Smoke, health, and climate: the unfinished global agenda of poor combustion

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300-400 thousand years ago, hearths became a regular feature in human habitation

The skill that many anthropologists use for defining the point when humanity switched from pre-human to human conditions was learning to control fire (e.g., Levi-Strauss 1969).

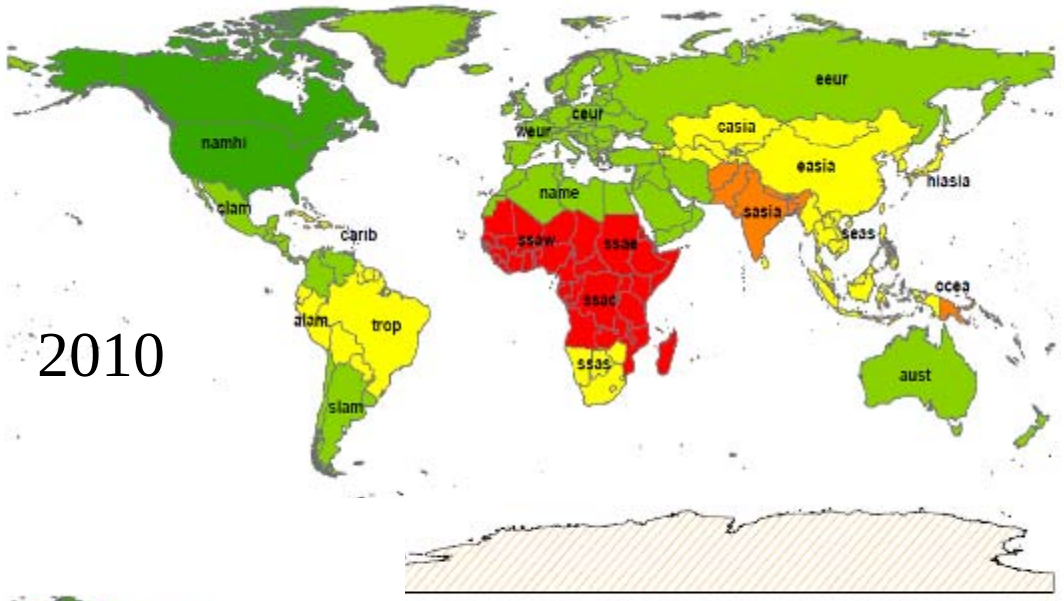
By this definition, cooking is the oldest task in human history.

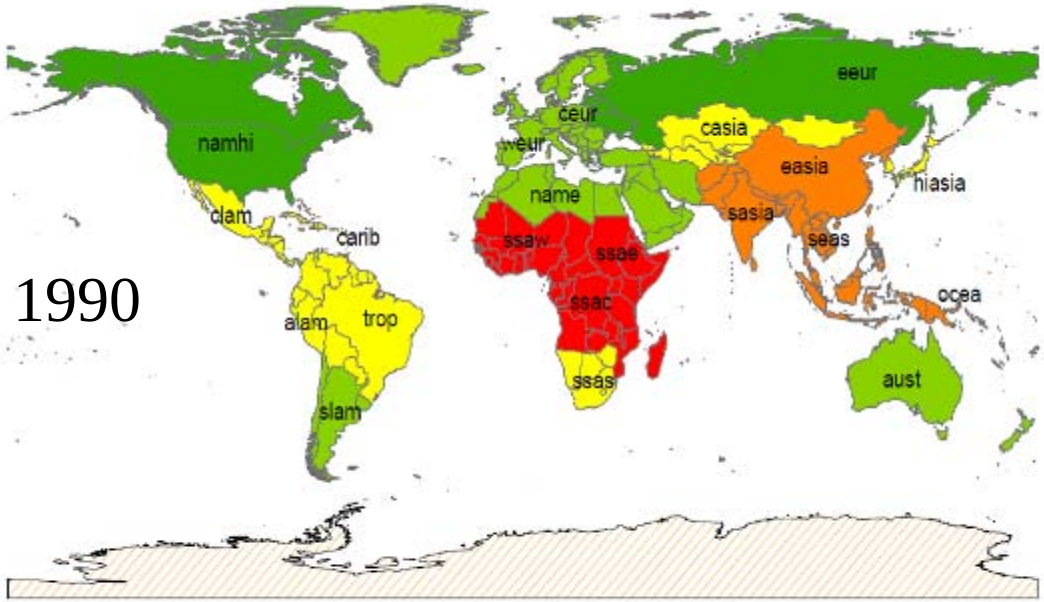
How long ago was this?

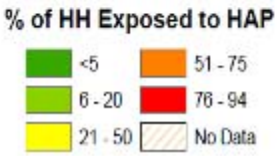
"On the earliest evidence for habitual use of fire" Roebroeks and Villa, PNAS, 2011


The three major solid fuels

Households using biomass or coal to cook

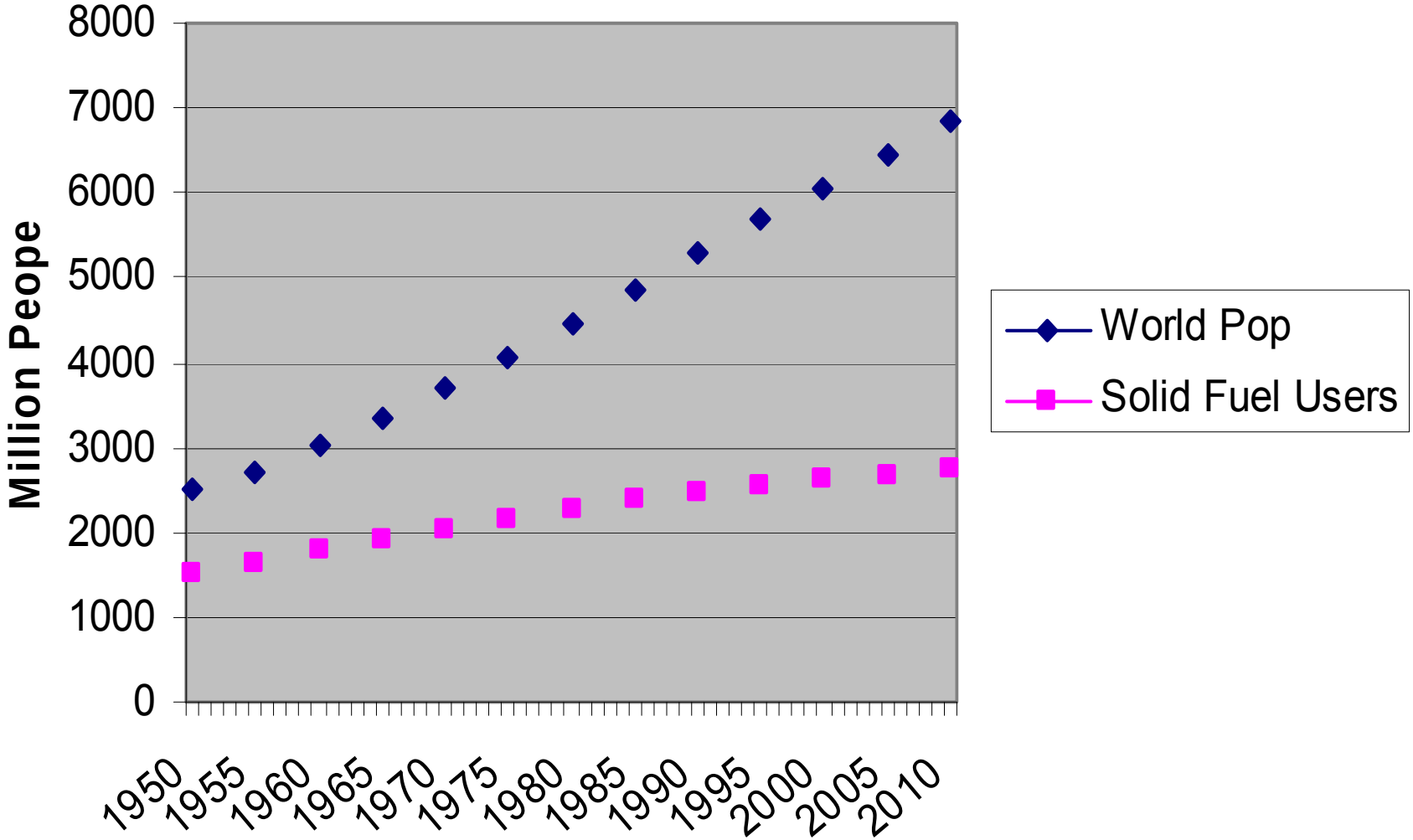






Comparative Risk Assessment (CRA) 2011- preliminary, Adair, et al.

World Population Using Solid Fuels



Woodsmoke is natural – how can it hurt you?

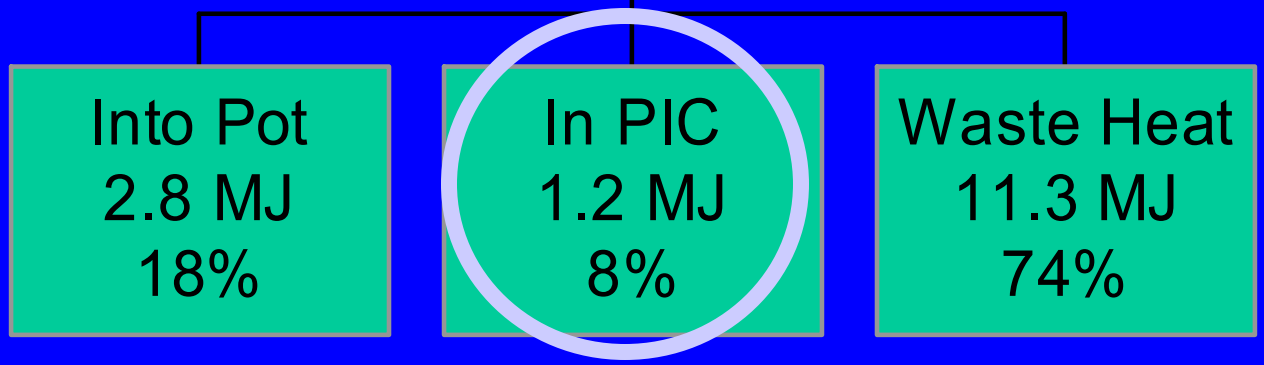
Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%

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



PIC = products of incomplete combustion = CO, HC, C, etc.

Source: Smith, et al., 2000

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

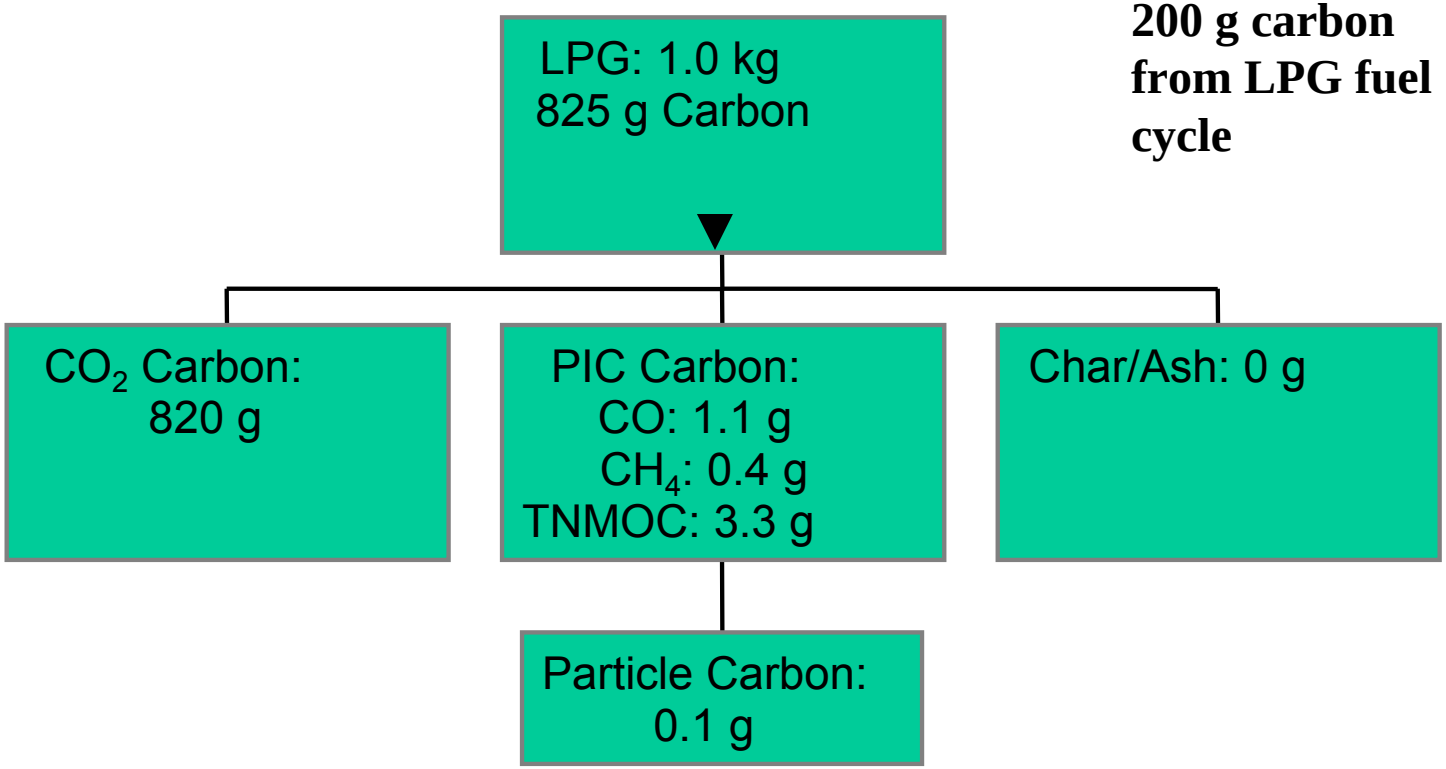
- Small particles, CO, NO_2
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*
  - 40+ unsaturated hydrocarbons such as *1,3 butadiene*
  - 28+ mono-aromatics such as *benzene & styrene*
  - 20+ polycyclic aromatics such as *benzo(α)pyrene*
- Oxygenated organics
  - 20+ aldehydes including *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

