Plenary Presentation

by
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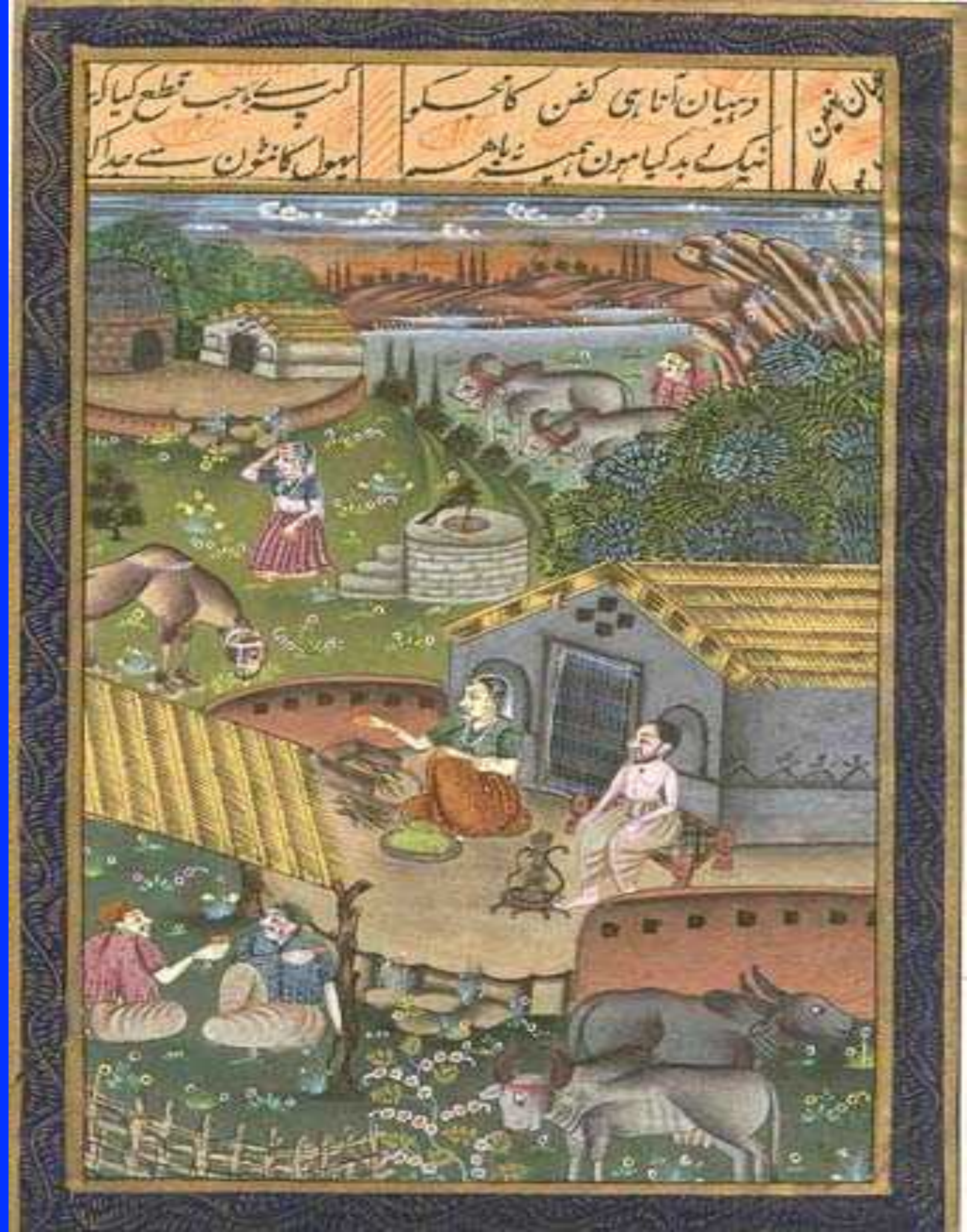
10th International Congress on Combustion By-Products and their Health Effects

Ischia, Italy

June 17-20, 2007

The role of incomplete combustion in the global burden of disease and what might be done



Combustion Particles:
The Oldest and Newest of Pollutants

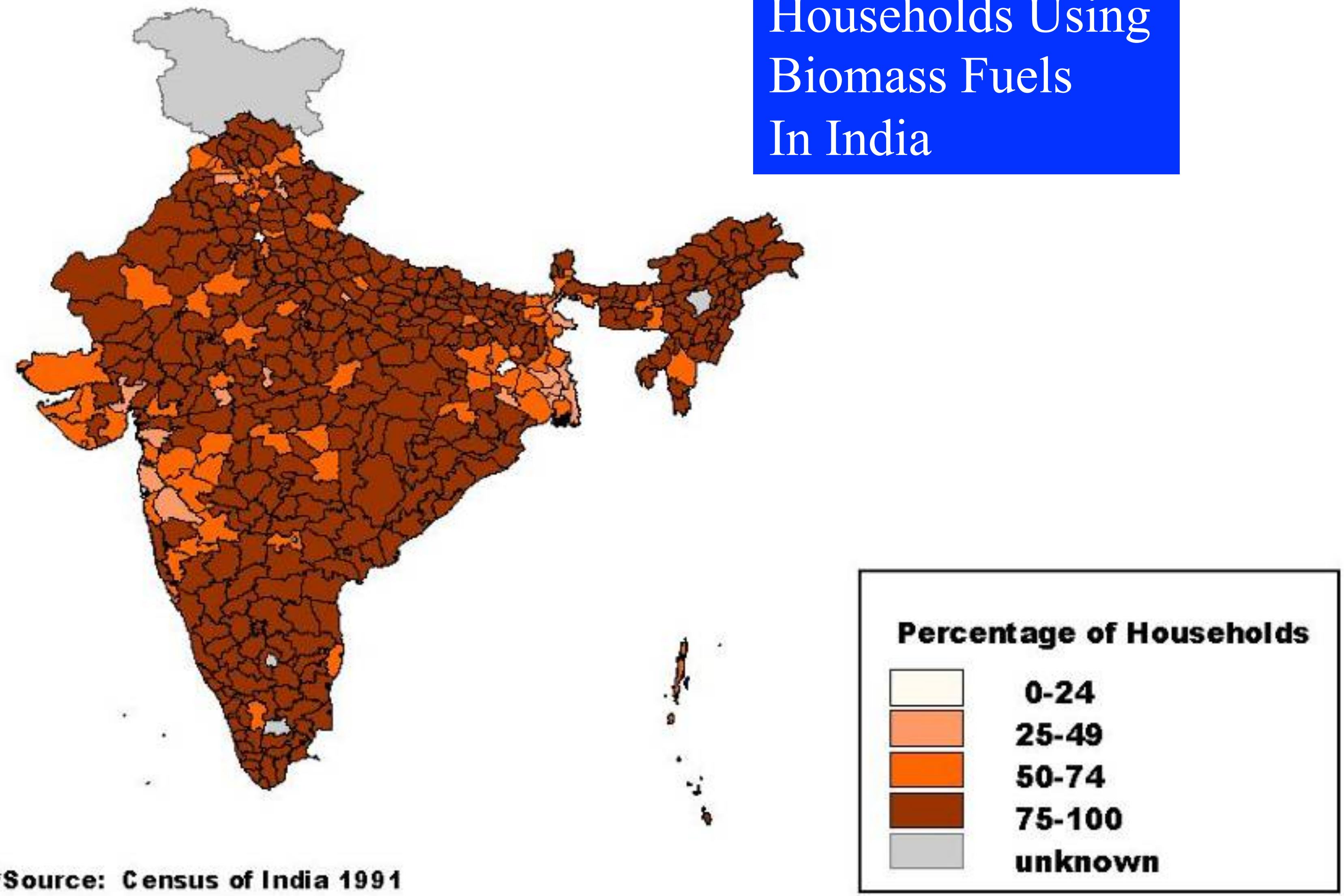
- Oldest: first measured and regulated
  - First Royal Air Pollution Commission in history
    - Appointed in 1265, completed its report in 1306
    - Recommendation (ban coal burning in London) taken up 650 years later by the authorities (1956)
- Newest:
  - largest global impact,
  - mechanisms of creation and impact are still not clear,
  - new health standards being implemented,
  - new measurement methods being developed,
  - even basic metrics in some doubt

Road Map for this Presentation

- What are major sources of exposure to combustion particles?
- What is meant by "burden of disease?"
- How do we calculate the burden from different risk factors in a compatible manner?
- How was this done globally for outdoor and indoor sources of combustion particles?
- How do the results compare with other major risk factors?
- What exposures are missing?
- What might the combustion and soot communities do about this?

Oldest Pollution Source in Human History

Households Using Biomass Fuels In India

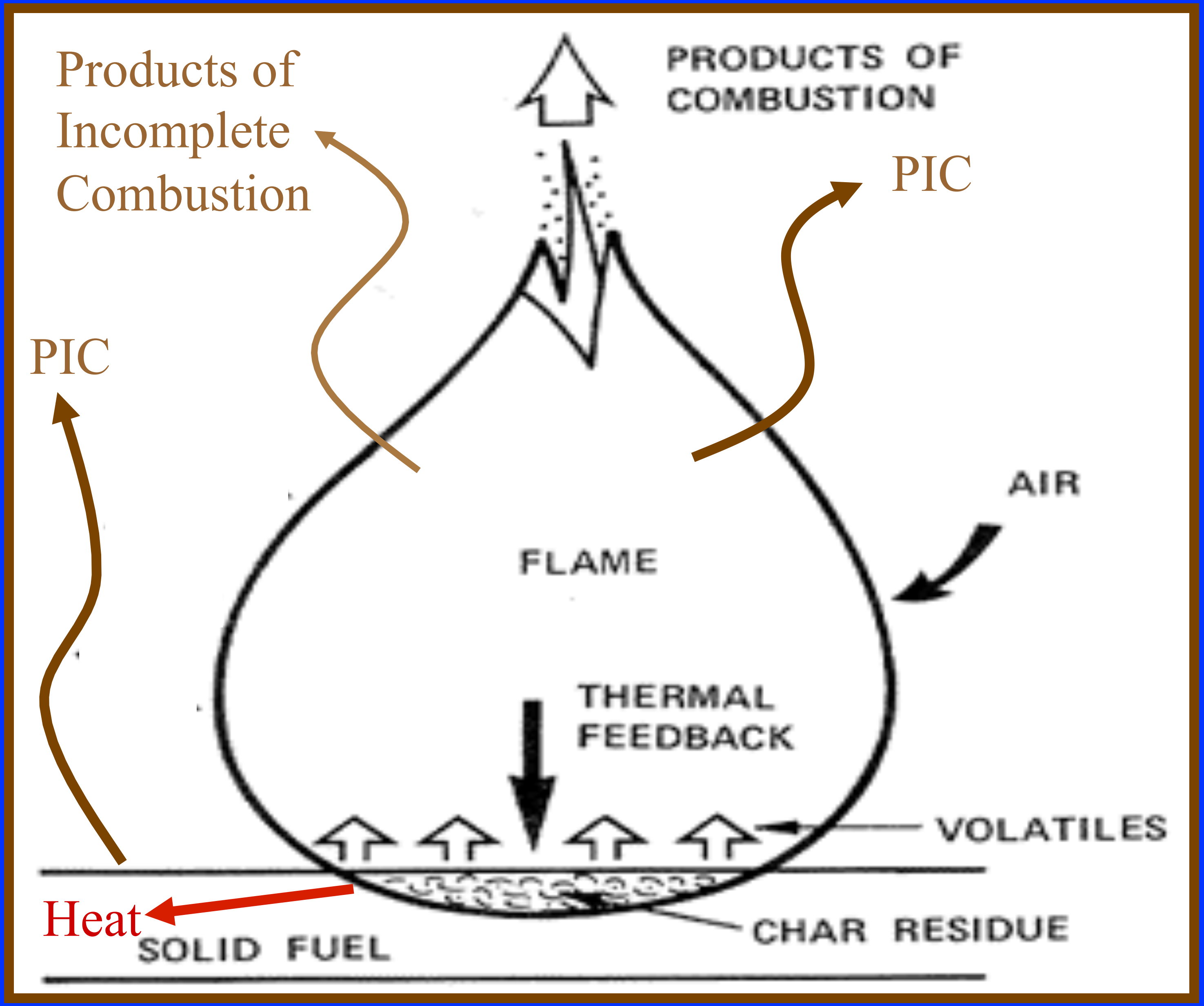


*Source: Census of India 1991

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)?

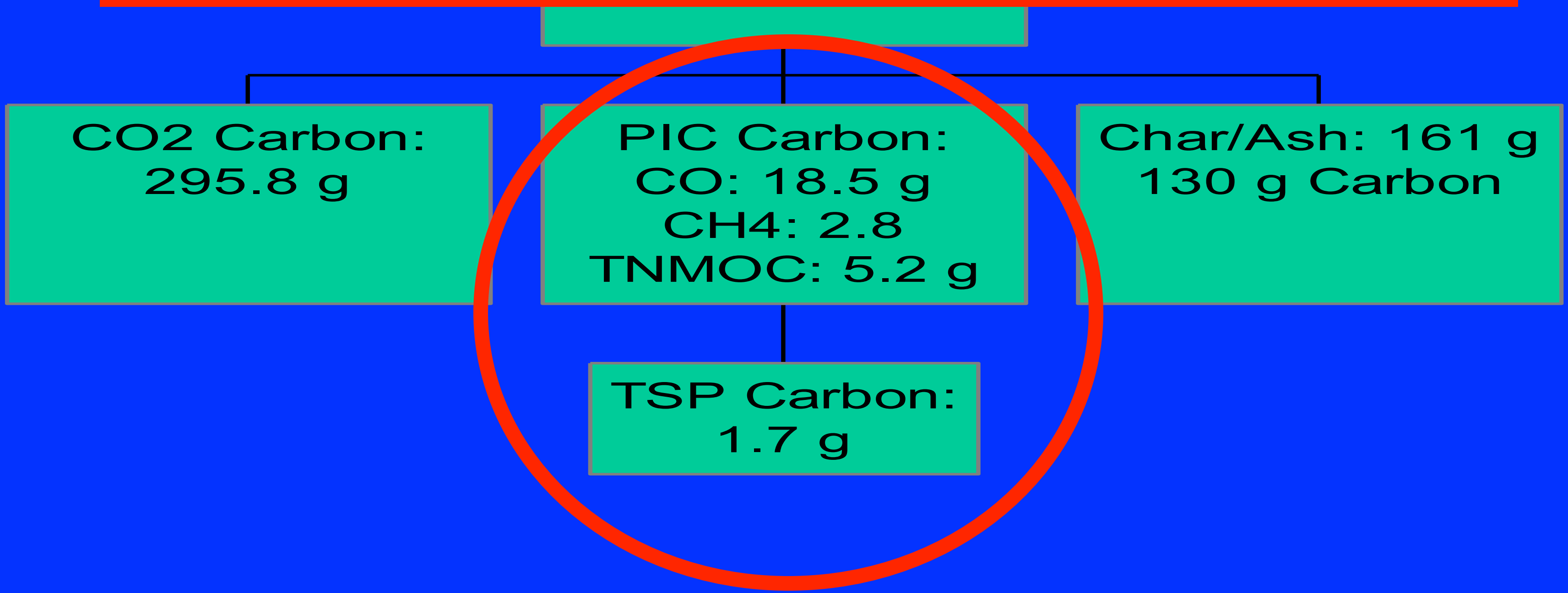
Reason: the combustion efficiency is far less than 100%


