How can simple cookfires cause so much ill-health?

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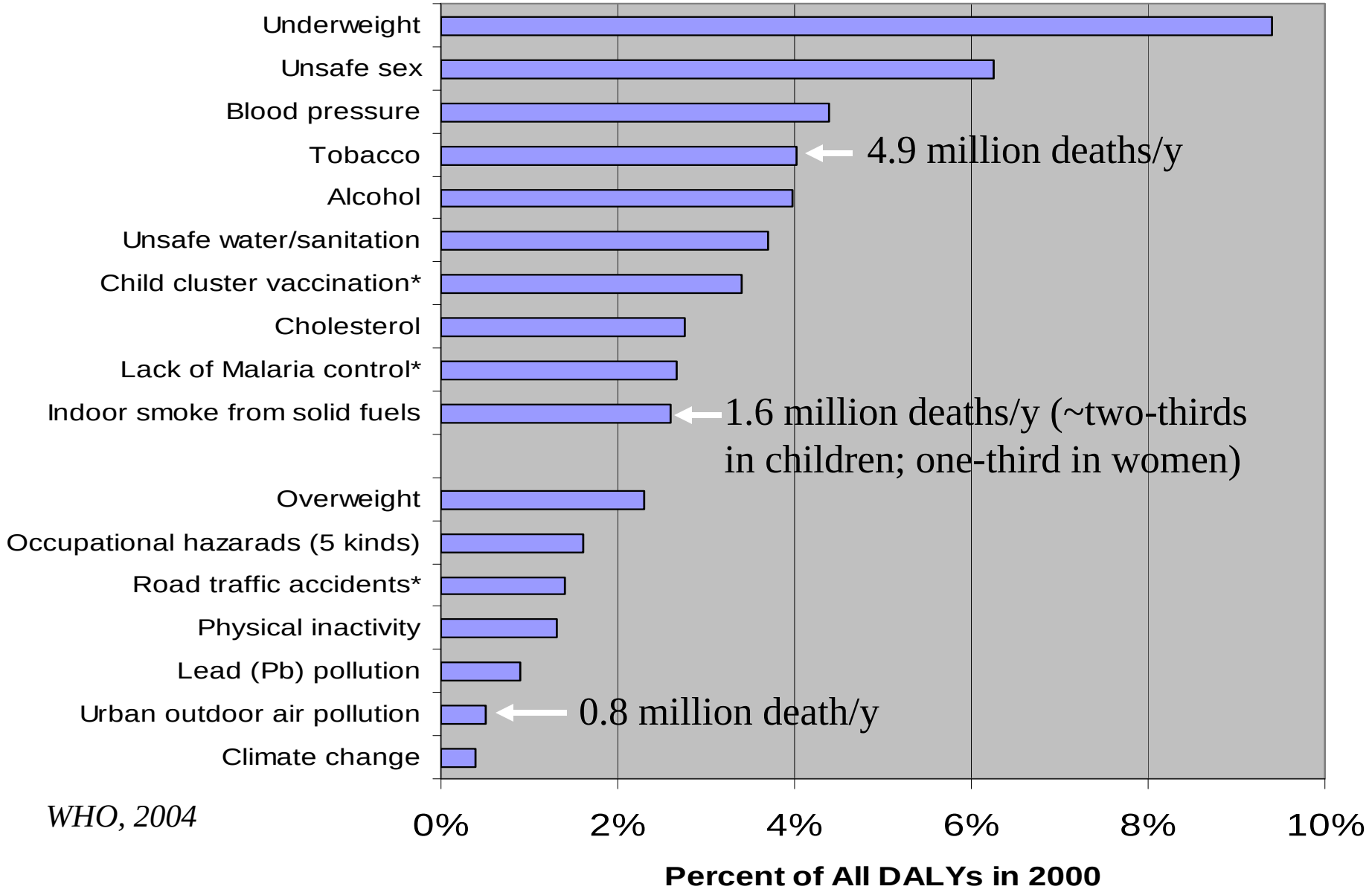
V Reunion Nacional RED Mexicana de Bioenergia
CIEco-UNAM, Morelia, Michoacan
September 30, 2008

Global Burden of Disease from Top 10 Risk Factors

plus selected other risk factors



WHO, 2004

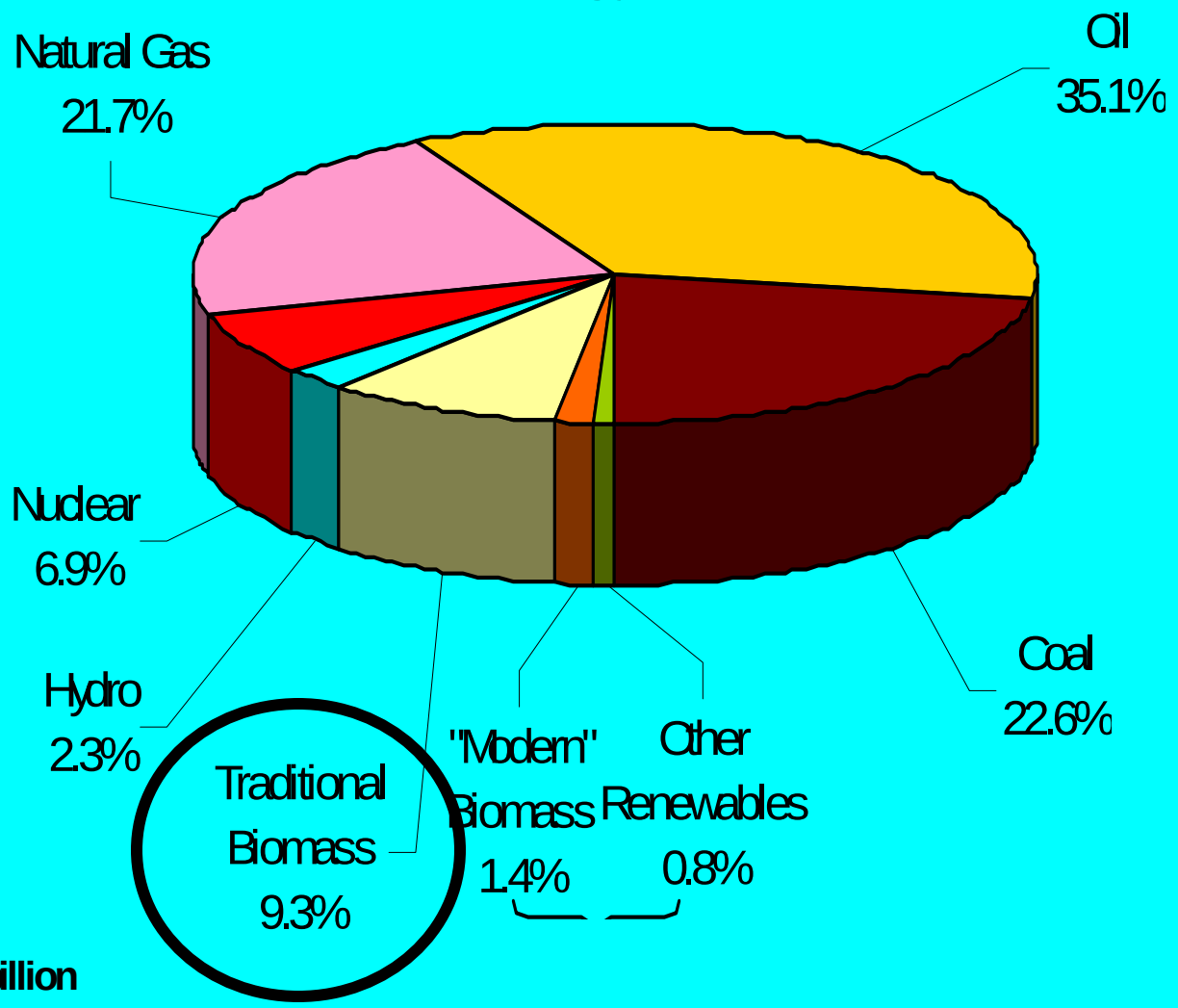
Oldest Pollution Source in Human History

Why does it still cause so much ill-health?

---Physical reasons
---Physiological reasons
---Political/economic/social reasons

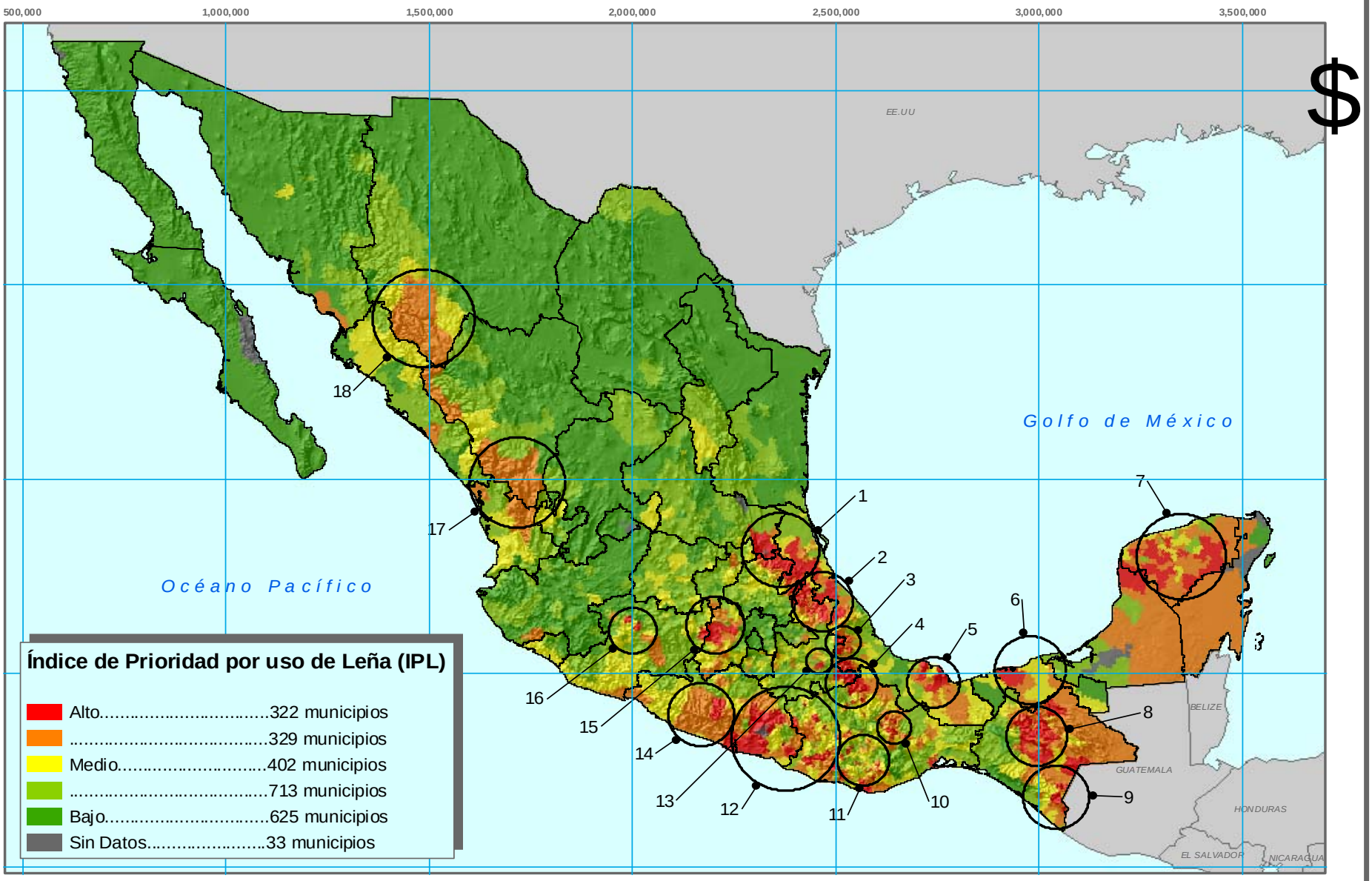
#1 Widely used

World Energy – 2001



Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004



Áreas prioritarias por uso residencial de leña en México - 2000

Áreas accesibles de ***10km*** de radio alrededor de localidades y ***3km*** al costado de caminos
Productividad ***media*** de madera para energía por hectárea por año.

