The Unfinished Agenda of Incomplete Combustion for Climate and Health

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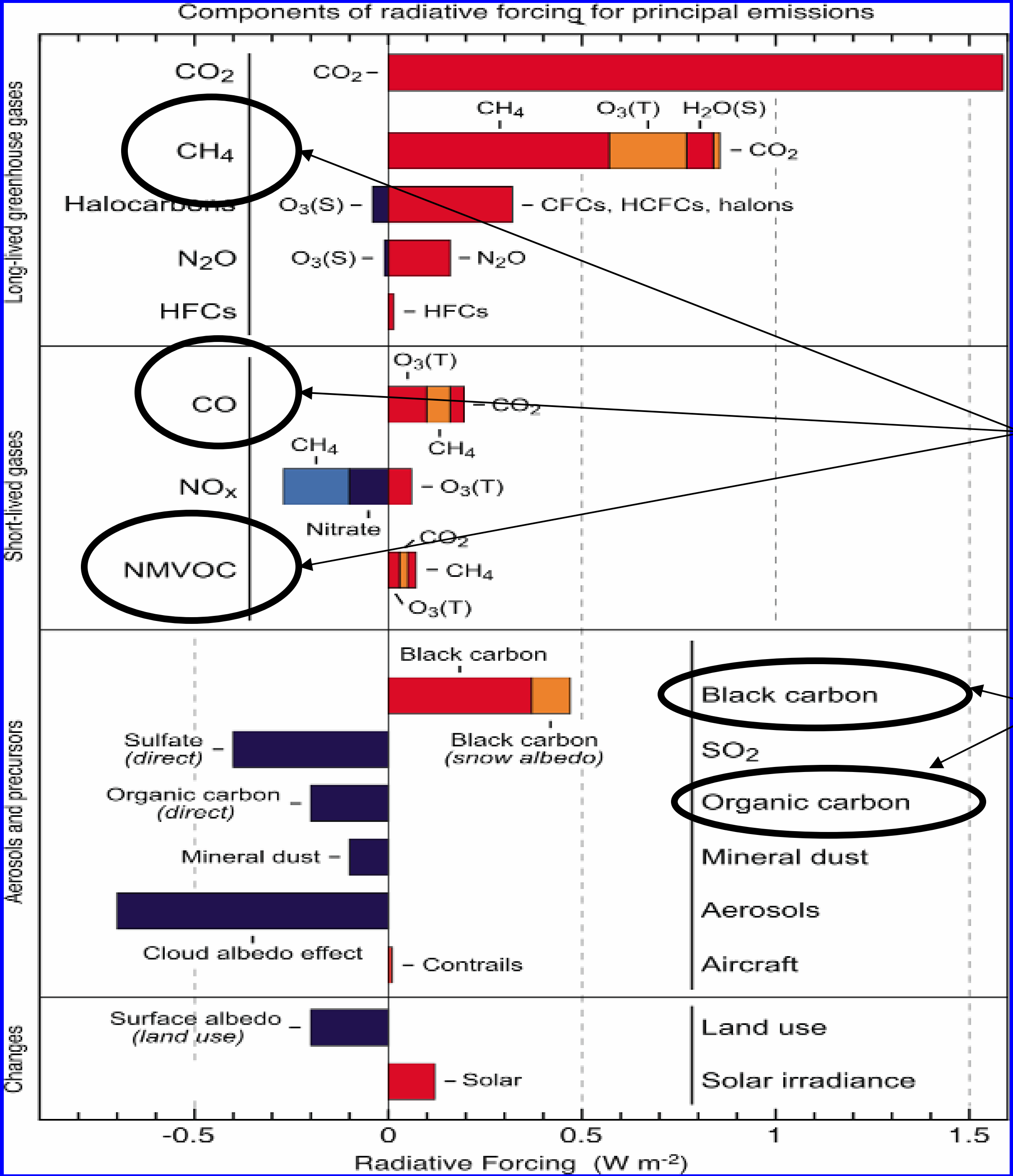
US Department of State
April 29, 2009

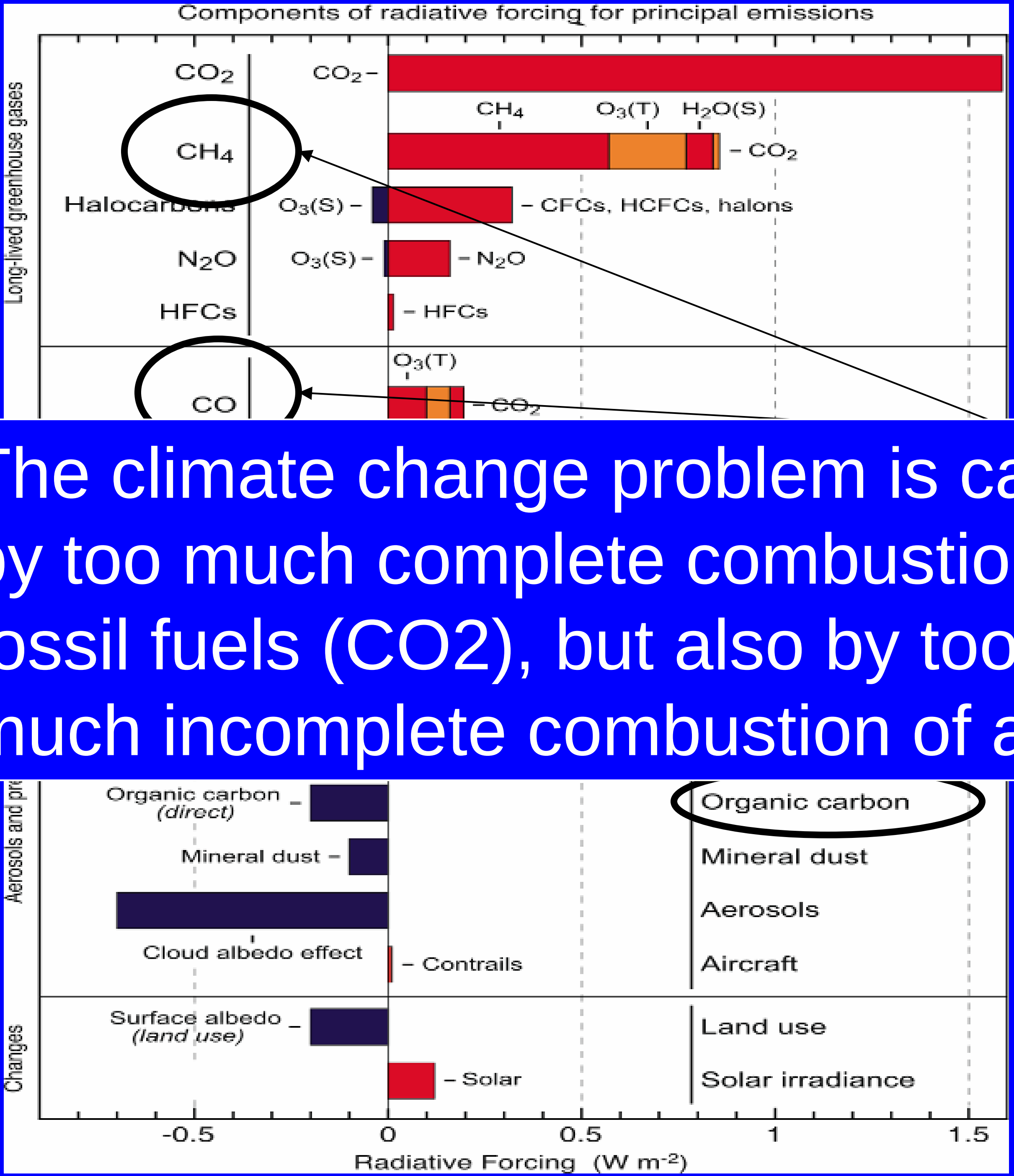
Warming in 2005 from emissions since 1750



A large part from PIC: products of incomplete combustion

IPCC, 2007

Warming in 2005 from emissions since 1750



The climate change problem is caused not only by too much complete combustion of fossil fuels (CO2), but also by too much incomplete combustion of all fuels (PIC)

IPCC, 2007

Where do these PIC come from?

From forest and savannah fires –
not directly human caused in general

Where else?