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

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%

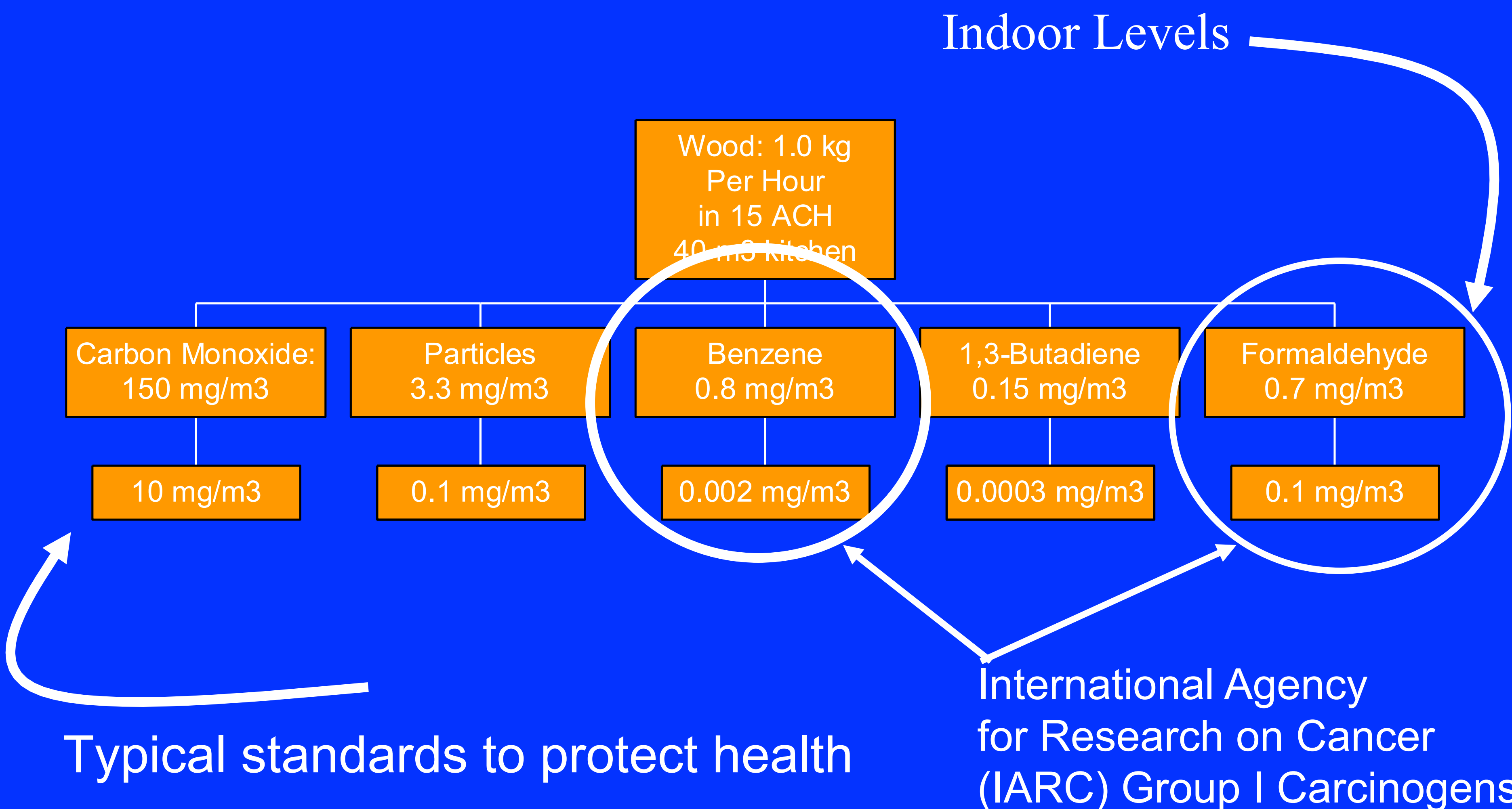
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles.
- 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

Indoor pollution concentrations from typical woodfired cookstove during cooking



Size Distribution of Biomass Smoke Particles

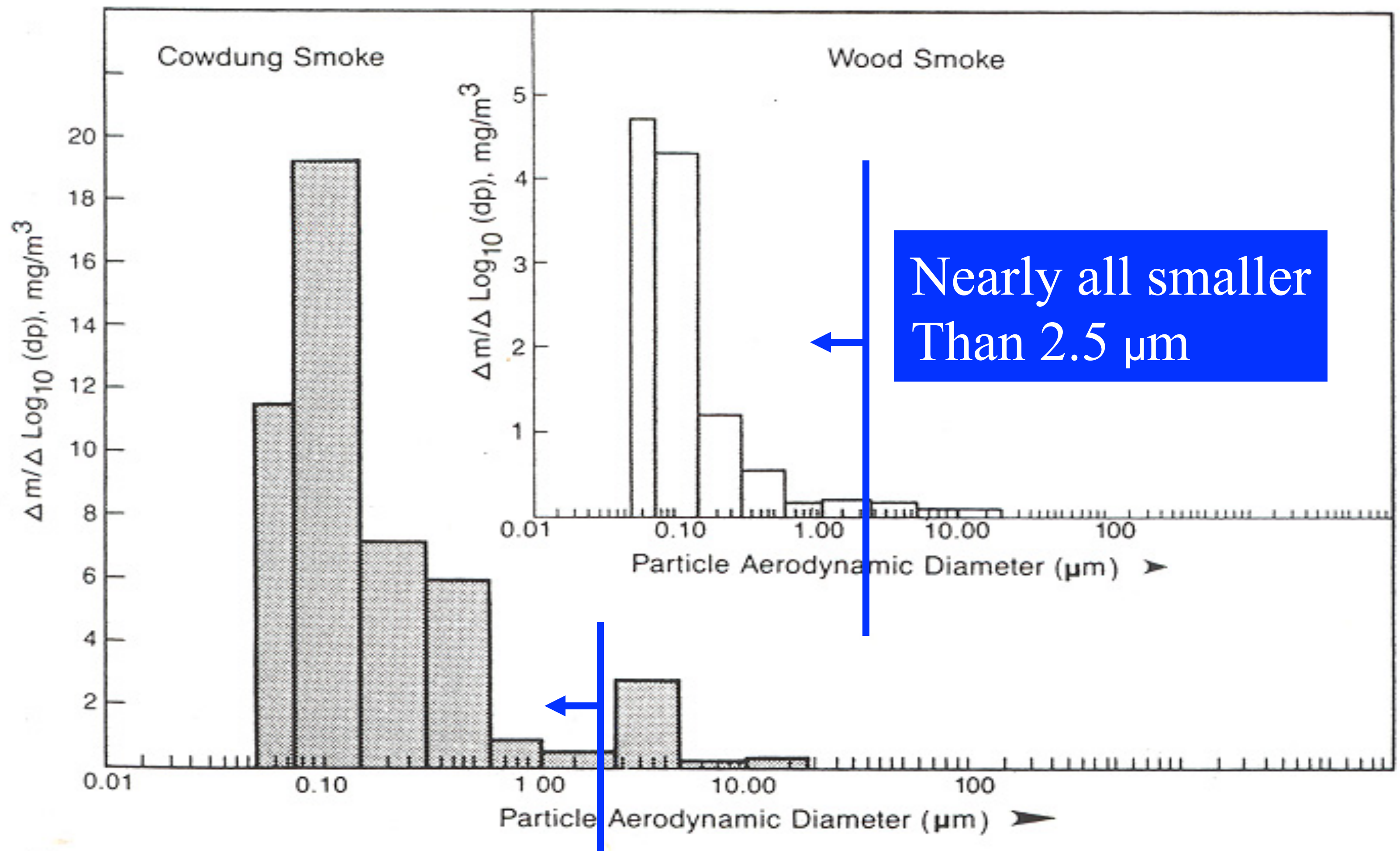
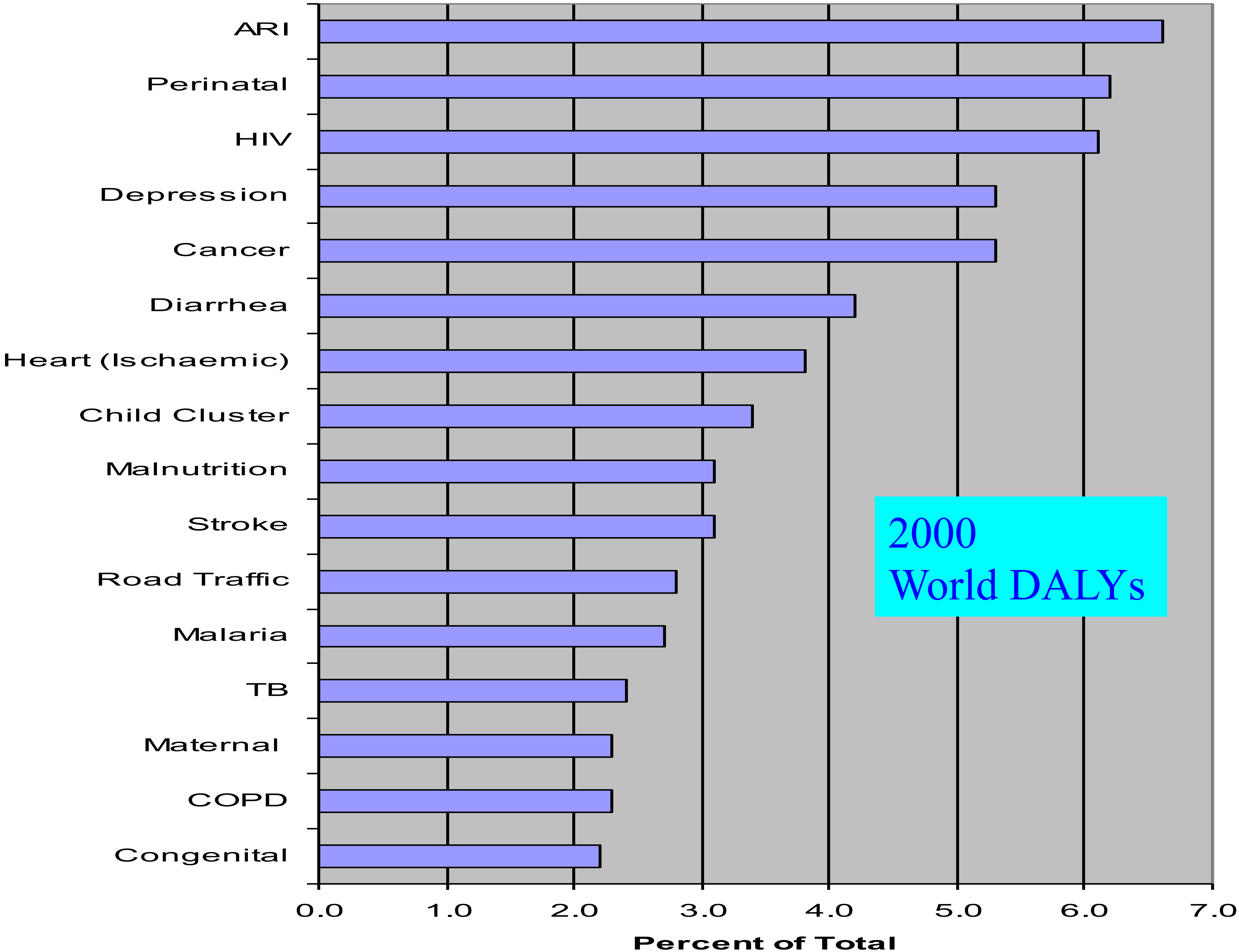


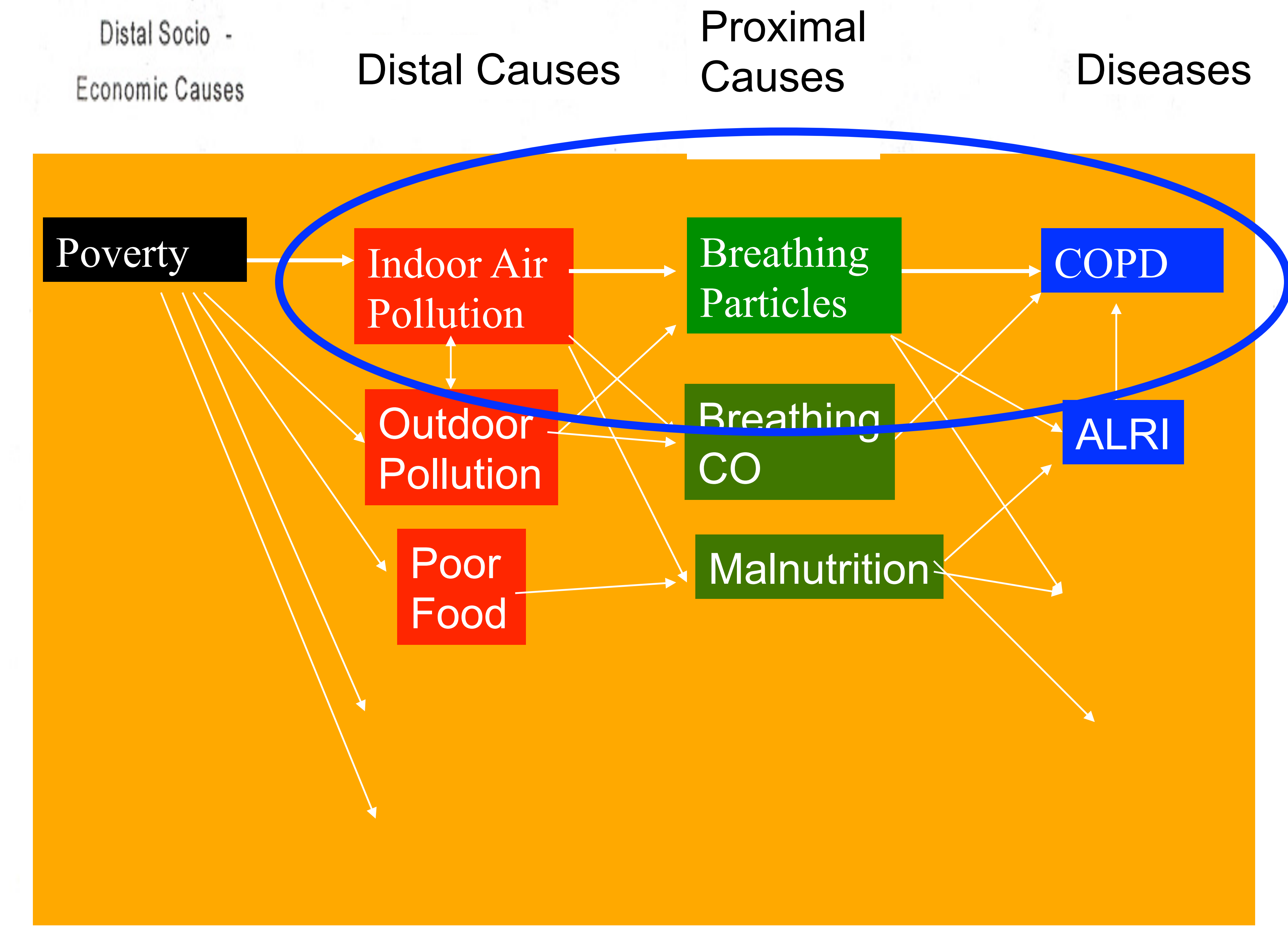
Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East–West Center simulated village house as reported in Smith *et al.* (1984b). (Figure prepared by Premlata Menon.)