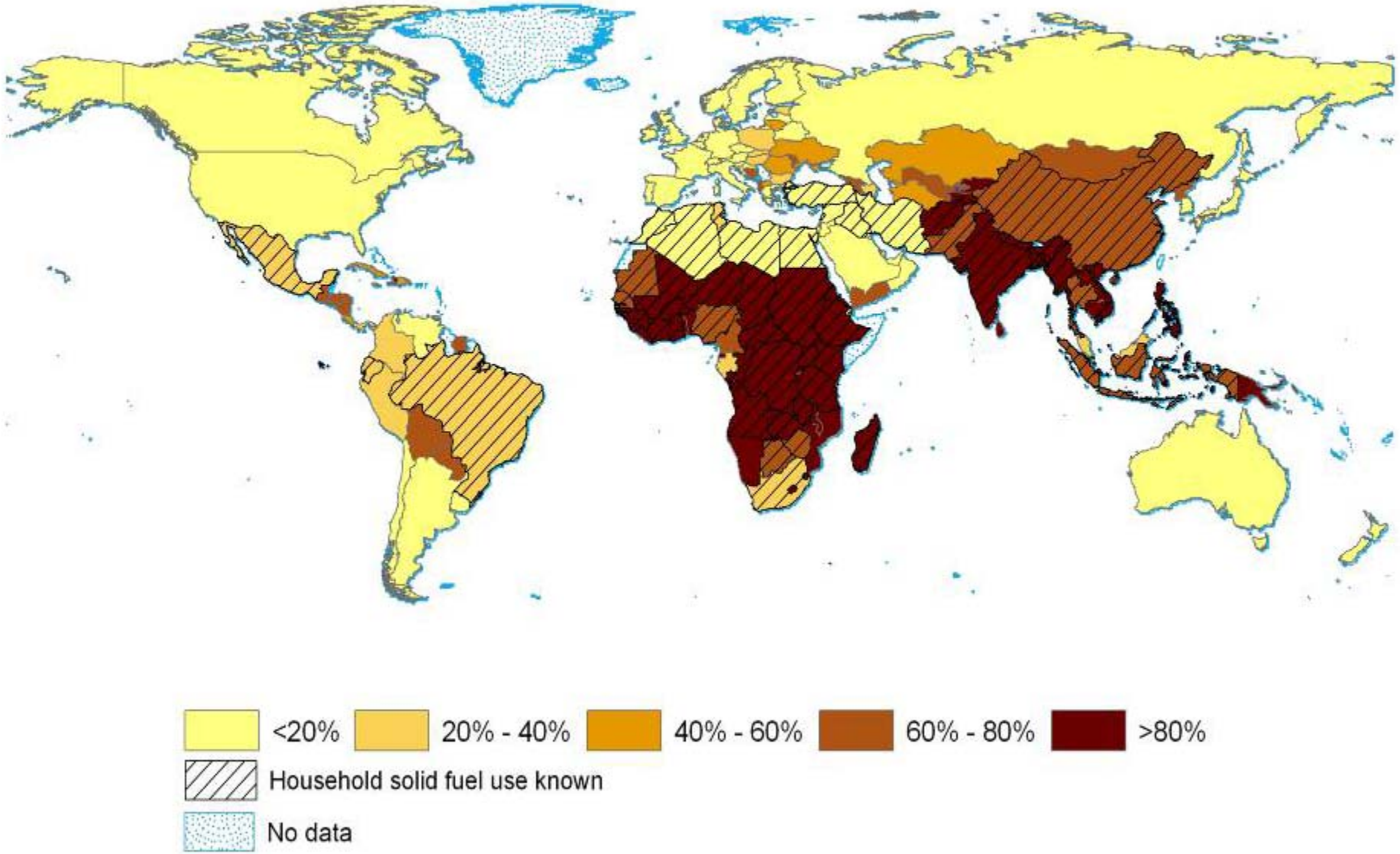
Fuente: Ghilardi 2007; IFN 2000; INEGI 2000; INEGI 1995.
Creado en ArcGIS 9.2 utilizando ArcMap.
Elaboró: Ghilardi A. Diciembre, 2007.

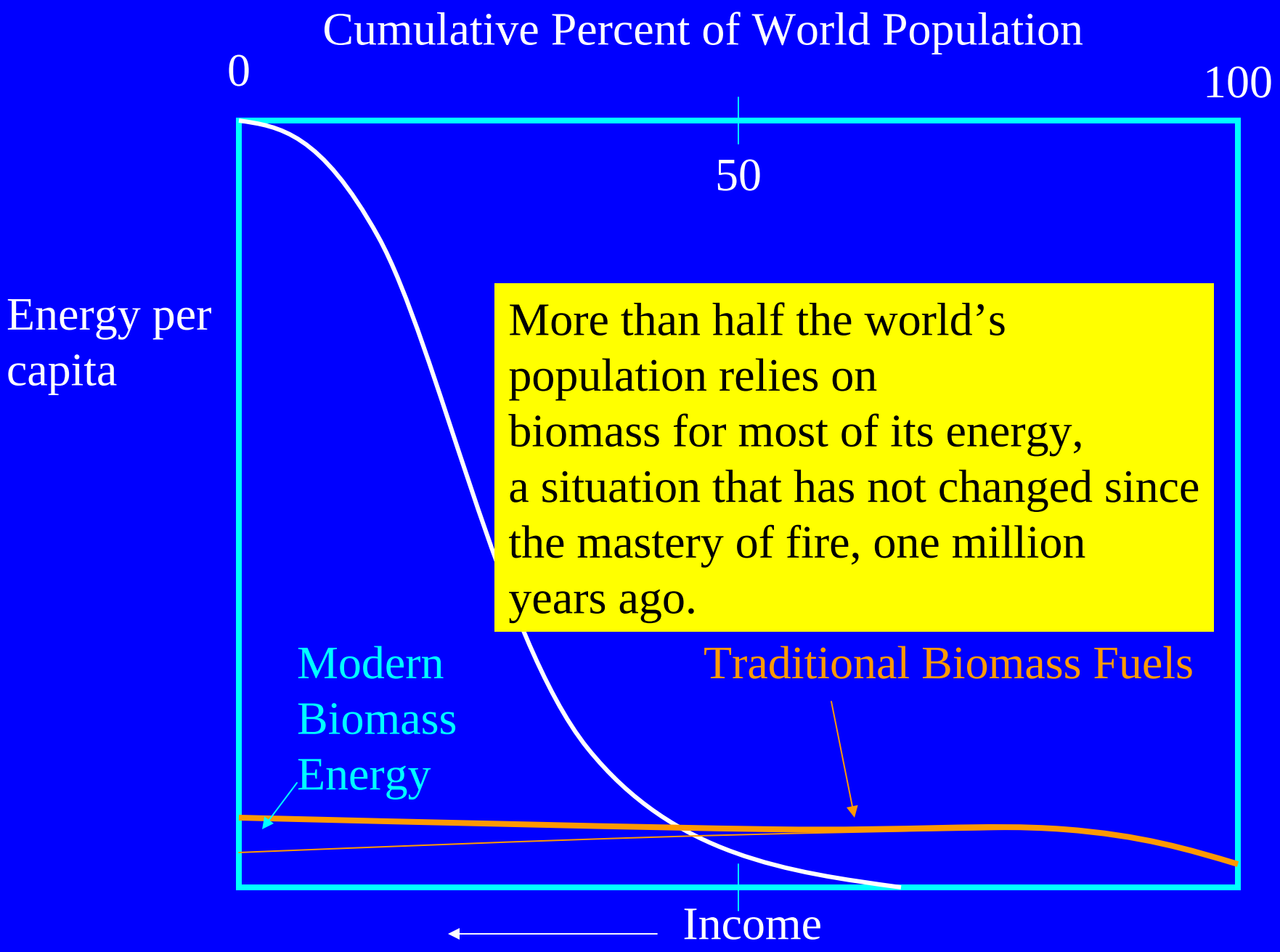
0 125 250 500 750 1,000 Km

1:12,500,000

Albers Equal Area Conic Projection
North American Datum 1927
Ver detalles en el Anexo III

National Household Solid Fuel Use, 2000



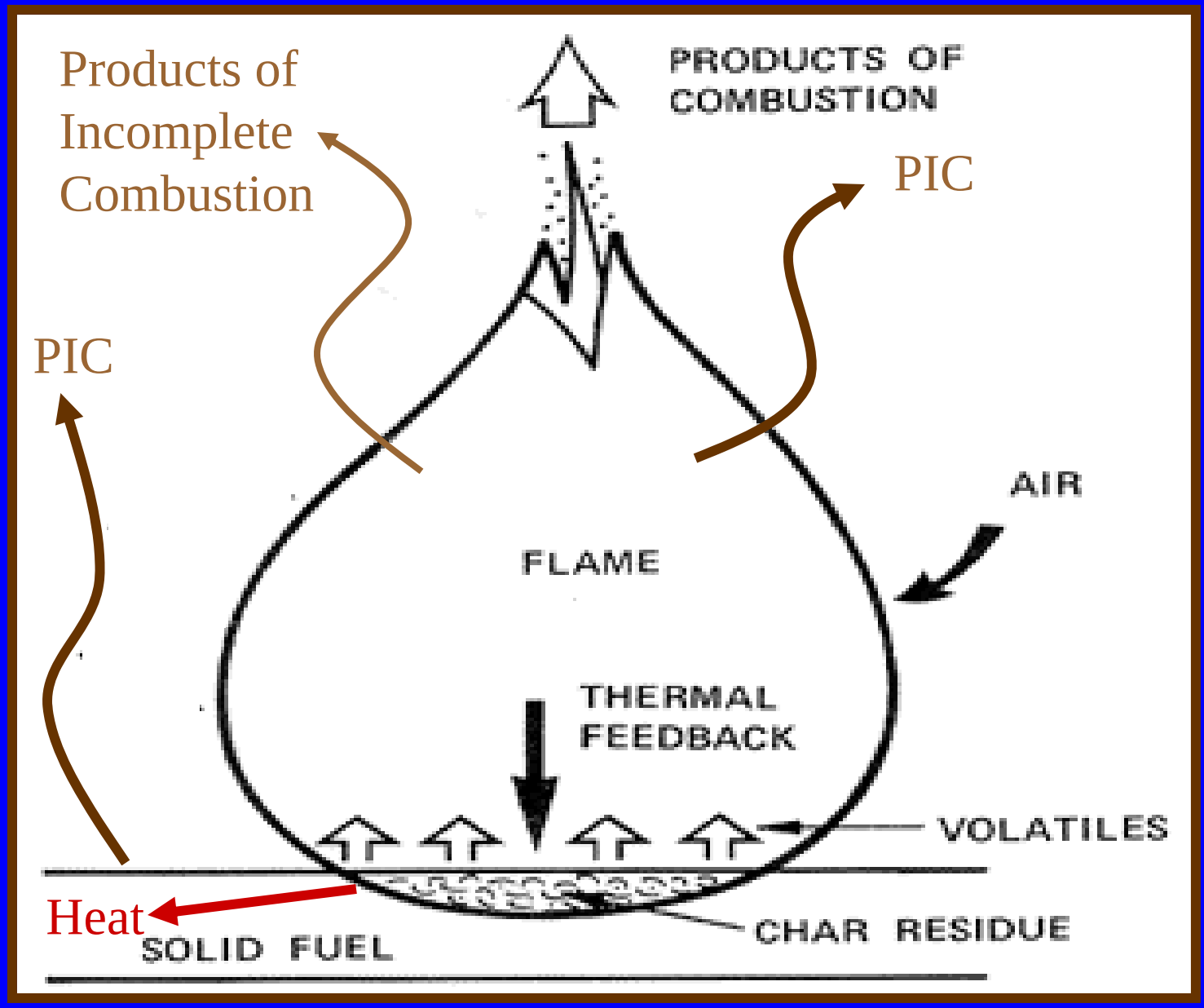

Cumulative Percent of World Population
0
100
50
Energy per capita
More than half the world's population relies on biomass for most of its energy, a situation that has not changed since the mastery of fire, one million years ago.
Modern Biomass Energy
Traditional Biomass Fuels
Income

#2 Highly polluting

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)?

