Household Cooking: The Neglected Technological Challenge

Kirk R. Smith
Professor of Global Environmental Health
University of California, Berkeley

Engineers Without Borders - USA
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Sustainable Engineering and Global Health

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Toxic Tsunami threatening planet's health

By OUR CORRESPONDENT

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Mildewed Police Files May Hold Clues to Atrocities in Guatemala

By GINGER THOMPSON

The documents promise perhaps the last best hope for some degree of justice for the victims of decades of state-sponsored kidnapping and killing.

Chinese Leader Gives President a Mixed Message

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President Hu Jintao told President Bush that he was willing to move more quickly to ease economic tensions but gave no ground on

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Routine, Yet Terrifying

Storming into buildings in a dangerous Iraqi town near the Syrian border, Marines are never sure what they'll find. Go to Article

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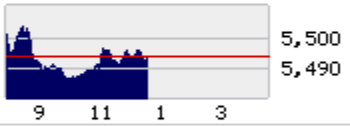

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It will wash across the countryside exposing the poorest half of humanity to a toxic soup containing

- Dozens of poisonous organic chemicals known to be mutagens, immune system suppressants, severe irritants, blood poisons, inflammation agents, central nervous system depressants, cilia toxins, endocrine disrupters, or neurotoxins.
- Several other chemicals firmly established as human carcinogens.
- Other toxic inorganic chemicals known to cause asphyxiation, stillbirth, infant death, heart disease, and severe acute and chronic lung disease.

The Toxic Tsunami

- It will be the result of a technology that pours this toxic soup directly into 100s of millions homes every day; all year; every year.
- It will expose families to toxic levels much higher those of people living on top of toxic waste dumps, working in most heavy industries, or residing in the dirtiest cities
- These toxic levels will be tens or hundreds of times the levels set by international and national organizations to protect health
- Insidiously, it will target women and young children in the poorest households

Why would it happen?

- Because a technology will be widely promoted that takes perfectly safe natural material and converts 10% of it to toxins in the course of functioning. Sometimes as much as 20%
- The efficiency of the technology is extremely low, leading to little human benefit per unit toxin created as well as waste of the natural resource.
- Instead of carefully disposing of this toxic material in safe places, this technology will spread the toxic soup by air right into neighborhoods where people live.
- All this, in spite of there being well-known alternative technologies producing little toxin.

What might be the health consequences if this happens?

- A vast epidemic of a respiratory illness that kills faster than SARS or Avian Flu – initiation to death in 2 days in some cases.
- So fast, that trying to apply medical care is often hopeless.
- Estimates are that soon it would be killing at least two thousand children a day.
- This would be equivalent to nearly 1000 SARS epidemics each year, and would occur year in and year out, with no end in sight.

What else?

- Millions of the poorest women would have their breath taken from them as their lung function is slowly eaten away by exposure to the toxins
- Thus, at tragically young ages they will become unable to breathe normally or do common tasks.
- Alarmingly, once a woman is affected, there is no known medical therapy to reverse the process.
- More than 1000 per day would soon start to die prematurely because their lungs would finally give out.

Will there be
a massive emergency meeting in Geneva of international agencies and donors with unlimited authority and funds to take action?

The answer is no – indeed nothing will be done.

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Shar... Witl...

By ST...

Ariel ... to dissolve parliament and call an early election; he was expected to announce the creation of a new party later in the day.

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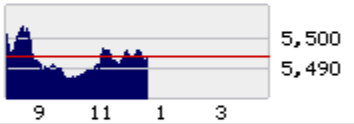

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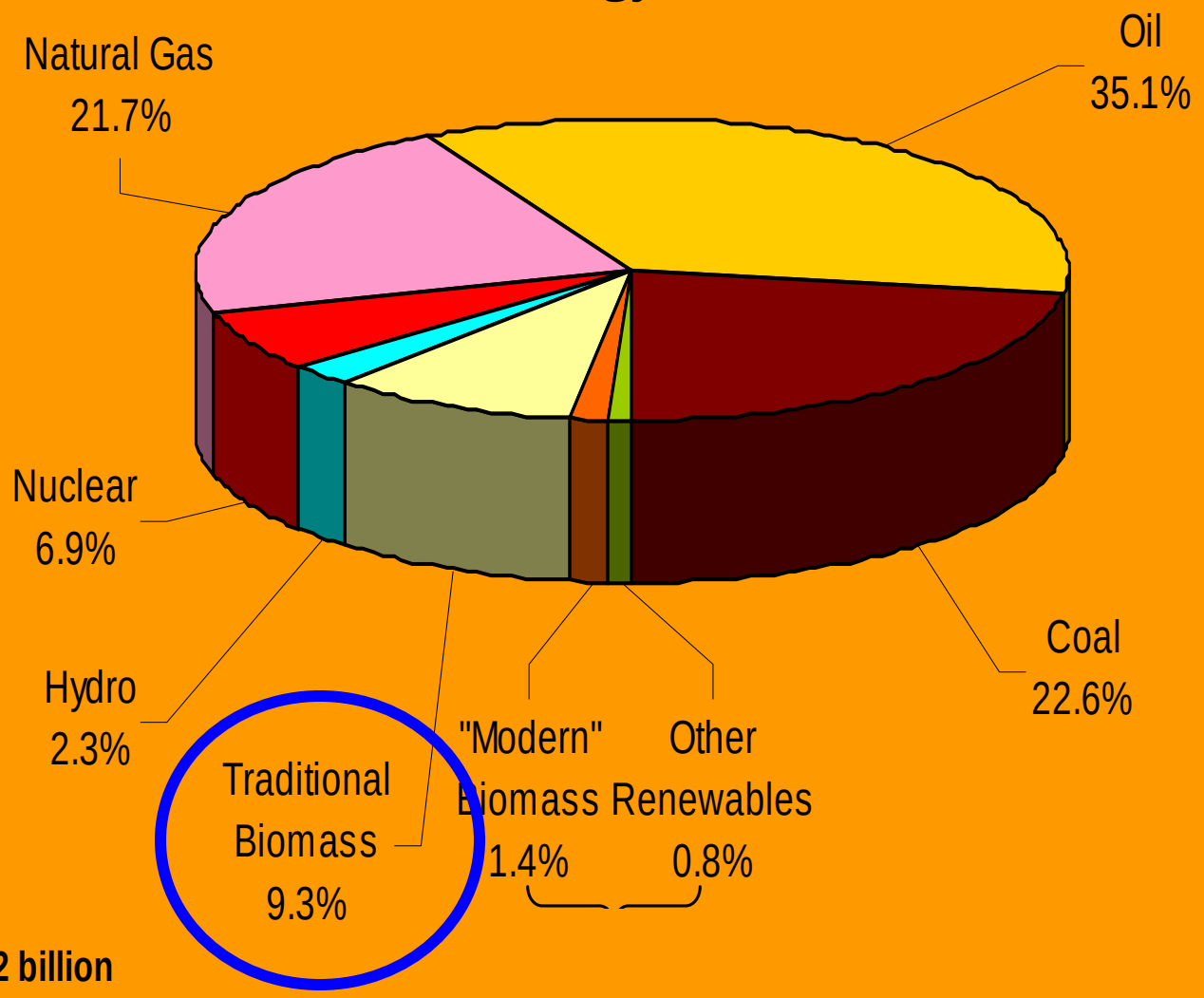
The Toxic Tsunami is not coming, it is here already

- Everything stated, however, is true as best we know, except stated as something coming and in more inflamatory language than typical in scientific discussions.
- Indeed, the facts as stated are at the low end of current estimates of effect, i.e., not even at the central estimates.