Carbon Balance in Typical LPG Stove

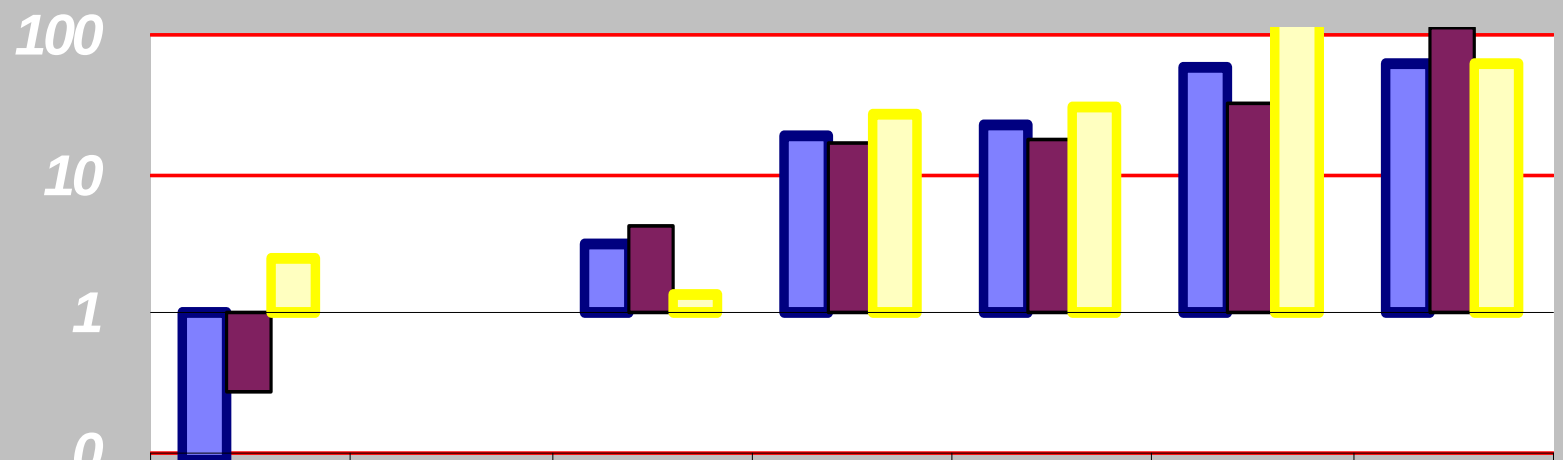
99.4% combustion efficiency

Plus perhaps 200 g carbon from LPG fuel cycle



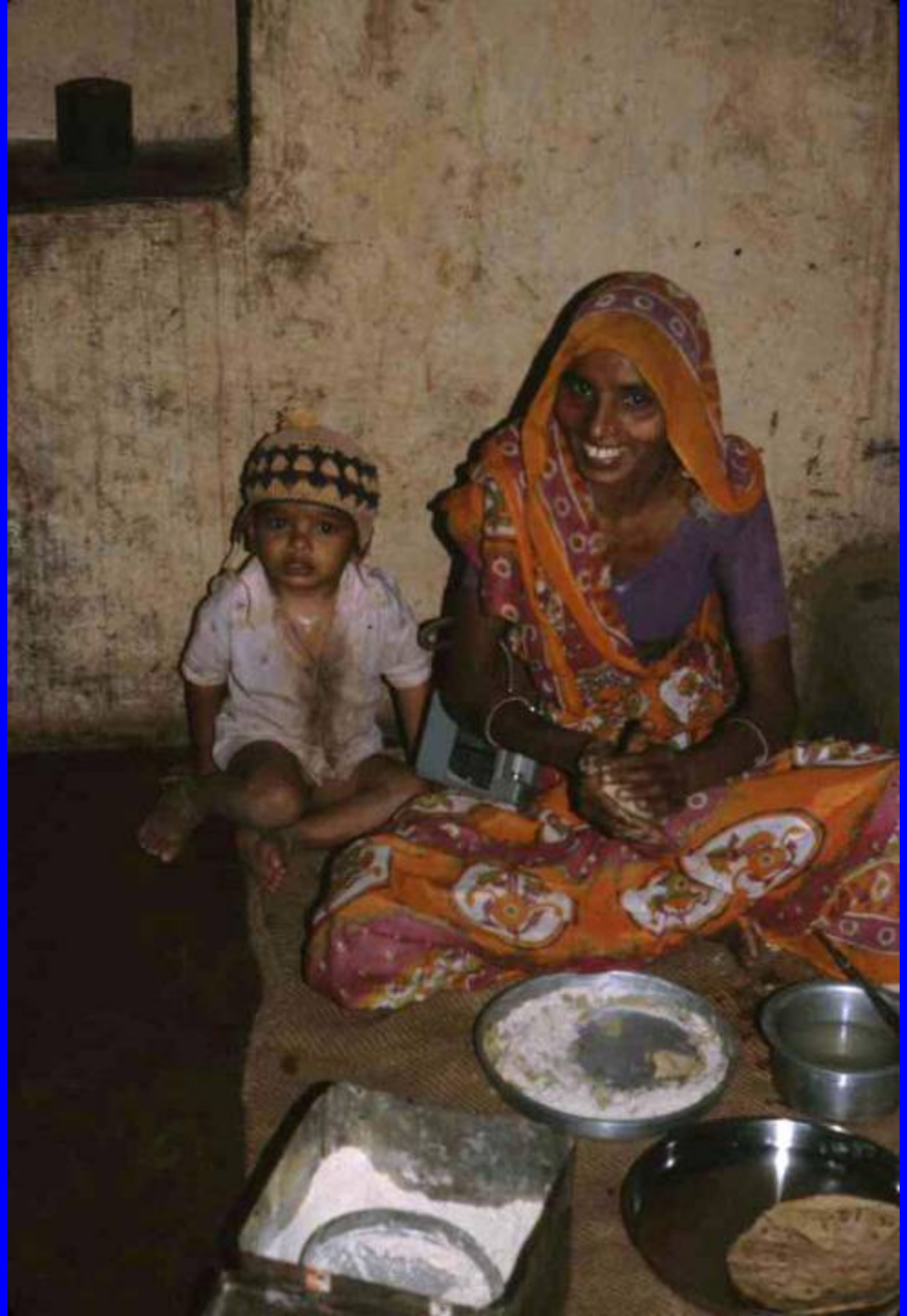
1.0 kg of LPG in this stove would deliver about 23 MJ to the pot ~9x that from a kg of wood

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



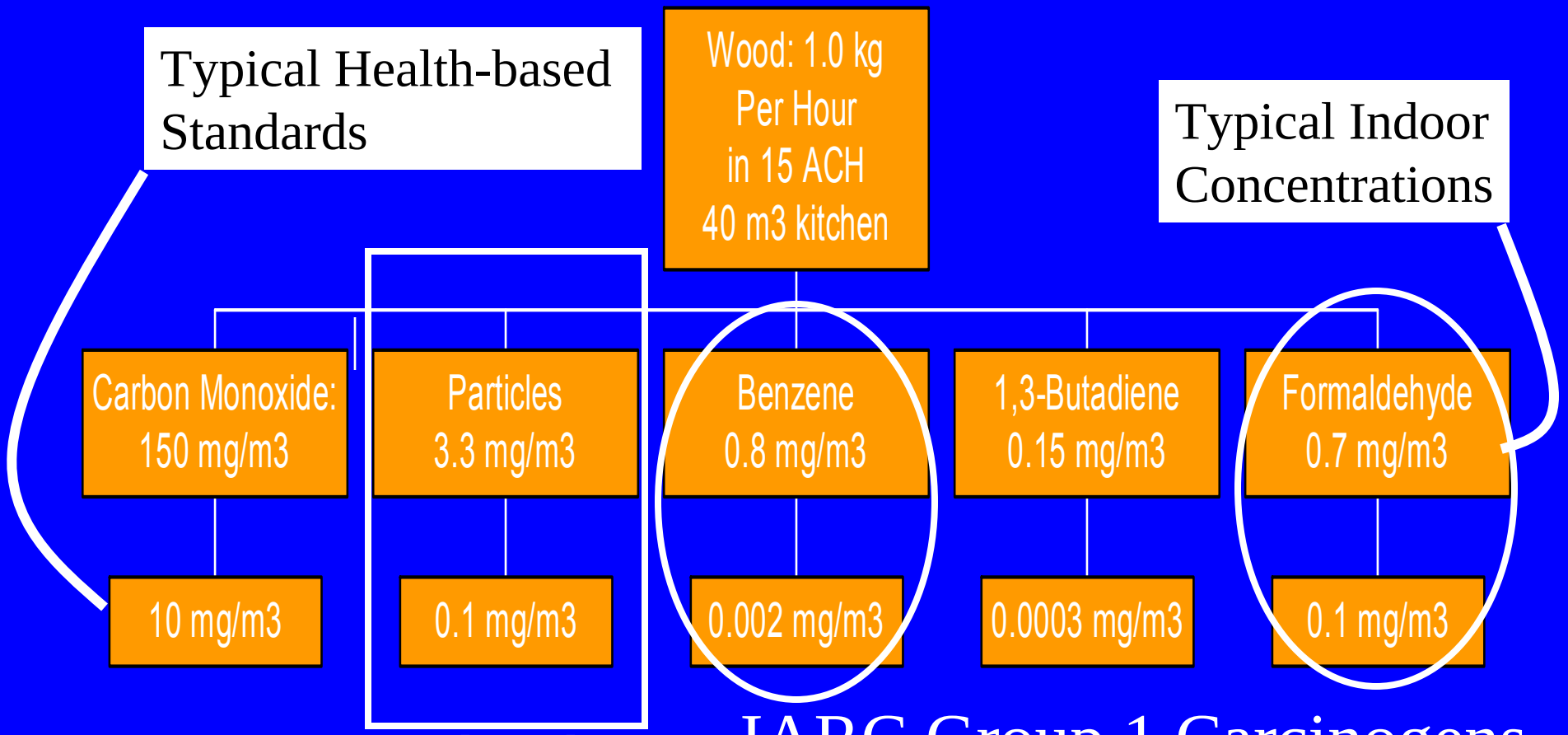
	Biogas	LPG	Kerosene	Wood	Roots	Crop Residues	Dung
CO	0.1	1.0	3	19	22	60	64
Hydrocarbons	0.3	1.0	4.2	17	18	32	115
PM	2.5	1.0	1.3	26	30	124	63

Smith, et al., 2005



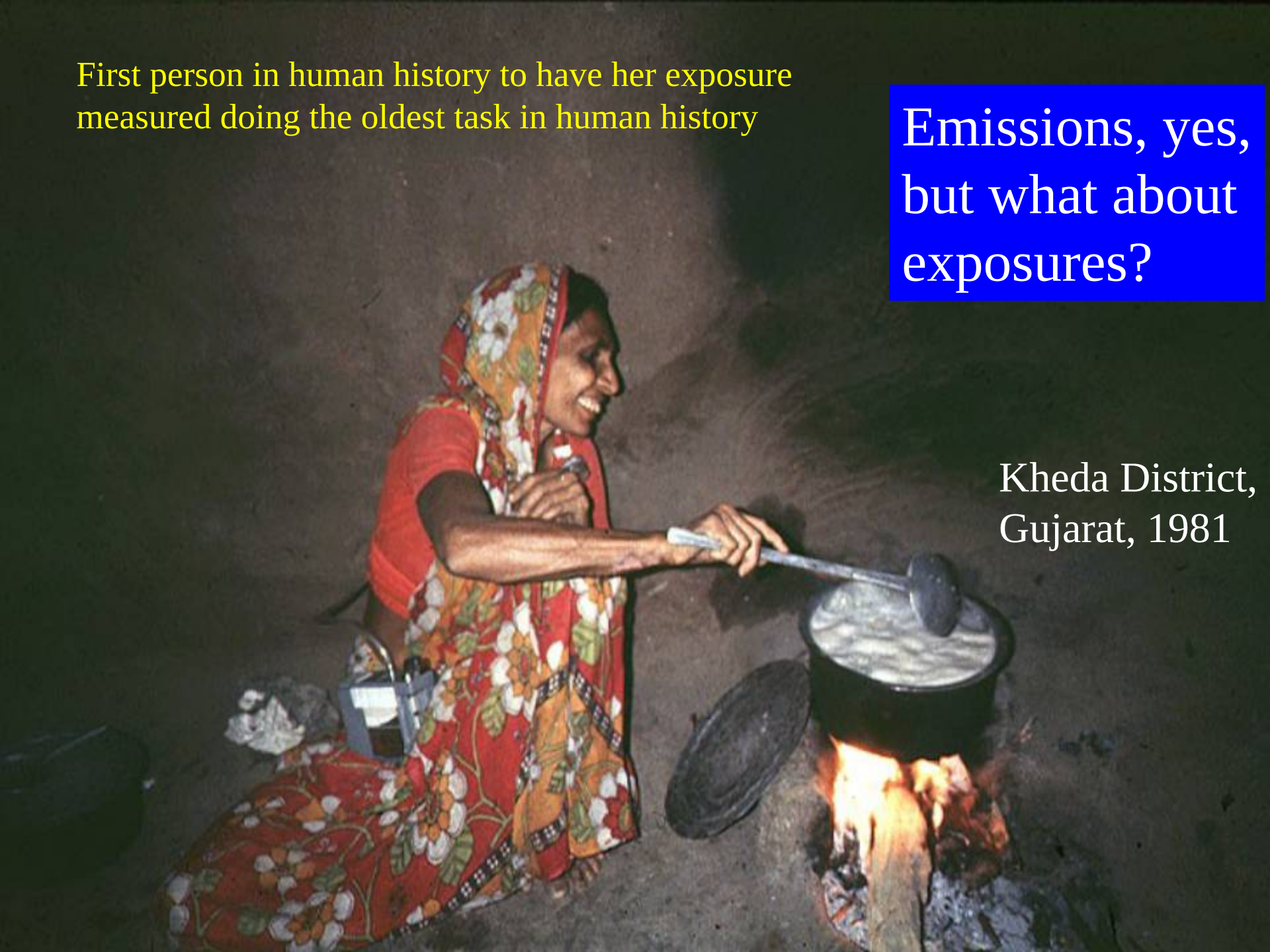
How much Ill-health?

Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.



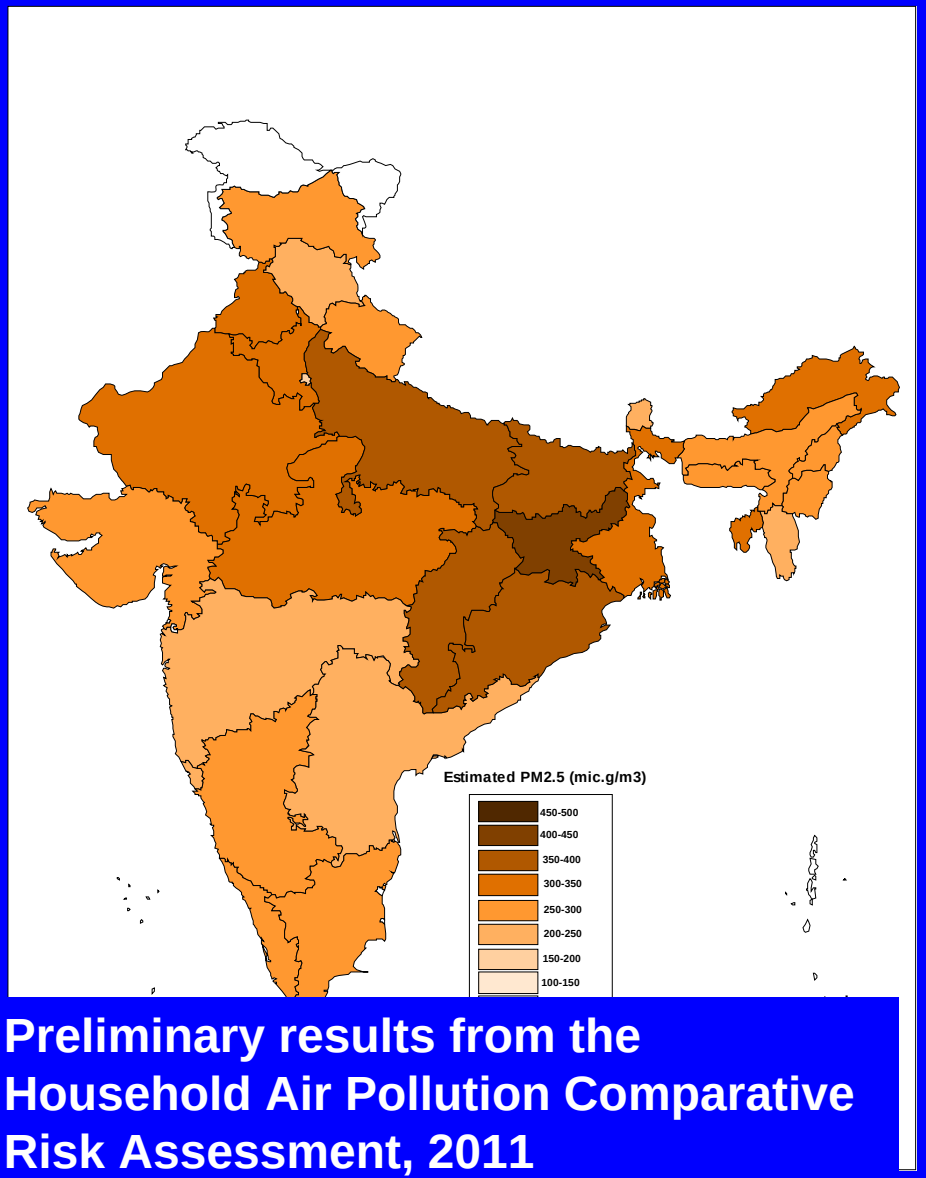
First person in human history to have her exposure measured doing the oldest task in human history

Emissions, yes, but what about exposures?



Kheda District, Gujarat, 1981

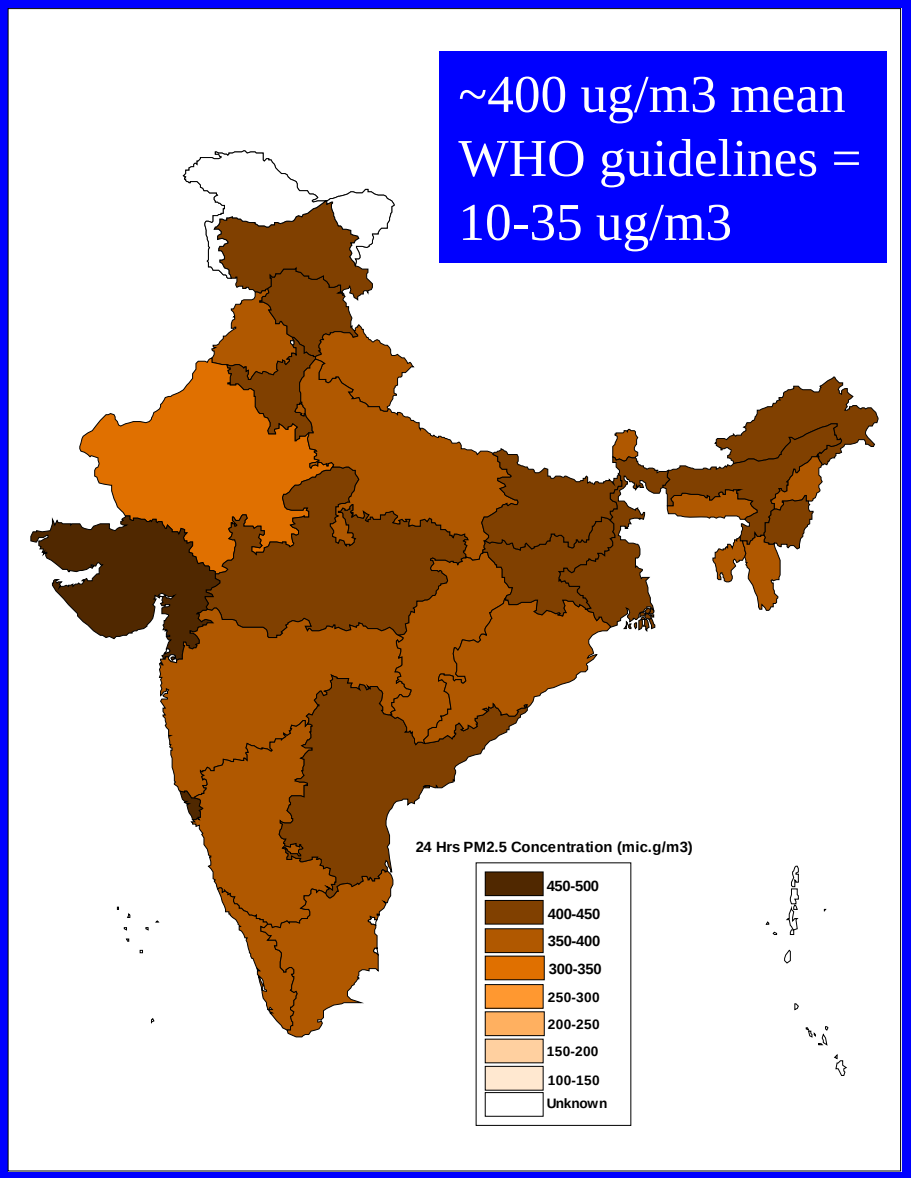
Estimated PM2.5 indoors for all households