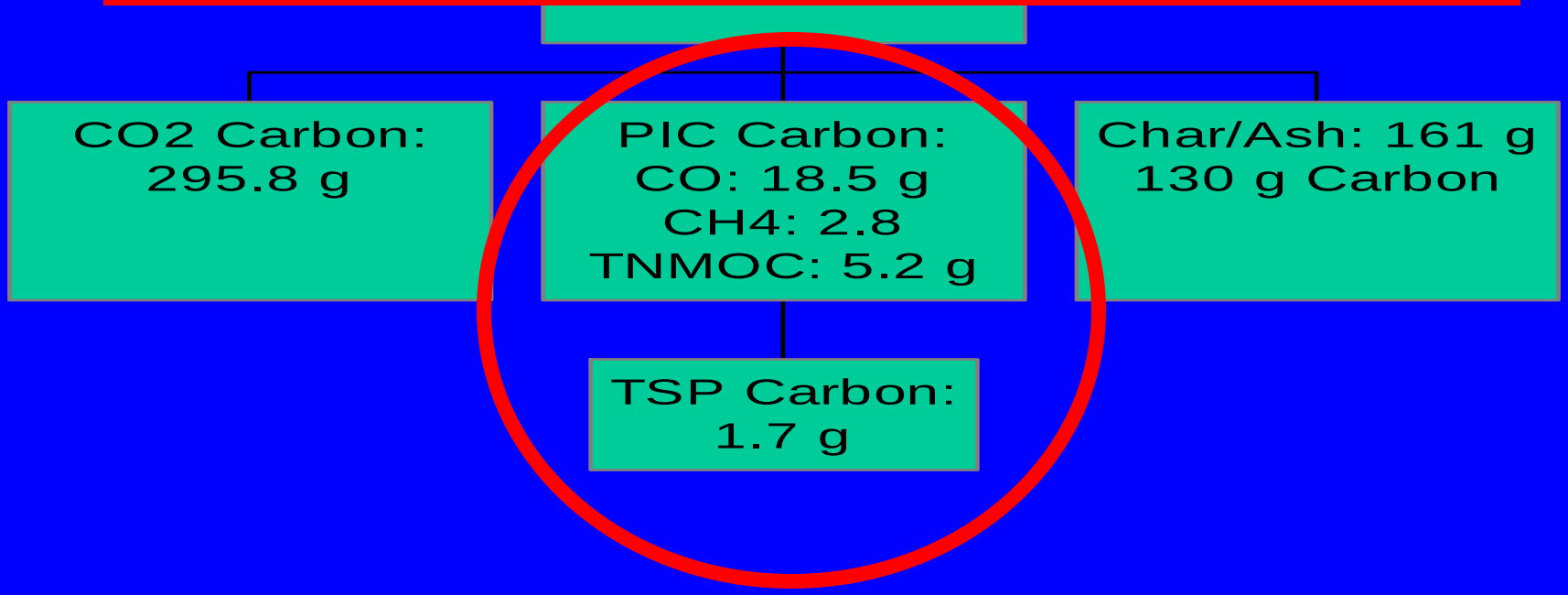
Reason: the combustion efficiency is far less than 100%


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

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%

Indian Cookstoves

Nominal Combustion Efficiency		Approximate % of Households - 2001
• 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

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

- Small particles. Best measure of risk ~ 0.1-0.4% of fuel weight
- 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*

Naeher et al. 2007, JIT

Size Distribution of Biomass Smoke Particles

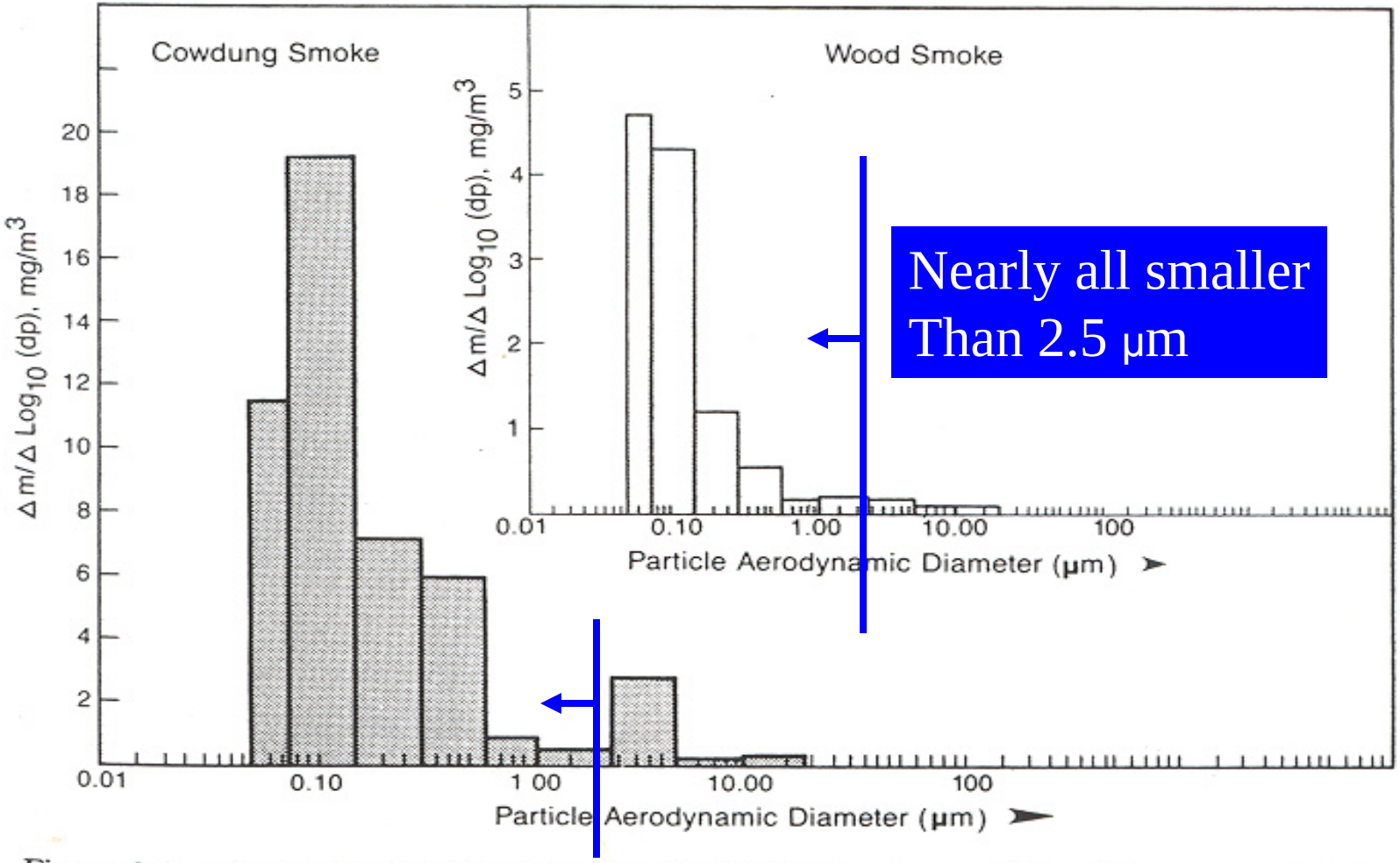
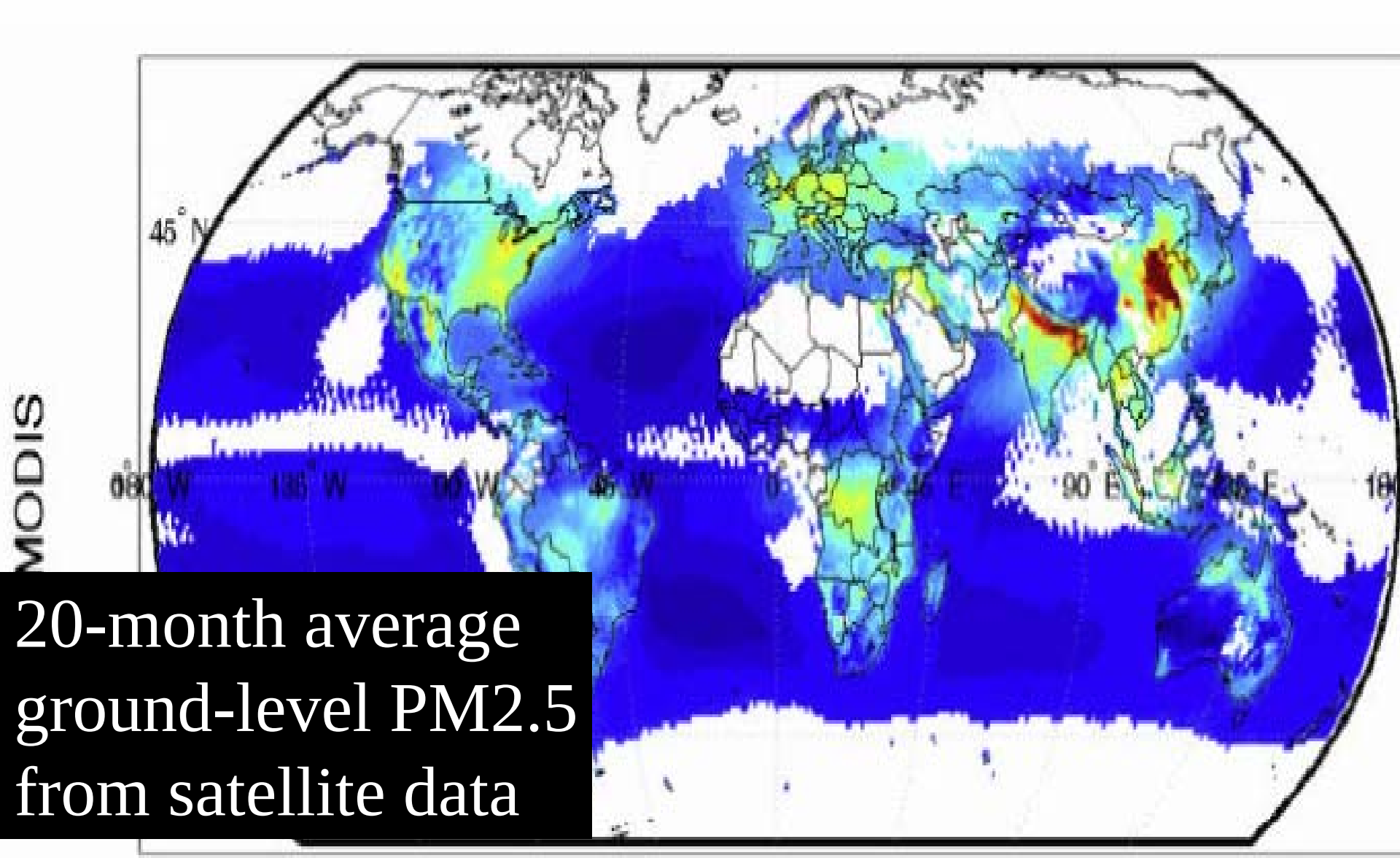


Figure 2.2. Size distribution of woodsmoke and dungsmoke particles. Measurements taken in the East–West Center simulated village house as reported in Smith *et al.* (1984b). (Figure prepared by Premlata Menon.)

Source: Smith, Apte et al. 1984



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

#3 High Intake Fraction

Intake Fraction (IF)

- *IF* is the fraction of material emitted that crosses some person's physiological barriers (skin, GI tract, Resp. tract, etc.)
- For air pollution, *IF* is the fraction breathed in by the exposed population.

Defining “Intake Fraction”

For an inhaled pollutant:

$$\text{Intake Fraction (iF)} = \frac{\text{Total Intake}}{\text{Total Emissions}} = \frac{\sum_t \sum_P C(P,t) * Q_B(P,t)}{\sum_t E(t)}$$

C = Concentration (g/m^3)

Q_B = Breathing Rate (m^3/s)

E = Emissions (g/s)

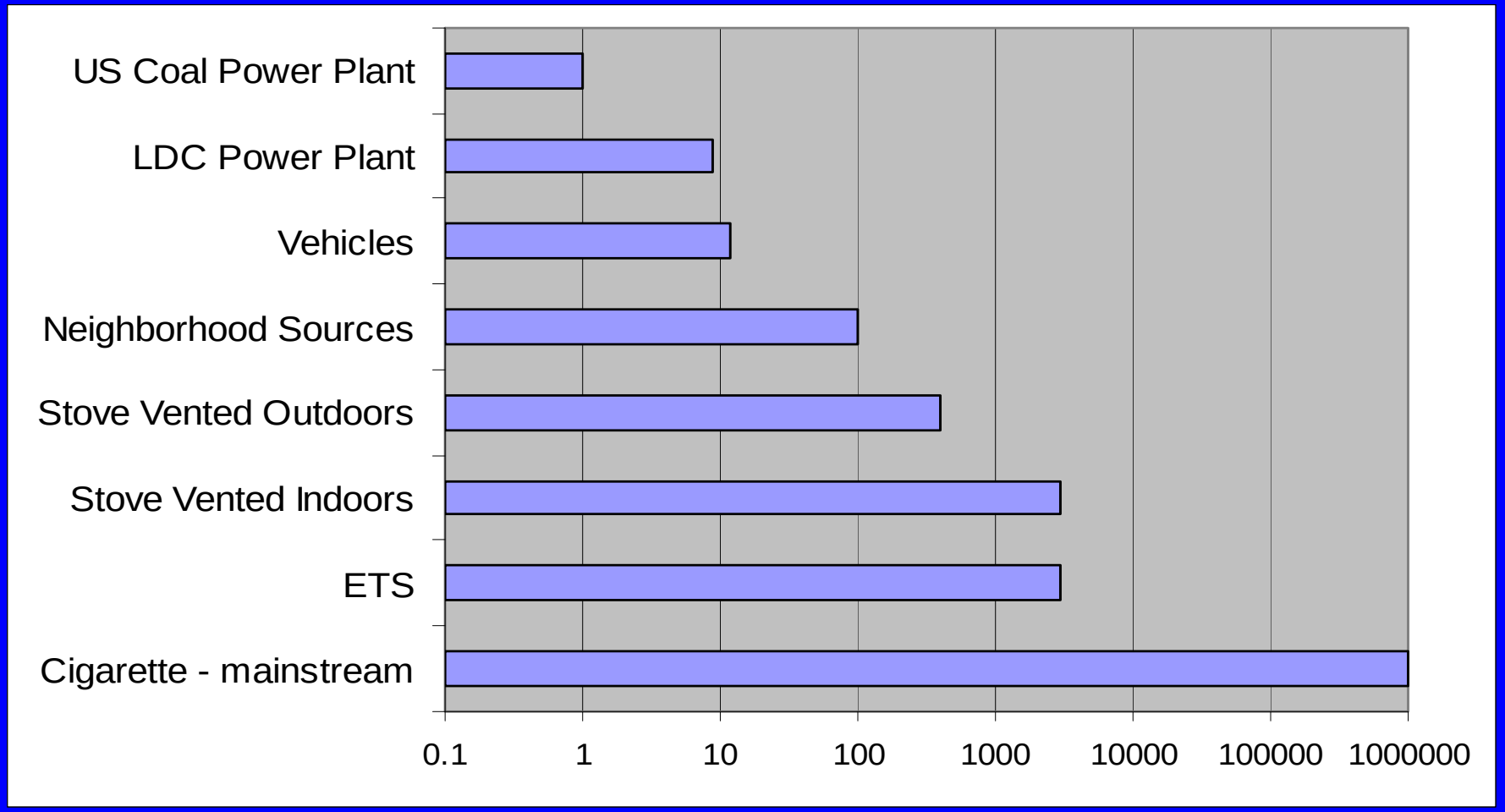
P = Population

t = time

Marshall et al., 2001

IF = 1.0

Intake Fraction Varies as Much as Toxicity (these are rough calculations for typical examples of sources in each class)



Smith, 1993

Grams Inhaled per Tonne Emitted

What Does iF (Inhalation) Depend On?