The Toxic Tsunami
The oldest pollution source in human history

World Energy – 2001



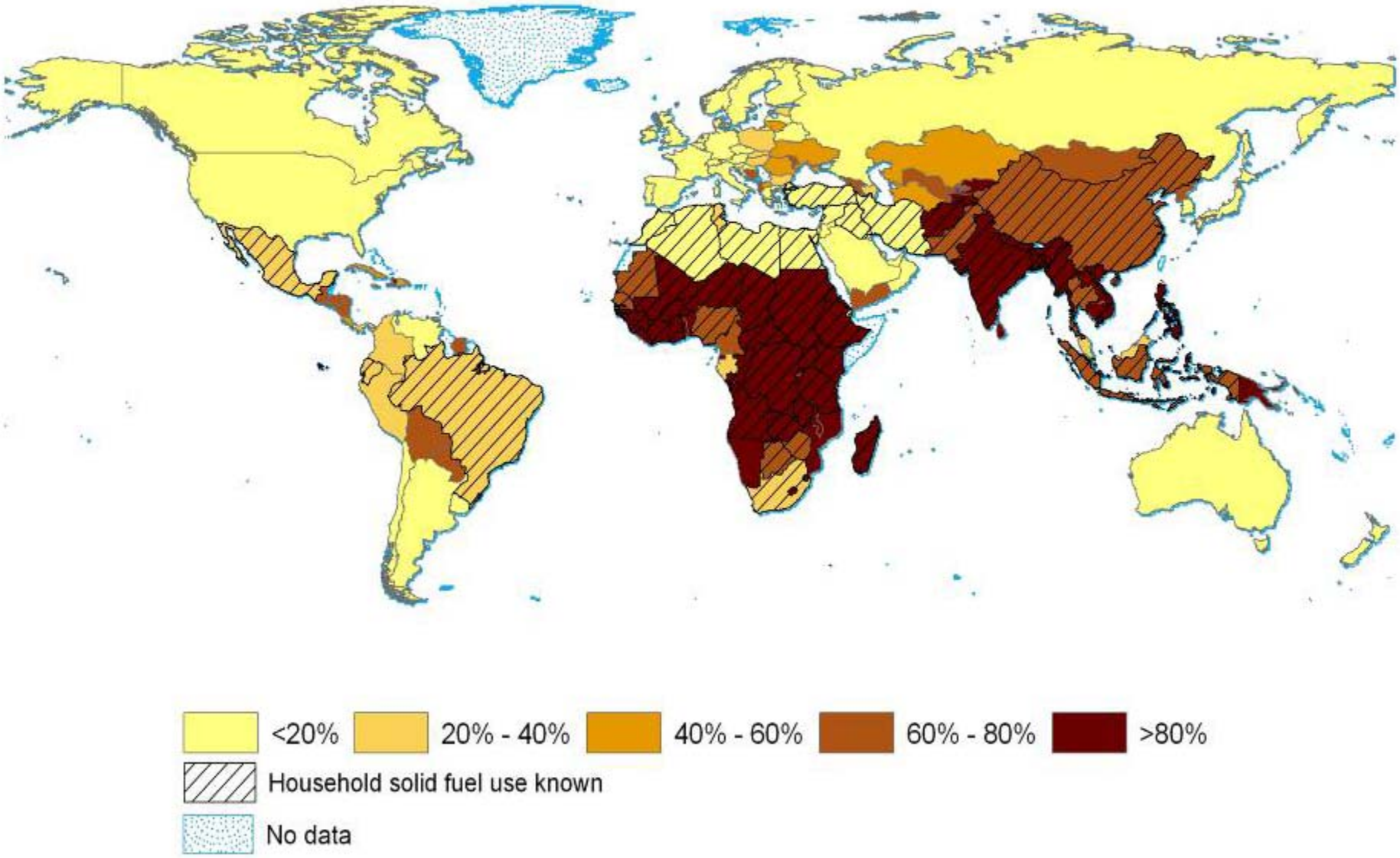
Population: 6.102 billion

Total energy use: 10.2 Gtoe

Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004

National Household Solid Fuel Use, 2000



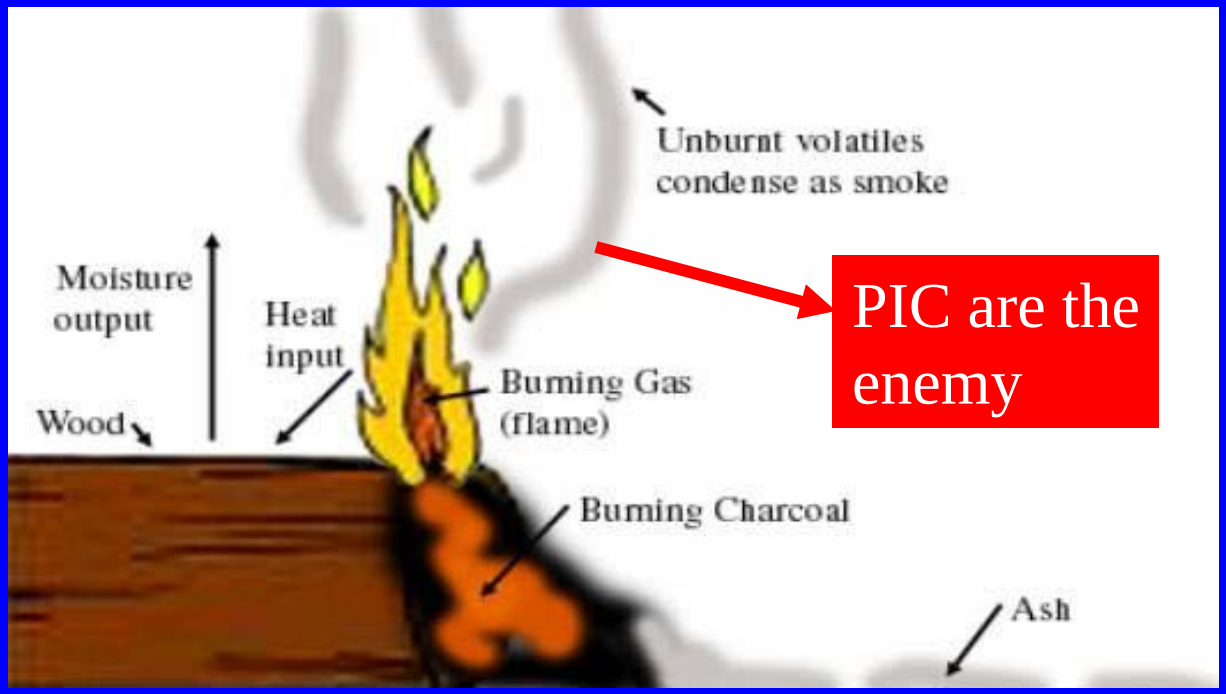
The solid fuels used by half the world's households

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%

Woodsmoke is natural – how can it hurt you?



$$[CH_2O]_x + O_2 \rightarrow CO_2 + H_2O + \text{heat}$$

--Wood is mostly carbon, hydrogen, and oxygen: $[CH_2O]_x$ and thus should burn to only CO_2 and water – yes?

