Worldwide Biomass Combustion: Energy, Air Pollution, and Health

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International Biomass Smoke
Health Effects Conference

University of Montana, Missoula
Center for Environmental Health Sciences

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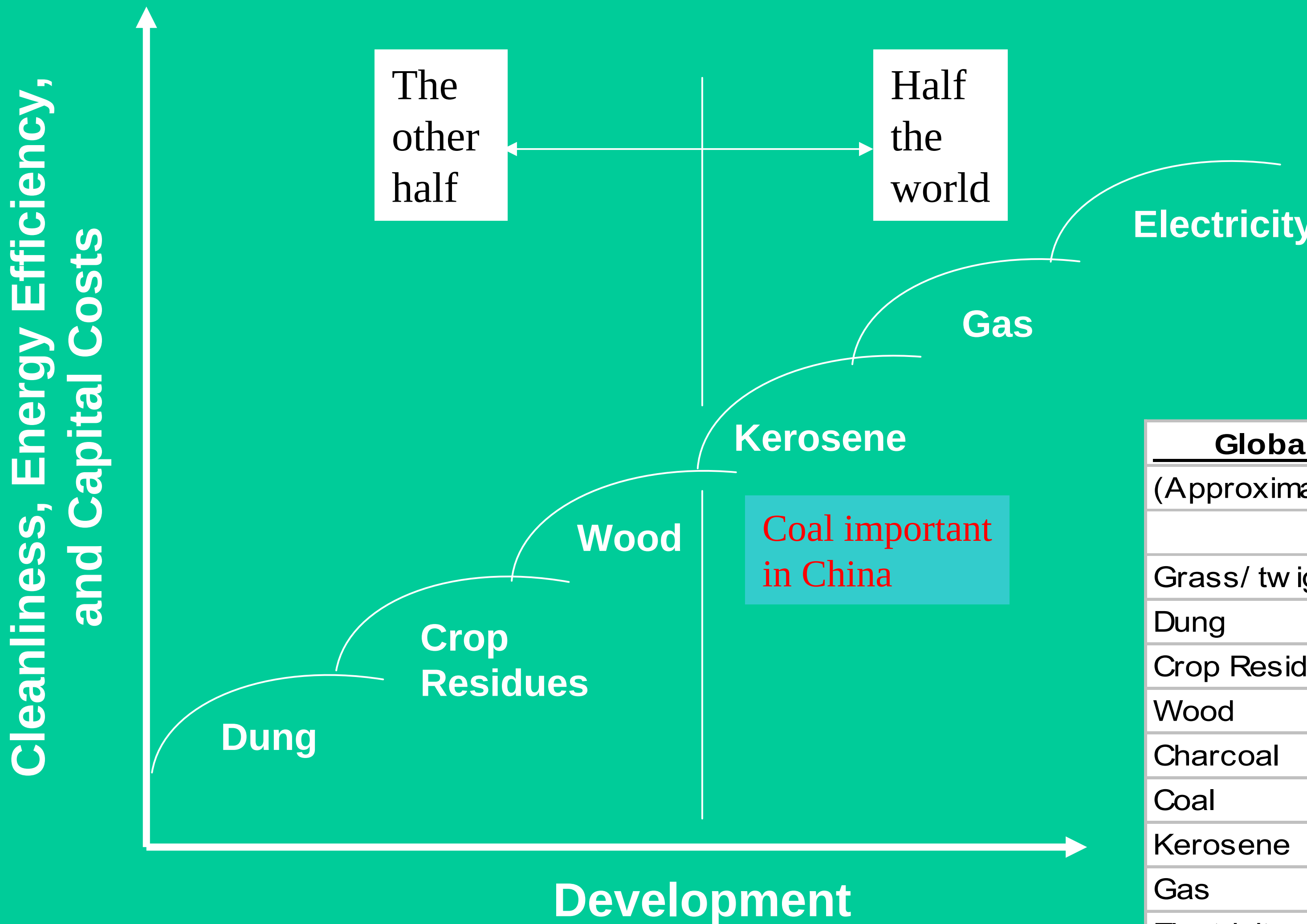
Itinerary Biomass Combustion

- Biomass combustion in the world
  – Fuel and non-fuel
  – Rich and poor
- Air pollution from biomass
  – Emissions
  – Exposures
- Health effects
  – Burden of disease calculations
  – Randomized trial in Guatemala

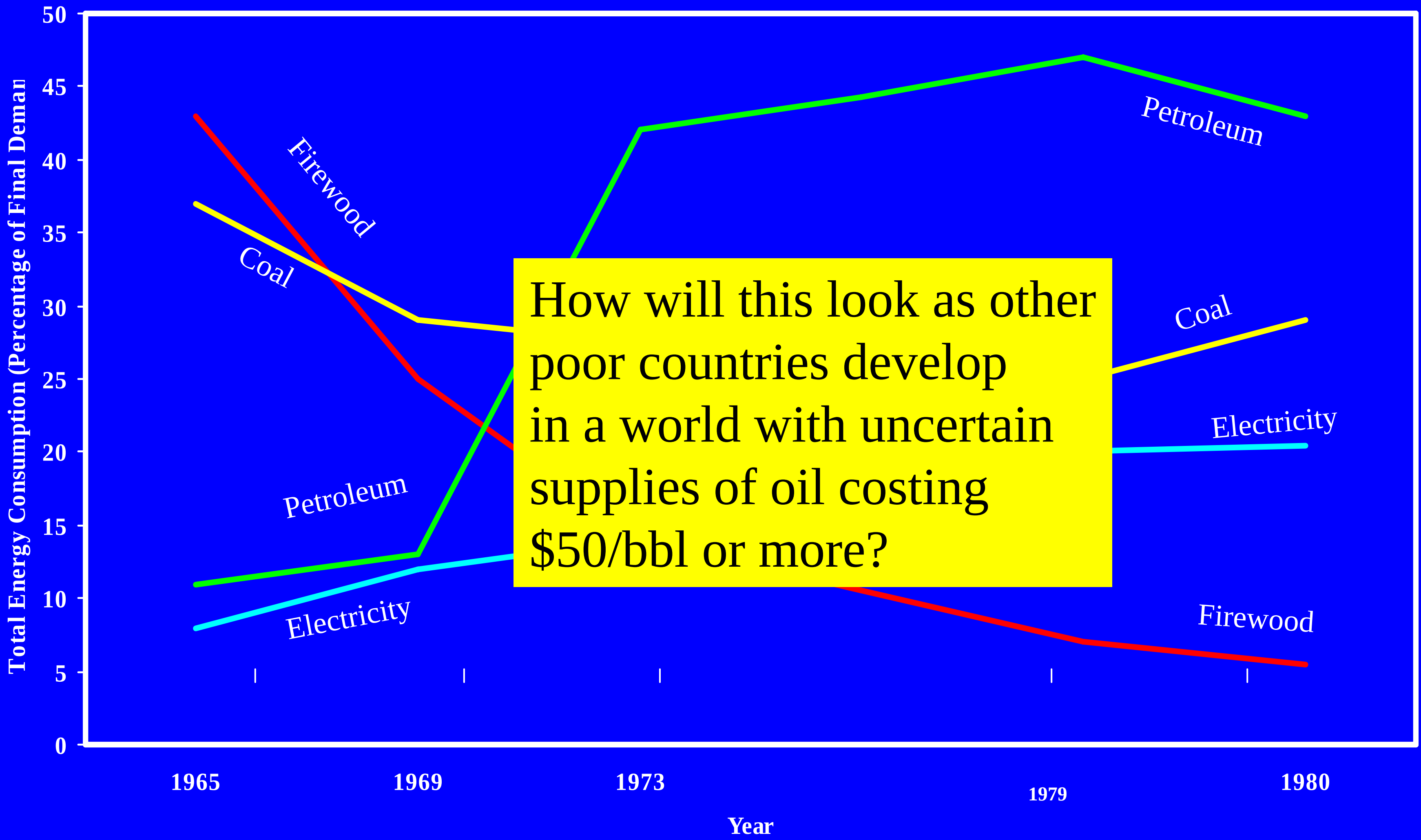
Oldest Pollution Source in Human History

Typical Household Energy Ladder



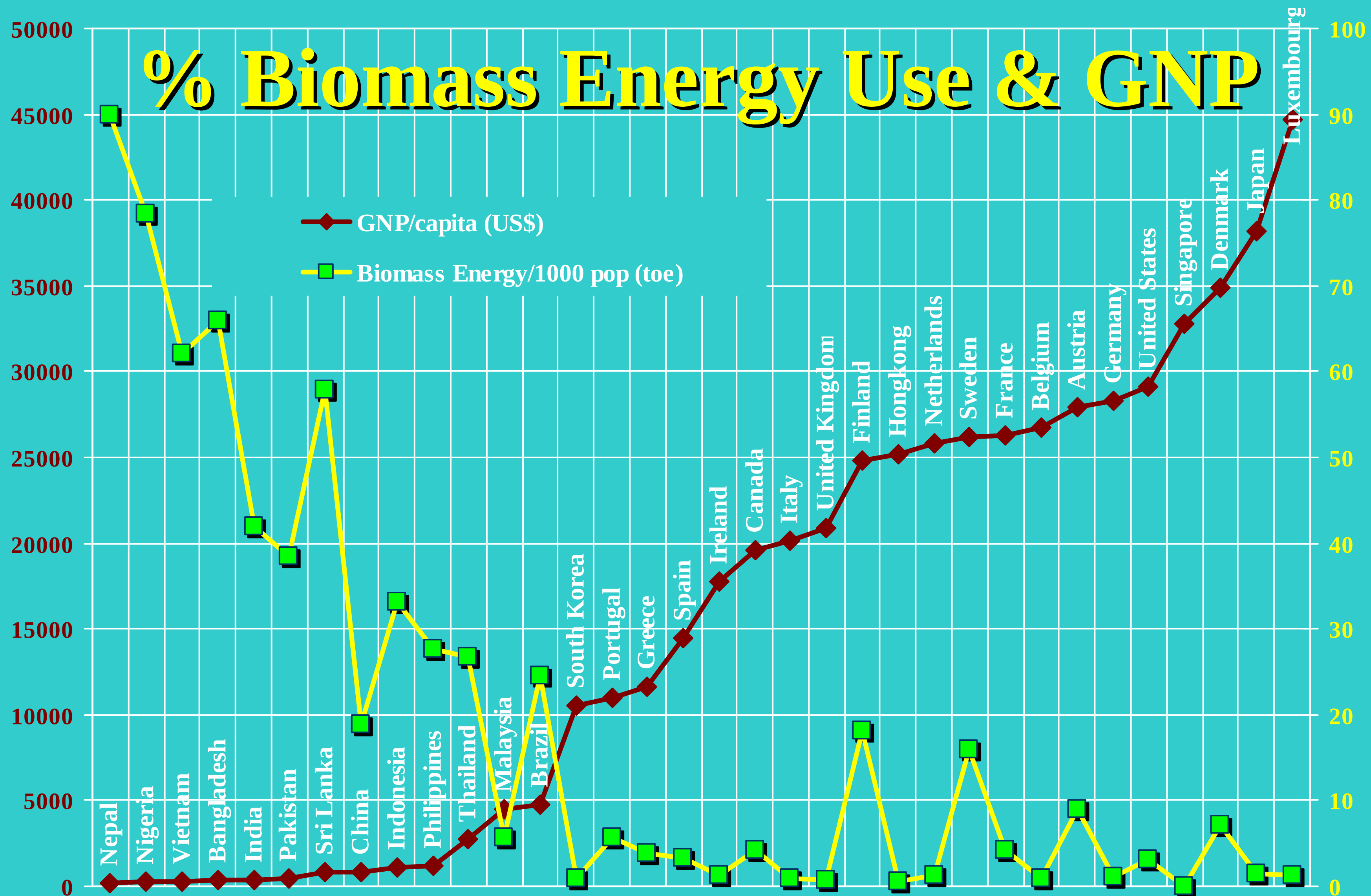
Global Energy Ladder		
(Approximate % of Population)		
Grass/ twigs	2	
Dung	4	
Crop Residues	18	
Wood	22	
Charcoal	4	
Coal	6	
Kerosene	10	
Gas	20	
Electricity	14	
1% = 60 million people		

Post - Biomass Energy Transition in the Republic of Korea, 1965-1980

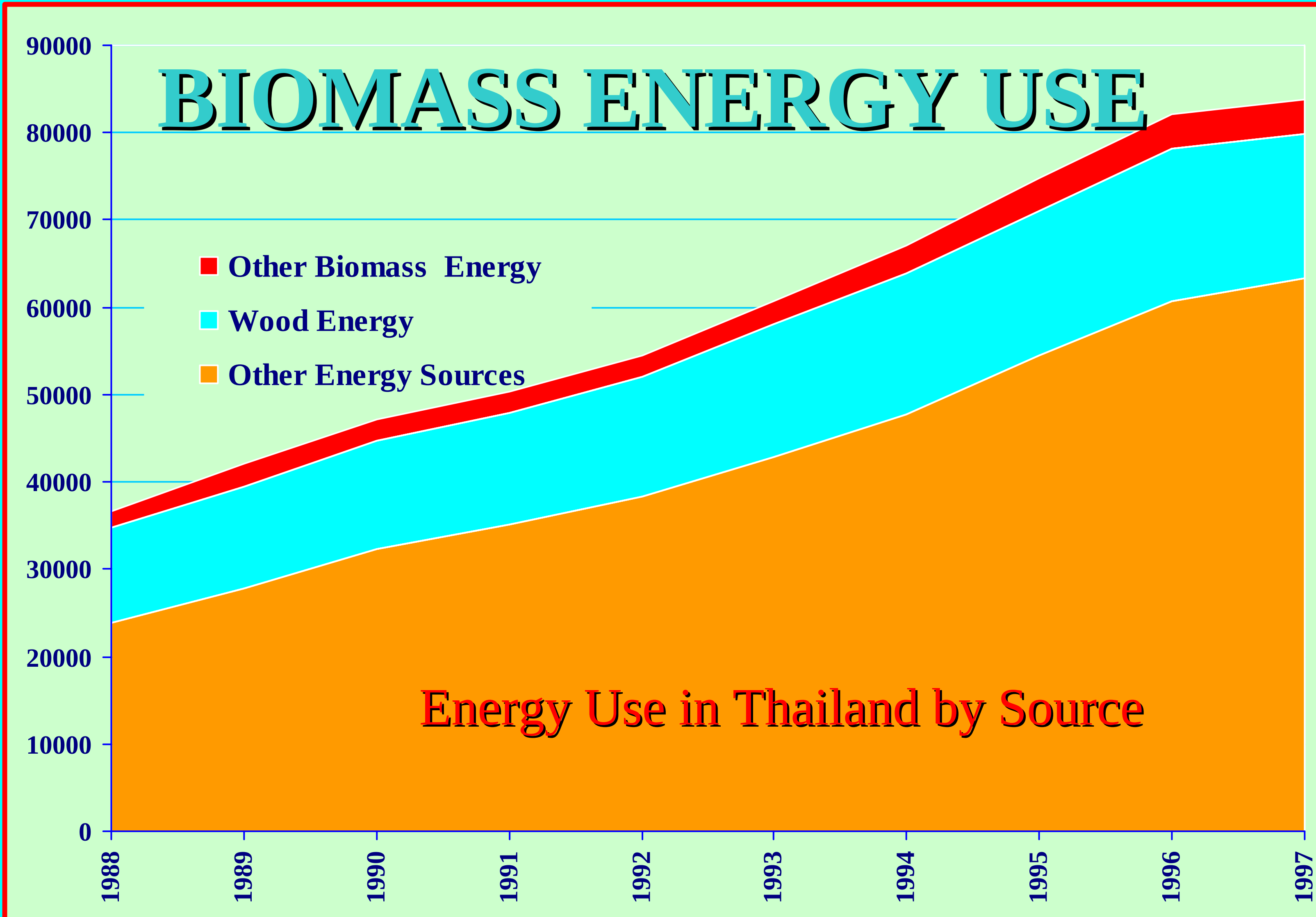


How will this look as other poor countries develop in a world with uncertain supplies of oil costing $50/bbl or more?