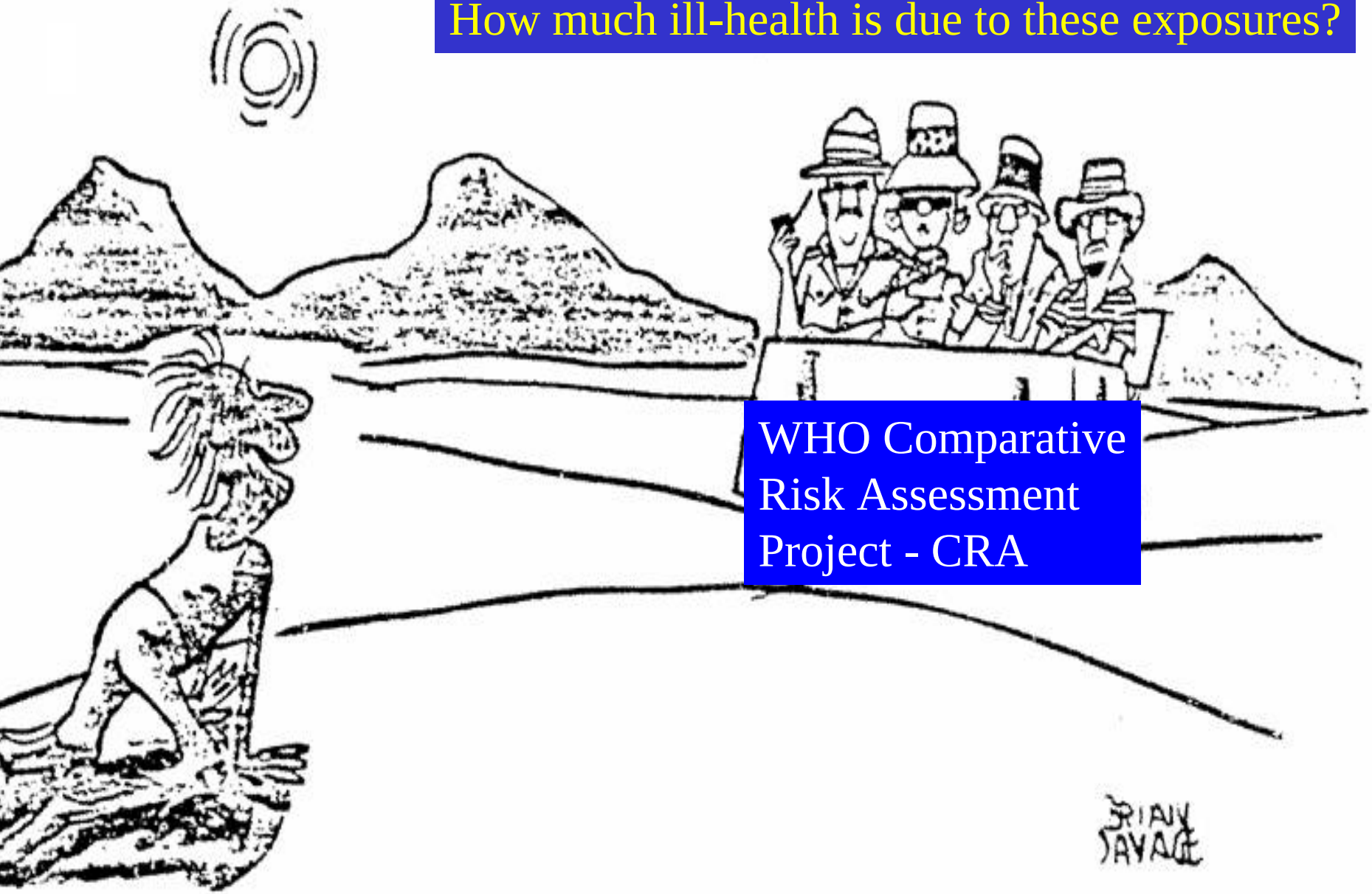
Preliminary results from the Household Air Pollution Comparative Risk Assessment, 2011

Estimated PM2.5 for only solid-fuel-using households

~400 ug/m3 mean
WHO guidelines = 10-35 ug/m3



How much ill-health is due to these exposures?



WHO Comparative Risk Assessment Project - CRA

"Thank God! A panel of experts!"

Courtesy of Ross Anderson

ALRI/
Pneumonia

Diseases for which we have epidemiological studies

COPD

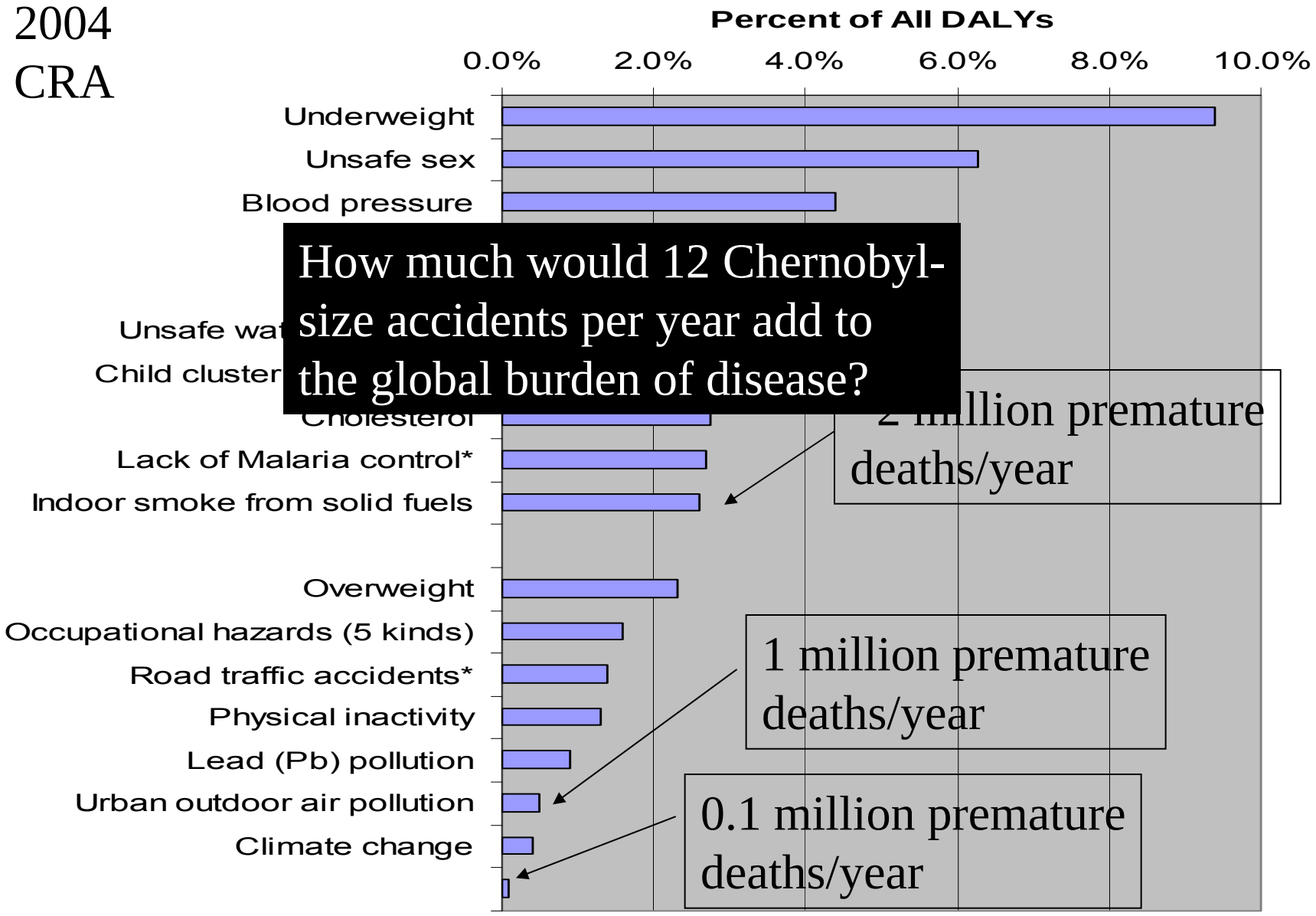
Lung cancer
(coal)

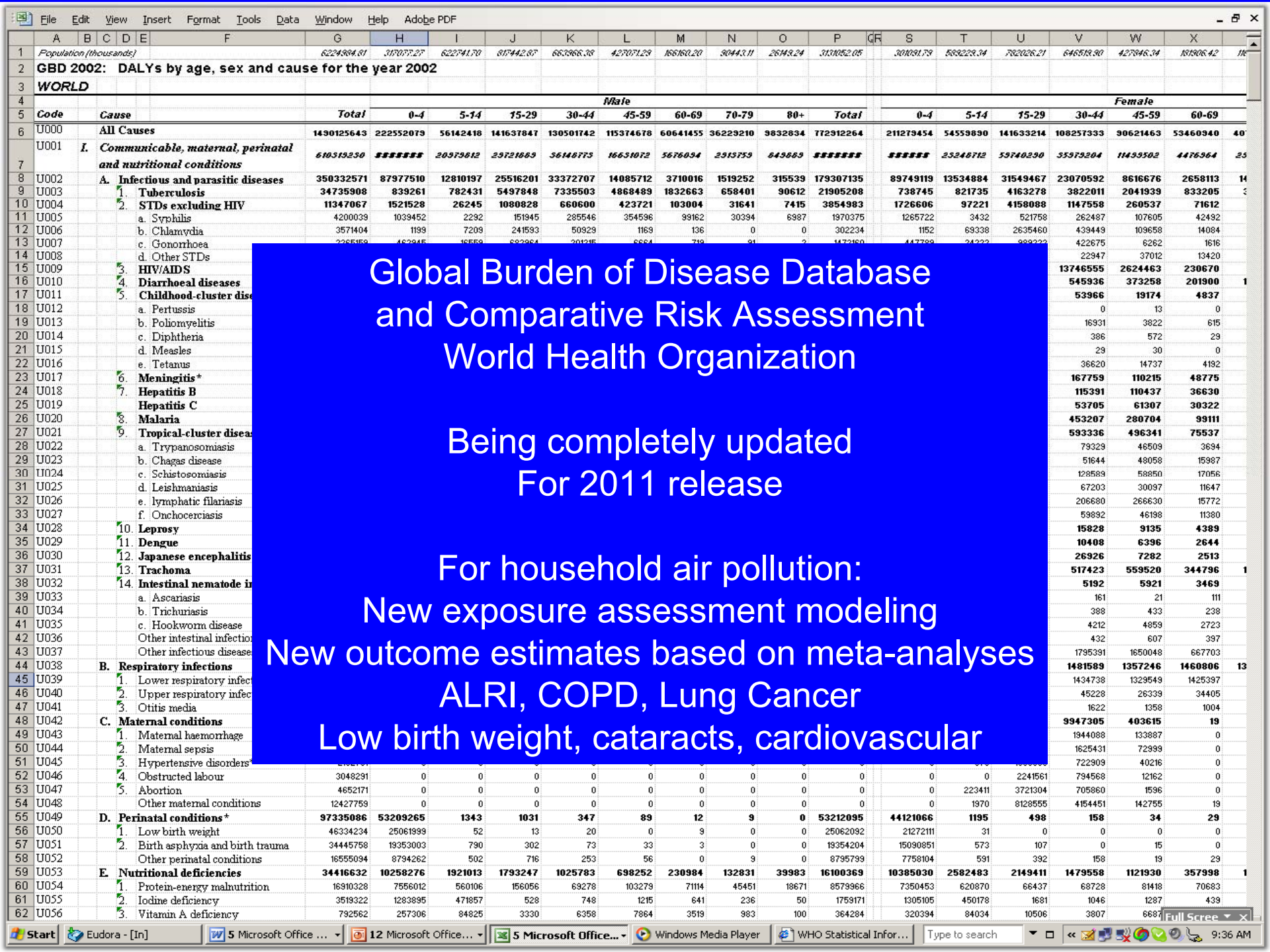
These three diseases were included in the 2004 Comparative Risk Assessment Managed and published by WHO

First ever comprehensive risk assessment with consistent rules of evidence and common databases

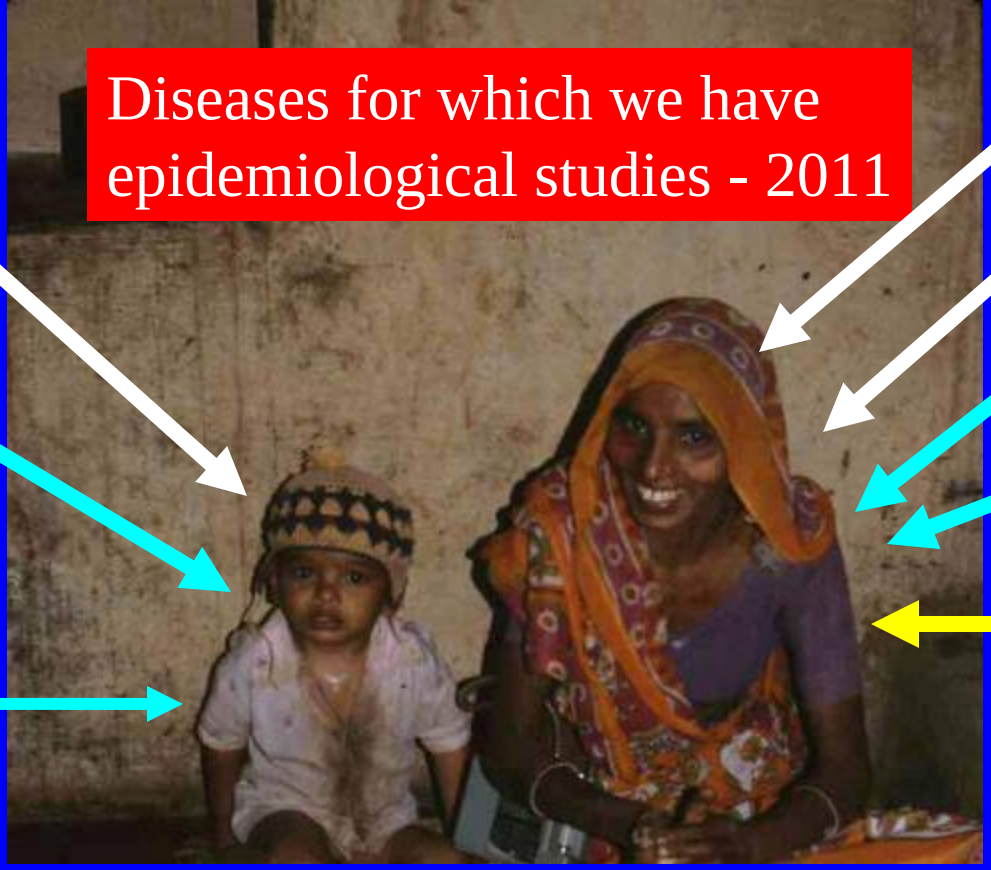
Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors

2004
CRA




Global Burden of Disease Database
and Comparative Risk Assessment
World Health Organization
Being completely updated
For 2011 release
For household air pollution:
New exposure assessment modeling
New outcome estimates based on meta-analyses
ALRI, COPD, Lung Cancer
Low birth weight, cataracts, cardiovascular

Diseases for which we have epidemiological studies - 2011



ALRI/
Pneumonia

Low birth
weight

Stillbirth

COPD

Lung cancer
(coal)

Lung cancer
(biomass)

Blindness
(cataracts, opacity)

CV disease
Blood pressure
ST-segment

These additional diseases will be included in the 2011 Comparative Risk Assessment

In addition, using evidence from other exposure sources, CVD will be included

There is epi evidence for these other diseases, but considered insufficient to include in the 2011 Comparative Risk Assessment

Cognitive Impairment

Birth defects

Asthma?

