The Danger of Incomplete Combustion for Environment, Health, and Climate

The Impacts of Humanity’s Oldest Occupation

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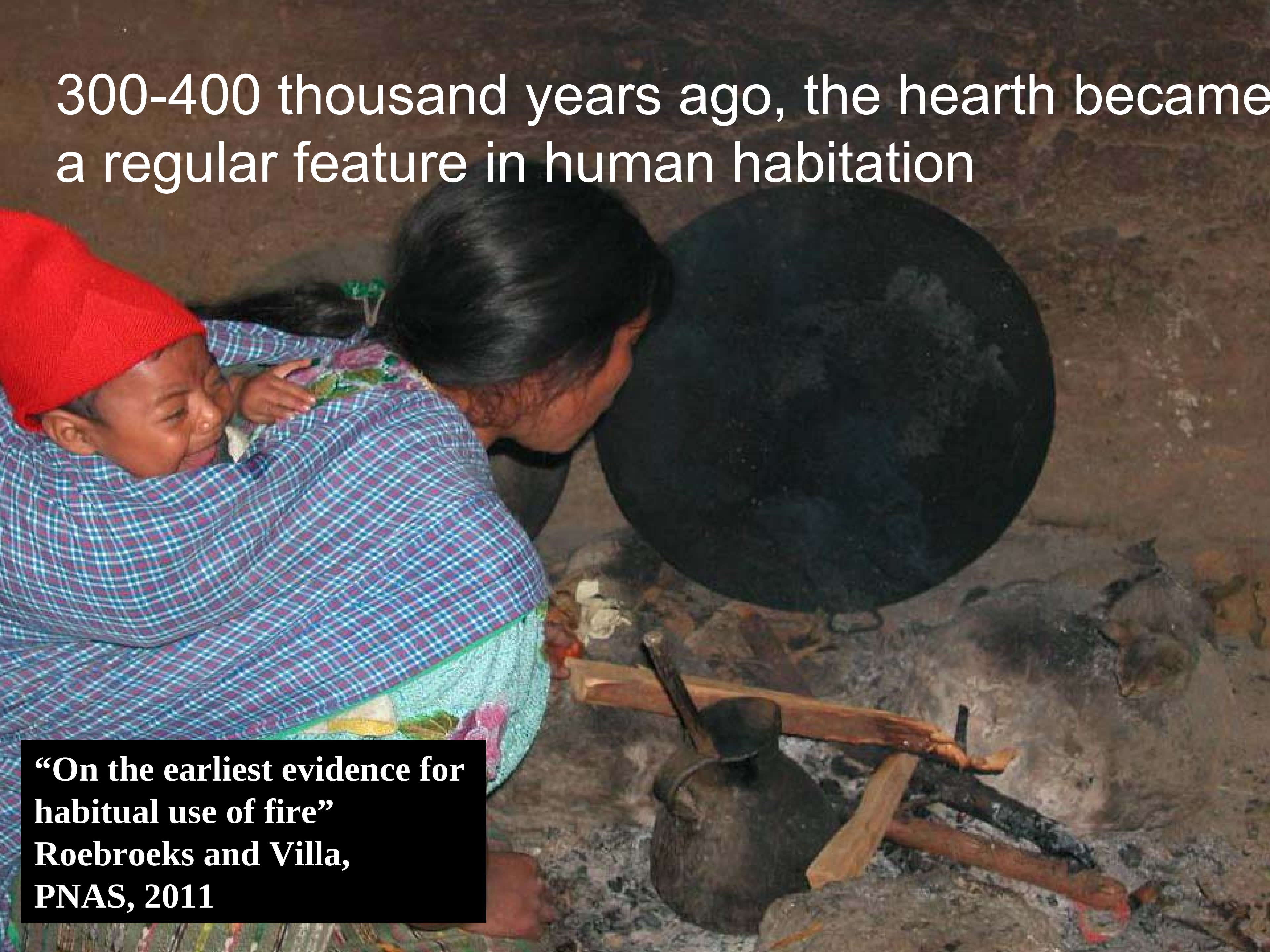
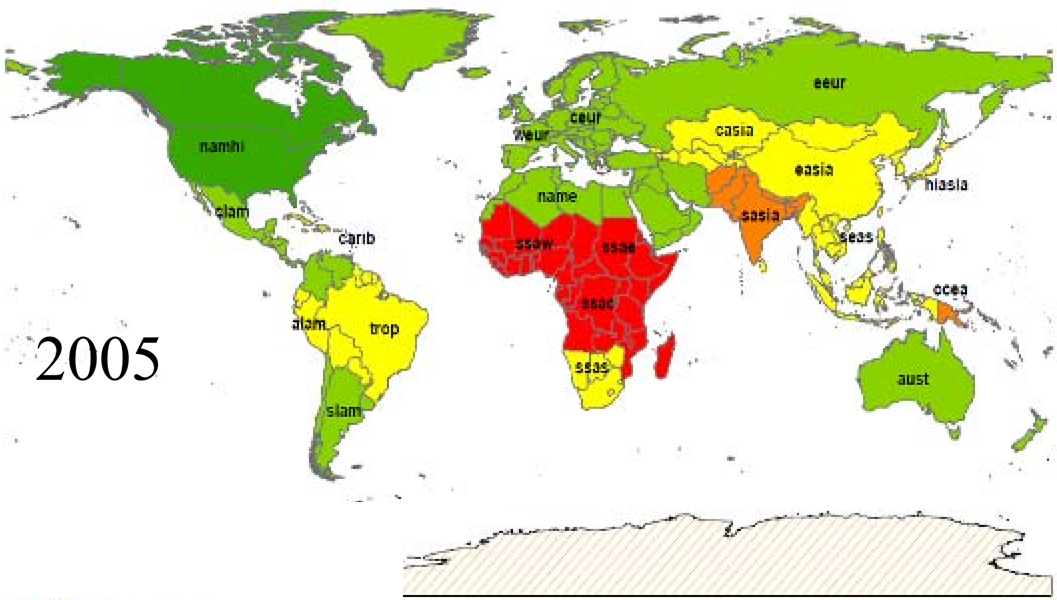
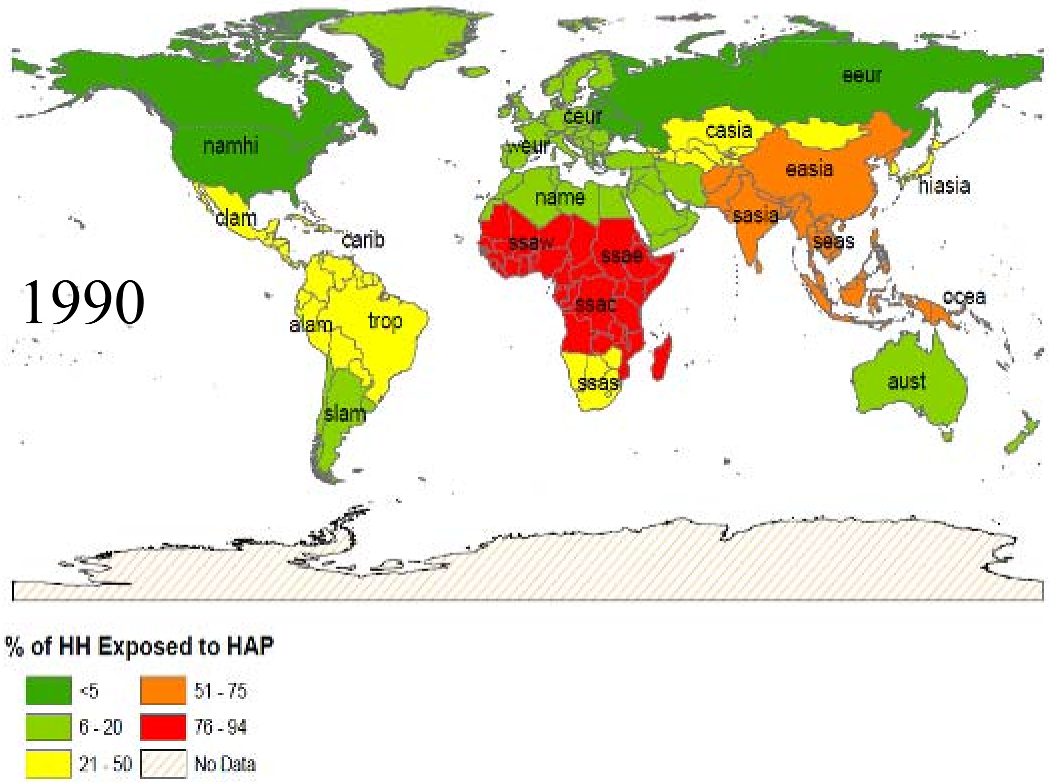


300-400 thousand years ago, the hearth became a regular feature in human habitation

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

Households using biomass or coal to cook today





Comparative Risk Assessment (CRA) 2011- preliminary,

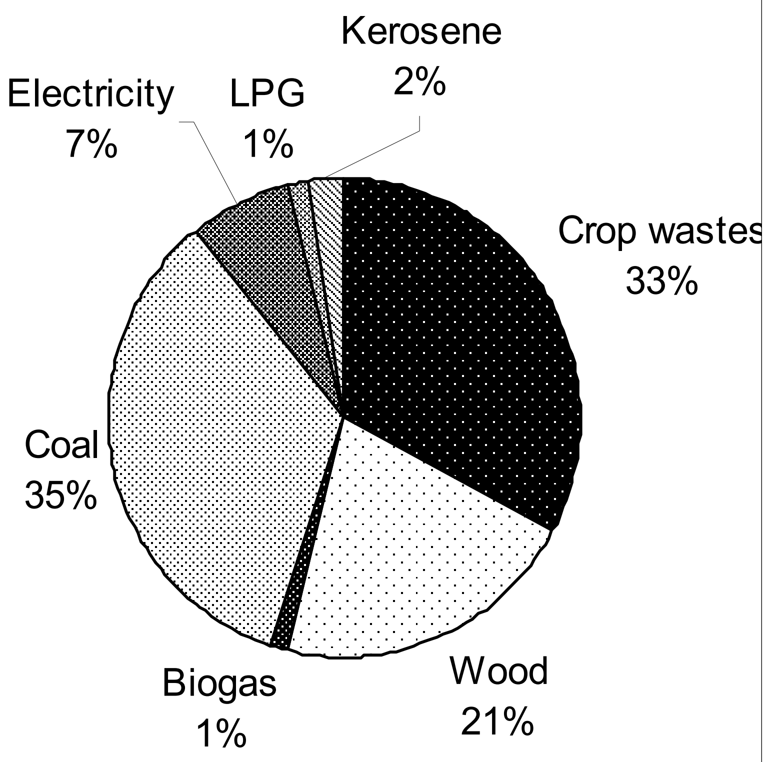
Biomass Cooking in History

- **Only quite recently in human history did more than half of households use non-solid fuels for cooking – perhaps around 1980.**
- **Today, ~43% use solid fuels, about 3 billion people**
- **Although the percentage is dropping, the absolute number is still rising.**
- **Perhaps 20 million people a year are added to the total each year.**
- **Indeed, there are more people using solid fuels today for cooking than the total world population in 1950**
- **Or any year previously**

A problem that has lasted one-third of a million years and is showing no sign of quickly going away by itself.

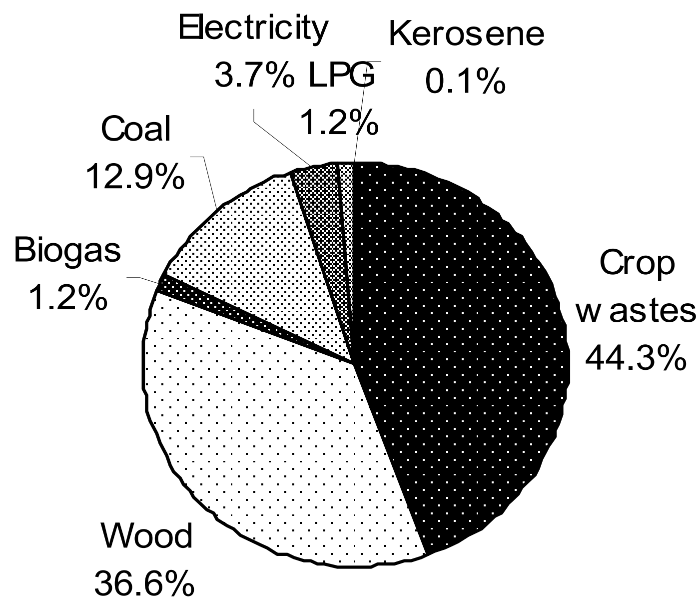
Rural Energy in China: 2004

Total



Ministry of Agriculture

Households

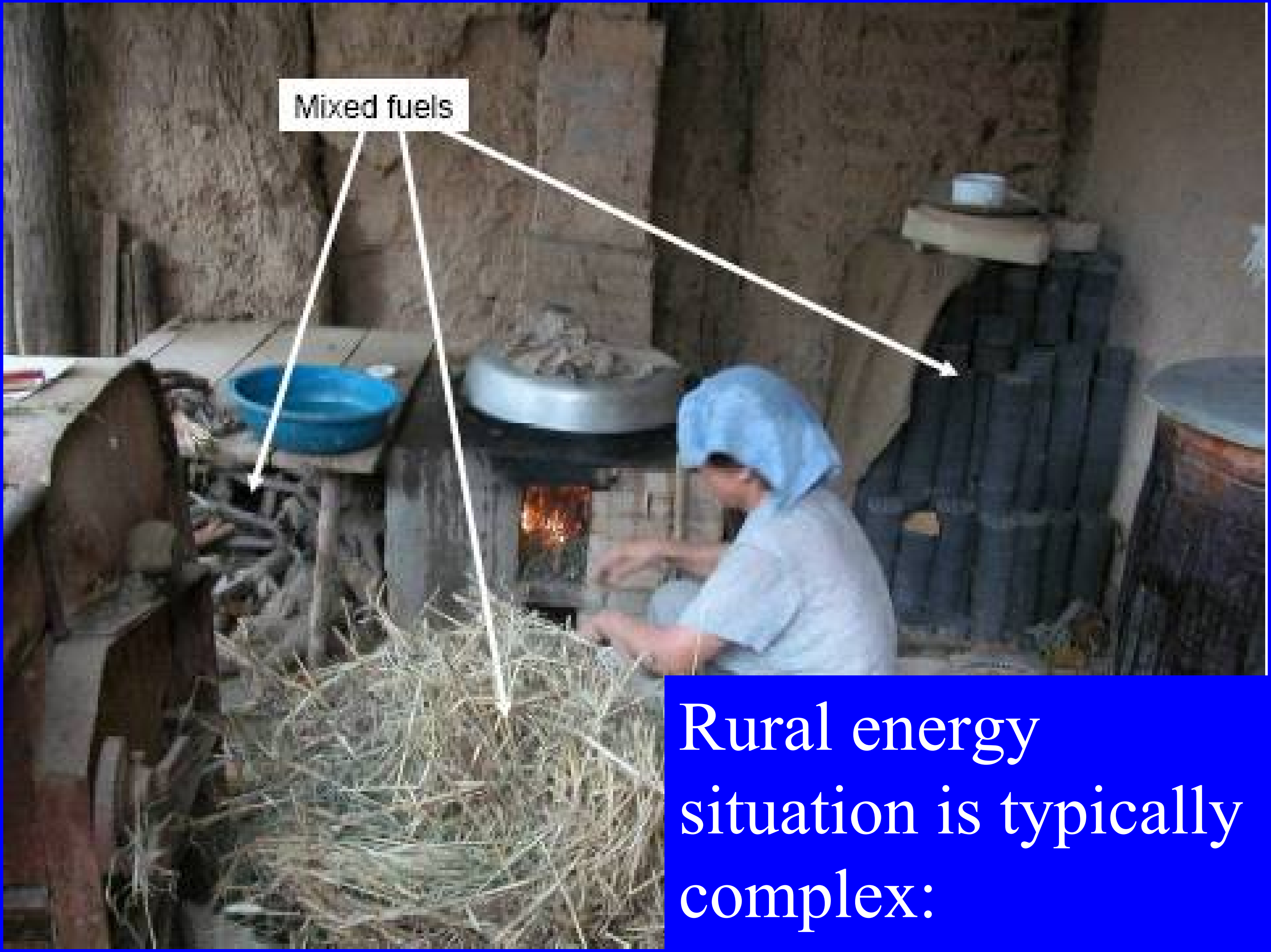


70% of total

National Bureau of Statistics

Household Energy in China

- ~60% of China's population is rural.
- >70% of energy use in rural areas is simple solid biomass (wood, agricultural wastes)
- >15% as coal
- Thus, it is still true to say that in China most people rely on biomass fuels for most of their energy
- Substitution of biomass by coal is increasing – probably worse for health and climate



Rural energy situation is typically complex:

Road Map

- Why is there so much pollution?
- What are the major constituents of the smoke?
- What adverse health effects have been measured?
- What is the climate connection?
- What interventions have been evaluated in China?

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 Chinese 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.

