5 degrees of freedom).

Table 2. Adjusted relative risk estimates[a] for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

Source of risk estimate	Increments of Exposure	Adjusted RR (95% CI) Lung Cancer	IHD	CVD	CPD	Estimated Daily Dose $PM_{2.5}$ (mg)[b]
ACS- present analysis	≤3 (1.5) cigs/day	10.44 (7.30-14.94)	1.61 (1.27-2.03)	1.58 (1.32-1.89)	1.72 (1.46-2.03)	18
ACS- present analysis	4-7 (5.5) cigs/day	8.03 (5.89-10.96)	1.64 (1.37-1.96)	1.73 (1.51-1.97)	1.84 (1.63-2.08)	66
ACS- present analysis	8-12 (10) cigs/day	11.63 (9.51-14.24)	2.07 (1.84-2.31)	2.01 (1.84-2.19)	2.10 (1.94-2.28)	120
ACS- present analysis	13-17 (15) cigs/day	13.93 (11.04-17.58)	2.18 (1.89-2.52)	1.99 (1.77-2.23)	2.08 (1.87-2.32)	180
ACS- present analysis	18-22 (20) cigs/day	19.88 (17.14-23.06)	2.36 (2.19-2.55)	2.42 (2.28-2.56)	2.52 (2.39-2.66)	240
ACS- present analysis	23-27 (25) cigs/day	23.82 (18.80-30.18)	2.29 (1.91-2.75)	2.33 (2.02-2.69)	2.33 (2.03-2.67)	300
ACS- present analysis	28-32 (30) cigs/day	26.82 (22.54-31.91)	2.22 (1.97-2.49)	2.17 (1.98-2.38)	2.39 (2.19-2.60)	360
ACS- present analysis	33-37 (35) cigs/day	26.72 (18.58-38.44)	2.58 (1.91-3.47)	2.52 (1.98-3.19)	2.83 (2.28-3.52)	420
ACS- present analysis	38-42 (40) cigs/day	30.63 (25.79-36.38)	2.30 (2.05-2.59)	2.37 (2.16-2.59)	2.61 (2.40-2.84)	480
ACS- present analysis	43+ (45) cigs/day	39.16 (31.13-49.26)	2.00 (1.62-2.48)	2.17 (1.84-2.56)	2.37 (2.04-2.76)	540
ACS-air pol. original	24.5 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	-----	1.31(1.17-1.46)	0.44
ACS-air pol. extend.	10 $\mu g/m^3$ ambient $PM_{2.5}$	1.14(1.04-1.23)	1.18(1.14-1.23)	1.12(1.08-1.15)	1.09(1.03-1.16)	0.18
HSC-air pol. original	18.6 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	-----	1.37(1.11-1.68)	0.33
HSC-air pol. extend.	10 $\mu g/m^3$ ambient $PM_{2.5}$	1.21(0.92-1.69)	-----	1.28(1.13-1.44)	-----	0.18
WHI-air pol.	10 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	1.24(1.09-1.41)[c]	-----	0.18
SGR-SHS	Low- moderate SHS exp.	-----	-----	1.16(1.03-1.32)	-----	0.36
SGR-SHS	Moderate-high SHS exp	-----	-----	1.26(1.12-1.42)	-----	0.90
SGR-SHS	Live with smoking spouse	1.21(1.13-1.30)	-----	-----	-----	0.54
SGR-SHS	Work with SHS exposure	1.22(1.13-1.33)	-----	-----	-----	0.72
INTERHEART	1-7 hrs/wk SHS exp.	-----	1.24(1.17-1.32)[d]	-----	-----	0.36
INTERHEART	Live with smoking spouse	-----	1.28(1.12-1.47)[d]	-----	-----	0.54