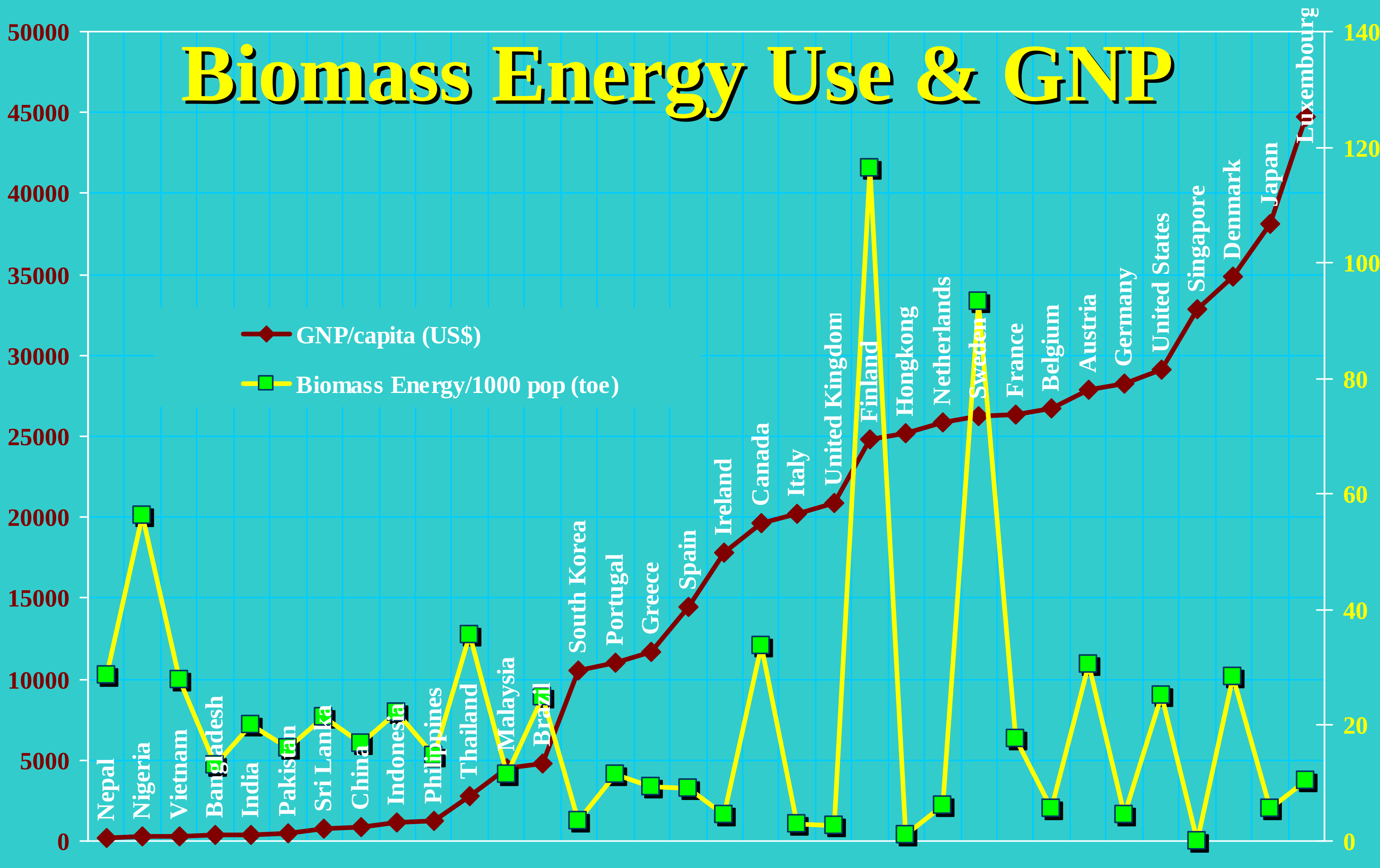
% Biomass Energy Use & GNP



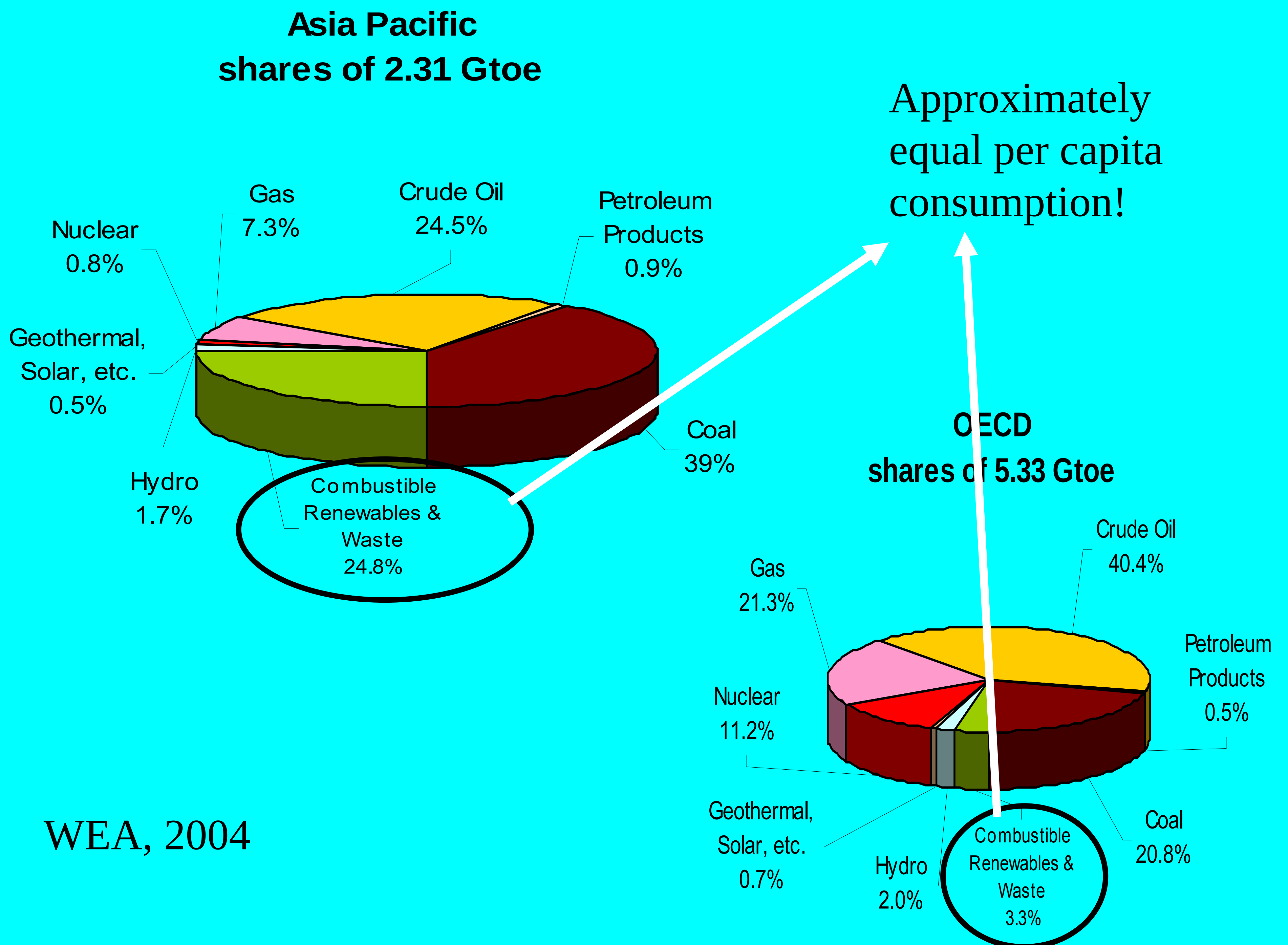
Source: RWEDP

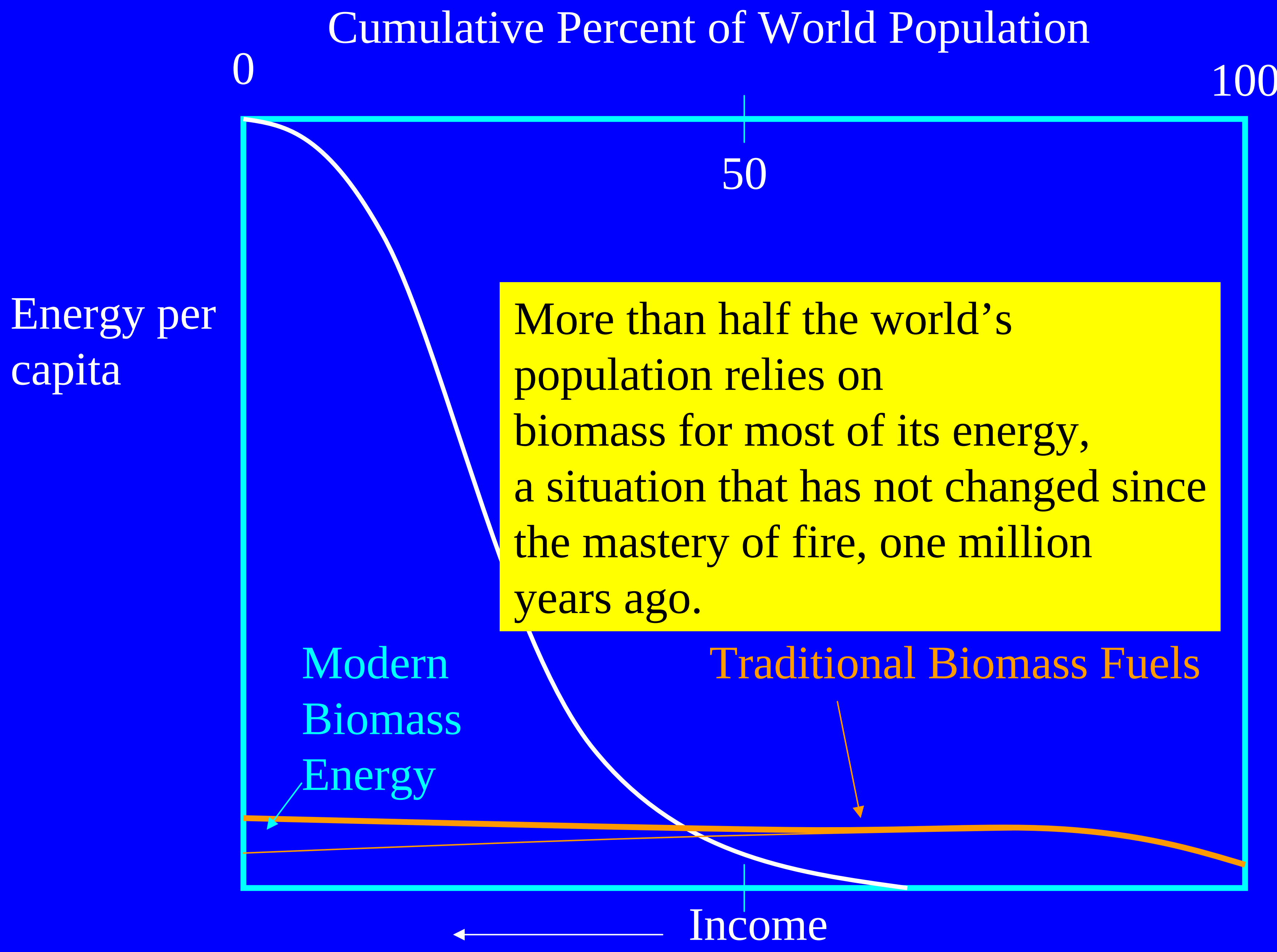


Source: RWEDP



Source: RWEDP

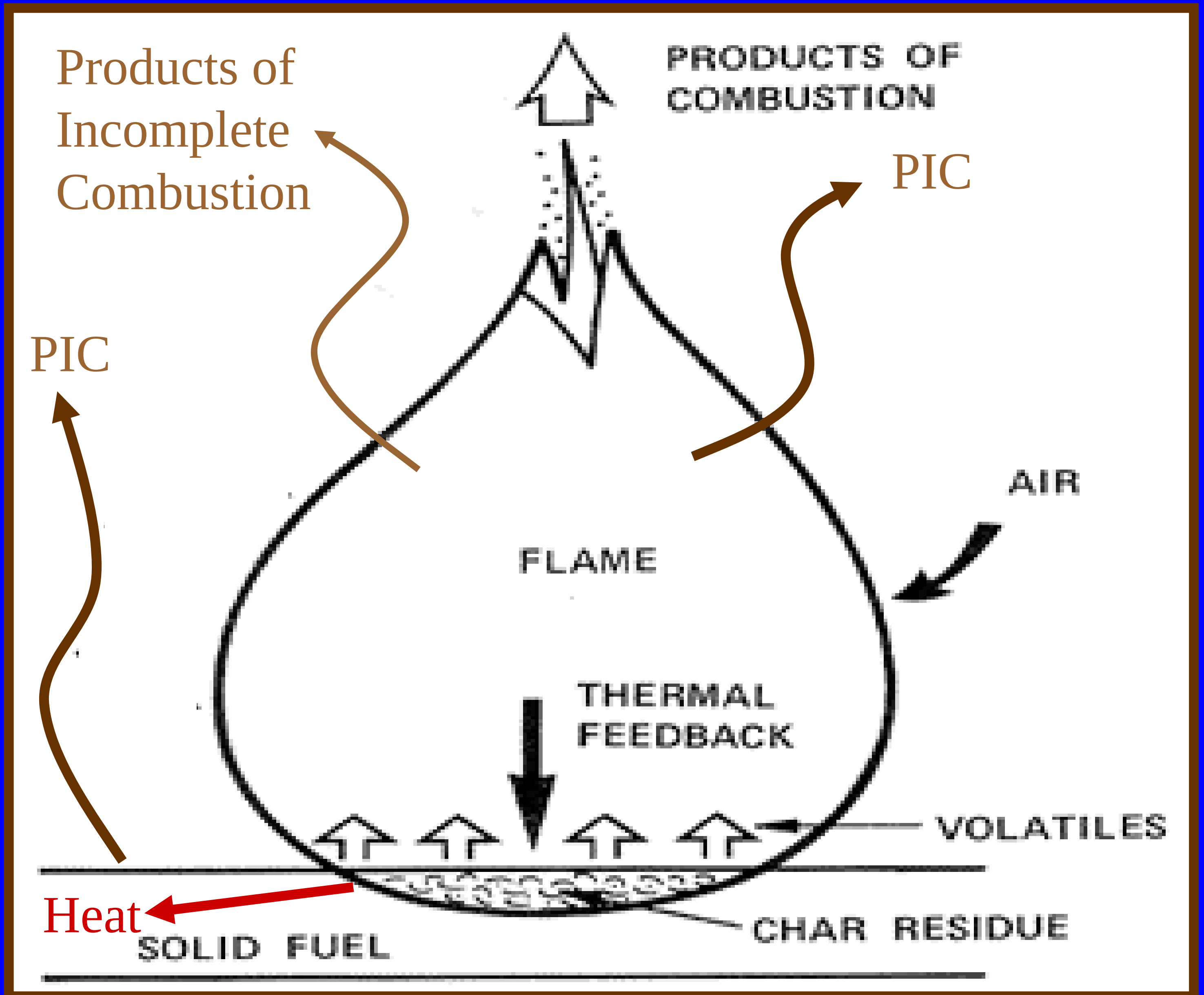

Asia Pacific
shares of 2.31 Gtoe
Nuclear 0.8%
Gas 7.3%
Crude Oil 24.5%
Petroleum Products 0.9%
Geothermal, Solar, etc. 0.5%
Coal 39%
Hydro 1.7%
Combustible Renewables & Waste 24.8%
Approximately equal per capita consumption!
OECD
shares of 5.33 Gtoe
Crude Oil 40.4%
Gas 21.3%
Petroleum Products 0.5%
Nuclear 11.2%
Geothermal, Solar, etc. 0.7%
Hydro 2.0%
Combustible Renewables & Waste 3.3%
Coal 20.8%
WEA, 2004