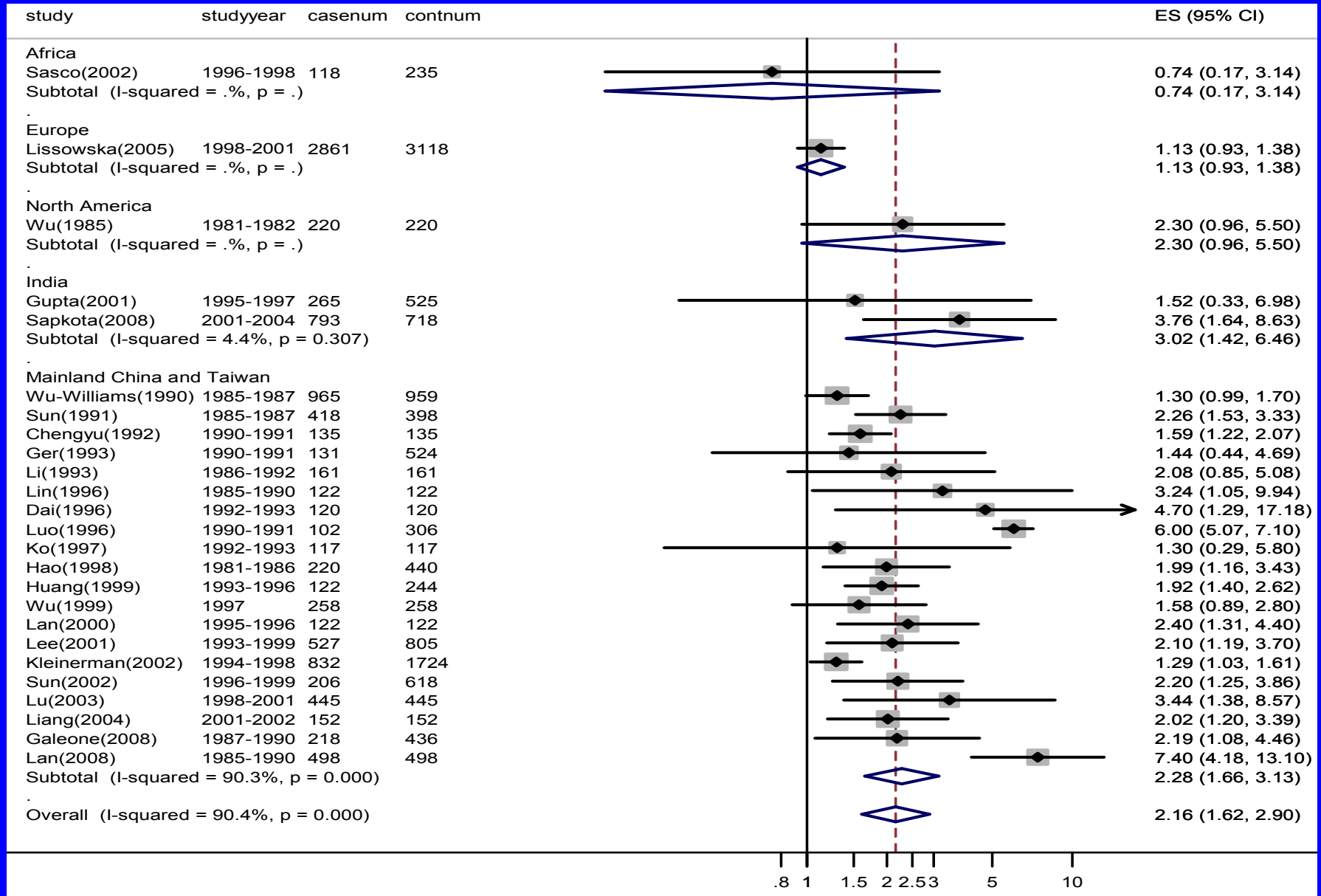
Tuberculosis

ALRI

Other cancers (cervical, NP, upper airway)

Burns and the health/safety impacts of fuel gathering

Summary risk estimates of lung cancer associated with in-home coal use for heating and cooking by geographic region



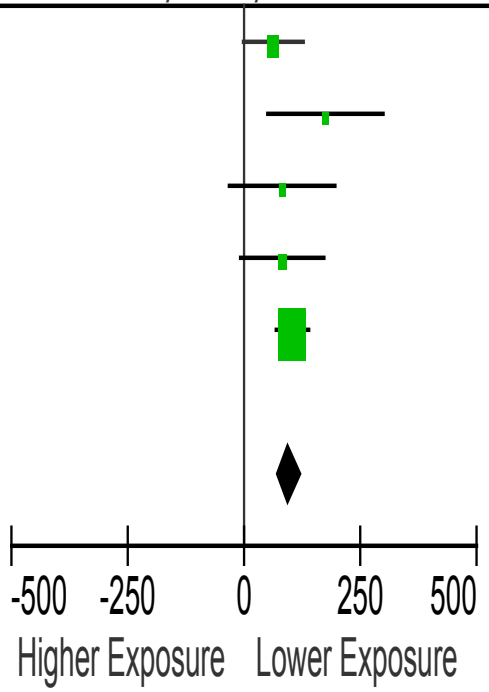
Pooled birth weight difference (low minus high exposure):

Adjusted estimates (Boy and Tielsch have GA)

Study or Subgroup	Lower Exposure Mean	SD	Total	Higher Exposure Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Boy 2002	2,835	533	357	2,772	525	871	18.5%	63.00 [-2.36, 128.36]
Mishra 2004	3,271	1,448	766	3,096	1,429	1535	5.0%	175.00 [50.00, 300.00]
Siddiqui 2008	2,812	404	80	2,730	385	108	6.0%	82.00 [-32.50, 196.50]
Thompson 2005	2,805	579	366	2,723	573	268	9.6%	82.00 [-8.69, 172.69]
Tielsch 2009	2,819	453	646	2,715	420	8958	60.9%	104.00 [68.00, 140.00]
Total (95% CI)			**2215**			**11740**	**100.0%**	**96.58 [68.49, 124.67]**

Heterogeneity: $Chi^2 = 2.85$, $df = 4$ ($P = 0.58$); $I^2 = 0\%$

Test for overall effect: $Z = 6.74$ ($P < 0.00001$)



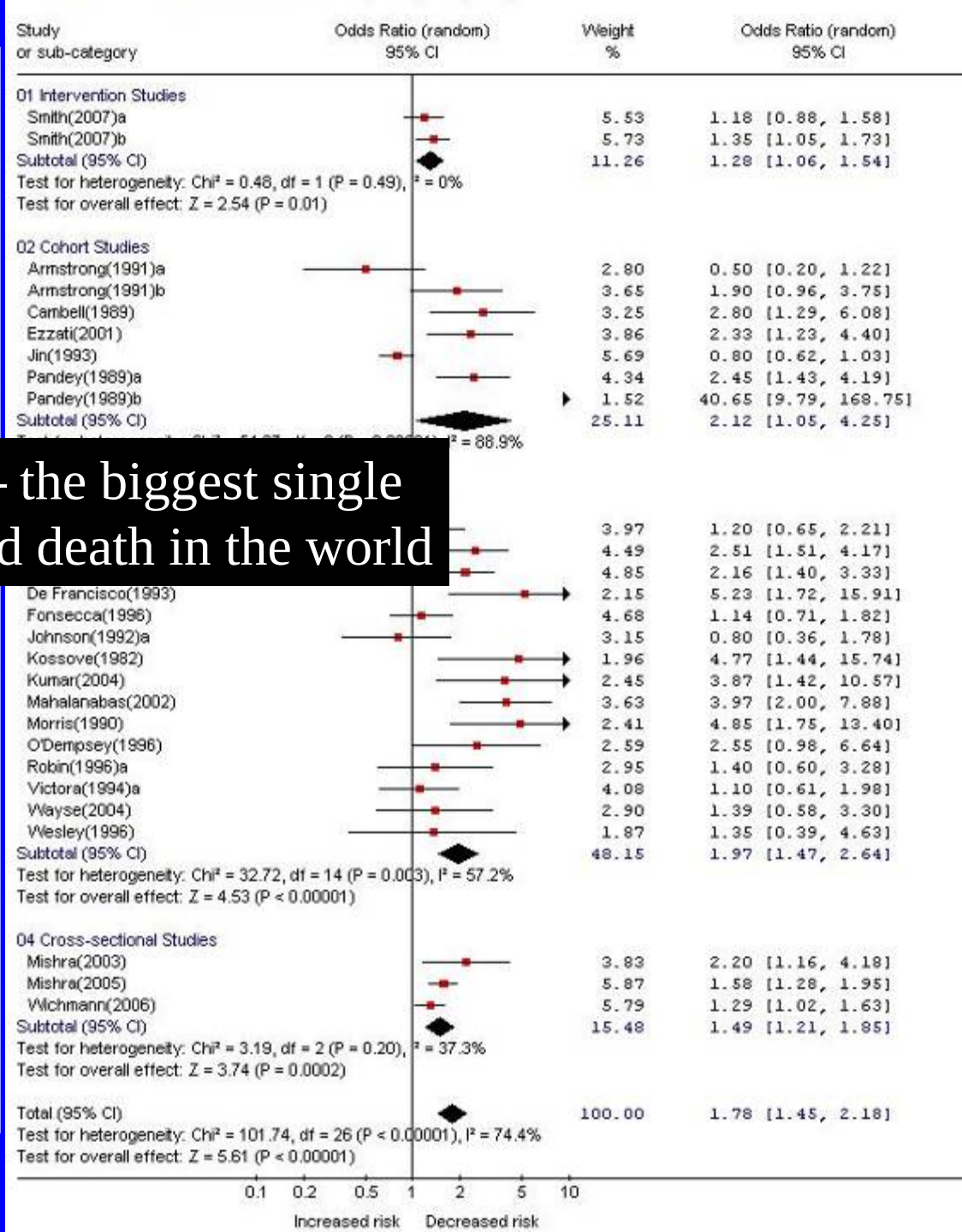
All estimates: +96.6g (68.5, 124.7)

Excluding self-reports +93.1g (64.6, 121.6)

CRA: Pope et al., 2010

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	
Cross-sectional	3	1.49	1.21, 1.85
All	26	1.78	1.45, 2.18

Dherani et al Bull WHO (2008)



Pneumonia – the biggest single cause of child death in the world

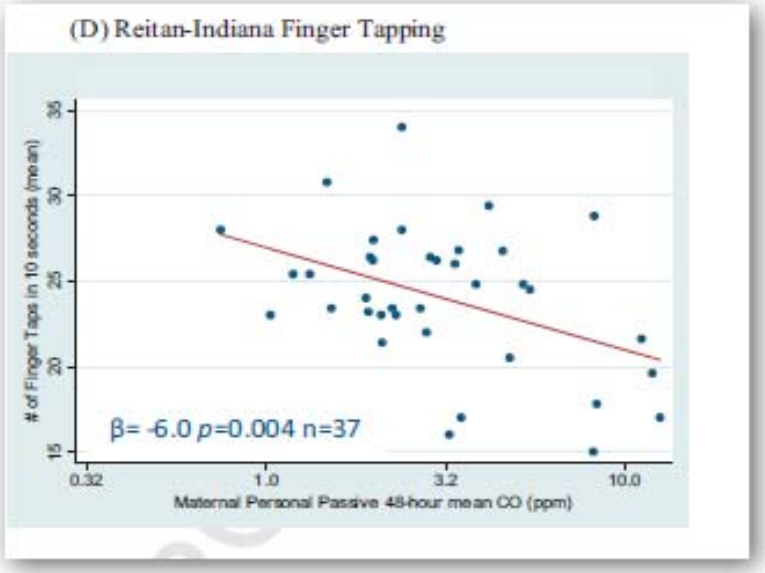
Contents lists available at SciVerse ScienceDirect

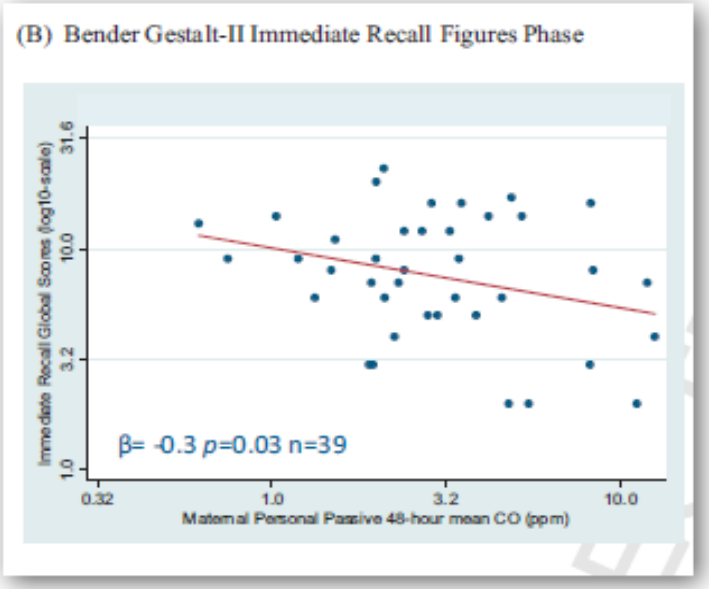
NeuroToxicology

Neurodevelopmental performance among school age children in rural Guatemala is associated with prenatal and postnatal exposure to carbon monoxide, a marker for exposure to woodsmoke

Linda Dix-Cooper[a], Brenda Eskenazi[b], Carolina Romero[c], John Balmes[a,d], Kirk R. Smith[a,*]

[a] Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, CA 94720-7360, USA
[b] Center for Environmental Research and Children's Health (CERCH), School of Public Health, University of California, Berkeley, CA, USA
[c] Centro de Estudios en Salud Universidad Del Valle, Guatemala
[d] Division of Occupational and Environmental Medicine, Department of Medicine, University of California, San Francisco, CA, USA





THELANCET-D-09-06268R3

S0140-6736(11)60921-5

Embargo: [add date when known]

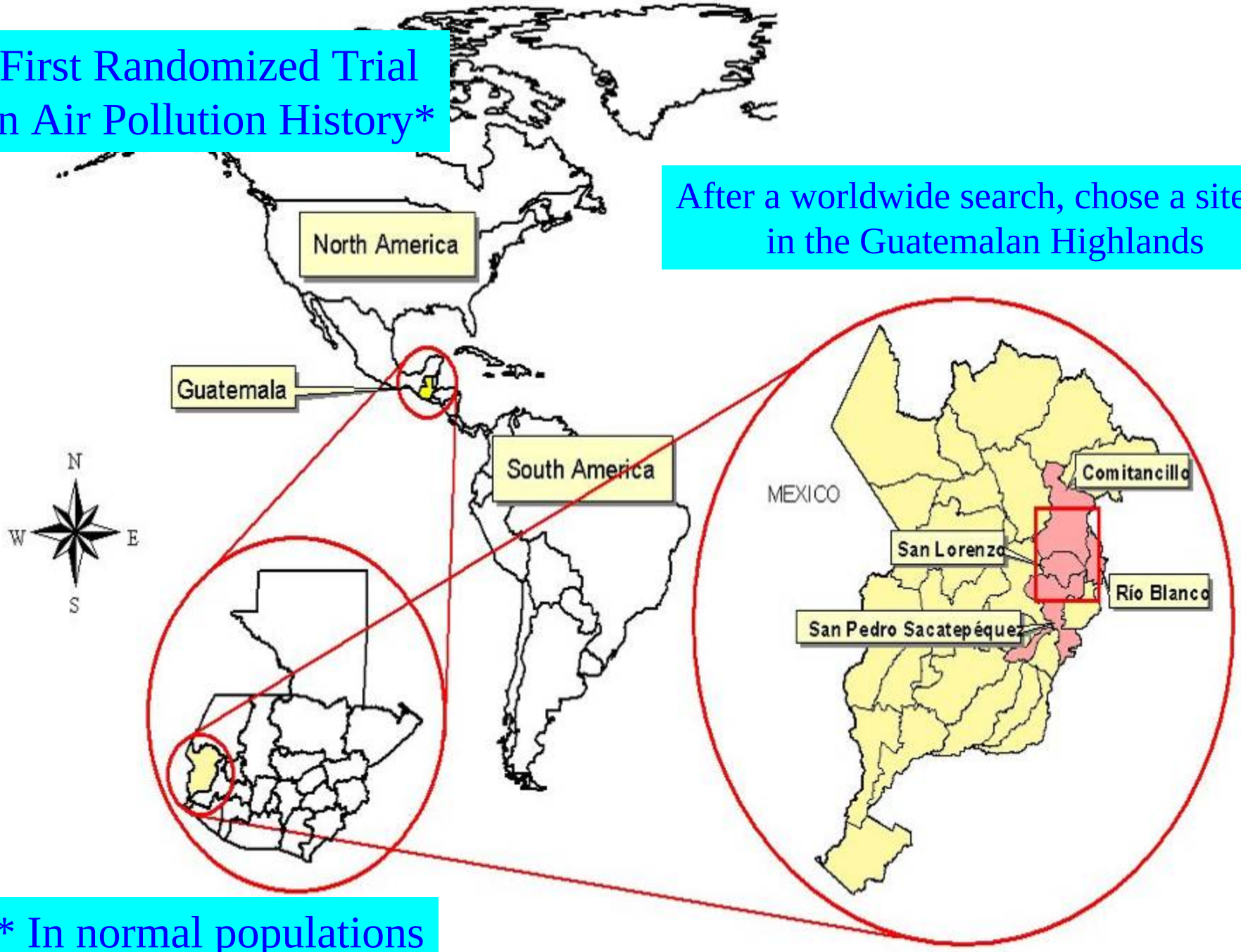
Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial

Kirk R Smith, John P McCracken, Martin W Weber, Alan Hubbard, Alisa Jenny, Lisa M Thompson, John Balmes, Anaite Diaz, Byron Arana, Nigel Bruce

Published Nov 2011

First Randomized Trial In Air Pollution History*

After a worldwide search, chose a site in in the Guatemalan Highlands



* In normal populations

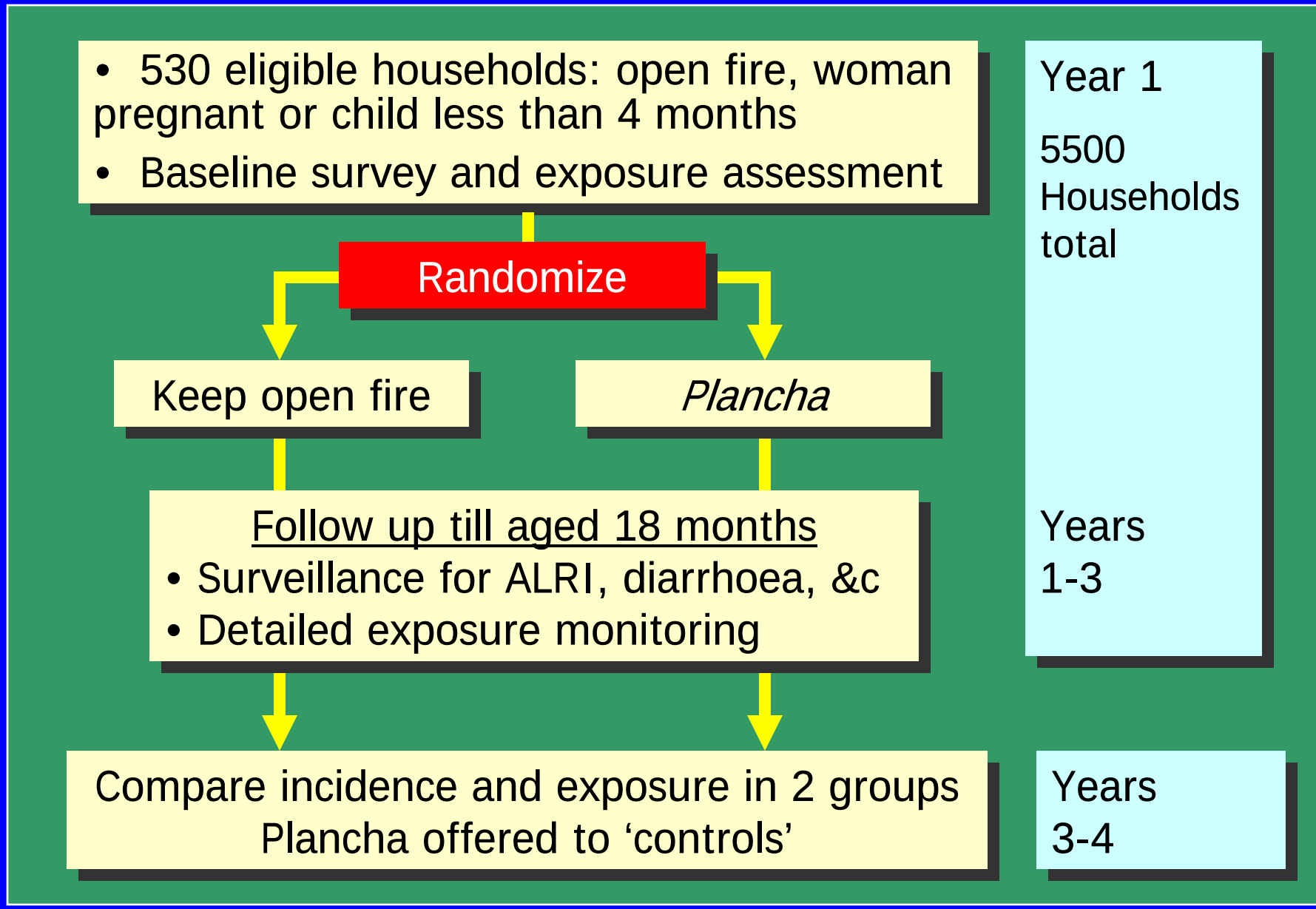
RESPIRE – Randomized trial (n=518)