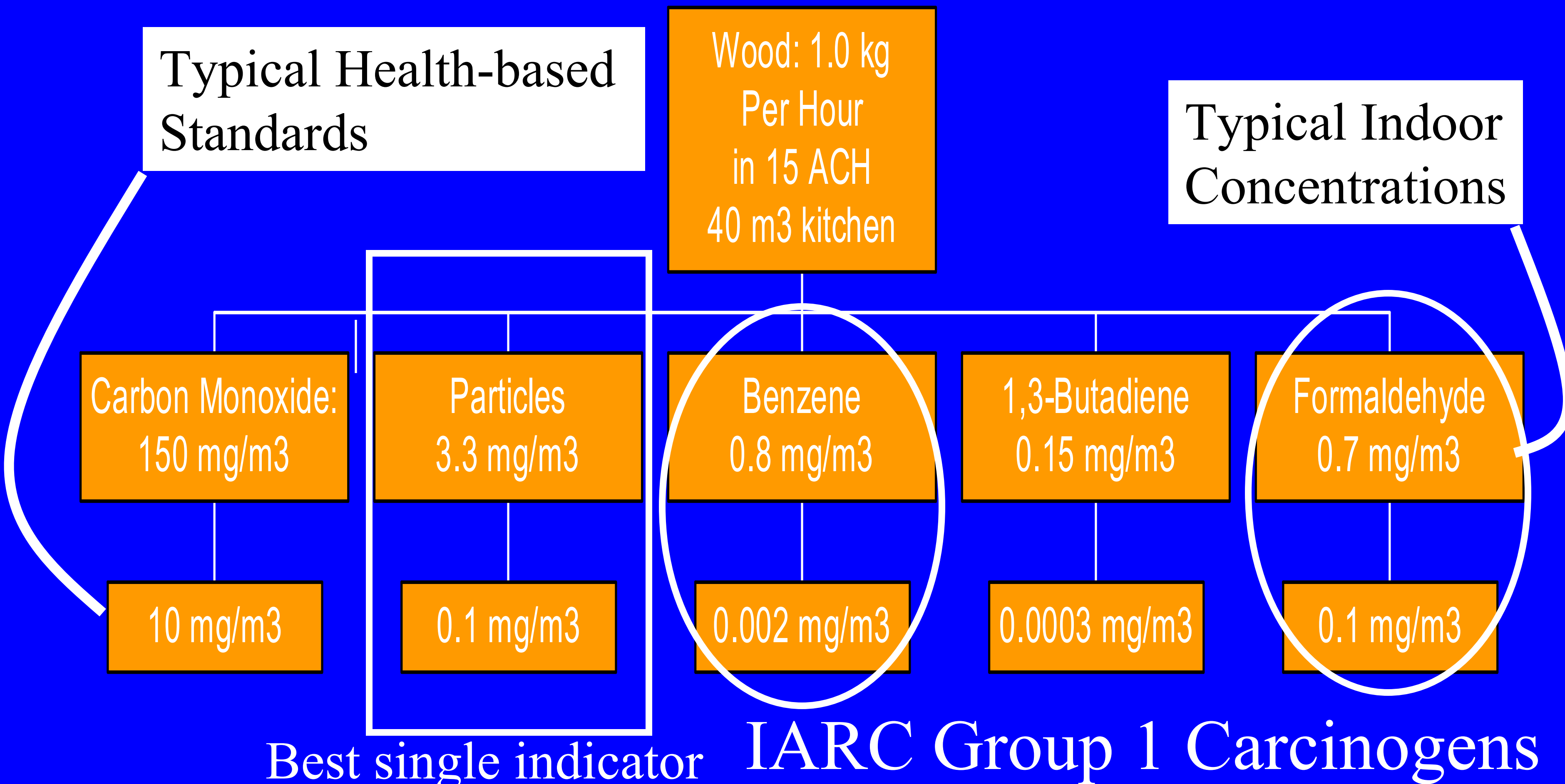
Source: Zhang, et al., 2000

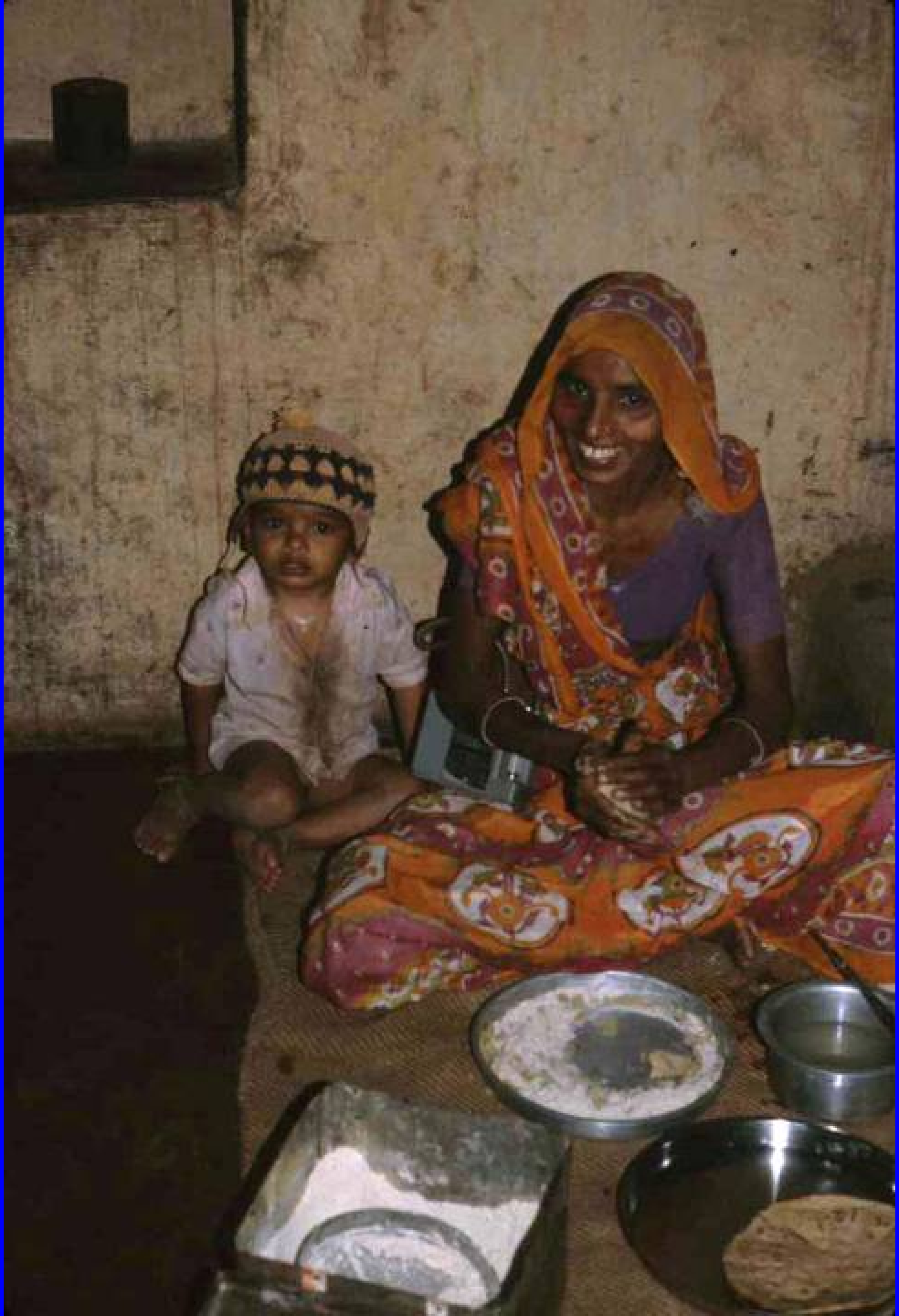
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- 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

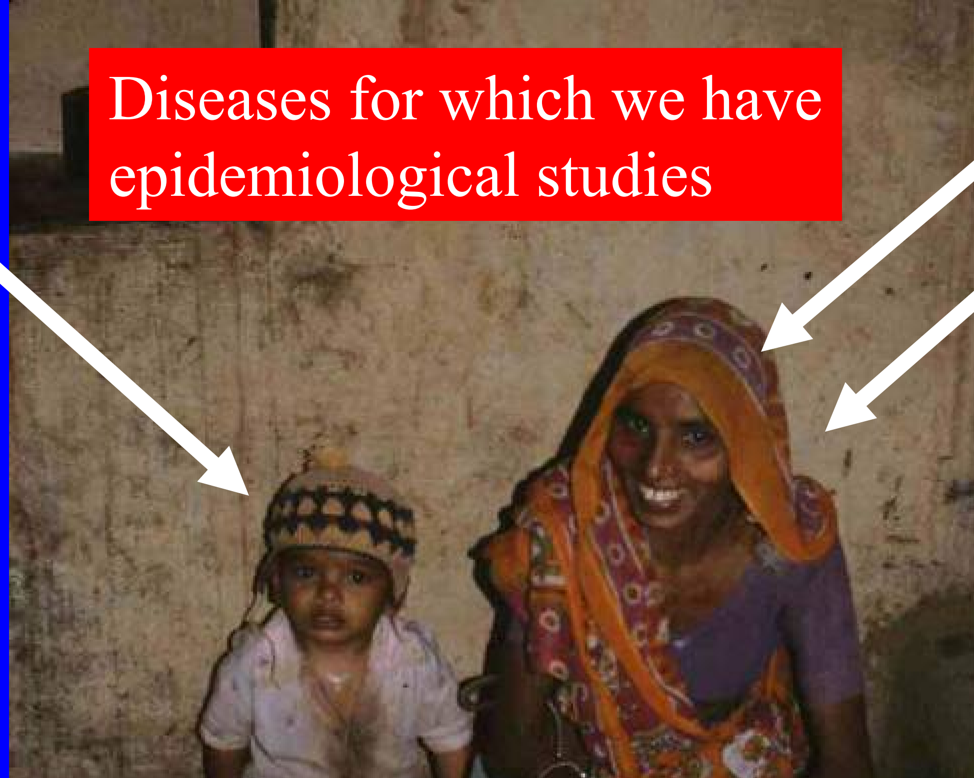
Health-Damaging Air Pollutants From Typical Woodfired Cookstove in China.





How much
Ill-health?

ALRI/
Pneumonia



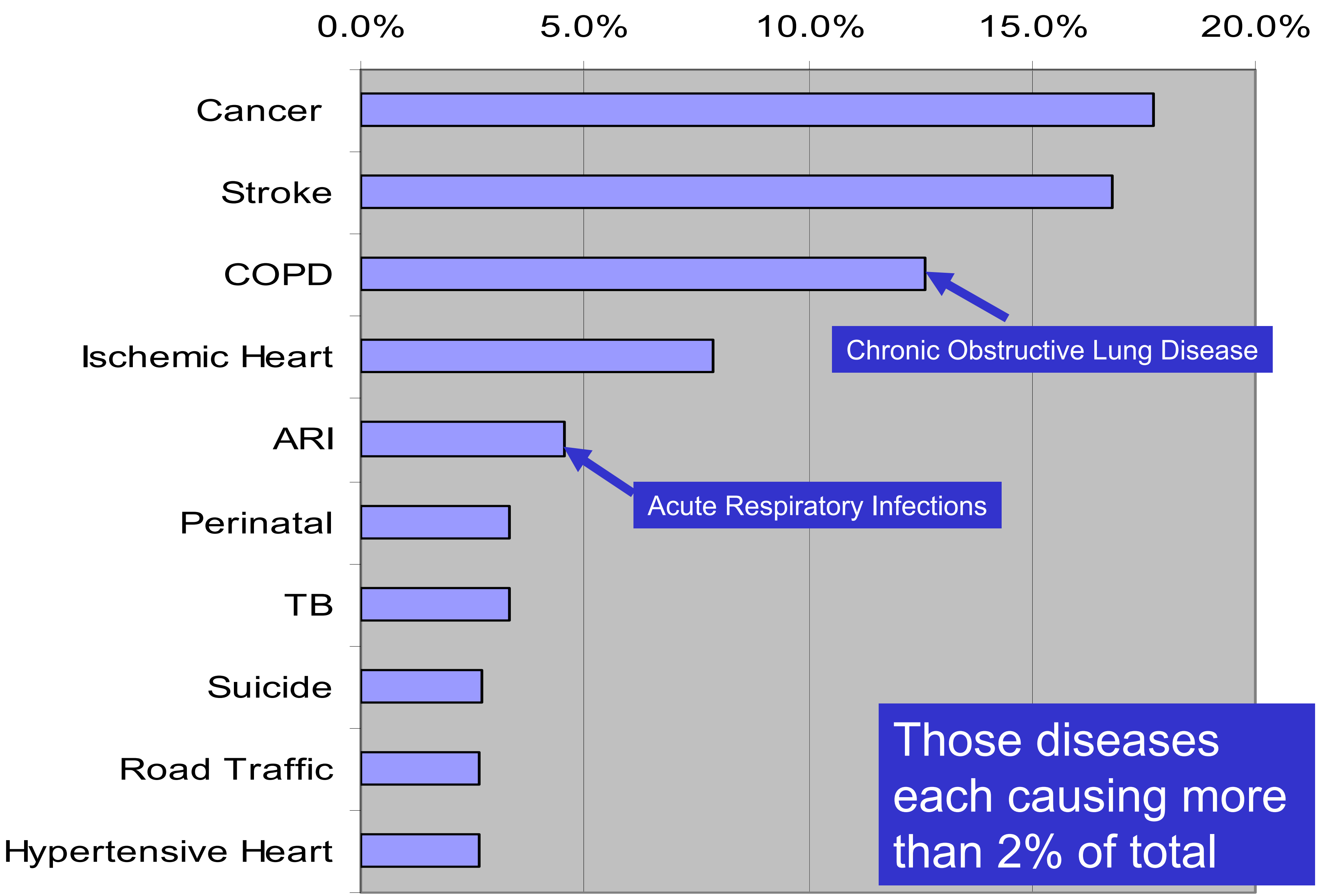
COPD

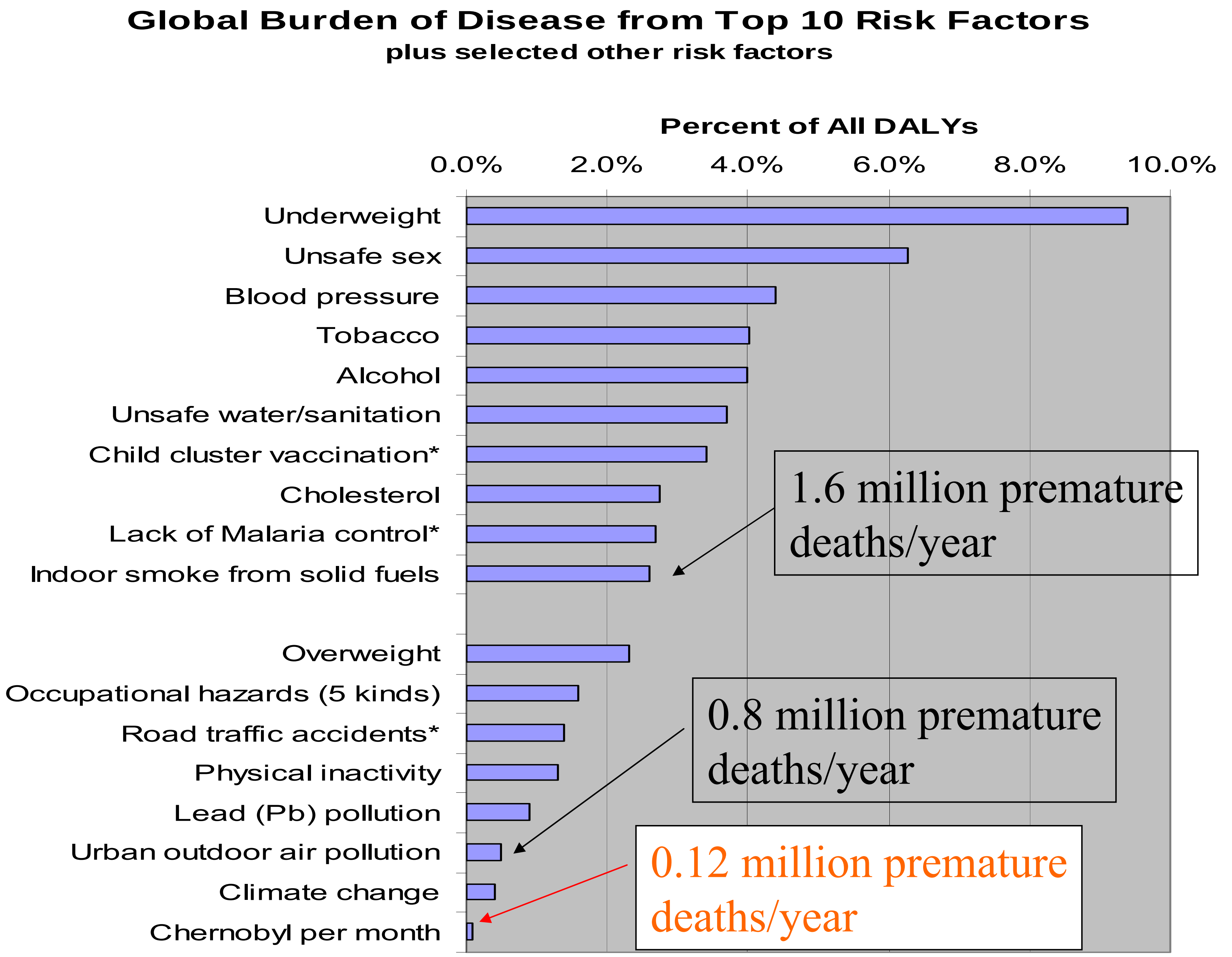
Lung cancer
(coal)

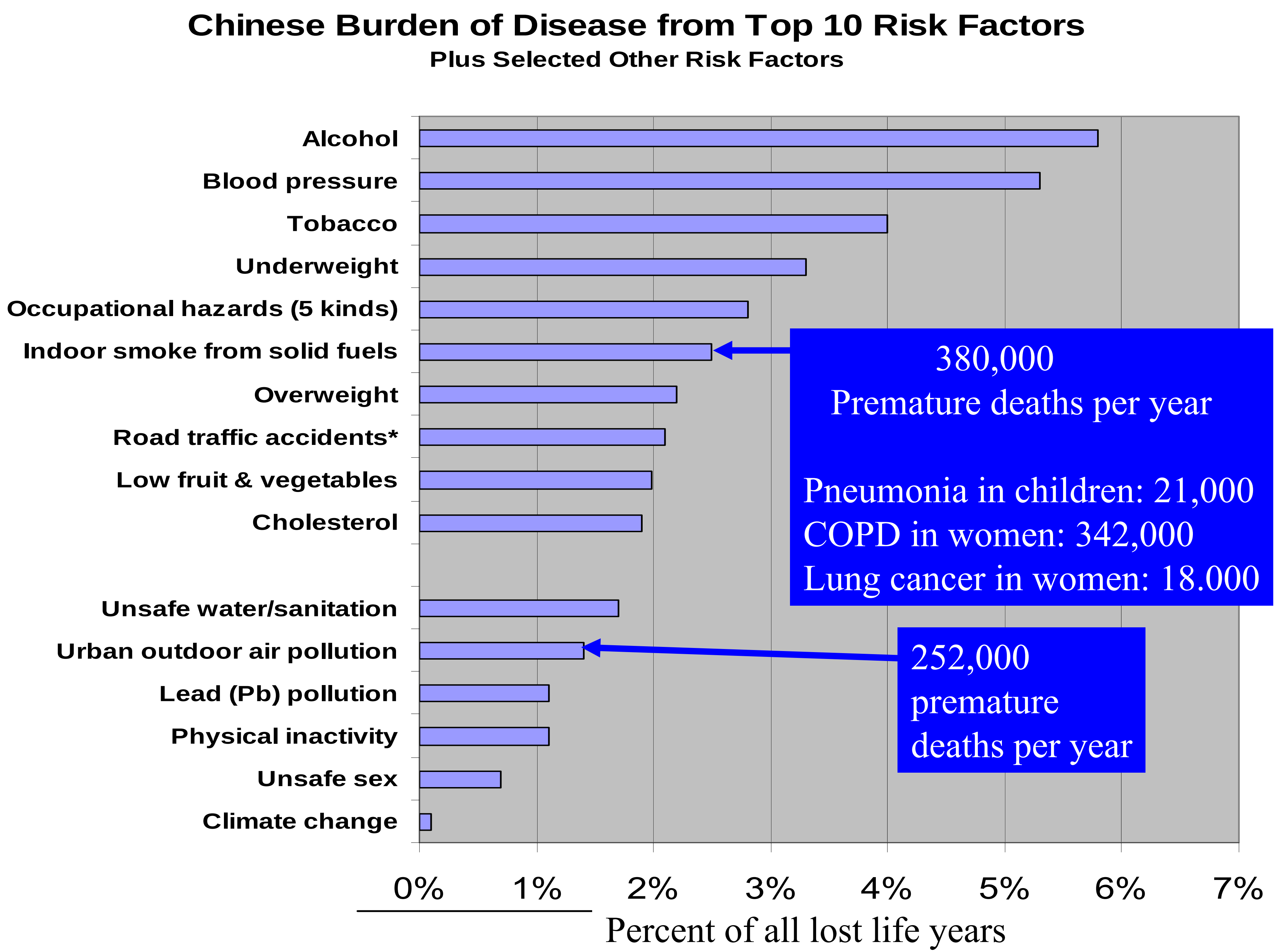
These three diseases were included in the
2004 Comparative Risk Assessment
Managed and published by the
World Health Organization