1. Proximity (Source type)
   - indoor / outdoor
   - stack / ground-level
2. Persistence (Pollutant dynamics)
   - reaction kinetics
   - removal mechanisms
3. Population
4. Breathing rate

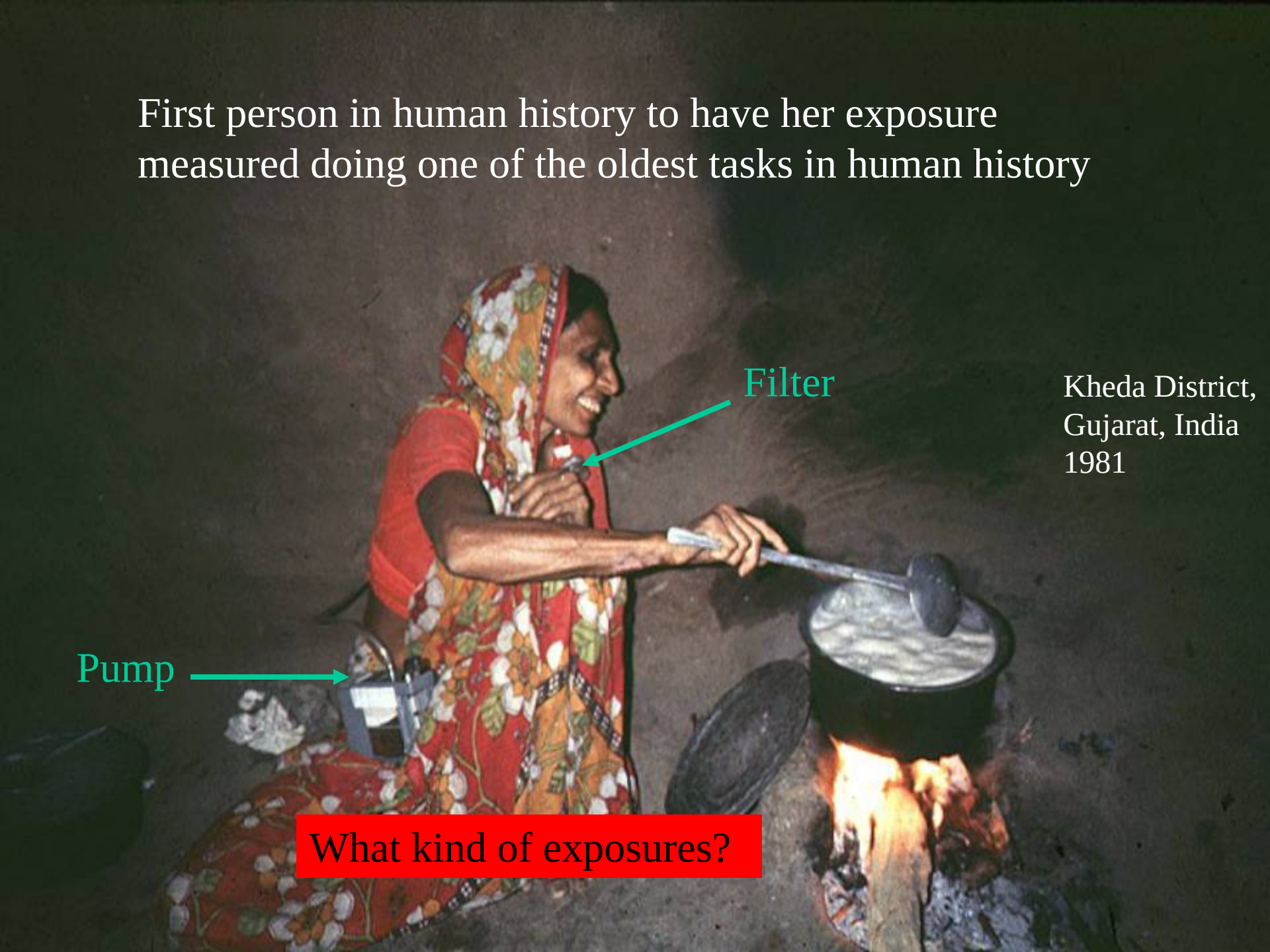
… and temporal and spatial variability of these factors

Power of Intake Fraction

- "Rule of One Thousand" = Pollutants released indoors are 1000 times more likely to reach someone's lungs than if released outdoors.
- Sample comparison: U.S. power plant versus cigarettes
  - Source:
    - 1 ton coal = 1 million cigarettes (1 g each)
  - Emissions of particles
    - 1 ton coal = 24,000 cigarettes
  - Approximate particle intake equivalence
    - 1 ton coal = 24 cigarettes (ETS)
- Thus, even though there are more than 40 times more primary particles released from coal power plants in the US than from cigarettes, less than a 2-5% reduction in passive smoking (ETS exposures) would be equivalent to eliminating all the power plants in the country in terms of particle exposure.