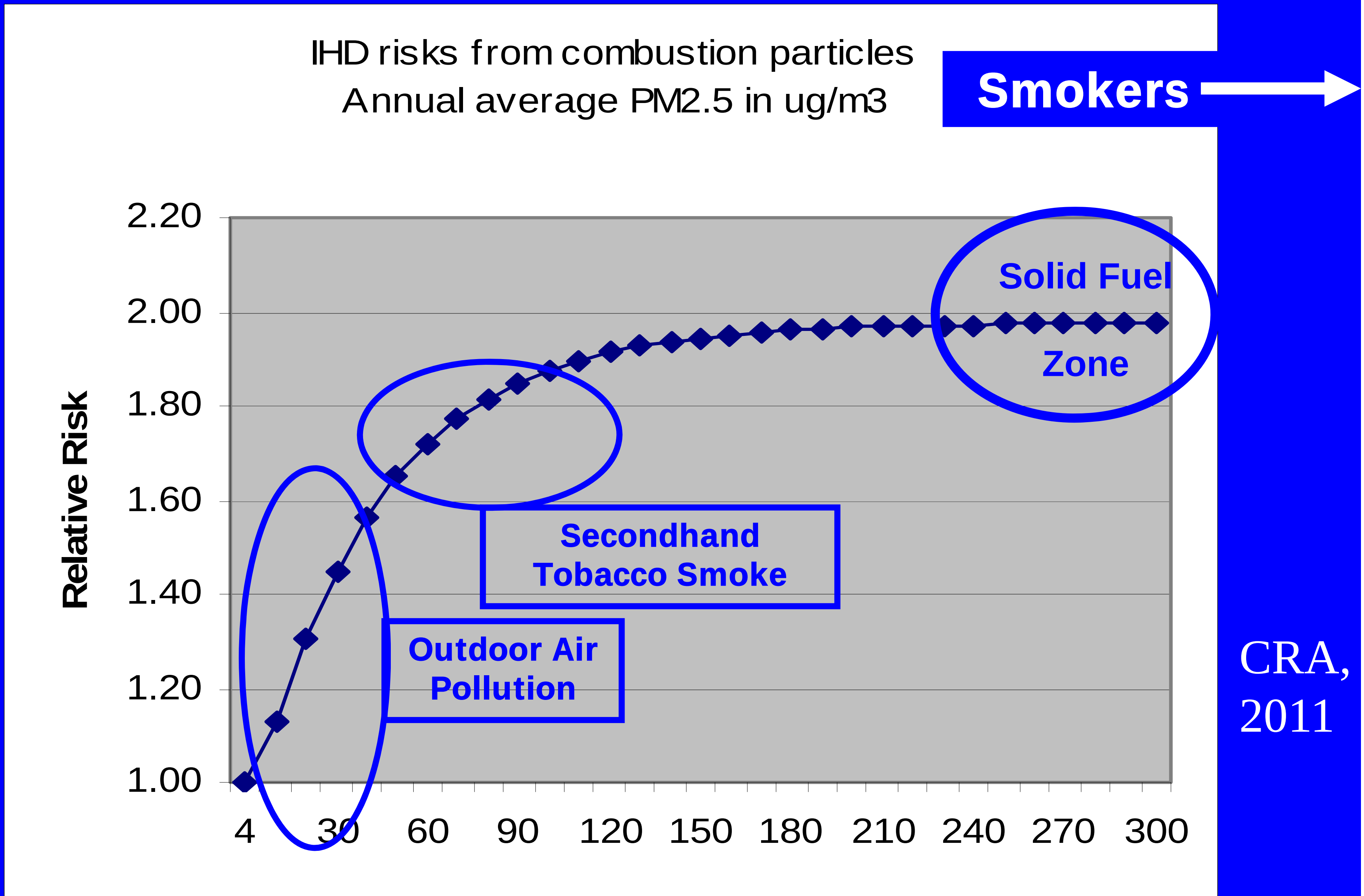
Pope et al.
Environmental Health Perspectives
2011, in press



CVD

Pope et al. Environmental Health Perspectives 2011

Generalized Exposure-Response: Outdoor Air, SHS, and Smoking and Heart Disease



CRA, 2011

Disease	Sex	Age	RR	Evidence
ALRI	M/F	<60 mo	2.71	SR/MA, RCT, IER
Cataracts	F	>25 y	2.47	SR/MA
COPD	F	>25 y	??	??
COPD	M	>25 y	??	??
Lung Cancer	F	>25 y	1.99	SR/MA, IER
Lung Cancer	M	>25 y	1.60	SR/MA, IER
IHD	F	25-80+ y	2.83-1.31	IER
IHD	M	25-80+ y	2.53-1.27	IER
Cerebro	F	25-80+ y	4.50-1.57	IER
Cerebro	M	25-80+ y	3.71-1.54	IER