--Unfortunately, in small-scale combustion much of the carbon is not combusted completely, but released as Products of Incomplete Combustion (PIC)

Energy flows in a well-operating traditional wood-fired Indian cooking stove

A Toxic Waste Factory!!

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

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

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

Source: Smith, et al., 2000

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)

Source: Smith, et al, 2000
Census, 2001

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

- Small particles, CO, NO_2
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*

In US regulatory terminology, there are significant emissions of 3 Criteria Air Pollutants and
at least 28 Hazardous Air Pollutants (HAPs)

- 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

Toxic pollutants yes, but are there significant exposures
And health effects?

Kheda District,
Gujarat, India
1981

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

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

Typical Health-based Standards

Wood: 1.0 kg
Per Hour
in 15 ACH
40 m3 kitchen

Typical Indoor Concentrations

Carbon Monoxide: 150 mg/m3	Particles 3.3 mg/m3	Benzene 0.8 mg/m3	1,3-Butadiene 0.15 mg/m3	Formaldehyde 0.7 mg/m3
10 mg/m3	0.1 mg/m3	0.002 mg/m3	0.0003 mg/m3	0.1 mg/m3

Best single indicator

IARC Group 1 Carcinogens

Diseases for which we have some epidemiological studies

ALRI/ Pneumonia
(meningitis)

Asthma

Low birth weight

Early infant death

Cognitive Impairment?

Chronic obstructive lung disease

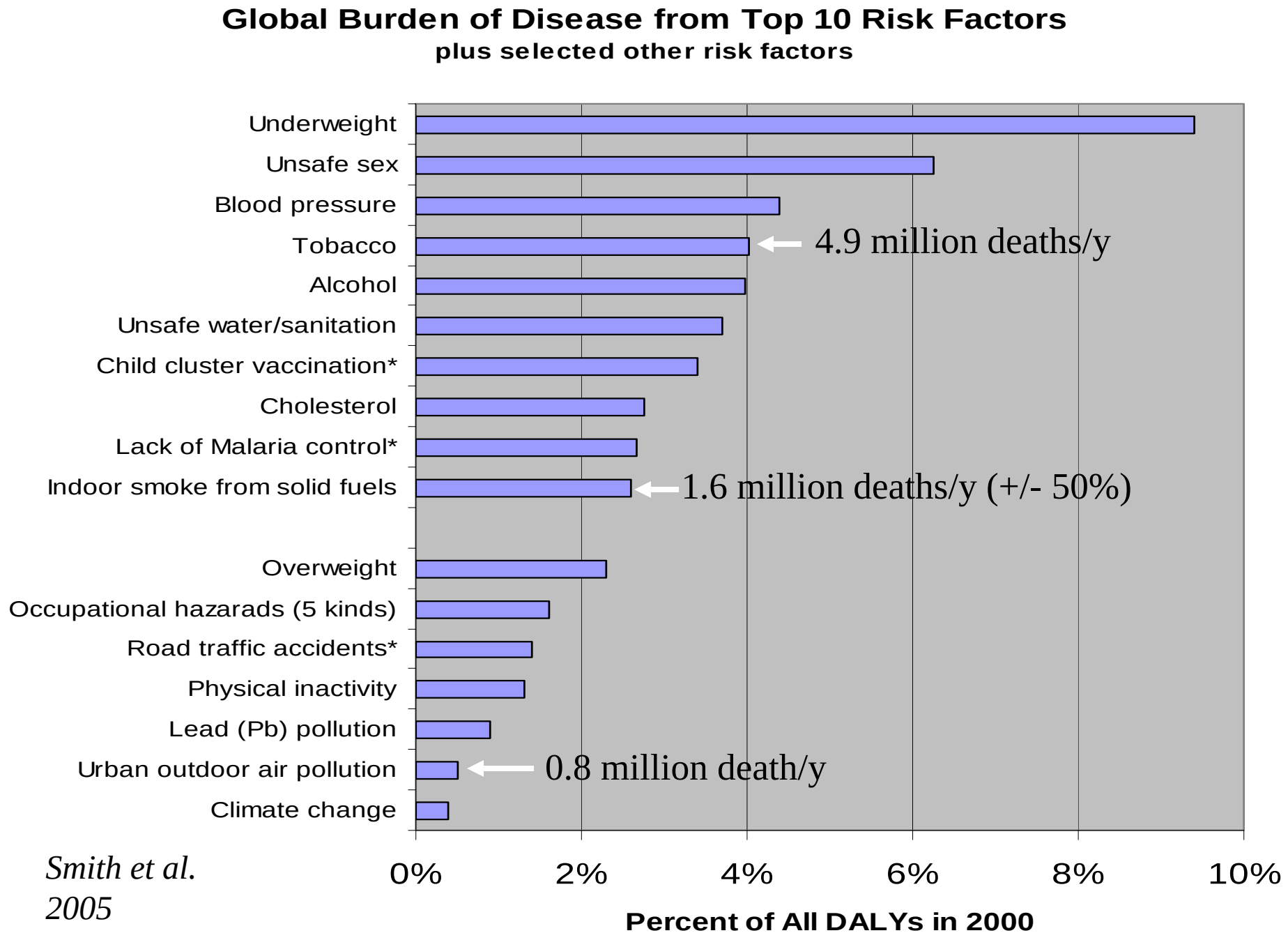
Interstitial lung disease

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

Blindness
(cataracts, trachoma)

Tuberculosis

Heart disease



Smith et al. 2005

Why then will nothing be done?

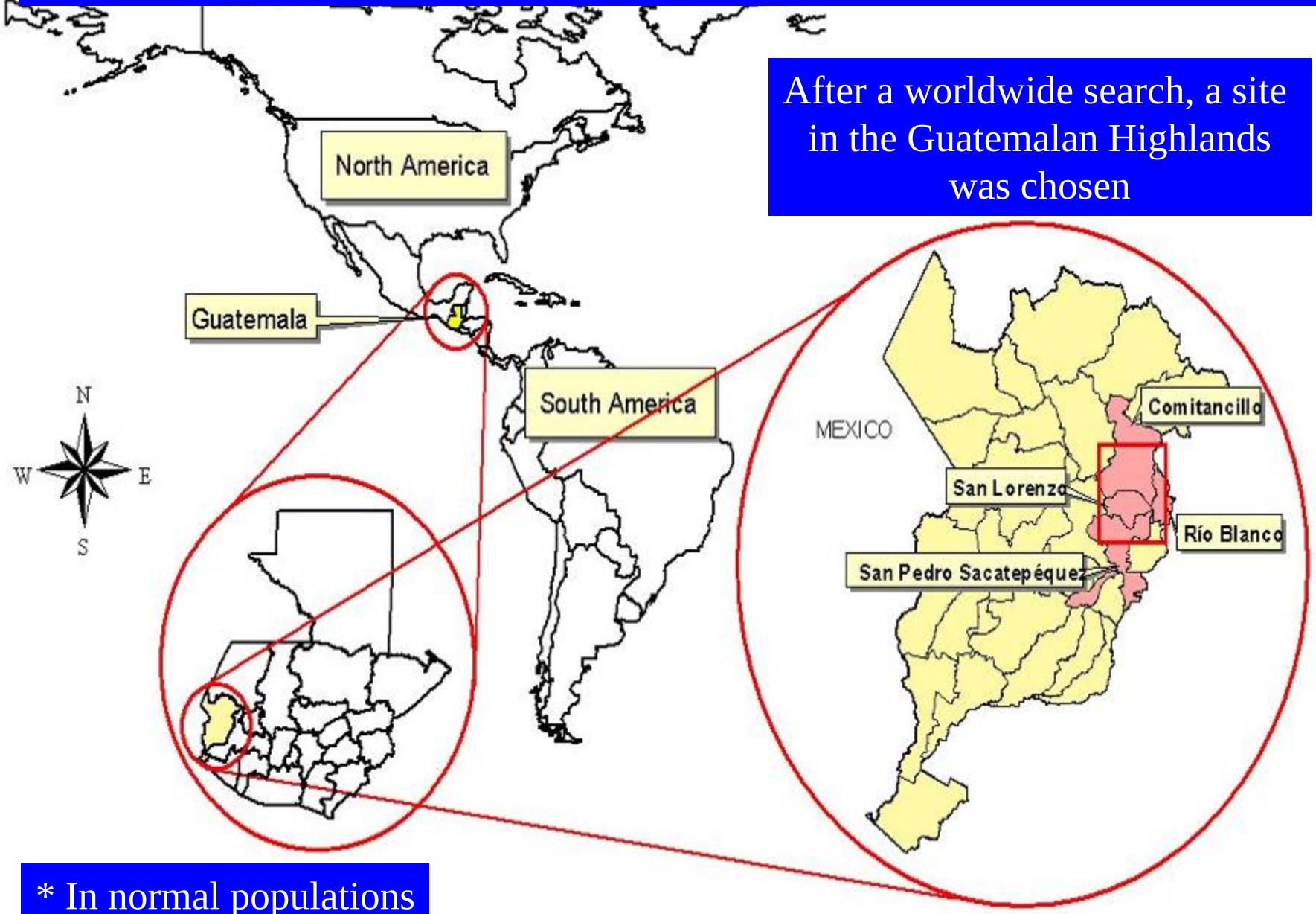
- Do we already know enough?
- The story of two conferences