Source: Smith, Apte et al. 1984

Combined Measure of Ill-health: Death and Illness

- Since potential life expectancy is something shared by everyone, the most fundamental deprivation is loss of healthy **time**
- Mortality measured as number of years death occurred before the longest life expectancy.
- Time can be used for morbidity, but need to weight relative severity of the illness or injury
- Disability Adjusted Life Year (DALY) =
  - Years of Lost Life (due to mortality) +
  - Years Lost to Disability (due to injury & illness) multiplied by a severity weight depending on the disease


ARI
Perinatal
HIV
Depression
Cancer
Diarrhea
Heart (Ischaemic)
Child Cluster
Malnutrition
Stroke
Road Traffic
Malaria
TB
Maternal
COPD
Congenital
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Percent of Total
2000
World DALYs


Distal Socio - Economic Causes
Distal Causes
Proximal Causes
Diseases
Poverty
Indoor Air Pollution
Outdoor Pollution
Poor Food
Breathing Particles
Breathing CO
Malnutrition
COPD
ALRI

Comparative Risk Assessment (CRA) 2-year 30-institution project organized by the World Health Organizaton

Disease, injury, and death due to 26 major risk factors calculated by age, sex, and 14 global regions.

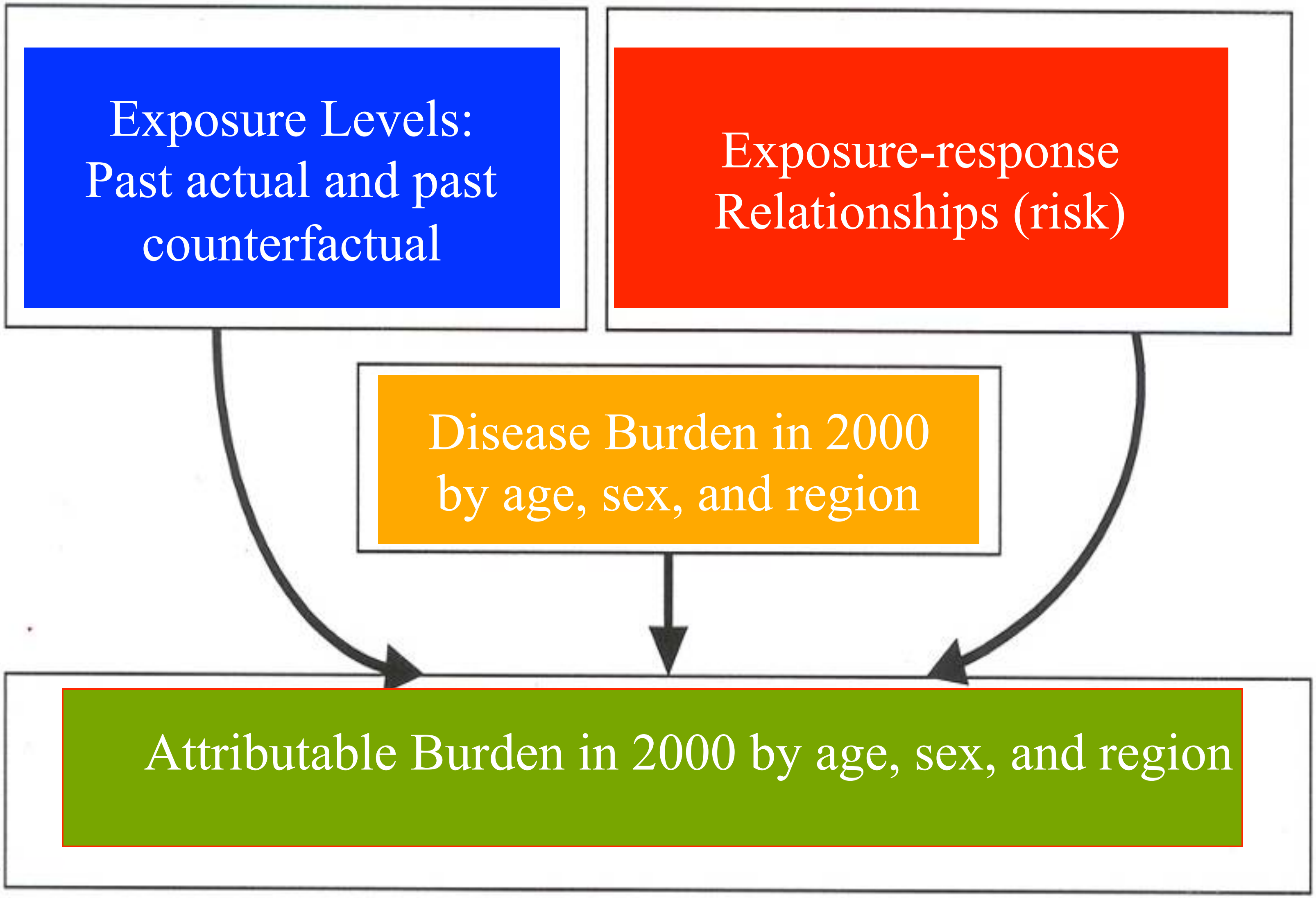
Fully published in late 2004 in two volumes by WHO

Environmental/Occupational Risk Factors

- Lead (Pb)
- Water/hygiene/sanitation
- Climate change
- **<u>Indoor air pollution from solid fuels</u>**
- **<u>Urban outdoor air pollution</u>**

- Occupational
  - Injuries
  - Particles/dust
  - Carcinogens
  - Noise
  - Ergonomics

Comparative Risk Assessment Method



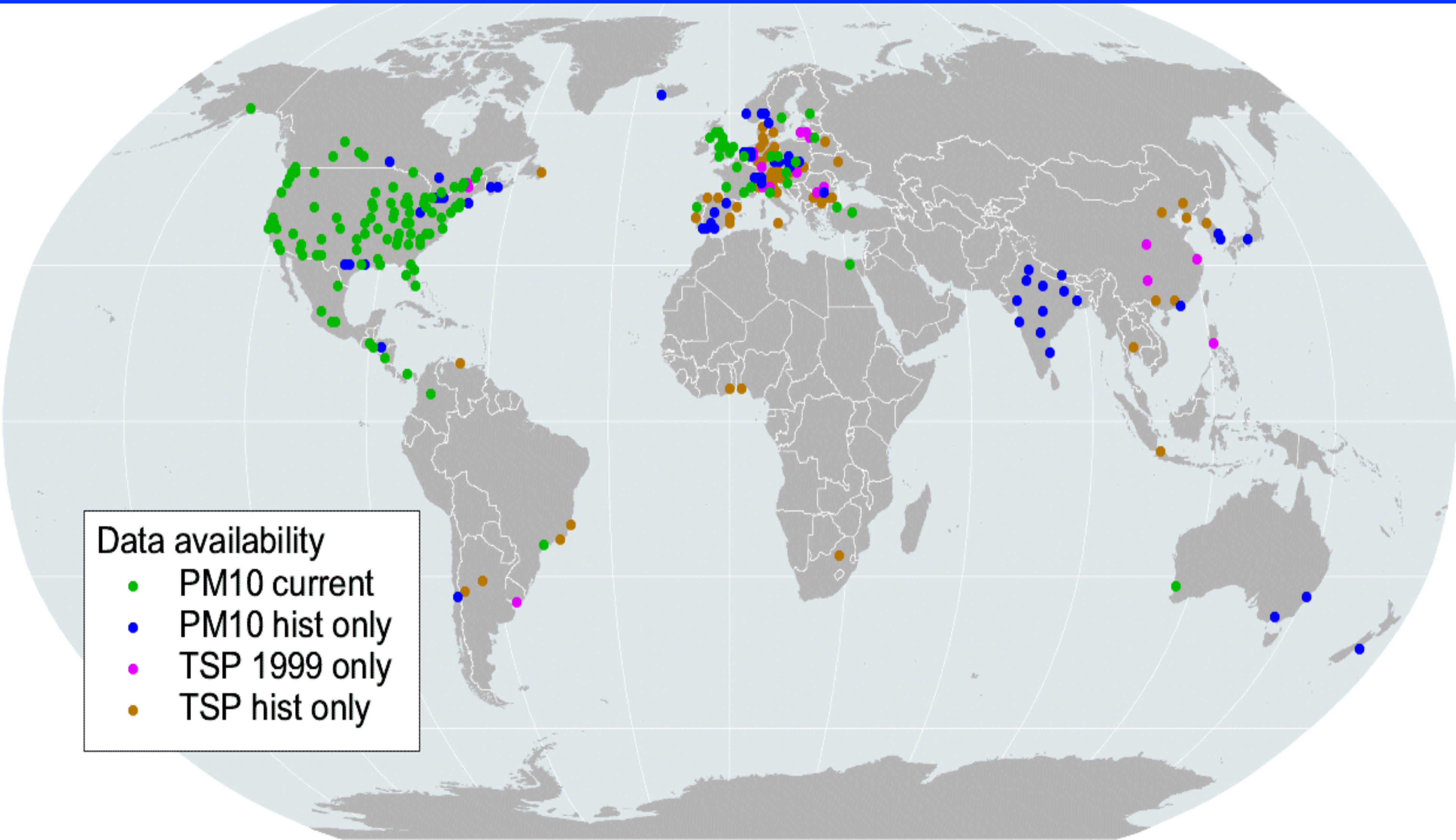
Outdoor Exposure - pollutant for exposure assessment

Criteria

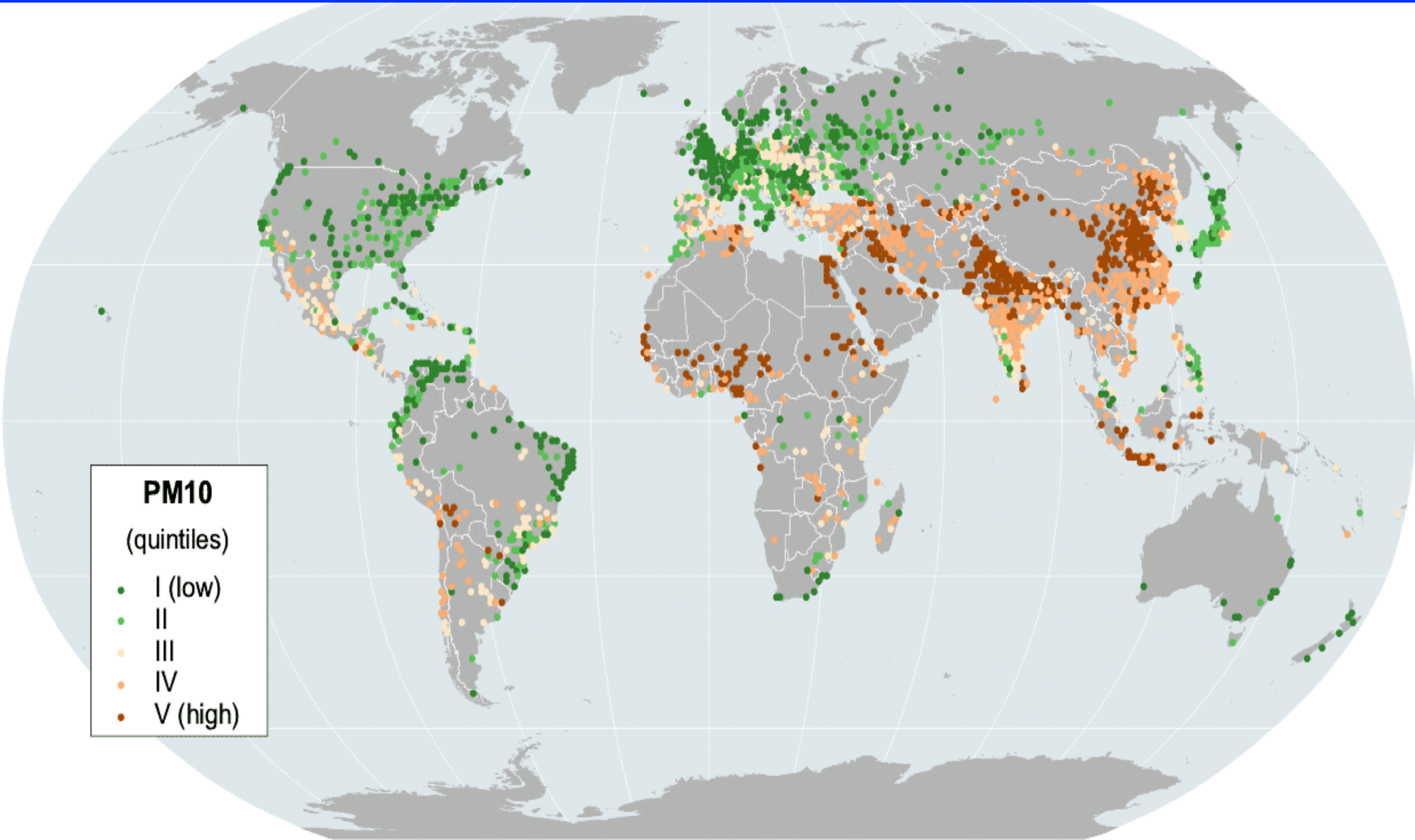
- Index of combustion processes
- Compelling evidence of health effect
- Widely available measure

- Inhalable particles (PM_{10}) and fine particles ($PM_{2.5}$)