Preliminary estimates suggest the HAP burden in the 2010 GBD is considerably higher than in the CRA-2000

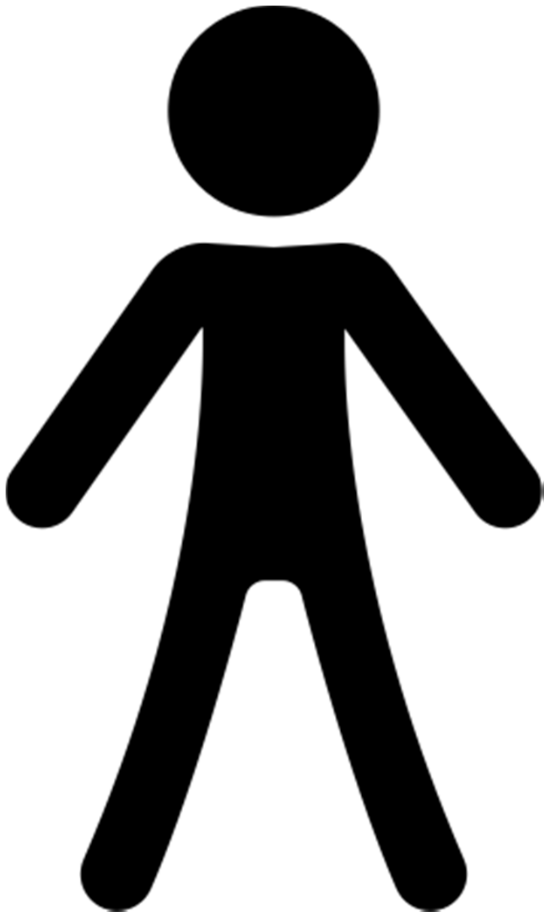
- Because evidence now supports
  - 1) impacts on men as well as women,
  - 2) inclusion of additional diseases (CVD, LC from biomass, and cataract);
  - 3) a portion of OAP burden is now included
  - 4) a lower counterfactual level is applied, equivalent to cooking with gas
- In spite of smaller COPD RRs and a smaller global background rate of ALRI

Slides from the 2010 GBD

- Have been removed because they are from the articles still under review
- Watch my website for the published version, expected late 2012.

What is to be done?

A fresh look



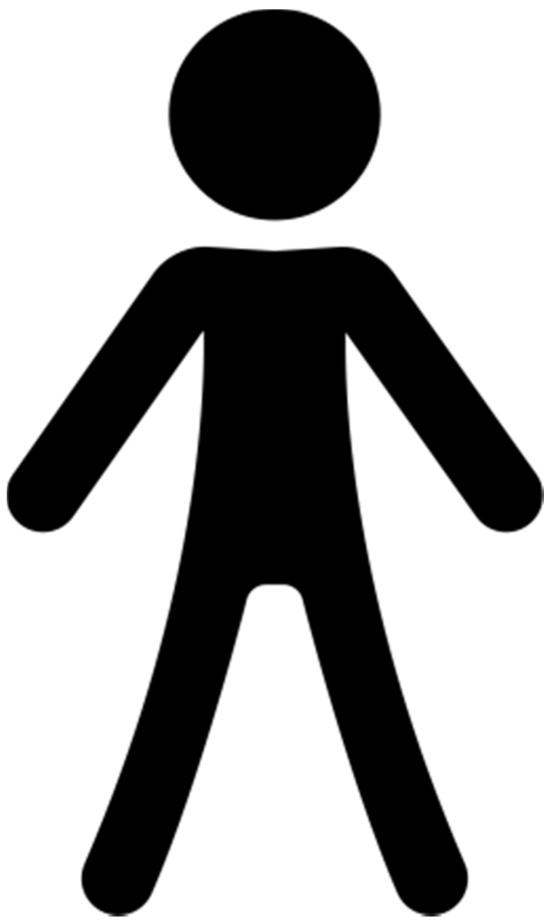
World cooking in Pictograms –

One billion people each

With apologies to
Hans Rosling at Gapminder*
*"Magic Washing Machine"