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 from NIEHS
- Publications coming out now

First Randomized Trial in Air Pollution History*

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



* In normal populations

RESPIRE: Randomized Exposure Study of Pollution Indoors and Respiratory Effects

Traditional 3-stone open fire

Plancha chimney wood stove

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

Preliminary Results

- 30-40% drop in severe bacterial pneumonia, the kind responsible for most child death
- Plus many others

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

Results:

3-4 mm lower systolic and diastolic blood pressure in women with improved stove compared to those using open fire – randomized design

2-3 mm drop in women after receiving improved stove ---longitudinal design

Kirk R

(Published in Environmental Health Perspectives, July 2007)

A few misconceptions leading some to conclude nothing needs to be done

- “The hazards are natural and thus benign”
- “The mundane is not important”
- “It is just a matter of poverty”
- “It is just a matter of engineering”
- “We have tried and failed many times and it is thus too hard”

“Mundane is not important”

- Clearly, day-to-day risks are not spectacular, but
  - It isn’t the big or weird things that kill most, but the little mundane ones
  - Public risk perception is quite different, however.
  - Dread, probability neglect, familiarity, etc.
- The mundane affect the most disenfranchised people in the world
  - Poor
  - Rural
  - Developing-country
  - Women and children

“It is just a matter of poverty”

- Yes, poverty is a large part of the problem, but poverty alleviation, unfortunately, is not a large part of the answer
  - Poverty alleviation is too slow, expensive, uncertain, unfocused, and unethical to be an effective health intervention
    - World Bank analyses
  - Fails to recognize the reverse causality, i.e., to obtain economic growth (and probably democracy) requires healthy populations with expectations of health security for themselves and their children
- The single (or at least one of few) best definition of public health is “The art and science of public health is finding ways to make people healthy before they are wealthy”

“It is just a matter of engineering”

- Could be said of nearly all we do, i.e., why not have zero pollution emissions of all sorts everywhere immediately?
  - Too expensive to do so.
  - We need to learn which exposures are most important and both how to reduce them more effectively and exactly how much health and other benefits result from doing so.
  - If this is true in the US, it is even more so in poor countries
    - $7 per year per capita in India for public health ($26 for all health)
- It also implies that the engineering approaches we have applied in the past are appropriate in the third world today. Not so because, inter alia
  - Cost structures are different: e.g., fossil fuels are now priced such that they are not even mid-term options for poor populations
  - Densities are different: second stage of environmental impacts (community impacts) are greater, water resources are less, etc
  - Understanding of sustainability is different (climate change, eutrophication , renewability, biodiversity, life-cycle analysis, etc)

“We have tried and failed”

- Yes, there have been many failed improved stove programs, but there have also been huge successes, i.e., the Chinese program
- “You don’t get what you expect, you get what you inspect.”
- The total resources spent by all programs, public and private, are less than the cost of the air pollution controls on one new coal-fired power plant anywhere in the world,
  - Two built per week

What Can be Done?