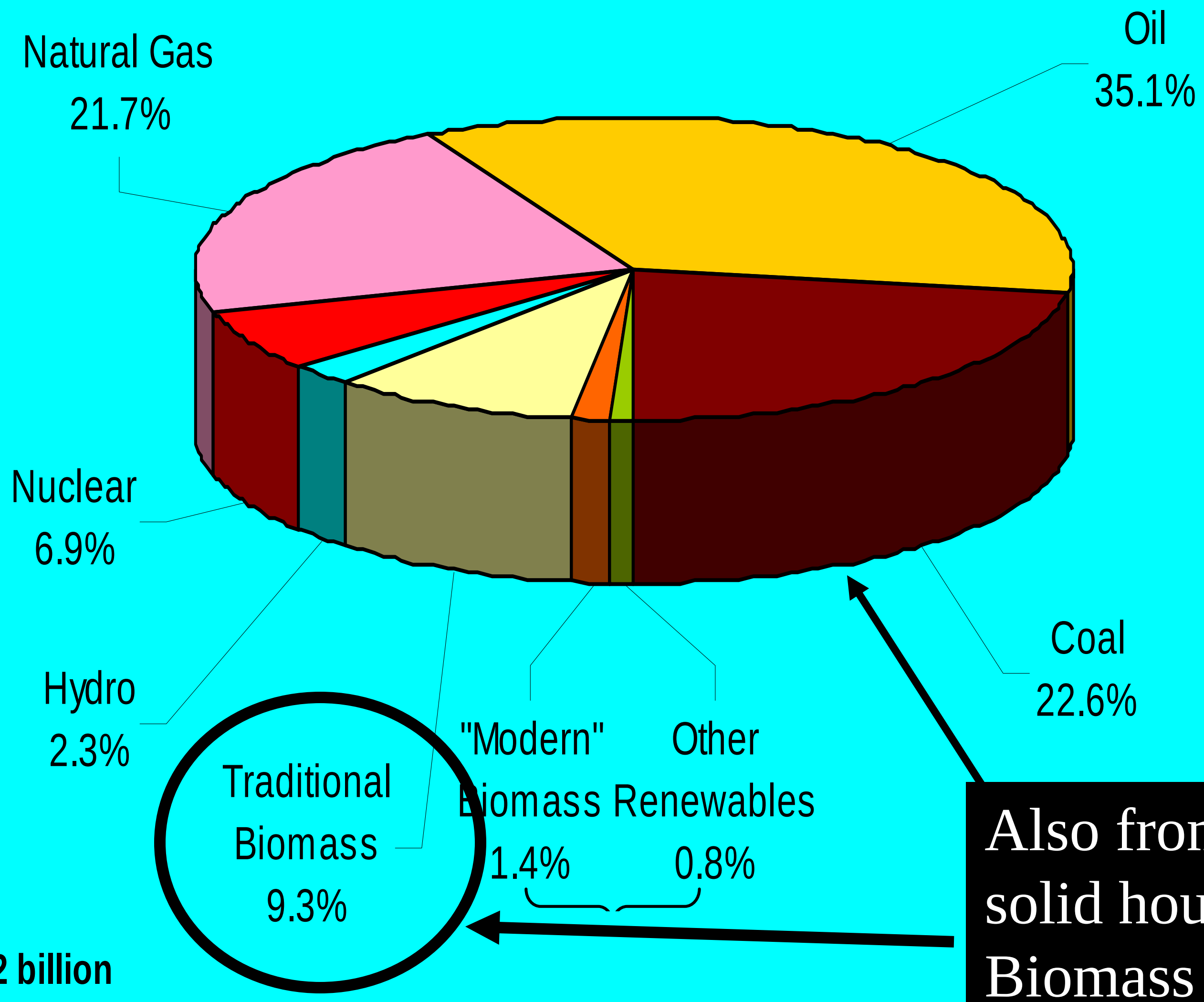
s

Popu

Total e

Per ca

World Energy – 2001



Also from
solid household fuels
Biomass and coal

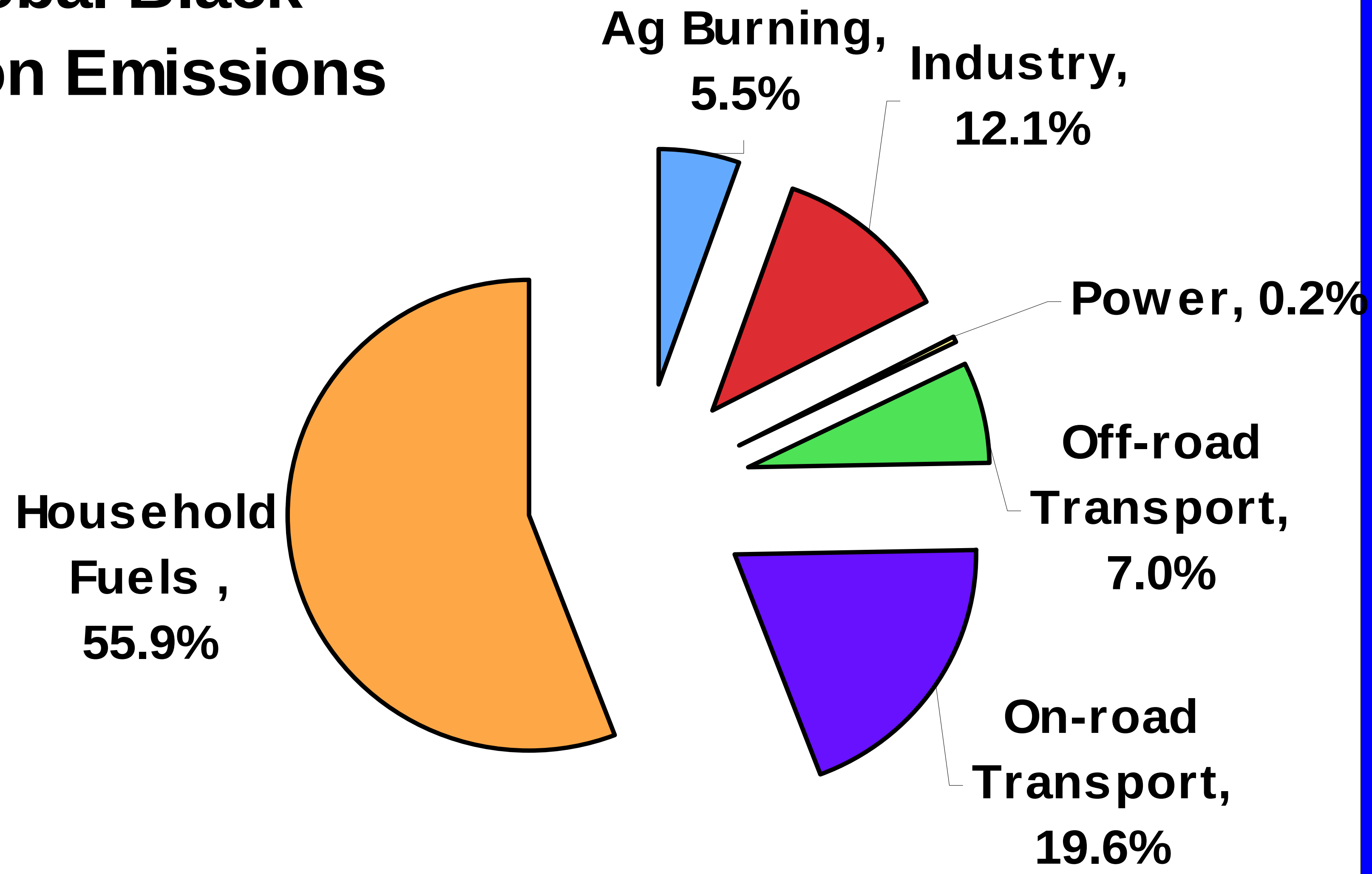
Population: 6.102 billion

Total energy use: 10.2 Gtoe

Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004

Global Black Carbon Emissions

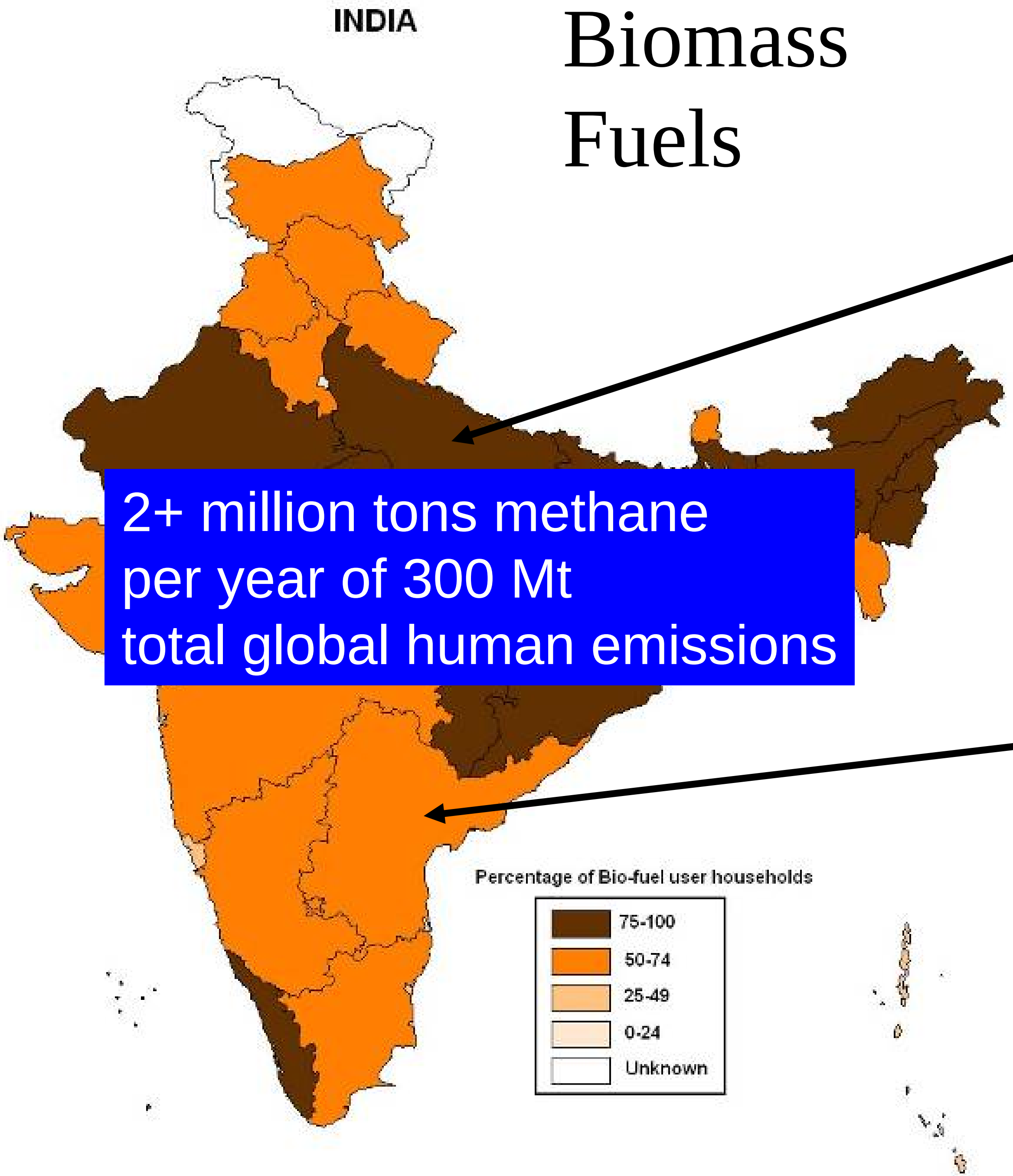


No forest fires

Total 6600 gigagrams in 2000

BC Campaign Data

Biomass Fuels



More than 75% of households

2+ million tons methane per year of 300 Mt total global human emissions

50-74% of households

2000 Census

Household Solid Fuel Burning

- What are the PIC and why are they created?
- Where do they sit in the climate landscape?
- What are their health implications – current estimates?
- Results from the first randomized trial – RESPIRE in the Guatemalan Highlands
- Need and prospects for advanced stoves
- New capabilities for M&E
- Summary of where we are now

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

Into Pot	In PIC	Waste Heat
2.8 MJ	1.2 MJ	11.3 MJ
18%	8%	74%

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

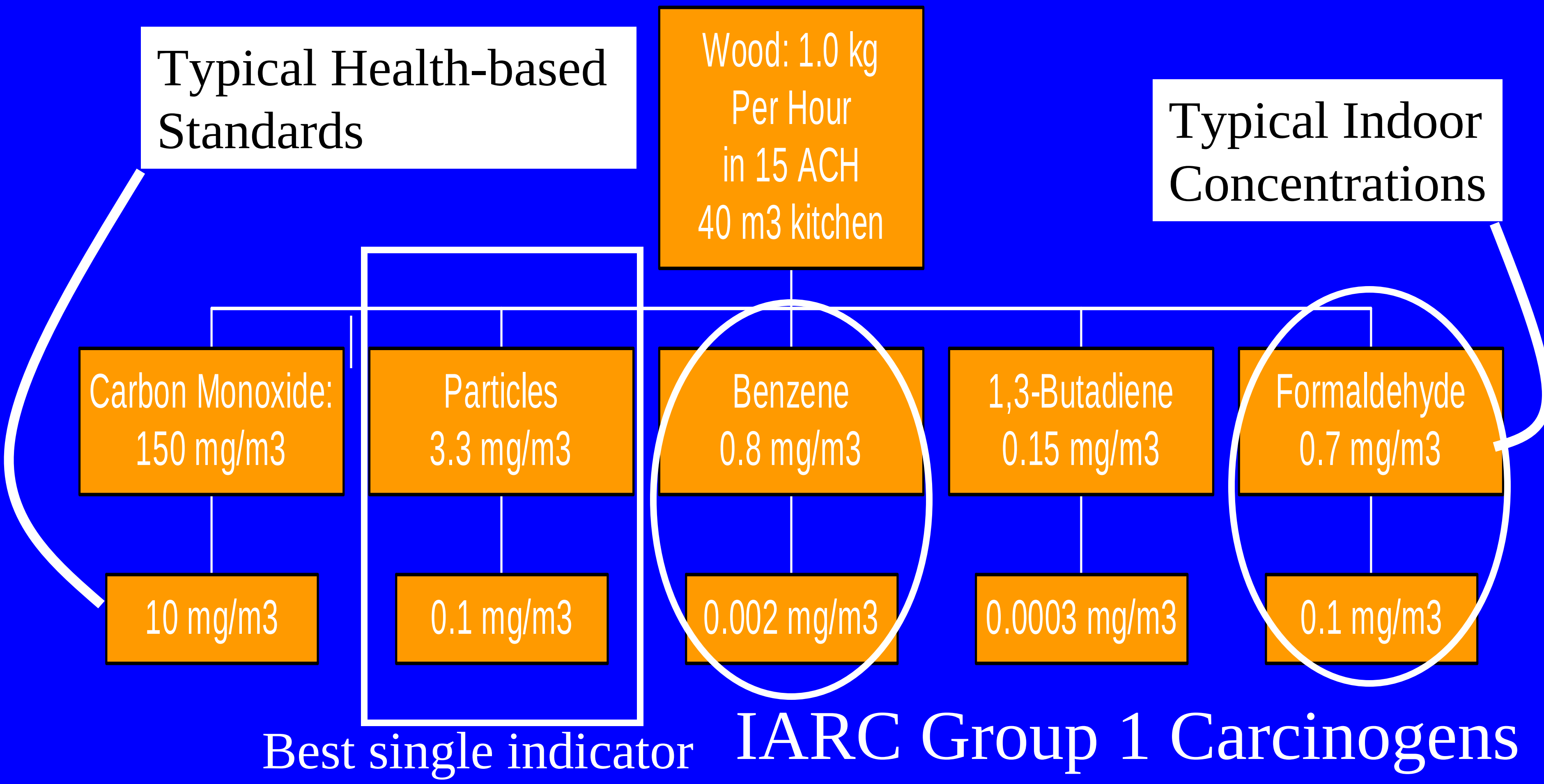
Source: Smith, et al., 2000

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

- Small particles, CO, 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

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



Location	Region	Number of households	Range (24 hour average of PM 10)	Mean (µg/m3) (24 hr average of Kitchen & Living Concentrations of PM10)	Other Determinants
Tamil Nadu	South	4		223	Fuel/ Kitchen/Stove
Andhra Pradesh	South	3		485	Fuel/ Kitchen
Karnataka	South	3		898	Fuel/ Stove
Madhya Pradesh	West/Central	7		690	Fuel/ Kitchen
Gujarat	West	6		780	Fuel/ Kitchen
Goa	West	1		635	Fuel/ Kitchen
West Bengal	East/North East	9		795	Fuel/ Kitchen
Haryana	North	1		850	Fuel/ Kitchen
Uttaranchal	North/Mountain	76	270-2240	620	Fuel/ Kitchen

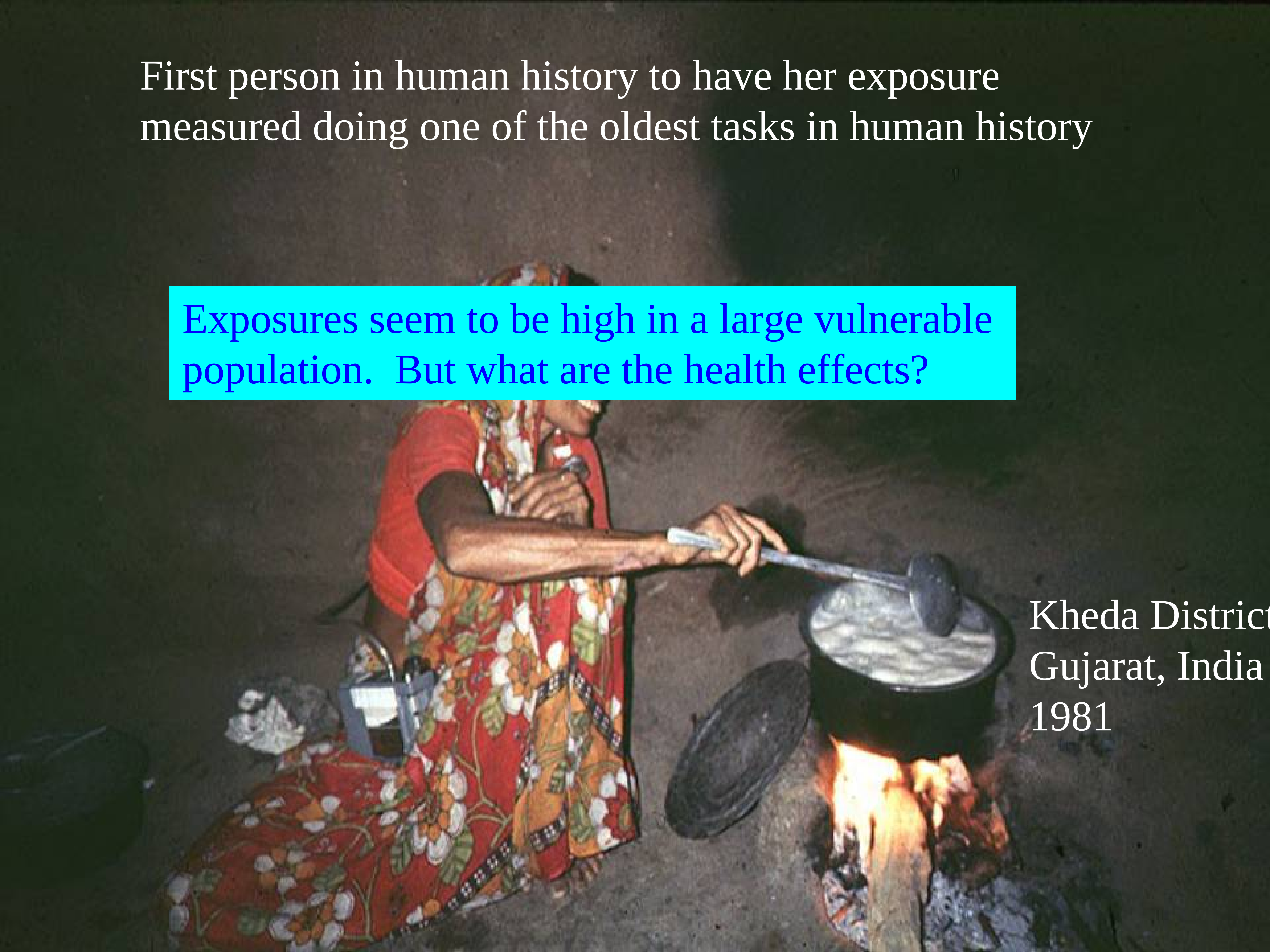
WHO Global Air Quality Guideline for Indoor/Outdoor particle Levels

20 µg/m3

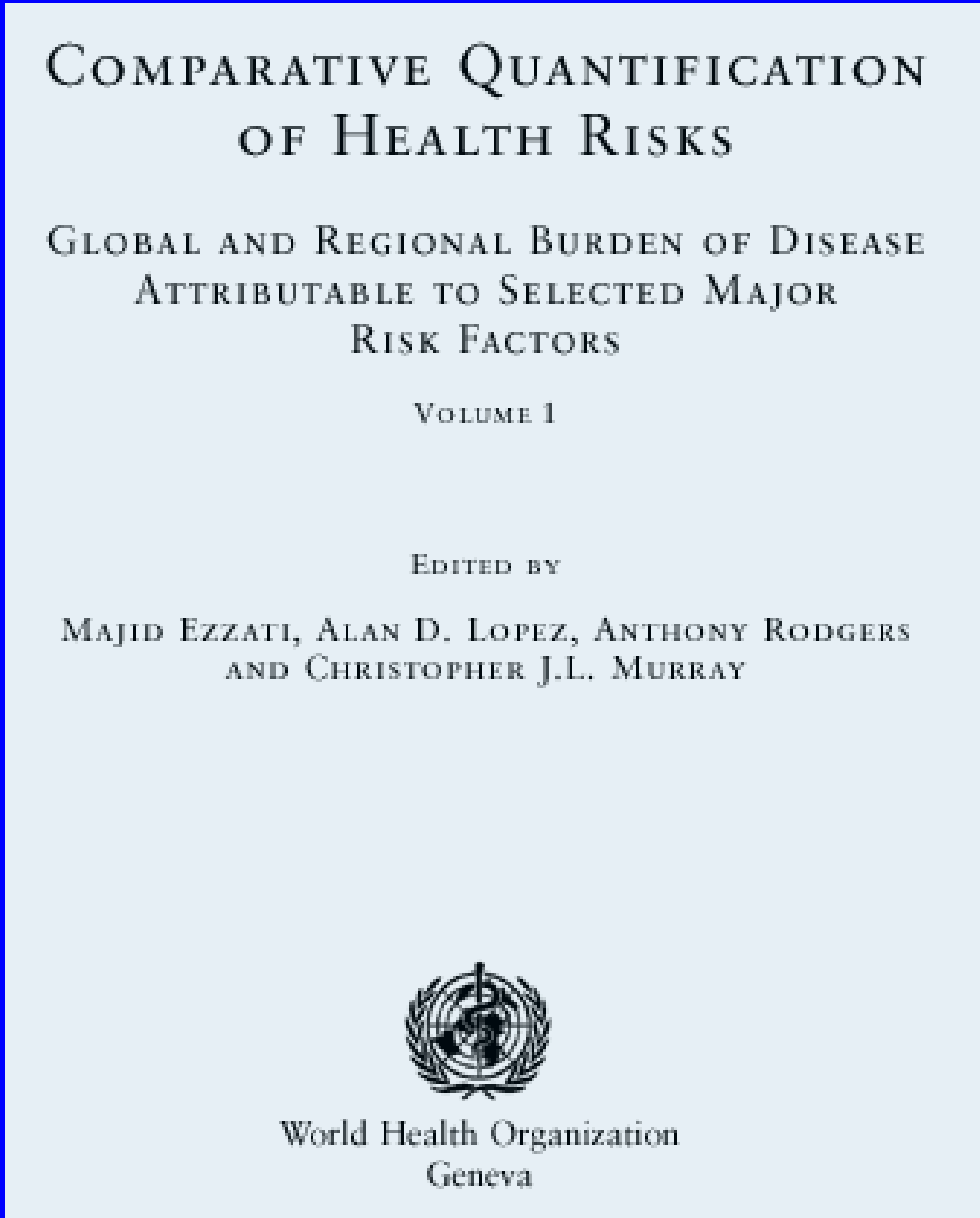
Absolutely no population even even poorest countries should be exposure to more than

70 µg/3

Data complild by SRU, Chennai


First person in human history to have her exposure measured doing one of the oldest tasks in human history
Exposures seem to be high in a large vulnerable population. But what are the health effects?
Kheda District
Gujarat, India
1981

How Much Global Ill-Health can be Attributed to Household Indoor Air Pollution?