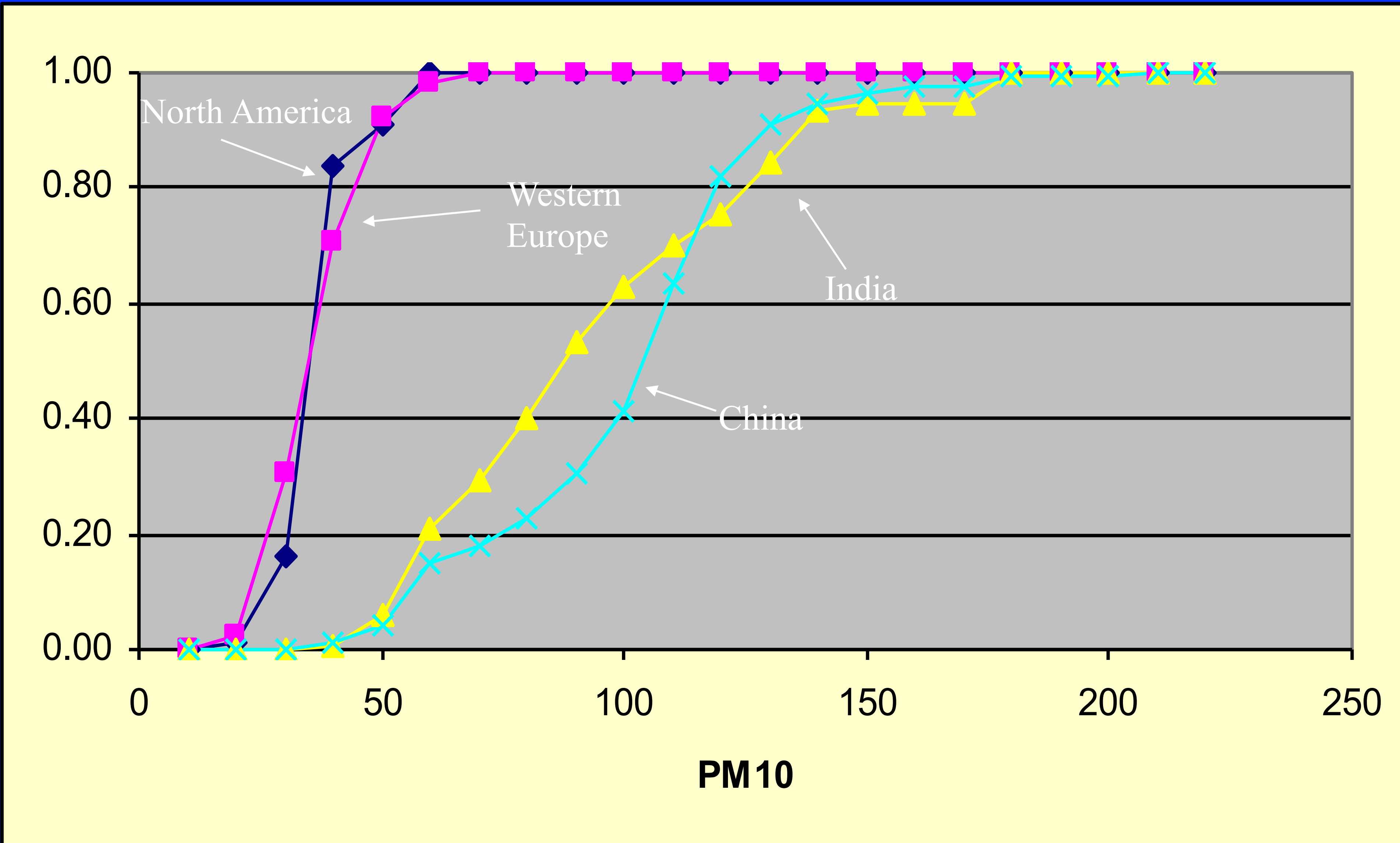
AVAILABILITY OF EXPOSURE DATA AT FIXED MONITORING SITES IN RESIDENTIAL AREAS



Estimated PM10 Concentration in World Cities (pop=100,000+)



Cumulative distribution of urban pollution ($\mu g/m^3$)



Two sources of epidemiological evidence

- Chronic exposure studies

  geographical comparisons

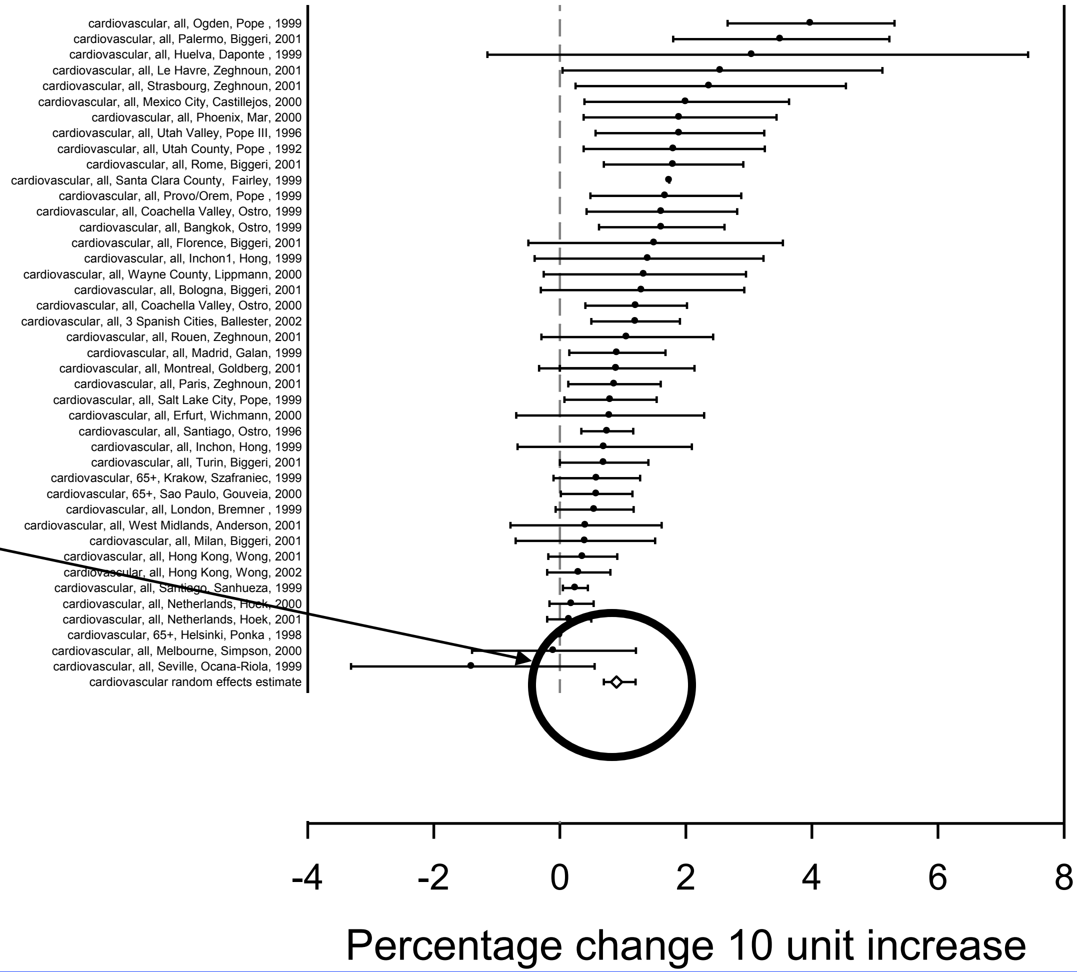
- Short-term exposure studies

  daily time series analyses

How generalizable is the existing evidence, which is mostly from Western Europe and North America?

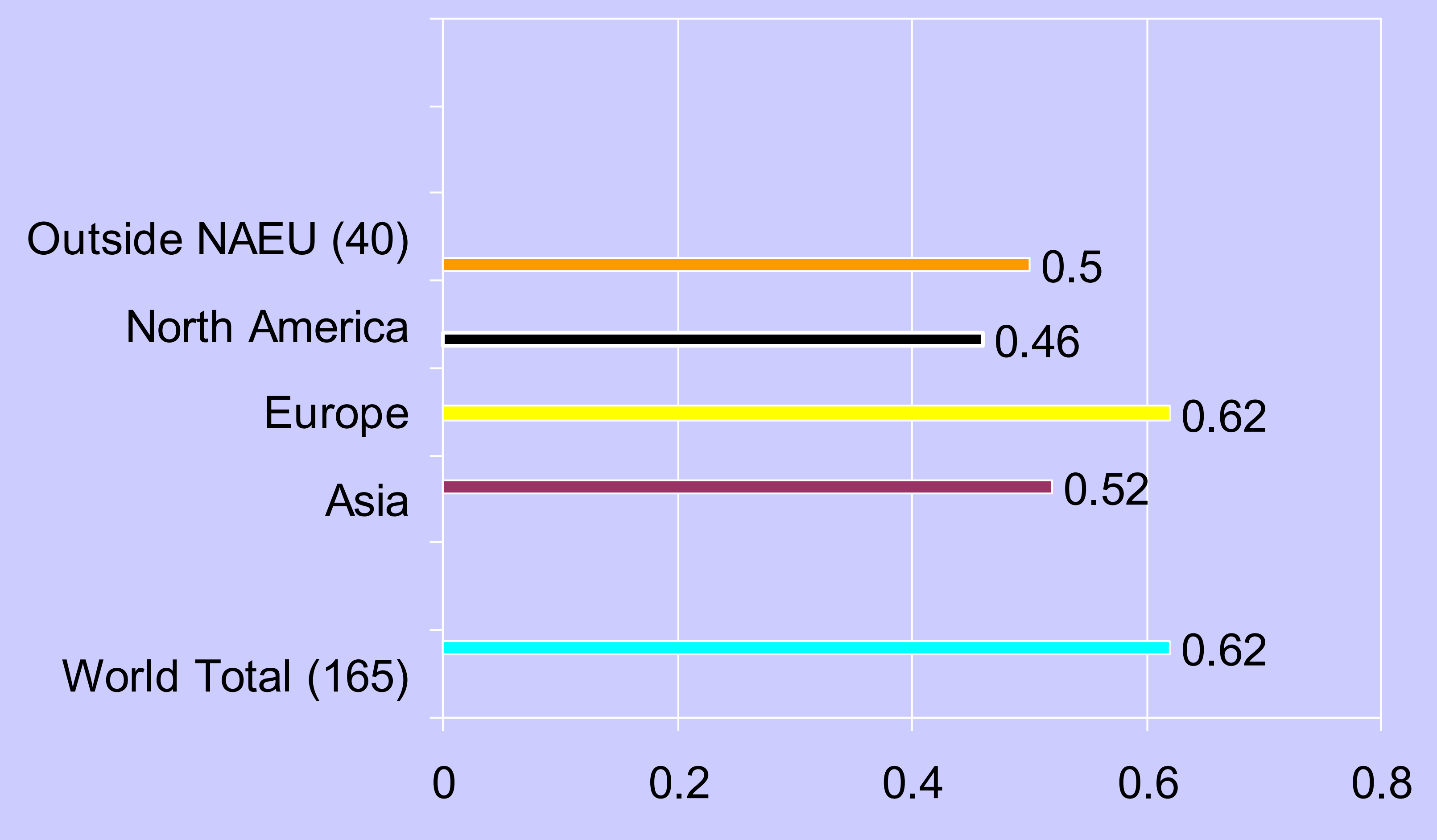
Example of Meta-analysis
Cardiovascular mortality and PM10

Combined Estimate



Effect estimates for daily mortality in existing time series studies

% change for 10µg/m^3 increase in particles



C-R functions for mortality

1. Effects of long-term exposure on cardiopulmonary and lung cancer mortality (Cases and years of life lost: ACS)

2. Effects of long-term exposure on all-cause and Acute Respiratory mortality in children < age 5

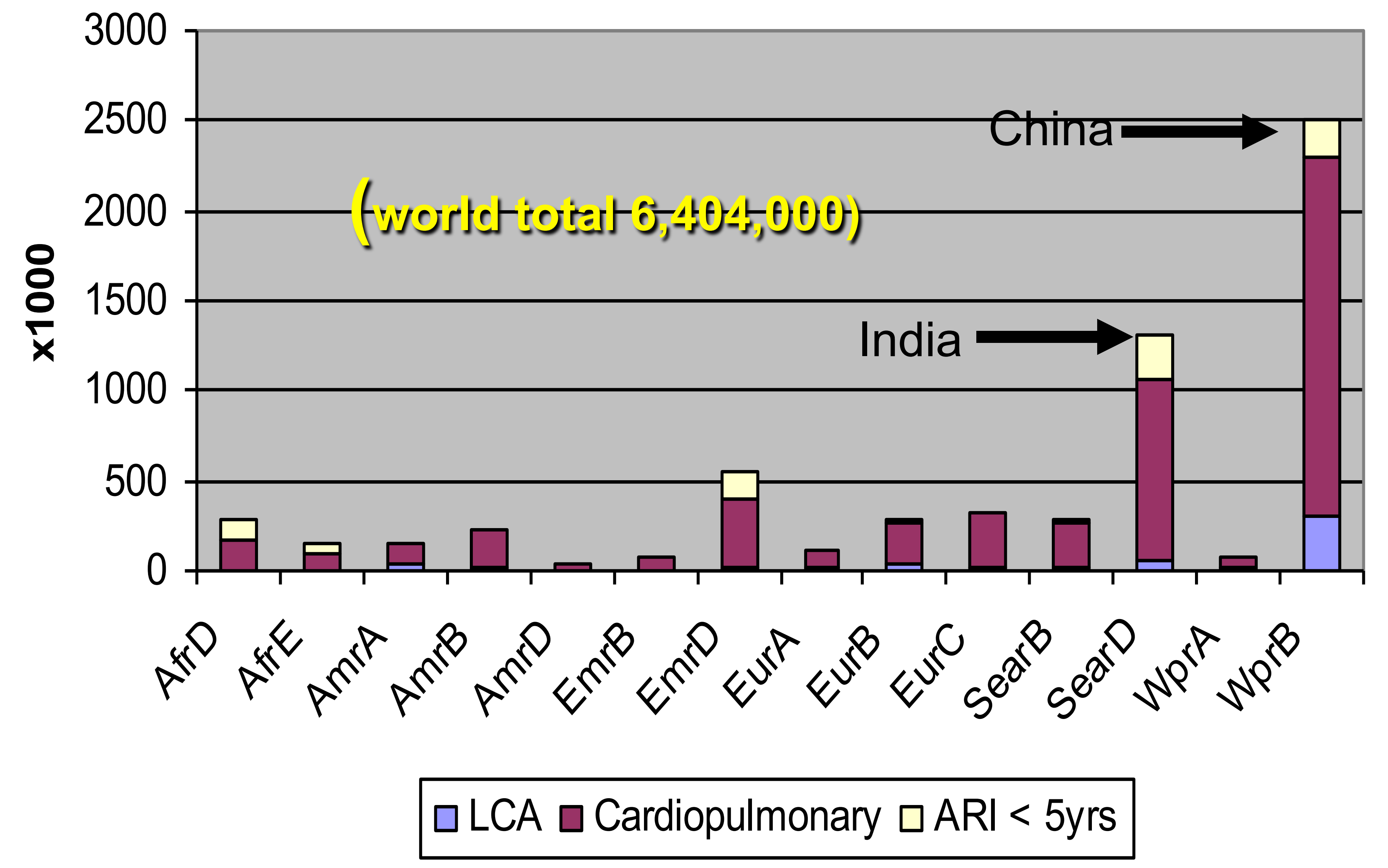
3. Effects of short-term exposure on all-cause mortality used to see if effects similar in different parts of world

ACS cohort (Pope et al JAMA 2002) 500 000 adults followed 1982 - 1998

RR (adj) per 10 $\mu g/m^3$ $PM_{2.5}$ 1979-83		
	RR	95% CI
Cardiopulmonary	1.06	1.02-1.10
Lung Cancer	1.08	1.01-1.16

Random effects Cox proportional hazards model controlling for age, sex, race, smoking, education, marital status, body mass, alcohol, occupational exposure and diet.