Impact on pneumonia up to 18 months of age

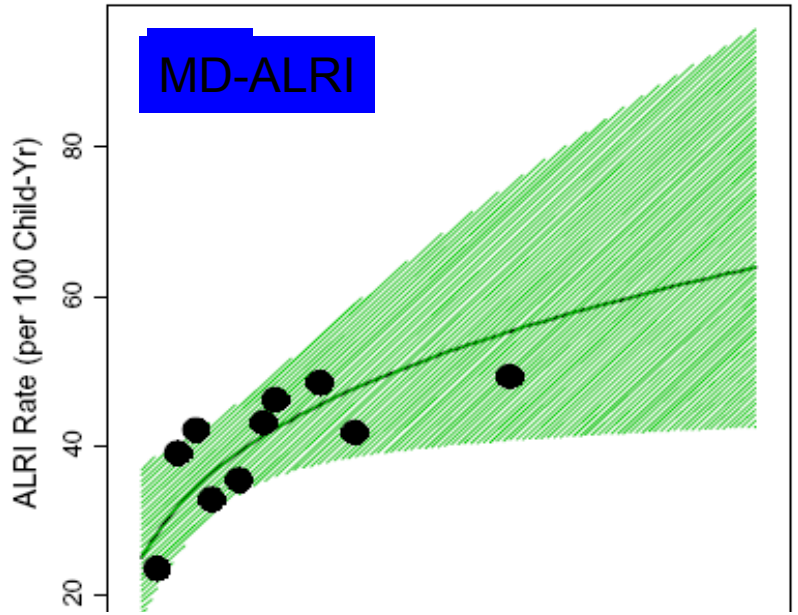
Traditional open 3-stone fire: kitchen 48-hour $PM_{2.5}$ levels of 600 - 1200 $\mu g/m^3$

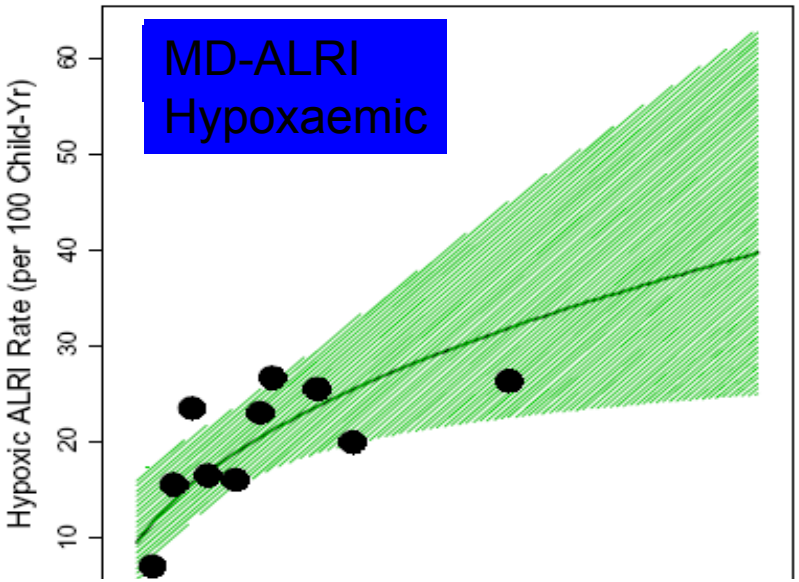
Chimney wood stove, locally made and popular with households

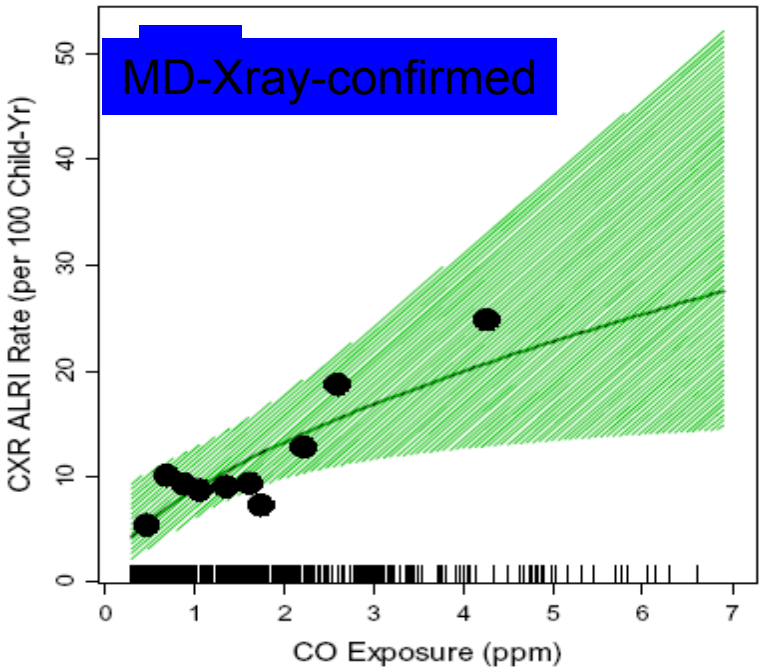
Overview of RESPIRE study design

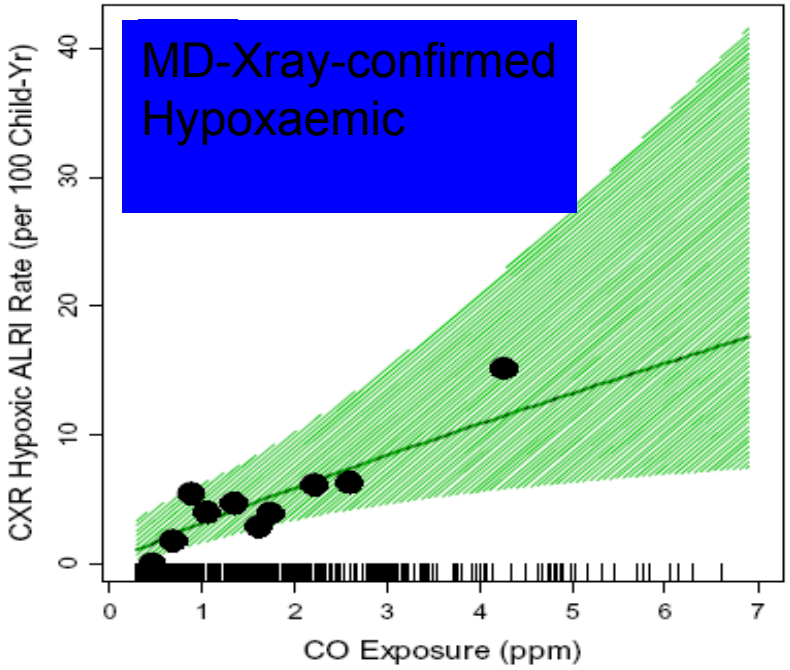



CO monitor
CO monitor


MD-ALRI
ALRI Rate (per 100 Child-Yr)
20
40
60
80


MD-ALRI
Hypoxaemic
Hypoxic ALRI Rate (per 100 Child-Yr)
10
20
30
40
50
60

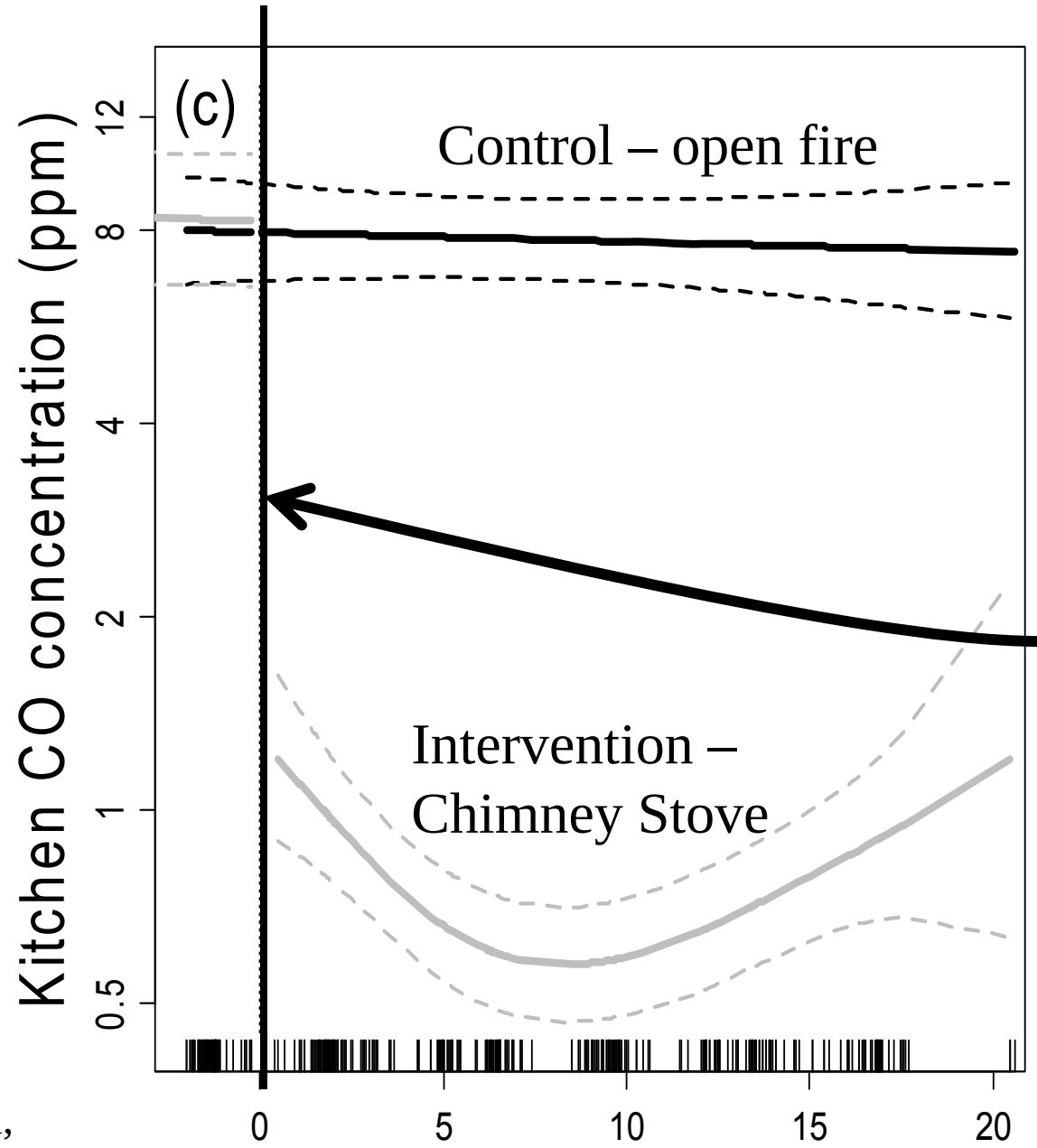

MD-Xray-confirmed
CXR ALRI Rate (per 100 Child-Yr)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
CO Exposure (ppm)


MD-Xray-confirmed
Hypoxaemic
CXR Hypoxic ALRI Rate (per 100 Child-Yr)
0
10
20
30
40
0
1
2
3
4
5
6
7
CO Exposure (ppm)

RESPIRE: Pneumonia Reductions with Exposure Reduction Preliminary Results

Exposure reduction	Overall MD-pneumonia	Severe (hypoxic) MD-pneumonia	CXR pneumonia	Severe (hypoxic) CXR pneumonia
25%	0.92 (0.86, 0.99)	0.88 (0.80, 0.97)	0.84 (0.74, 0.96)	0.79 (0.69, 0.95)
50%	0.82 (0.70, 0.98)	0.73 (0.59, 0.92)	0.66 (0.49, 0.91)	0.56 (0.40, 0.88)
75%	0.67 (0.50, 0.96)	0.53 (0.35, 0.84)	0.44 (0.24, 0.83)	0.31 (0.16, 0.78)
90%	0.51 (0.31, 0.93)	0.35 (0.17, 0.76)	0.26 (0.09, 0.74)	0.15 (0.05, 0.67)

Guatemala RCT: Kitchen Concentrations



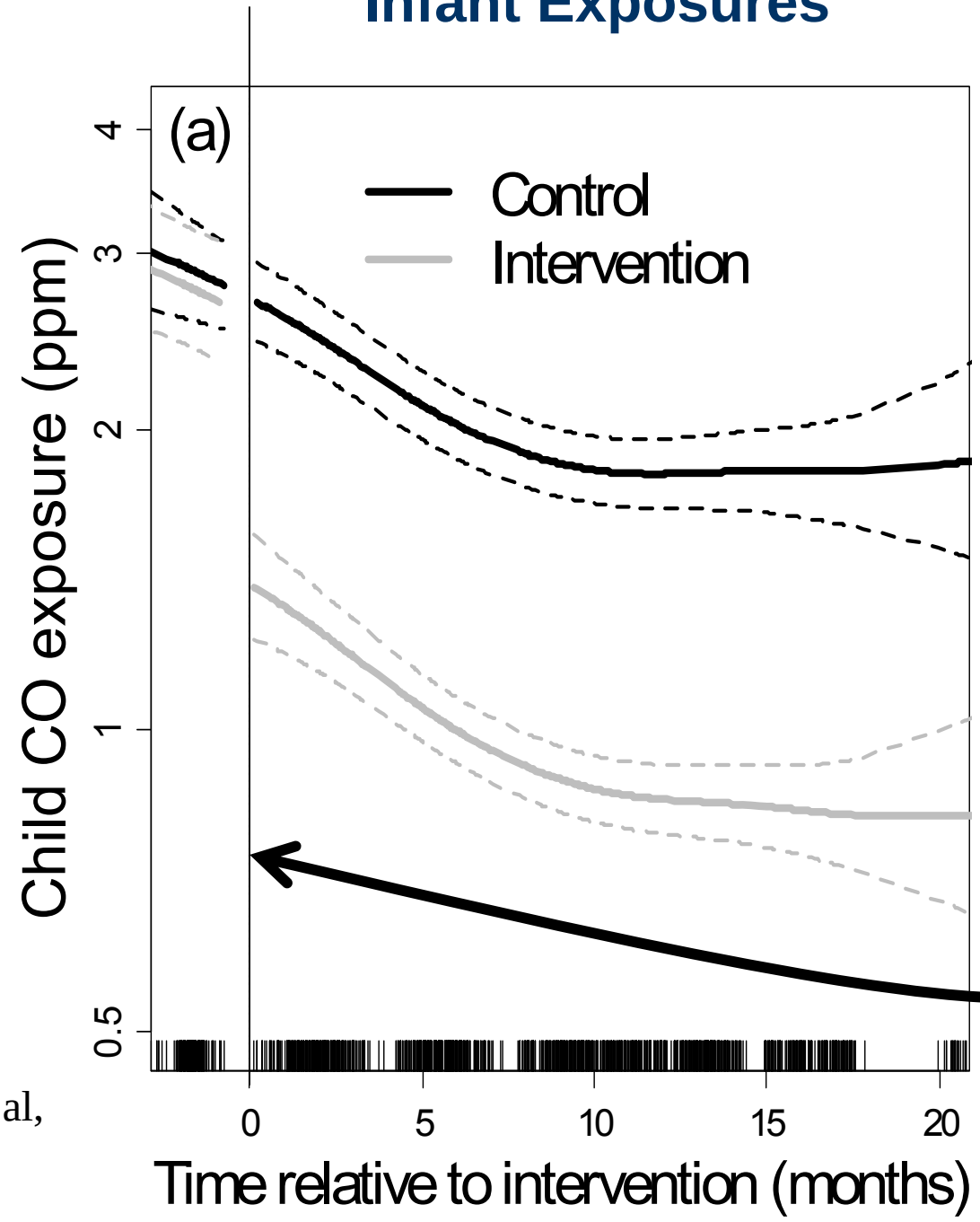
Effect of Chimney Stove On Kitchen CO Levels