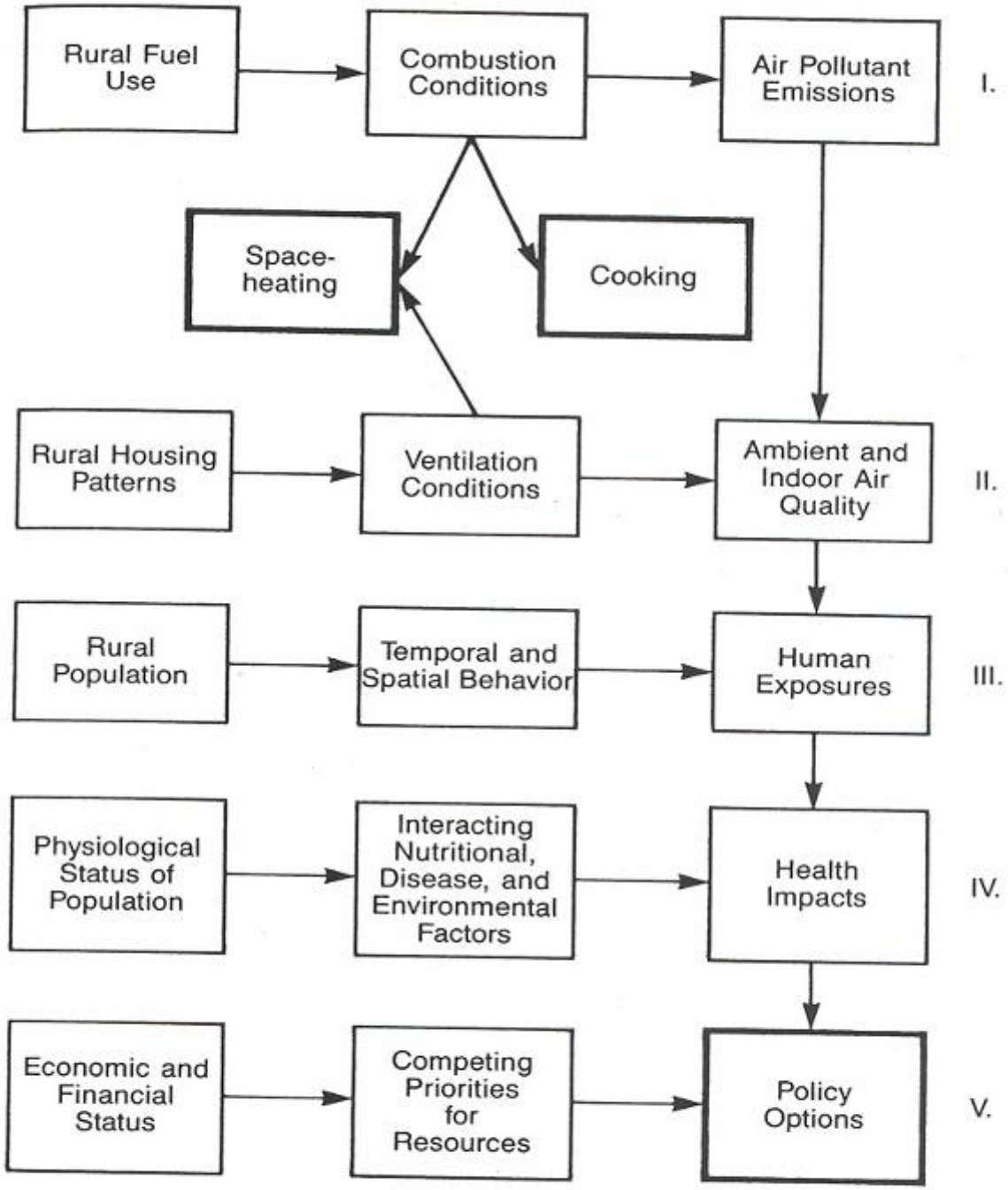


Figure 1.8 Categorization and flow

Engineering Interventions to Reduce Health Burden from Household Solid Fuel Use

- Ventilation changes (put smoke outside)
  - More windows/openings
  - Chimneys on stoves
- Stoves with better combustion (low emissions)
  - Using existing biomass fuels, e.g., “gasifier” stoves
  - Using processed biomass, e.g., pellet stoves
  - Better energy efficiency alone may not help
- Liquid/gaseous fuels (much easier to burn cleanly)
  - Made from biomass, e.g., biogas, alcohol, DME
  - Fossil fuels, e.g., LPG

Improved Stoves in Gujarat??

Mean pollution: traditional stoves = 6400 ug/m3

+/- 4600 ug/m3

Mean pollution: “smokeless chulas” 4600 ug/m3

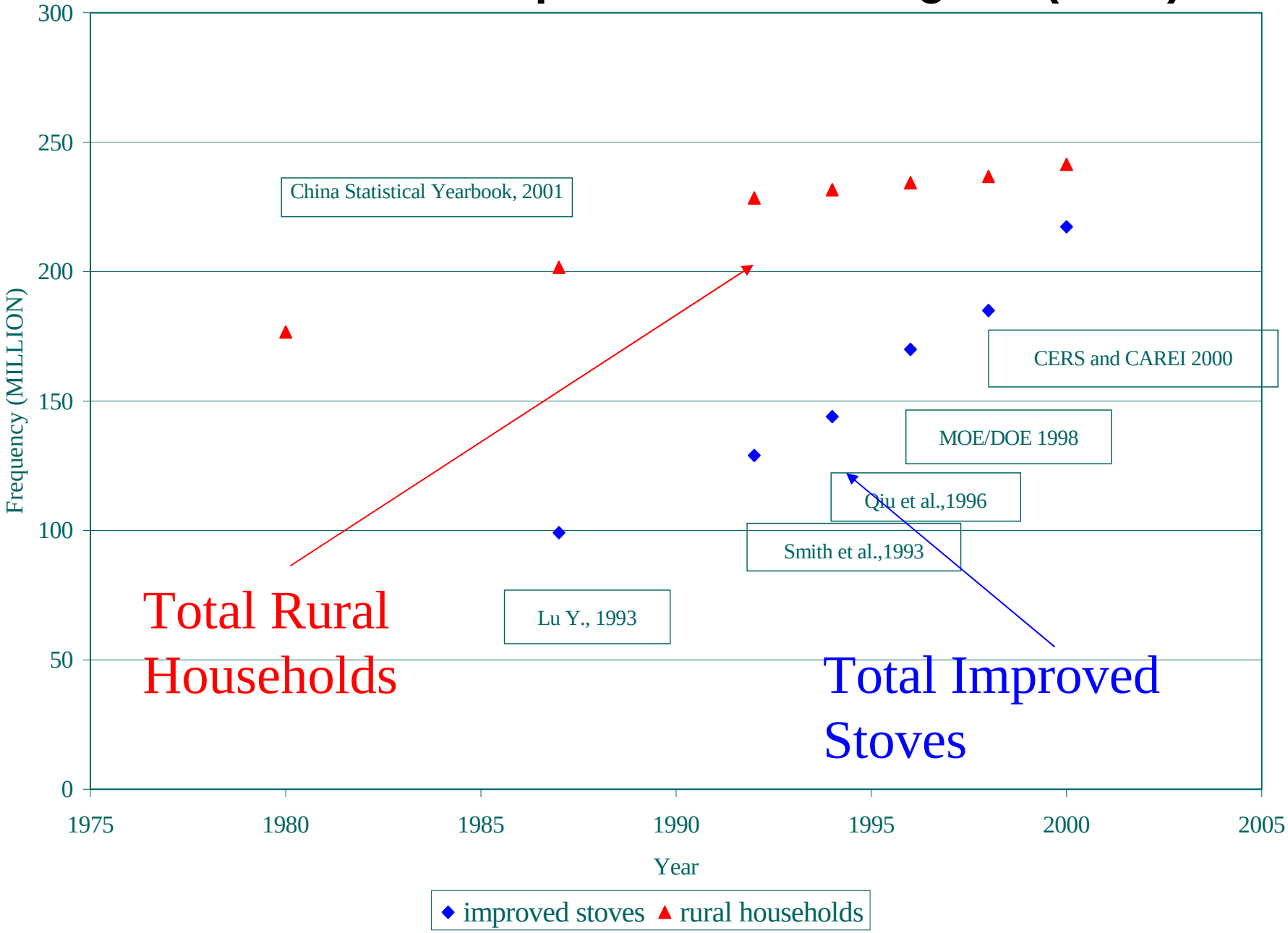
+/- 2900 ug/m3

China has shown itself capable of major achievement in rural energy, including one of the largest rural development programs in human history and, purportedly, the most cost-effective energy efficiency measure undertaken in China.

Improved Biomass Stoves in China

More than 180 million introduced 1981-1998

China's National Improved Stove Program (NISP)