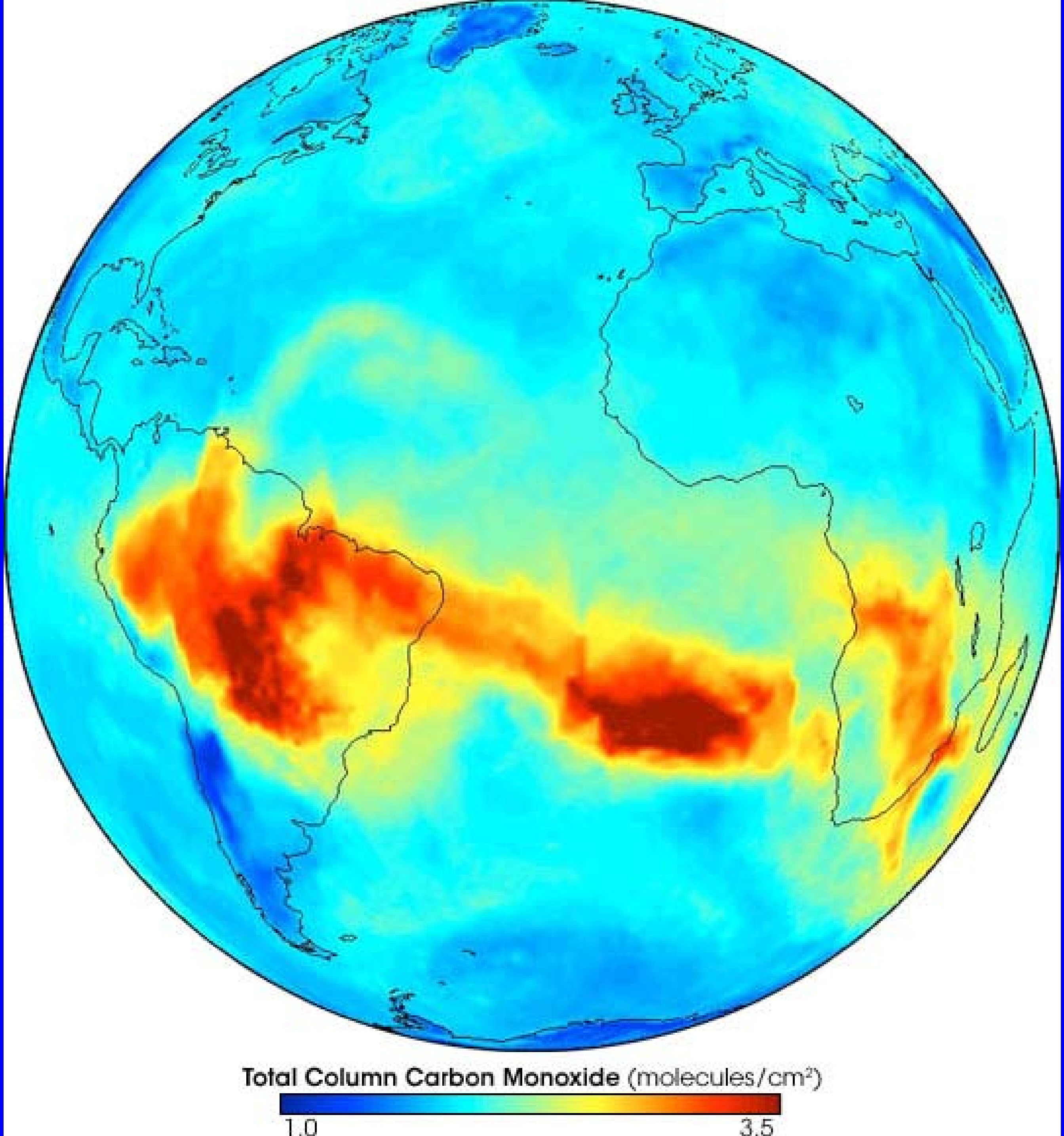

Cumulative Percent of World Population
0
100
50
Energy per capita
More than half the world's population relies on biomass for most of its energy, a situation that has not changed since the mastery of fire, one million years ago.
Modern Biomass Energy
Traditional Biomass Fuels
Income

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%


Products of Incomplete Combustion
PRODUCTS OF COMBUSTION
PIC
PIC
AIR
FLAME
THERMAL FEEDBACK
VOLATILES
Heat
SOLID FUEL
CHAR RESIDUE



CO levels
Sep 2005

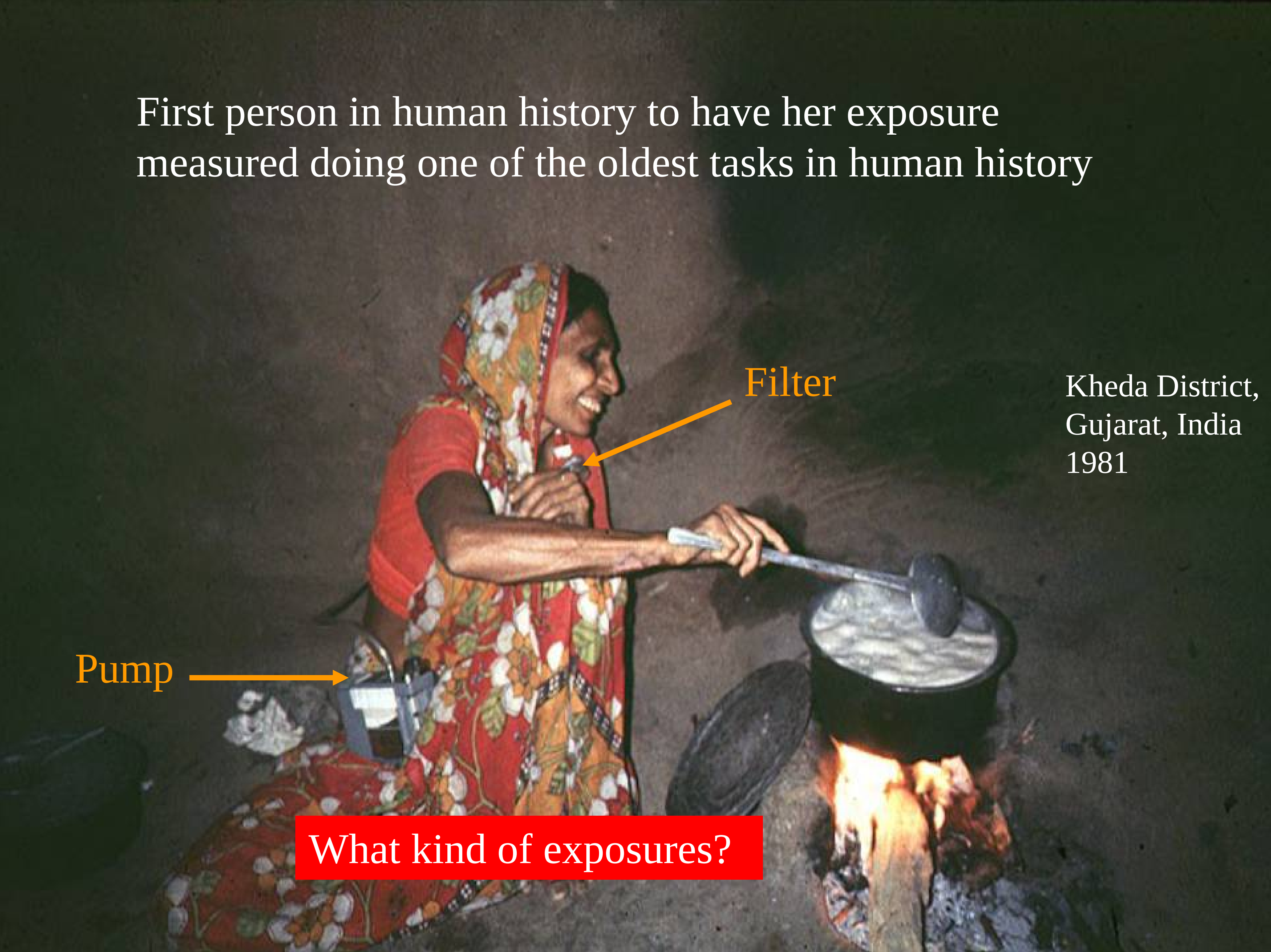
Indian Cookstoves

Nominal Combustion Efficiency

- Gas: ` 99% (98-99.5)
- Kerosene: 97 (95-98)
- Solid Fuels
- Wood: 89 (81-92)
- Crop resid: 85 (78-91)
- Dung: 84 (81-89)
- Coal (variable)

NCE = Carbon as CO2 /carbon in fuel burned

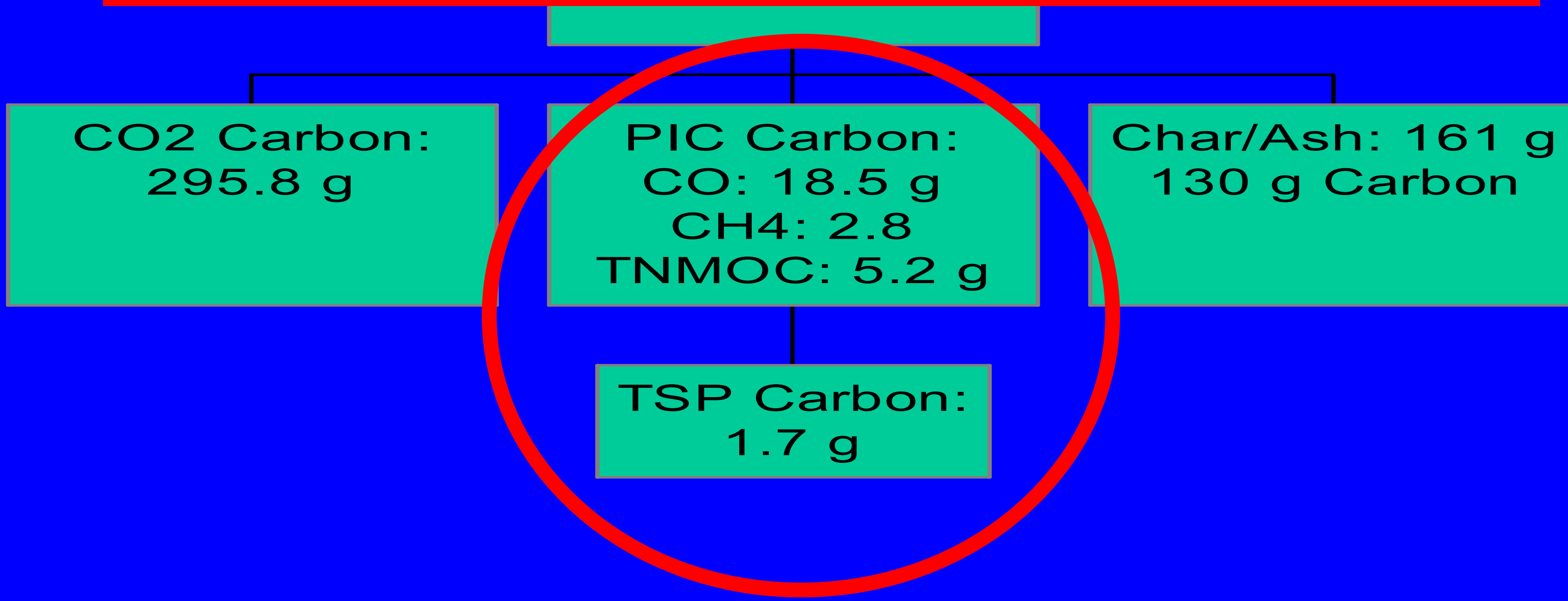
Source: Smith, et al, 2000
Census, 2001


First person in human history to have her exposure measured doing one of the oldest tasks in human history
Filter
Kheda District, Gujarat, India 1981
Pump
What kind of exposures?

Carbon Balance:

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances



Nominal Combustion Efficiency = 1/(1+k) = 89%

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

- Small particles, C
- 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*

Best measure of risk
~ 0.1-0.4% of fuel weight

Naeher et al. 2007, JIT

Size Distribution of Biomass Smoke Particles

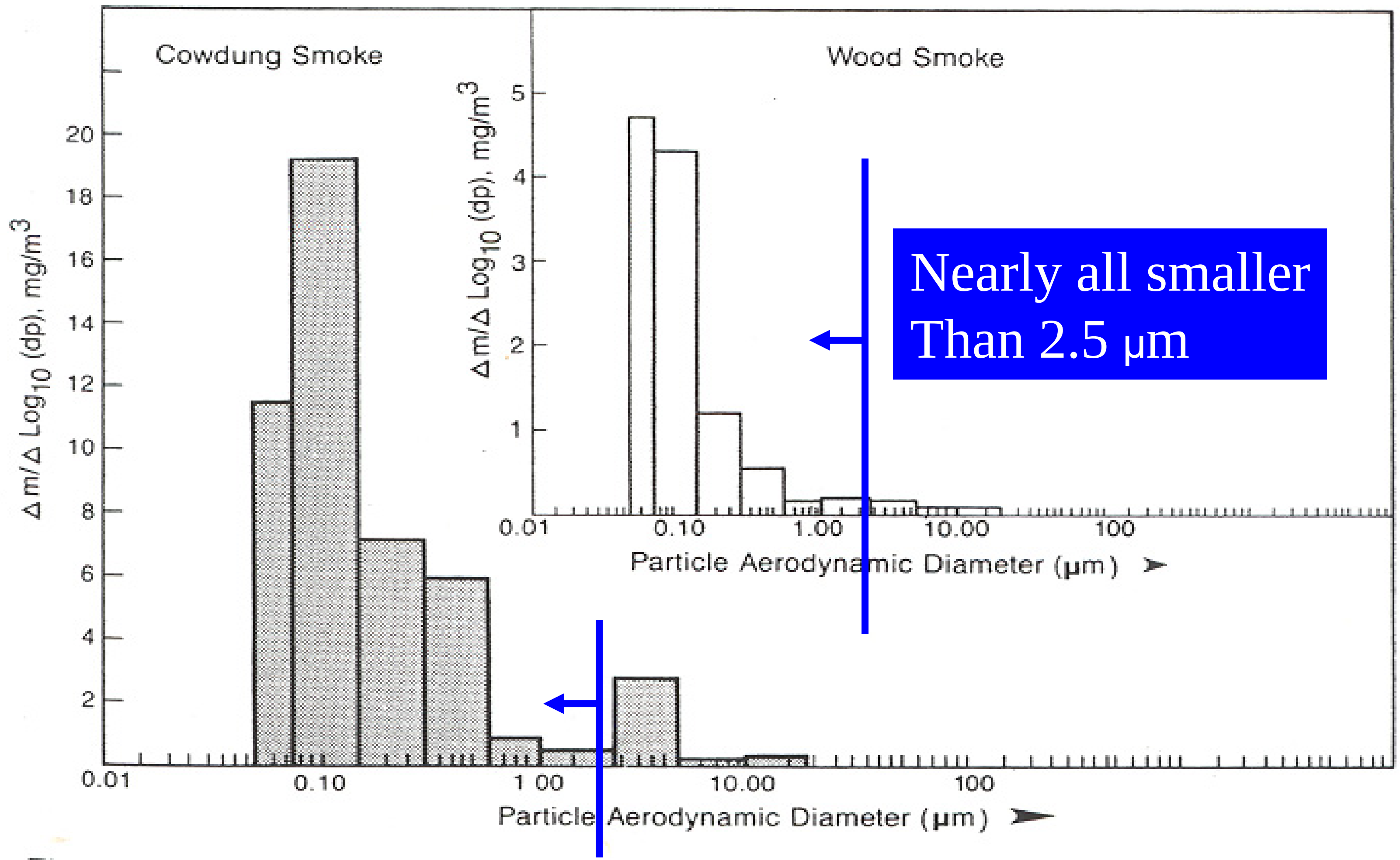
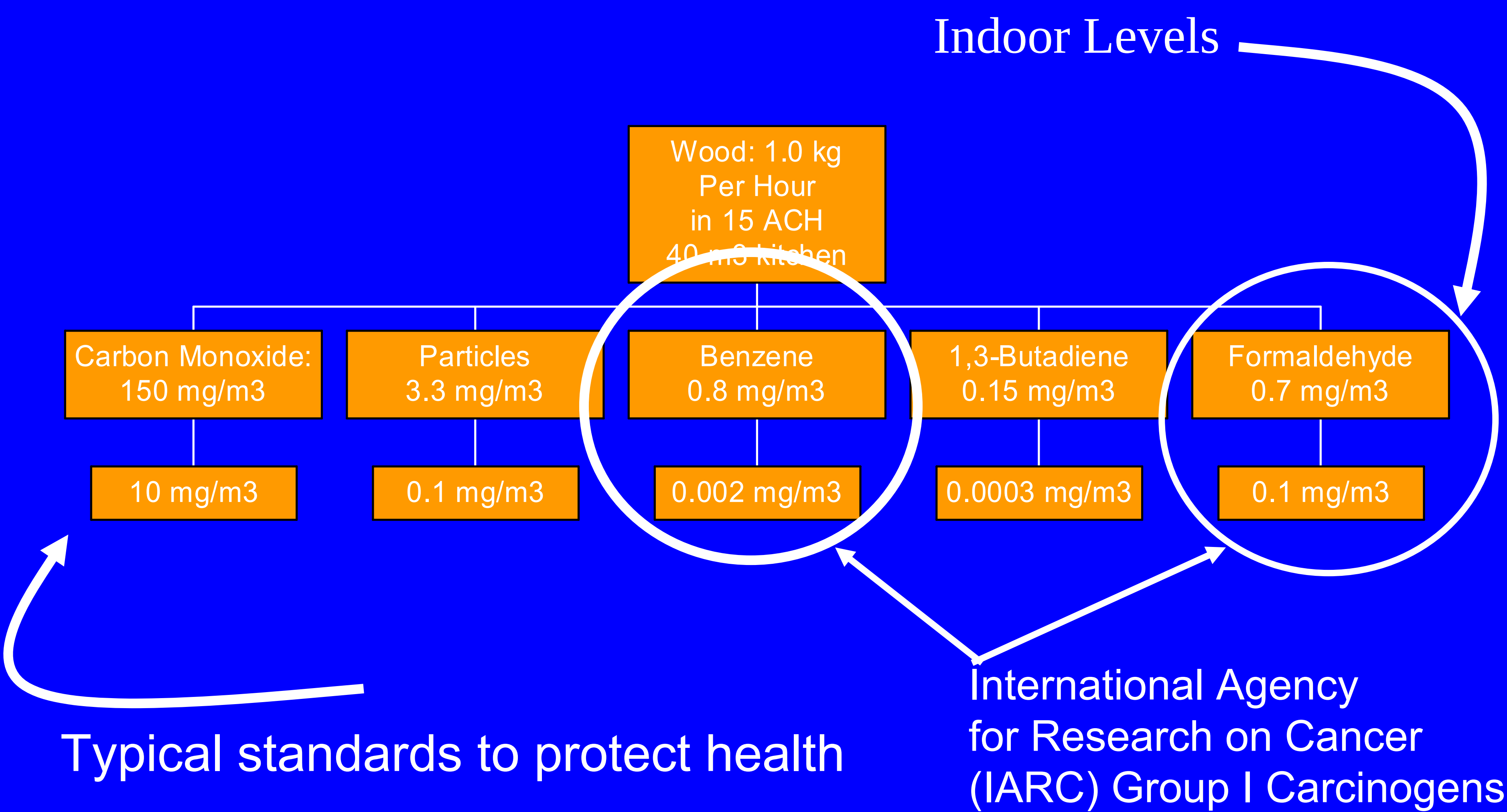


Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East–West Center simulated village house as reported in Smith *et al.* (1984b). (Figure prepared by Premlata Menon.)