Factor of ~10 less

285 48-h measurements

Smith, et al, 2010

Infant Exposures



1888 48-h measurements

Effect of Chimney Stove On Infant Exposures - 2x less

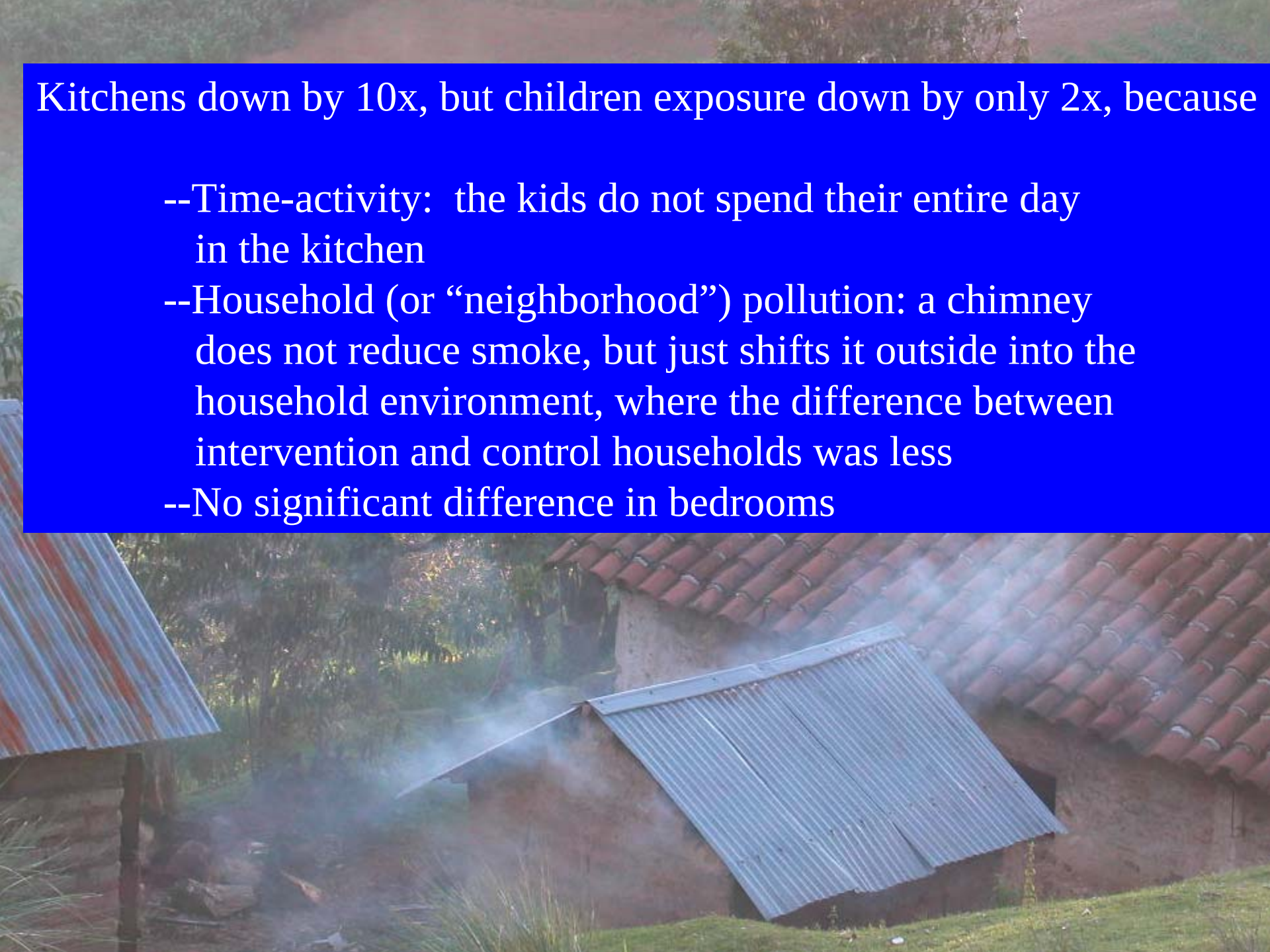
Smith, et al, 2010

Kitchens down by 10x, but children exposure down by only 2x, because

--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

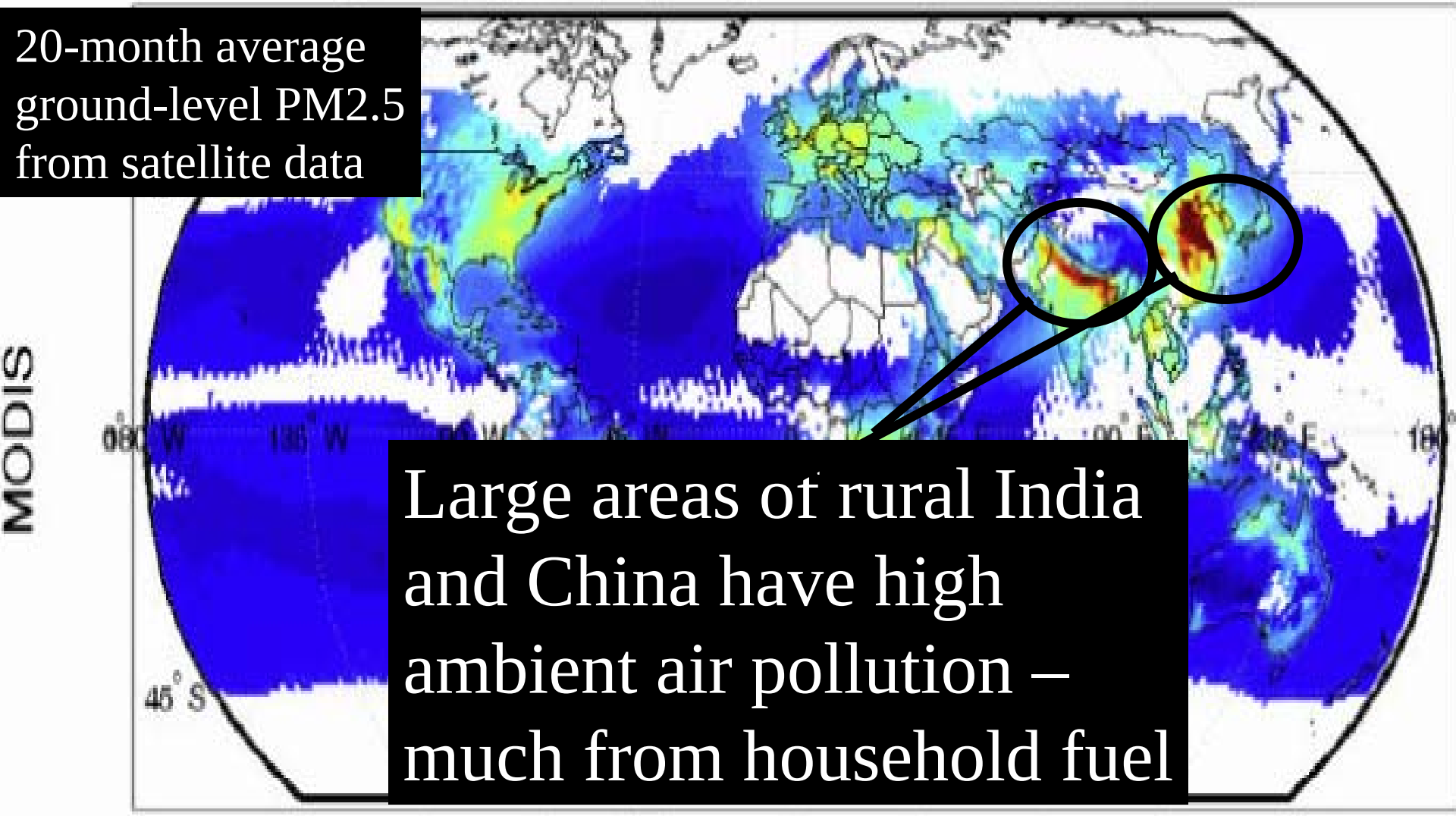
--No significant difference in bedrooms



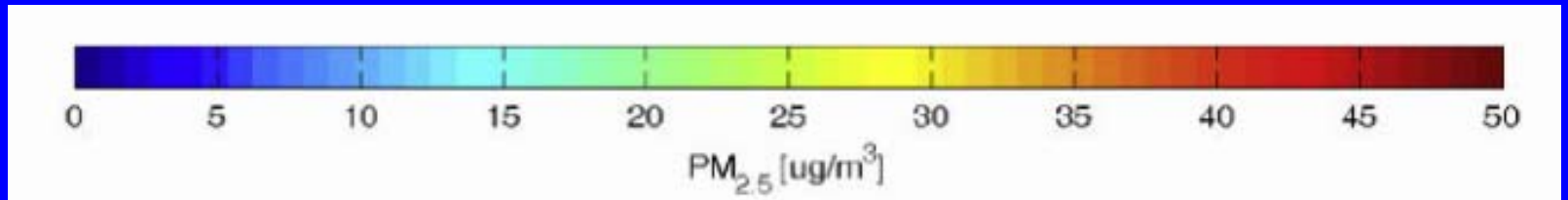
You have heard of secondhand smoke – from tobacco burning

But there is another kind – from cookfires

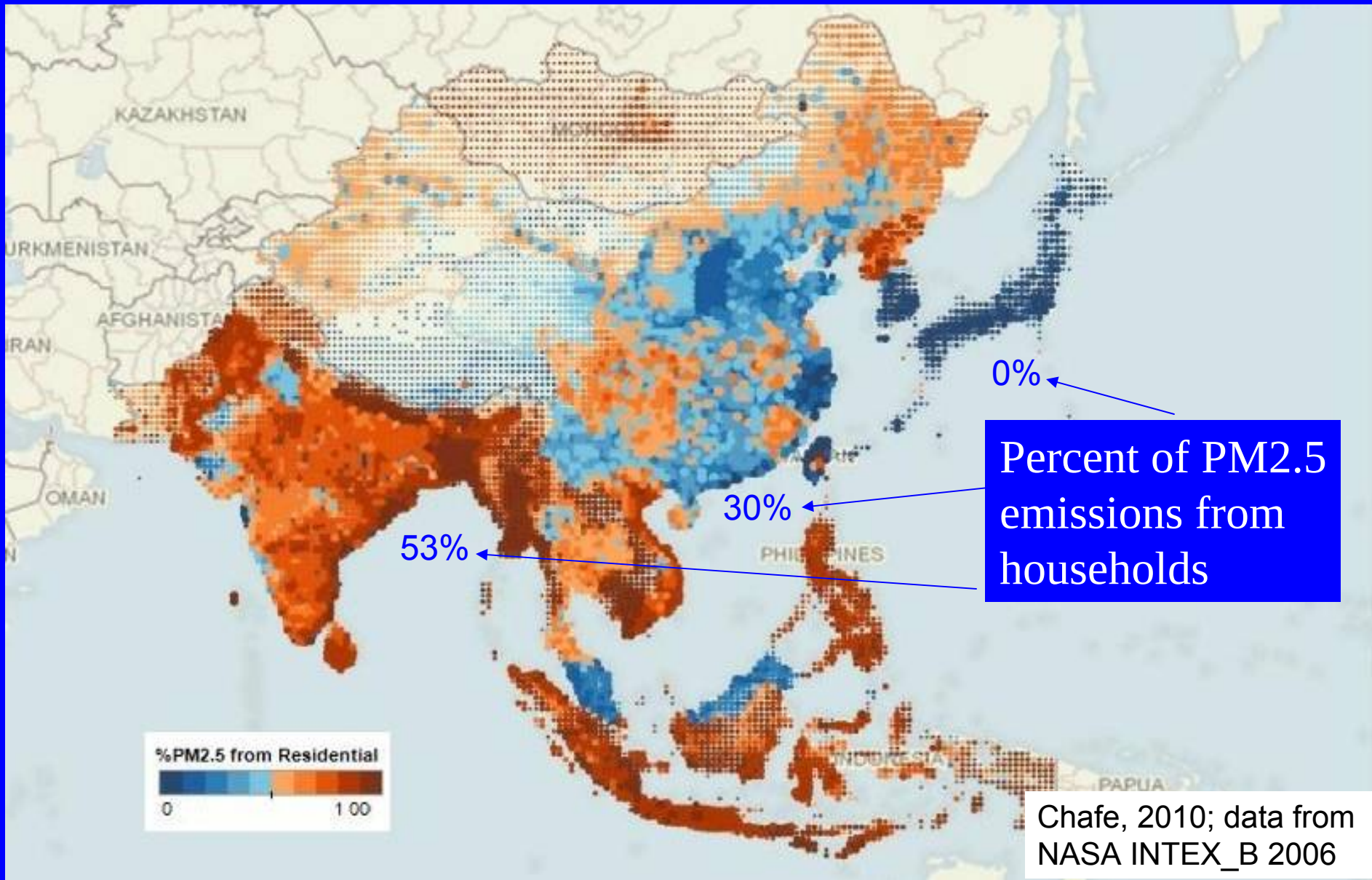
20-month average ground-level PM2.5 from satellite data