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

Major Causes of Death in China




Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
Percent of All DALYs
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
Underweight
Unsafe sex
Blood pressure
Tobacco
Alcohol
Unsafe water/sanitation
Child cluster vaccination*
Cholesterol
Lack of Malaria control*
Indoor smoke from solid fuels
Overweight
Occupational hazards (5 kinds)
Road traffic accidents*
Physical inactivity
Lead (Pb) pollution
Urban outdoor air pollution
Climate change
Chernobyl per month
1.6 million premature deaths/year
0.8 million premature deaths/year
0.12 million premature deaths/year


Chinese Burden of Disease from Top 10 Risk Factors
Plus Selected Other Risk Factors
Alcohol
Blood pressure
Tobacco
Underweight
Occupational hazards (5 kinds)
Indoor smoke from solid fuels
Overweight
Road traffic accidents*
Low fruit & vegetables
Cholesterol
Unsafe water/sanitation
Urban outdoor air pollution
Lead (Pb) pollution
Physical inactivity
Unsafe sex
Climate change
380,000
Premature deaths per year
Pneumonia in children: 21,000
COPD in women: 342,000
Lung cancer in women: 18.000
252,000
premature
deaths per year
0%
1%
2%
3%
4%
5%
6%
7%
Percent of all lost life years

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Population (thousands) 6224984.81 3170?7.27 622741.70 617442.67 663966.36 427071.29 166160.20 30443.11 26143.24 3130652.05 301091.79 589229.34 782026.21 646513.90 427846.34 181906.42

GBD 2002: DALYs by age, sex and cause for the year 2002

WORLD

Code	Cause	Total	Male 0-4	Male 5-14	Male 15-29	Male 30-44	Male 45-59	Male 60-69	Male 70-79	Male 80+	Male Total	Female 0-4	Female 5-14	Female 15-29	Female 30-44	Female 45-59	Female 60-69
U000	All Causes	1490125643	222552079	56142418	141637847	130501742	115374678	60641455	36229210	9832834	772912264	211279454	54559890	141633214	108257333	90621463	53460940
U001	I. Communicable, maternal, perinatal and nutritional conditions	610319230	########	20979812	29721889	36148773	16631072	5676094	2913759	849889	########	########	23248712	59740290	35979204	11499502	4476964
U002	A. Infectious and parasitic diseases	350332571	87977510	12810197	25516201	33372707	14085712	3710016	1519252	315539	179307135	89749119	13534884	31549467	23070592	8616676	2658113
U003	1. Tuberculosis	34735908	839261	782431	5497848	7335503	4868489	1832663	658401	90612	21905208	738745	821735	4163278	3822011	2041939	833205
U004	2. STDs excluding HIV	11347067	1521528	26245	1080828	660600	423721	103004	31641	7415	3854983	1726606	97221	4158088	1147558	260537	71612
U005	a. Syphilis	4200039	1039452	2292	151945	285546	354596	99162	30394	6987	1970375	1265722	3432	521758	262487	107605	42492
U006	b. Chlamydia	3571404	1199	7209	241593	50929	1169	136	0	0	302234	1152	69338	2635460	439449	109658	14084
U007	c. Gonorrhoea														422675	6262	1616
U008	d. Other STDs														22947	37012	13420
U009	3. HIV/AIDS														13746555	2624463	230670
U010	4. Diarrhoeal diseases														545936	373258	201900
U011	5. Childhood-cluster dise														53966	19174	4837
U012	a. Pertussis														0	13	0
U013	b. Poliomyelitis														16931	3822	615
U014	c. Diphtheria														386	572	29
U015	d. Measles														29	30	0
U016	e. Tetanus														36620	14737	4192
U017	6. Meningitis*														167759	110215	48775
U018	7. Hepatitis B														115391	110437	36630
U019	Hepatitis C														53705	61307	30322
U020	8. Malaria														453207	280704	99111
U021	9. Tropical-cluster diseas														593336	496341	75537
U022	a. Trypanosomiasis														79329	46509	3694
U023	b. Chagas disease														51644	48058	15987
U024	c. Schistosomiasis														128589	58850	17056
U025	d. Leishmaniasis														67203	30097	11647
U026	e. lymphatic filariasis														206680	266630	15772
U027	f. Onchocerciasis														59892	46198	11380
U028	10. Leprosy														15828	9135	4389
U029	11. Dengue														10408	6396	2644
U030	12. Japanese encephalitis														26926	7282	2513
U031	13. Trachoma														517423	559520	344796
U032	14. Intestinal nematode in														5192	5921	3469
U033	a. Ascariasis														161	21	111
U034	b. Trichuriasis														388	433	238
U035	c. Hookworm disease														4212	4859	2723
U036	Other intestinal infectio														432	607	397
U037	Other infectious disease														1795391	1650048	667703
U038	B. Respiratory infections														1481589	1357246	1460806
U039	1. Lower respiratory infec														1434738	1329549	1425397
U040	2. Upper respiratory infec														45228	26339	34405
U041	3. Otitis media														1622	1358	1004
U042	C. Maternal conditions														9947305	403615	19
U043	1. Maternal haemorrhage														1944088	133887	0
U044	2. Maternal sepsis														1625431	72999	0
U045	3. Hypertensive disorders*														722909	40216	0
U046	4. Obstructed labour	3048291	0	0	0	0	0	0	0	0	0	0	0	2241561	794568	12162	0
U047	5. Abortion	4652171	0	0	0	0	0	0	0	0	0	0	223411	3721304	705860	1596	0
U048	Other maternal conditions	12427759	0	0	0	0	0	0	0	0	0	0	1970	8128555	4154451	142755	19
U049	D. Perinatal conditions*	97335086	53209265	1343	1031	347	89	12	9	0	53212095	44121066	1195	498	158	34	29
U050	1. Low birth weight	46334234	25061999	52	13	20	0	9	0	0	25062092	21272111	31	0	0	0	0
U051	2. Birth asphyxia and birth trauma	34445758	19353003	790	302	73	33	3	0	0	19354204	15090851	573	107	0	15	0
U052	Other perinatal conditions	16555094	8794262	502	716	253	56	0	9	0	8795799	7758104	591	392	158	19	29
U053	E. Nutritional deficiencies	34416632	10258276	1921013	1793247	1025783	698252	230984	132831	39983	16100369	10385030	2582483	2149411	1479558	1121930	357998
U054	1. Protein-energy malnutrition	16910328	7556012	560106	156056	69278	103279	71114	45451	18671	8579966	7350453	620870	66437	68728	81418	70683
U055	2. Iodine deficiency	3519322	1283895	471857	528	748	1215	641	236	50	1759171	1305105	450178	1681	1046	1287	439
U056	3. Vitamin A deficiency	792562	257306	84825	3330	6358	7864	3519	983	100	364284	320394	84034	10506	3807	6687	

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

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Diseases for which we have epidemiological studies - 2011

ALRI/ Pneumonia

Low birth weight

Stillbirth

COPD

Lung cancer (coal)

Lung cancer (biomass)

Blindness (cataracts, opacity)

Heart 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

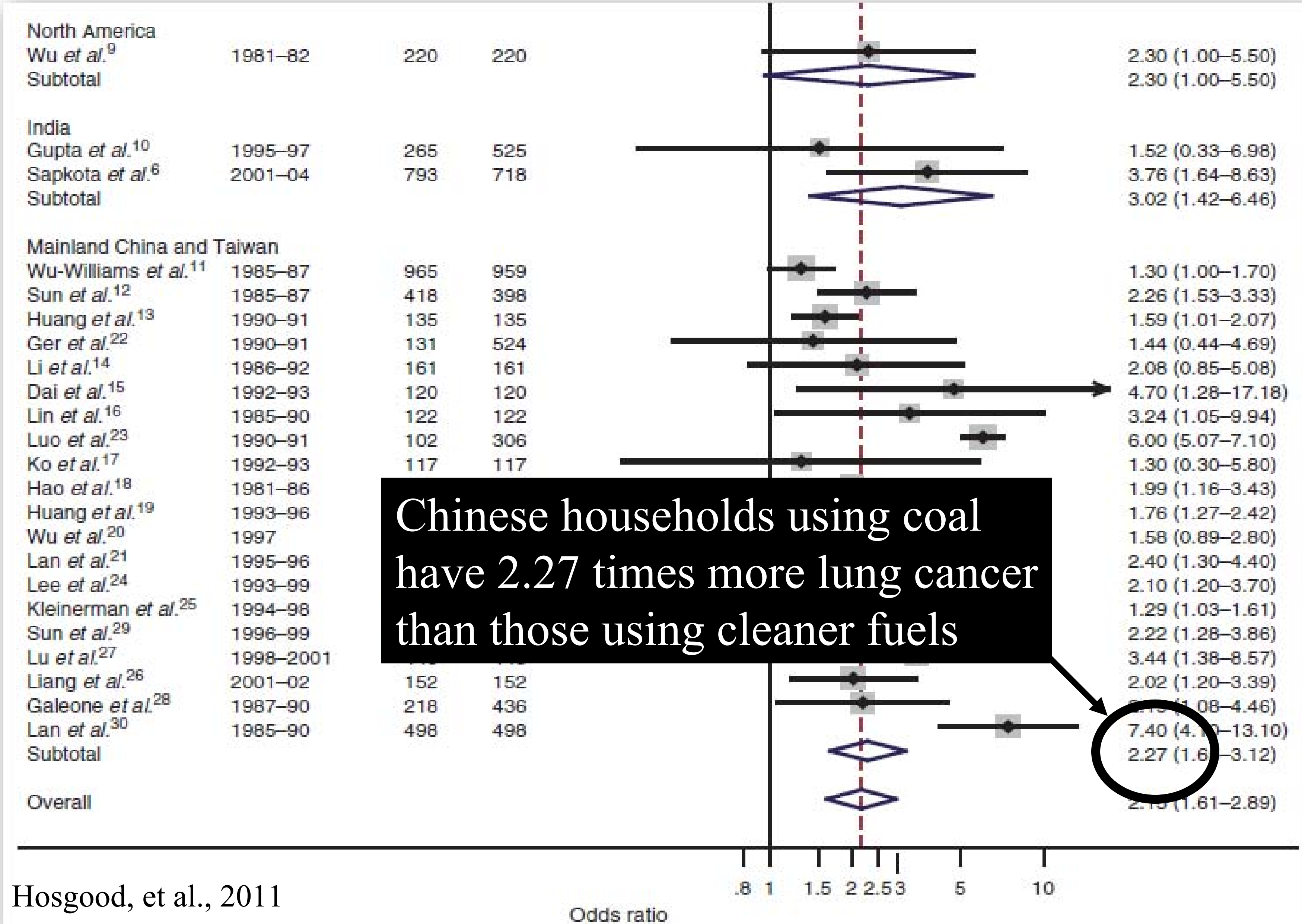
Pollution and health effects of indoor fuel smoke exposure in China*

- Lung cancer
- Respiratory illnesses
- Lung function impairment
- Immune system weakening
- CO poisoning
- Endemic arsenism and fluorosis

* 120+ publications from studies conducted in China

Coal stoves

Household Coal Use and Lung Cancer



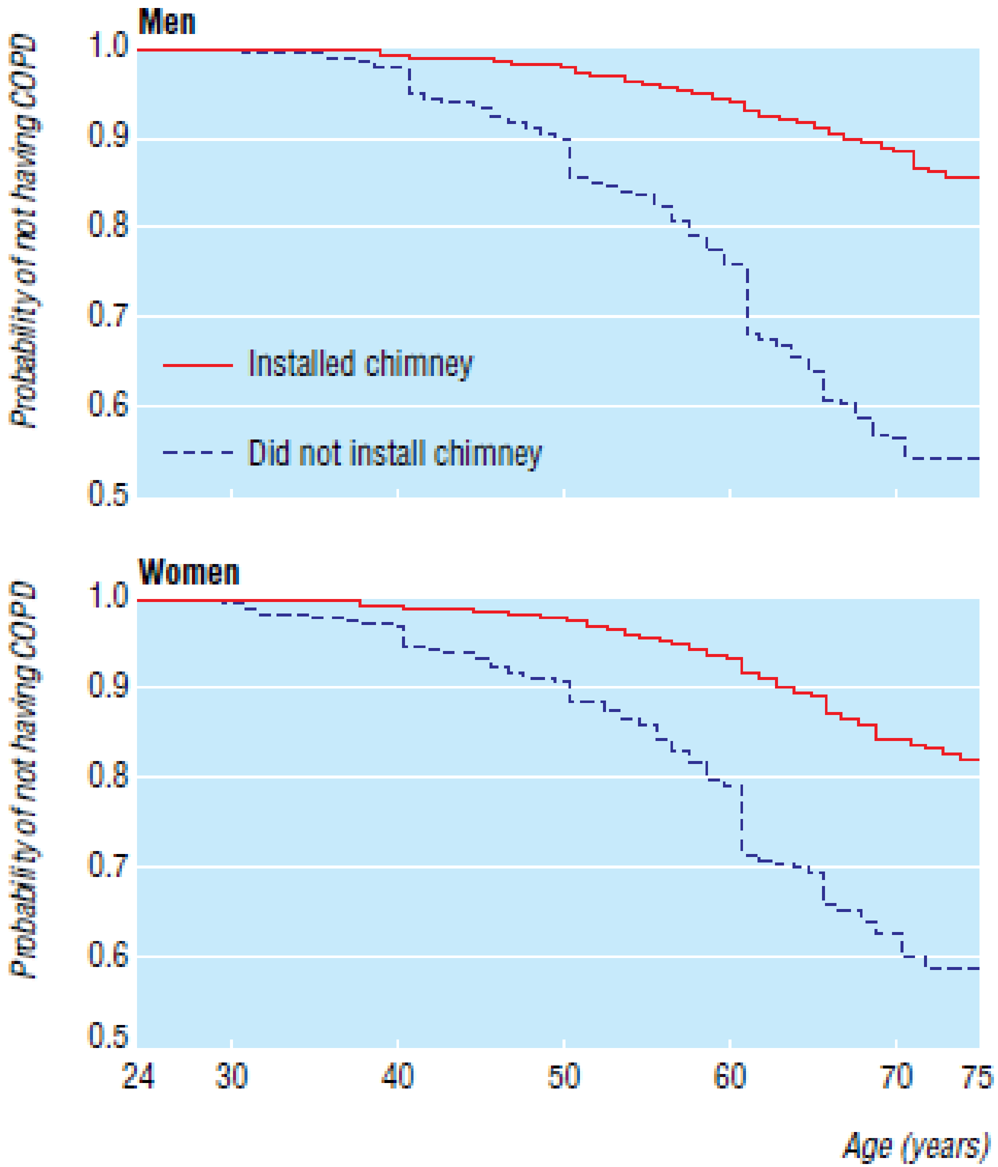
Hosgood, et al., 2011

Health Benefits of Fuel/stove Intervention

Best published studies in the world were done by examining introduction of improved coal stoves in China

Improved Stoves Brought to Xuanwei County in early 1980s

- The reduction in particle levels was ~a factor of about three.
- Reduction in lung cancer was ~40% in men and ~45% in women. (*Journal of the National Cancer Institute*)
- Reduction in COPD rates was also significant at about 50% in both men and women (*British Medical Journal*)
- Reduction in lung cancer and COPD took 10 years to fully develop after IAQ improvement.