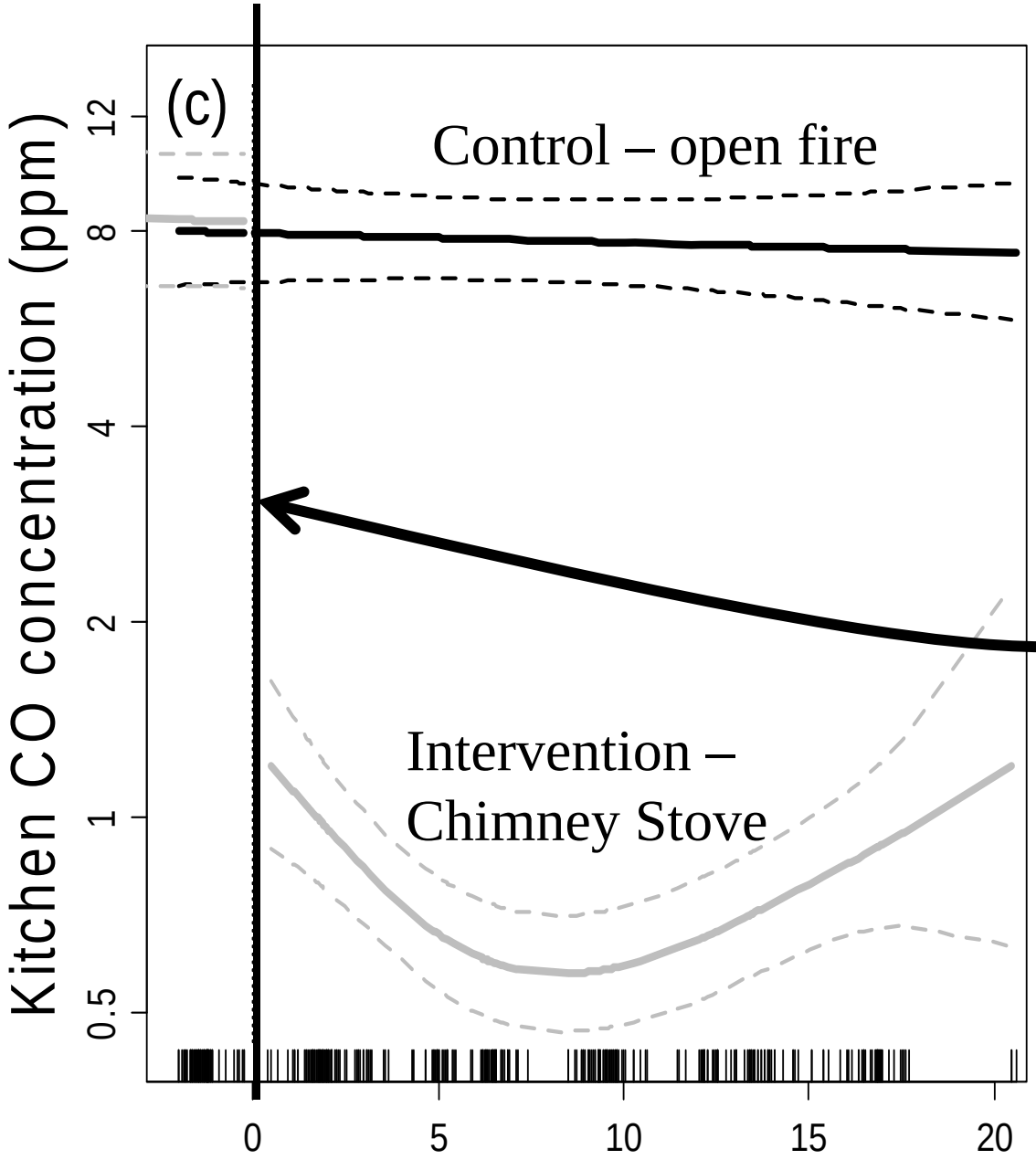
Improved Stove Programs

- No other country has had anything like the success of the Chinese program – the Indian program, for example, is generally considered to have not succeeded and has been abandoned
- Much has been learned, however, and newer programs linked to commercial viability are doing better.
- Monitoring and evaluation are critical
- Nepal has largest program in the world today, purportedly doing well, but no independent evaluations yet done

Can chimneys alone solve the problem, however?

- China's program produced lower IAP levels, but still above Chinese 24-h indoor standard of 150 ug/m3 of PM_{10}
- Similar results seen in other countries
- Smoke does not go away, but is merely vented from kitchen into household environs.
- All developed countries that once used solid fuels in households have found them unacceptable eventually – they just pollute too much

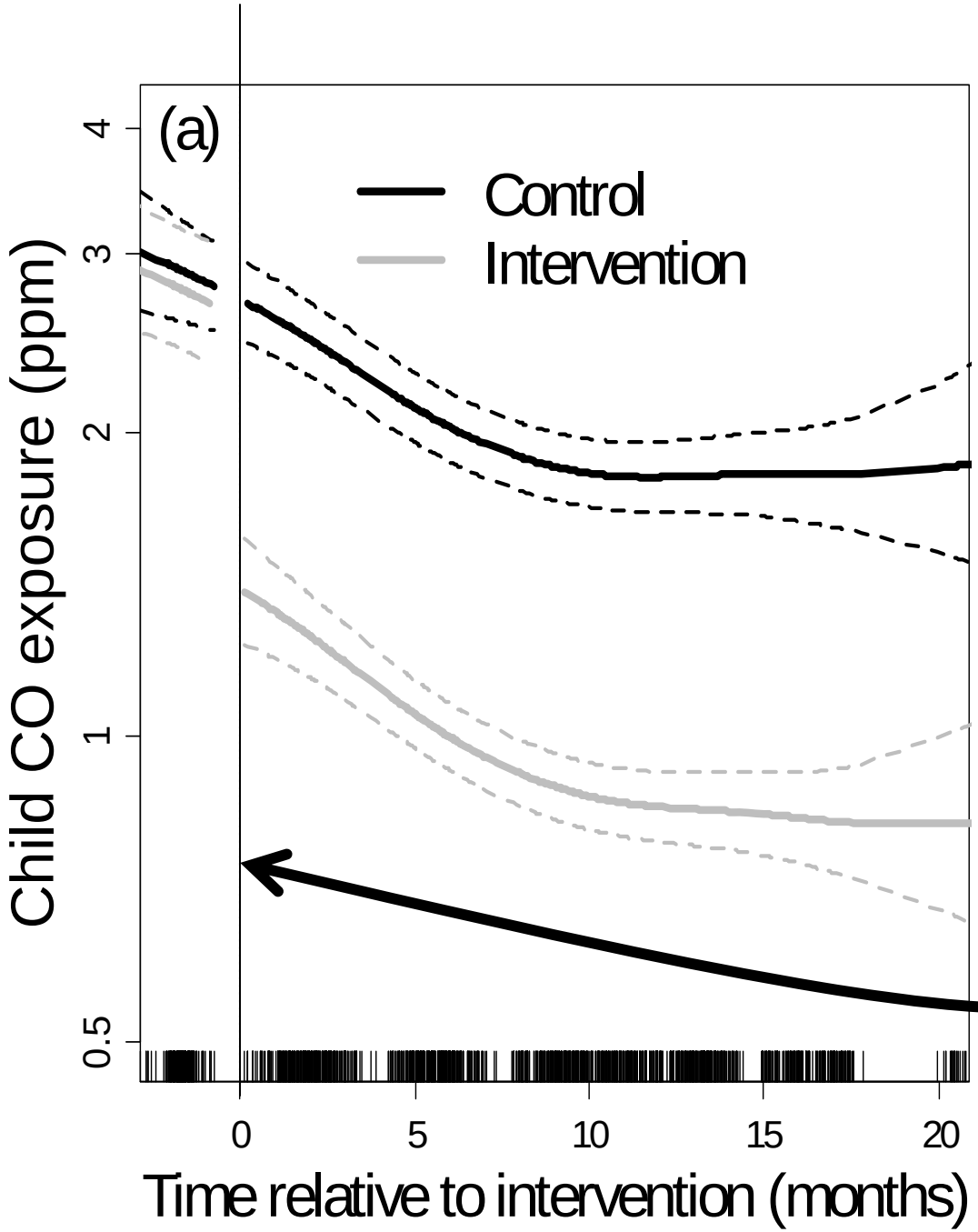
Guatemala Randomized Intervention Trial



Effect of Chimney Stove On Kitchen CO Levels

Factor of ~10 less

Months



Effect of Chimney Stove On Infant Exposures - 2x less


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

Guatemala RESPIRE Project
PM2.5 in open fire households and households with chimneys