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

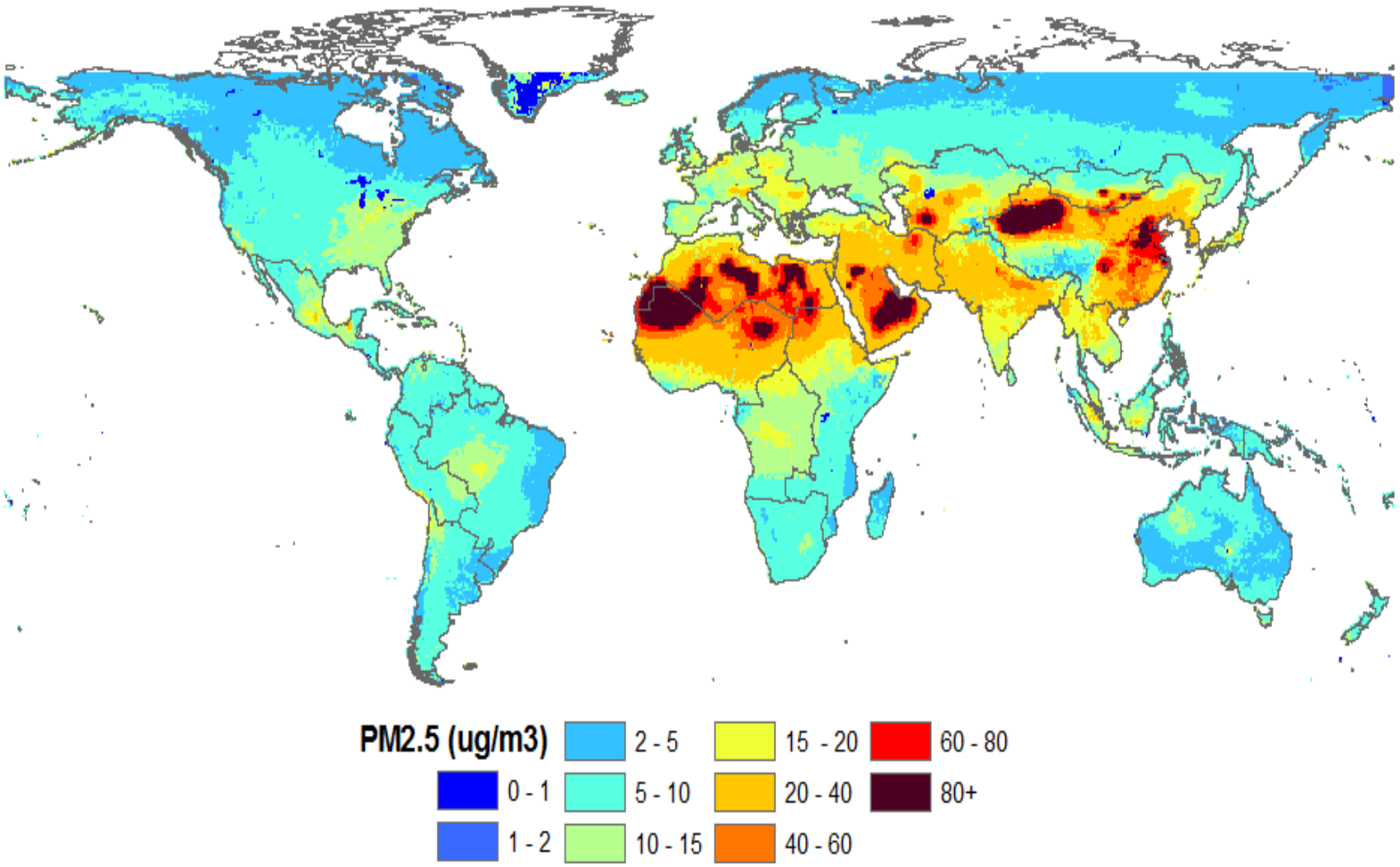


NASA INTEX_B Database
Percent $PM_{2.5}$ emissions from households



Chafe, 2010; data from NASA INTEX_B 2006

Mean $PM_{2.5}$ in 2005

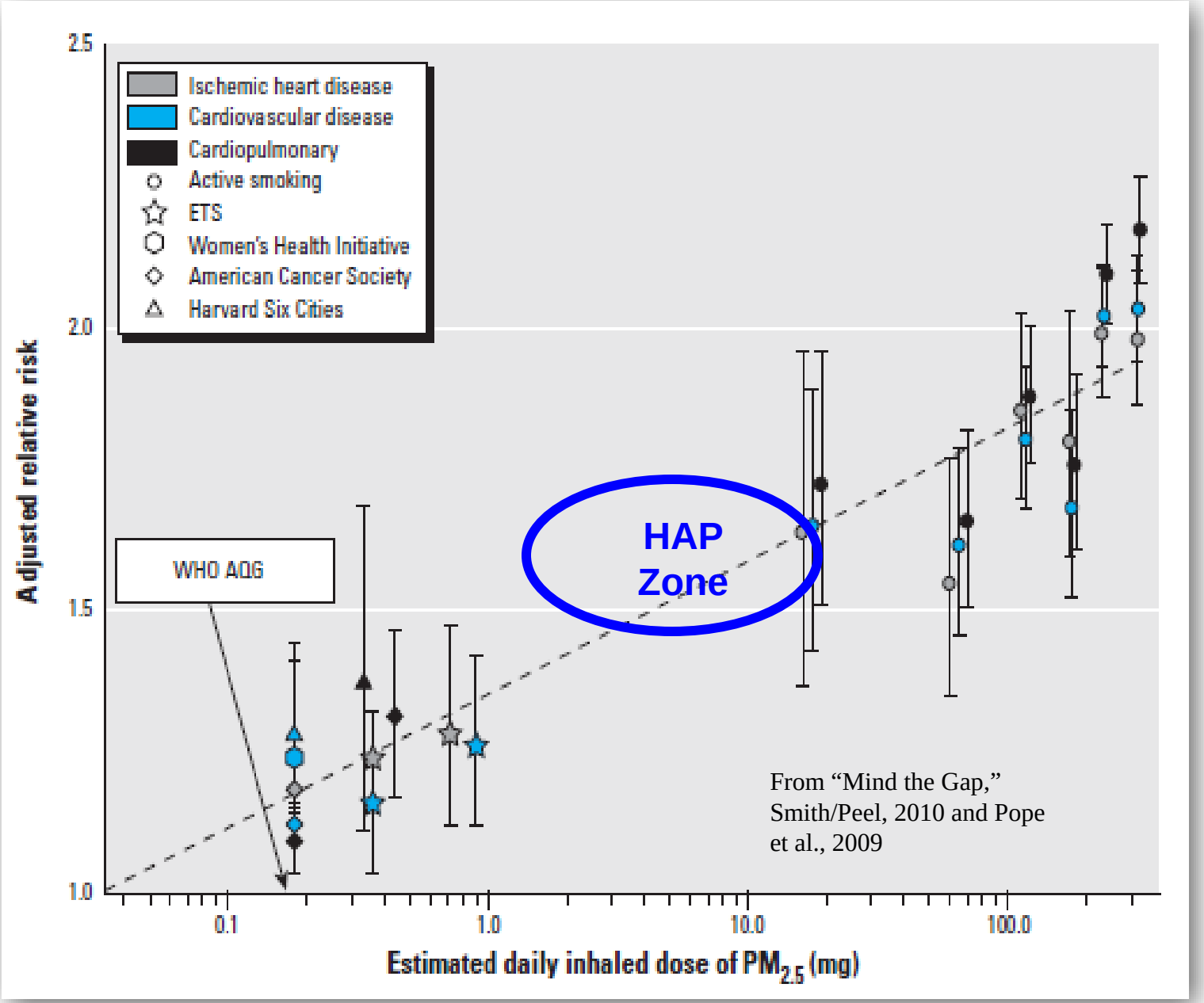


Brauer et al. EST 2011

Combustion Particles

The Generalized Exposure Response (GER)

Heart Disease and Combustion Particle Doses



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

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.

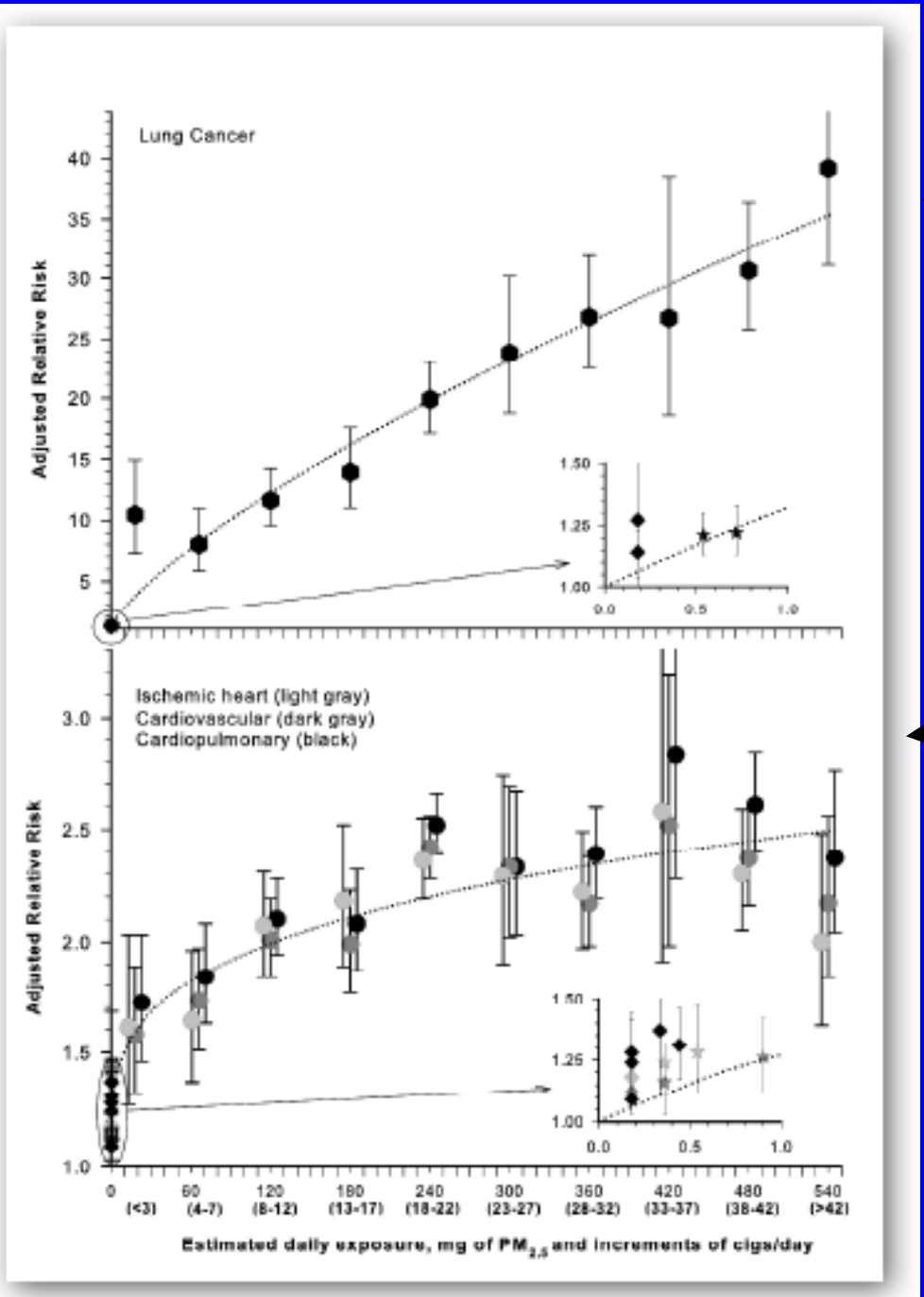
	Crude		Adjusted	
Comparison	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value
Between-groups	0.34 (0.15, 0.81)	0.015	0.26 (0.08, 0.90)[a]	0.033
Before-and-after (only control group)	0.41 (0.24, 0.70)	0.001	0.28 (0.12, 0.63)[b]	0.002

[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)				Estimated Daily Dose $PM_{2.5}$ (mg)[b]
		Lung Cancer	IHD	CVD	CPD	
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