Source: Smith, Apte et al. 1984

Indoor pollution concentrations from typical woodfired cookstove during cooking



All data contribute to an evaluation

Cancer in humans

Sufficient evidence
Limited evidence
Inadequate evidence
Evidence suggesting lack of carcinogenicity

Cancer in experimental animals

Sufficient evidence
Limited evidence
Inadequate evidence
Evidence suggesting lack of carcinogenicity

Mechanistic and other relevant data

For each mechanism:

- Mechanistic data "weak," "moderate," or "strong"?
- Mechanism likely to be operative in humans?

Overall evaluation

Group 1	*Carcinogenic to humans*
Group 2A	*Probably carcinogenic to humans*
Group 2B	*Possibly carcinogenic to humans*
Group 3	*Not classifiable as to its carcinogenicity to humans*
Group 4	*Probably not carcinogenic to humans*

A tour of IARC's classifications

— Preamble, Part B, Section 6(d)

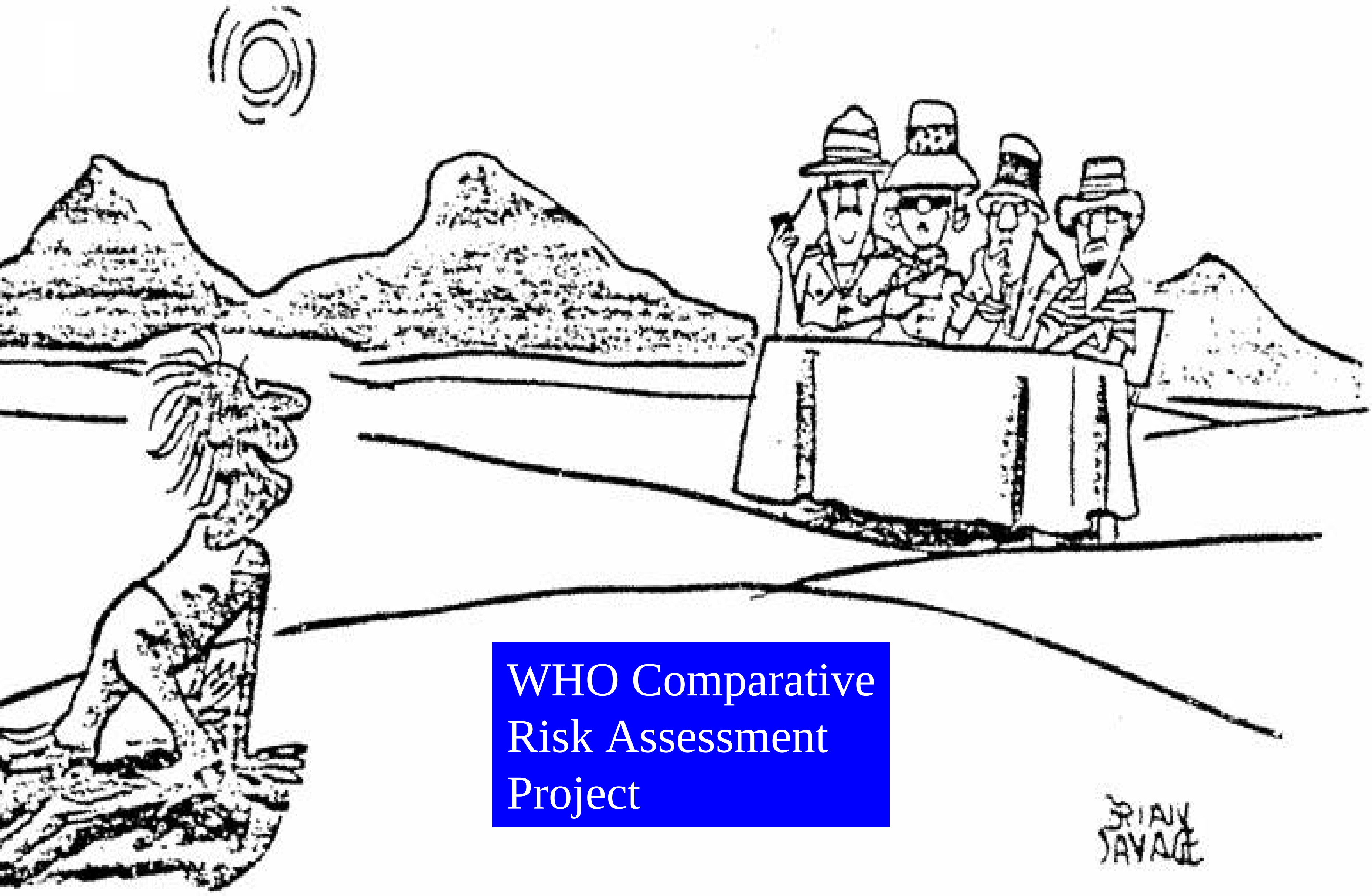
		EVIDENCE IN EXPERIMENTAL ANIMALS			
		Sufficient	*Limited*	*Inadequate*	*ESLC*
EVIDENCE IN HUMANS	*Sufficient*				
	Limited				
	Inadequate				
	ESLC				

Group 1 (*carcinogenic to humans*) whenever there is *sufficient evidence* in humans

EVIDENCE IN HUMANS	EVIDENCE IN EXPERIMENTAL ANIMALS: *Sufficient*	*Limited*	*Inadequate*	*ESLC*
Sufficient	Group 1			
Limited				
Inadequate				
ESLC				

Group 2A (*probably carcinogenic*) with *limited evidence* in humans and *sufficient evidence* in animals

EVIDENCE IN HUMANS	EVIDENCE IN EXPERIMENTAL ANIMALS: *Sufficient*	*Limited*	*Inadequate*	*ESLC*
Sufficient	Group 1			
Limited	Group 2A ←	Woodsmoke		
Inadequate				
ESLC				



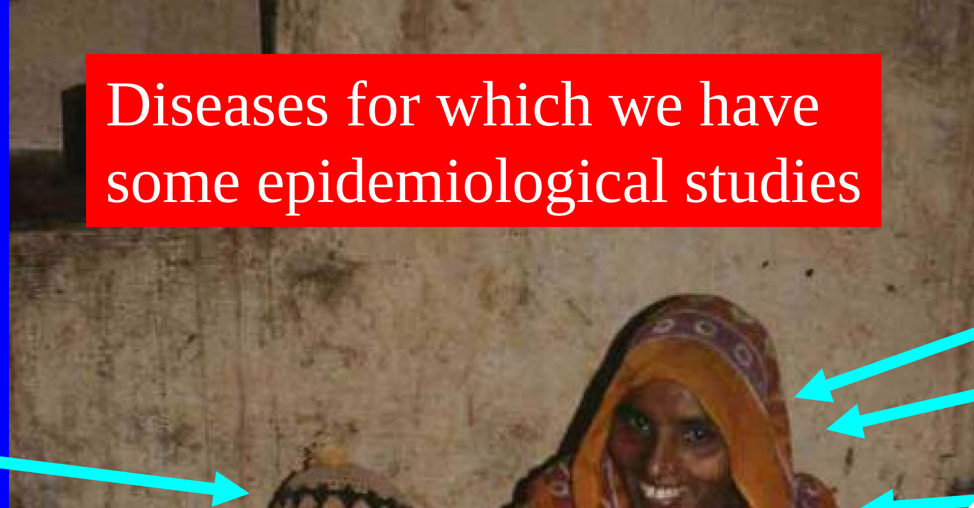
"Thank God! A panel of experts!"

Courtesy of Ross Anderson

Comparative Risk Assessment

- 26 major risk factors
- Common methods and databases
- Consensual discipline on acceptance of evidence
- Mortality and morbidity by age, sex, and 14 world regions
- Lost healthy life years (DALYs) final metric

Diseases for which we have some epidemiological studies



ALRI/ Pneumonia (meningitis)

Chronic obstructive lung disease

Only two qualified with sufficient evidence to be included in the CRA

Acute lower respiratory infections (ALRI)

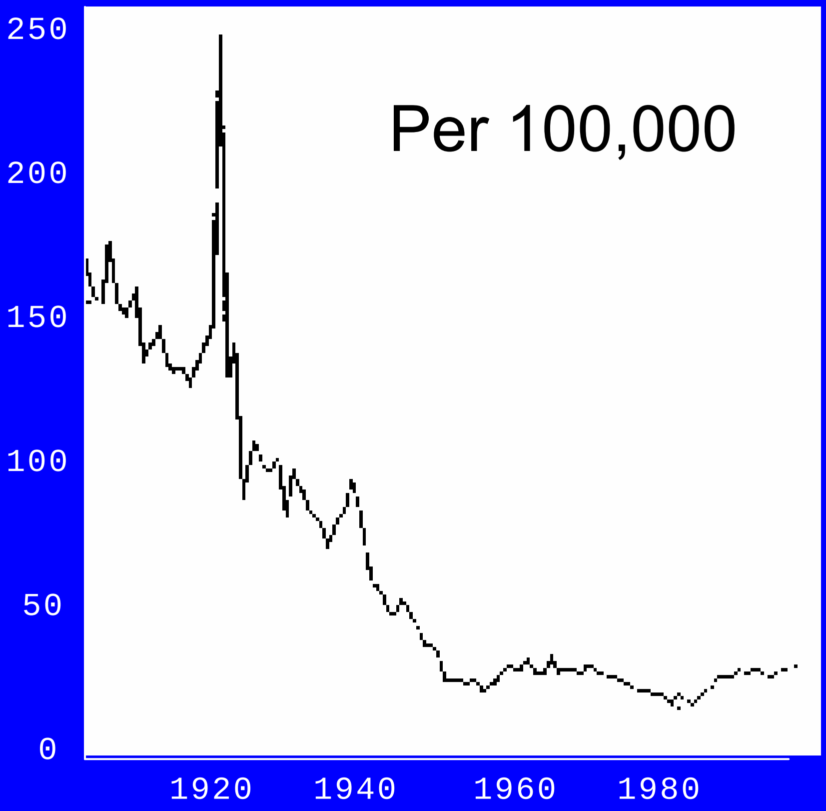
Chief cause of death among the world's children (~2 million per year). Thus, it is the chief global cause of lost healthy life years.

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.

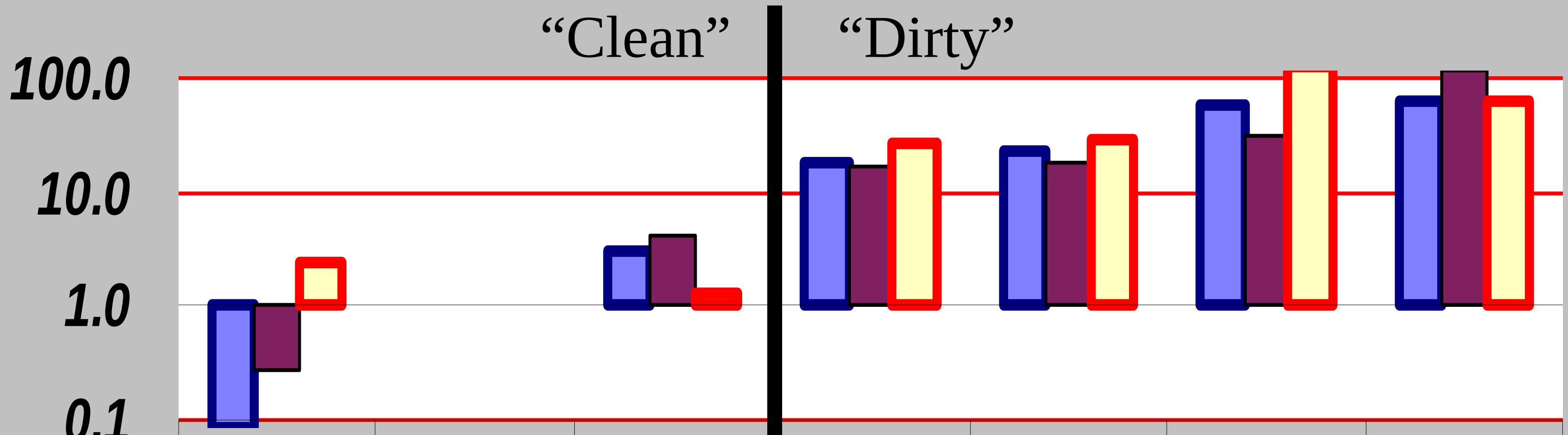
Pneumonia Deaths in the United States

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



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

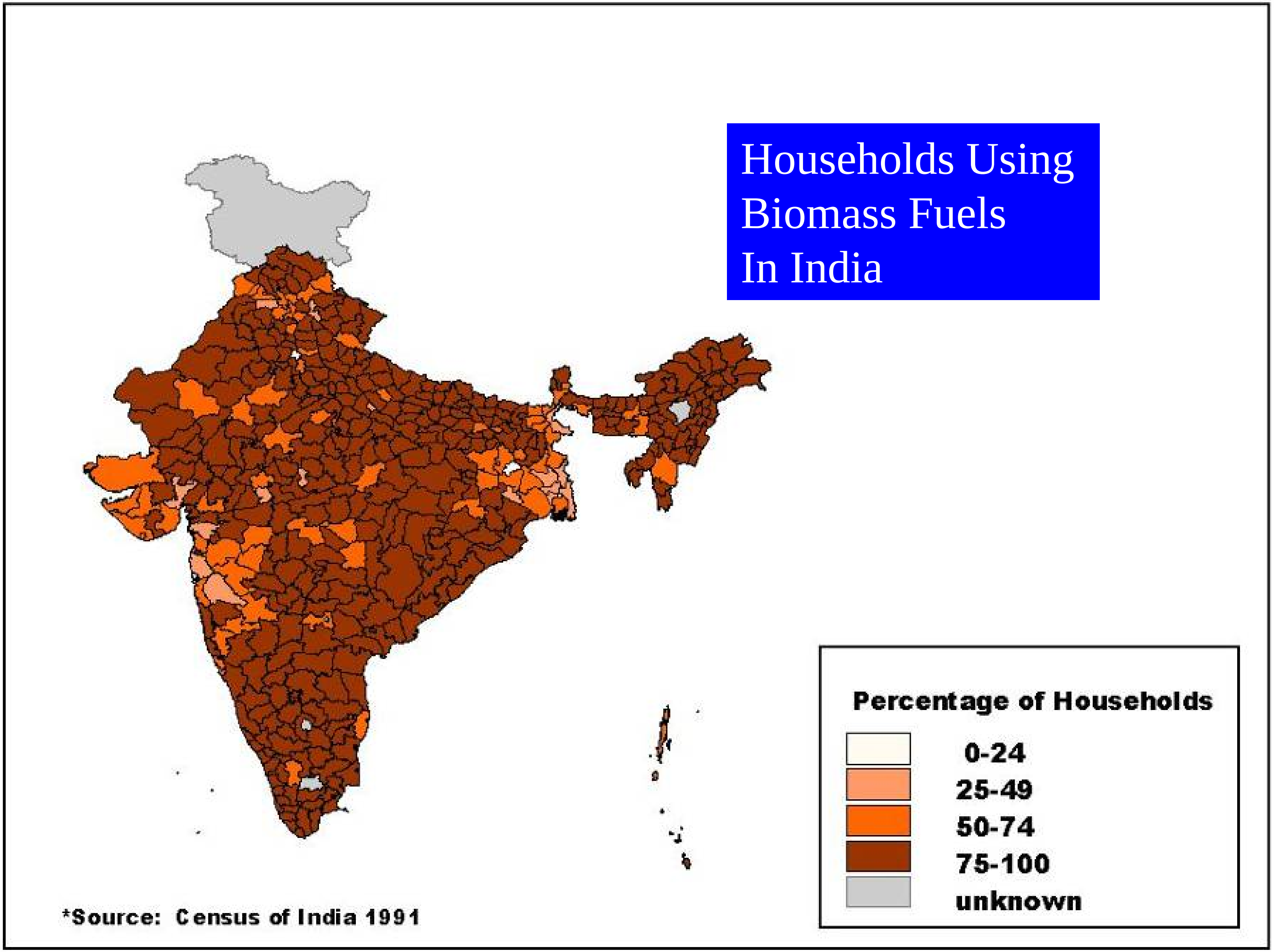
The Energy Ladder: Relative Pollutant Emissions Per Meal