		N	Mean $\mu g/m^3$	SD $\mu g/m^3$	Median $\mu g/m^3$	Min $\mu g/m^3$	Max $\mu g/m^3$	% Reduction	p-value
Kitchen									
	Open Fire	87	931	1490	582	37	12494		
	Plancha	57	81	181	33	1	1297	91%	9.50E-07 **significant**
Bedroom									
	Open Fire	54	40	39	35	1	270		
	Plancha	45	33	28	23	1	123	17%	3.20E-01 **non-significant**
Outdoor									
	Open Fire	4	44	31	37	14	87		
	Plancha	2	14	3	14	11	16	69%	1.47E-01 **non-significant**

Open Fire

Plancha

A way to actually reduce emissions?
One of the Chinese Semi-Gasifier Biomass Stoves

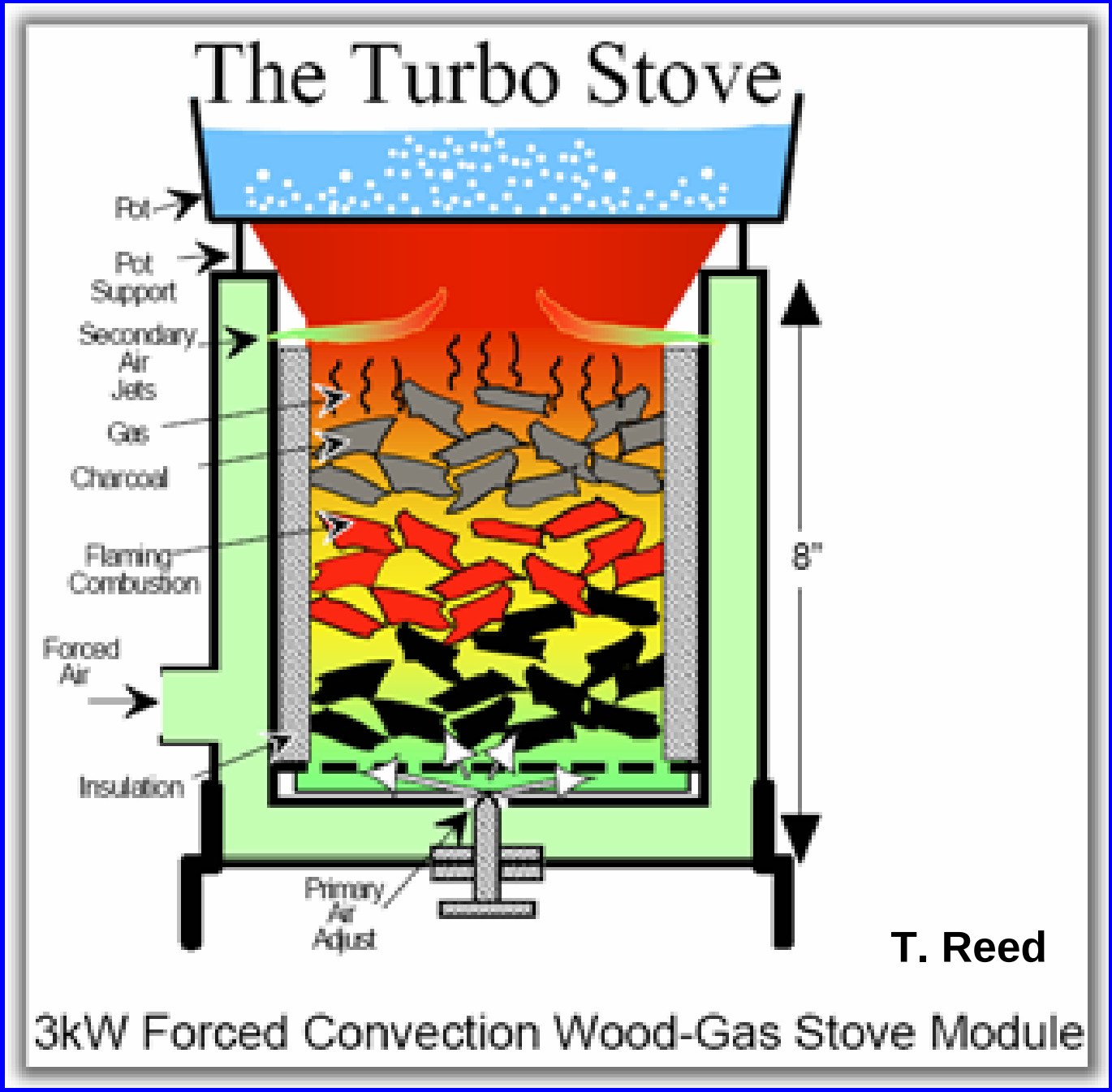
Tests show PIC emissions nearly at LPG levels.

Winner of 2007 Chinese national contest for best stove meeting emissions and reliability criteria: cost $45

But what is field performance?

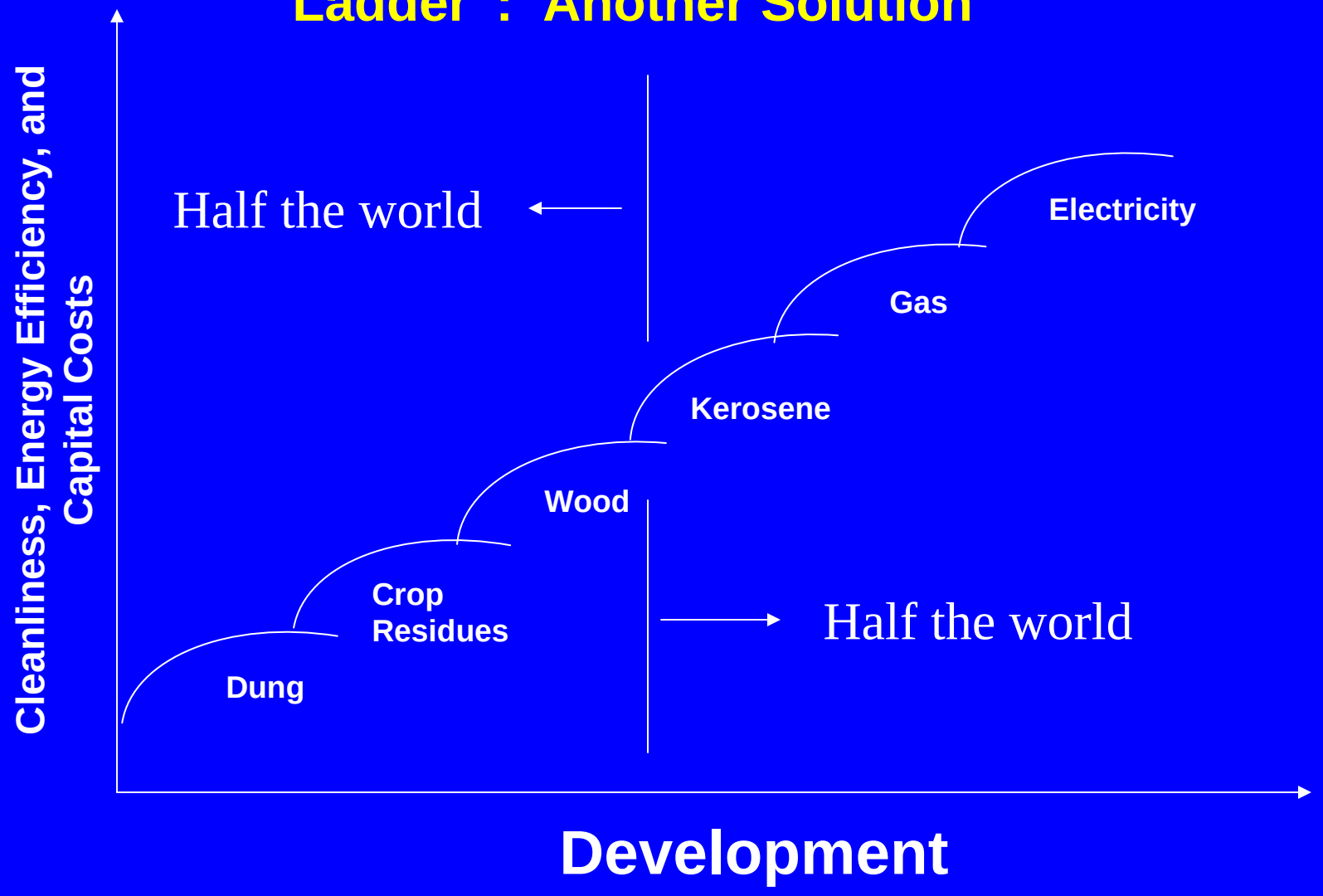
- The semi-gasifier stove customers do not need to buy fuel at present. They only need simply processed fuel. The gasification efficiency can be as high as 60%, and thermal efficiency more than 45%. The most significant character is it doesn't emit dark smoke, and is friendly to the environment and the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