Product limit survival plots showing probability of not having chronic obstructive pulmonary disease (COPD) by age in years in men and women according to whether they had a chimney, Xuanwei, 1976-92

One of the few stove intervention studies in the world with a health outcome. A "natural experiment" – retrospective study of COPD after introduction of chimney stoves in a Yunnan county in late 1970s

Coal is the primary fuel in these households

Chapman et al. BMJ, 2005

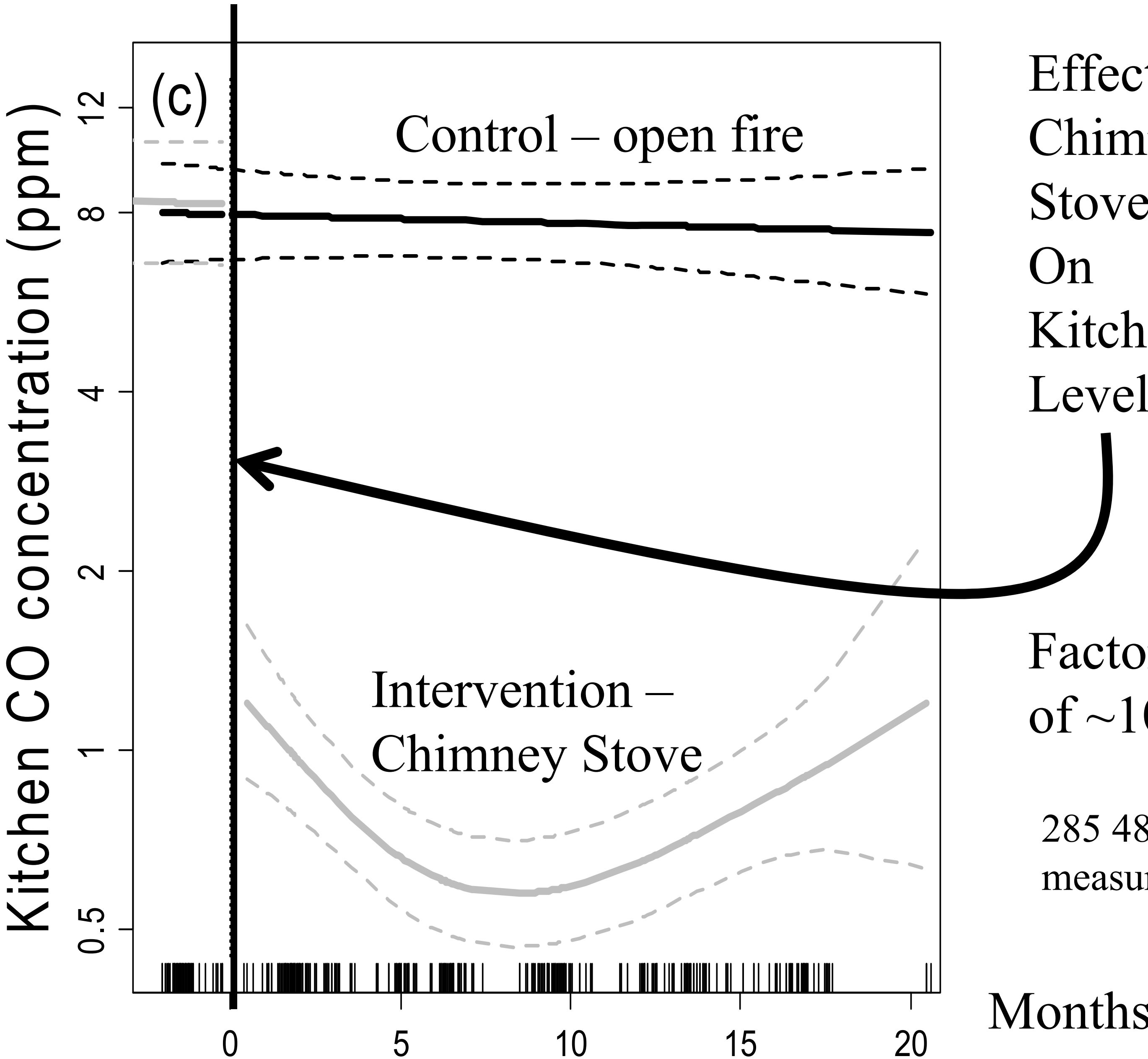
Why We Know Now that Chimneys are not Enough

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

Chimney wood stove, locally made and popular with households


Tubito
Tubito

Guatemala RCT: Kitchen Concentrations



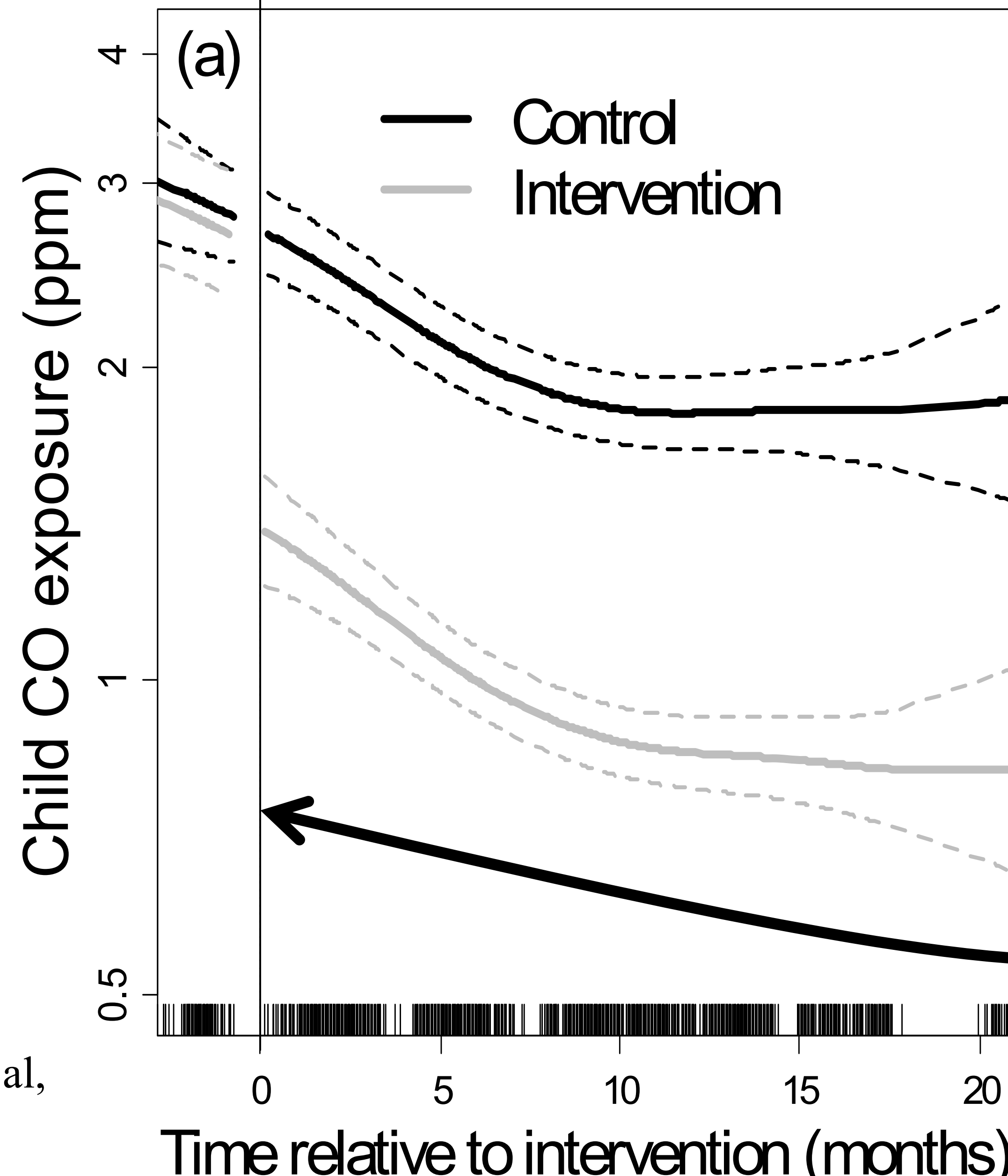
Effect of Chimney Stove On Kitchen CO Levels

Factor of ~10 less

285 48-h measurements

Smith, et al, 2010

Infant Exposures

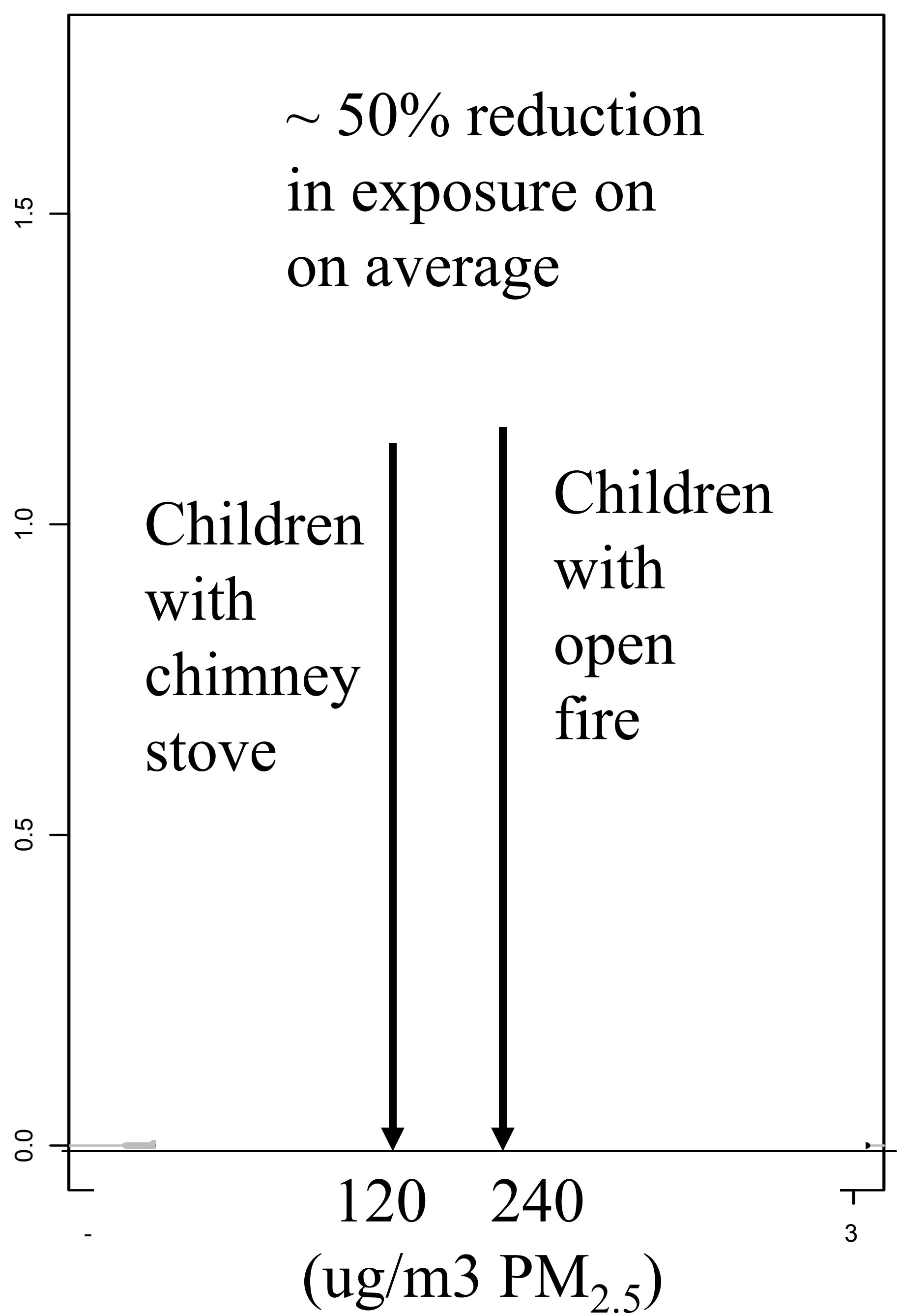


1888 48-h measurements

Effect of Chimney Stove On Infant Exposures - 2x less

Smith, et al, 2010

(b)

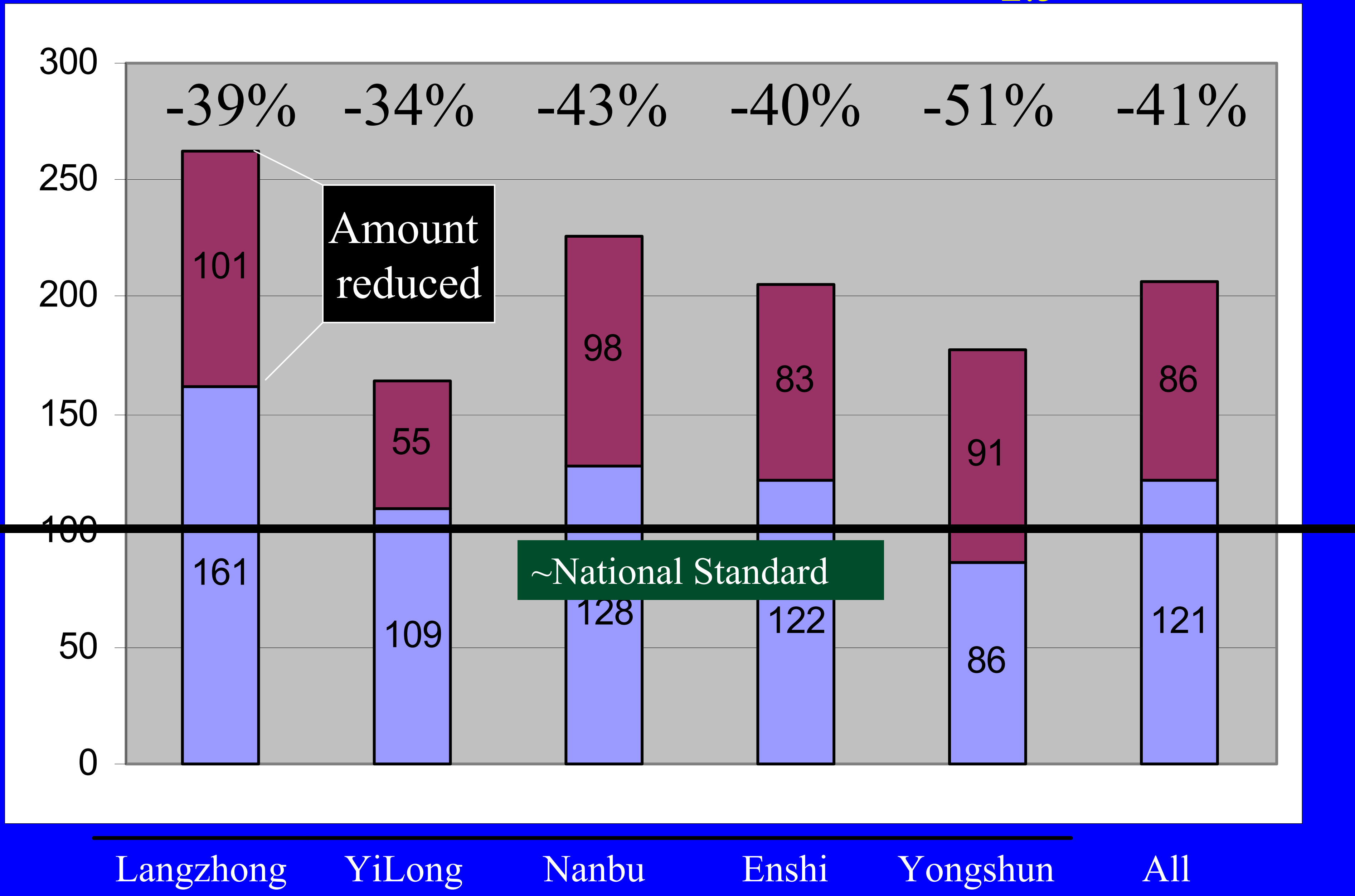


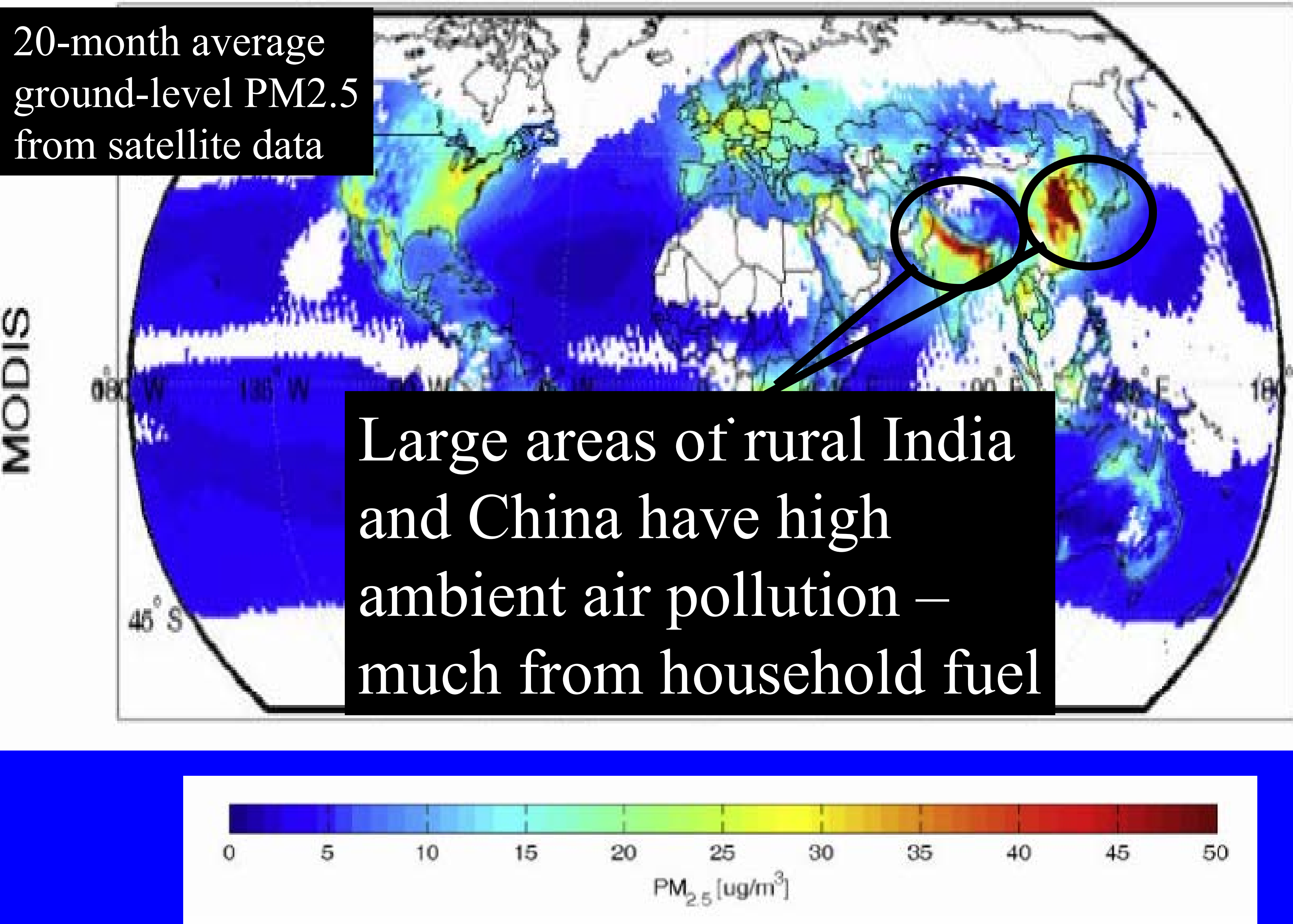
Chimney stove did not protect all children