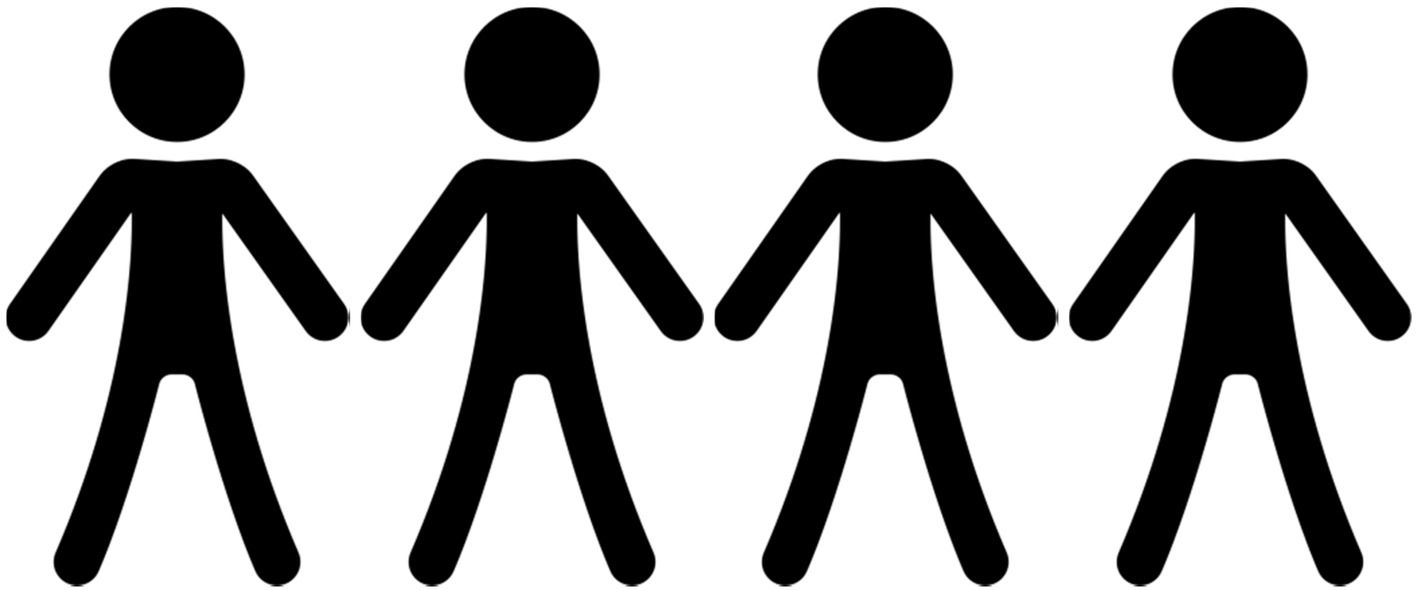
And thanks to Ajay Pillarisetti

What do the richest one billion people cook with?