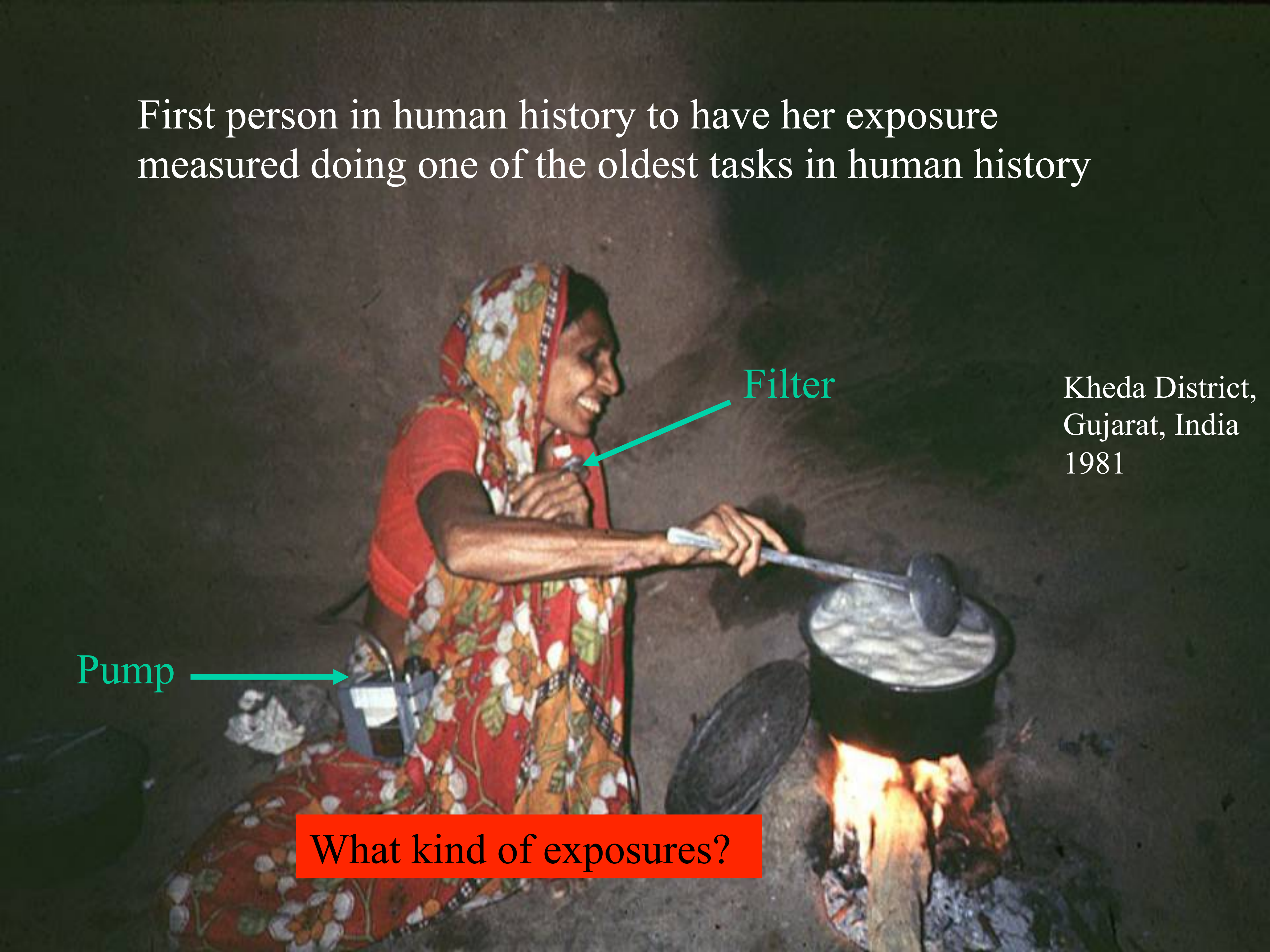
Lost healthy life years (DALYs)



Household Combustion Sources with Potentially Significant Global Health Impact

- Stoves and furnaces
- Environmental Tobacco Smoke – ETS
- Candles, incense, mosquito coils, etc.

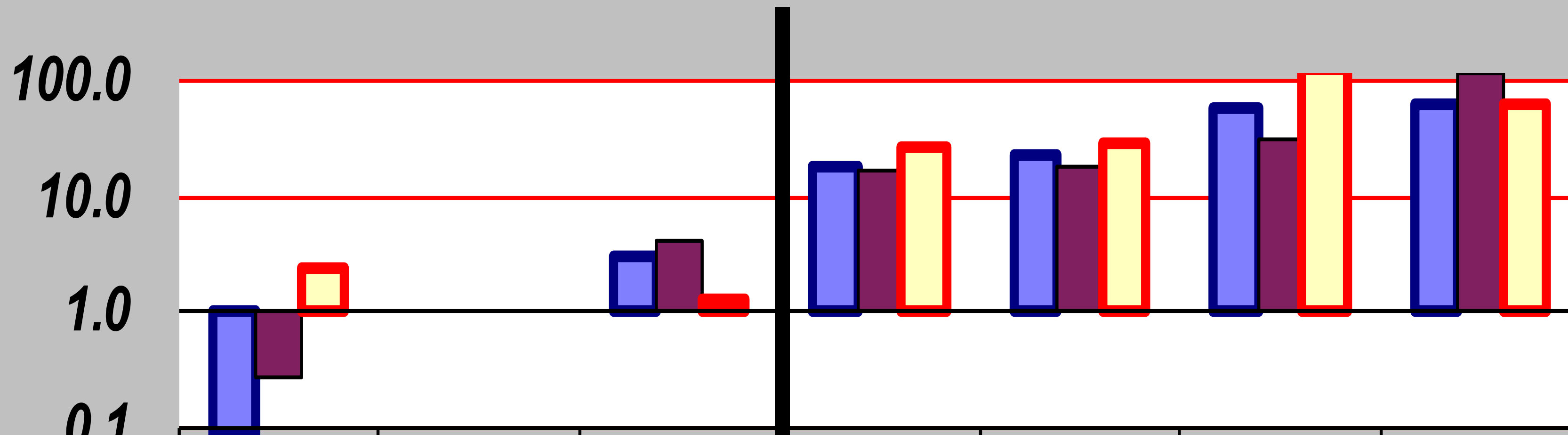
First person in human history to have her exposure measured doing one of the oldest tasks in human history



IAQ Exposure Measure for CRA

- Insufficient measurements of indoor exposures worldwide to use concentration
- Binary metric is possible: use or no use of solid fuels for household cooking and heating: biomass (wood, crop residues, dung) and coal
- Household survey data available for 50 nations
- Model developed to estimate levels in other 100+ countries.

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

CO Hydrocarbons PM

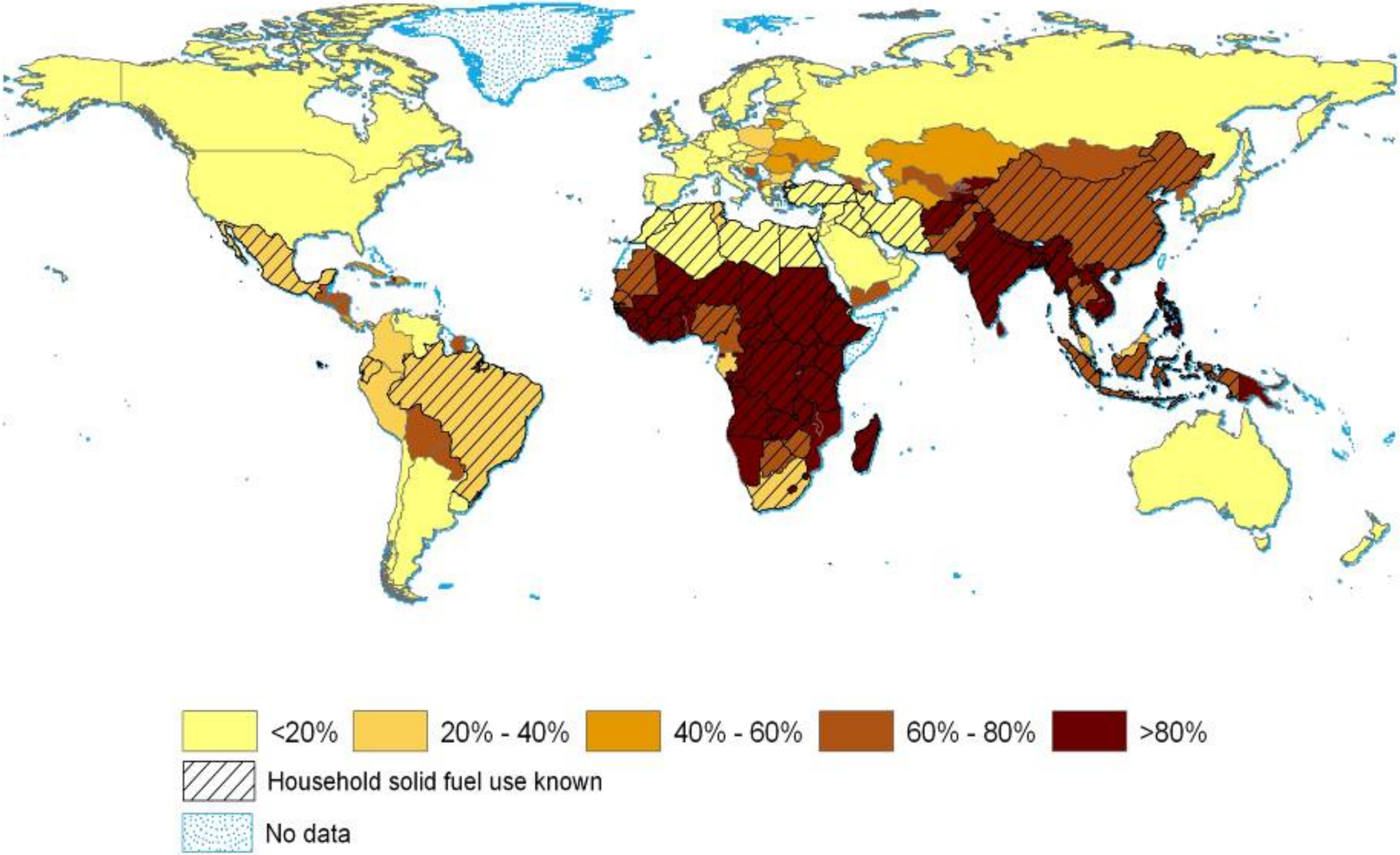
Final Fuel Prediction Model

	Standardized Coefficients			95% Confidence Interval for B	
	Beta	t	Sig.	Lower	Upper
(Constant)		3.1926	0.0025	0.4135	1.8223
RURAL	0.3527	3.0938	0.0033	0.2312	1.0908
EMR	-0.2838	-3.4968	0.0010	-0.3904	-0.1053
LNGNP	-0.2646	-2.5648	0.0136	-0.1852	-0.0224
per capita Petroleum Use	-0.2244	-2.5454	0.0143	-0.0006	-0.0001

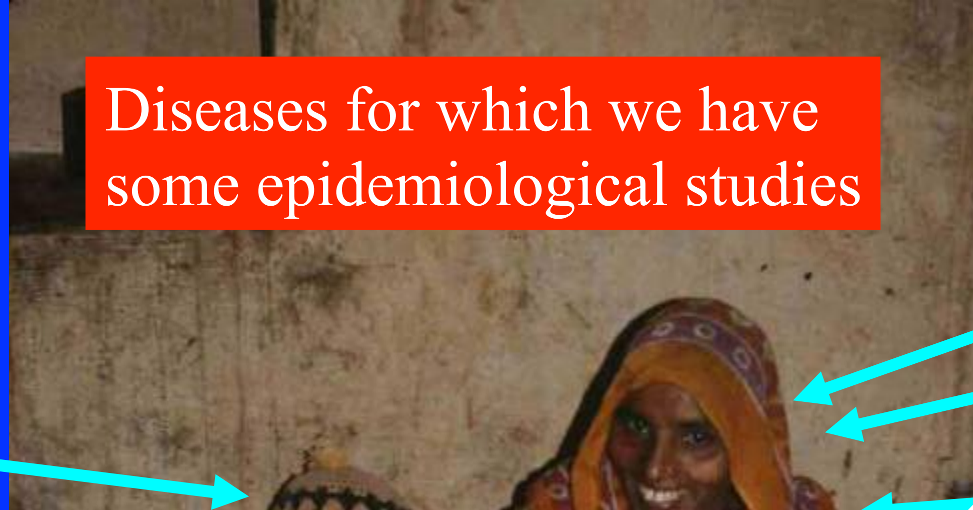
ln GNP/cap
Percent Rural
Petroleum use
Eastern Mediter.

- Model Summary:
  - R: 0.8637
  - R^2: 0.7460
  - Adjusted R^2: 0.7244
  - Standard Error of the Estimate: 0.1891
- Model meets assumptions of normalcy, constant variance.
- Collinearity and Tolerance also assessed.

National Household Solid Fuel Use, 2000



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.