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

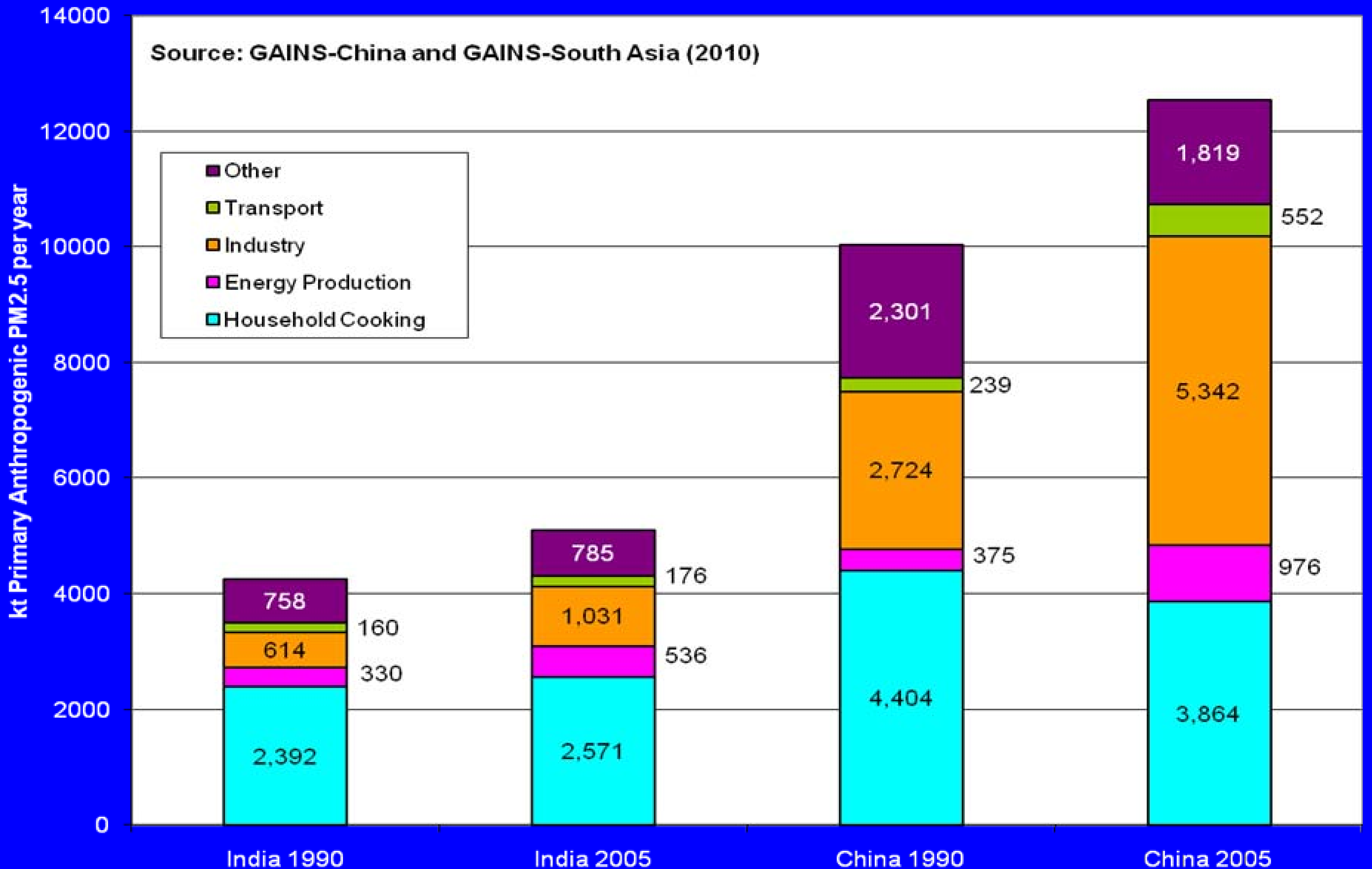
- --Time-activity: the kids do not spend their entire day in the kitchen
- --Household (or "neighborhood") pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less
- --No significant difference in bedrooms

Reduction in Kitchen 24-h $PM_{2.5}$ (ug/m^3)



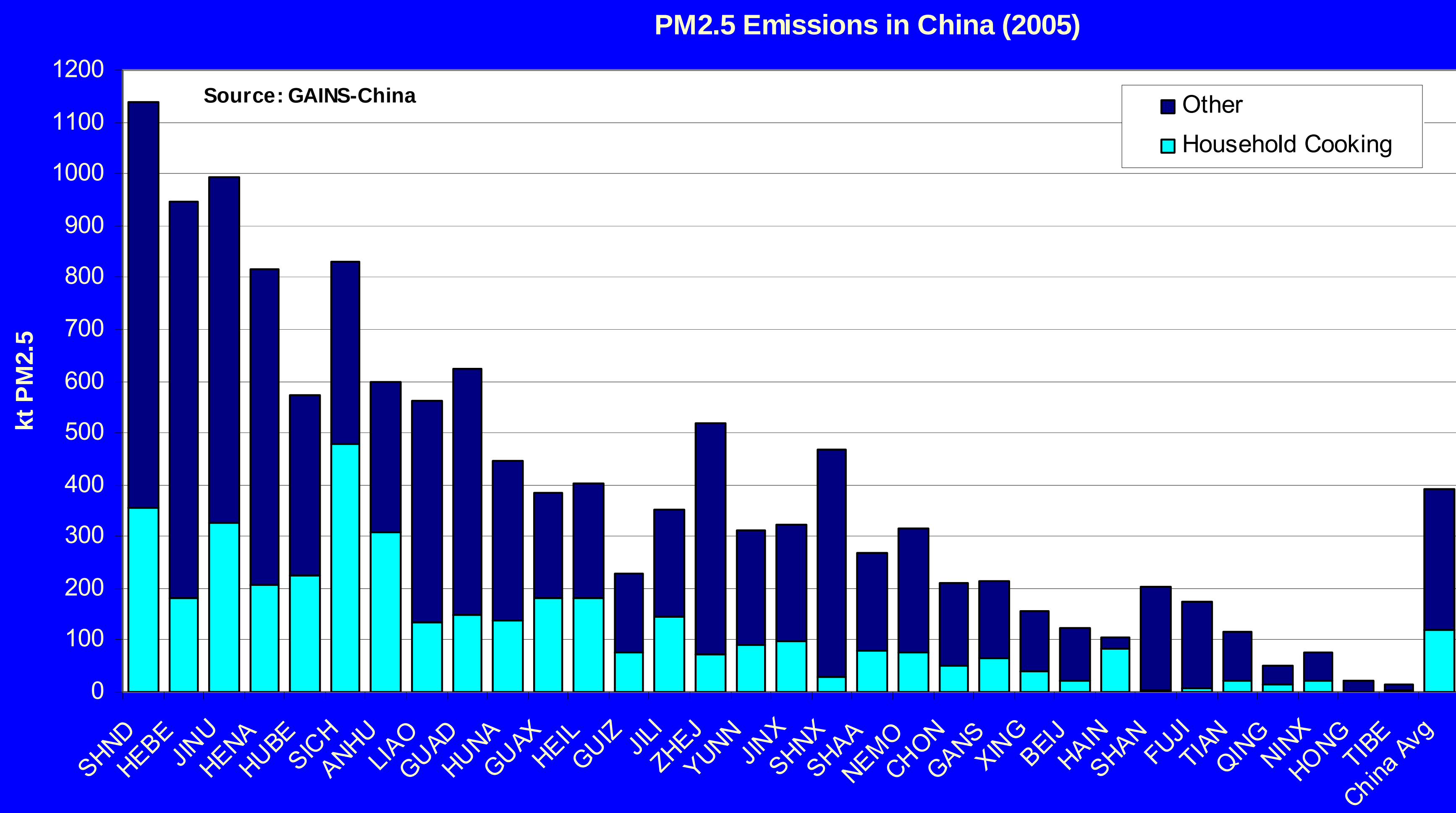

20-month average
ground-level PM2.5
from satellite data
Large areas of rural India
and China have high
ambient air pollution –
much from household fuel
MODIS
45° S
0
5
10
15
20
25
30
35
40
45
50
PM$_{2.5}$ [ug/m^3]

Sources of Primary $PM_{2.5}$: India and China



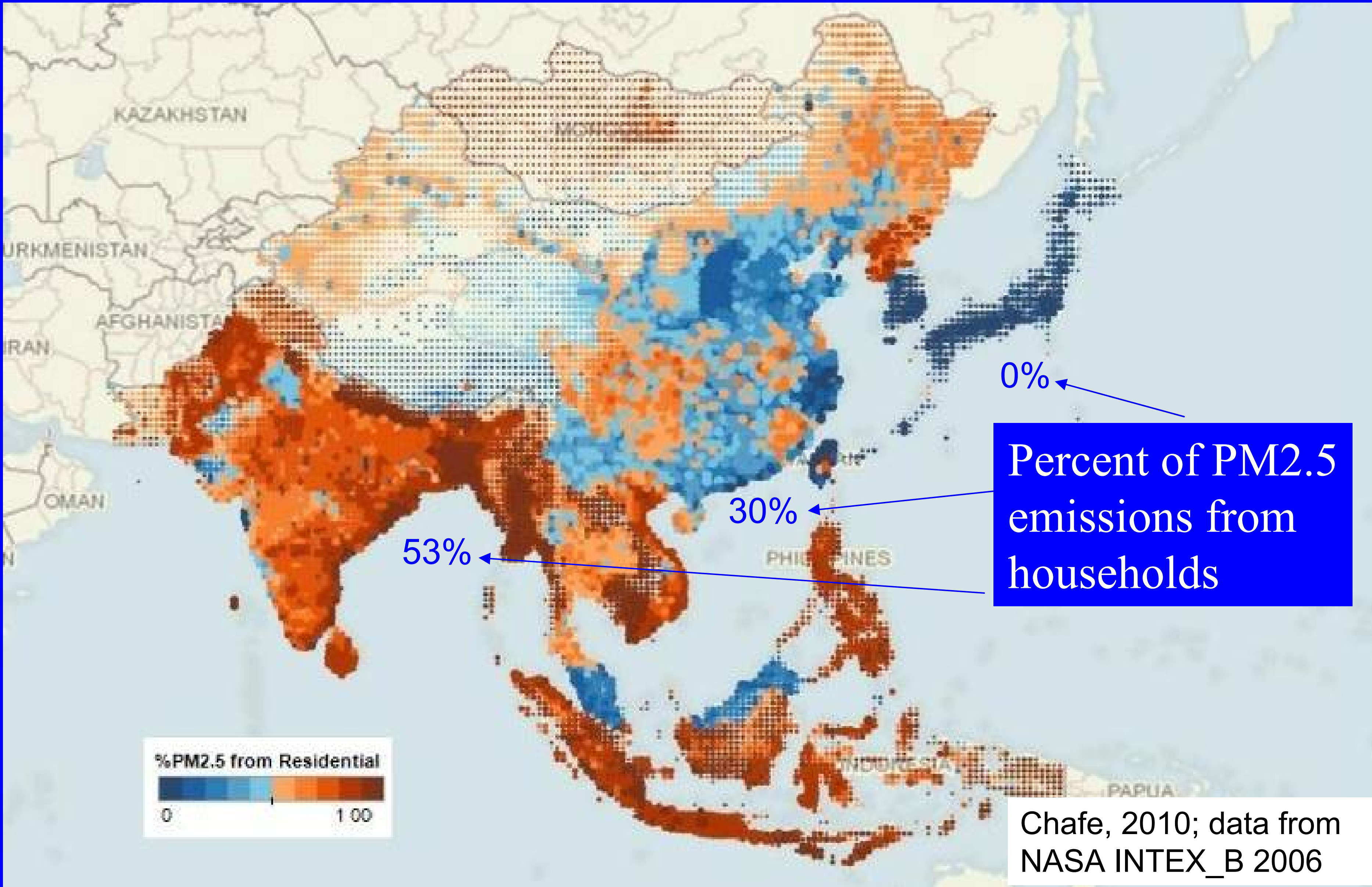
Chafe, 2010

China: PM2.5 mass by province (2005)



Chafe, 2010; data from GAINS-China (2010) http://gains.iiasa.ac.at

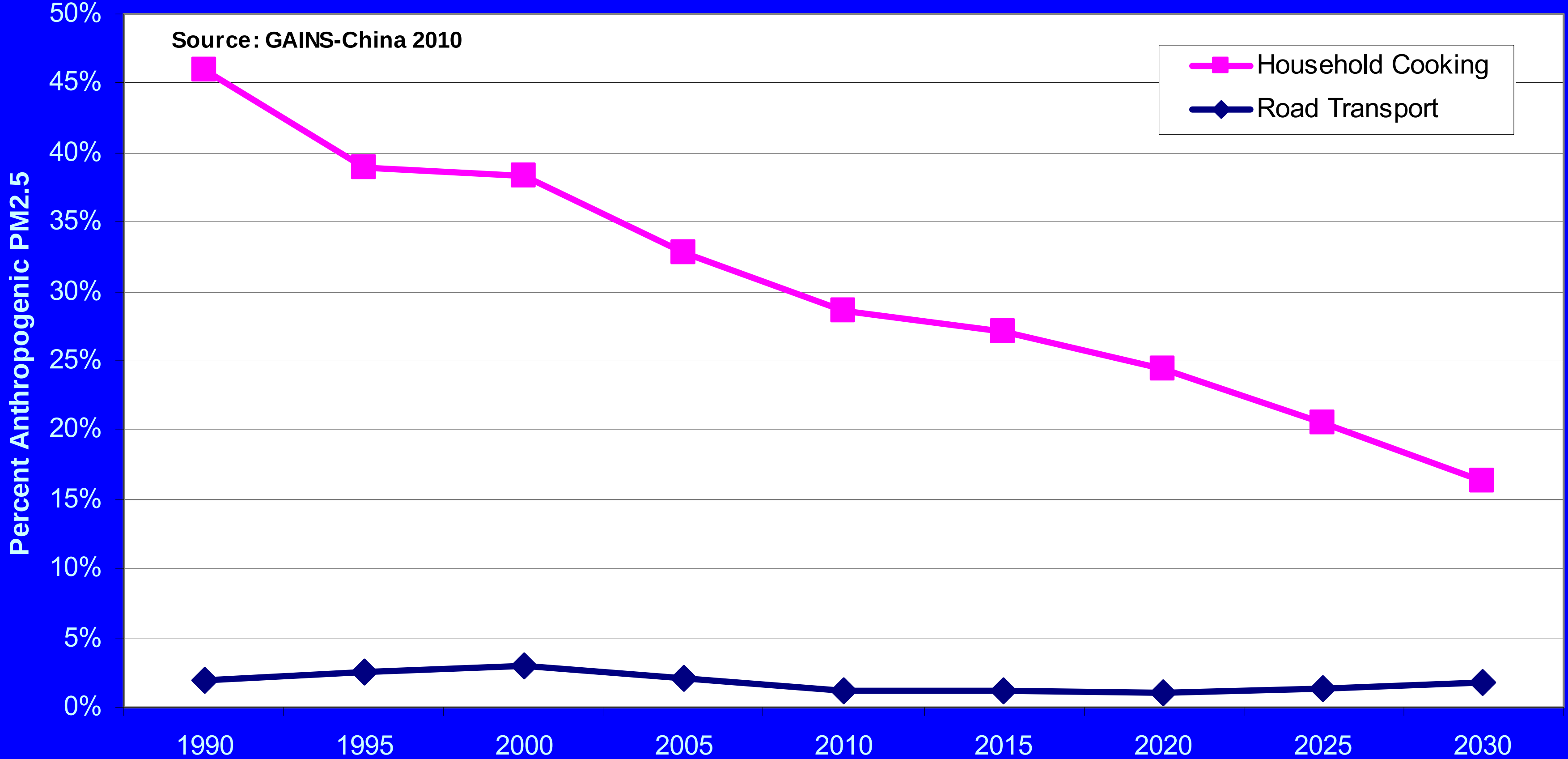
NASA INTEX_B Database
Percent $PM_{2.5}$ emissions from households



Percent of PM2.5 emissions from households

Chafe, 2010; data from NASA INTEX_B 2006

China Primary PM2.5 Emissions



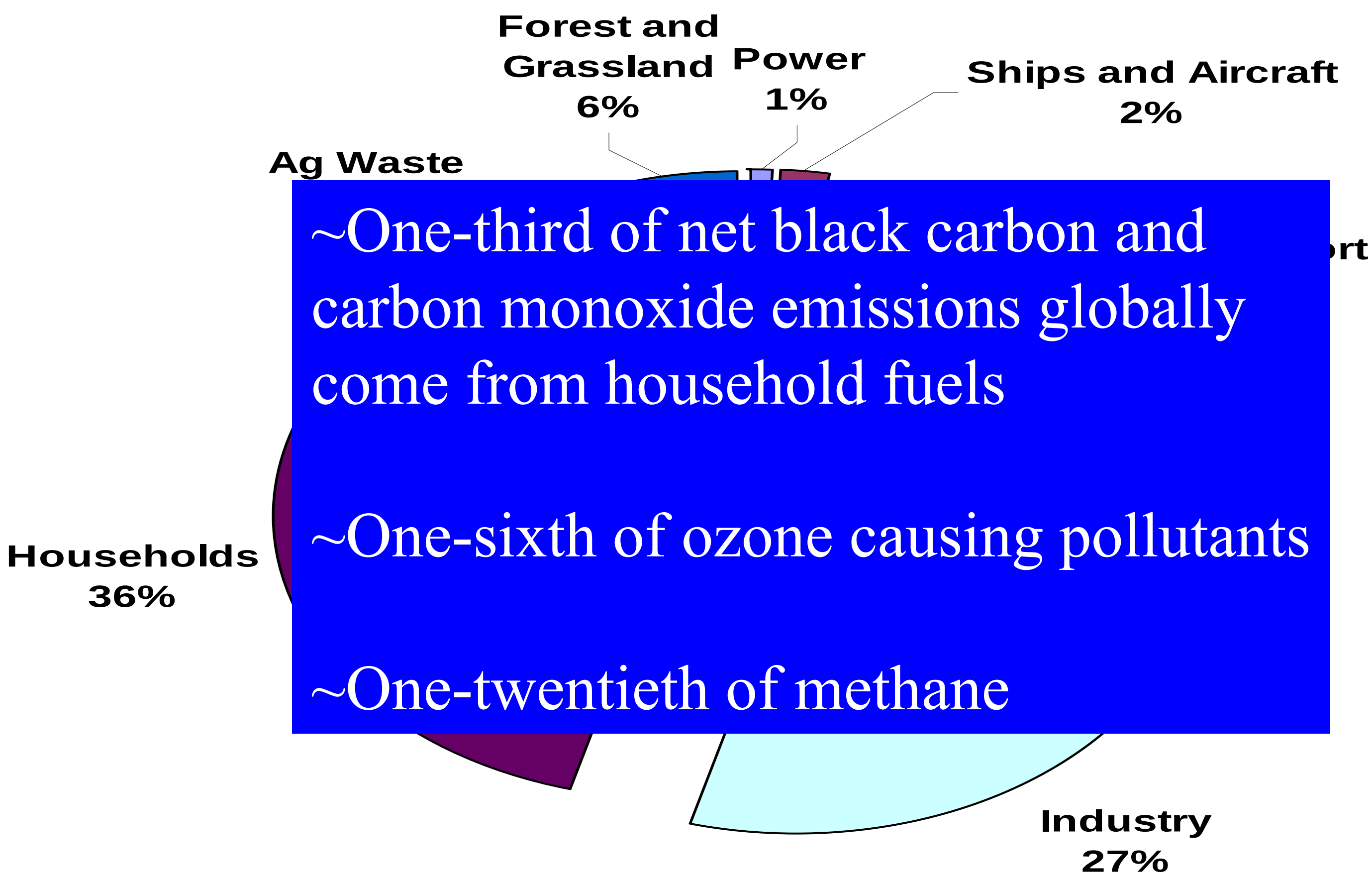
Percent of Total PM2.5 Primary Emissions