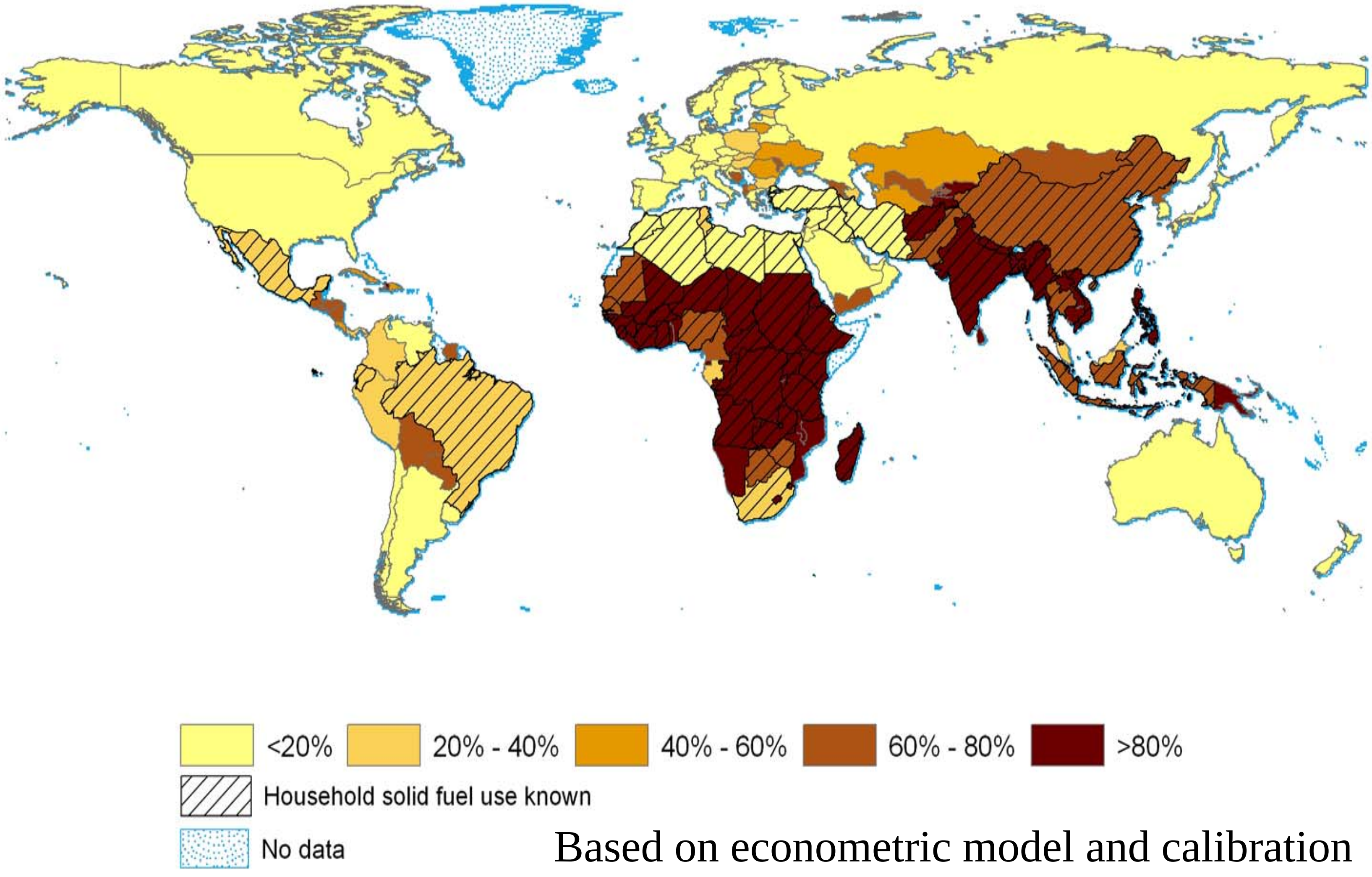
	Biogas	LPG	Kerosene	Wood	Roots	Crop Residues	Dung
CO	0.1	1.0	3	19	22	60	64
Hydrocarbons	0.3	1.0	4.2	17	18	32	115
PM	2.5	1.0	1.3	26	30	124	63

Smith, et al., 2005

Households Using Biomass Fuels In India



National Household Solid Fuel Use, 2000



Based on econometric model and calibration against household surveys in ~50 countries

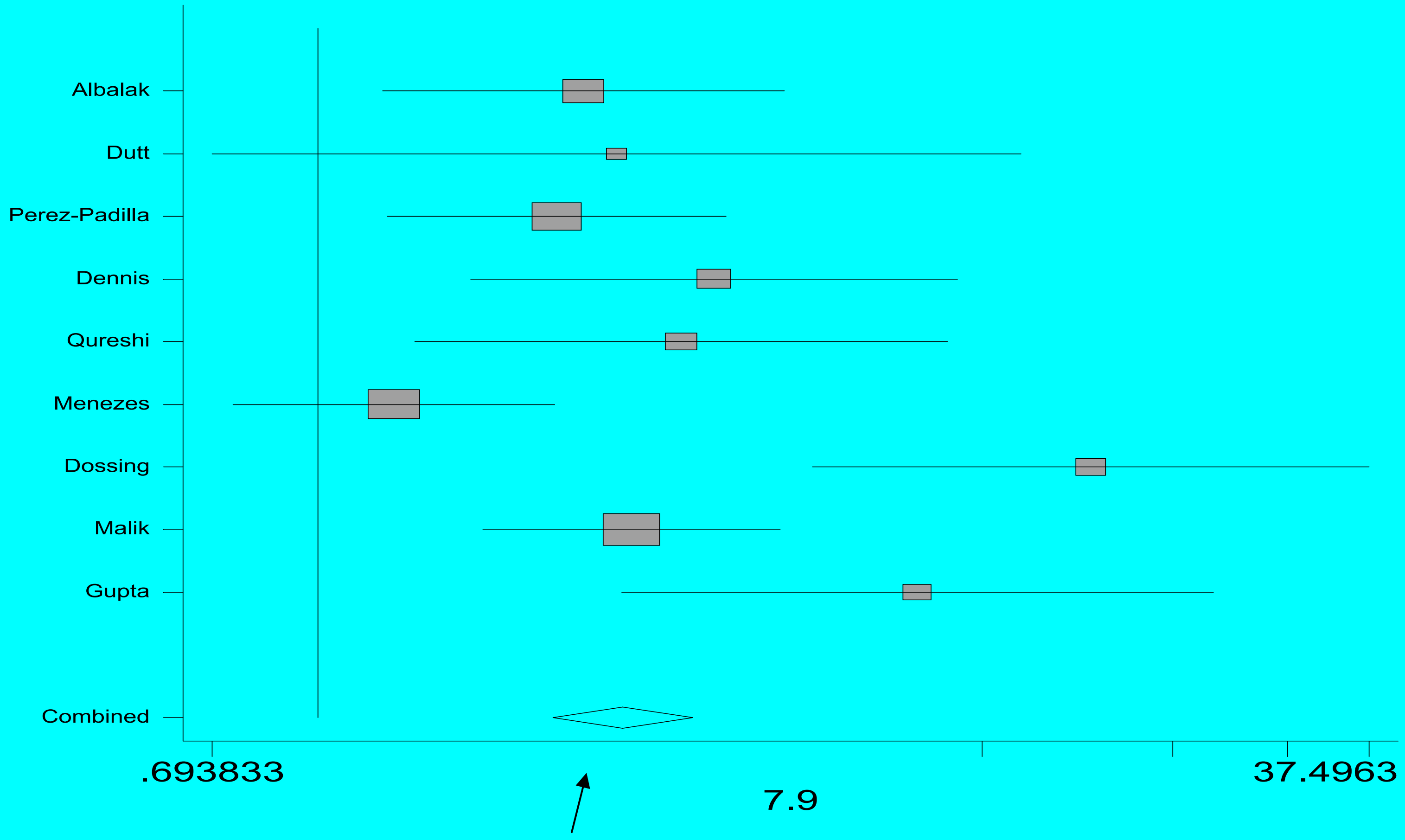
Meta-analysis of studies of ALRI and solid fuels, in children aged <5 years

Subgroup analyses of ~14 studies	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 fi[illegible]	2.3 (1.8-2.9)
[illegible]	[illegible])
Studies not adjusting for nutritional 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)

Children in households using solid fuels have twice the rate of serious ALRI

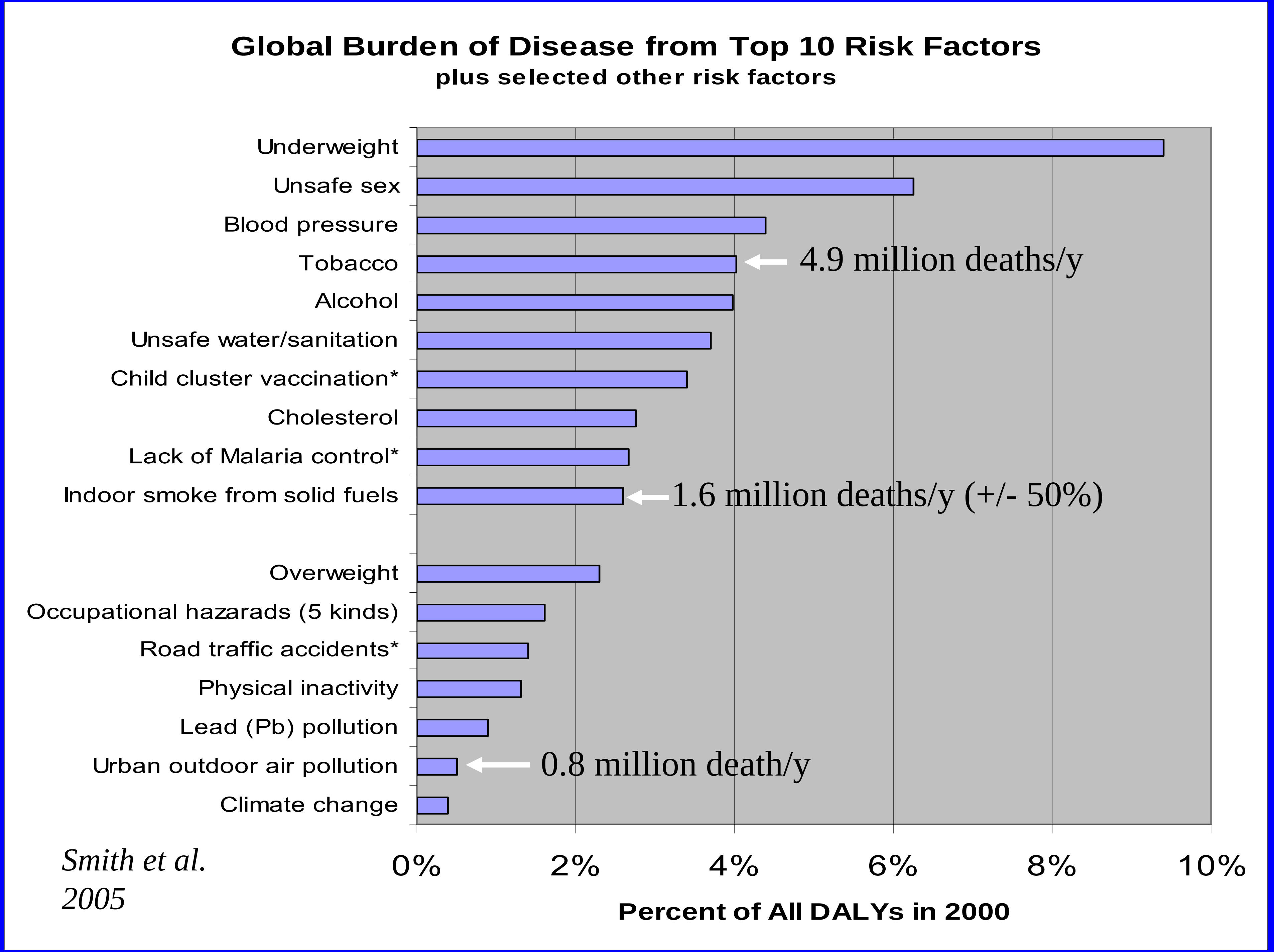
Smith et al in WHO, Comparative quantification of health risks, 2004

Meta-analysis of all studies adjusted for age Chronic Obstructive Pulmonary Disease (COPD) in women



OR = 3.2 (95% CI: 2.3-4.8)

Smith et al., 2004

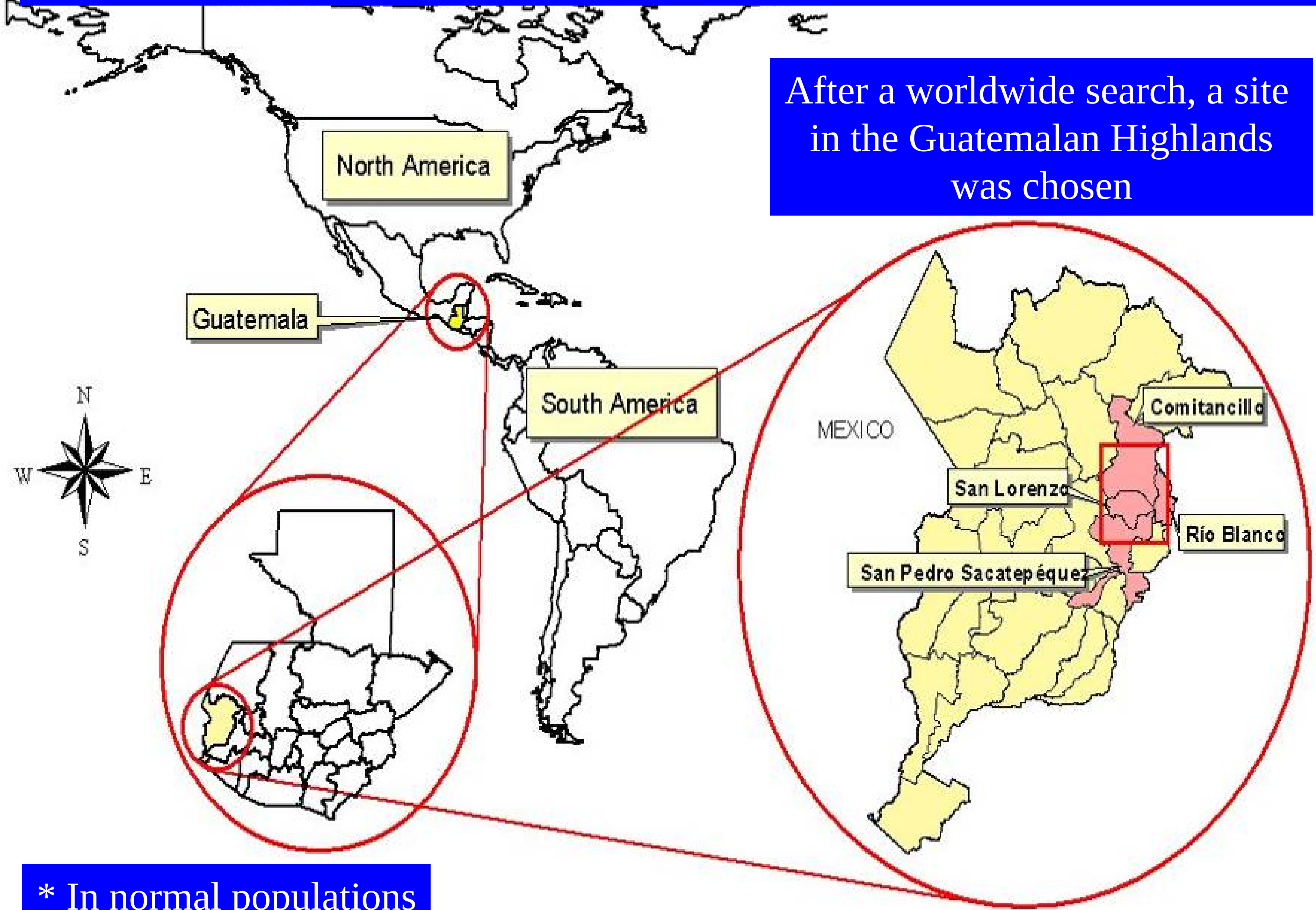

Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
Underweight
Unsafe sex
Blood pressure
Tobacco
4.9 million deaths/y
Alcohol
Unsafe water/sanitation
Child cluster vaccination*
Cholesterol
Lack of Malaria control*
Indoor smoke from solid fuels
1.6 million deaths/y (+/- 50%)
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
Smith et al.
2005