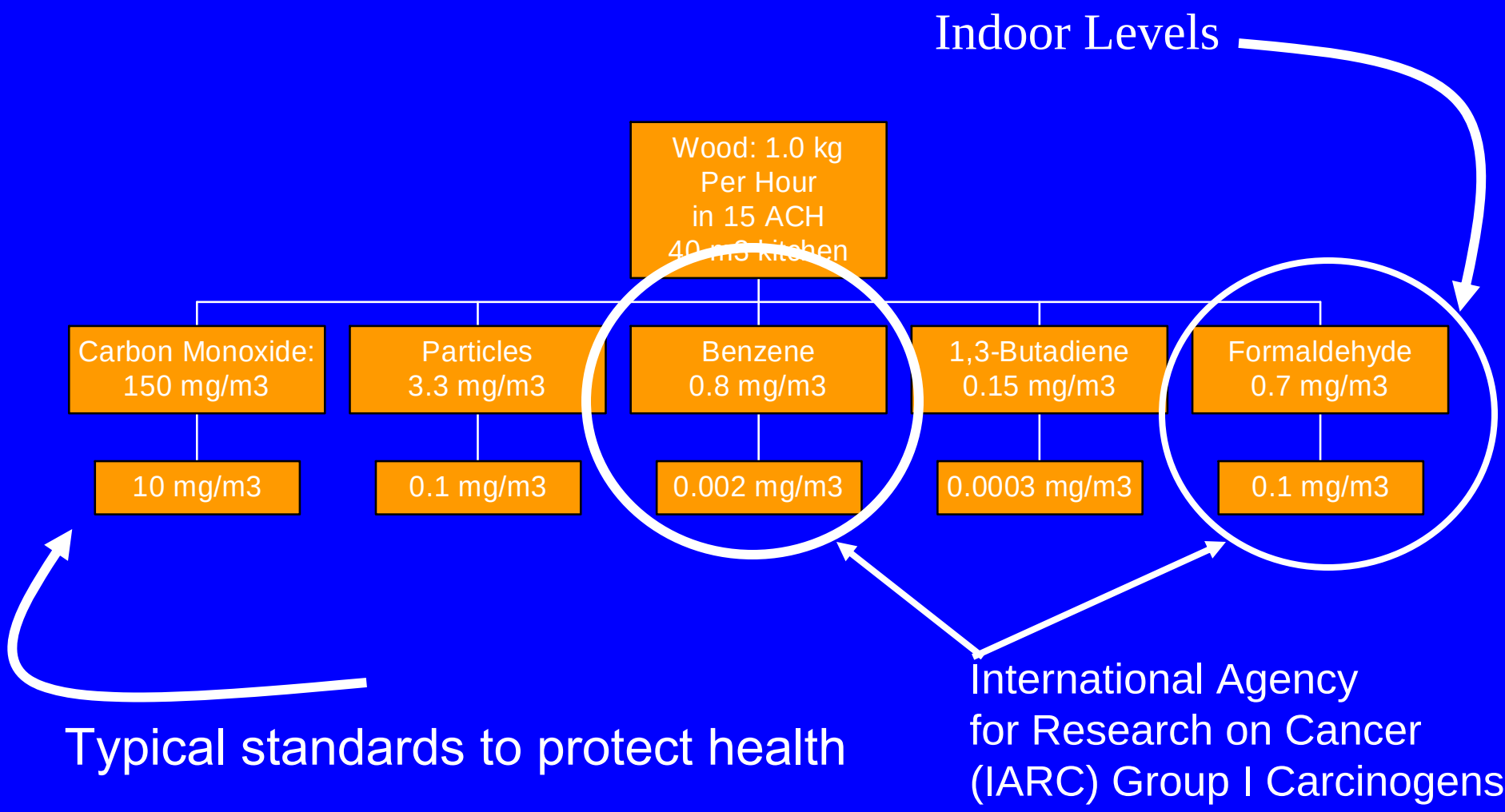
Smith, 1988

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



Kheda District, Gujarat, India 1981

Indoor pollution concentrations from typical woodfired cookstove during cooking

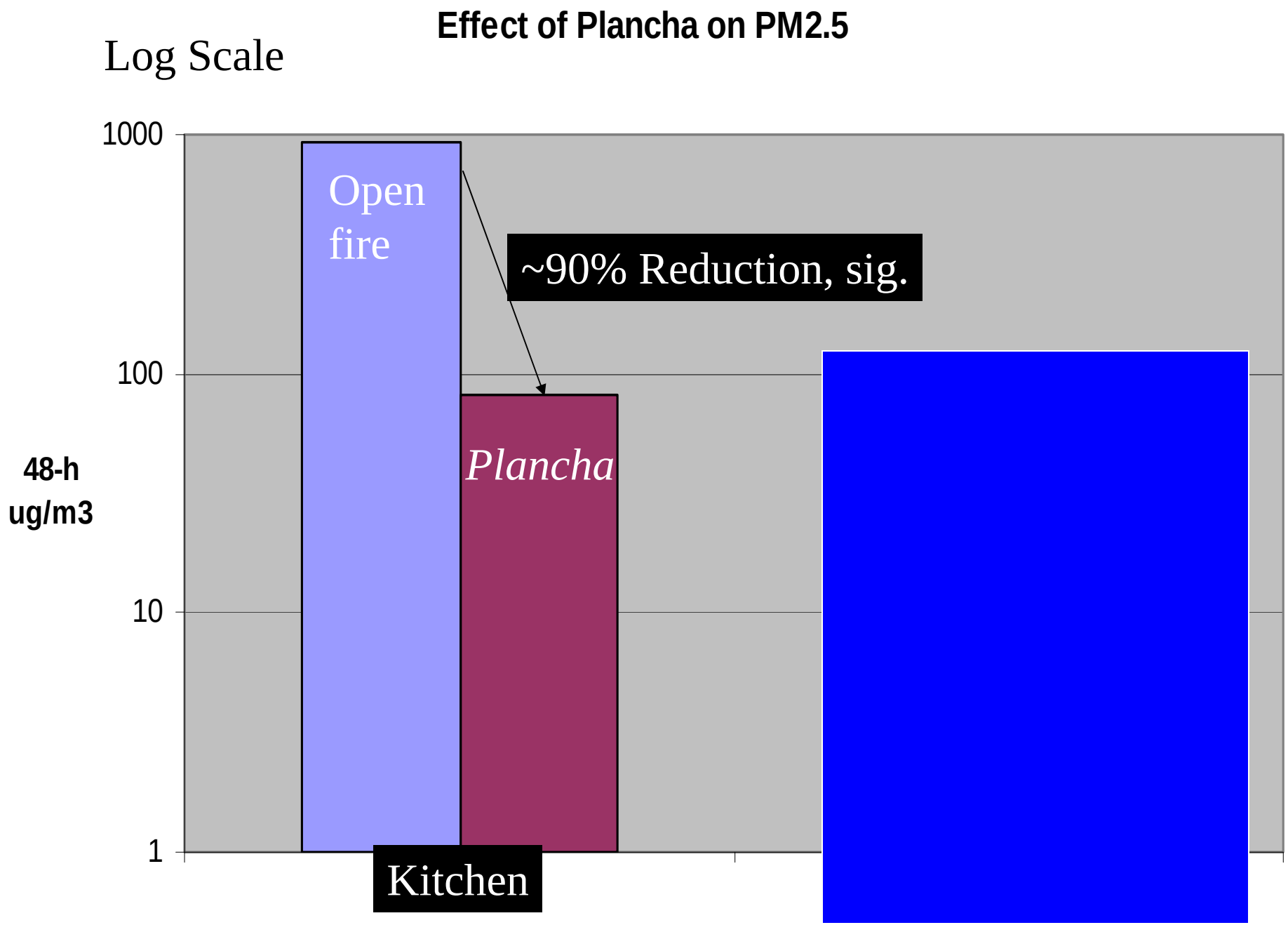


#4 Not easy to fix - ventilation

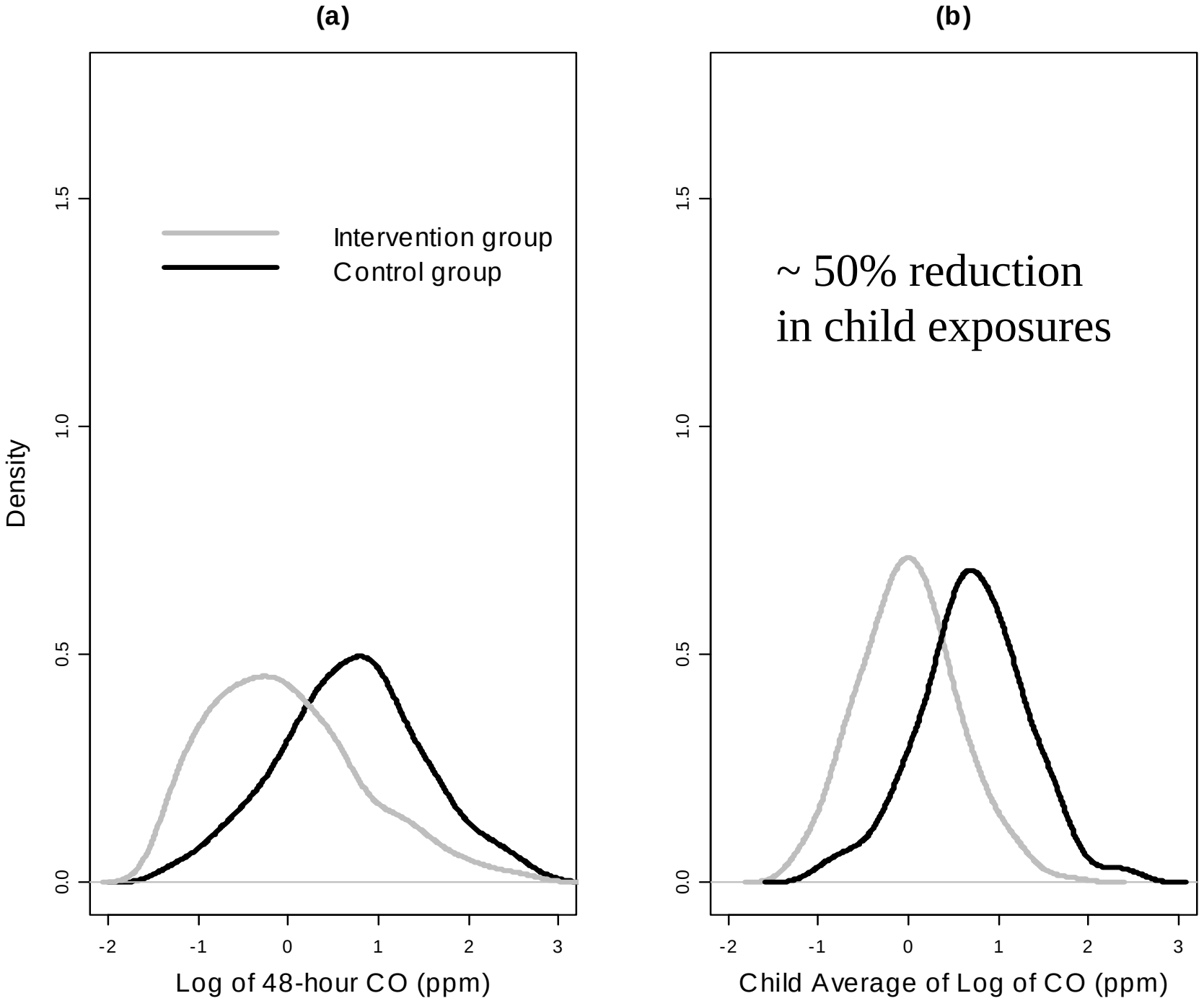
RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)

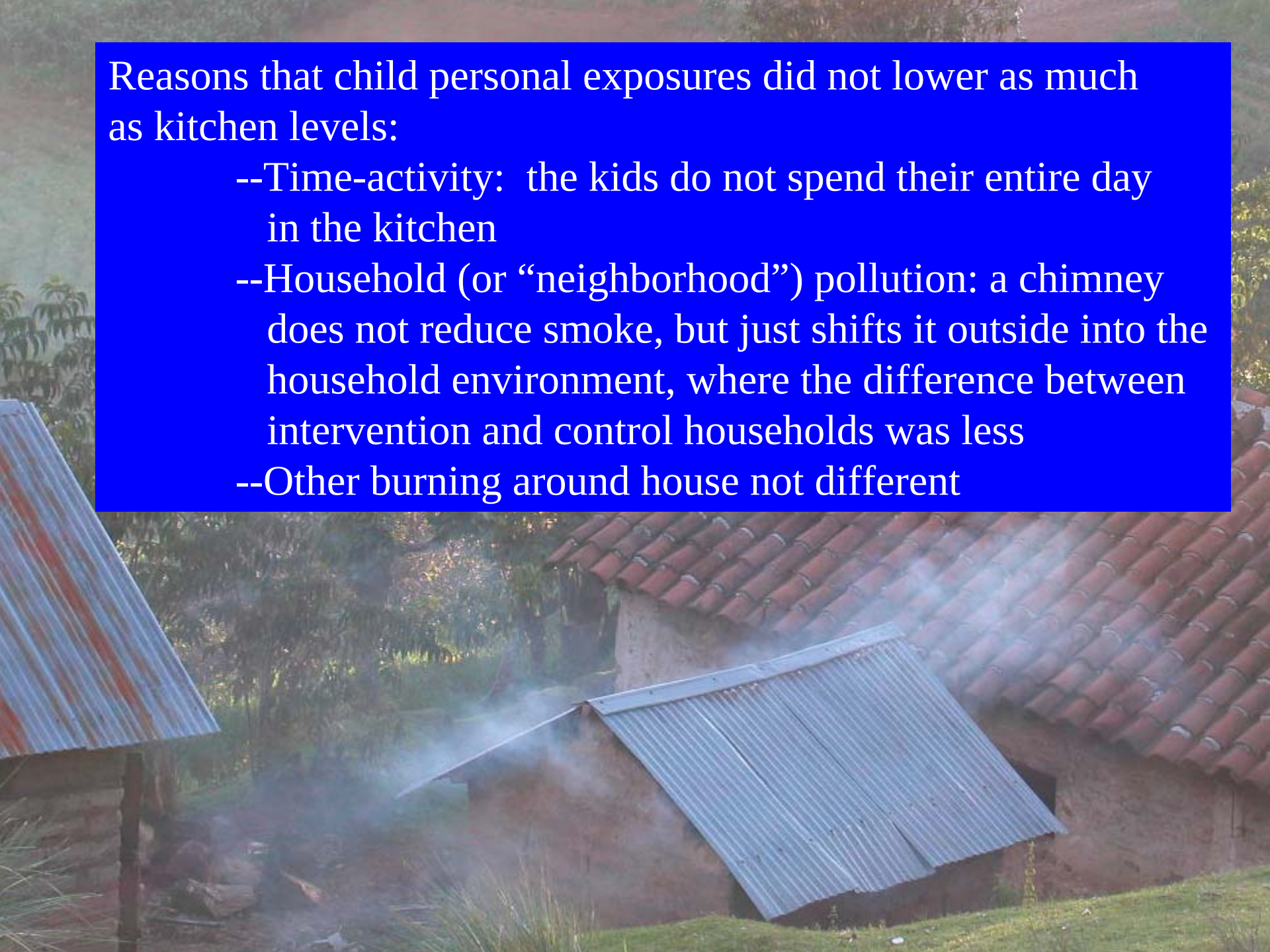
Traditional 3-stone open fire

Plancha chimney wood stove


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


Tubito
Tubito


(a)
(b)
Density
1.5
1.0
0.5
0.0
Intervention group
Control group
~ 50% reduction
in child exposures
-2
-1
0
1
2
3
Log of 48-hour CO (ppm)
Child Average of Log of CO (ppm)

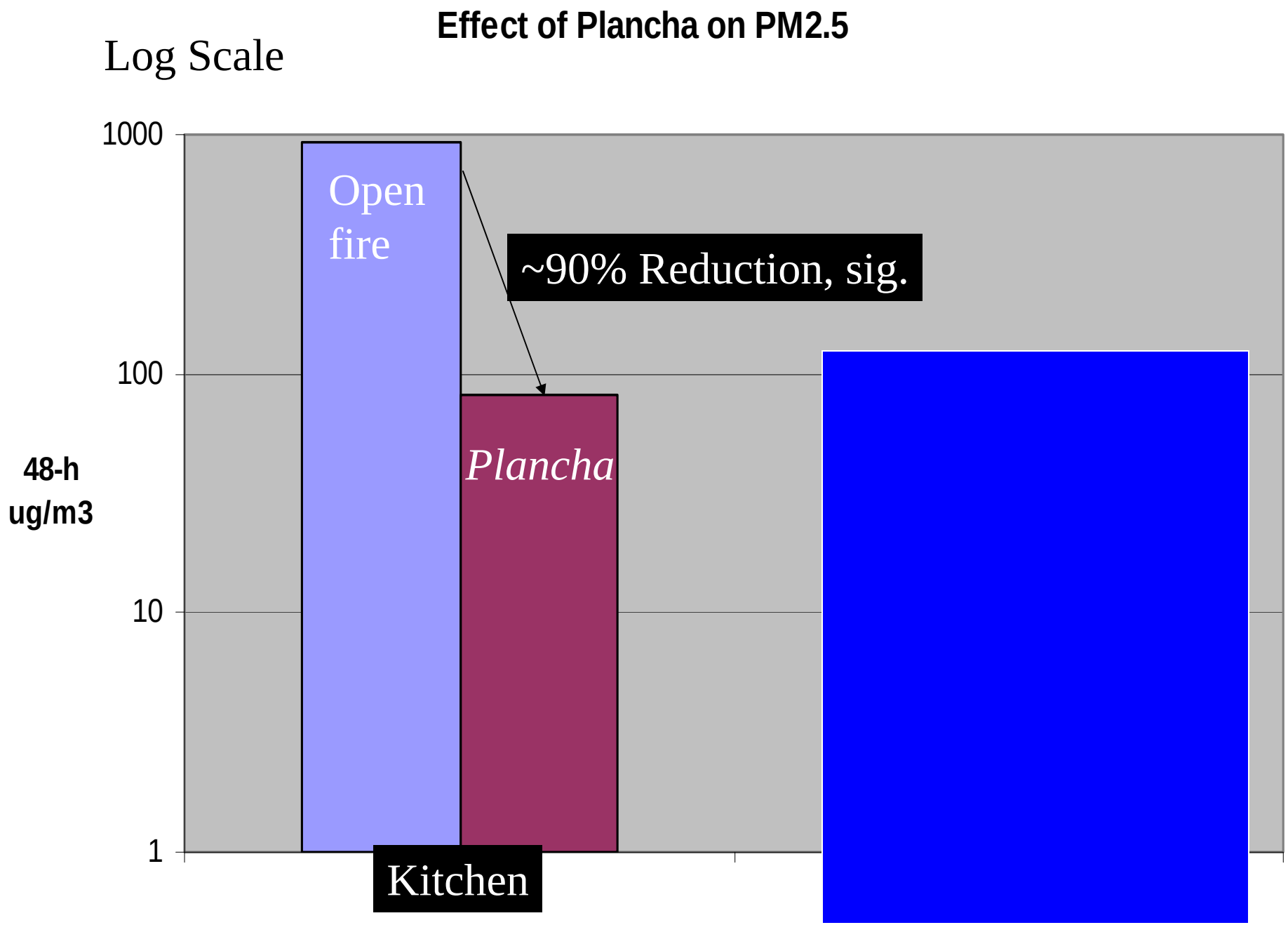


Reasons that child personal exposures did not lower as much as kitchen levels:

--Time-activity: the kids do not spend their entire day in the kitchen

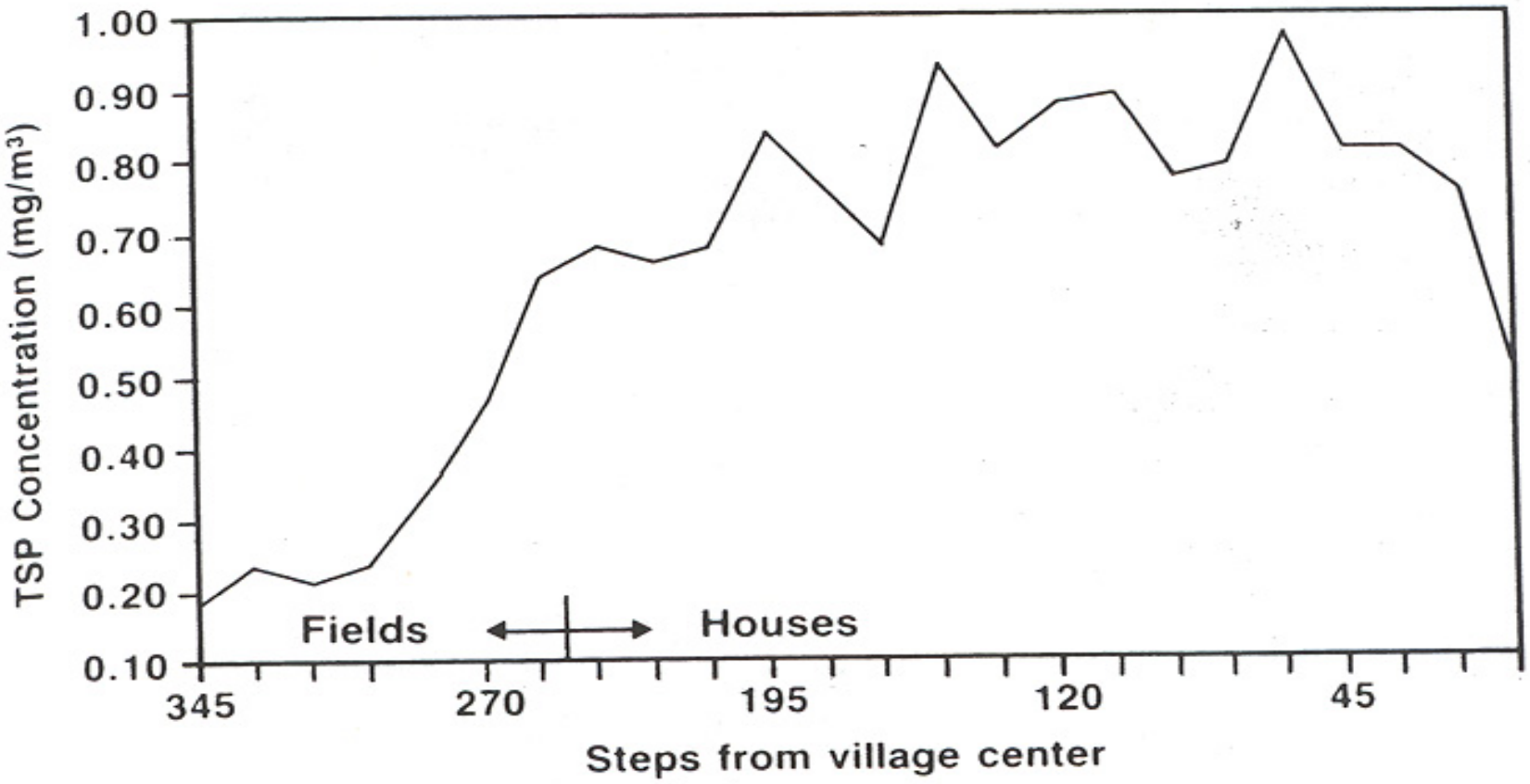
--Household (or “neighborhood”) pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less

--Other burning around house not different


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


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

Neighborhood Pollution in an Indian Village



#5 Not easy to fix--combustion

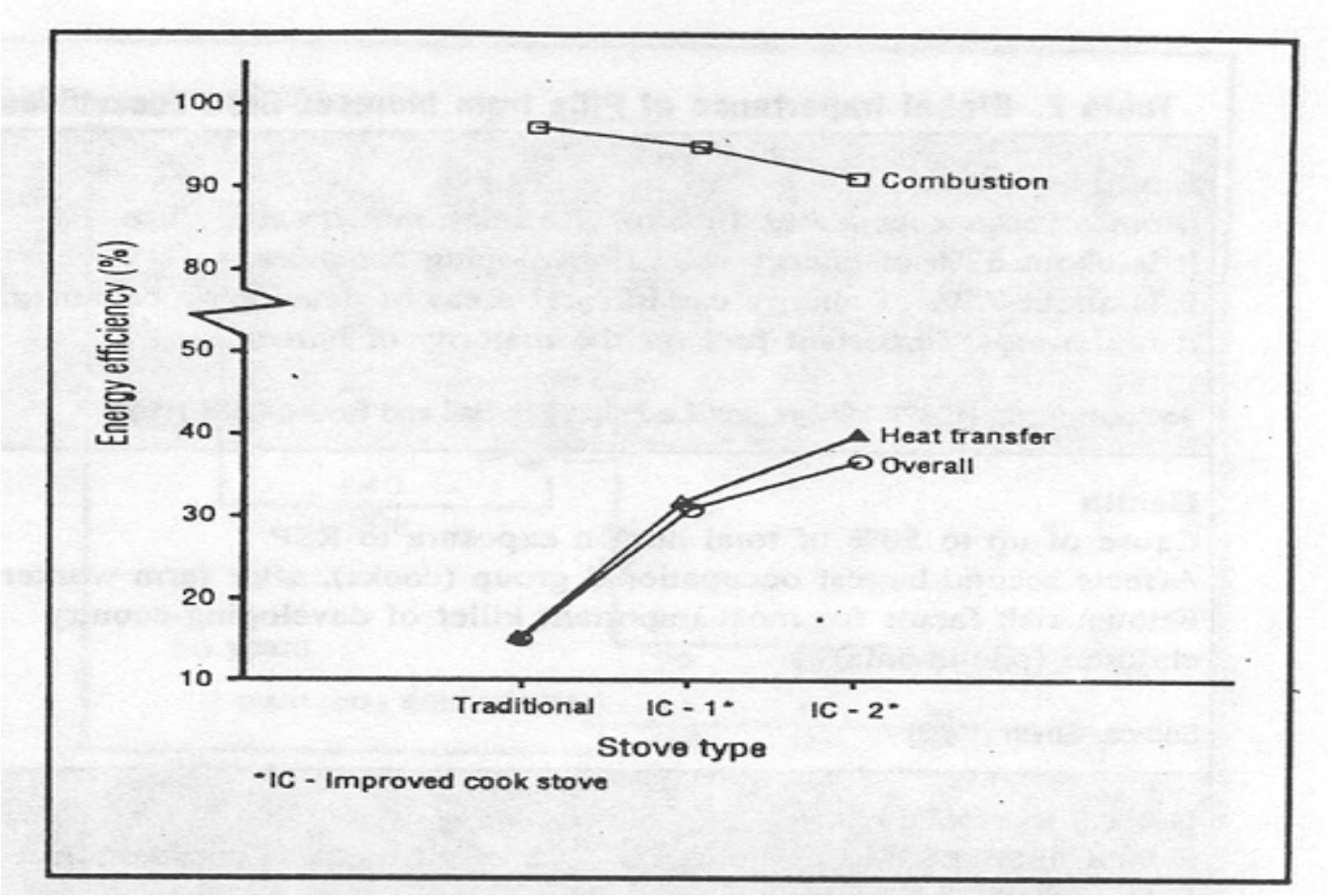
Internal Stove Efficiencies (carbon balance method)

- Overall efficiency is function of two internal efficiencies: OE = NCE * HTE
- Nominal Combustion Efficiency (NCE) = percent of fuel carbon released as CO_2
- Heat transfer efficiency (HTE) = OE/NCE
- NCE = $CO_2/(CO_2 + PIC)$ -- on a carbon basis

Energy flows in well-operating traditional woodfired cookstove

PIC = products of incomplete combustion.

Increasing Fuel Efficiency Does not Always Decrease Emissions Per Meal

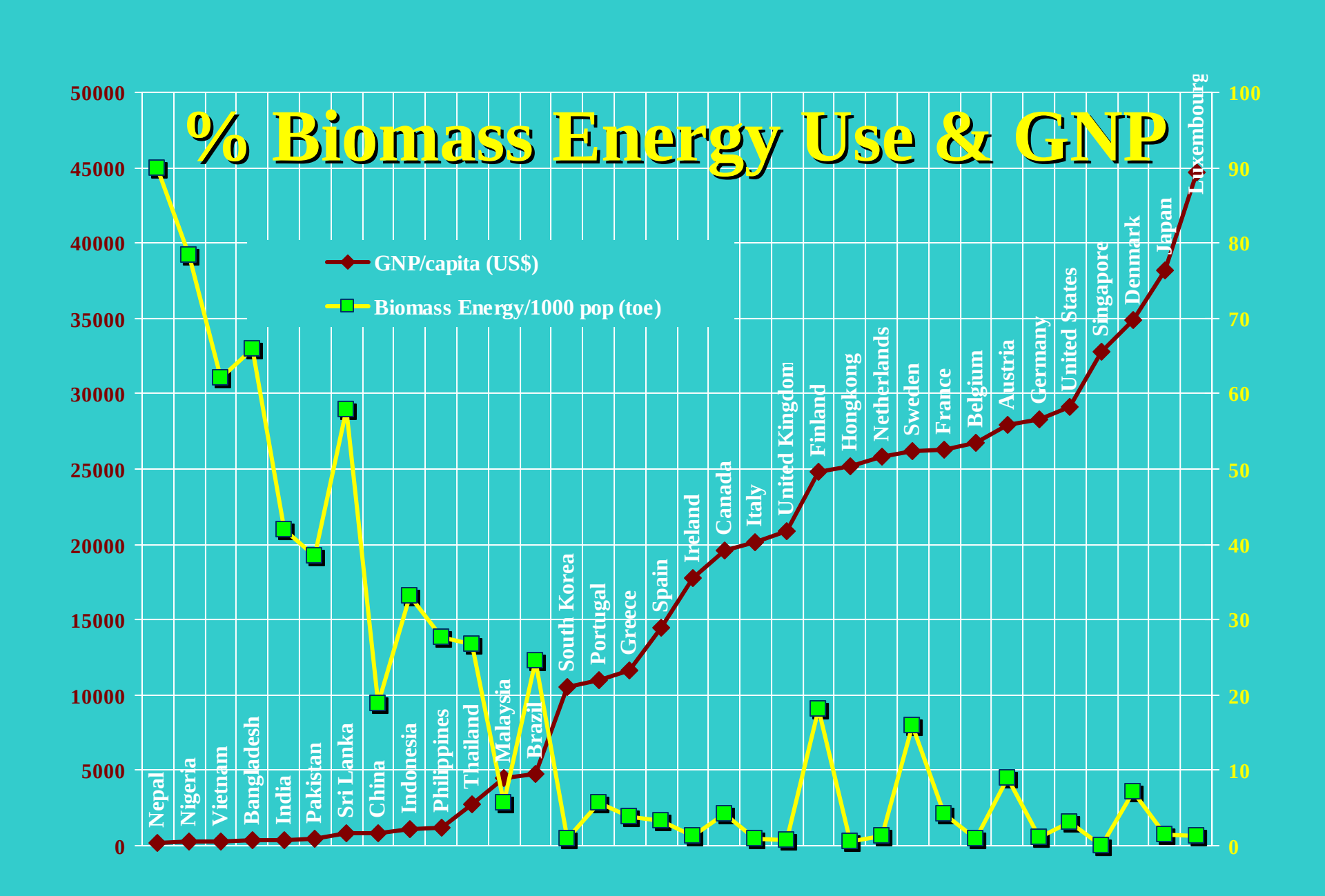


How can less fuel mean more pollution?