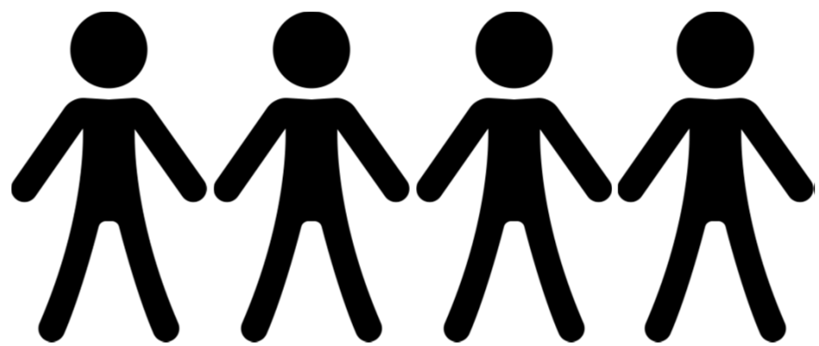
Gas or electric stoves

Plus



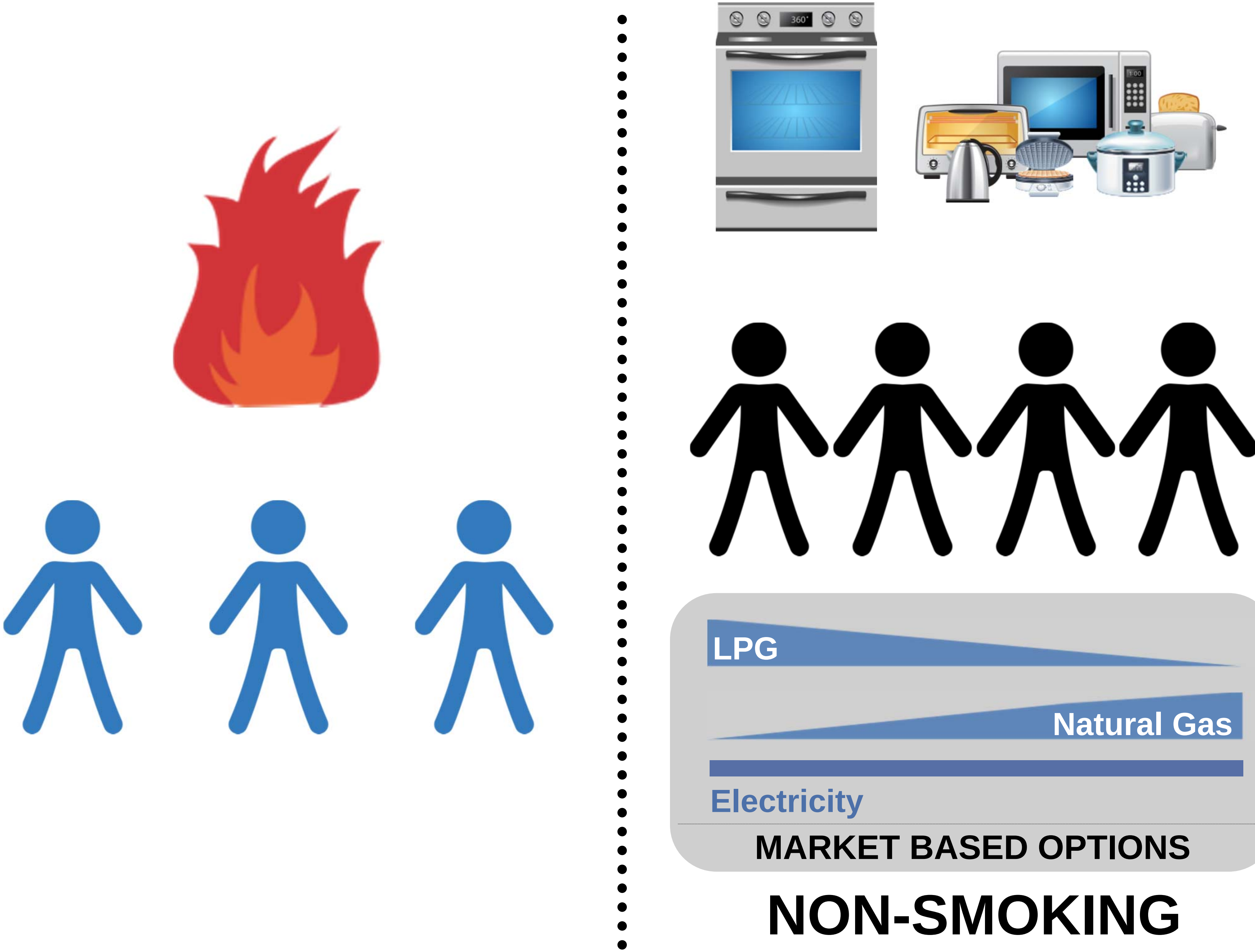
~4 billion worldwide cook with liquified petroleum gas, natural gas, and electricity