COMPARATIVE QUANTIFICATION OF HEALTH RISKS

GLOBAL AND REGIONAL BURDEN OF DISEASE ATTRIBUTABLE TO SELECTED MAJOR RISK FACTORS

VOLUME 1

EDITED BY

MAJID EZZATI, ALAN D. LOPEZ, ANTHONY RODGERS AND CHRISTOPHER J.L. MURRAY

World Health Organization
Geneva

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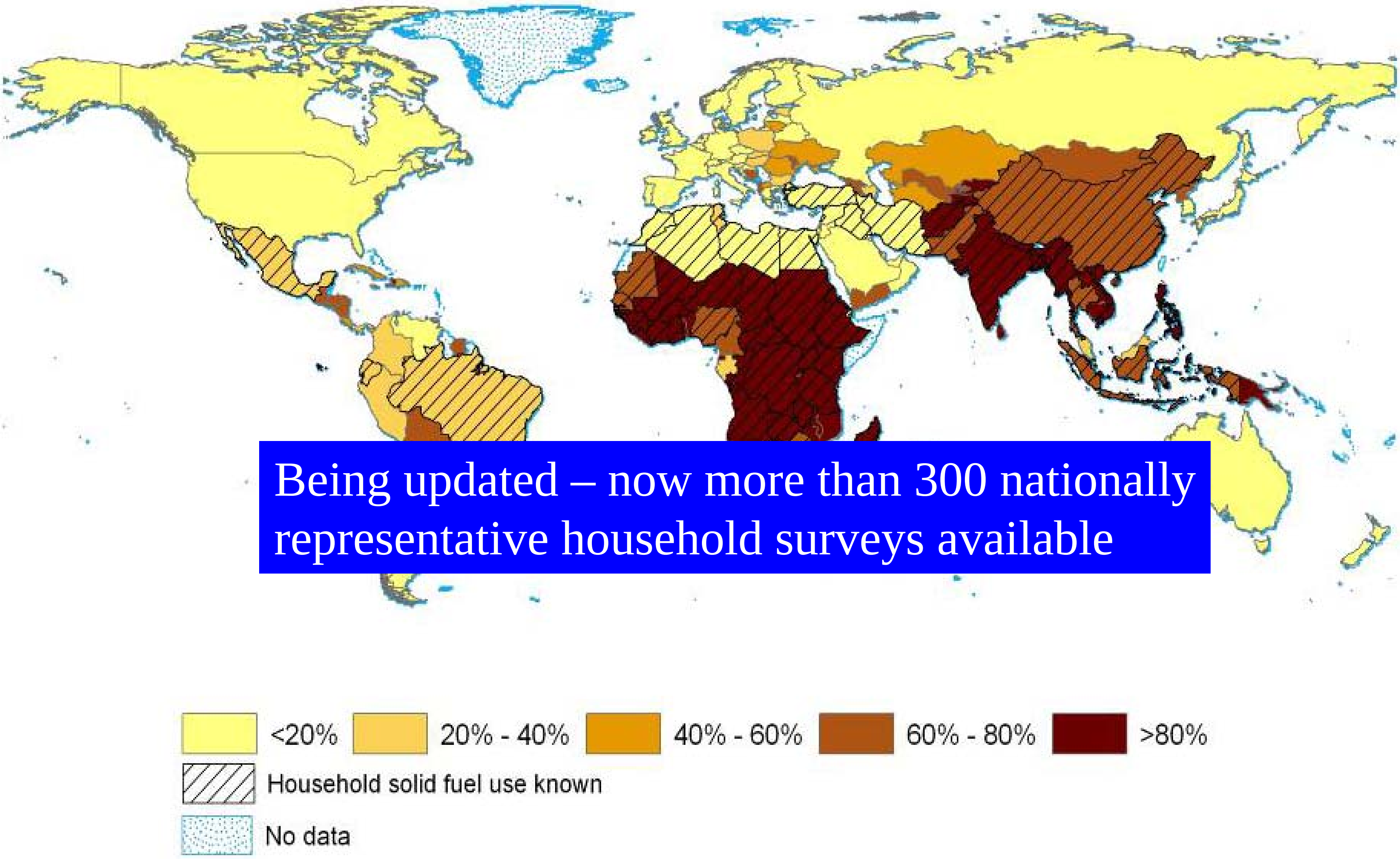
2 vols, ~2500 pp

Available on World Health Organization website

Being completely revised
Publication in 2010

http://www.who.int/publications/cra/en/

National Household Solid Fuel Use, 2000



Being updated – now more than 300 nationally representative household surveys available

The Energy Ladder: Relative Pollutant Emissions Per Meal

India Data

	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

Smith, et al., 2005

Diseases for which we have studies showing links to household solid fuel use

ALRI/ Pneumonia (meningitis)

Low birth weight & stillbirth

Asthma?

Early infant Death?

Cognitive Effects (lower IQ)?

Birth defects?; cleft

Chronic obstructive lung disease

Interstitial lung disease

Cancer (lung, NP, cervical, aero-digestive)

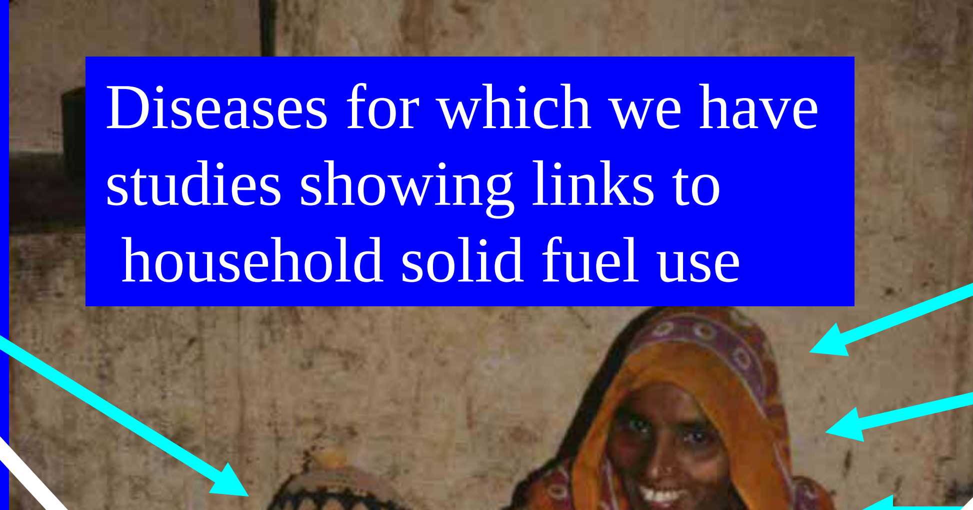
Blindness (cataracts, trachoma)

Tuberculosis

Heart disease?

Fire-related deaths and burns

Diseases for which we have studies showing links to household solid fuel use



ALRI/
Pneumonia
(meningitis)

Chronic obstructive lung disease

Only two qualified with sufficient evidence to be included in the original WHO Comparative Risk Assessment – 2004

More to be added in the update, slated for 2010

The Lancet, March 2, 2009

Fire-related deaths in India in 2001: a retrospective analysis of data

106,000 deaths in women/y

Prachi Sanghavi, Kavi Bhalla, Veena Das

Summary

Background Hospital-based studies have suggested that fire-related deaths might be a neglected public-health issue in India. However, no national estimates of these deaths exist and the only numbers reported in published literature come from the Indian police. We combined multiple health datasets to assess the extent of the problem.

Methods We computed age–sex-specific fire-related mortality fractions nationally using a death registration system based on medically certified causes of death in urban areas and a verbal autopsy based sample survey for rural populations. We combined these data with all-cause mortality estimates based on the sample registration system and the population census. We adjusted for ill-defined injury categories that might contain misclassified fire-related deaths, and estimated the proportion of suicides due to self-immolation when deaths were reported by external causes.

Findings We estimated over 163 000 fire-related deaths in 2001 in India, which is about 2% of all deaths. This number was six times that reported by police. About 106 000 of these deaths occurred in women, mostly between 15 and 34 years of age. This age–sex pattern was consistent across multiple local studies, and the average ratio of fire-related deaths of young women to young men was 3:1.

Interpretation The high frequency of fire-related deaths in young women suggests that these deaths share common causes, including kitchen accidents, self-immolation, and different forms of domestic violence. Identification of populations at risk and description of structural determinants from existing data sources are urgently needed so that interventions can be rapidly implemented.

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Acute lower respiratory infections (ALRI)

Chief cause of death among the world’s children (>2 million per year). Thus, it is the chief global cause of lost healthy life years.

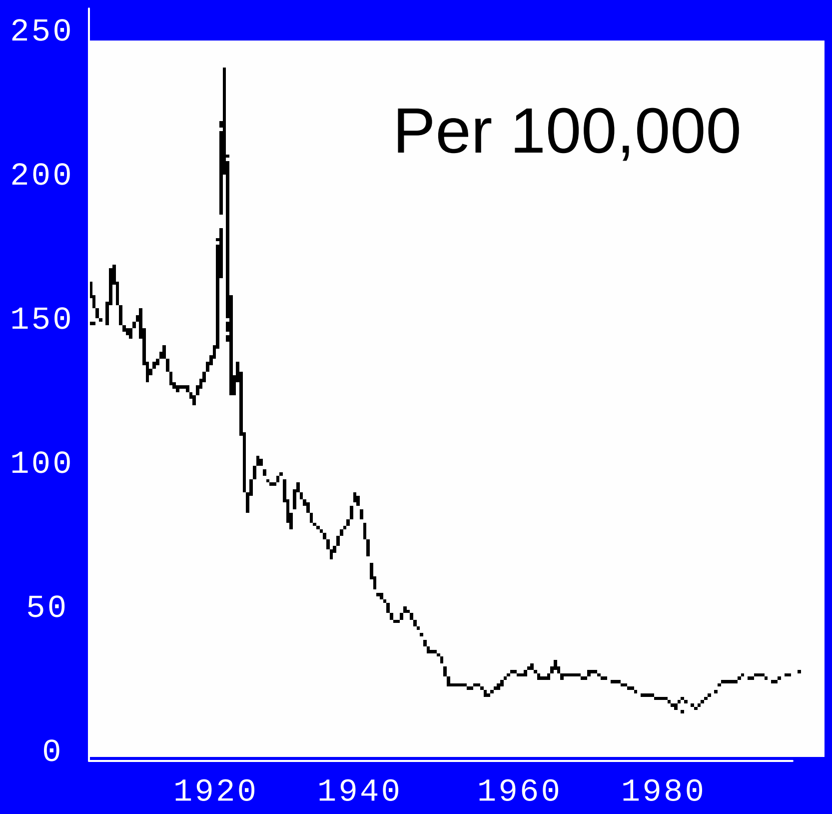
Child mortality occurs almost entirely in developing countries, and as pneumonia.

Well-accepted risk factors (malnutrition, micro-nutrient deficiencies, other diseases, crowding, chilling) do not account for its scale.

Pneumonia Deaths in the United States

Not so long ago pneumonia was chief cause of death in developed countries

SOURCE: National Center for Health Statistics, 2004. No age adjustment



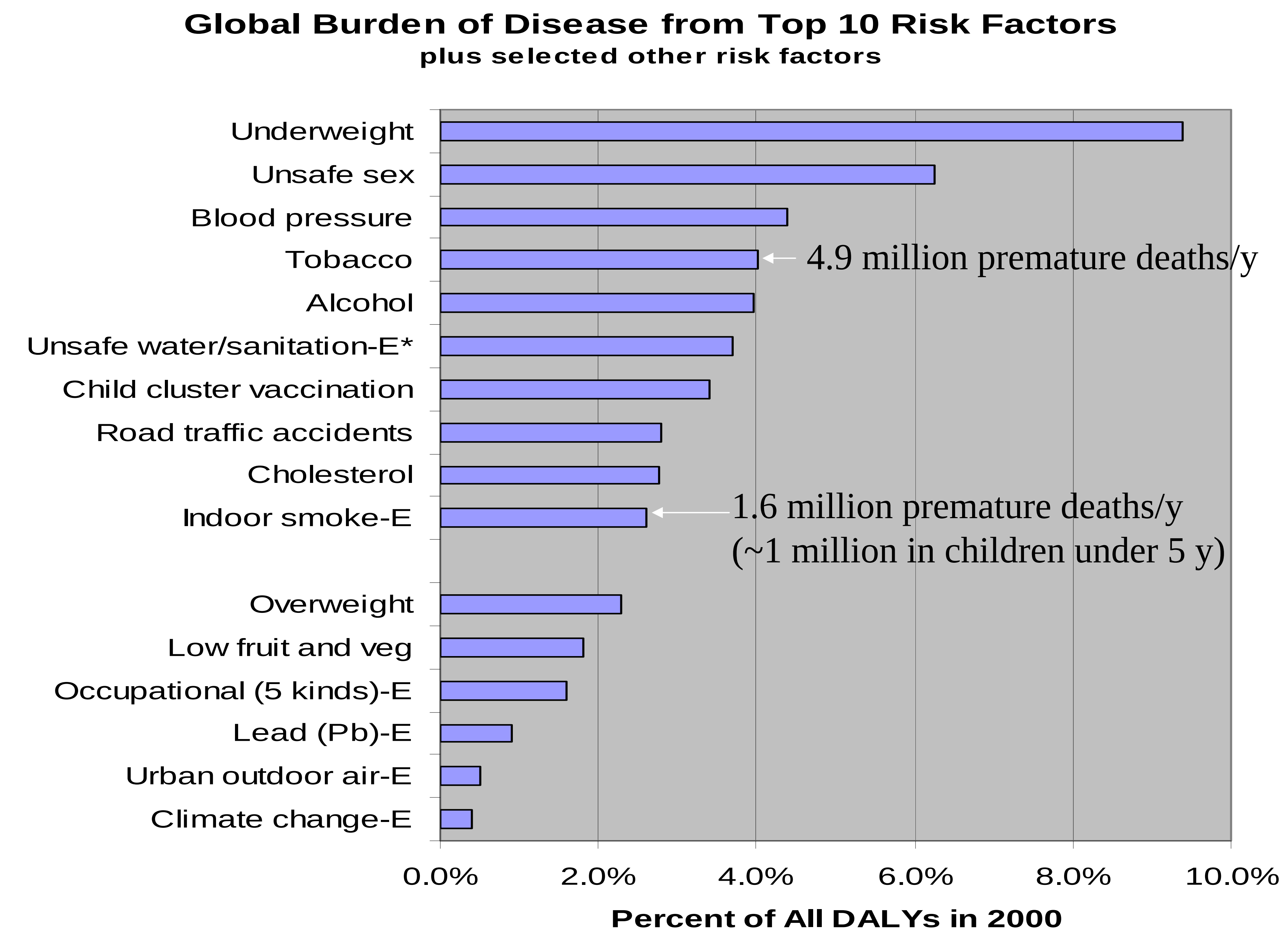
ALRI associated with use of solid fuels: analysis of ~10 observational studies