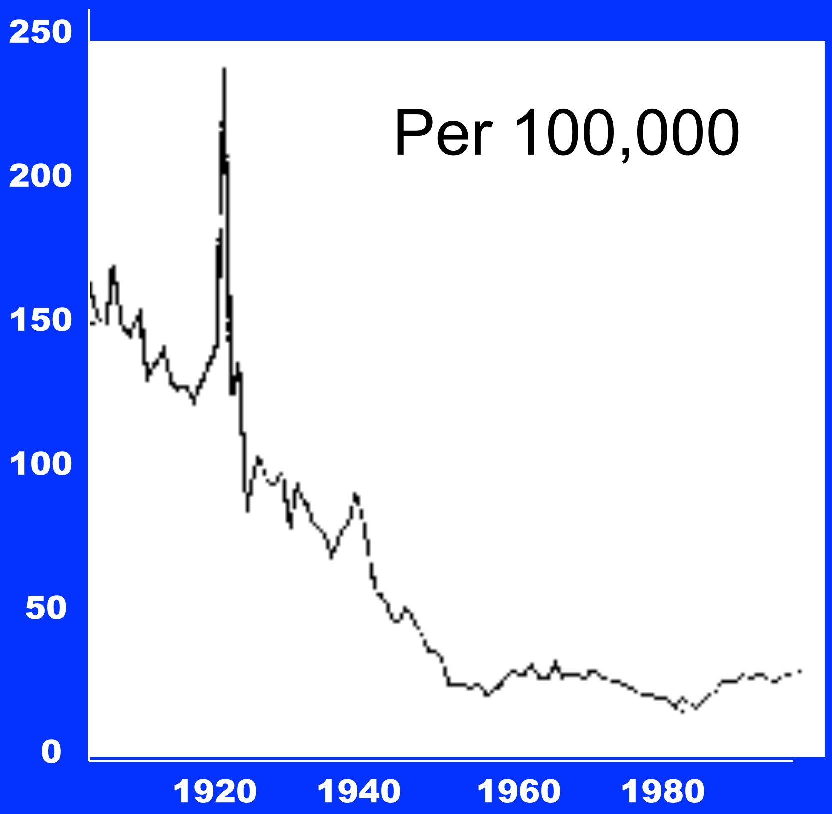
Child mortality occurs almost entirely in developing countries, and as pneumonia.

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



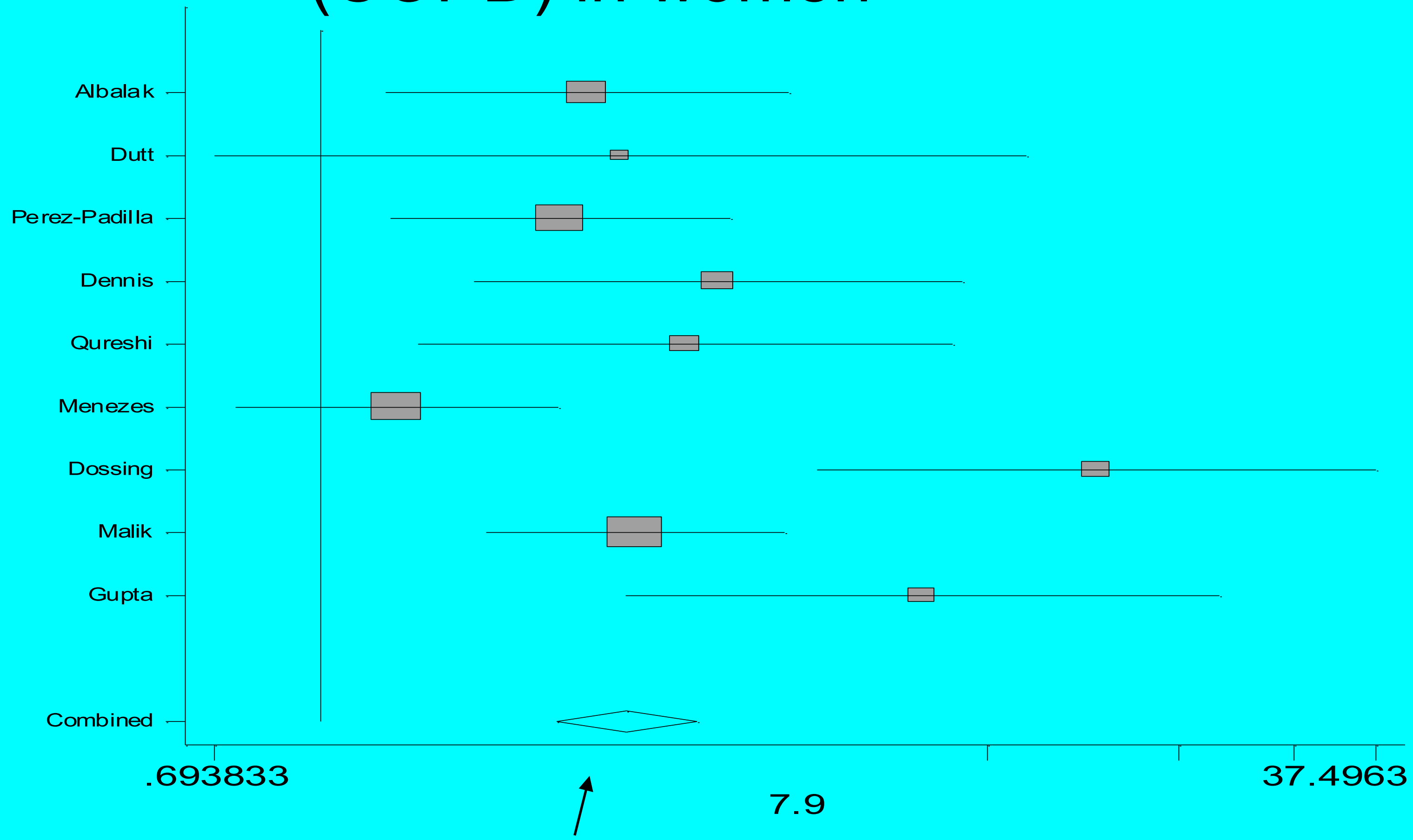
Meta-analysis of studies of ALRI and solid fuels, in children aged <5 years

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 [illegible]	2.3 (1.8-2.9)
[illegible]	[illegible]3)
Studies not adjusting for nutritional status	2.2 ([illegible]-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