Source: GAINS-China (2010) http://gains.iiasa.ac.at

Controllable Global Warming from Black Carbon Emissions

Net of OC, Forcings from IPCC, 2007: 0.25 W/m^2

Inventory from T Bond Database, V 7.1.1 Feb 2009

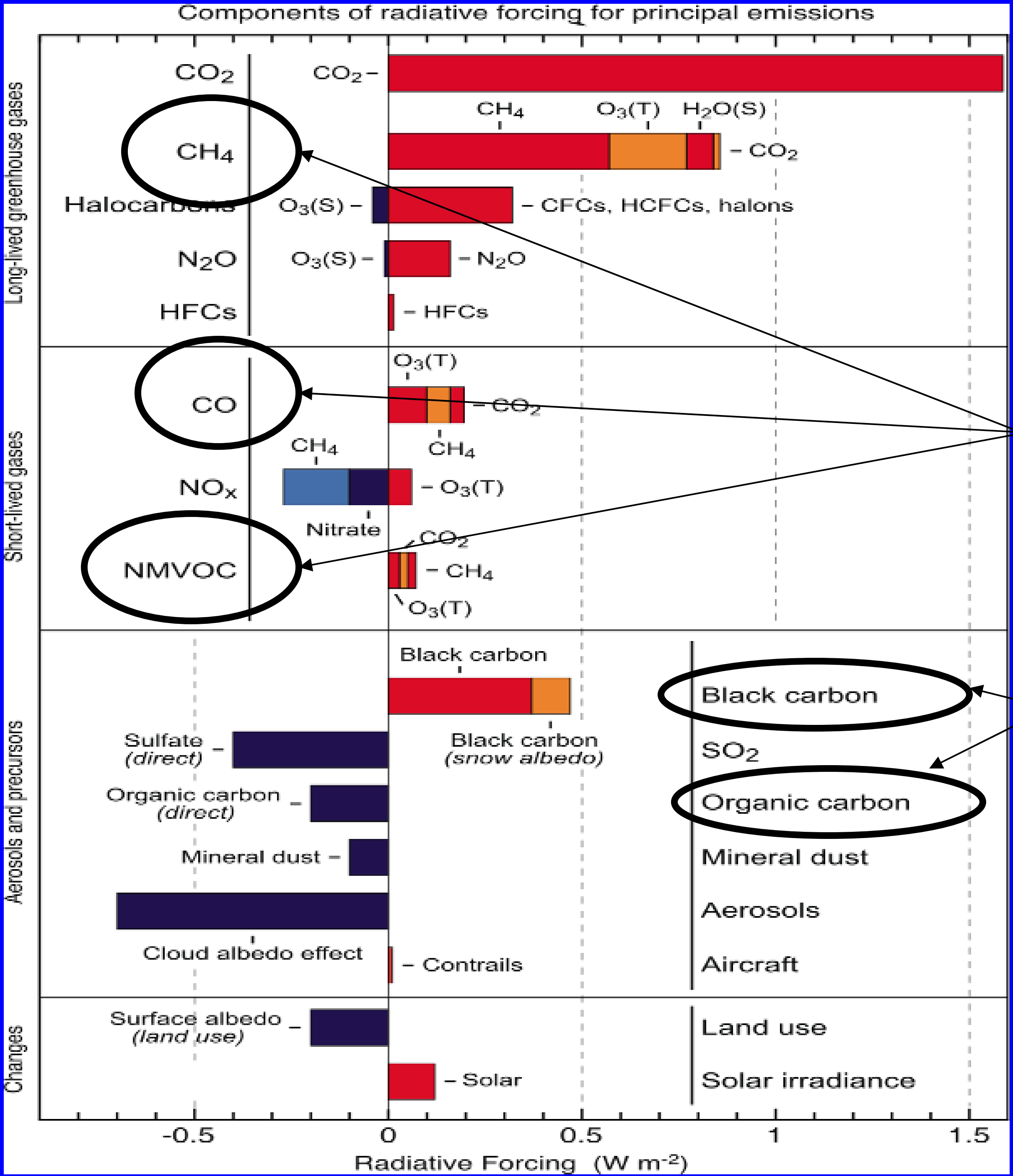


~One-third of net black carbon and carbon monoxide emissions globally come from household fuels

~One-sixth of ozone causing pollutants

~One-twentieth of methane

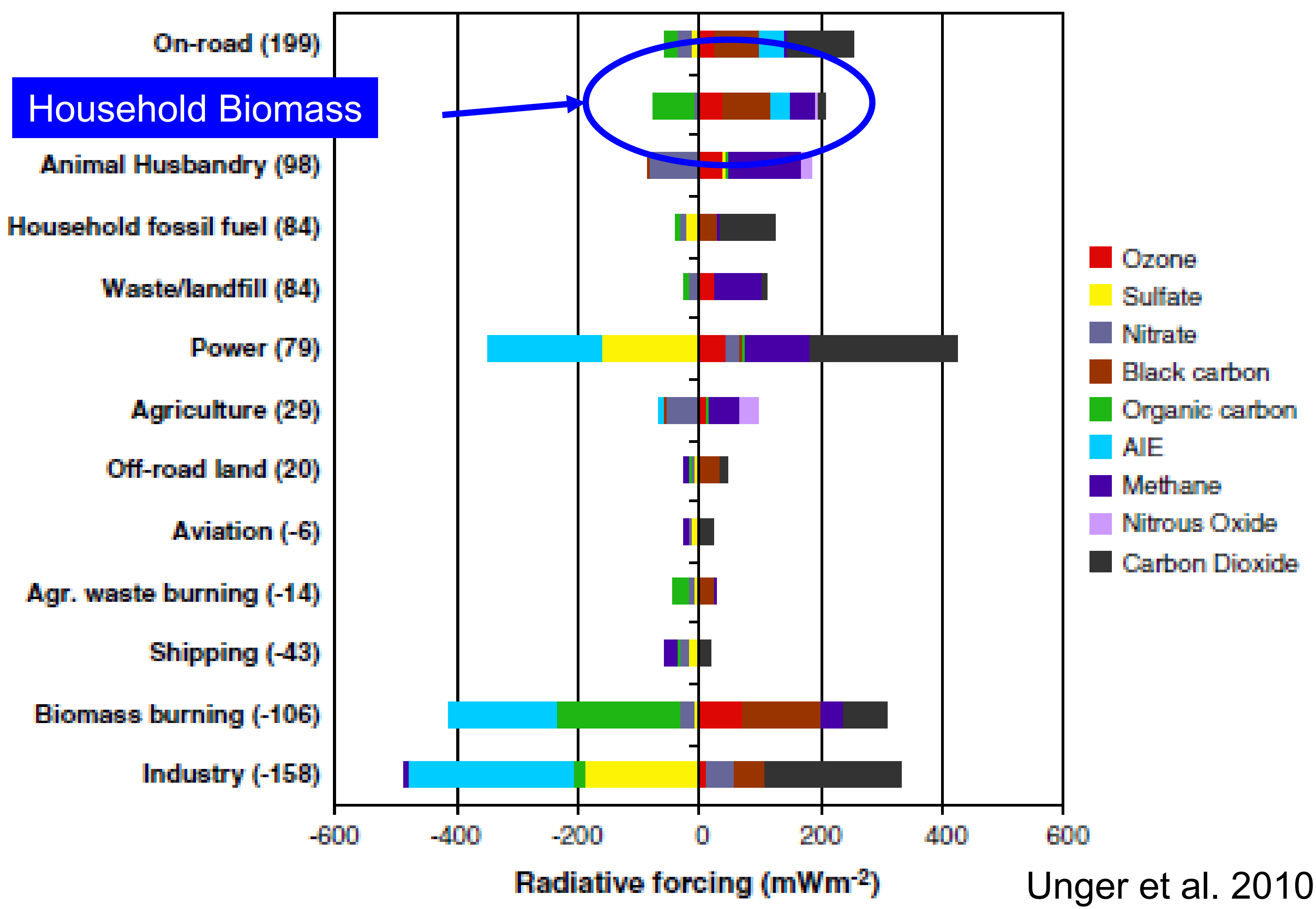
Warming in 2005 from emissions since 1750



A large part from PIC: products of incomplete combustion

IPCC, 2007

Climate Warming in 2020 Under Present Trends

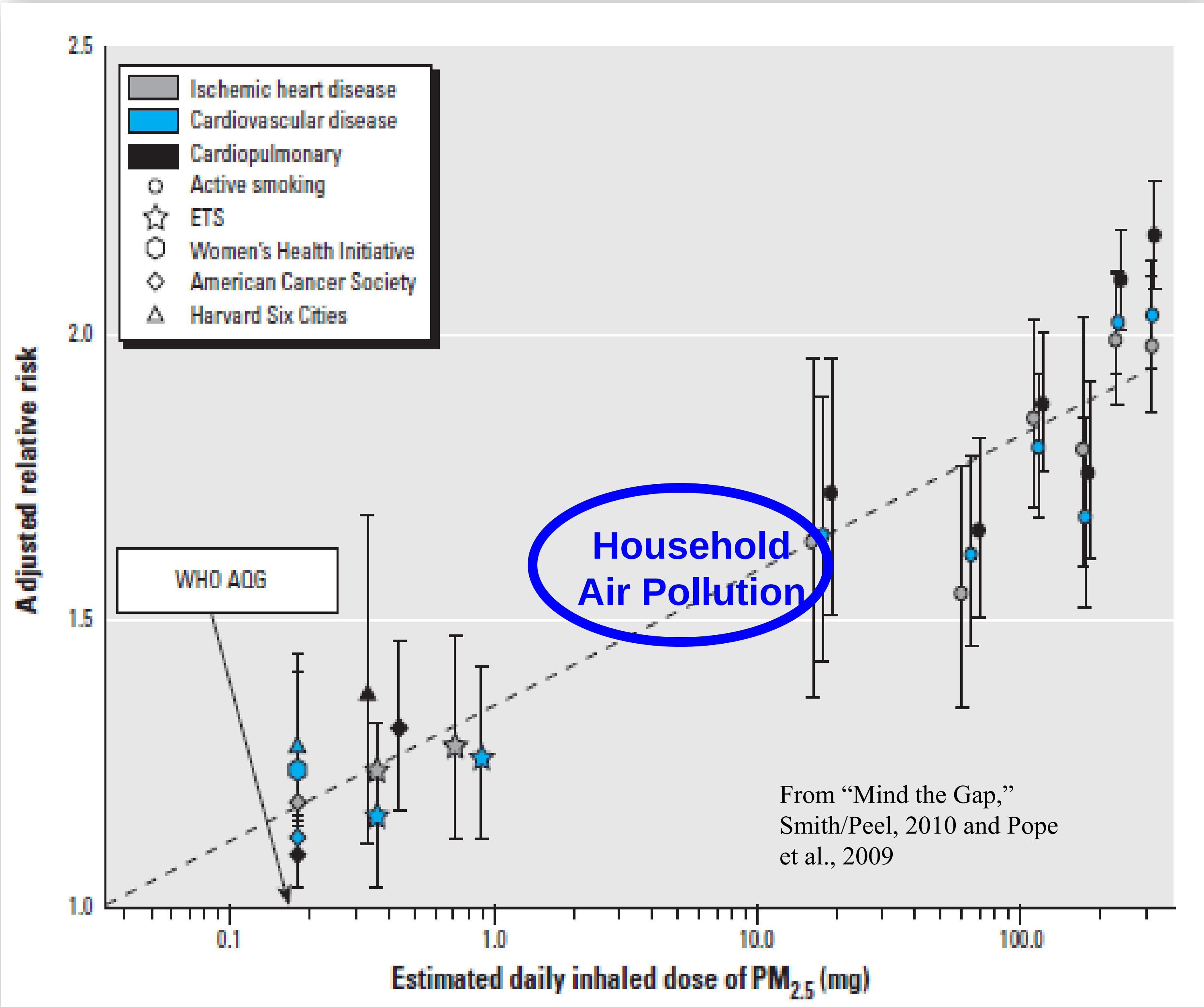


Unger et al. 2010

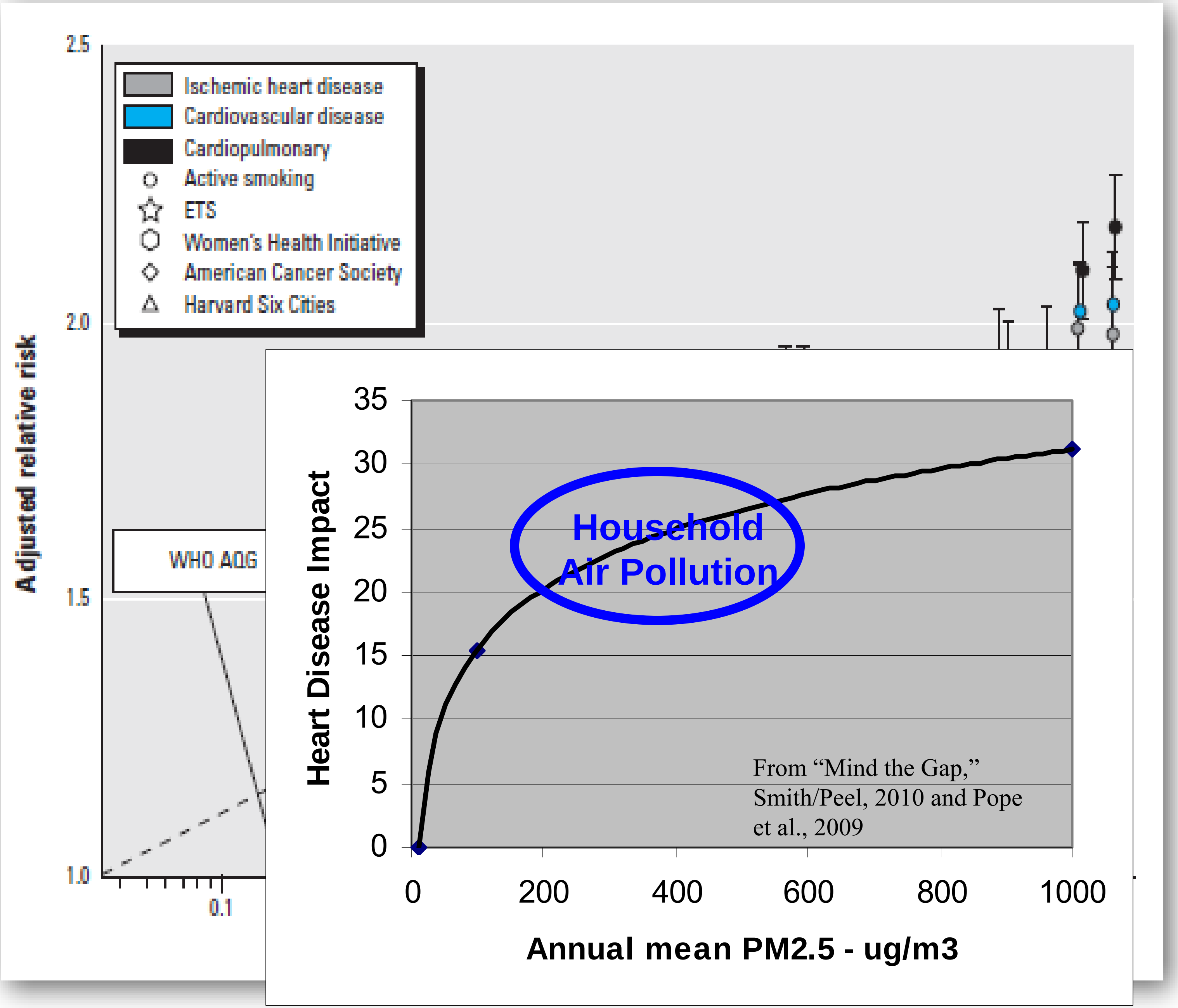
Why we need really clean combustion

- Chimneys by themselves do nothing for outdoor air pollution or climate
- We now know they do not help very much with health – only a factor of two reduction in exposure
- This is not enough to either reach WHO or Chinese standards
- Or to obtain the health benefits needed