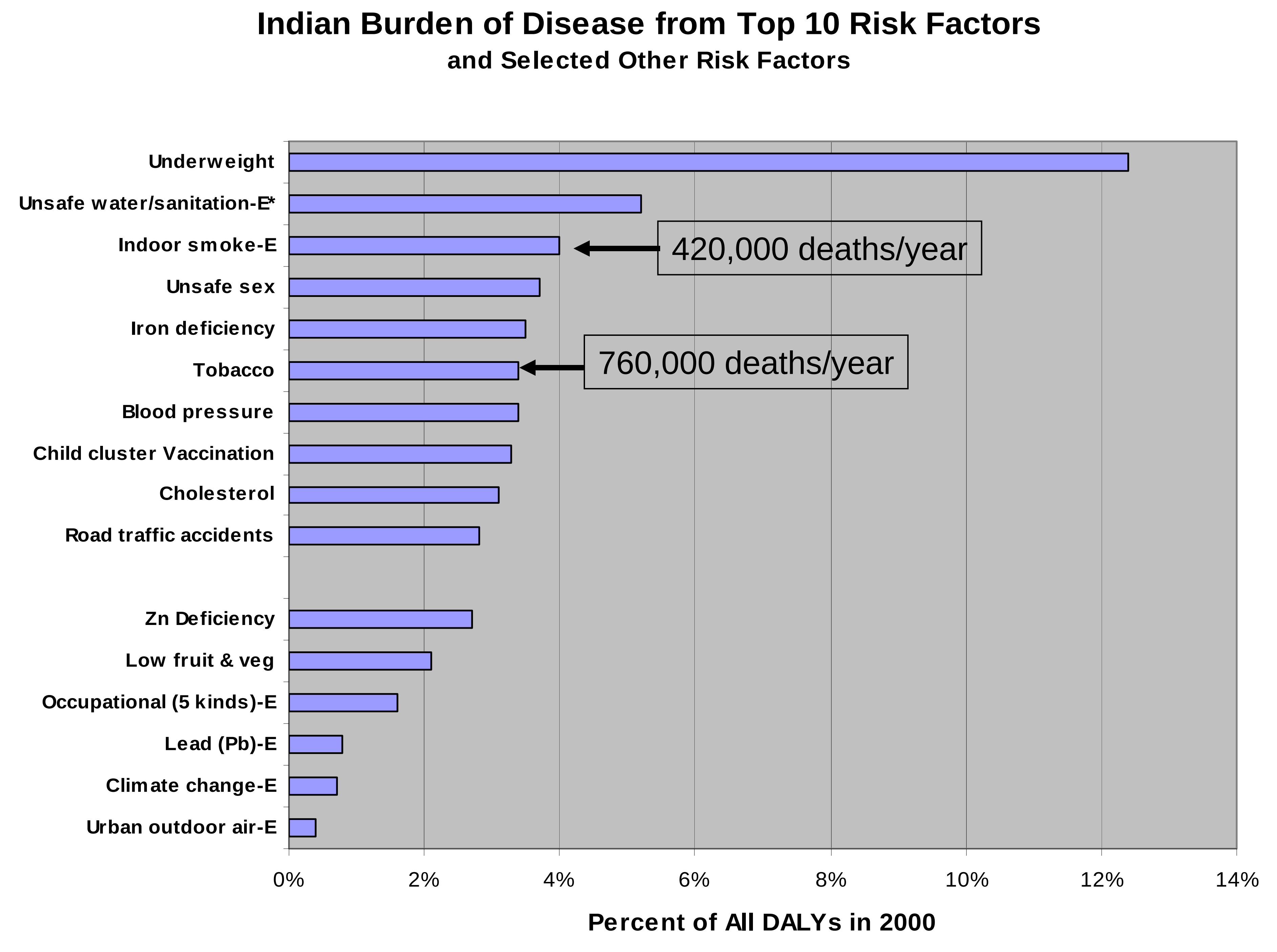
Subgroup analyses	Odds ratio (95% CI)
All studies	2.3 (1.9-2.7)
Use of solid fuel	2.0 (1.4-2.8)
Duration of time child spent near the cooking fire	2.3 (1.8-2.9)
Studies adjusting for nutritional status	3.1 (1.8-5.3)
Studies not adjusting for nutritonal status	2.2 (2.0-3.0)
Children aged <2 years old	2.5 (2.0-3.0)
Children aged <5 years old	1.8 (1.3-2.5)

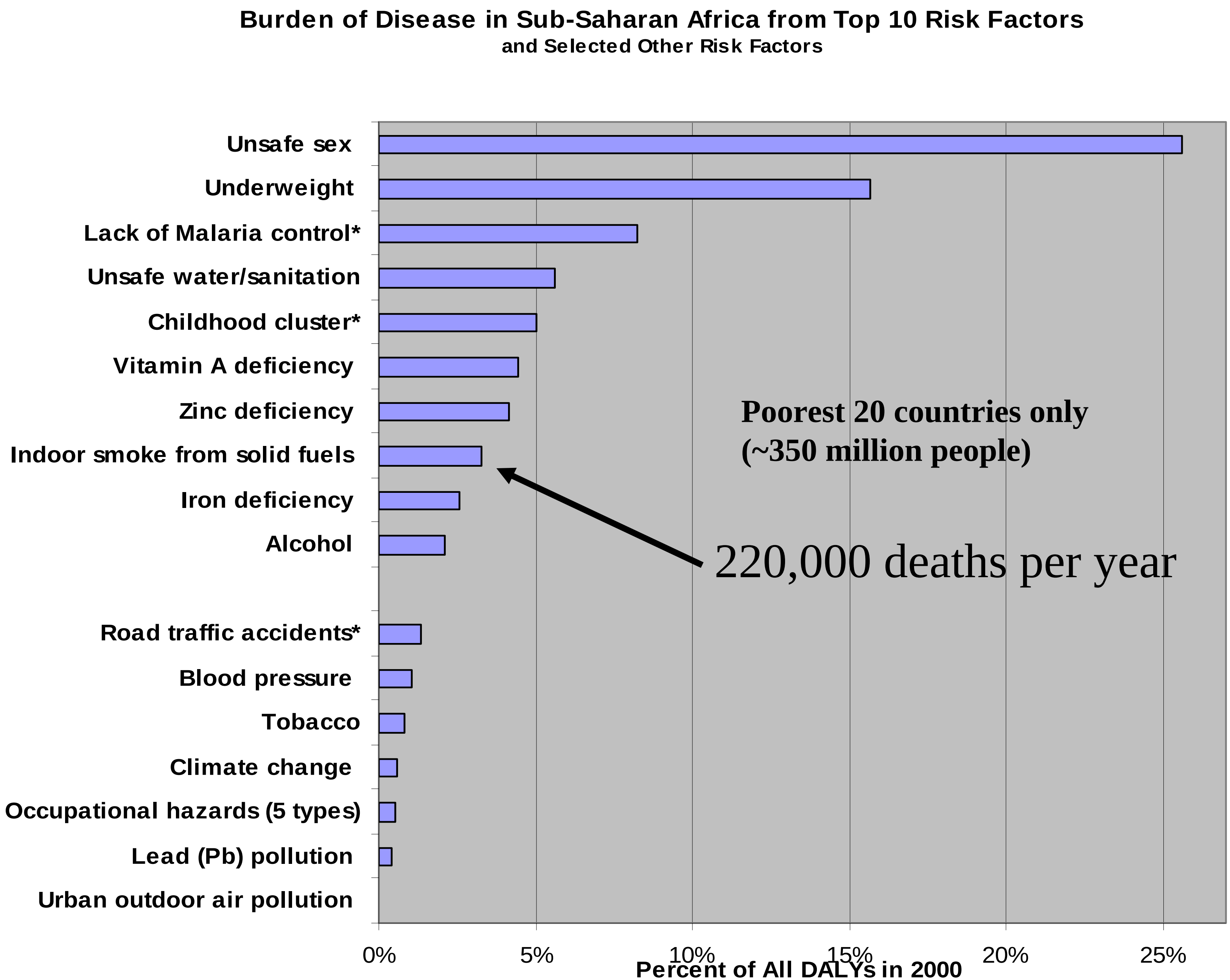
Smith et al in WHO, Comparative quantification of health risks, 2004

Consistent with

- Controlled animal and human exposures showing effects on respiratory immune system
- Dozens of studies of the effect of environmental tobacco smoke exposures in children
- A few studies of outdoor air pollution


Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
Underweight
Unsafe sex
Blood pressure
Tobacco
4.9 million premature deaths/y
Alcohol
Unsafe water/sanitation-E*
Child cluster vaccination
Road traffic accidents
Cholesterol
Indoor smoke-E
1.6 million premature deaths/y
(~1 million in children under 5 y)
Overweight
Low fruit and veg
Occupational (5 kinds)-E
Lead (Pb)-E
Urban outdoor air-E
Climate change-E
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
Percent of All DALYs in 2000


Indian Burden of Disease from Top 10 Risk Factors
and Selected Other Risk Factors
Underweight
Unsafe water/sanitation-E*
Indoor smoke-E
Unsafe sex
Iron deficiency
Tobacco
Blood pressure
Child cluster Vaccination
Cholesterol
Road traffic accidents
Zn Deficiency
Low fruit & veg
Occupational (5 kinds)-E
Lead (Pb)-E
Climate change-E
Urban outdoor air-E
420,000 deaths/year
760,000 deaths/year
0%
2%
4%
6%
8%
10%
12%
14%
Percent of All DALYs in 2000



In Smith et al., 2005. Derived from WHO data

Problems with all Previous ALRI and IAP Studies

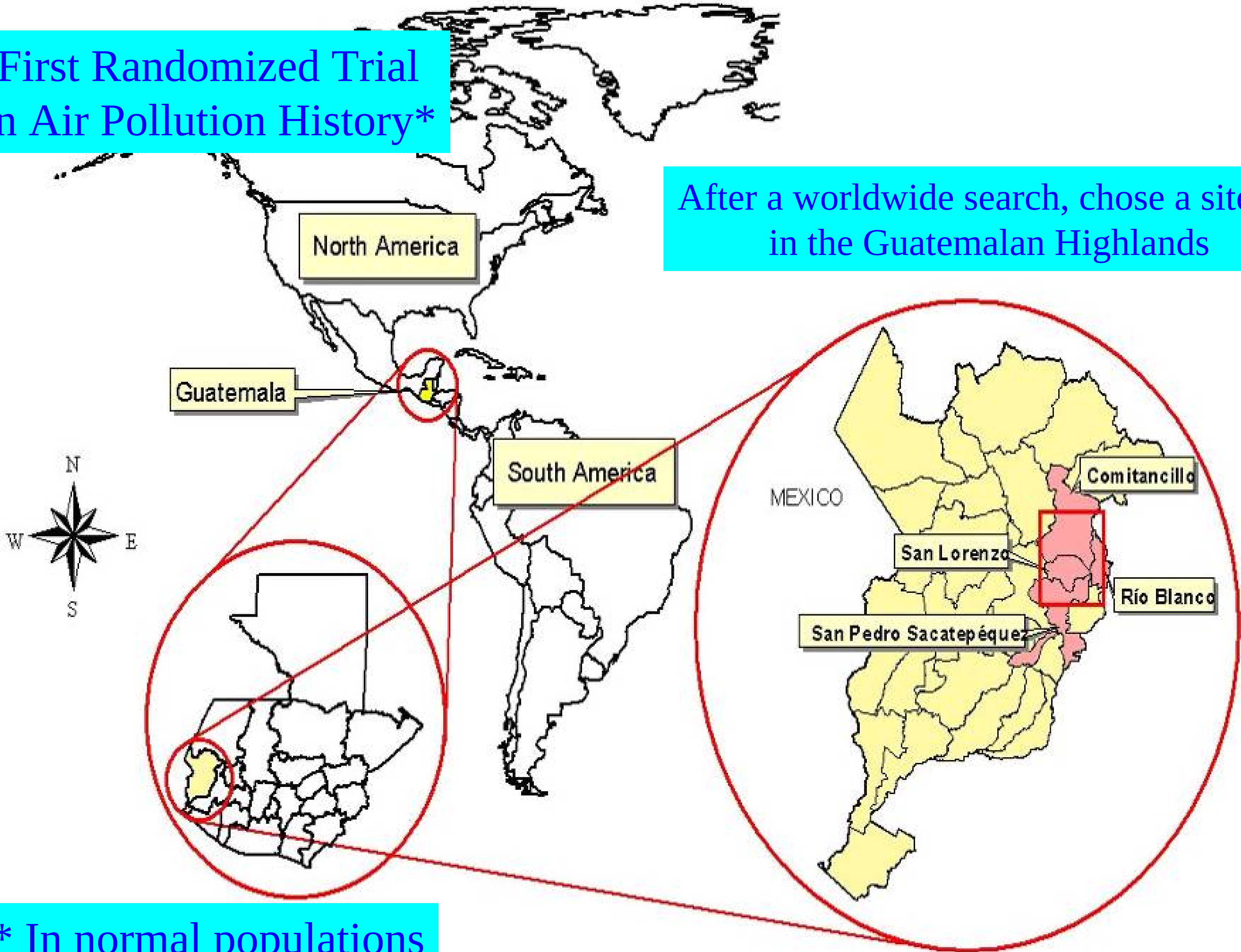
- Studies were all observational and thus not able to be sure the effect was not due just to poverty and not air pollution.
- Too much confusion with upper respiratory infections
- Little or no exposure assessment.
- Solution is a
  - Randomized control trial (RCT) in which half households receive improved stove on a random basis at the start, other keep open fires until end
  - Much better diagnosis of disease
  - Full exposure assessment

History of a RCT

- ~1980: Early studies of health effects in Nepal and elsewhere
- 1981: First measurements of pollution levels in India
- 1984: International meeting to decide on needed research
  - <u>Chose randomized control trial (RCT) of ALRI</u>
- 1986-89: Unfunded proposals to do RCT in Nepal
- 1990: WHO establishes committee to find best sites
- 1990-1992: Criteria established and site visits made
- 1992: Highland Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: Unfunded proposals
- <u>2001: NIEHS funding secured</u>
- 2002-2005: Fieldwork completed
- 2007: First results published
- 23+ years from deciding to conduct RCT to results!

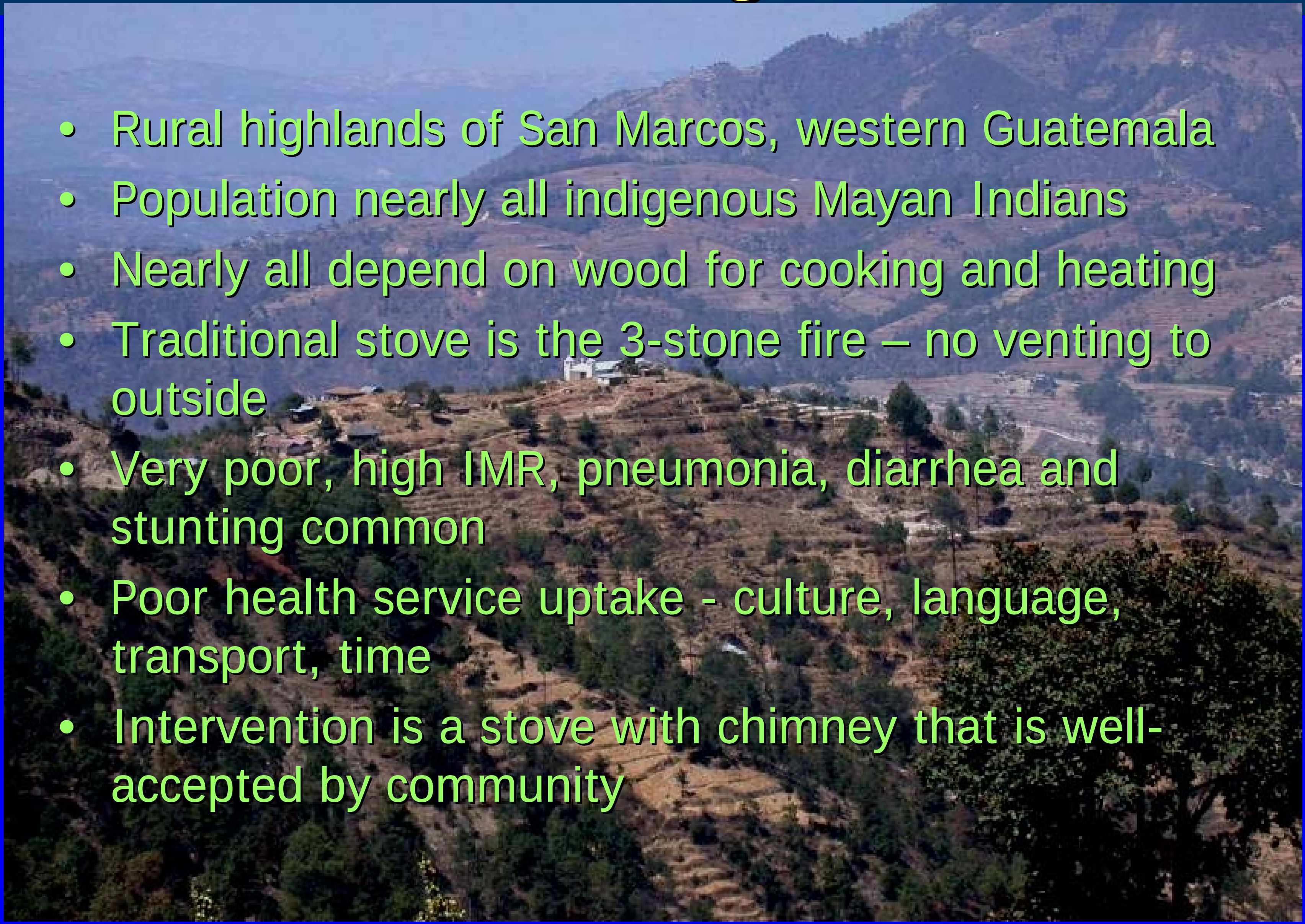
First Randomized Trial In Air Pollution History*