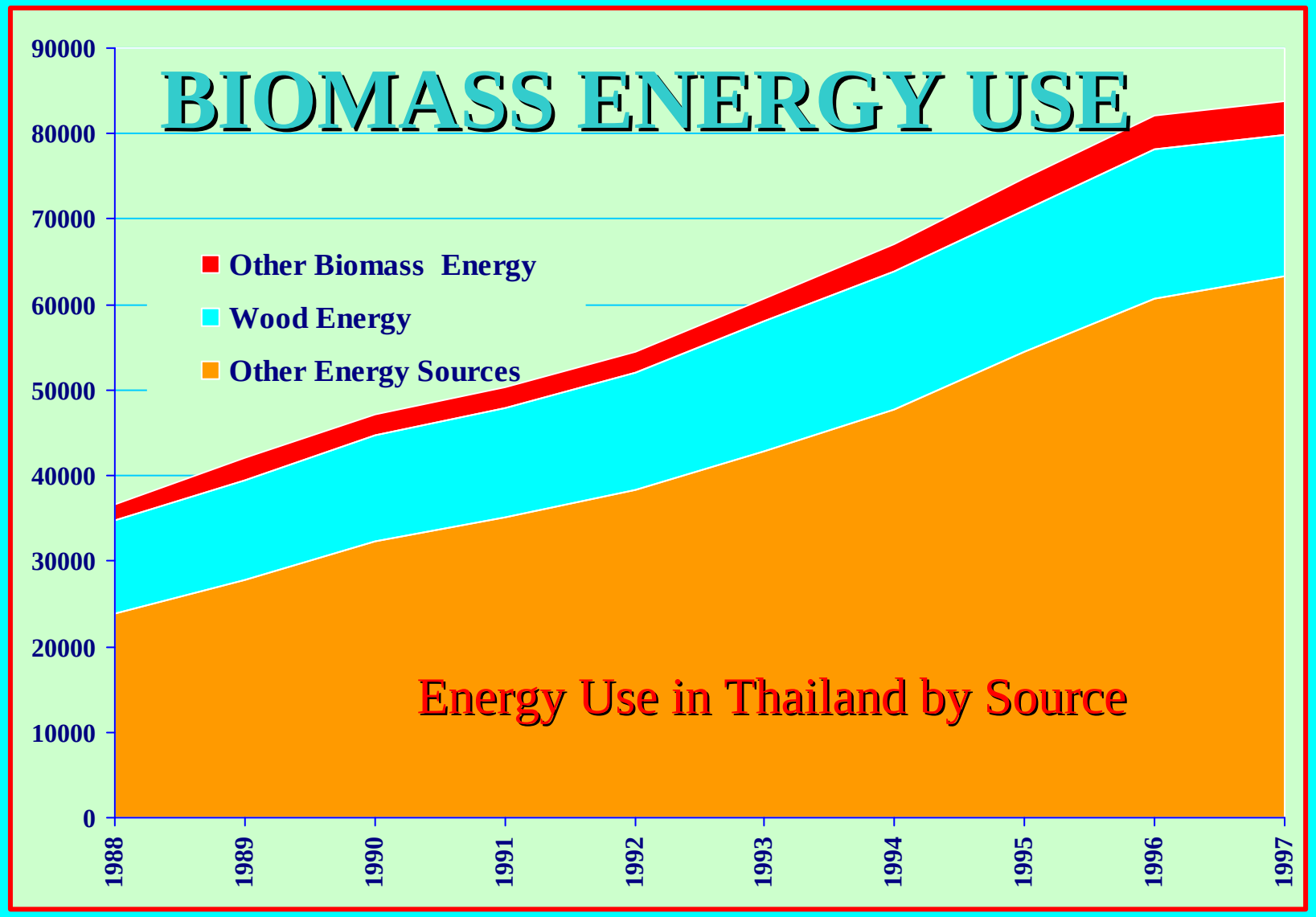
Stove	Overall Efficiency	Heat Transfer Efficiency	Nominal Combustion Efficiency
Traditional	14	15	97
“Improved”	27	30	90
Change = 73% more pollution per meal!	27/14 = 1.93x fewer kg fuel per meal		(1-0.90)/ (1/0.97) = 3.33x more PIC per kg fuel

Biomass smoke – a global concern

- A significant contribution to PM2.5 emissions around the world – more than half in many developed countries (Canada, Denmark, much of USA, etc.)
  - Ag burning a function of ag production, not income - California
  - Wood heating and fireplace use common in many developed countries – Silicon Valley
- Growing because of energy prices
- And climate change