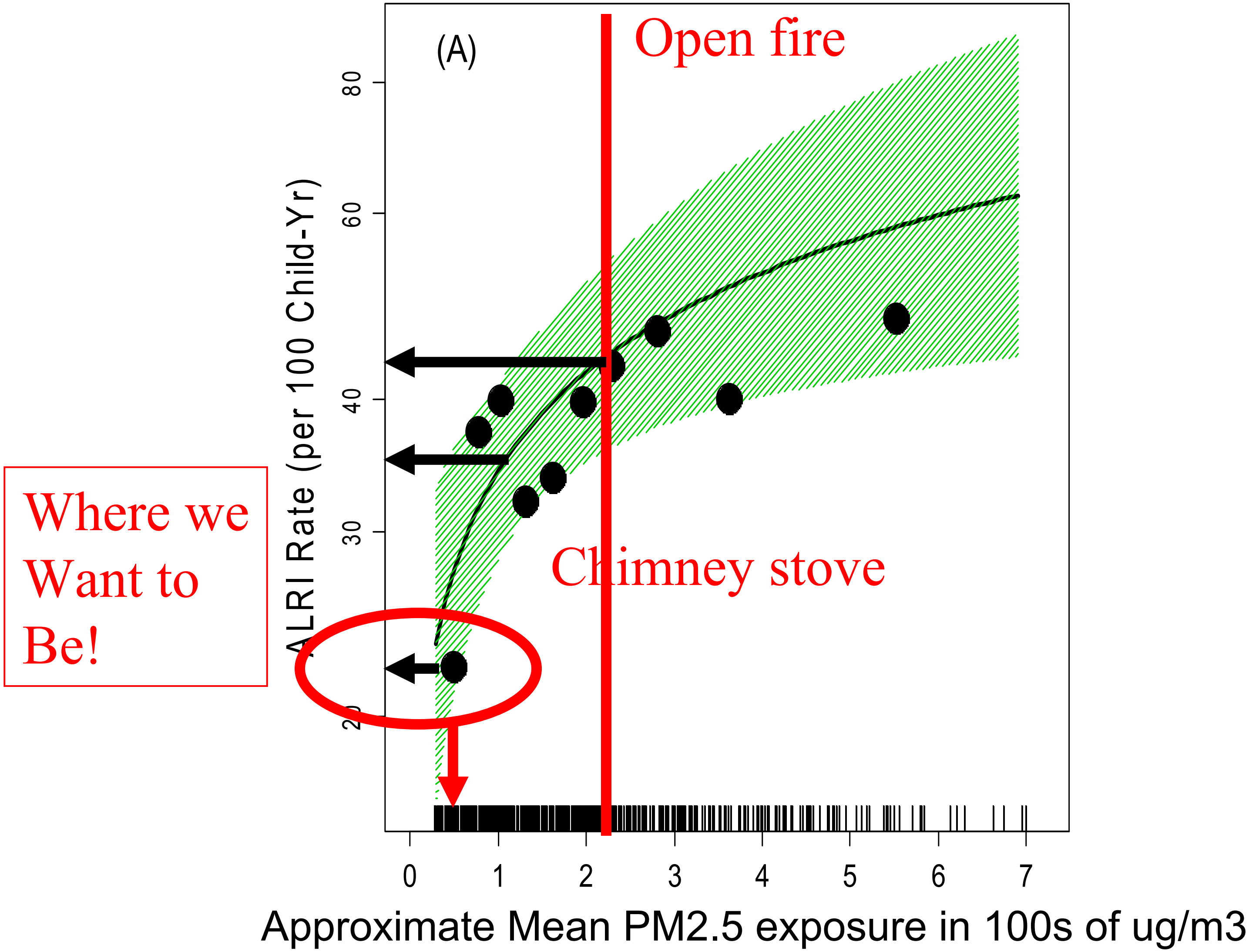
Heart Disease and Combustion Particle Doses



Heart Disease and Combustion Particle Doses



MD-diagnosed Child Pneumonia



RESPIRE-Guatemala

After independence, China had special concerns for rural areas than were reflected in energy programs for decades

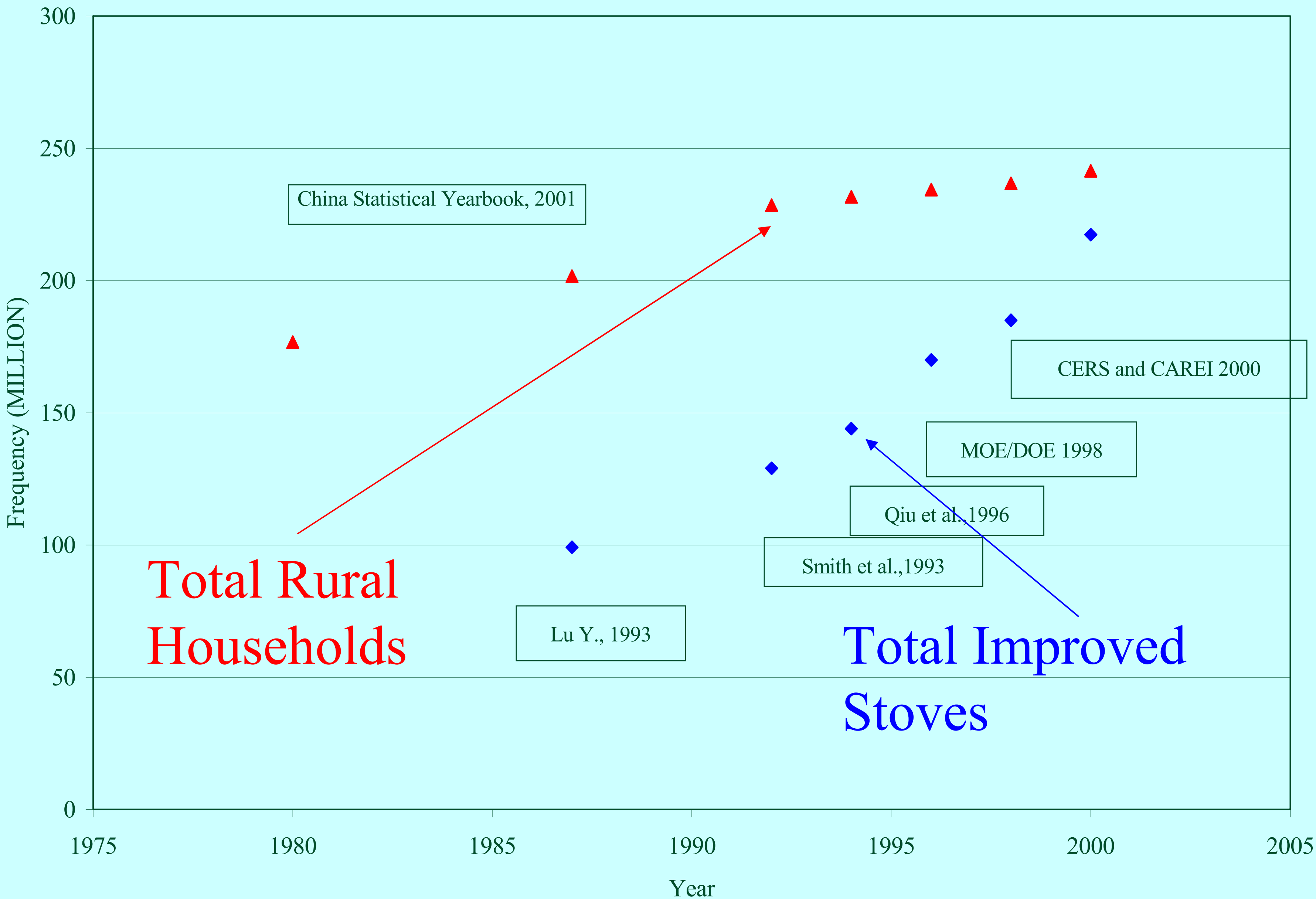
- China led the world in rural energy development in the 1970s and 80s
- It introduced ~180 million improved biomass stoves, for example – one of the largest rural development projects in world history

China’s National Improved Stove Program (NISP)

- More than 180 million improved stoves with chimneys were introduced from early 80s to mid 90s
- Evaluation showed that NISP improved energy efficiency and IAQ in rural households, but not sufficiently to meet current Chinese air pollution standards or WHO guidelines.
- It focused on biomass; the rising coal use in rural areas is threatening to erode the benefits unless action is taken soon. This is particularly a problem in the areas of “poisonous coals”.

Improved Stove in Shanxi

China's National Improved Stove Program (NISP) 1981-1998



New generation of Chinese stoves show low particle emissions.

But can they be reliably achieved in the field?

How clean do they need to be?

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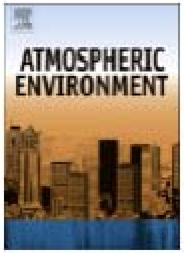

Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model

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Box model for Indoor Pollution

$$C_t = \frac{qf}{\propto V}(1 - e^{-\propto t}) + C_o\,(e^{-\propto t})$$

Ct = Concentration of pollutant (PM2.5 or CO) at time t (mg m-3)

q = emission rate (mg min-1)

α = nominal air exchange rate (ventilation rate) (min-1)

V = kitchen volume (m3)

t = time (min)

Co = concentration from preceding time unit (mg m-3)

f = fraction of emissions that enter kitchen

(Note: time and emissions rates are a function of thermal efficiency, emission factor, stove power, and daily cooking energy needs.)

Top Performers in the Chinese National Cookstove Competition – 2007

	CO/CO_2	Nominal Combustion Efficiency	PM_{10} g/kg	Efficiency	grams PM_{10}/MJ delivered
Daxu	0.020 (24%)**	98.1%	0.28 (13%)	41.9% (3%)	0.037
Luoyang*	0.019 (37%)	98.1%	0.24 (8%)	35.2% (2%)	0.038
Xintai*	0.025 (43%)	97.6%	0.36 (7%)	32.6% (2%)	0.061
Zhenghong	0.019 (19%)	98.1%	0.24 (22%)	35.9% (4%)	0.037
Mean	**0.021**	**98.0%**	**0.28**	**36.4%**	**0.043**

How clean does the stove have to be to meet the WHO Guidelines to protect health?

% meeting WHO Annual Interim Target-1 $PM_{2.5}$ (35 µg m^{-3})	**50%**	**75%**	**90%**
g MJ-delivered^{-1}	0.055	0.030	0.018
Mean Concentration (µg m^{-3})	52	28	17
Median Concentration (µg m^{-3})	35	19	11

Mean performance of 4 top stoves in the Chinese National Cookstove Contest was about 0.043 g/MJ-delivered.

Thus, if the fraction of particles entering the house from stove is less than 0.18/0.43 ~40%, 90% or more of households will meet the WHO Air Quality Guideline

Conclusions: Intervention.

- Reductions in exposures through simple improvements, such as chimney stoves, are intrinsically limited because smoke from the solid fuel is still around the household.
- Future improvements should focus on stoves and fuels that reduce emissions, such as the biomass gasifier stoves being developed in the country.
- Advanced combustion stoves can lower pollution levels substantially, with 90+% reduction documented
- Substituting cleaner fuels for the poisonous coals used in tens of millions of households should have an especially high priority.

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

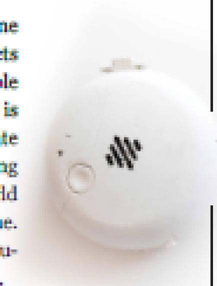
Time-of-use measuring devices allow more accurate estimations and objective definitions of usage patterns including cooking periods, meal times, and technology adoption rates.

Stove Use Monitors (SUMS) quantify utilization of cookstoves to improve estimates of personal exposure and environmental 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



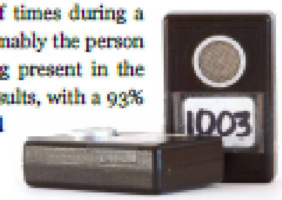
The ability to measure concentrations of small airborne particles is vital in understanding adverse health effects from combustion-derived air pollution. Available instrumentation to conduct such measurements is complex and expensive. Such devices are appropriate for developed countries and ambient air 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.

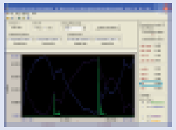
Time-Activity Monitoring System (TAMS) detects the presence or absence of individuals in an enclosed space. The system consists of one to five small ultrasound emitting devices worn on an individual's clothing. Each produces a distinct pattern that is emitted every few seconds. An ultrasound receiver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

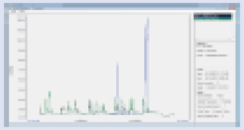
If the identifying signal pattern emitted from a particular locator is received a certain number of times during a minute, that locator, and presumably the person wearing it, is recorded as being present in the room. Field trials show good results, with a 93% accuracy rate as measured against direct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

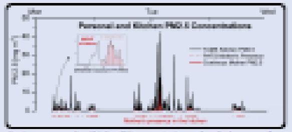


Device Software & Sample Output

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 converter.

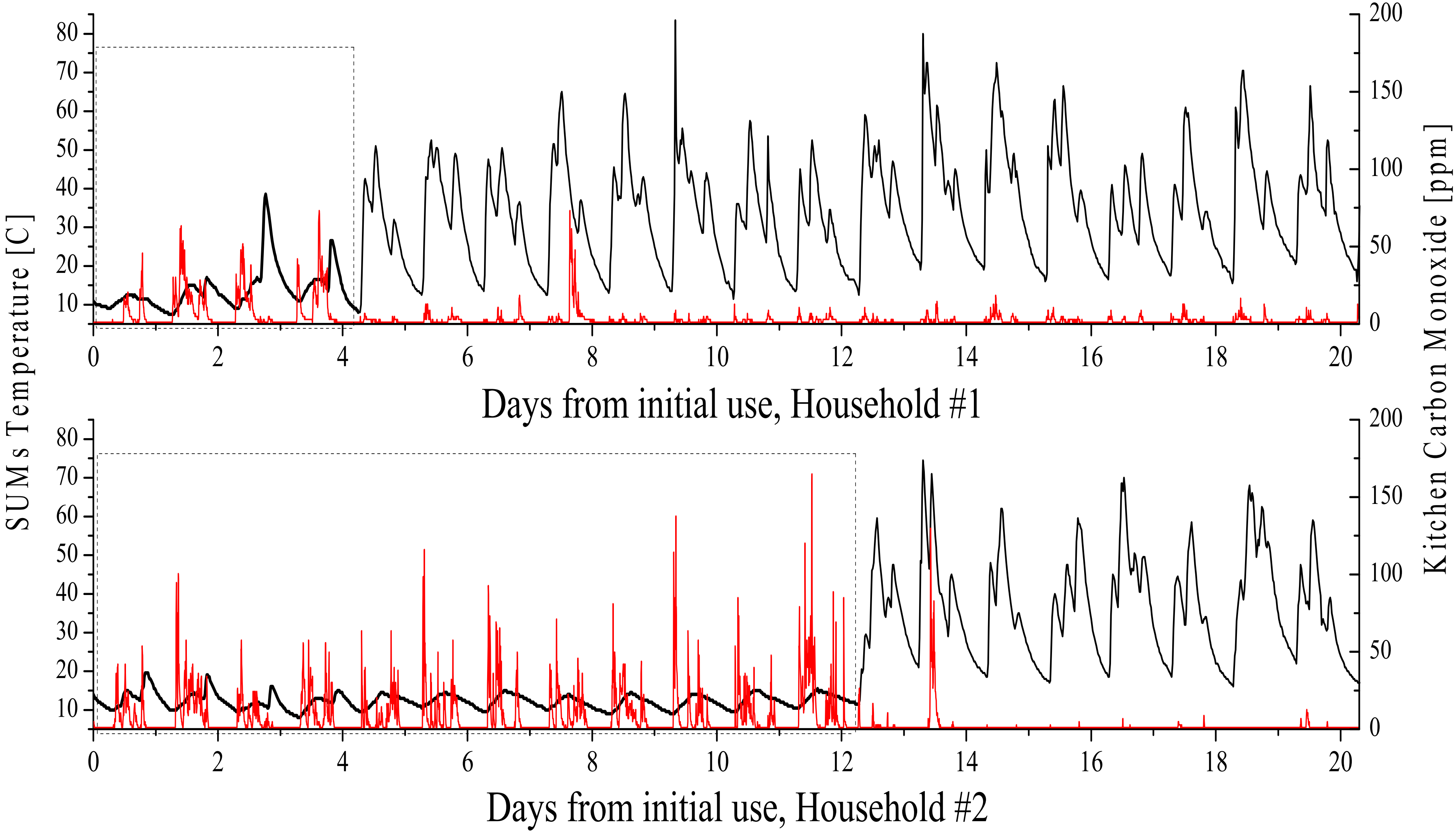




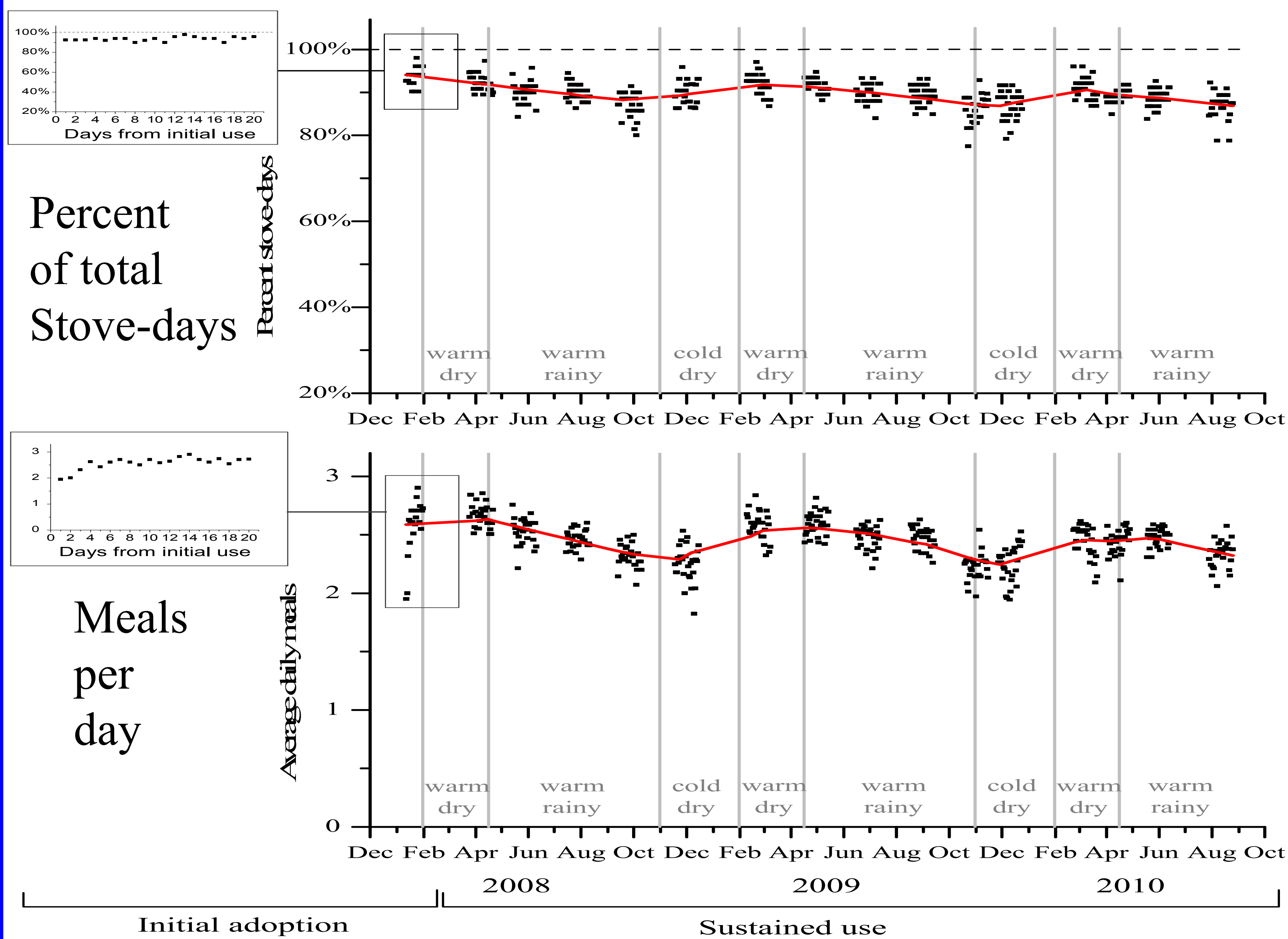


For more information, google "Kirk R Smith" • To acquire devices, visit berkeleyair.com