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



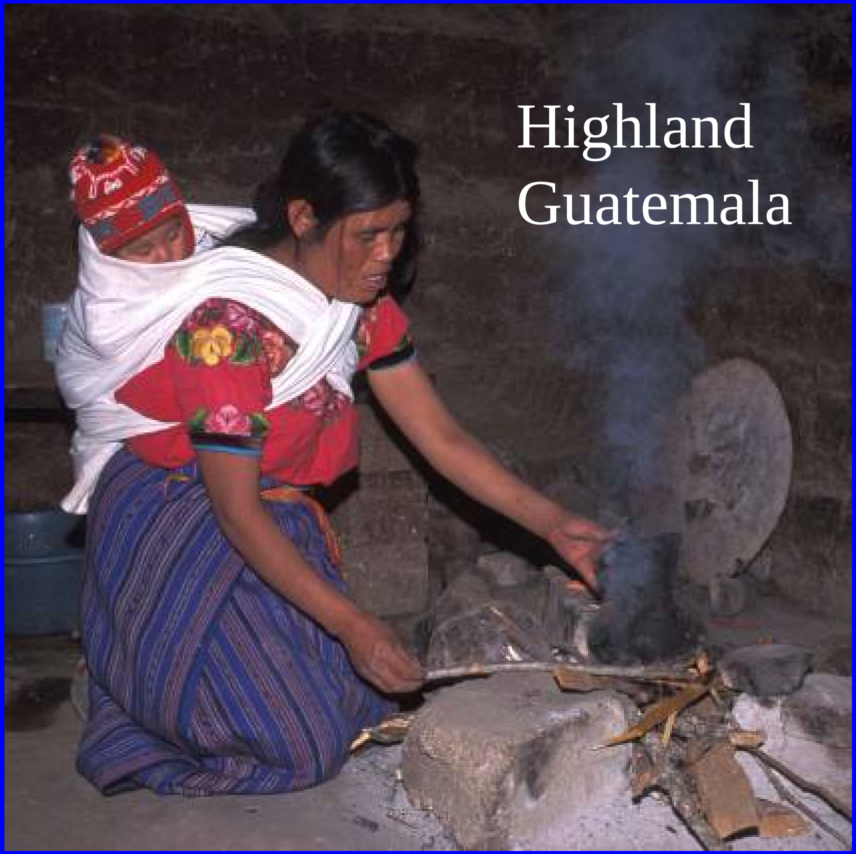
* In normal populations

Setting



- Rural highlands of San Marcos, western Guatemala
- Population nearly all indigenous Mayan Indians
- Nearly all depend on wood for cooking and heating
- Traditional stove is the 3-stone fire – no venting to outside
- Very poor, high IMR, pneumonia, diarrhea and stunting common
- Poor health service uptake - culture, language, transport, time
- Intervention is a stove with chimney that is well-accepted by community

RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)



Traditional 3-stone open fire

Plancha chimney wood stove

RESPIRE Teams

- 25-35 fulltime field staff
  - 17-25 locally hired bilingual (Mam-Spanish) fieldworkers
  - Field manager
  - 2 field supervisors
  - Data manager
  - 2-3 physicians
  - Environment engineer for air pollution monitoring
  - 4-6 office/data entry staff
  - All Guatemalan
- Investigators and students in Berkeley, Guatemala, Liverpool, Boston, Geneva, and Bergen
- International **Data Safety Management Board** for ongoing protection of human subjects
- NIH and several other funders

Overview of RESPIRE study design

- 530 eligible households: open fire, woman pregnant or child less than 4 months
- Baseline survey and exposure assessment

Randomize

Keep open fire

Plancha

<u>Follow up till aged 18 months</u>

- Surveillance for ALRI, diarrhoea, &c
- Detailed exposure monitoring

Compare incidence and exposure in 2 groups
Plancha offered to ‘controls’

Year 1

5500 Households total

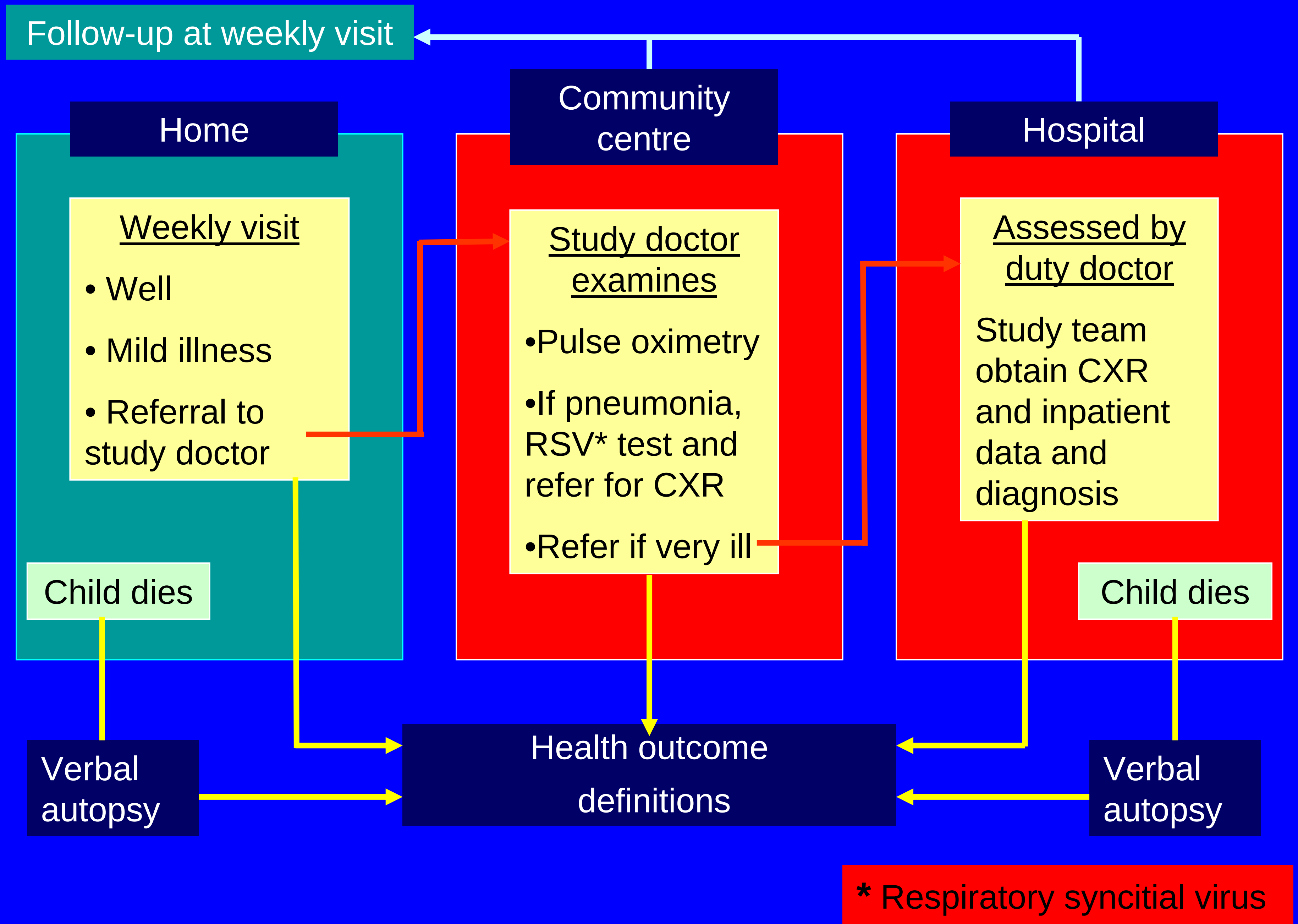
Years 1-3

Years 3-4

Randomisation: balance of groups at baseline

Variable	Control	Intervention
Socio-demographic factors		
Mother's Age (years)	27.0	26.4
Pregnant at recruitment (%)	48.3	51.3
Own home (%)	92.8	94.1
Migrates part of year (%)	17.7	17.1
House structure		
Separate enclosed cooking area (%)	76.2	74.3
Completely open eaves (%)	42.7	40.6
Walls – adobe (mud) (%)	88.7	90.7
Roof – metal (%)	77.4	74.3
Floor – earth (%)	92.5	88.8
Leaks in roof (water) (%)	24.5	33.3
Electricity (%)	70.8	69.3
Other sources of smoke		
Other fire near house (%)	14.6	14.4
Smoking (tobacco) indoors (%)	26.8	20.4
Use traditional sauna bath (%)	84.5	87.8
Geographic		
Mean altitude (metres)	2613	2601

Overview of child health outcomes assessment



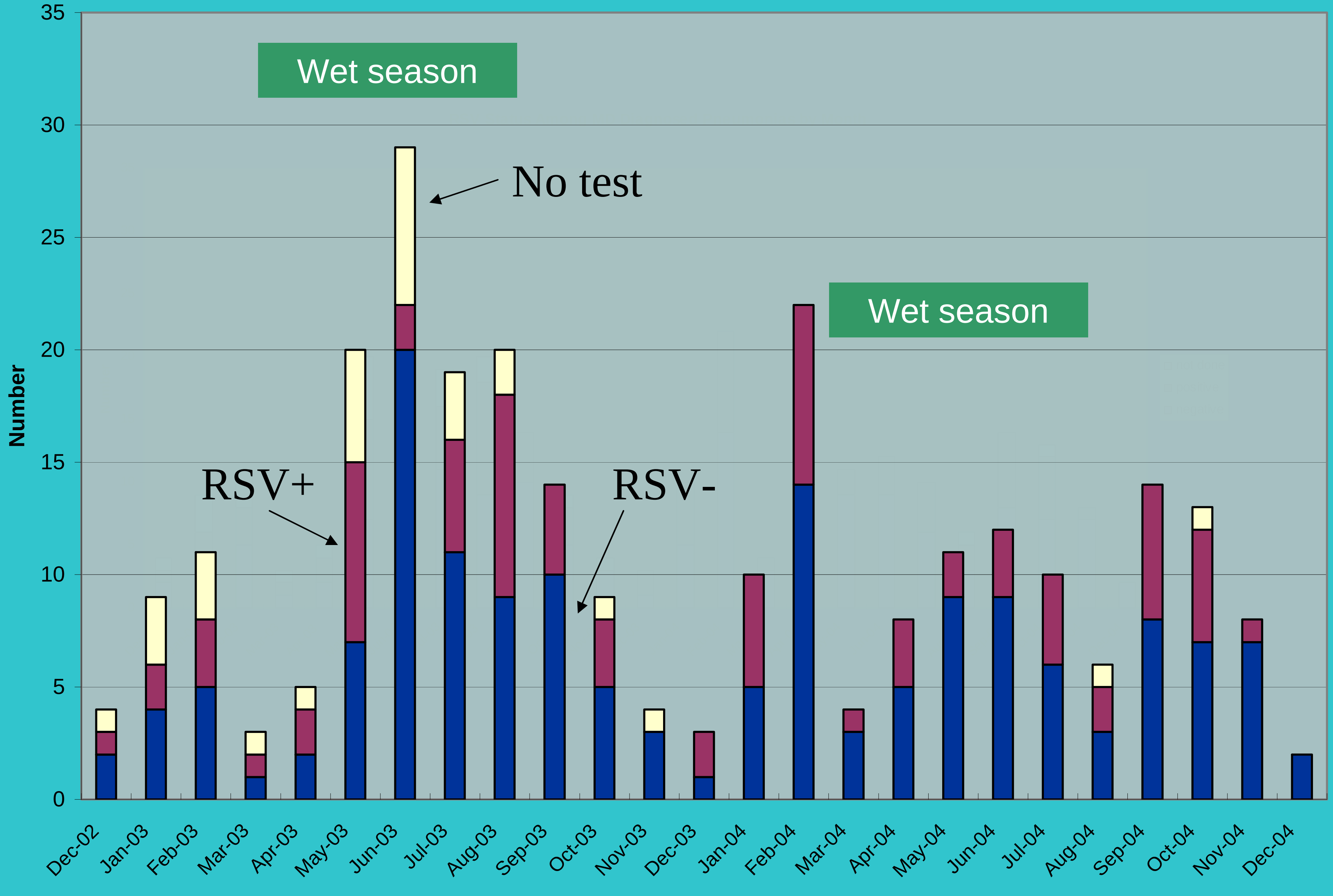
PHYSICIAN ASSESSMENT

- Clinical assessment is the key outcome
- Needed to standardise
- Six employed (four assessed 96.4% referrals)
- Use of agreed terms and signs
- Initial 'calibration' and ongoing ($\pm$ monthly) clinical sessions

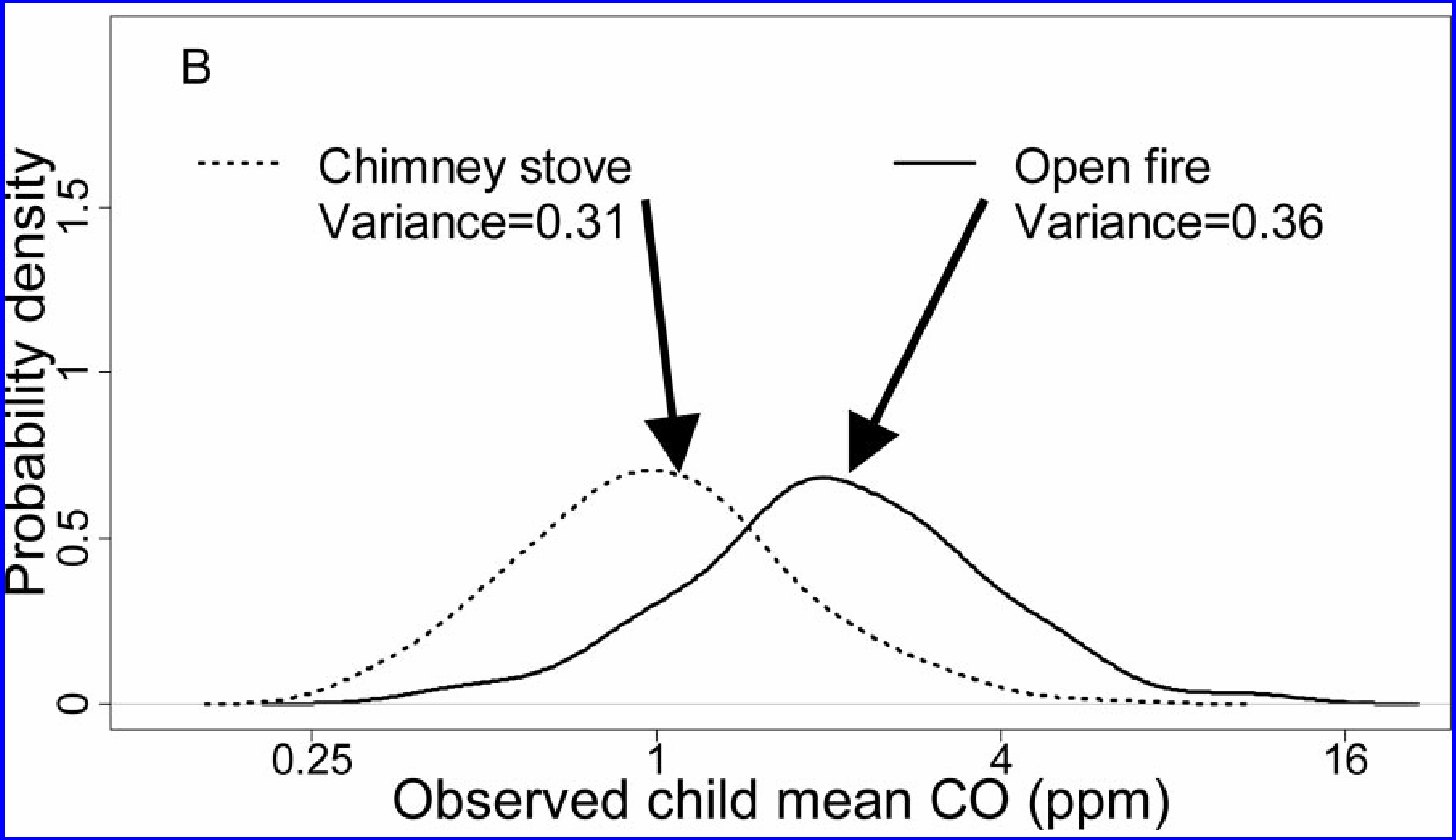
PULSE OXIMETRY

- Non-invasive and well-accepted (99%)
- Measure of severity (of respiratory illness):
  - mortality up to x5 in hypoxaemic
- Well children (n=55)
  - Mean (SD) 93.2% (3.0)
  - Hypoxaemic defined as mean – 2SD = 87%
- Bogota (5d – 24mo) altitude 2640m, mean (SD) 93.3% (2.1)