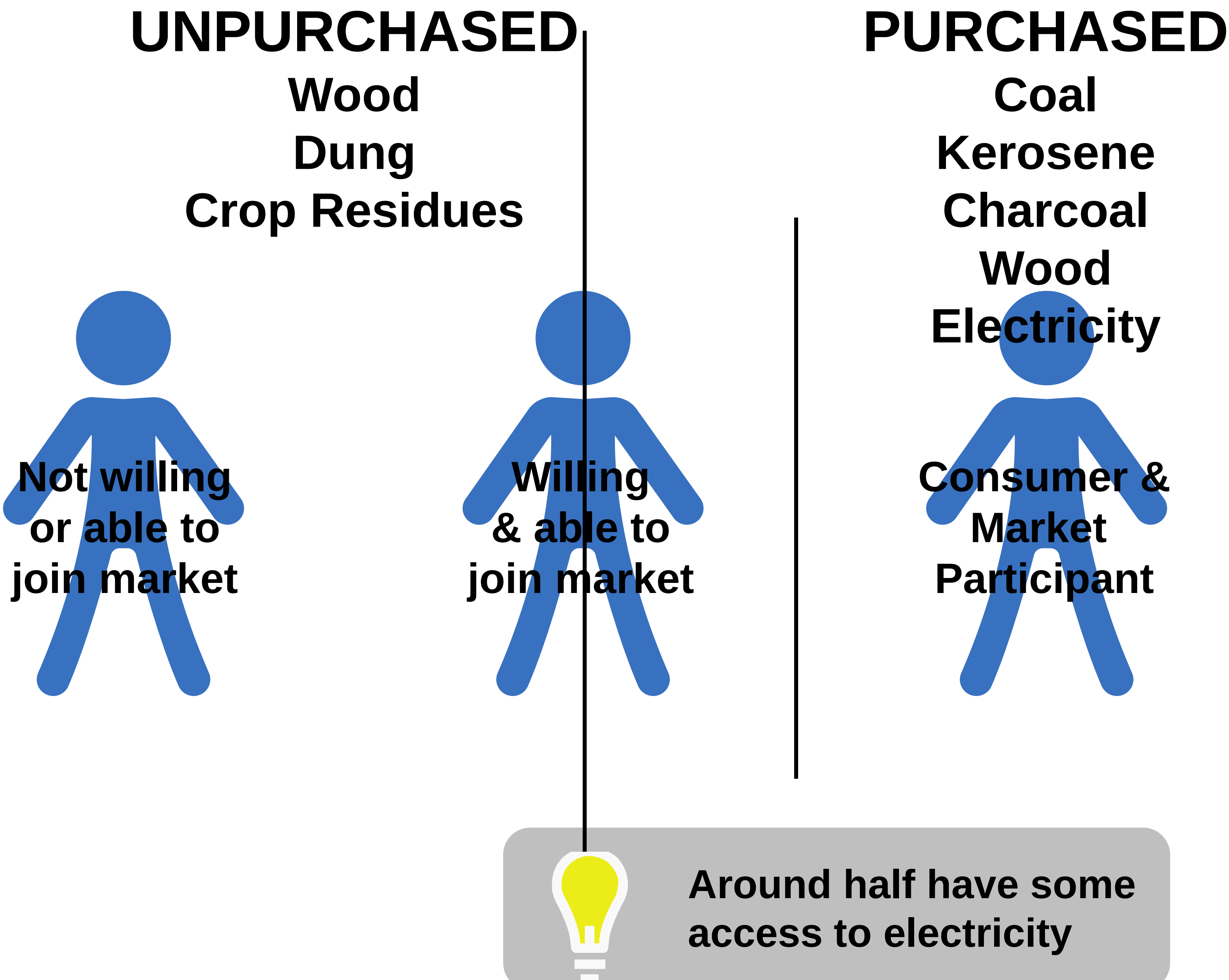
What about the other 3 billion?