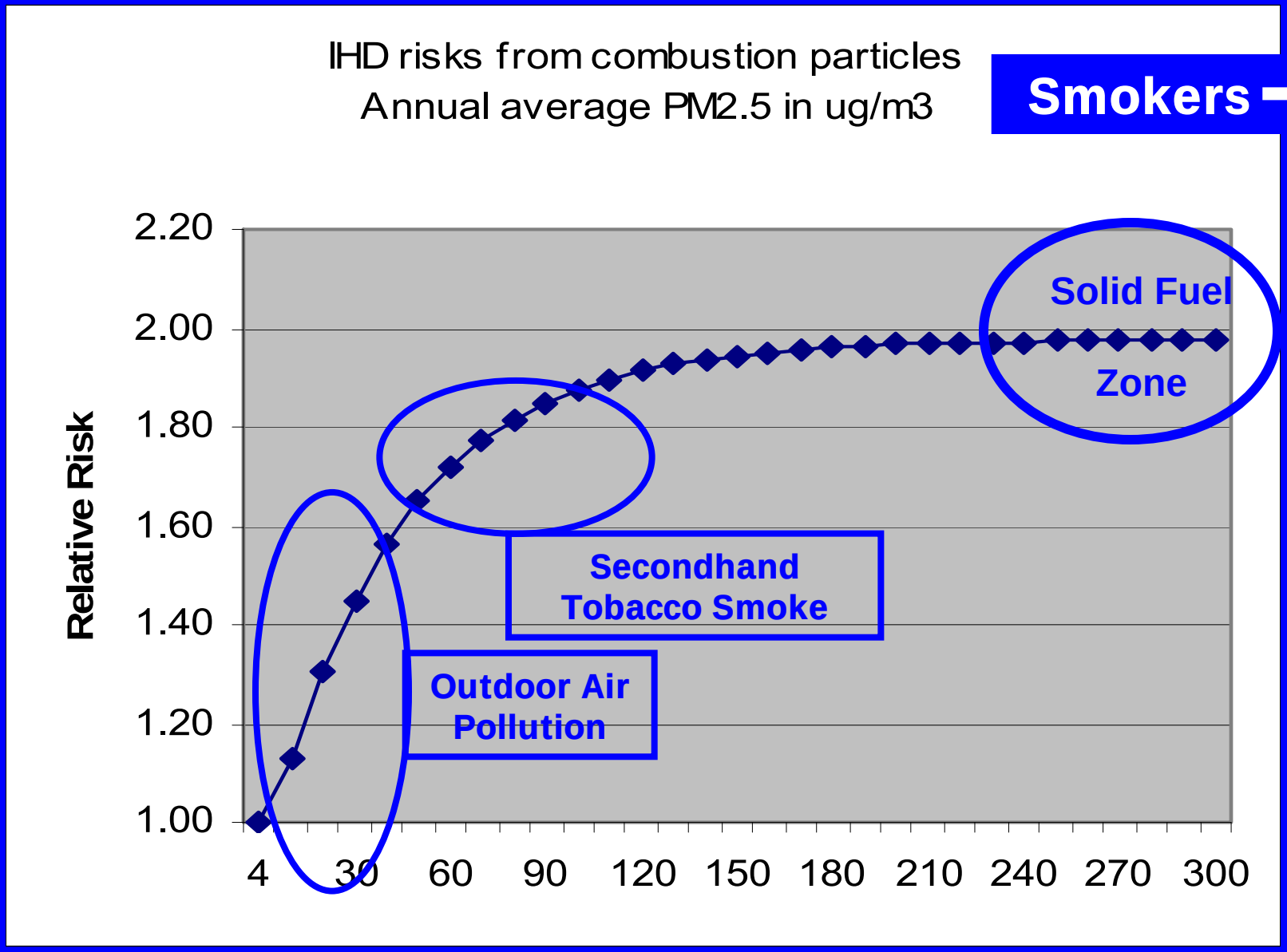


Lung Cancer

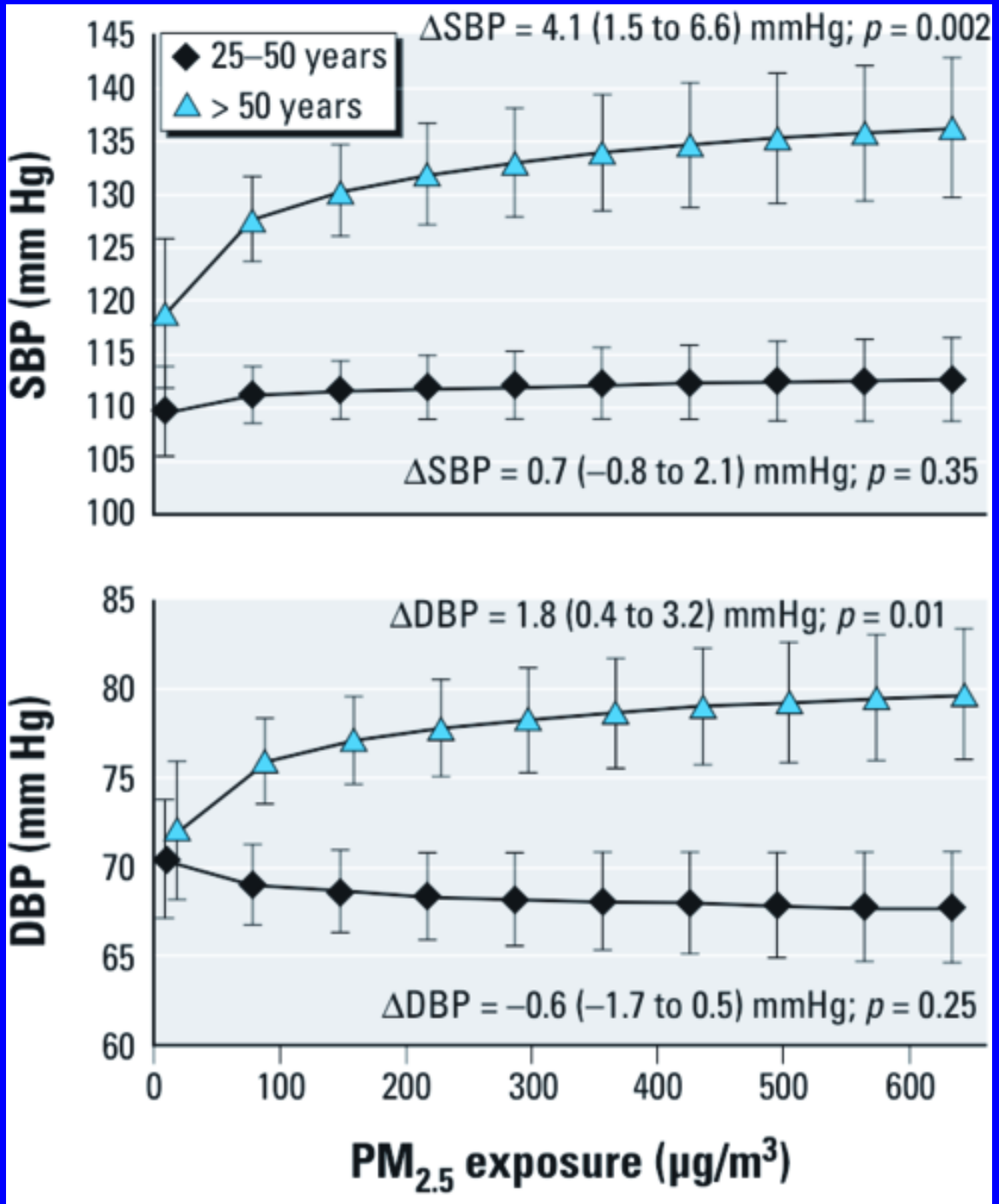
Heart Disease

Pope et al. Environmental Health Perspectives 2011, in press

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



CRA, 2011

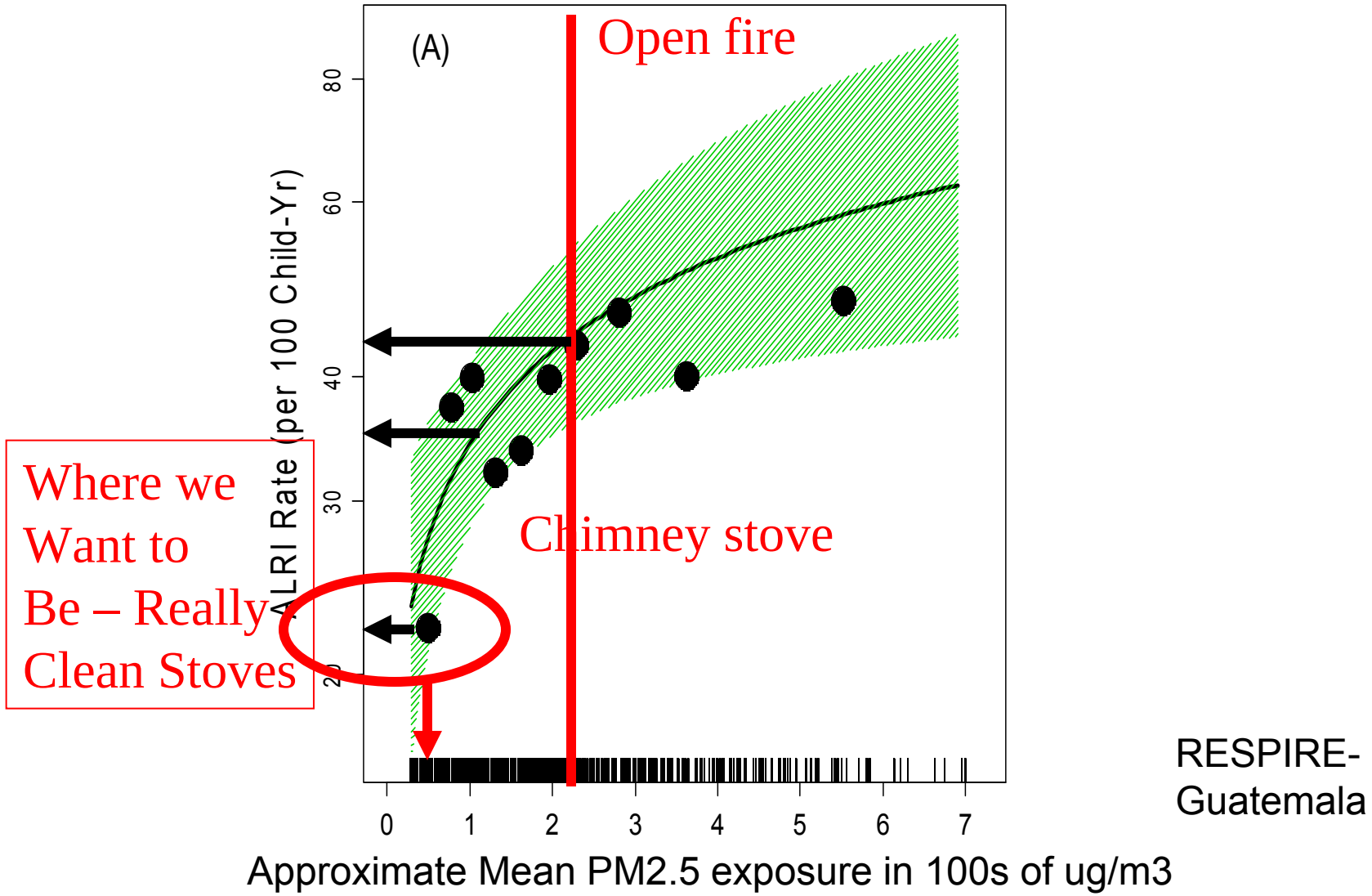


Household Air Pollution and Blood Pressure

In Yunnan

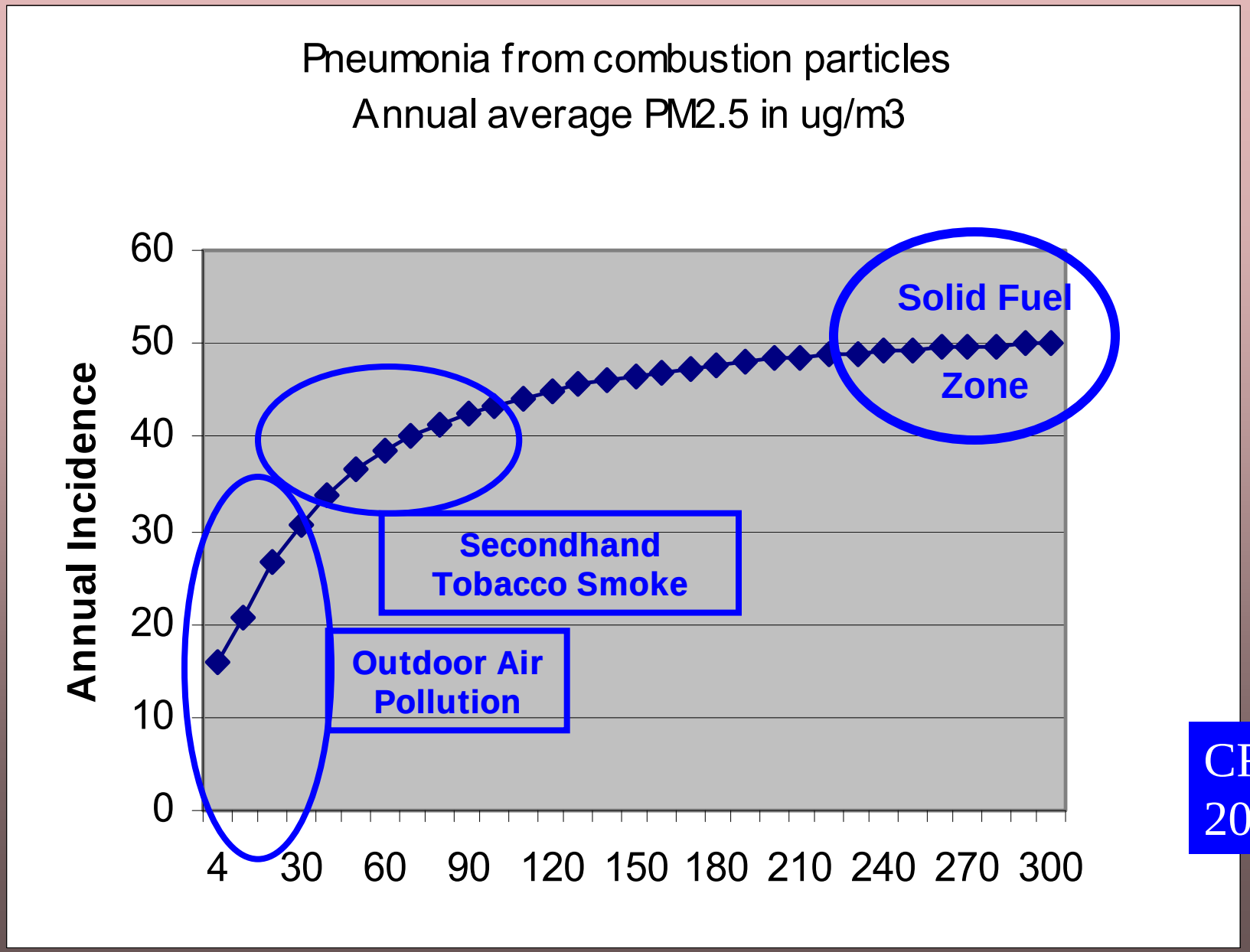
Baumgartner et al. Environmental Health Perspectives 2011, Oct

MD-diagnosed Acute Lower Respiratory Infection



RESPIRE-
Guatemala

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



CRA, 2011

Summary

- Worst thing to do is stick burning stuff in your mouth – 5+ million premature deaths
- Next worse is burning in your house – 2 million deaths
- Next worse is having someone else nearby sticking in their mouth – 400k deaths
- Even bad to have on your planet – 2+ million deaths
- Chimneys do not help – need to stop producing the pollution at all.

Wood

- “The fuel the heats you twice” - Thoreau
  - Once when you chop it
  - Once again when you burn it
- But actually through the smoke it heats you four times
  - Also the fever from the pneumonia
  - And the global warming it generates
- Get rid of incomplete combustion, however, and you eliminate the second two

Laws of Carbon-thermodynamics

I. Keep all fossil and forest carbon out of the atmosphere

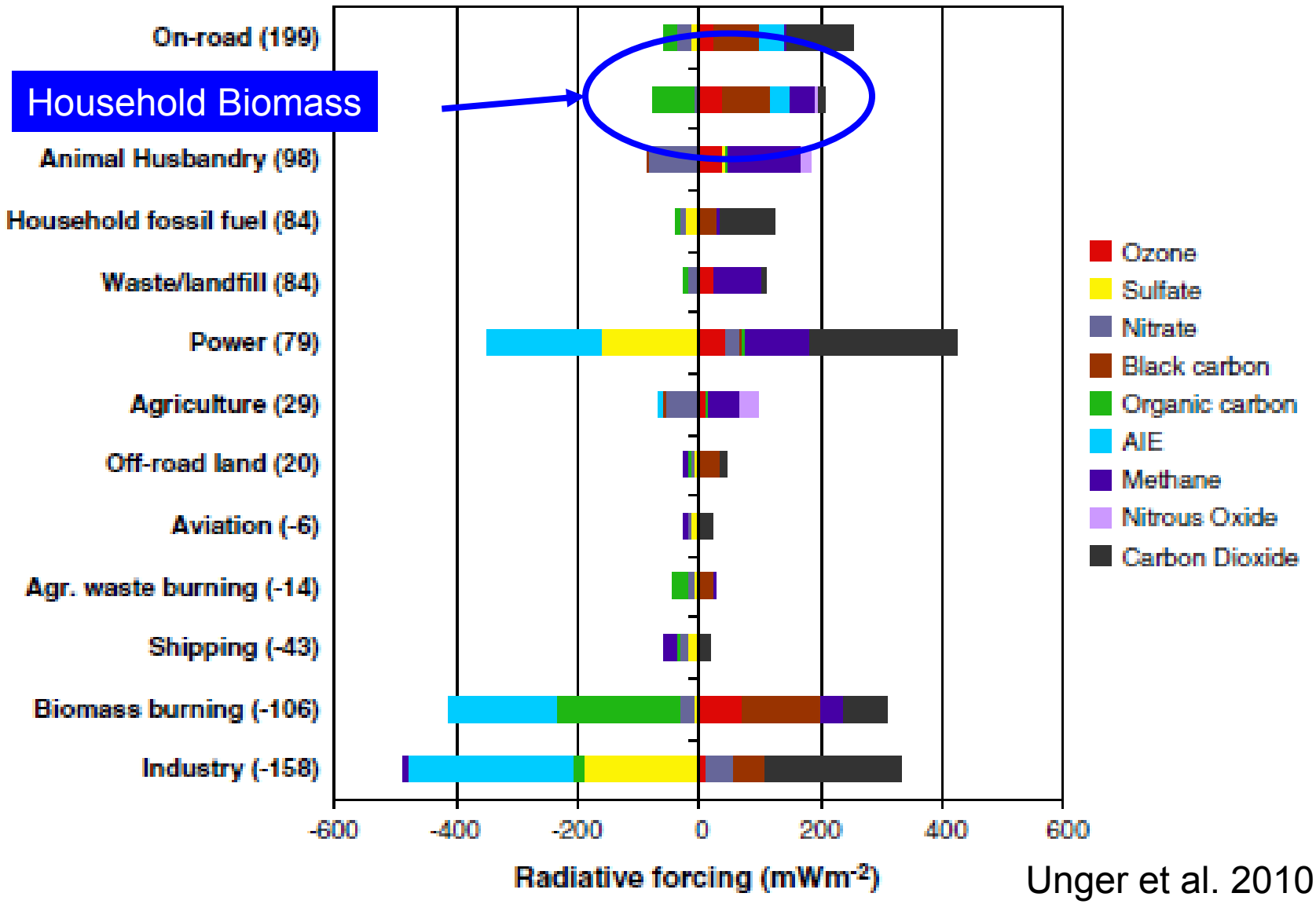
II. If you cannot do so, the least-damaging form to release is carbon dioxide because all other forms are worse for climate and health.

III. Even renewable (non-fossil) carbon is damaging for climate and health if not released as carbon dioxide.

Ranking of Carbon Emissions:
The Pharmaceutical Index

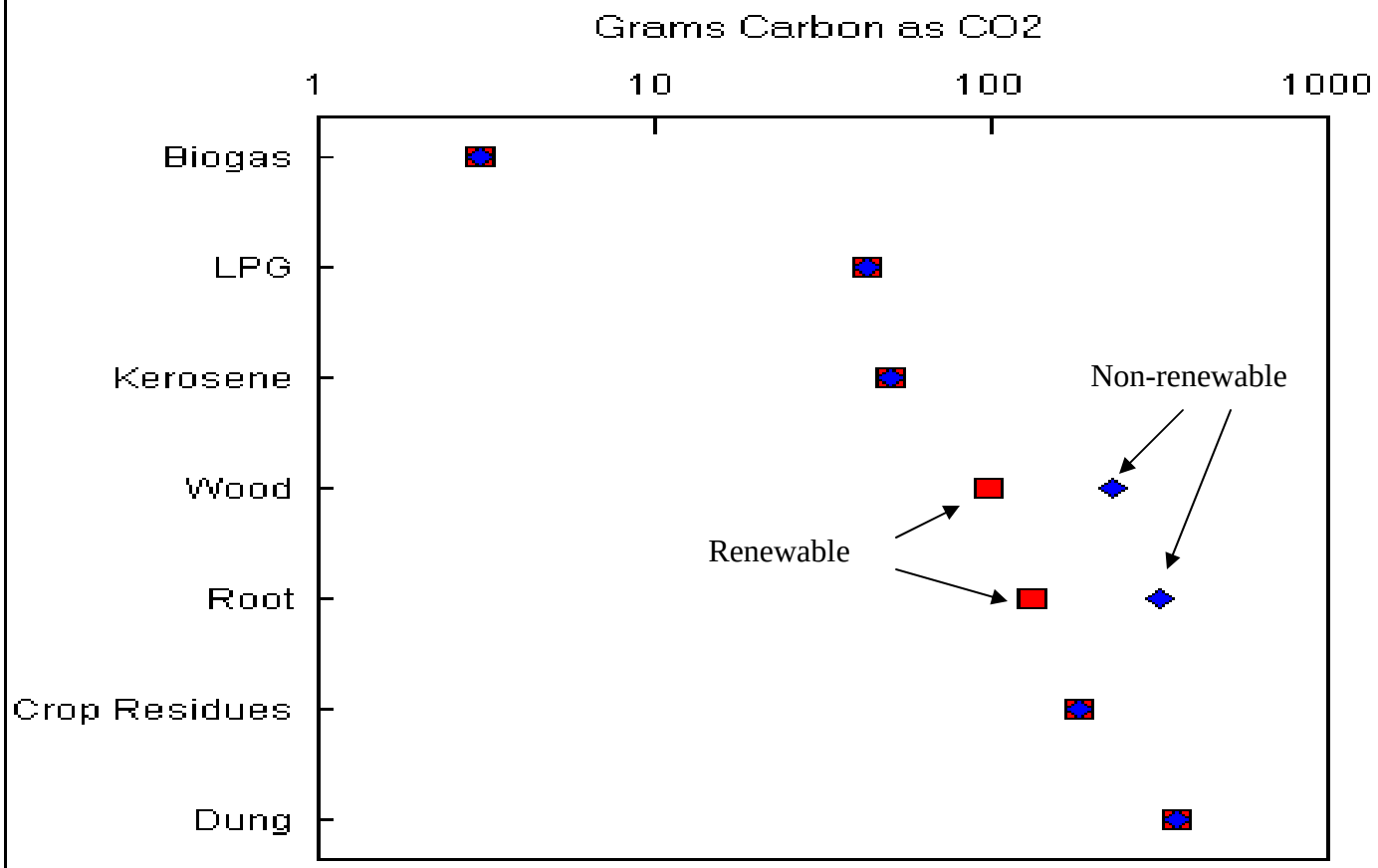
- Carbon dioxide is noxious if fossil or forest derived, but benign if from renewable sources
- Products of incomplete combustion (PIC) such as carbon monoxide and hydrocarbons are like CO_2 on caffeine – several times worse
- Methane from any source (fossil, biologic, or incomplete combustion) is like CO_2 on steroids – dozens of times worse.
- Black carbon in particles from incomplete combustion is like CO_2 on crack cocaine – hundreds of times worse.

Climate Warming in 2020 Under Present Trends



Unger et al. 2010

Global Warming Commitment
Per Unit Energy (MJ) Delivered in India
All GHGs counted



LPG has lower carbon footprint than biomass, even though non-renewable.

SMALL, SMART, FAST, & CHEAP

monitoring devices for household energy & health

Ajay Pillarisetti, Ilse Ruiz-Mercado, and Nick Lam on behalf of Prof. Kirk R. Smith's Research Group at University of California, Berkeley
Visit ehs.sph.berkeley.edu/krsmith for more information

STOVE USE MONITORS
UTILIZATION

Time-of-use measuring devices allow more accurate estimations and objective definitions of usage patterns including cooking periods, meal times, and technology adoption rates.

Stove Use Monitors (SUMS) quantify utilization of cookstoves to improve estimates of personal exposure and enviromental benefits related to household energy use. SUMS are based on commercially available, low-cost, small temperature loggers.

The stainless steel temperature sensors are the size of a coin and can record time, date, and temperature. Programming and downloading data can be easily performed in the field. They are easy to use, unobtrusive, waterproof and tamper-resistant. They come with algorithms and software to systematically assess stove use patterns.

Measurements of stove surface temperature can be used to test the effectiveness of behavioral interventions on stove use. Because they give precise, unbiased measures of a simple physical parameter, statistically reliable information is provided using smaller sample sizes than required for a household survey.

PARTICLE AND TEMP SENSOR
CONCENTRATION

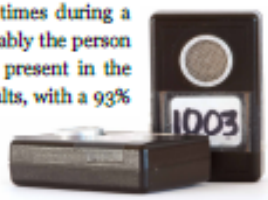
The ability to measure concentrations of small airborne particles is vital in understanding adverse health effects from combustion-derived air pollution. Available instrumentation to conduct such measurements is complex and expensive. Such devices are appropriate for developed countries and ambient air monitoring stations. However, their routine use in real-world household environments is expensive & cumbersome. Monitoring locations may also be remote, where security is questionable and electrical power not available, limiting the applicability of conventional instruments. In an effort to fulfill the needs for small, smart, fast, and cheap particle monitors that could be deployed easily in remote settings, a commercial smoke detector that uses optical scattering was identified and modified so that real-time signals could be logged continuously. This modified particle and temperature sensor is dubbed the UCB-PATS. Customized software handles data importing, graphing, and manipulation.

TIME-ACTIVITY MONITORING
LOCATION

Measurement of exposure to pollutants is vital to the field of environmental health. The significance of a hazard depends on the amount of time a person is in contact with it. For instance, high indoor air pollution levels have been found in many homes globally. The risk of respiratory disease depends on the amount of time people spend in the presence of this pollution.

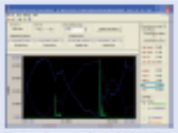
Time-Activity Monitoring System (TAMS) detects the presence or absence of individuals in an enclosed space. The system consists of one to five small ultrasound emitting devices worn on an individual's clothing. Each produces a distinct pattern that is emitted every few seconds. An ultrasound receiver is mounted on the wall of a room and detects the unique pattern from the device worn by an individual.

If the identifying signal pattern emitted from a particular locator is received a certain number of times during a minute, that locator, and presumably the person wearing it, is recorded as being present in the room. Field trials show good results, with a 93% accuracy rate as measured against direct observation.



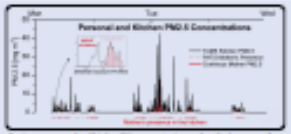
Device Software & Sample Output

Each device is controlled by software allowing equipment launch, data download and manipulation, and exporting of data files for further analysis. Devices connect with the software over a serial port or via an USB to Serial connector.



Viewing and processing downloaded data in the UCB-PATS Data Browser

Graphical view of reading on three sensors – Oregon, traditional wood and improved wood in one household from UCBPATS software.



Continuous personal and kitchen $PM_{2.5}$ concentrations and mother's presence/location in a home utilizing an open fire stove.

For more information, google "Kirk R Smith" • To acquire devices, visit berkeleyair.com

Many thanks

Publications and presentations on website – easiest to just "google" Kirk R. Smith