Pneumonia by month and RSV status

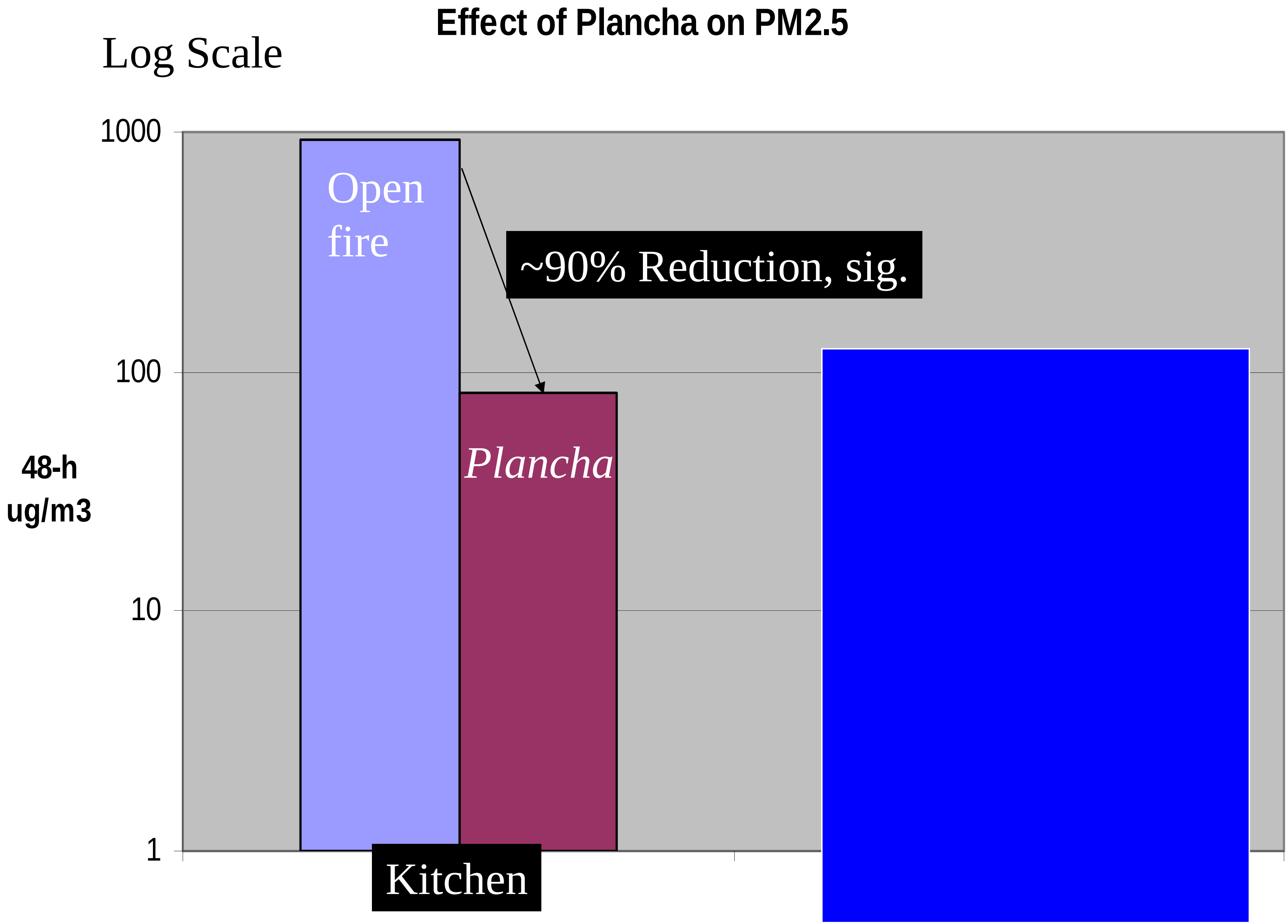



Tubito
Tubito



What a Well-Operating Chimney Does

McCracken, et al., 2009


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

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

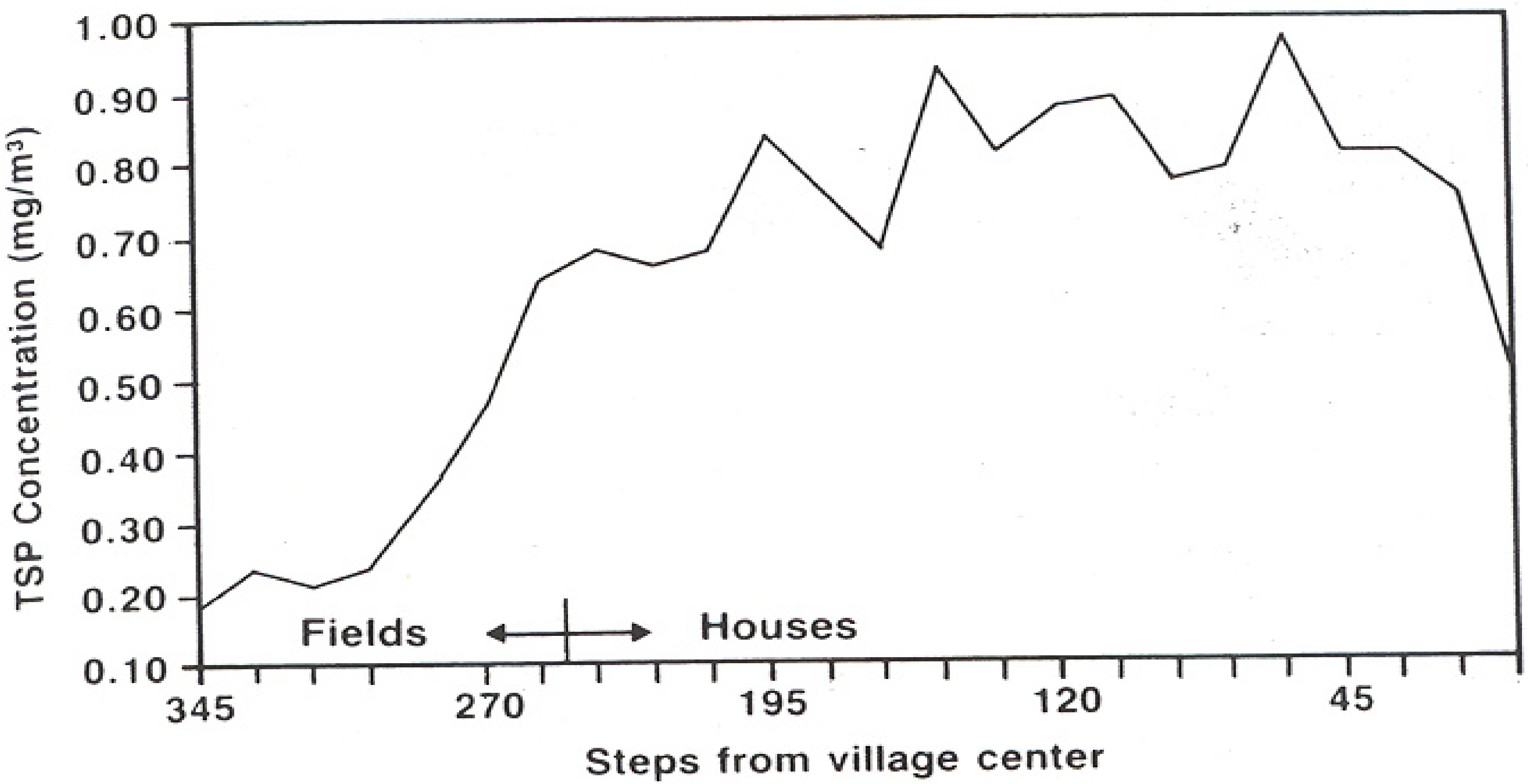
Regrets/KR Smith

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

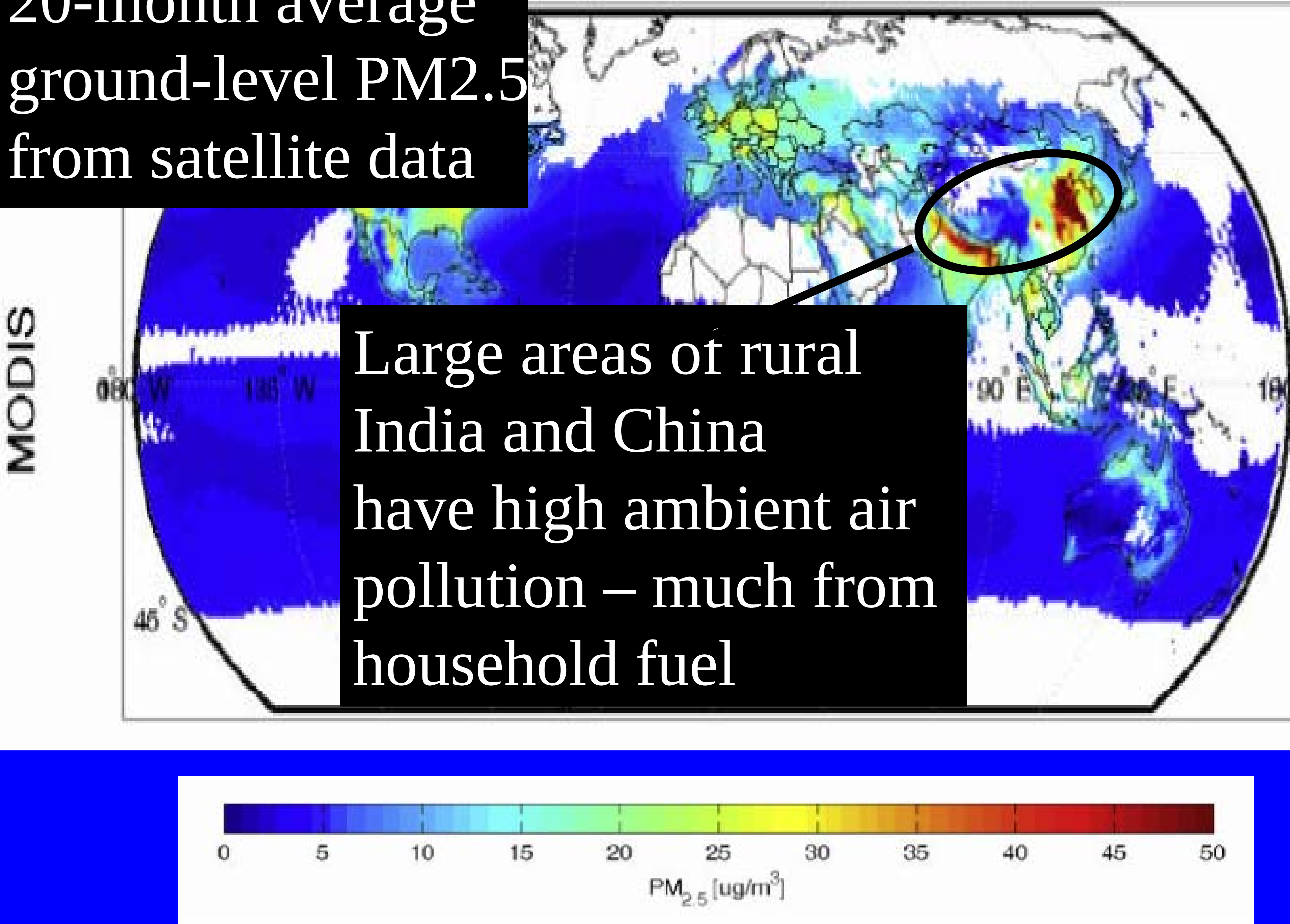

Neigborhood Pollution
Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM

Neighborhood Pollution in an Indian Village



Smith, 1987

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

China National Stove Contest - 2007

	CO/CO2	Efficiency %	PM g/kg
Coal#	[illegible]	[illegible]	1.6
Tradition[illegible]	[illegible]	[illegible]	4.0
Biomass[illegible]			
Daxu	[illegible]	[illegible]	0.28
Jinqilin	[illegible]	[illegible]	0.20
Xintai	[illegible]	[illegible]	0.36
Zhengho[illegible]	[illegible]	[illegible]	0.24

<u>Compared to traditional biomass stove</u>

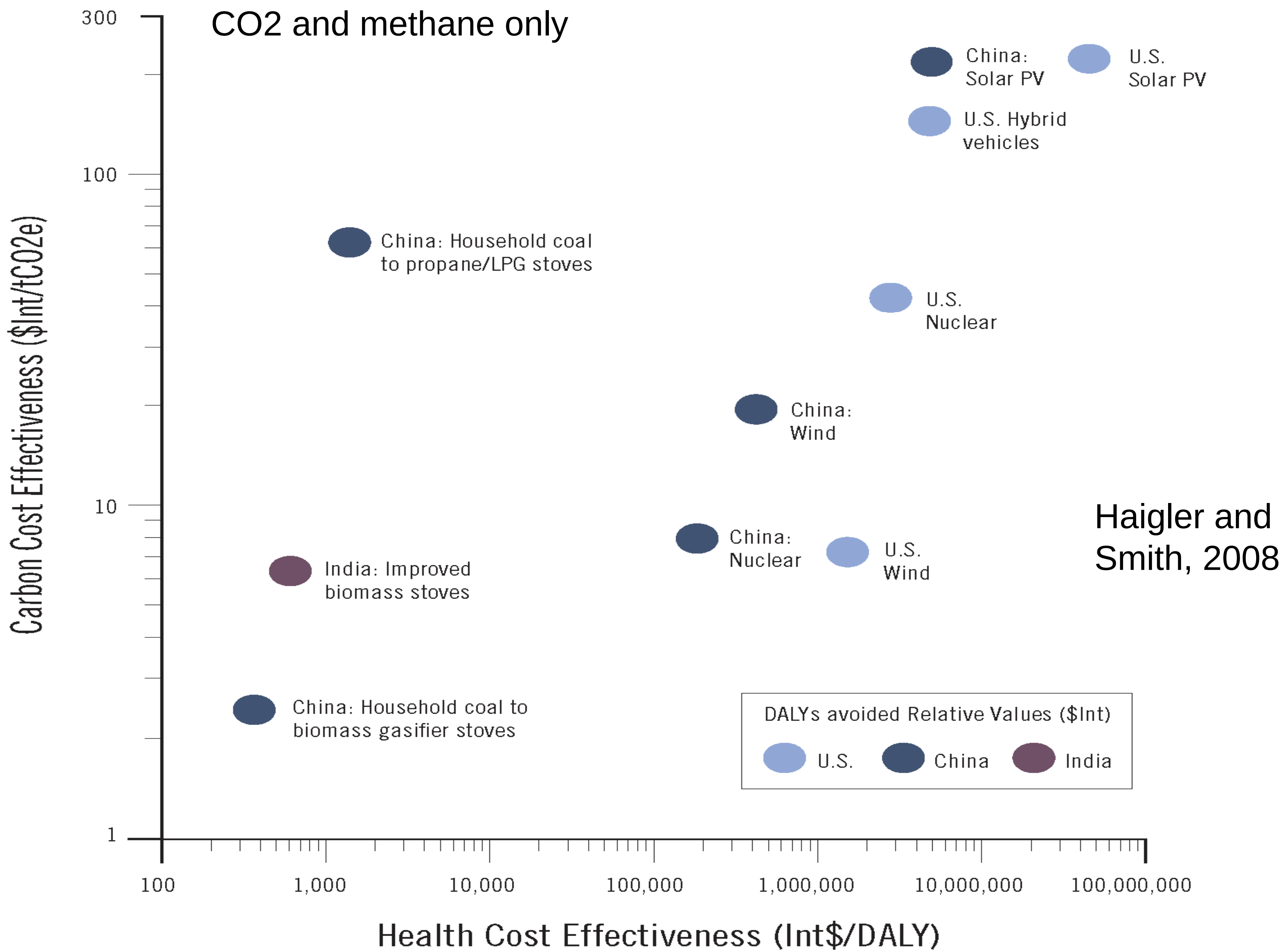
28.7 g to 1.2 g small particles/meal

>20x less

Zhang, et al., 2000

*Not including water heating function


矛盾
08.11.2008



CO2 and methane only
300
100
10
1
Carbon Cost Effectiveness ($Int/tCO2e)
China: Solar PV
U.S. Solar PV
U.S. Hybrid vehicles
China: Household coal to propane/LPG stoves
U.S. Nuclear
China: Wind
China: Nuclear
U.S. Wind
India: Improved biomass stoves
China: Household coal to biomass gasifier stoves
DALYs avoided Relative Values ($Int)
U.S.
China
India
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
Health Cost Effectiveness (Int$/DALY)
Haigler and Smith, 2008

Why M&E?
You don't get what you expect, but what you inspect

Abandoned improved stove, *Guatemala*

Misplaced self-polluting chimney, *Guatemala*

Standard Methods are too slow, too imprecise, too labor intensive, and too expensive for use with millions of stoves

Fuel savings *estimation through KPT (kitchen performance test) and sales records*

Monitoring ***reductions in indoor air pollution and black carbon emissions***

Tracking ***drop out rates*** *through surveys, visits and phone interviews*

What can be done?