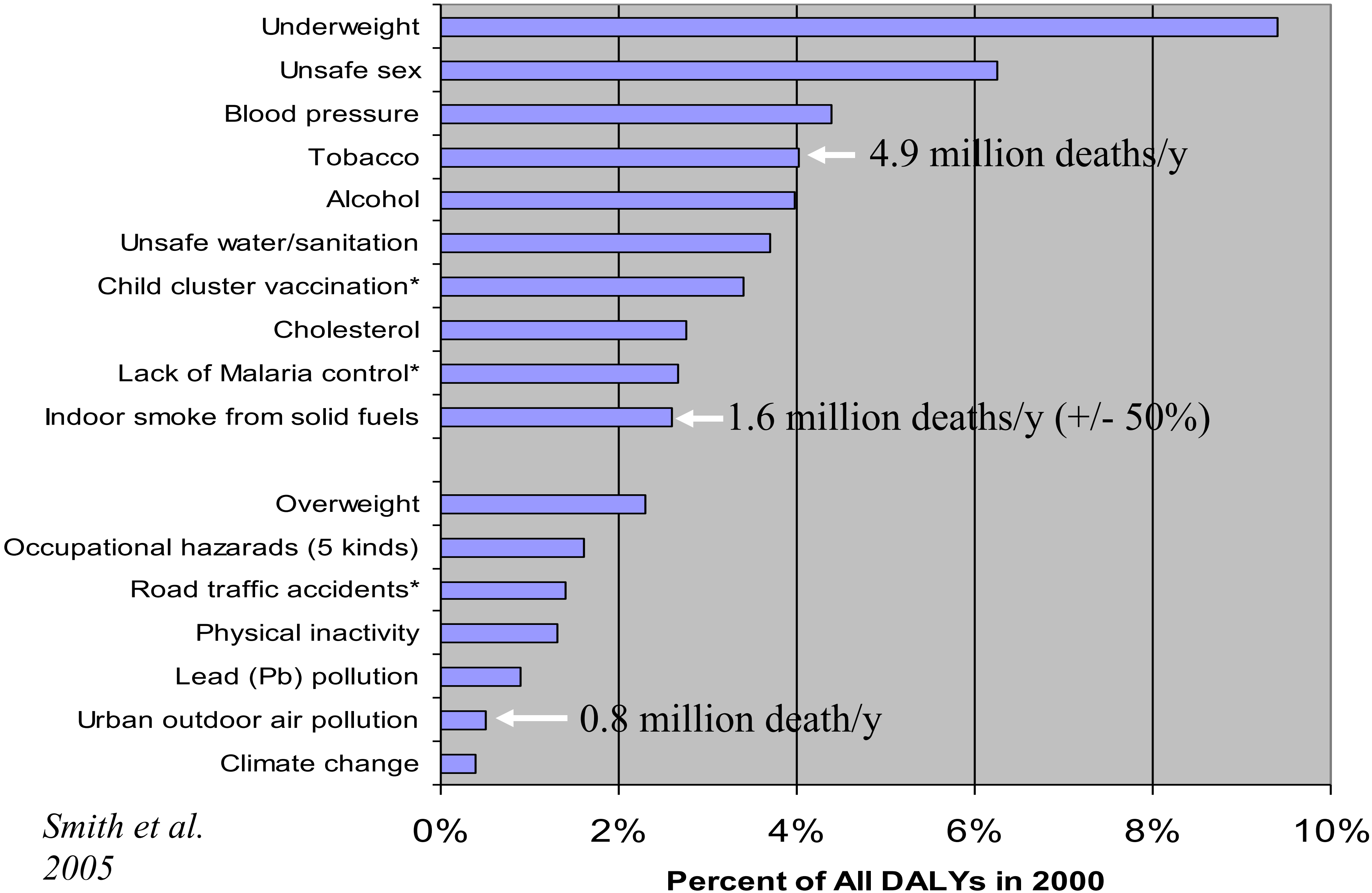


<u>OR = 3.2 (95% CI: 2.3-4.8)</u>

Smith et al., 2004

Global Burden of Disease from Top 10 Risk Factors

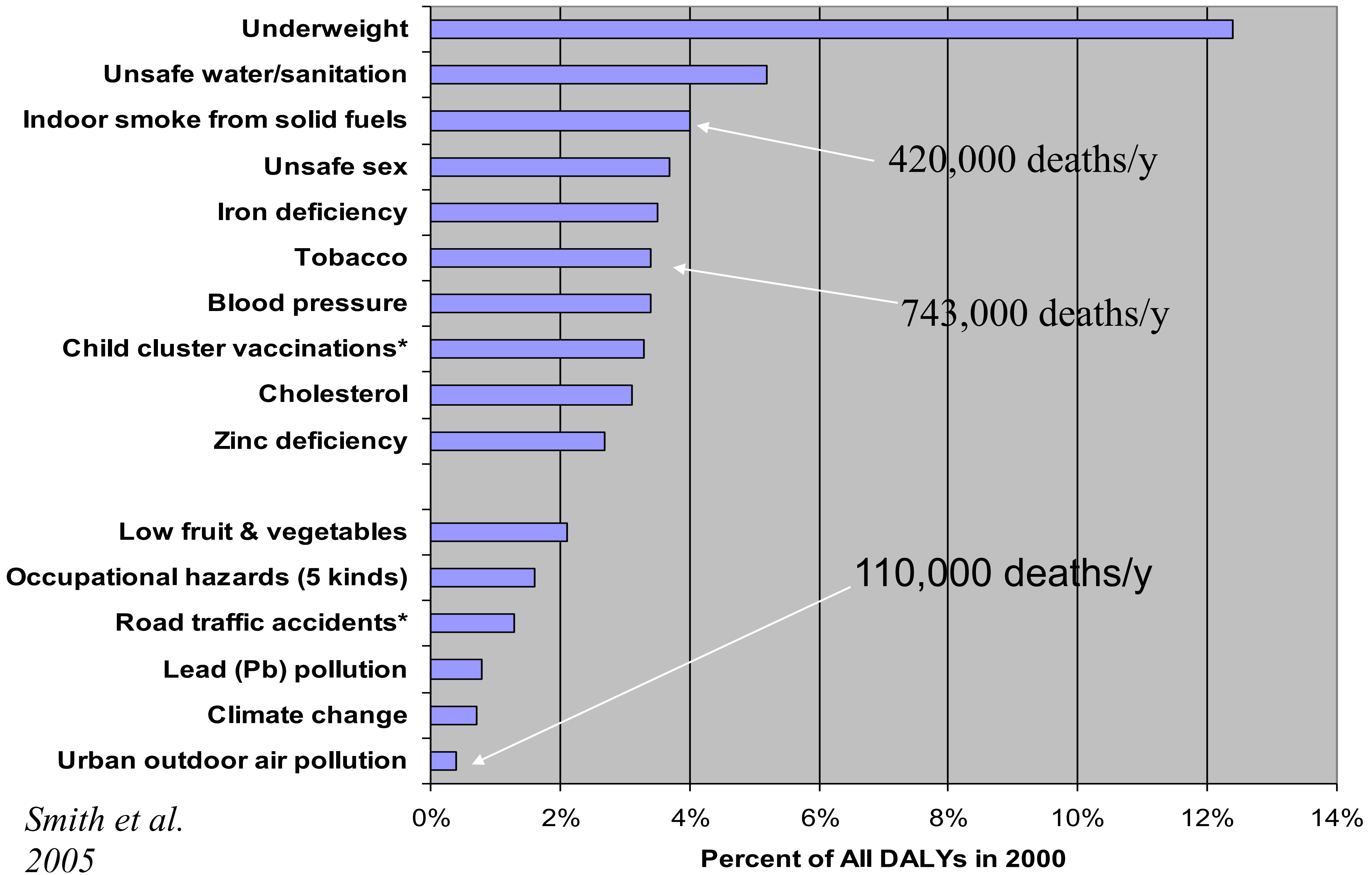
plus selected other risk factors



Smith et al. 2005

Indian Burden of Disease from Top 10 Risk Factors

Plus Selected Other Risk Factors



Smith et al. 2005

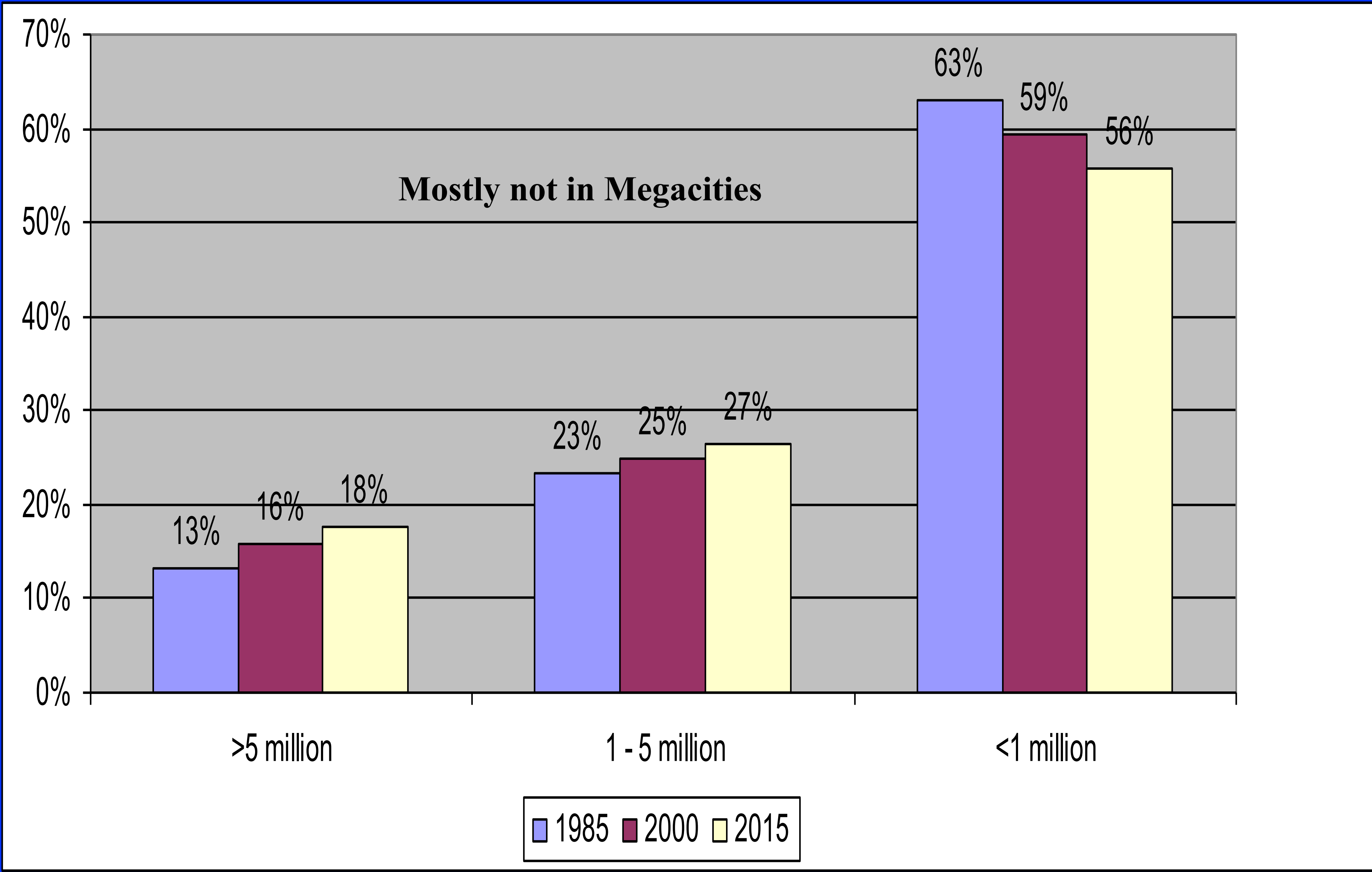
Global Health Effects of Combustion Particles: Premature Deaths Per Year

- Urban outdoor air pollution: ~800,000
- Household use of solid fuels: ~1,600,000
- Environmental tobacco smoke: ~300,000
- Occupational exposures: ~250,000
- Total ~ 3 million per year
  - With active smoking: ~8 million
- Compare with global totals for
  - Dirty water: 2 million
  - HIV: 3 million
  - All cancer: 7 million
  - Malnutrition: 4 million

Particle exposures to large populations are missing from these analyses:

- Small cities (<100,000)
- Non-urban outdoor exposures
- Transboundary pollution

Urban Population in Developing Countries




India

Energy flows in well-operating traditional woodfired cookstove

PIC = products of incomplete combustion.

Indian Cookstoves

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

Source: Smith, et al, 2000
Census, 2001

Biomass Gasifier Stove: Chinese Examples

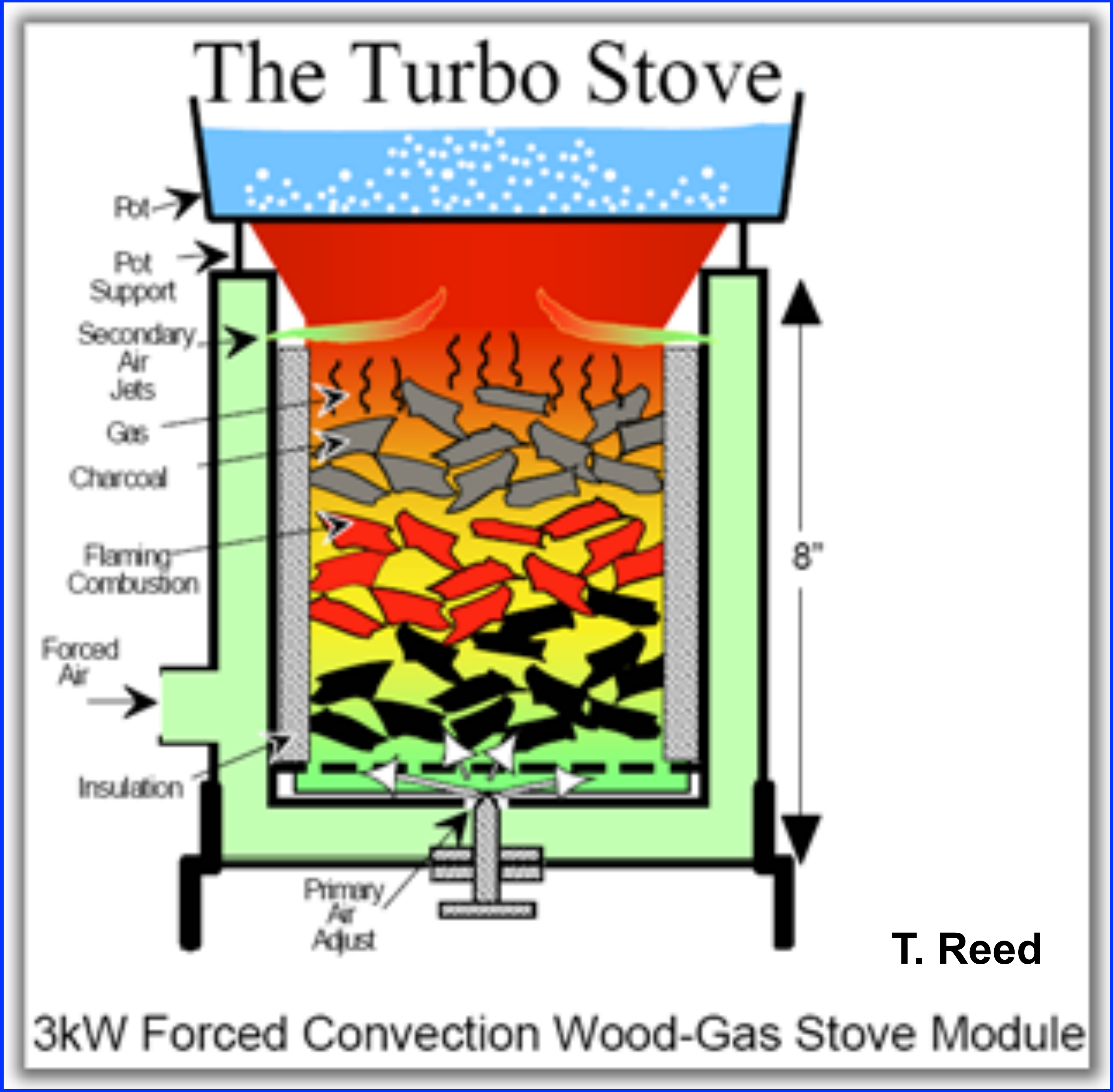
Preliminary tests show PIC levels nearly at LPG levels.
But can it be reliably achieved in the field?

Domestic Biomass Gasifier and Semi-Gasifier Stoves

In recent years, a series of biomass gasifier and semi-gasifier low emission stove was introduced into the market. The industrialization and commercialization of this kind of stove is at a low level but growing strongly. There are more than 10 companies manufacturing gasifier and semi-gasifier stove, mainly in 6 provinces or autonomous regions (Please refer to Figures 13 and 14).

- The semi-gasifier stove customers do not need to buy fuel at present. They only need simply processed fuel. The gasification efficiency can be as high as 60%, and thermal efficiency more than 45%. The most significant character is it doesn't emit dark smoke, and is friendly to the environment and the farmers' health.

Figure 18. Some types of Gasifier and Semi-gasifier Stoves on the Chinese Market



Gasifier Stove With Forced Air

Increase turbulence with steam

Need for fast, cheap, and easy monitoring and testing techniques: something the combustion community can help with

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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Tracy Allen
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Charles D. Litton
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Susanne Hering
Aerosol Dynamics,

ABSTRACT
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ARTICLE

Journal of Environmental Monitoring]

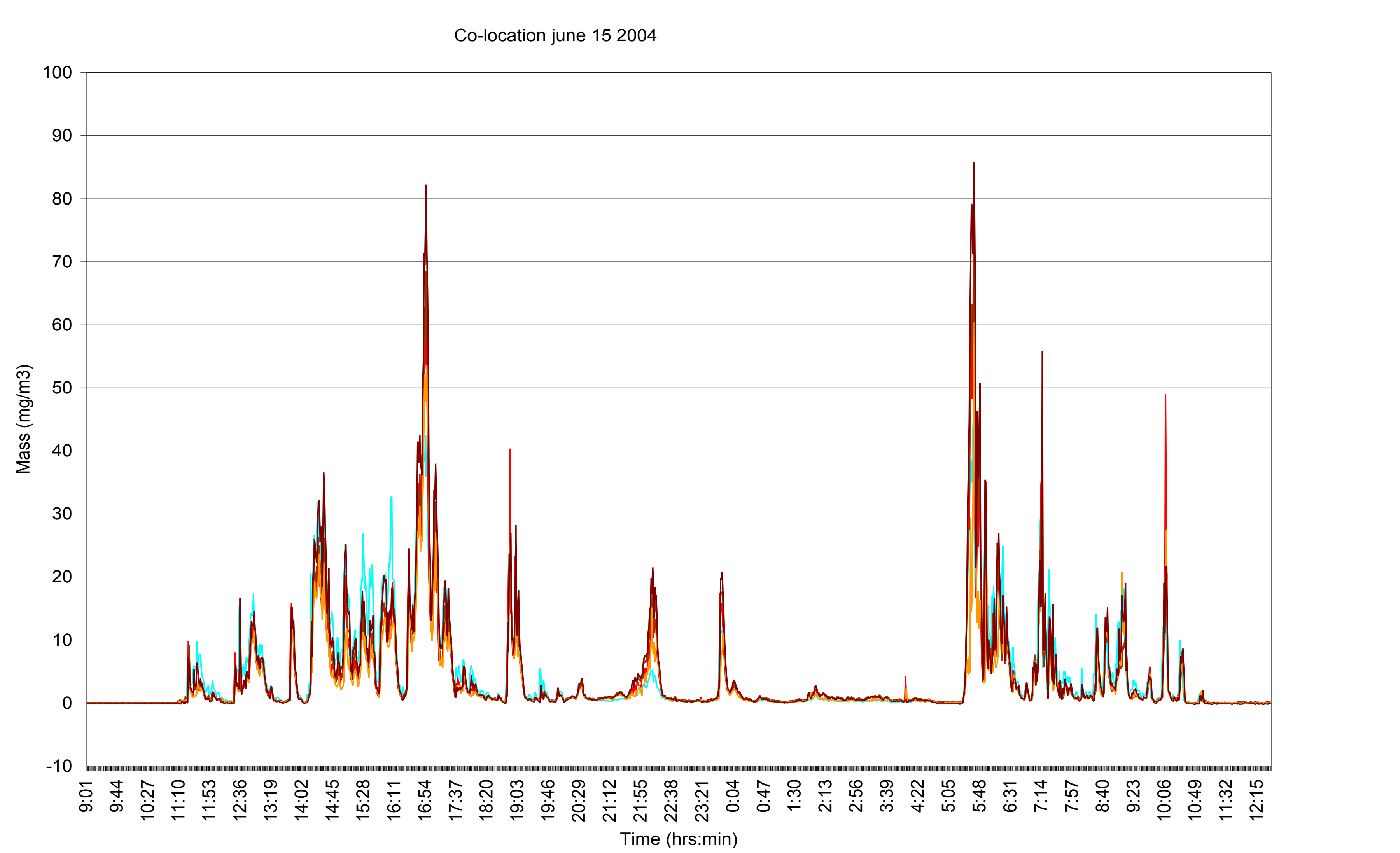
An inexpensive light-scattering particle monitor: field validation

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

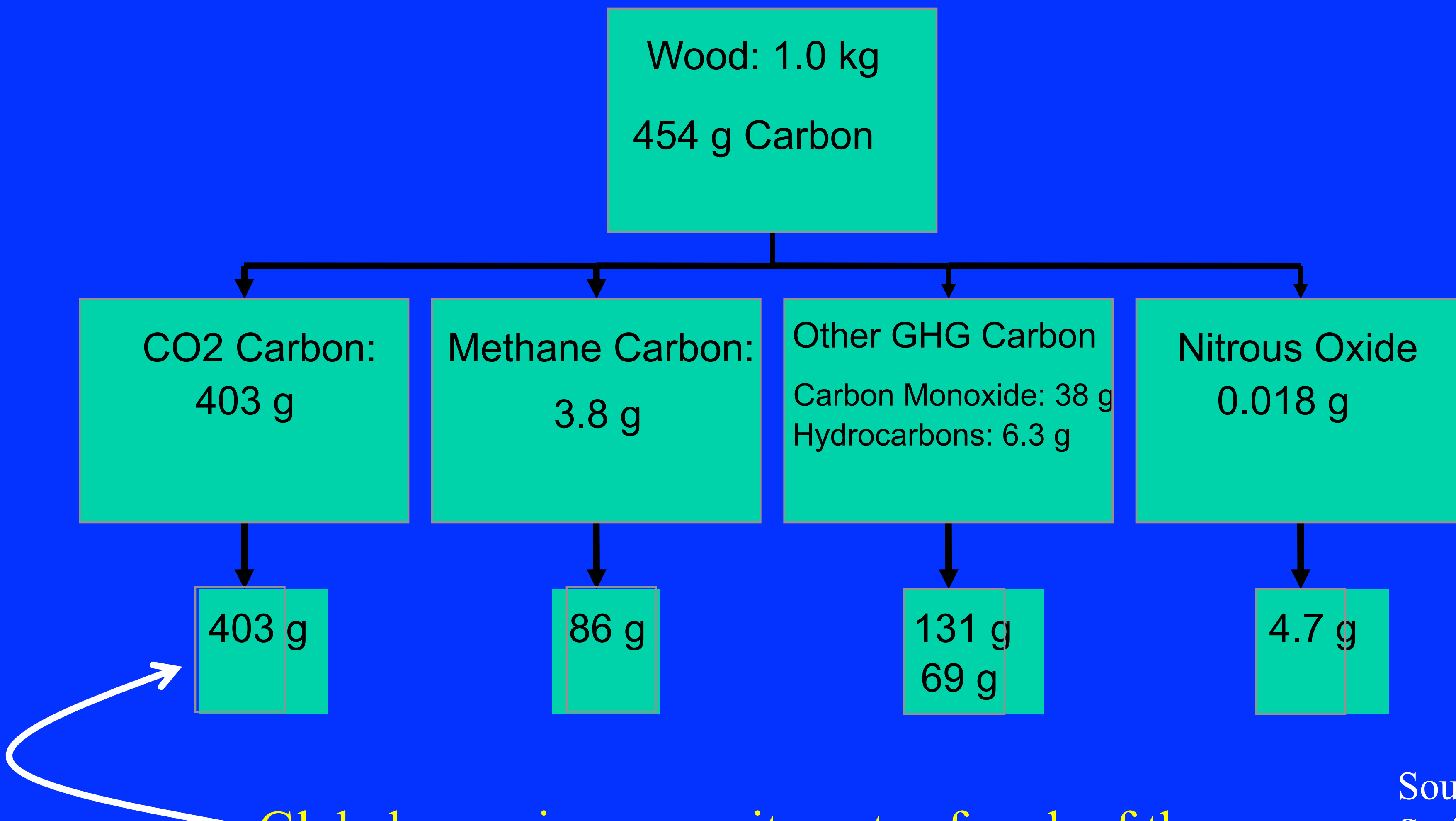
***Receipt/Acceptance Data*: Forthcoming 2007**
Publication data
DOI: 10.1039/b000000x

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



Greenhouse warming commitment per meal for typical wood-fired cookstove in India



Global warming commitments of each of the gases as CO_2 equivalents

Source: Smith, et al., 2000

Determining GHG Emissions

- Methane is most difficult
- Requires gas chromatograph at levels in flue gas
- Are other approaches possible?