Stove Use Monitors (SUMs) in Action



Ruiz et al., submitted

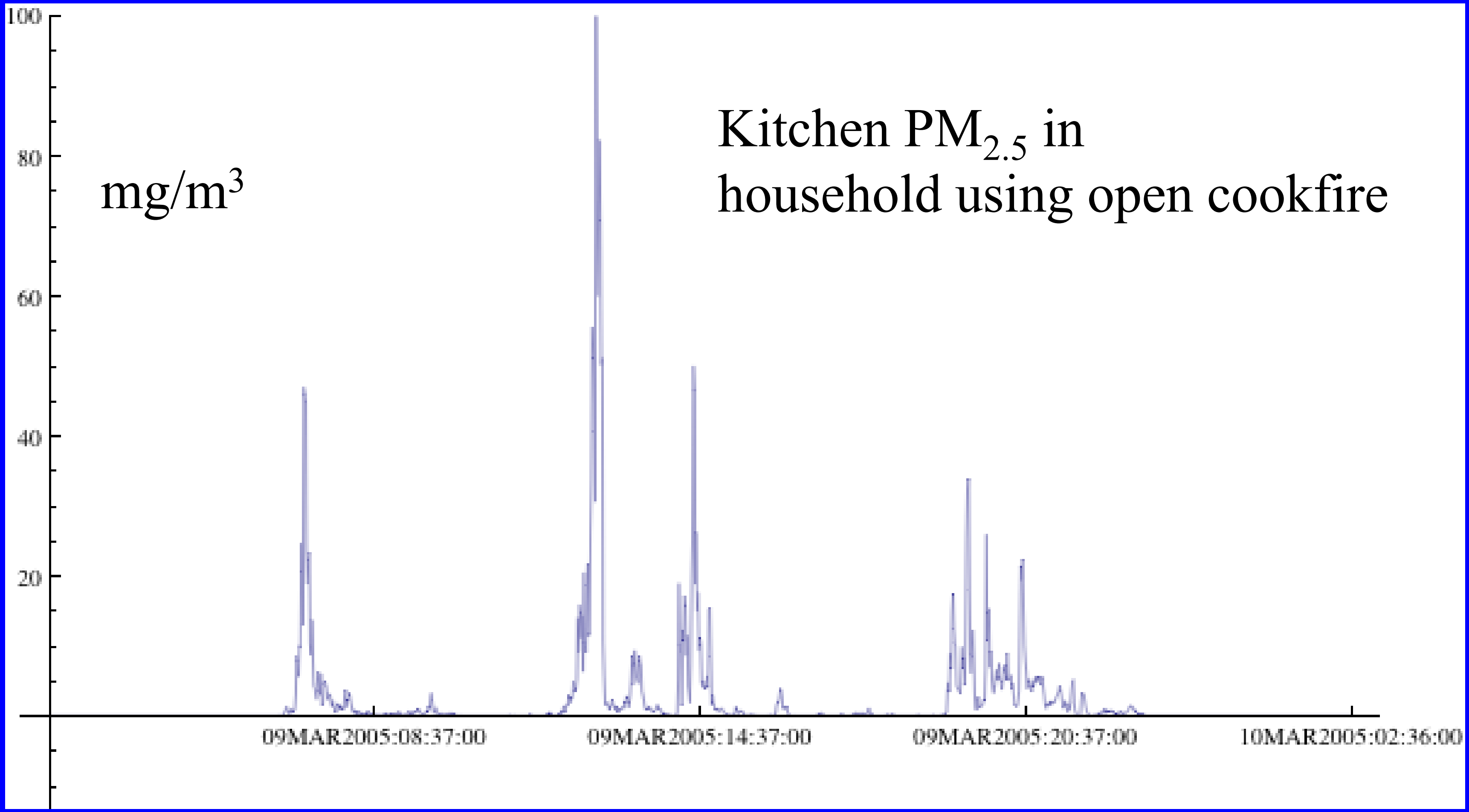


Ruiz et al., submitted

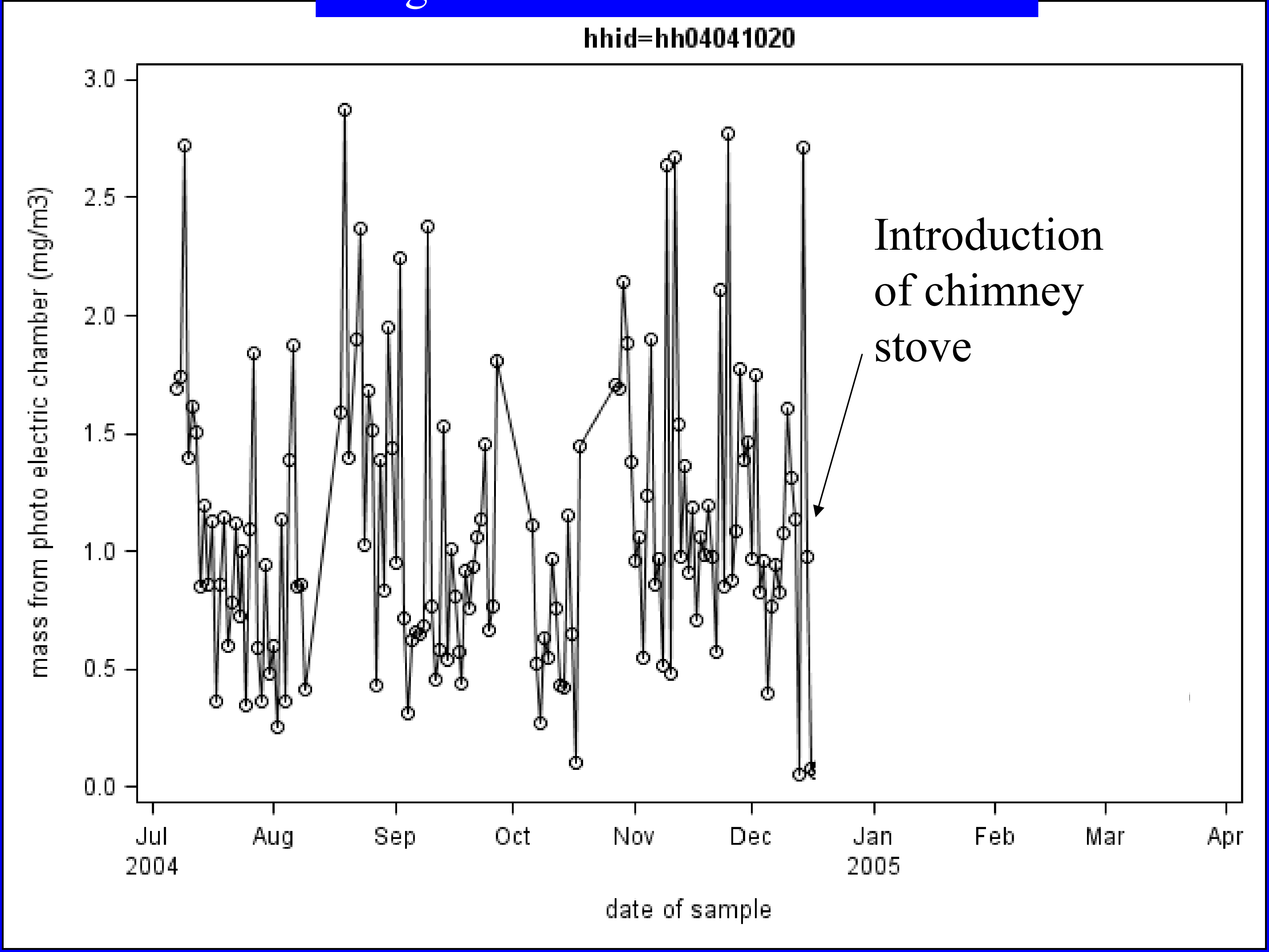
Inter-instrument Comparison: 30 UCB-PATS
UCB Particle and Temperature Monitoring System
(custom PM monitor using smoke alarm technology)

UCB Particle Monitor

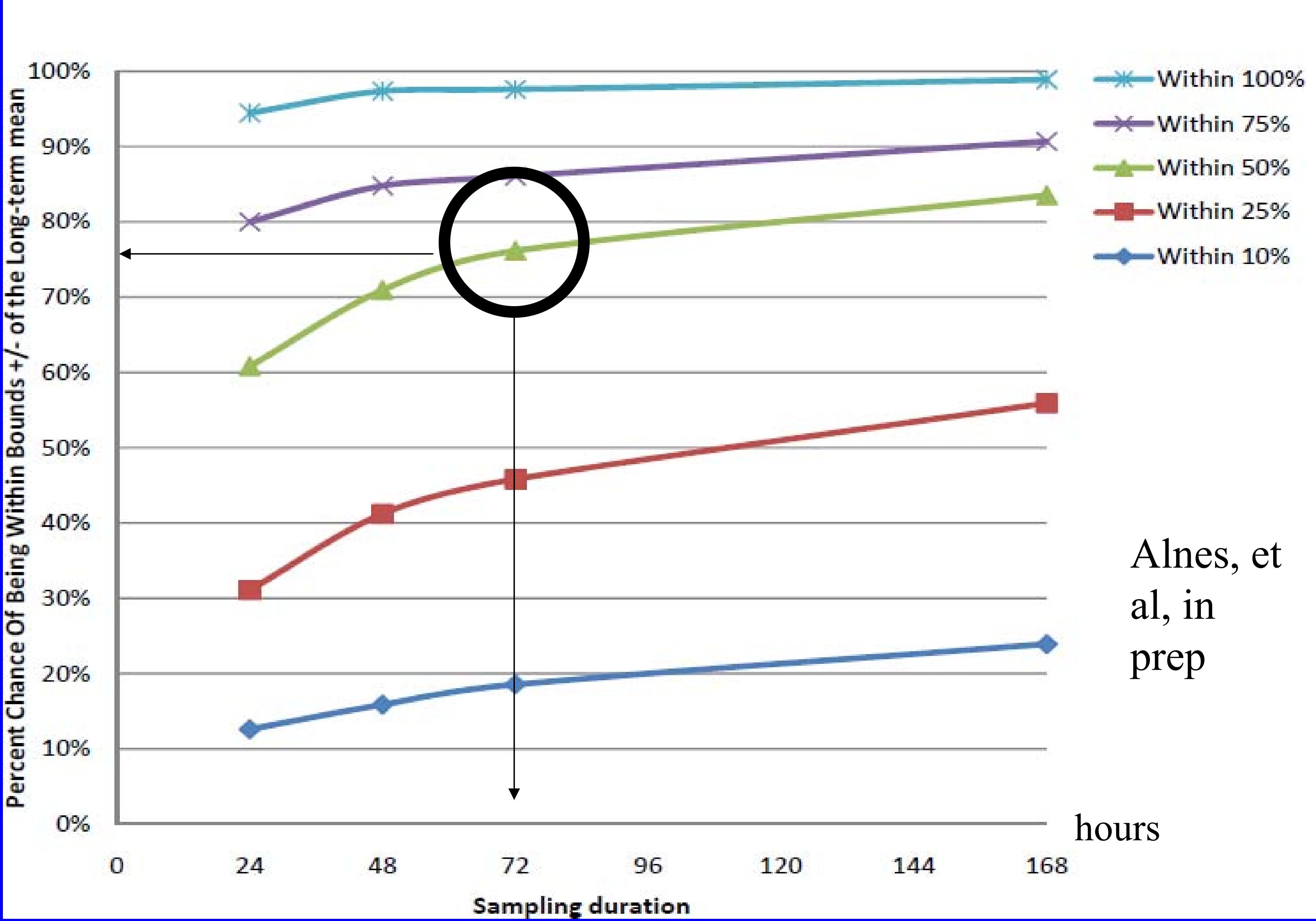
How many hours should we measure to obtain good estimate of the long-term mean?



Long-term Household Measurements



How Close to the True Mean With One Measurement?



Alnes, et al, in prep

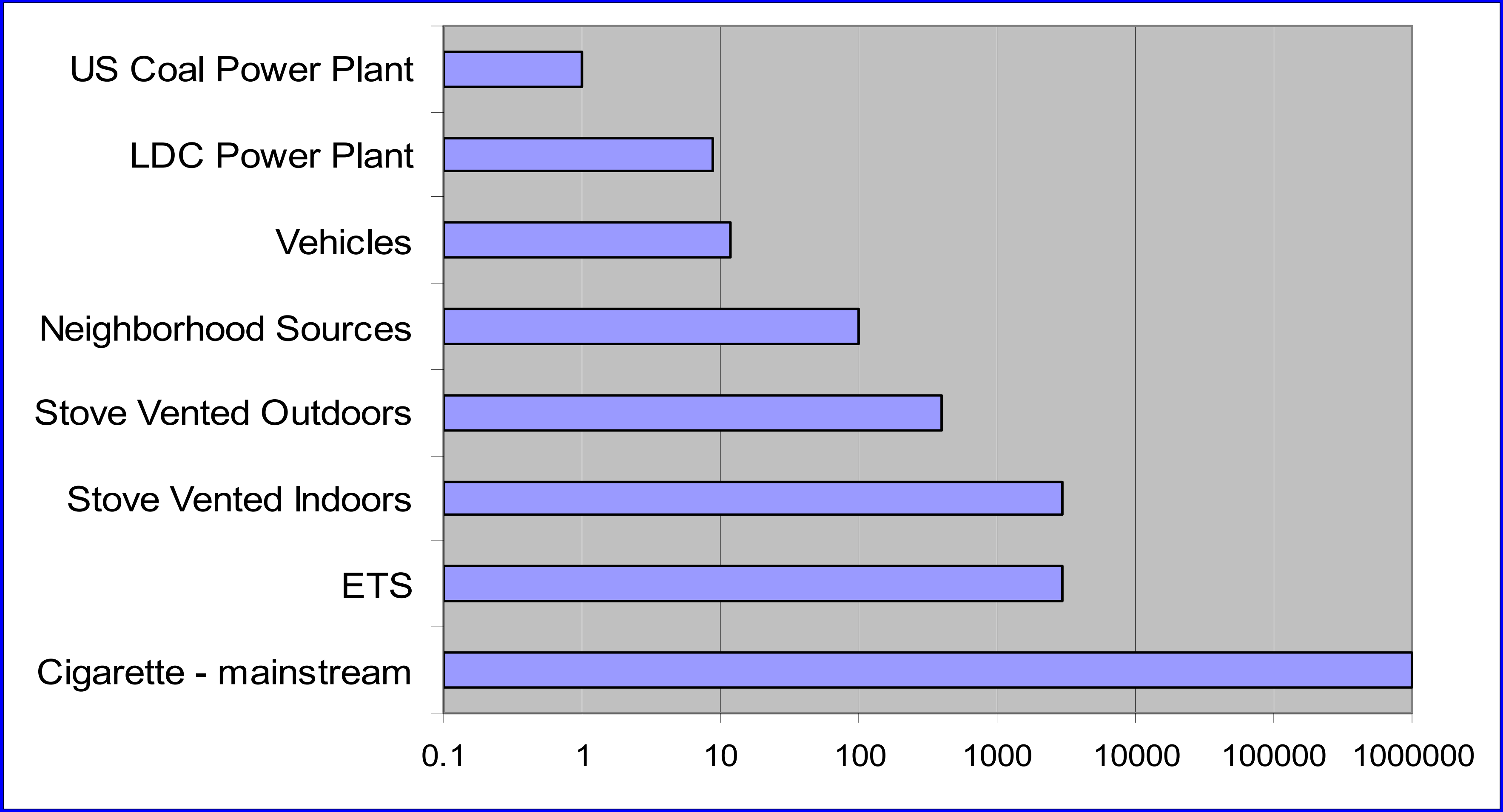
The main reason household air pollution causes so much ill-health is

The Intake Fraction is large

IF is the fraction of material emitted that is actually breathed in by someone

IF = 1.0

Intake Fractions : these are rough calculations for typical examples of sources in each class



Smith, 1993

Grams Inhaled per Ton Emitted

Combustion Particles cause more health damage than any other environmental contaminant

- **Worst thing to do is stick burning stuff in your mouth ~5 million deaths globally**
- **Not so great to have other people sticking in their mouths nearby ~ 300k deaths**
- **Bad even to have poorly burning stuff in your city ~ 1 million deaths**
- **The oldest of burning practice, however -- poorly combusted fuels in the home -- is still the cause of more ill-health than any other particle source except smoking ~ 1.6 million deaths**

Origins of the Chinese Rural Energy Program

At a biogas stove exhibit in Wuhan on April 11, 1958, Mao Zhedong instructed,

“This should be well promoted.”

1958 年 4 月 11 日毛主席视察武汉地方工业展览馆观看沼气灶演示， 指示 “这要好好地推广”

Being demonstrated of biogas stove on Wuhan local industry exhibition on April 11, 1958, Chairman Mao Zhedong instructed “ This should be well promoted”

Publications and presentations available at my website. Just "google" Kirk R. Smith

Thank You