Where can we monitor what we do?

Small, Smart, Fast, and Cheap monitors

Available or under testing

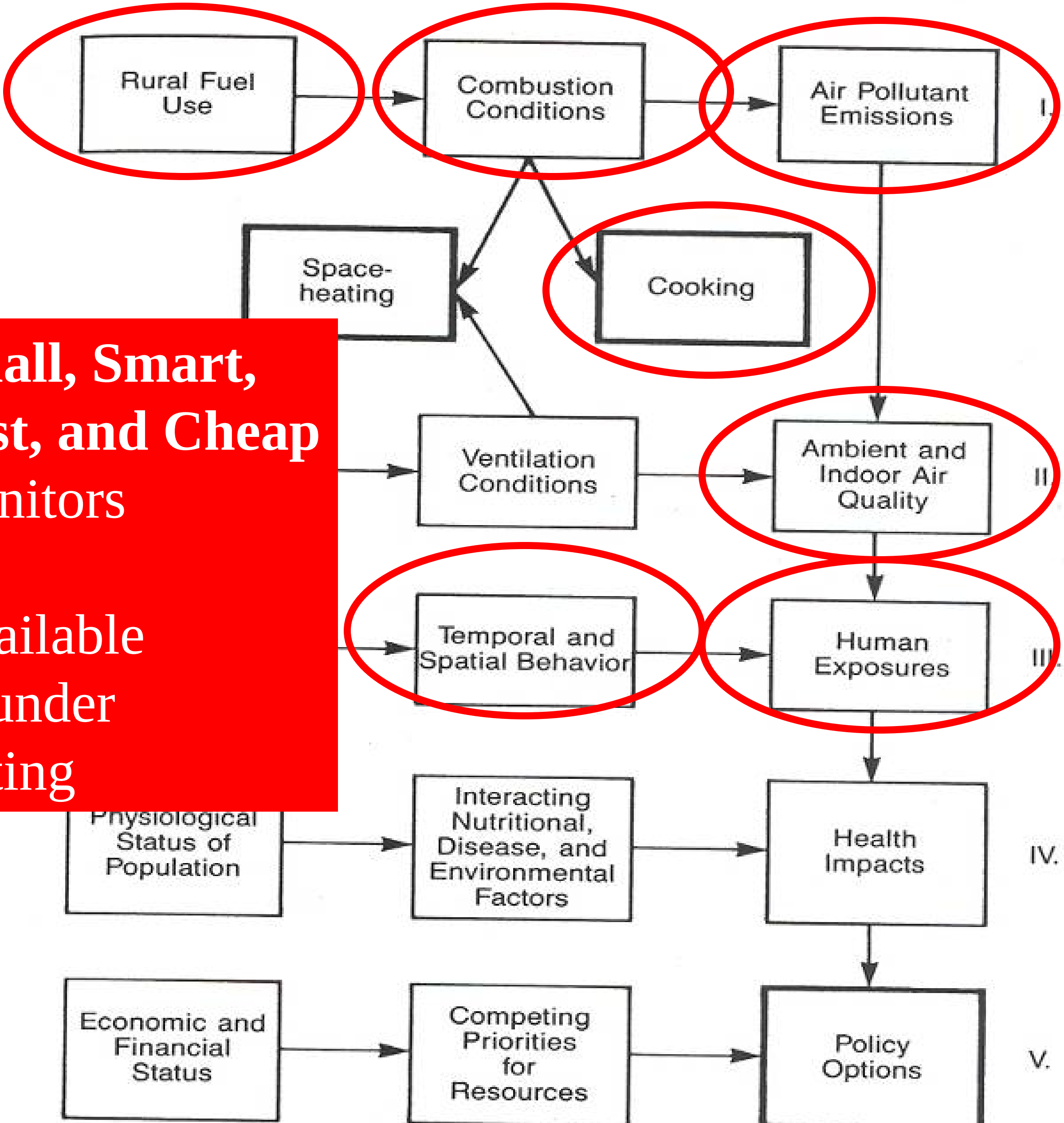


Figure 1.8. Categorization and flowchart of separate topics involved in investigating the extent and impact of air pollution exposures from combustion of biofuels in developing countries. Modified from Smith *et al.* (1983).

Smith, 1983

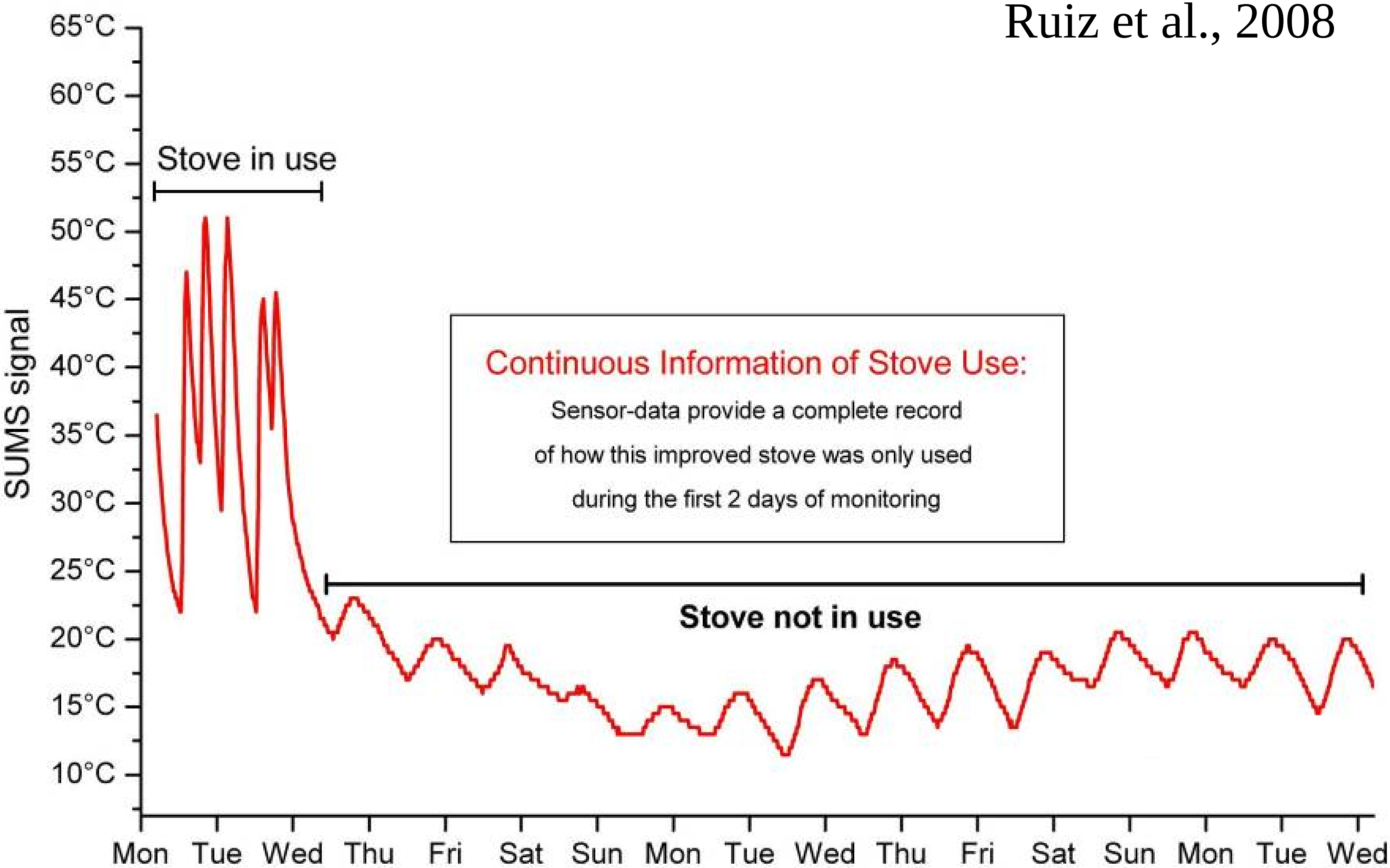
UCB-SUMS:
The Stove Use Monitoring System

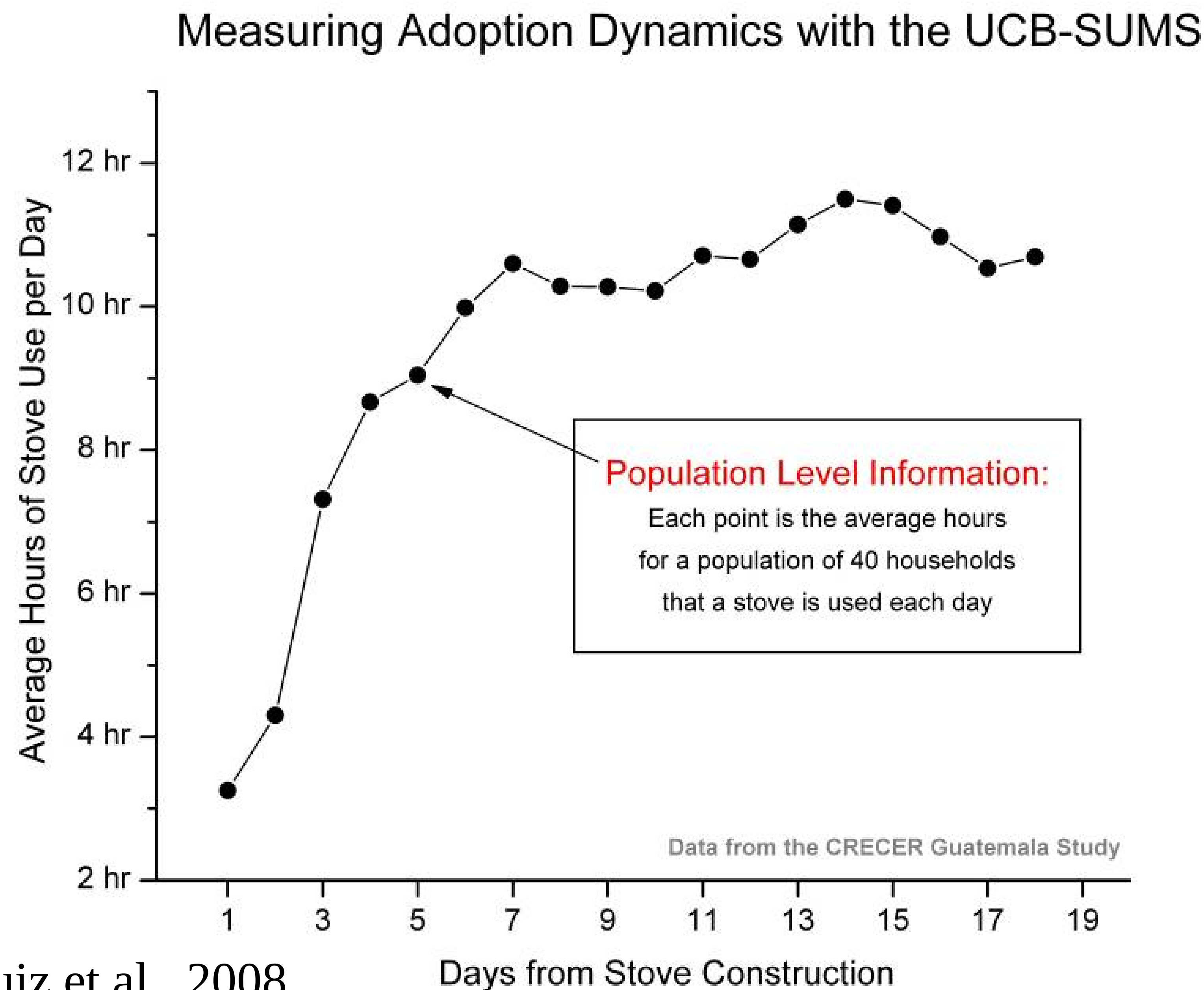
***Fuel savings** quantification using the SUMS system*

*Monitoring **drop out rates** and **patterns of use** with the SUMS system*

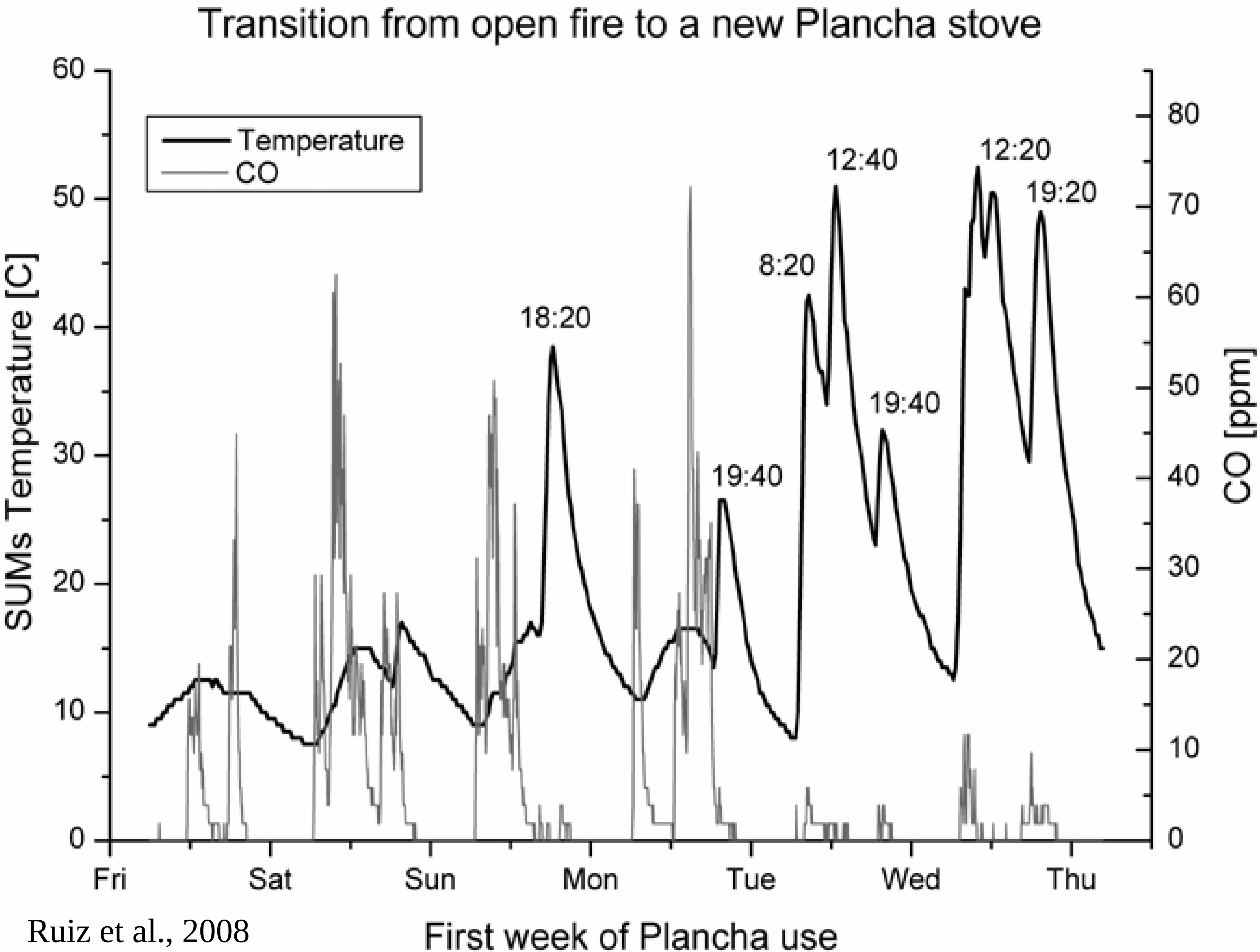
Objective Monitoring with the UCB-SUMS System