[Summary of slides removed with unpublished UCI data]

- Laboratory results do not match field results: Need to measure in real use in real households
- A few relatively simple measurements do well in predicting total GHG emissions
- Portable instruments do almost as well as lab instruments in monitoring emissions
- Probe does almost as well as the more difficult-to-employ hood in determining emissions

Another approach

- Human nose is extremely sensitive
- If a strong odorant is not detected after burning, then combustion efficiency is likely high
- Need an odorant that is easily and cheaply available, non-toxic, and biodegradable
- Preferably carbon-neutral
- Problem actually solved in 1686 and published in UK Royal Society Proceedings

PHILOSOPHICAL
TRANSACTIONS.

May the 25th. 1686.

THE CONTENTS.

An Account of an Engine that conſumes Smoak, ſhown lately at St. Germans Fair in Paris Communicated by Mr. Juſtell R.S.S.

TO burn all ſorts of Wood in the middle of a Room without making any Smoak, is a thing ſo extraordinary, that all thoſe that have heard ſpeak of it, as well Philoſophers as others, have aſſerted it impoſſible: but Mr. Daleſme Enginier, proſecuting his diſcoveries, has found out a Machine, which tho very little and portable, conſumes all the Smoak of all ſorts of Wood whatſoever, and that ſo, that the moſt curious eye cannot diſcover it in the Room, nor the niceſt Noſe ſmell it, altho' the Fire be perfectly open. This has given ſuch ſatisfaction to all that have ſeen it, and to the King himſelf, that he has cauſed the Experiment to be made ſeveral times before Him.

This Engine is made after the manner repreſented in Fig. 1. and is compoſed of ſeveral hoops of hammer'd Iron of about 4 or 5 Inches diameter, which ſhut one into the other: It ſtands upright in the middle of the Room, upon a ſort of Trevet made on purpoſe.

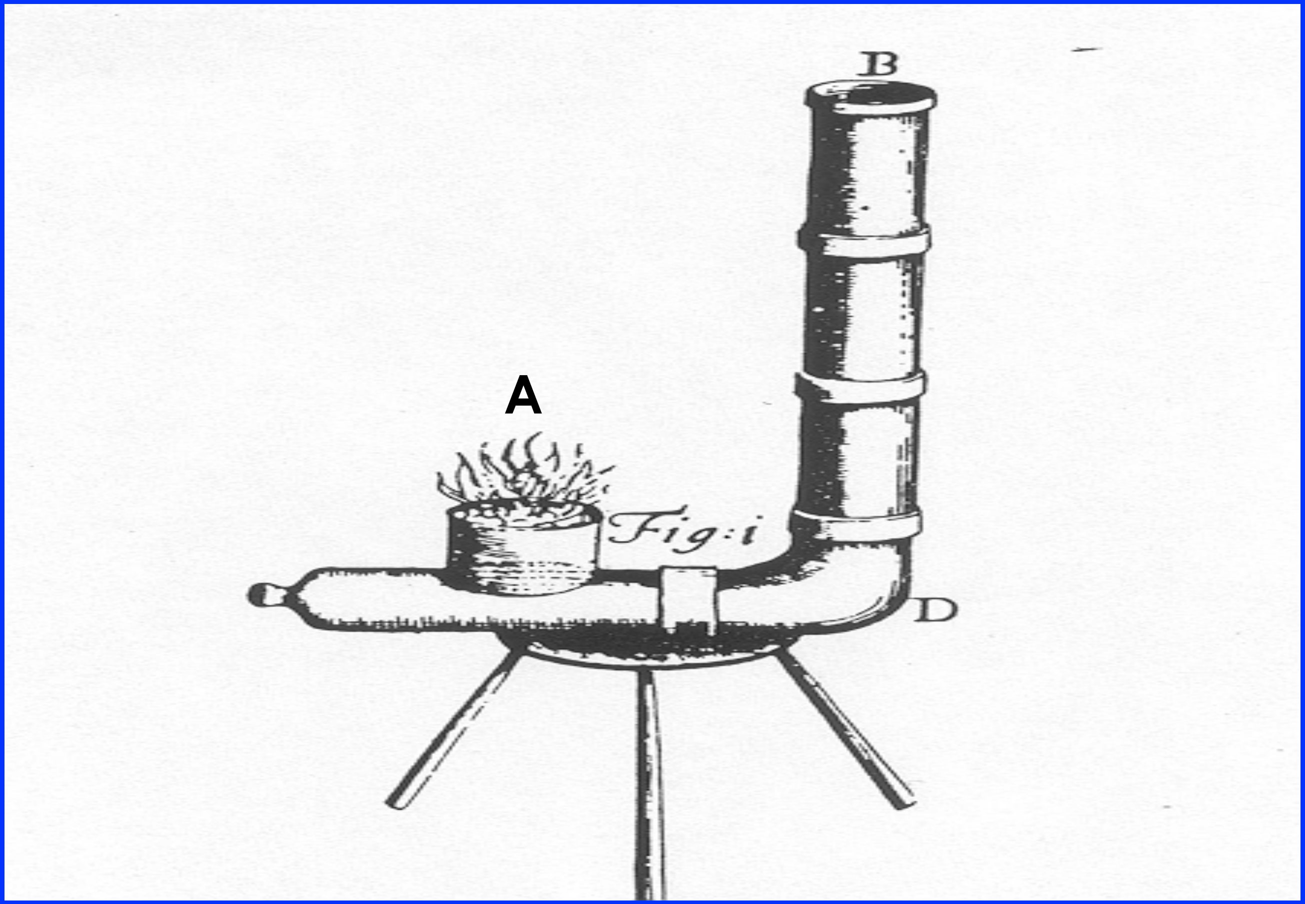
Philosophical Transactions of the Royal Society, London, Num 181, page 78, May the 25th, 1686

<u>An Account of an Engine that consumes Smoak, shown lately at ST. Germans Fair in Paris</u>

Communicated by Mr. Justell R.S.S.

"To burn all sorts of Wood in the middle of a room without making any Smoak is a thing so extraordinary, that those that have heard speak of it, as well philosophers as others, have asserted it impossible, but Mr. Dalesme, Enginier, prosecuting his discoveries, has found out a Machine, which tho very little and portable, consumes all the Smoak of all sorts of Wood whatsoever, and that so, that the most curious eye cannot discover it in the Room, nor the nicest Nose smell it, although the Fire be perfectly open. This has given such satisfaction to all that have seen it, and to the King himself, that he has caused the experiment to be made several times before him."

“This Engine is made after the manner represented in Fig. 1…. A is the place where the fire is made, where if you put little pieces of Wood, it will make the least Smoak, neither at A nor B, over which you cannot hold your hand within half a foot, there comes out so great a heat. …”



Odorant Employed for Testing

- "The most fetid things, as a coal steept in ?? which stinks abominably when taken out of the Fire, notwithstanding in this Engine makes not the least ill scent."
- Widely and cheaply available
- Non-toxic and biodegradable
- Renewable and carbon neutral

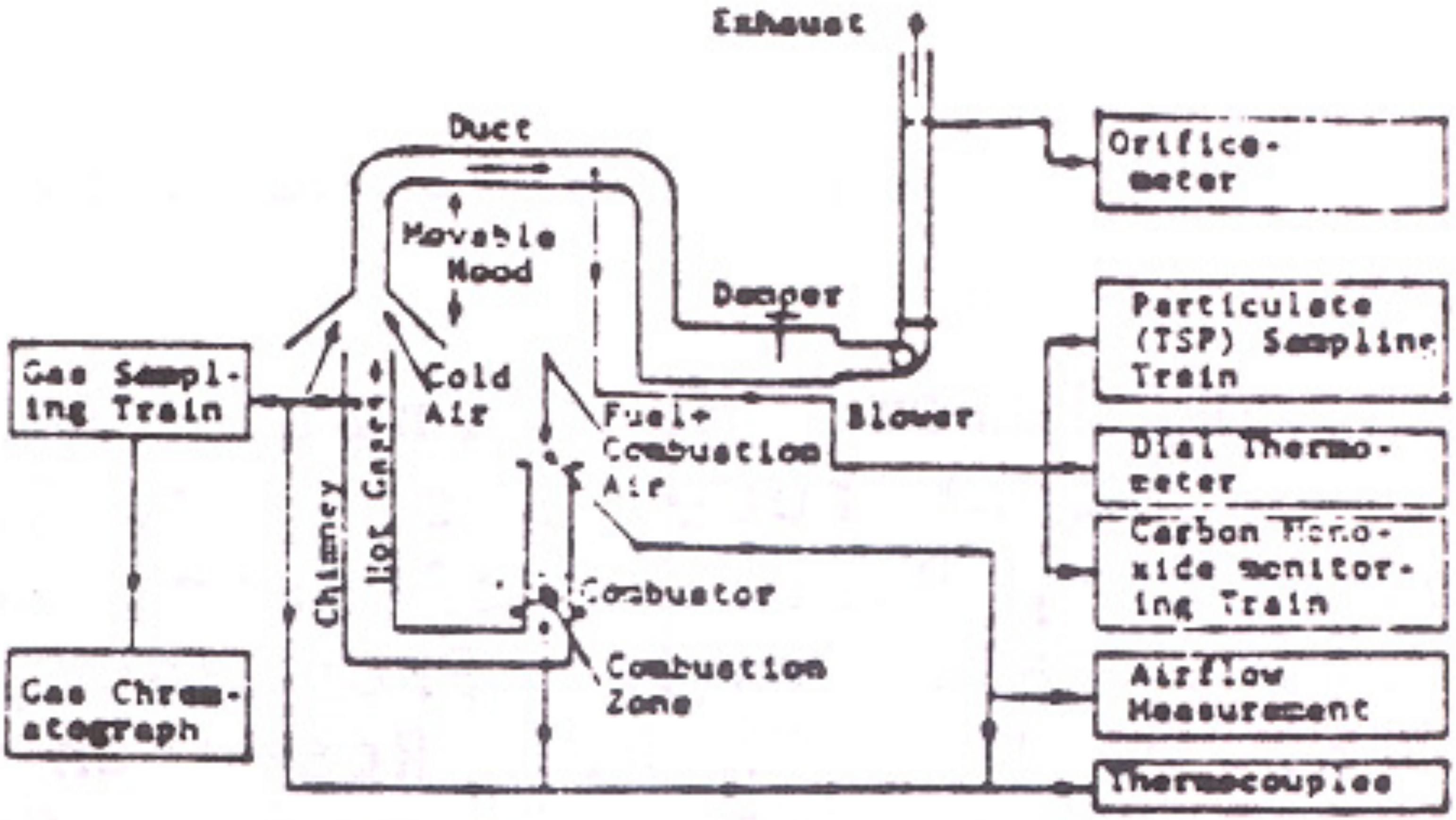


Figure 2: Experimental setup showing location of various instrumentation. Fresh fuel and combustion air are fed from the top and react in the combustion zone at the bottom of the combustor. The reactants pass up, and are diluted with cold air turning vaporised tar to aerosol.

LABORATORY PROTOTYPE COMBUSTER

-*	MOISTURE CONTENT** (%)	FIRING RATE (KG/HR)	**Forced Air**	EMISSION FACTOR CO-G/KG	EMISSION FACTOR TSP-G/KG	COMBUSTION EFFICIENCY
	6	0.59	NO	319	45.5	75.6
	9	1.00	NO	410	17.4	68.0
	9	0.88	NO	385	56.7	70.0
	9	0.89	NO	433	22.7	67.0
	12	0.75	NO	336	13.5	77.5
	33	0.85	NO	9.7	0.30	99.5
	9	0.91	YES	12.4	0.1	99.3
	9	0.94	YES	3.2	0.6	99.7
	9	0.86	YES	5.4	0.3	99.8

Conclusions

- It is difficult to burn unprocessed solid fuels completely in simple household-scale devices.
- Consequently, a large fraction of the fuel C is diverted to PIC
- Leading to inefficient use of the primary resource
- And, because of the proximity to population, the PIC seem to be responsible for much ill-health in developing countries.

Conclusions (cont.)

- Because the average Global Warming Potential of PIC carbon is greater than CO_2, there is significant GWC per unit energy use for household devices, even when the biomass is harvested renewably.
- To be greenhouse-gas neutral, therefore, a biomass fuel cycle must not only be based on renewable harvesting, but it also must have good combustion efficiency, i.e., produce little PIC

Conclusions (cont.)

- Careful improvements/reductions in solid household fuel use offer multiple benefits in energy, health, and global warming.
- Probably requires coordinated improvement of fuel and stove
- Cost-effectiveness compares well with other interventions:
  - in India, health value = $60/stove (40% effective)
- **Significant engineering challenge to reliably produce high combustion and overall efficiencies cheaply with simple solid fuels**

Summary: The Hazards of Combustion Mismanagement

- Sticking burning stuff in your mouth
- In your home
- In your workplace
- In your community
- On your planet
- Letting it burn down your house

•

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
Fires	0.24	0.4	0.7
Adjusted totals	**~ 8**	**~ 14%**	**~ 10%**

Combustion Mismanagement

An ancient but still large source of death and disease around the world

One out of seven deaths each year occurs prematurely because of combustion mismanagement, mostly from small particles.

And growing!

Most the papers and other publications from which these data were taken are available at http://ehs.sph.berkeley.edu/krsmith

Thank you