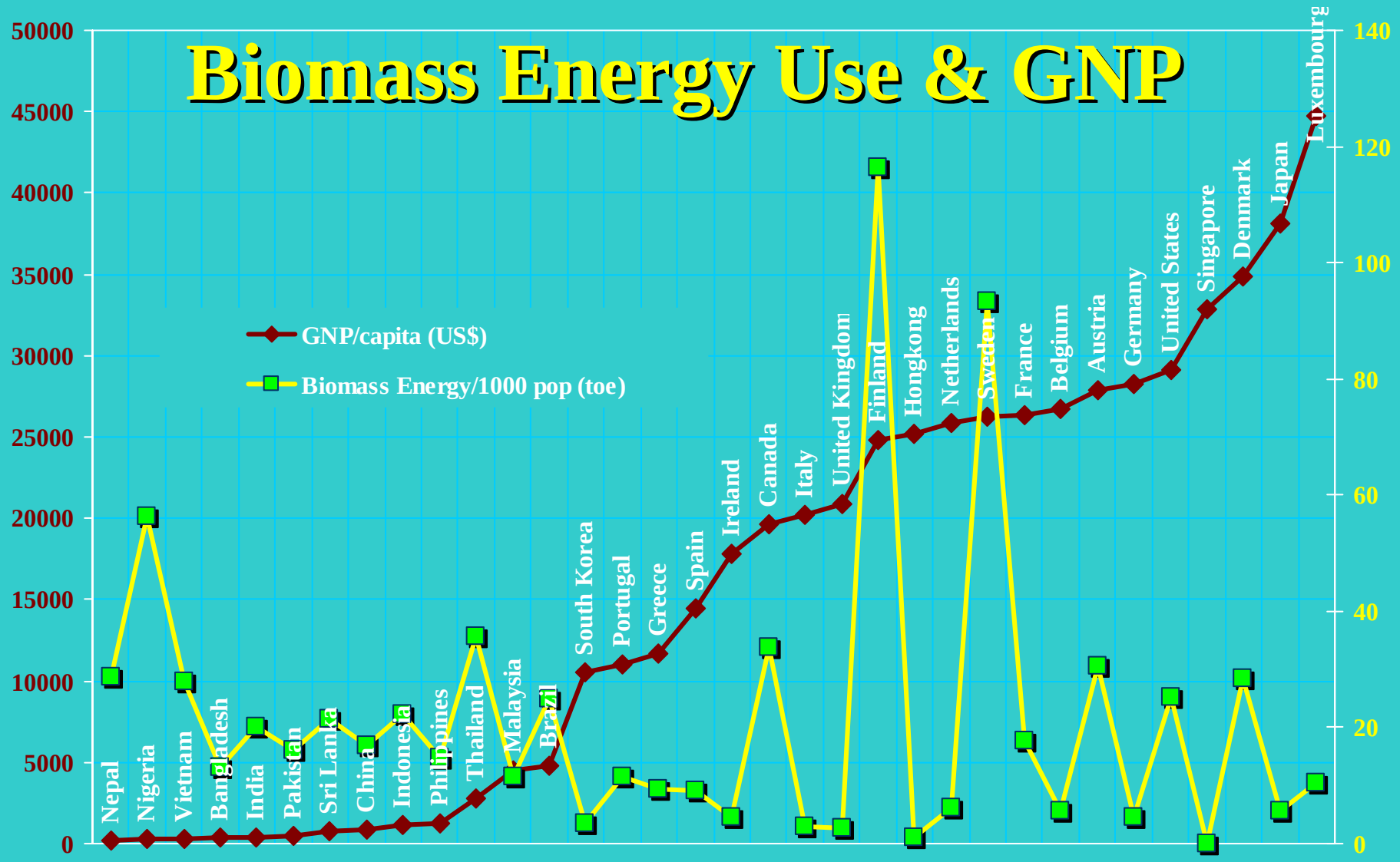


Source: RWEDP

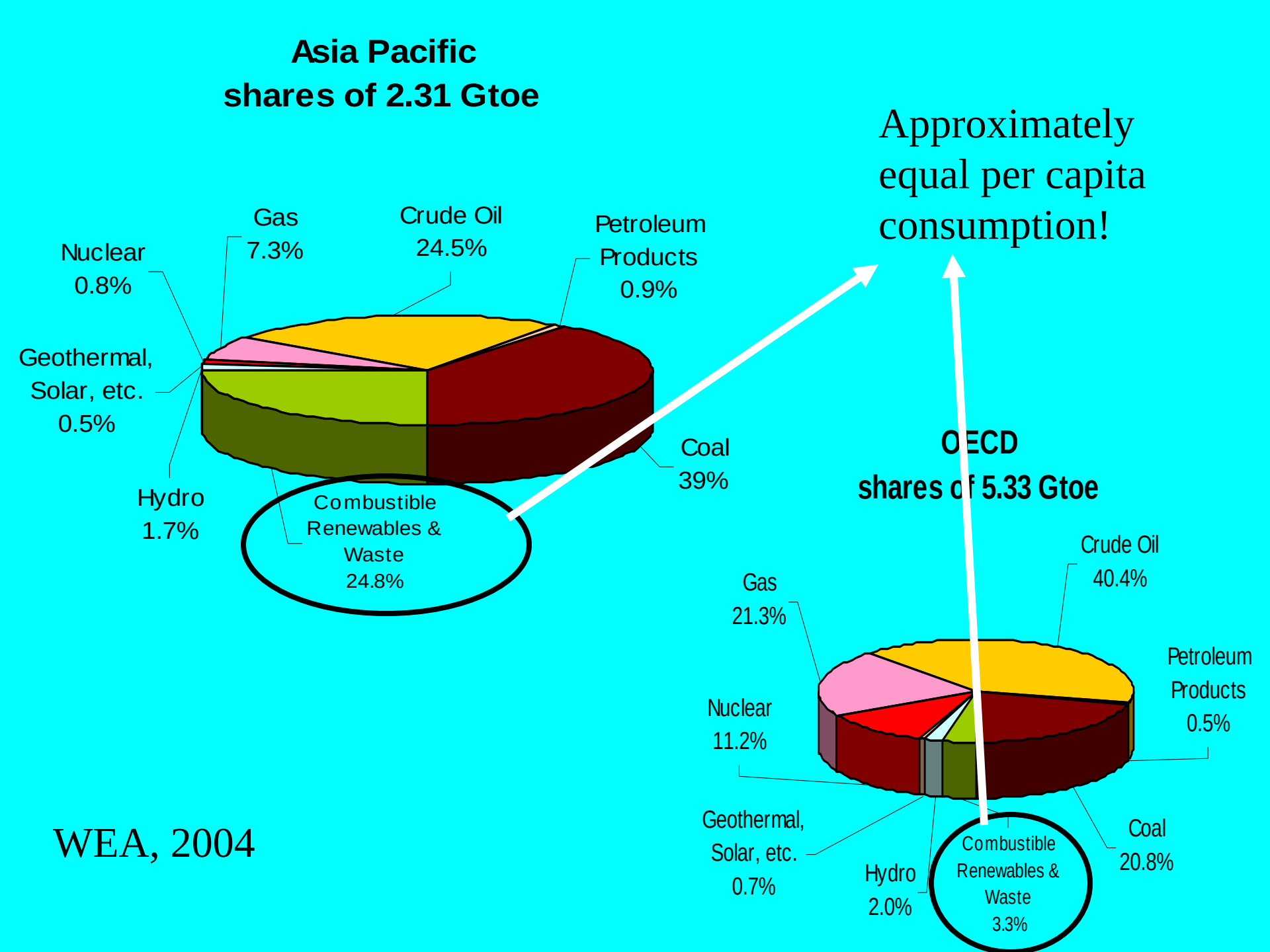


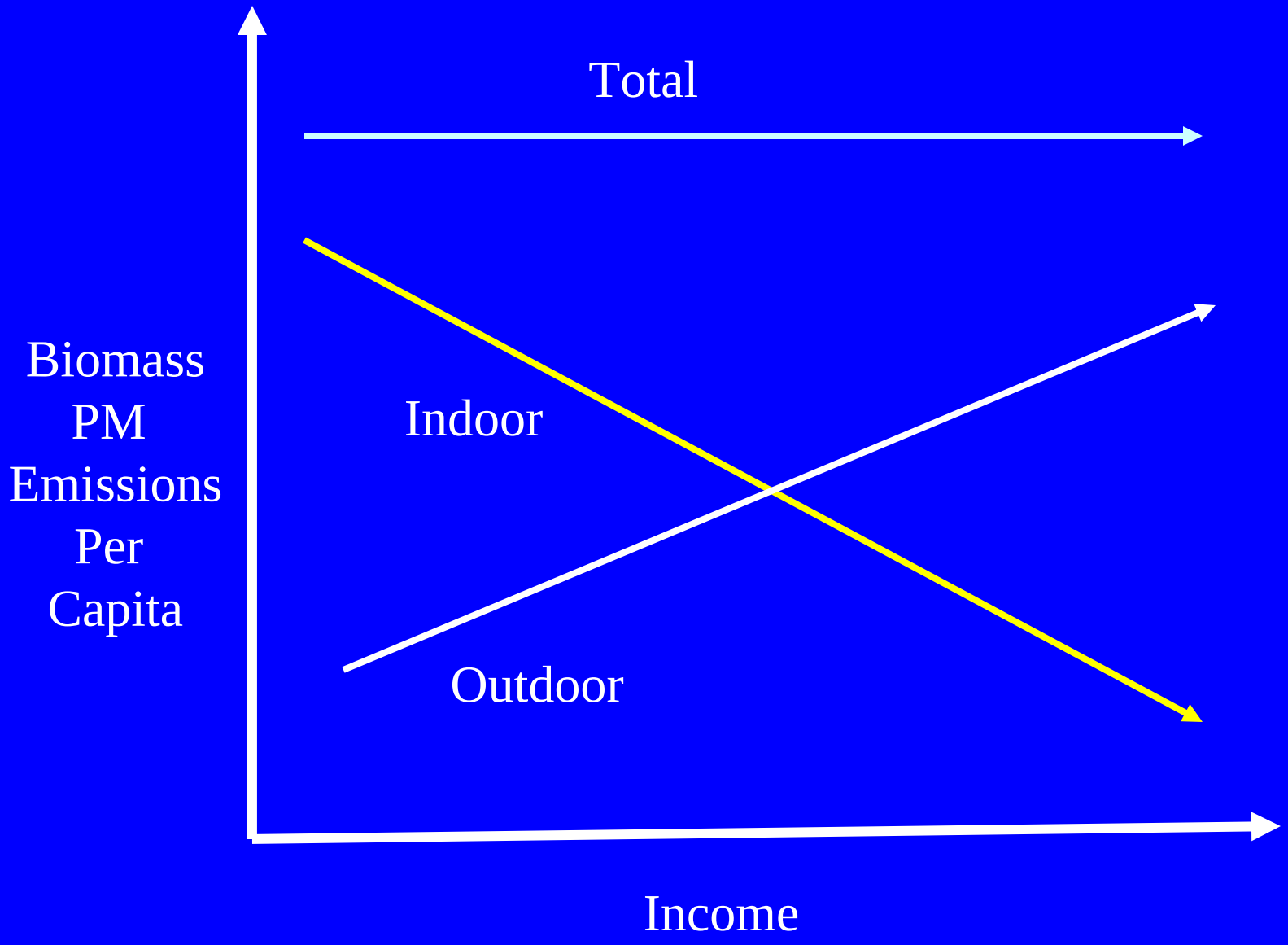
Source: RWEDP

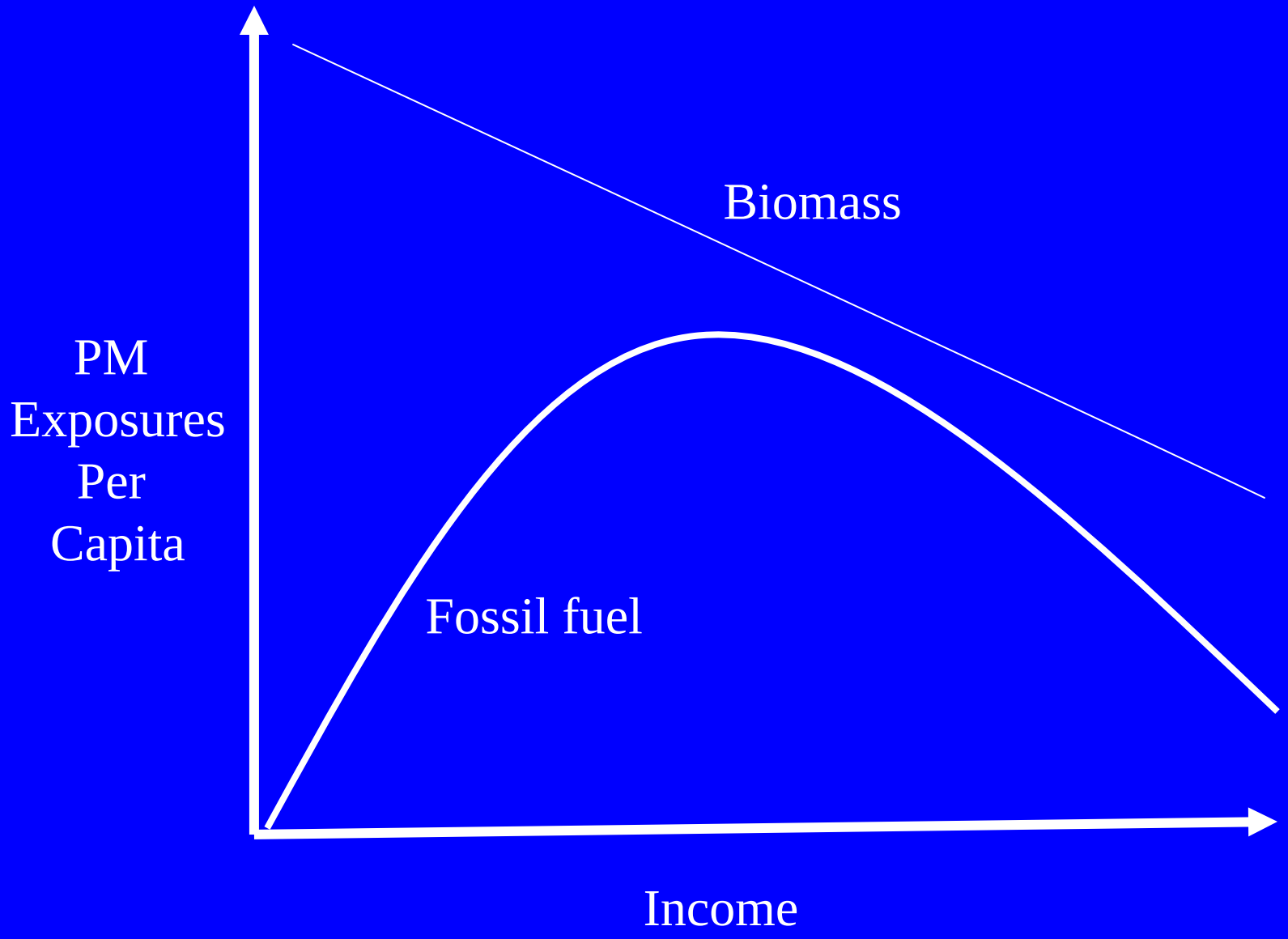
Biomass Energy Use & GNP



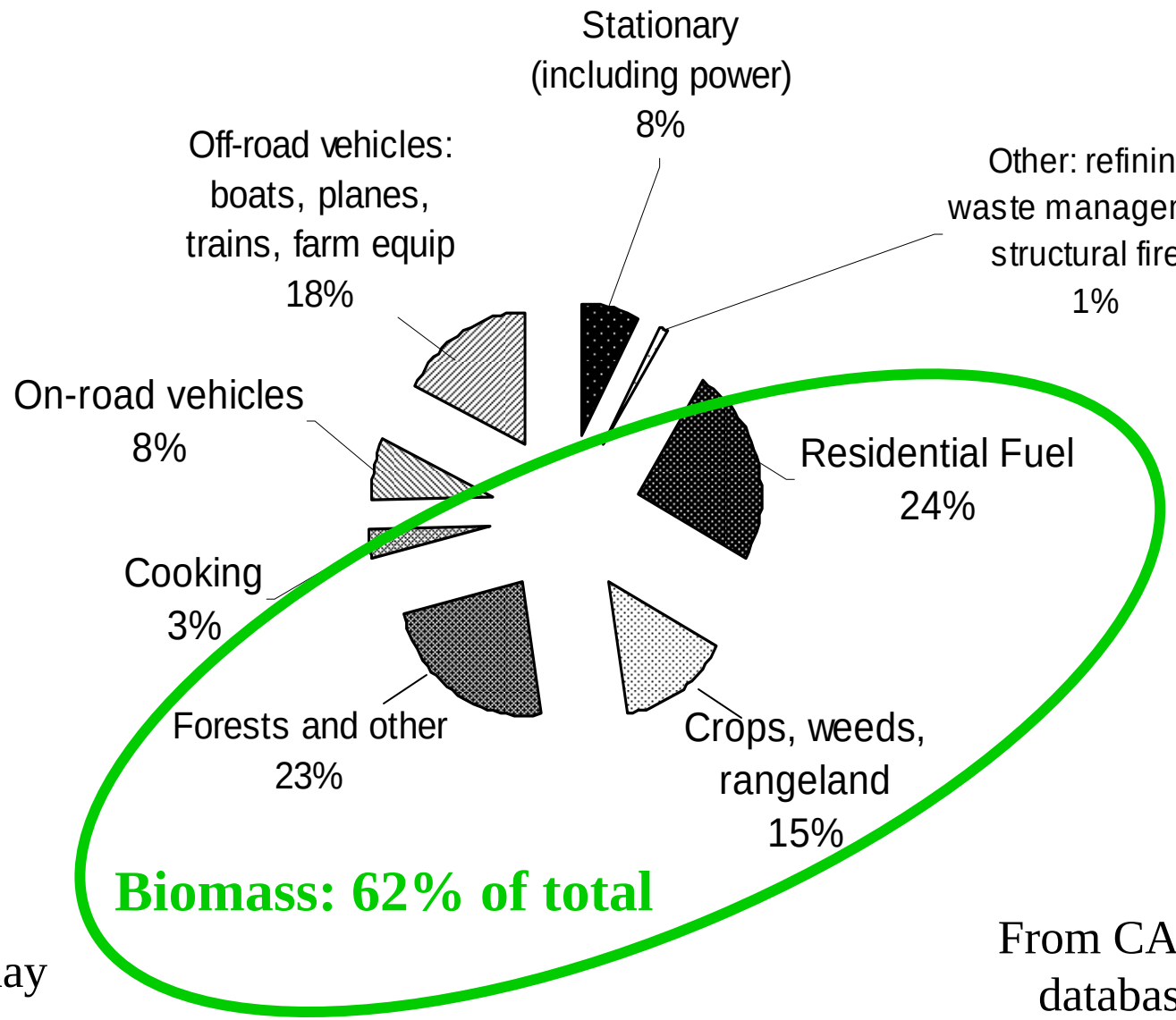
Source: RWEDP


Asia Pacific
shares of 2.31 Gtoe
Gas
7.3%
Crude Oil
24.5%
Petroleum
Products
0.9%
Nuclear
0.8%
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%
Coal
20.8%
Hydro
2.0%
Combustible
Renewables &
Waste
3.3%
WEA, 2004


Total
Biomass PM Emissions Per Capita
Indoor
Outdoor
Income


PM
Exposures
Per
Capita
Biomass
Fossil fuel
Income

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



~450 t/day

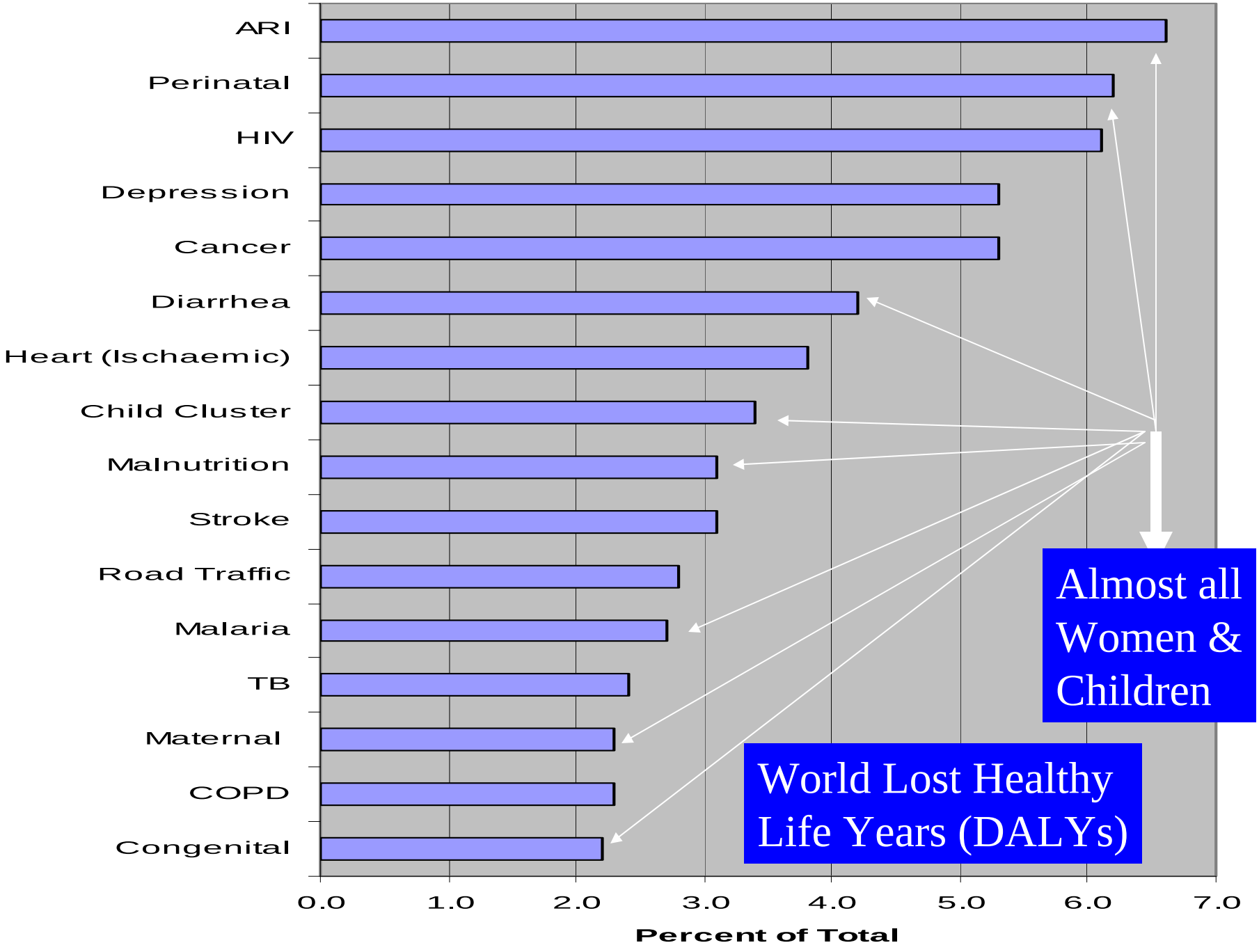
From CARB database

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

Thank you

Physiological Reason #1

- Smoke's main impact is not by causing new diseases
- But by exacerbating risk of existing diseases
- Thus, populations with high background disease rates are most vulnerable
- Women and children in rural areas of poor countries are the most vulnerable in the world


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
Almost all Women & Children
World Lost Healthy Life Years (DALYs)