Need for Stronger Evidence

- Problem with observational data
- Randomized control trials (RCTs) are coin of realm in international health
- Decided to do RCT in 1984
- Received funding in 2001
- Publications coming out in 2007

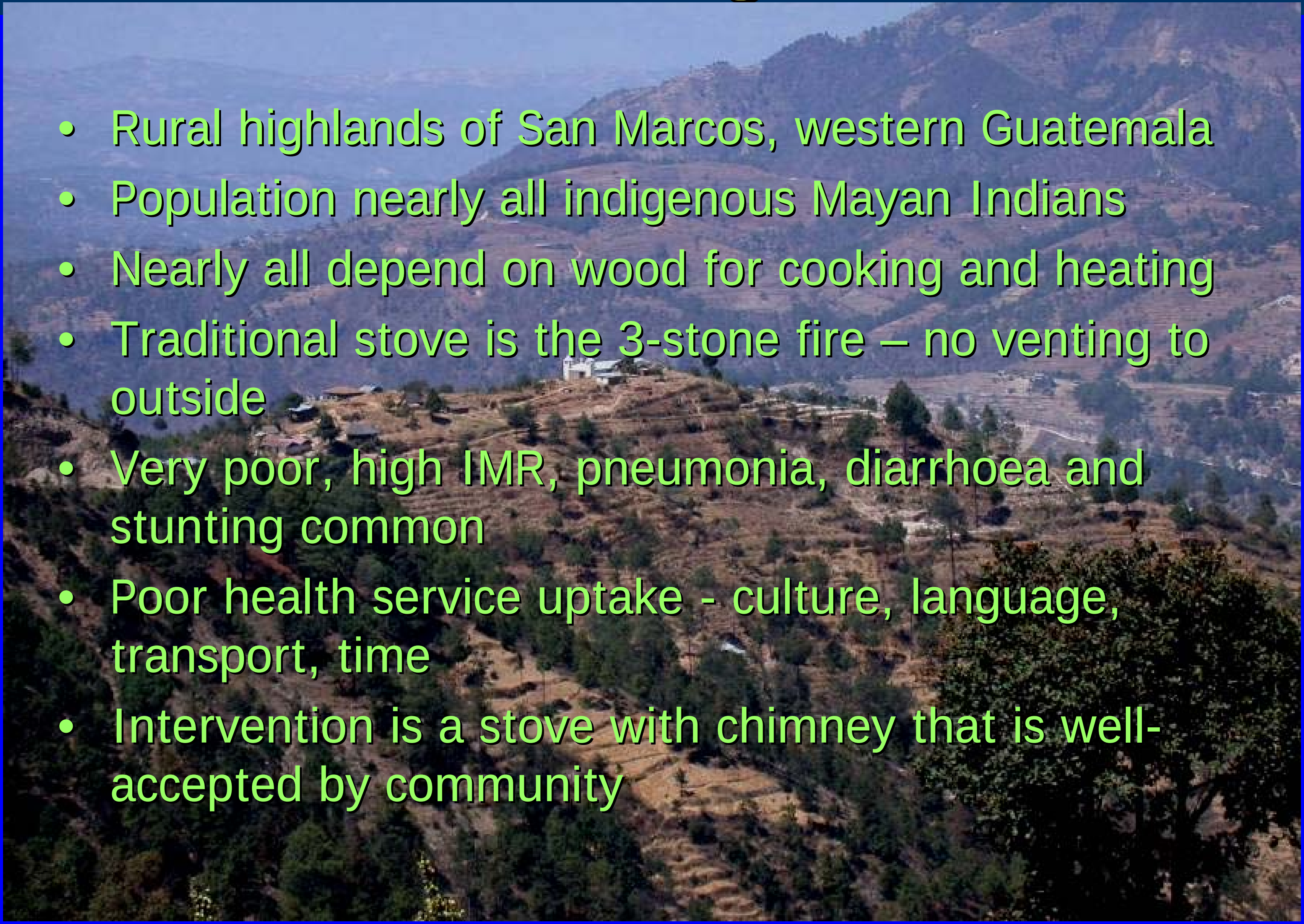
First Randomized Trial in Air Pollution History*

After a worldwide search, a site in the Guatemalan Highlands was chosen



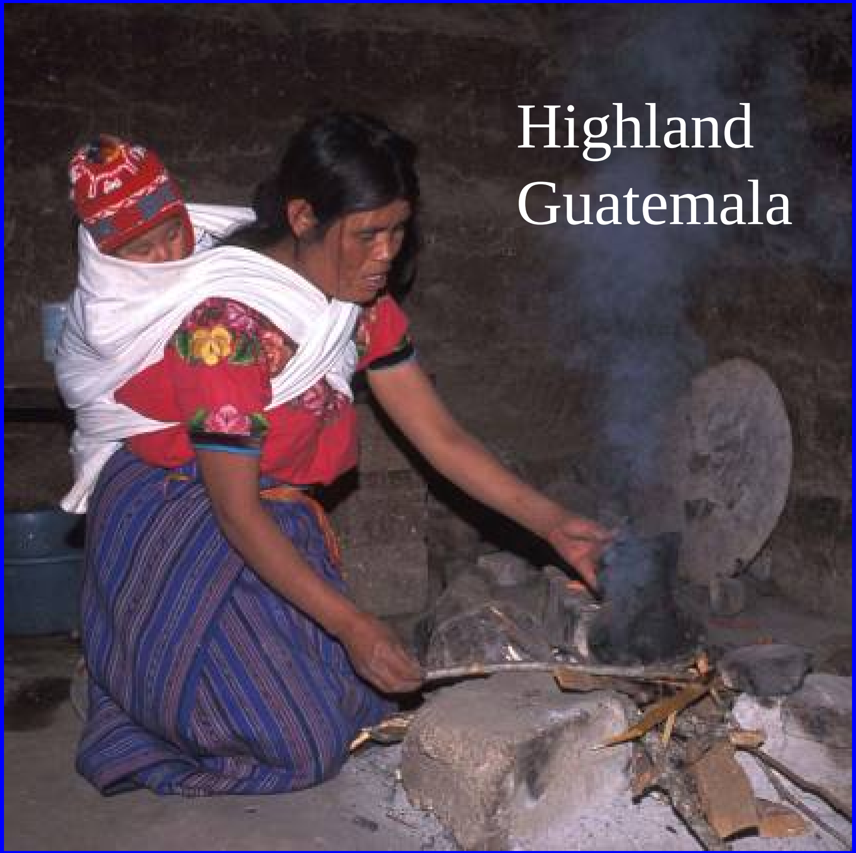
* In normal populations

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, diarrhoea 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

Need for fast, cheap, and easy monitoring for particles so that widespread temporal and spatial measurements can be done in easily in many places

Aerosol Science and Technology, 38:1054–1062, 2004

ISSN: 0278-6826 print / 1521-7388 online
DOI: 10.1080/027868290883333

Combined Optical and Ionization Measurement Techniques for Inexpensive Characterization of Micrometer and Submicrometer Aerosols

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TECHNICAL PAPER

ISSN 1047-3289 *J. Air &*

An Inexpensive Dual-Chamber Particle Monitor: Laboratory Characterization

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ABSTRACT
In developing countries, hi
from the use of coal and bio
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ARTICLE Journal of Environmental Monitoring]

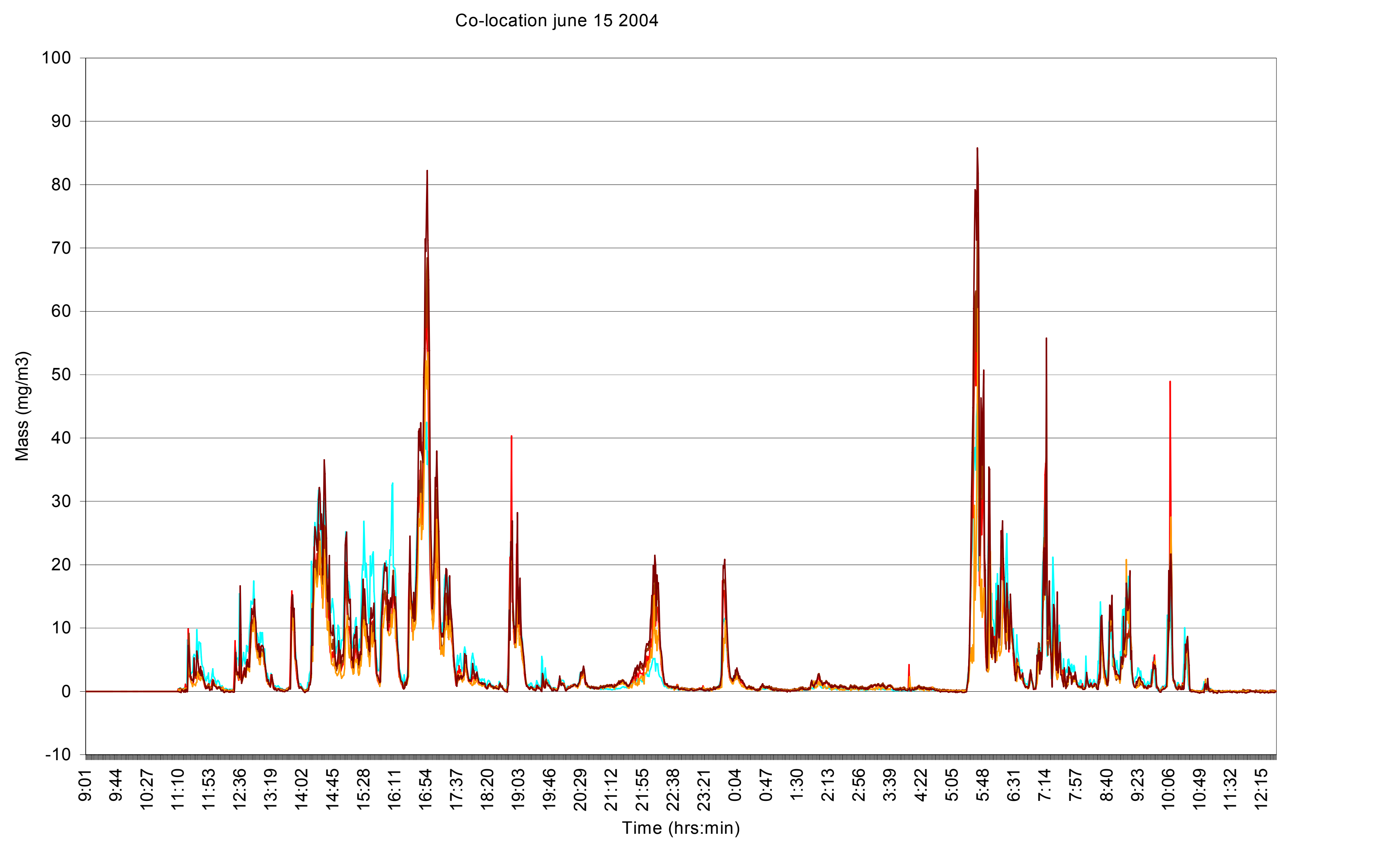
An inexpensive light-scattering particle monitor: field validation

Zohir Chowdhury,[*a] Rufus Edwards,[b] Michael Johnson,[c] Kyra Naumoff Shields,[a] Tracy Allen,[d] Eduardo Canuz[a] and Kirk R. Smith[a]

Receipt/Acceptance Data: Forthcoming 2007
Publication data
DOI: 10.1039/b000000x

We have developed a small, light, passive, inexpensive, datalogging particle monitor called the "UCB" (University of California Berkeley Particle Monitor). Following previously published laboratory assessments, we present here results of tests of its performance in field settings. We demonstrate the mass sensitivity of the UCB in relation to gravimetric filter-based $PM_{2.5}$ mass estimates as well as commercial light-scattering instruments co-located in field chamber tests and in kitchens of wood-burning households. Although requiring adjustment for differences in sensitivity, Inter-monitor performance was consistently high (r^2>0.99). Moreover, the UCB can consistently estimate $PM_{2.5}$ mass concentrations in wood-burning kitchens (Pearson r^2= 0.885; N=99), with good agreement between duplicate measures (Pearson r^2= 0.940; N=88). In addition, with appropriate cleaning of the sensing chamber, UCB mass sensitivity does not decrease with time when used intensively in open woodfire kitchens, demonstrating the significant potential of this monitor.

Guatemala house with open fire
DustTrak vs UCB particle monitor



Overview of study design

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

Year 1

5500 Households total

Randomize

Keep open fire

Plancha

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

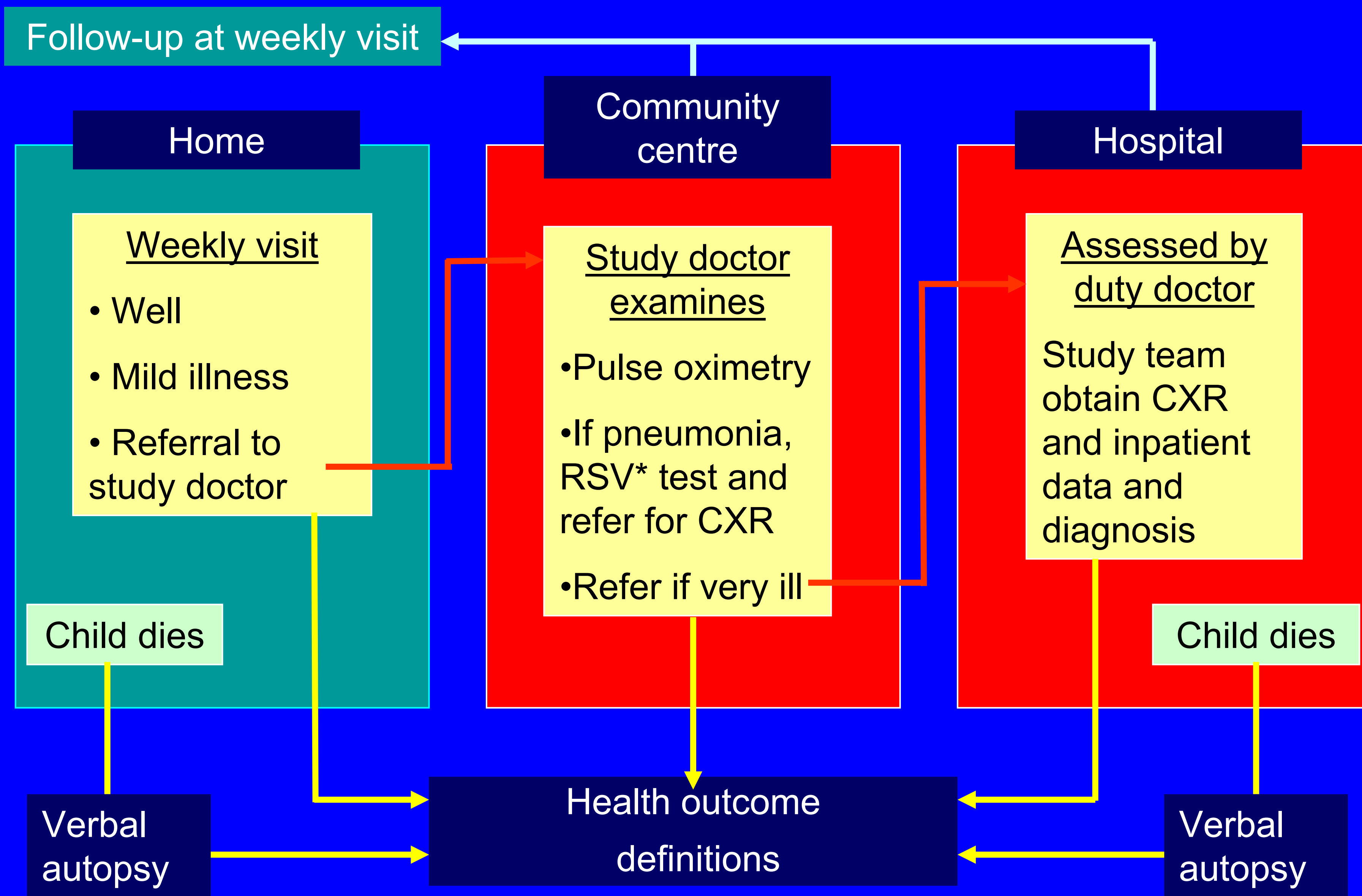
- Surveillance for ALRI, diarrhoea, &c
- Detailed exposure monitoring