Ruiz et al., 2008



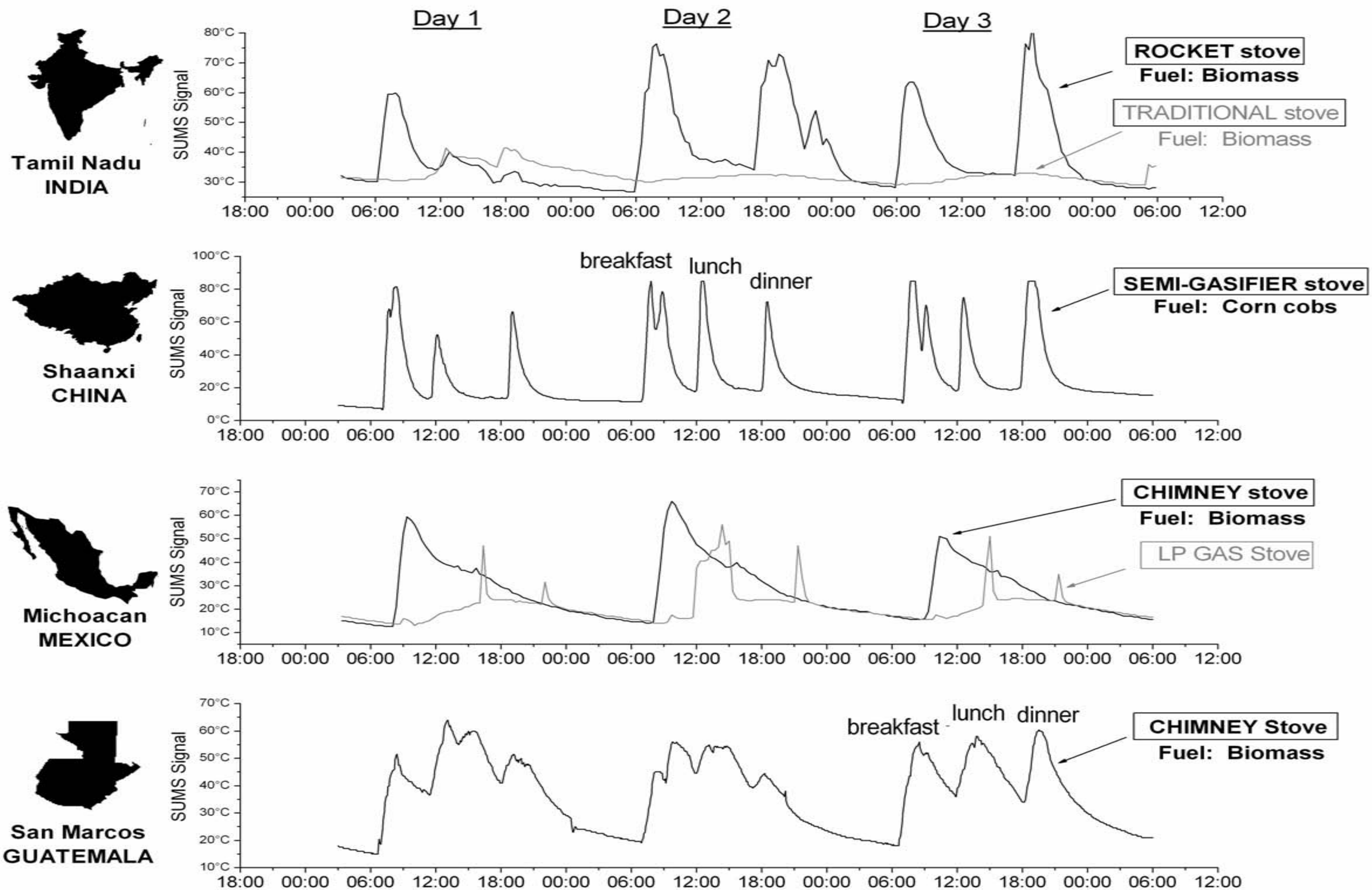


Ruiz et al., 2008



Ruiz et al., 2008

Patterns of Stove Use from Around the World
captured with the UCB-SUMS



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 bad 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 – hundreds of times worse.

Combustion Mismanagement and Health

- Sticking burning stuff in your mouth
- In your home
- In your workplace
- In your community
- On your planet

Combustion Risk Factor	Million Deaths	Percent of Global Deaths	Percent of Disease Burden
Tobacco	4.9	8.7%	4.1%
Indoor smoke from household solid fuel	1.6	2.9	2.6
ETS and Workplace	0.5	0.6	1.5
Urban outdoor air pollution	0.80	1.4	0.8
Climate change	0.15	0.3	0.4
Adjusted totals	**~ 8**	**~ 14%**	**~ 10%**

The Unfinished Agenda

- Products of Incomplete Combustion, an ancient but still large risk to health and climate

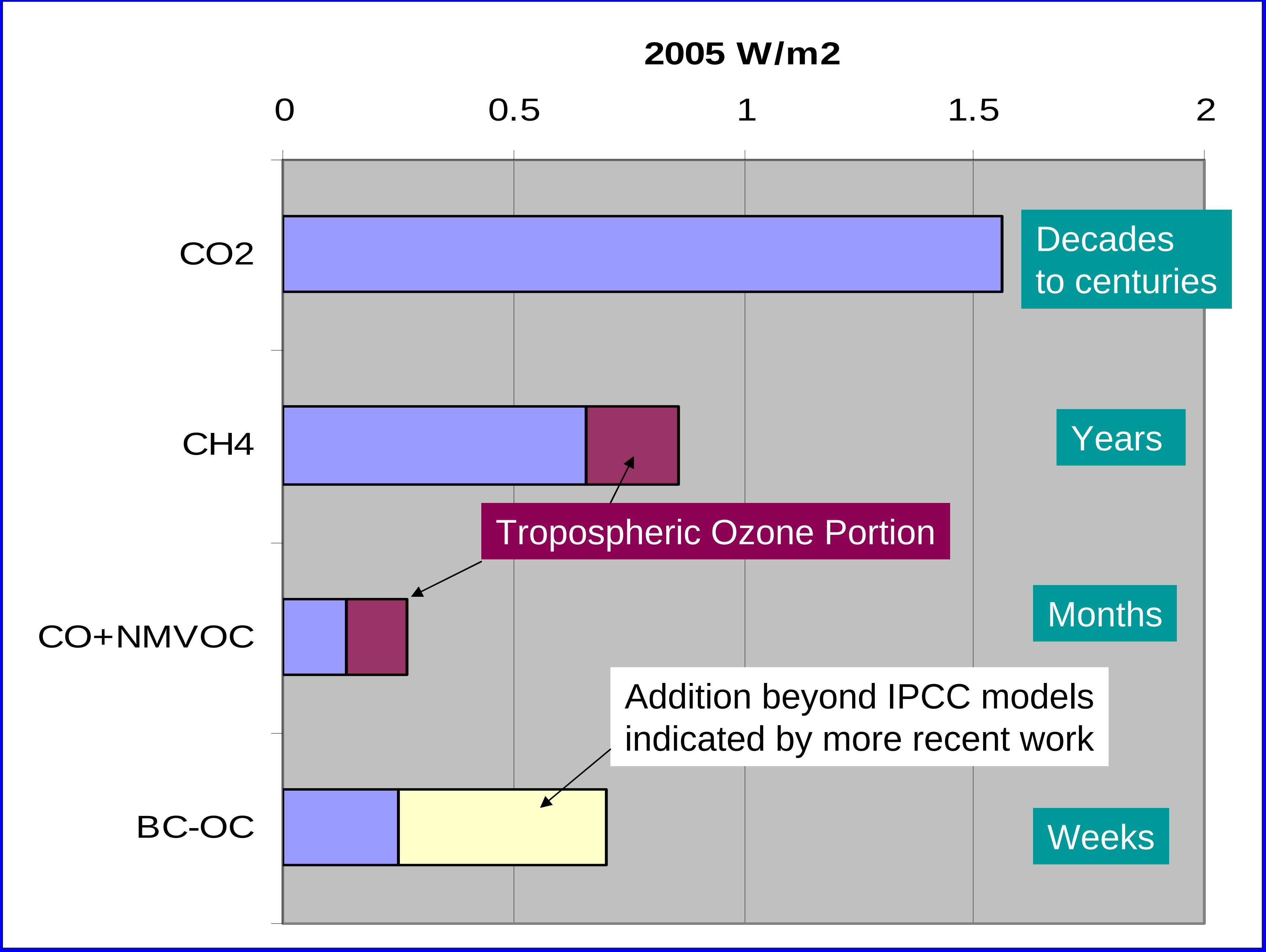
- One out of seven deaths each year occurs prematurely because of combustion mismanagement - PIC

- As PIC, a major reason for global warming – nearly half that from CO_2

- Short-lived – fix today and many impacts stop in a few months – all in a few years

- Time to move on

Warming from Carbon Emissions Since 1750



Stove Dissemination Lessons

- Need to start in places/populations where success is easier and quicker
- Need to create a modest range of models for different fuels, foods, and incomes – perhaps designed to be phased (model for bride, for the first child, etc)
- Need to have sophisticated supply chains to assure quality and availability
- Need to consider innovative financing approaches to lower perceived cost to households (micro-finance, smart subsidies, etc.)
- Need to consider dissemination in conjunction with other widespread programs, e.g., pre-natal care
- Need to create incentives for purchase and proper use: marketing and service contracts

Technical Lessons

- Extremely low emissions are possible with good designs, particularly “semi-gasifier” stoves
- Better to have low emissions than rely on chimney, but reliability of low emissions an issue particularly with fuel variability
- Best to have both: chimneys will last longer with lower emissions
- Hybrid designs (with electric blowers) may have sufficiently reliable low emissions to be promoted without chimneys
- Need to have robust devices that require as little operator thinking as possible
- Need to move to manufactured units made with ceramic and/or metal to maintain performance

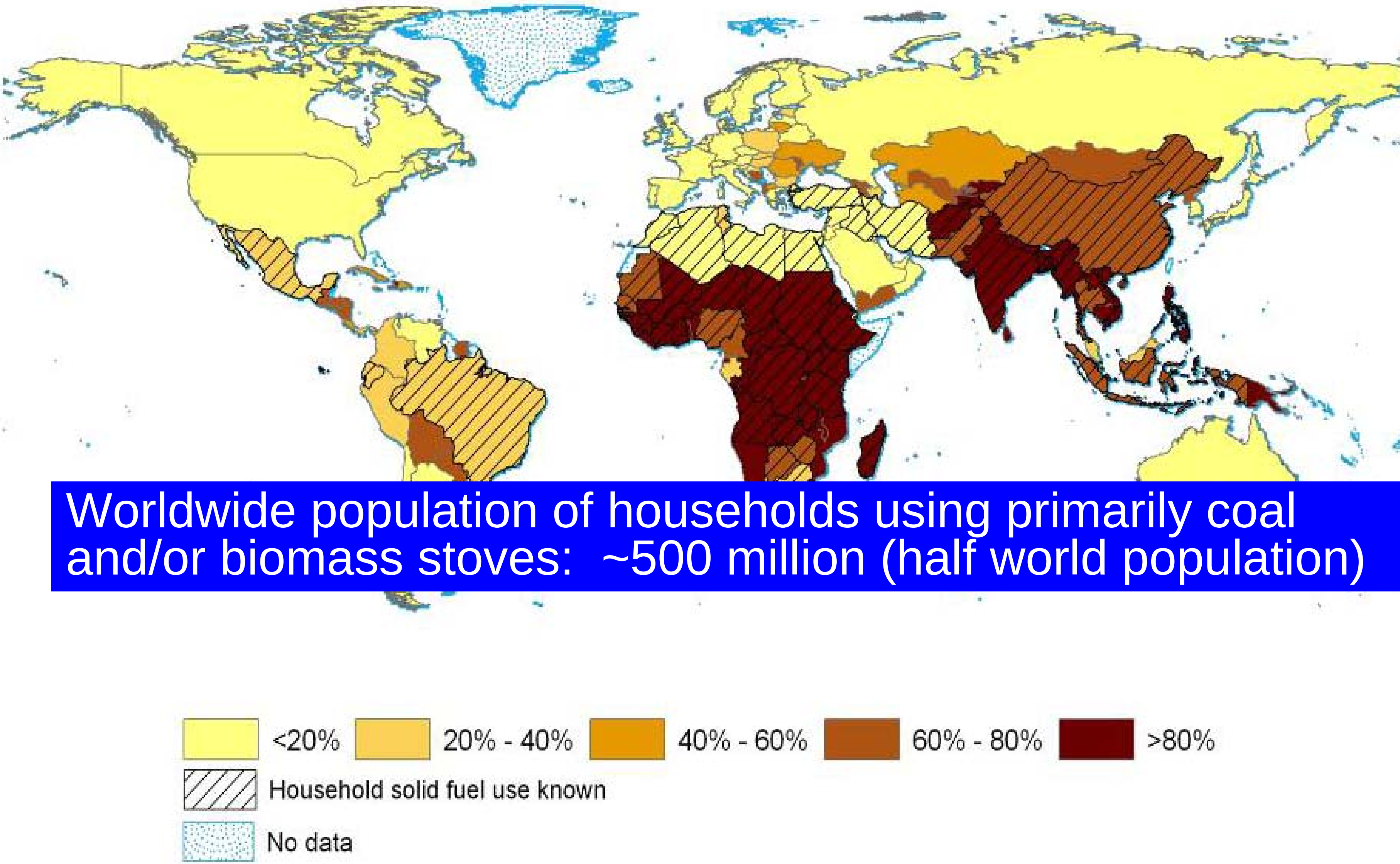
Joint Lessons

- Need to incorporate both lab and field-based M&E for determining impact and providing mid-course corrections
- Need to have government certification/ benchmarking as with other household appliances
- Protection of IPR will be important at some stage
- Only government and private business probably have sufficient capabilities for the sustained effort to deal with the hundreds of millions needed
- As a purely market-based approach will probably not be able to disseminate technology of sufficient performance, a hybrid approach is needed until rural incomes grow.

Bottom lines

- Health effects information is growing – more diseases and age groups
- RESPIRE provides first serious exposure-response data for one major endpoint – child pneumonia (ALRI)
  - Consistent with outdoor air pollution studies
  - Non-linear at higher levels
- Chimneys alone do not seem to reduce exposures down to levels sufficient to fully protect health
- Need to move to low-emission stoves ASAP
- M&E is vital, but new methods needed for interventions measured in 10s of millions of households

National Household Solid Fuel Use, 2000



Worldwide population of households using primarily coal and/or biomass stoves: ~500 million (half world population)

On behalf of all my colleagues and students

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And to all our participants and fieldworkers

Publications available at
http://ehs.sph.berkeley.edu/krsmith/