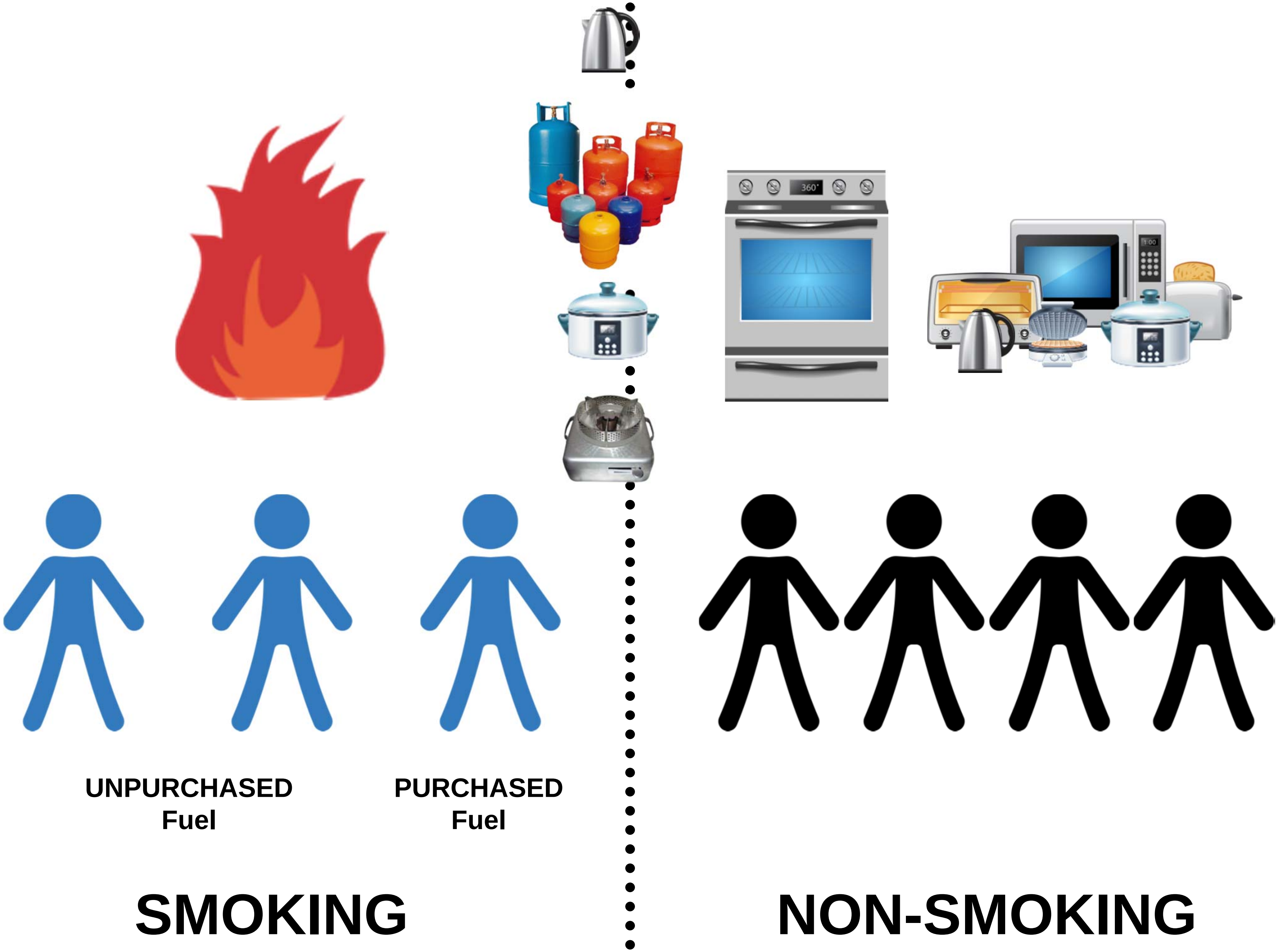


SMOKING SECTION

NON-SMOKING


LPG
Natural Gas
Electricity
MARKET BASED OPTIONS
NON-SMOKING


UNPURCHASED
Wood
Dung
Crop Residues
PURCHASED
Coal
Kerosene
Charcoal
Wood
Electricity
Not willing or able to join market
Willing & able to join market
Consumer & Market Participant
Around half have some access to electricity


UNPURCHASED
Fuel
PURCHASED
Fuel
SMOKING
NON-SMOKING

UNPURCHASED
MARKET ☹

Incentives to move to new cooking technologies?
Subsidized fuel / capital cost?
Access to electricity, infrastructure, and improved markets?