Years 1-3

Compare incidence and exposure in 2 groups
Plancha offered to 'controls'

Years 3-4

Overview of child health outcomes assessment



* Respiratory syncitial virus

Results for MD-diagnosed Severe Pneumonia:

RSV+, hypoxic

OR (SE)	**p**	**95%CI**
0.93 (0.25)	0.79	0.55 – 1.57

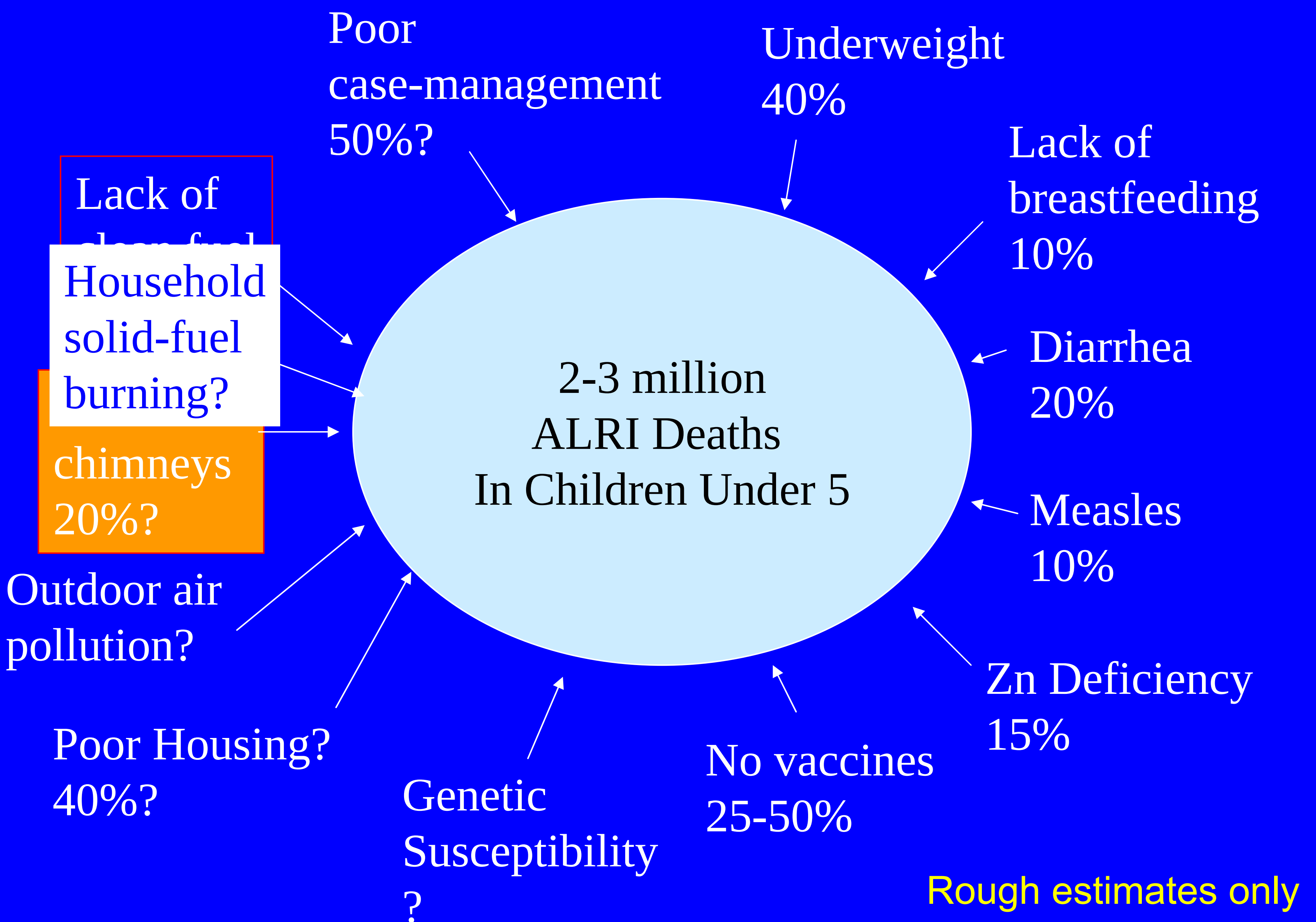
Non-RSV, hypoxic

Preliminary
Results
Please do not cite

OR (SE)	**p**	**95%CI**
0.59 (0.15)	0.031	0.36 – 0.95

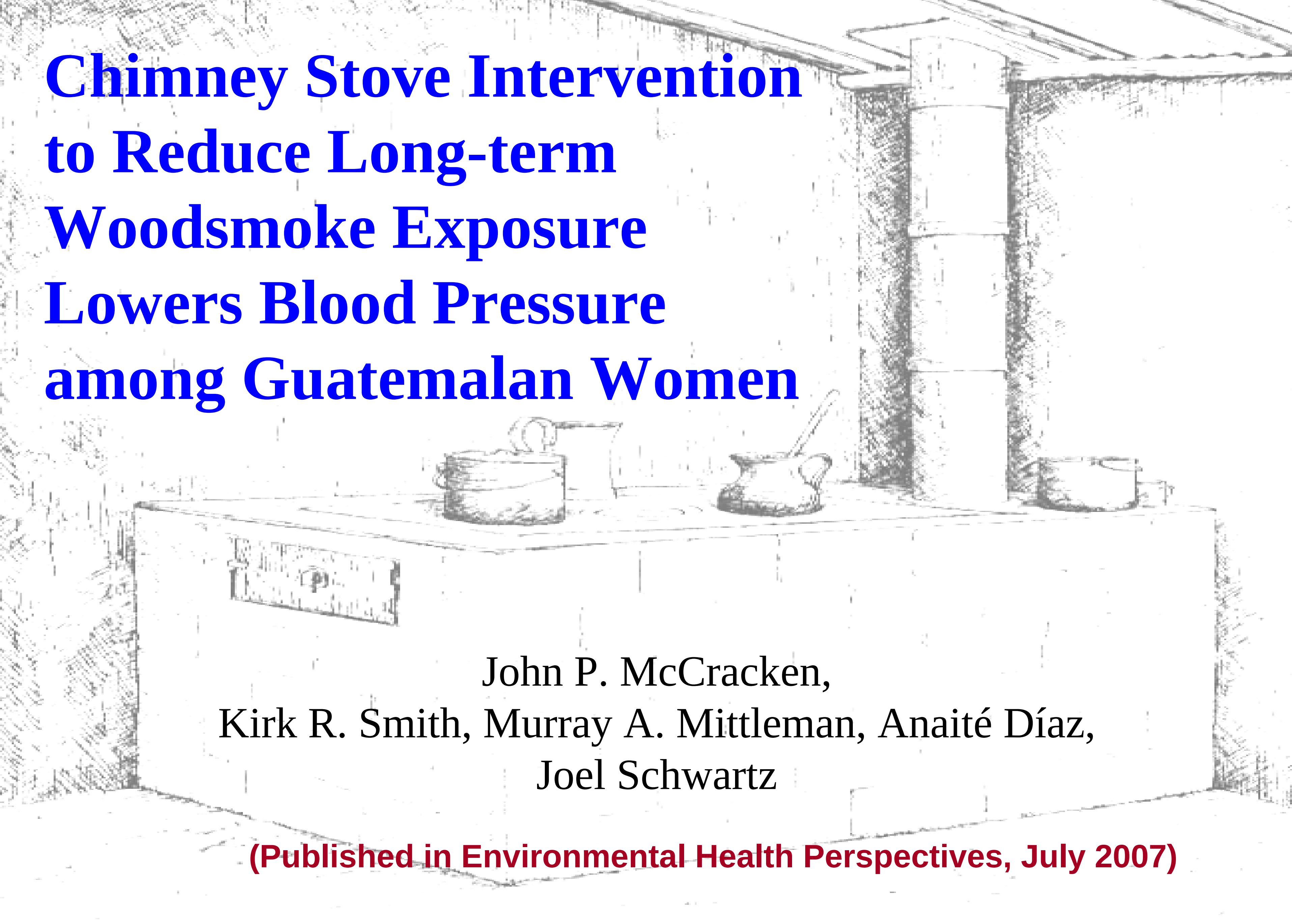
Interpretation: Children in households with open woodfires seem to have ~ two-thirds (1/0.60) more serious non-RSV pneumonia than those in households with well-operating woodstoves with chimneys

Attributable Fractions do not add to 100%



Rough estimates only

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



John P. McCracken,
Kirk R. Smith, Murray A. Mittleman, Anaité Díaz,
Joel Schwartz

(Published in Environmental Health Perspectives, July 2007)

Background

- Ambient particles associated with increased blood pressure (BP) (e.g. Linn, 1999; Zanobetti, 2004)
- Elevated BP predicts increased cardiovascular risk
- No studies of long-term air pollution exposures and BP
- Effects of biomass smoke have not been studied

Objectives

Goal: To evaluate the effect of long-term reductions in woodsmoke exposure on systolic (SBP) and diastolic blood pressure (DBP).

Specific hypotheses:

1. Personal fine particle ($PM_{2.5}$) exposures will be lower among women using chimney stoves to cook.
2. Chimney stove intervention will be associated with lower SBP and DBP.

Study Design

- Study population
  - Eligible: Women ≥ 38 years, cooking daily
  - Excluded: pregnant, breastfeeding
- Two follow-up periods
  - Trial period (7/03-12/04)
  - Echo-intervention period (3/04-3/05)

Personal $PM_{2.5}$

SBP and DBP

Measures by Group and Period

Subjects (Measures)

	Trial Period	Echo-Intervention Period
Intervention Group	49 (115)	
Control Group	71 (111)	55 (65)

Between-Groups Results

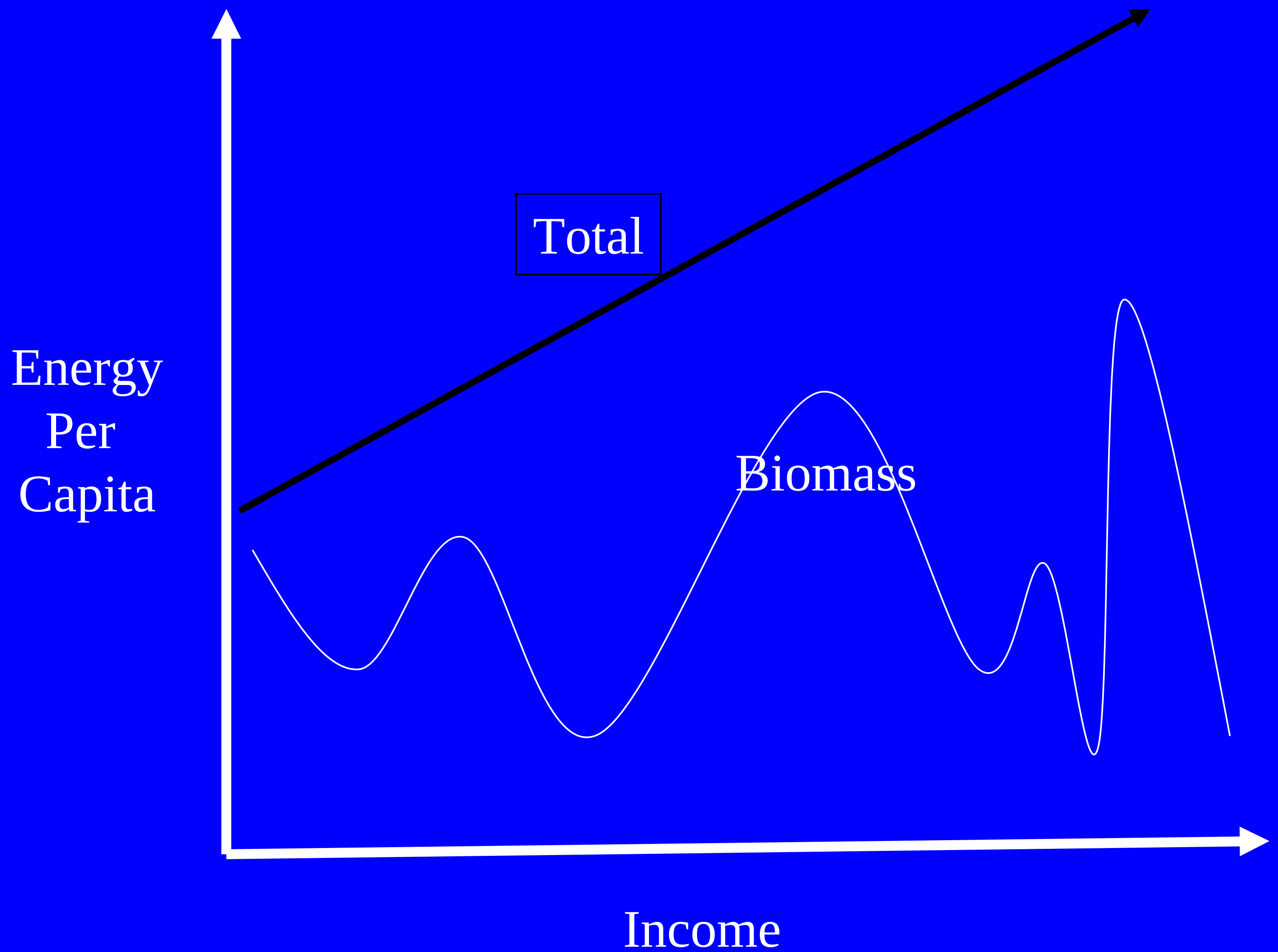
	Number of subjects (measures)		Adjusted mean difference*		
	Control group	Intervention group	Estimate	95% CI	p-value
SBP	71 (111)	49 (115)	-3.7	-8.1, 0.6	0.10
DBP	71 (111)	49 (115)	-3.0	-5.7, -0.4	0.02

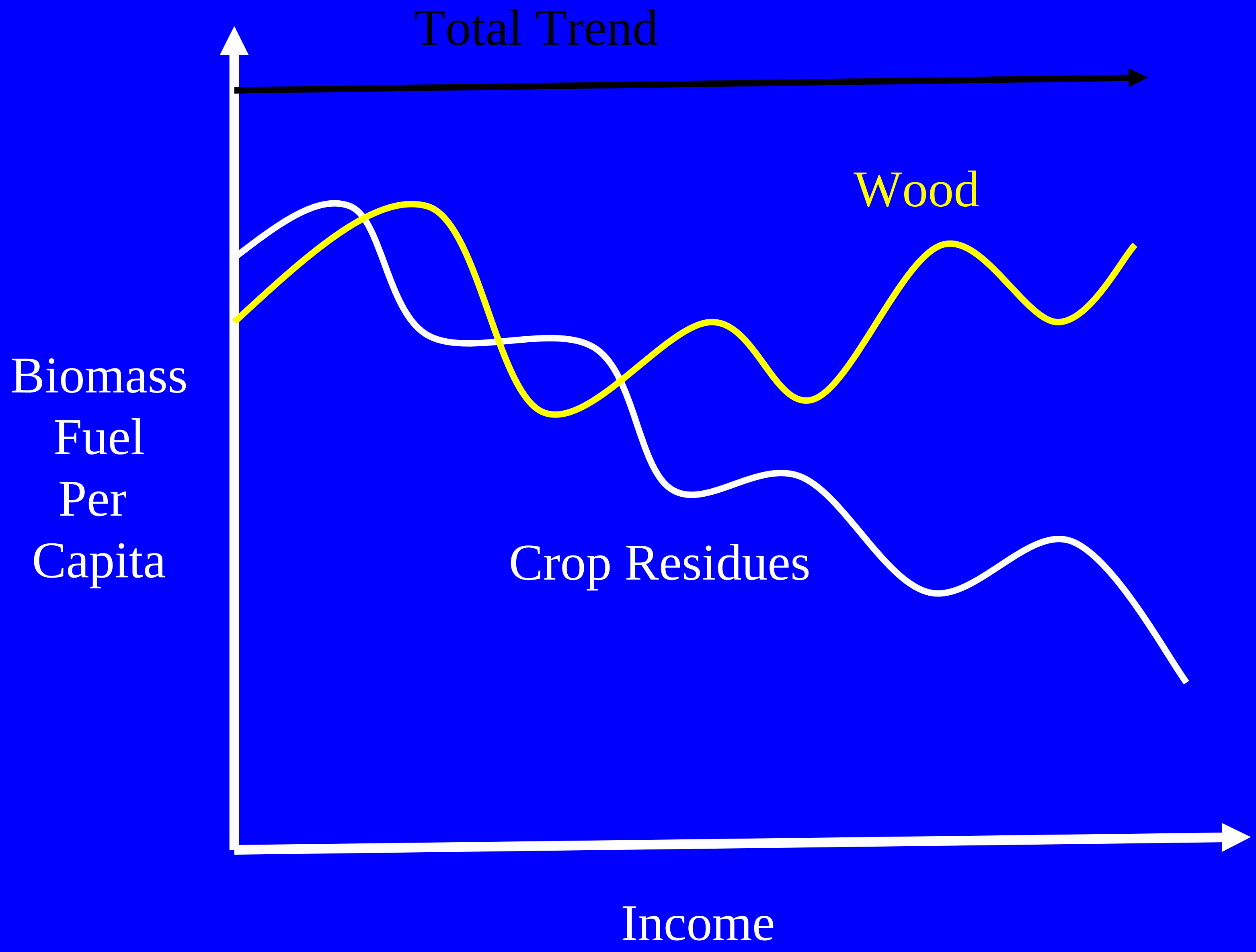
* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure

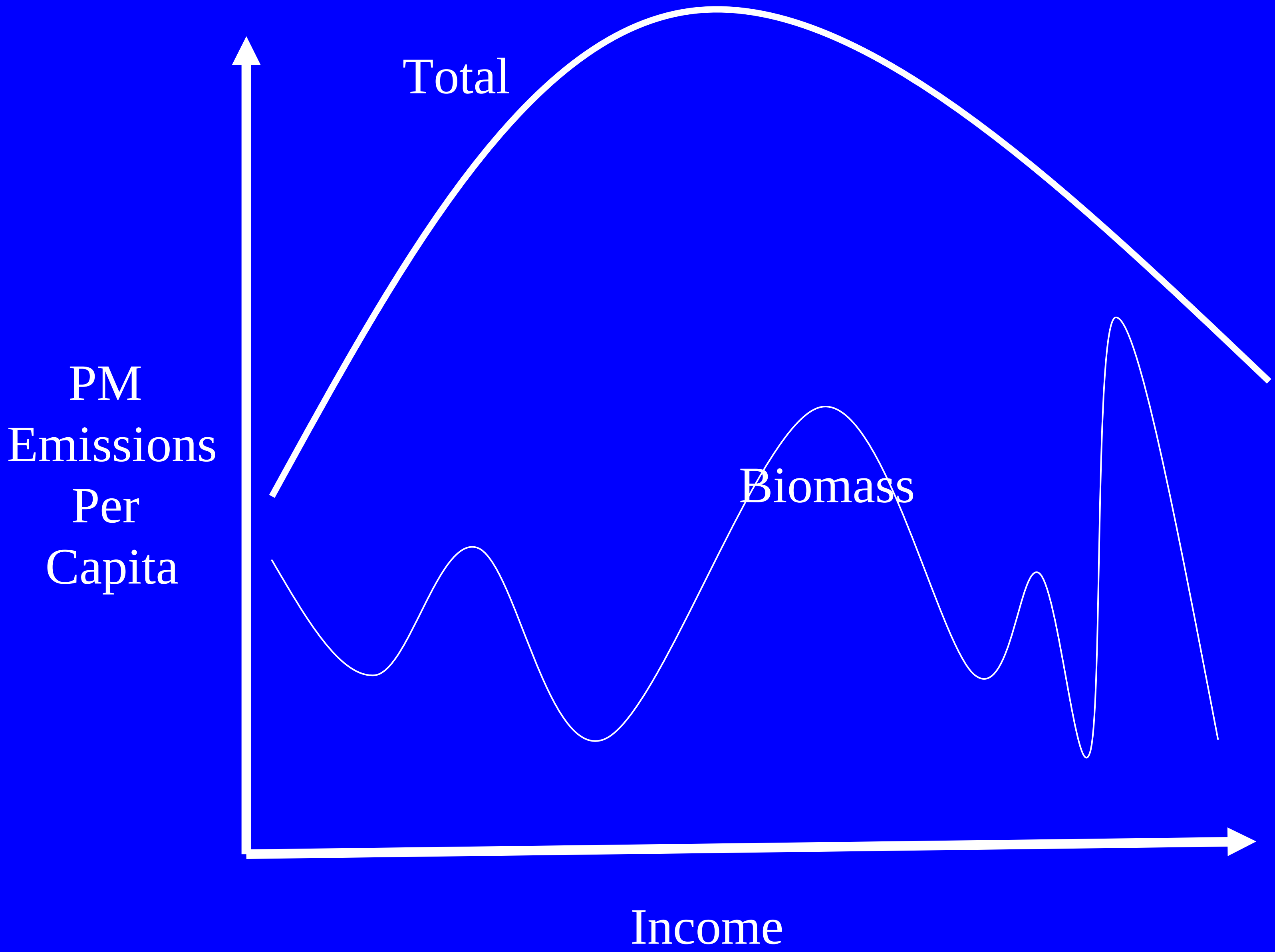
Before-and-After Results

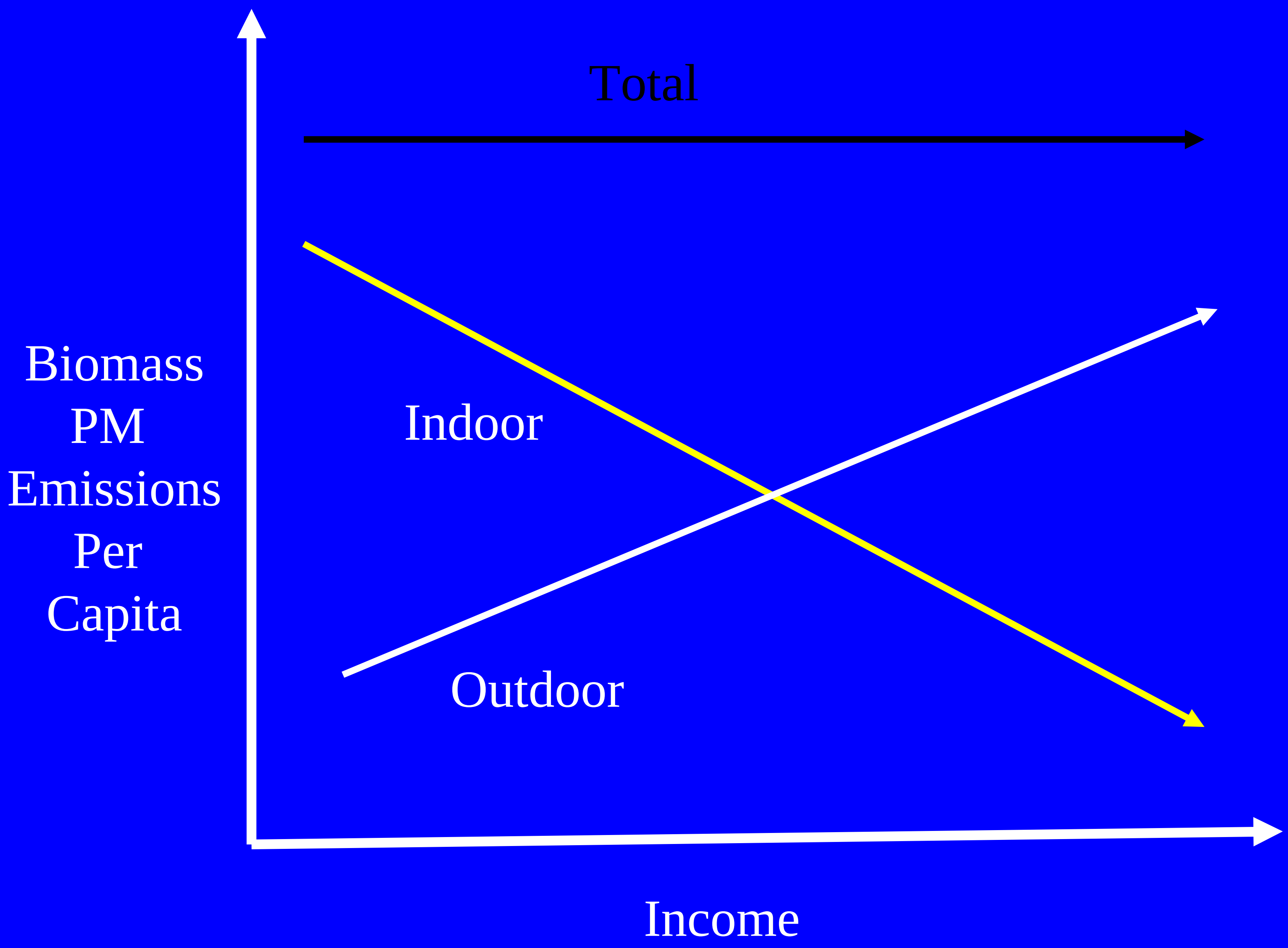
	Number of subjects (measures)		Adjusted mean difference*		
	Trial period	Echo-intervention	Estimate	95% CI	p-value
SBP	55 (88)	55 (65)	-3.1	-5.3, -0.8	0.01
DBP	55 (88)	55 (65)	-1.9	-3.5, -0.4	0.01

* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure

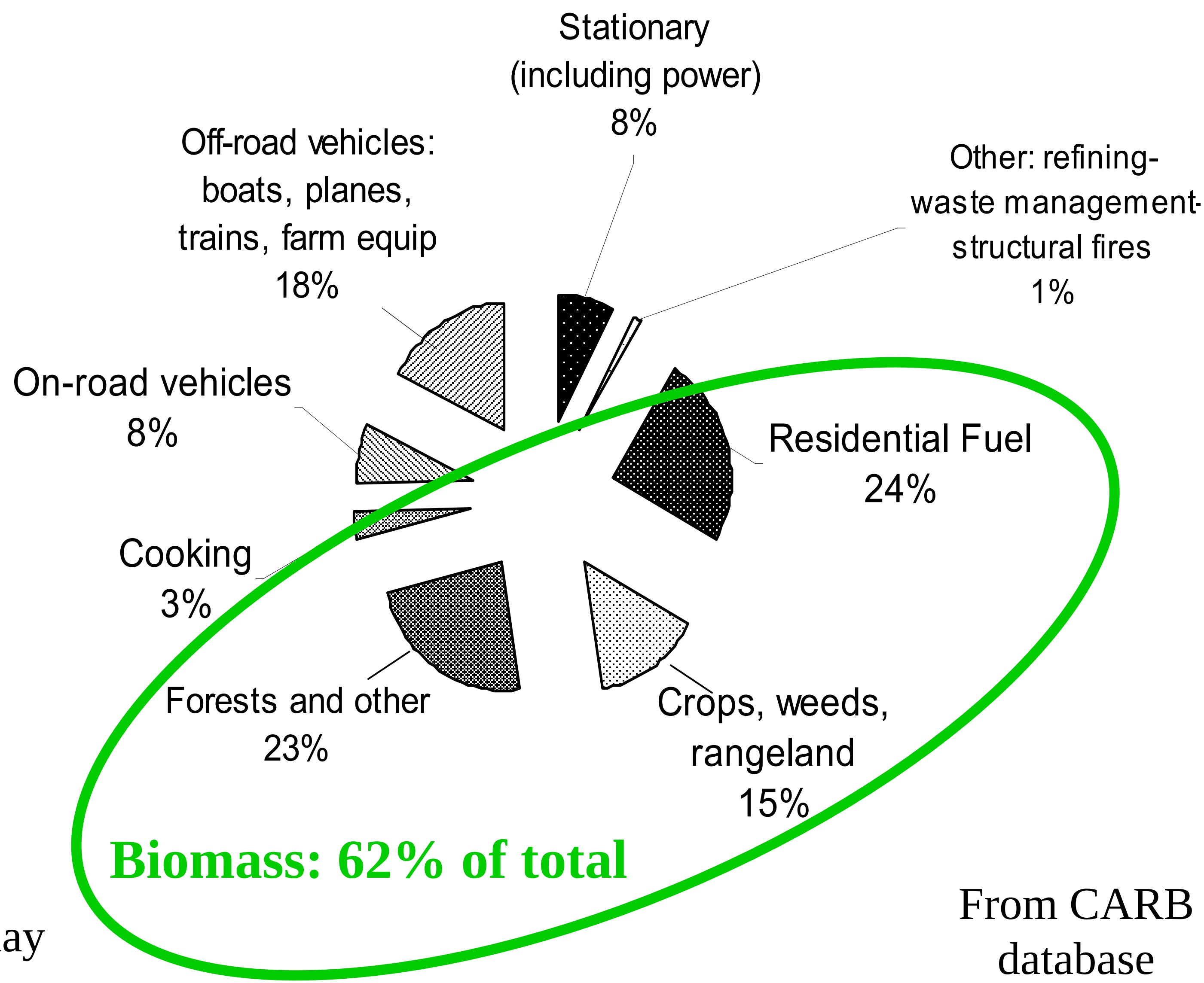

Total
Energy
Per
Capita
Biomass
Income


Total Trend
Wood
Biomass
Fuel
Per
Capita
Crop Residues
Income


Total
PM
Emissions
Per
Capita
Biomass
Income

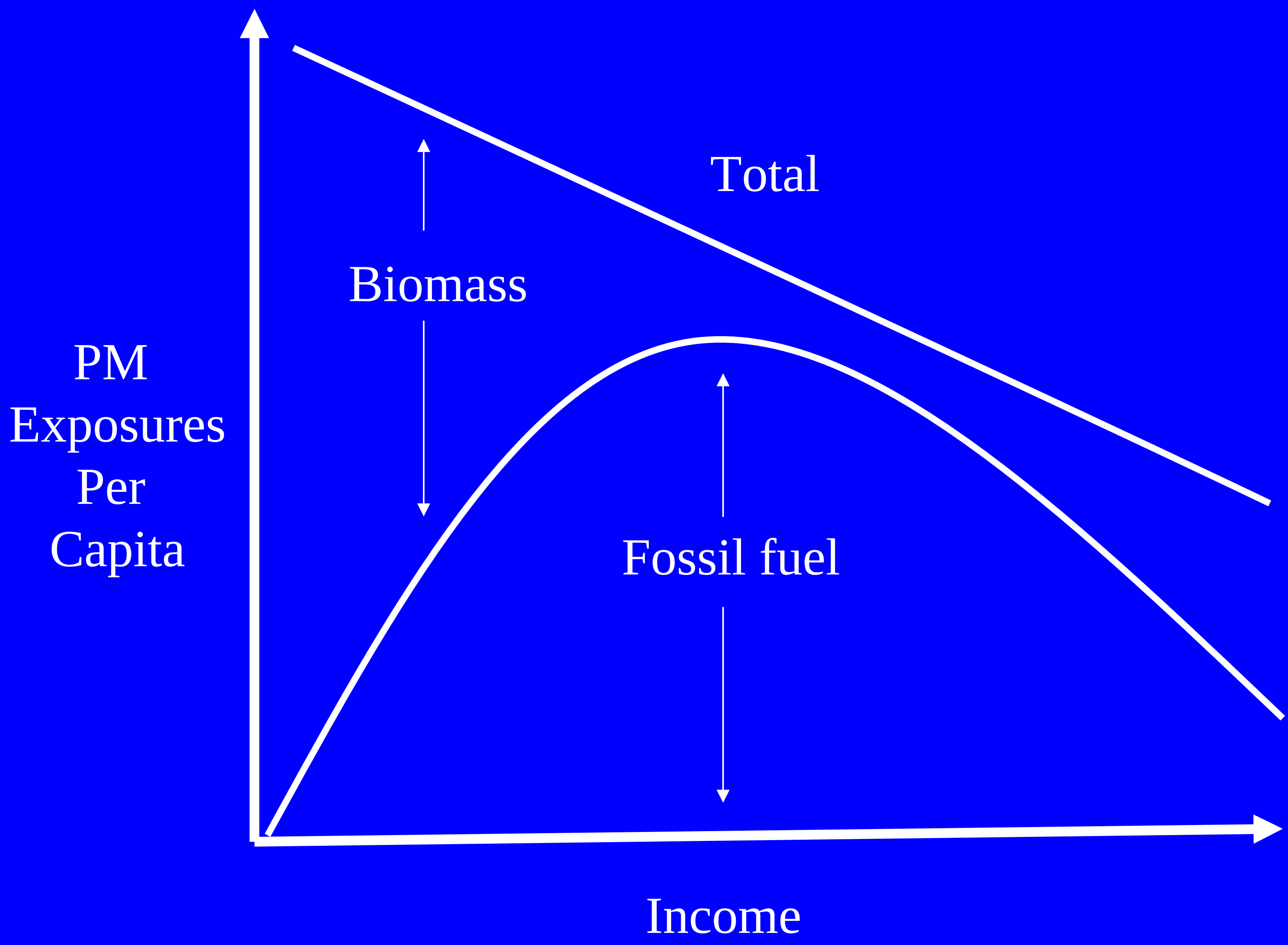

Total
Biomass
PM
Emissions
Per
Capita
Indoor
Outdoor
Income

California's 2005 Combustion $PM_{2.5}$ Emissions



~450 t/day

From CARB database



Total
Biomass
PM Exposures Per Capita
Fossil fuel
Income

Thank you