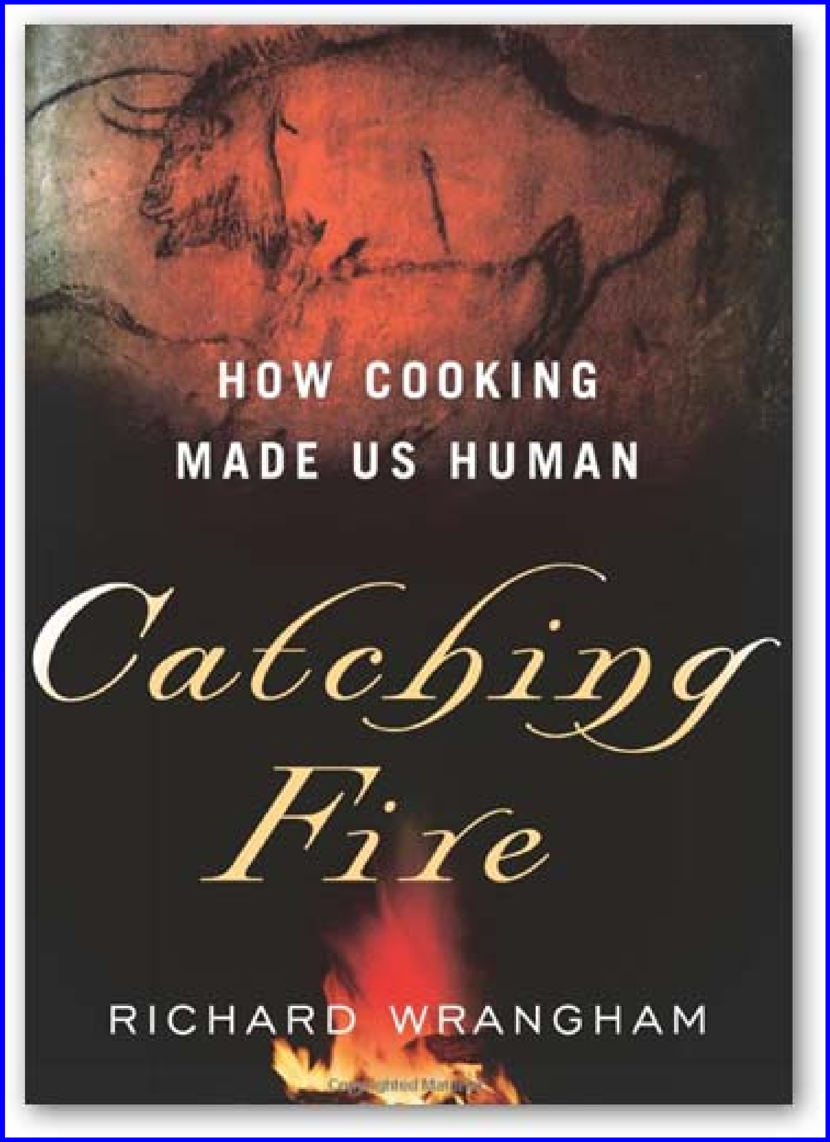
UNPURCHASED
MARKET ☺

ELECTRICAL APPLIANCES

BLOWER STOVE

PELLETS

Market-ready advanced stoves + fuels



Basic Books, 2009

- Fascinating, well-researched, and convincing argument that cooking is the primary distinction between us and animals.
- Dominated early human evolution and shaped our physiology, anatomy, activity, and, by inference, society
- Nearly all done with smoky fires until very recently in human history
- Only since 1980 or so has half of humanity finally freed itself from the major negative side effect of this fundamental transition in our identity as a species.

Thanks to Funders

Shell Foundation

US Environmental Protection Agency

Bill and Melinda Gates Foundation

HAP CRA Website: http://ehs.sph.berkeley.edu/krsmith/page.asp?id=25