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



Gasifier Stove With Forced Air

Movement up the Household "Energy Ladder": Another Solution



How to promote Clean Fuels?

- Cost effectiveness criteria only met when a range of benefits are included beyond health
  - Time savings, protection of forests, greenhouse emissions (gases and black carbon)
  - Difficult to make case across disparate arenas
- Strict subsidies do not work well
  - More spent on kerosene and LPG subsidies in India and Indonesia than on primary education
  - Kero subsidies are ‘leaky” – people use it for other purposes
  - LPG/kero subsidies are inefficient, they do not benefit only the poor

Bottom lines

- The exotic may enthrall and scare people, but the mundane is killing them
- Anti-PIC is Pro-Poor
- You don’t get what you expect, you get what you inspect
- Great potential for modern careful engineering applied to this problem
  - Better stoves and fuels, with careful linked lab and field tests, combined with social/marketing work
  - Better monitoring and evaluation methods using smart, cheap, reliable IT and other devices

Need for fast, cheap, and easy monitoring and testing techniques: something the engineering 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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An Inexpensive Dual-Chamber Particle Monitor: Laboratory Characterization

Rufus Edwards
School of Social Ec
University of Califo

Kirk R. Smith
School of Public H

Brent Kirby
Chemistry Departm

Tracy Allen
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Charles D. Litton
Pittsburgh Researc
Disease Control an

Susanne Hering
Aerosol Dynamics,

ABSTRACT
In developing countries, hi
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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[e] and Kirk R. Smith[a]

***Receipt/Acceptance Data*: Forthcoming 2007**
Publication data
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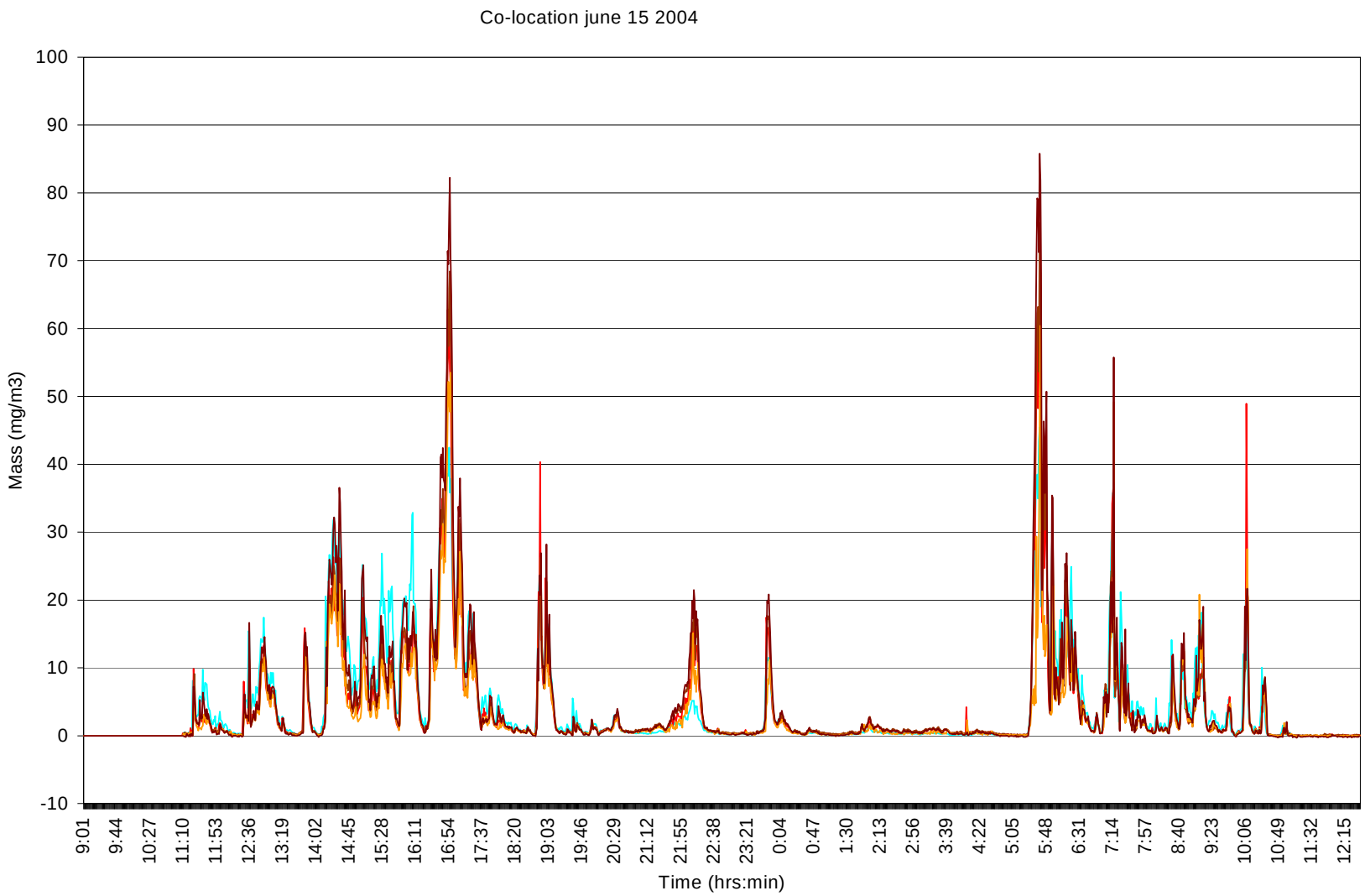
We have developed a small, light, passive, inexpensive, datalogging particle monitor called the "UCB" (University of California Berkeley Particle Monitor). Following previously published laboratory assessments, we present here results of tests of its performance in field settings. We demonstrate the 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.

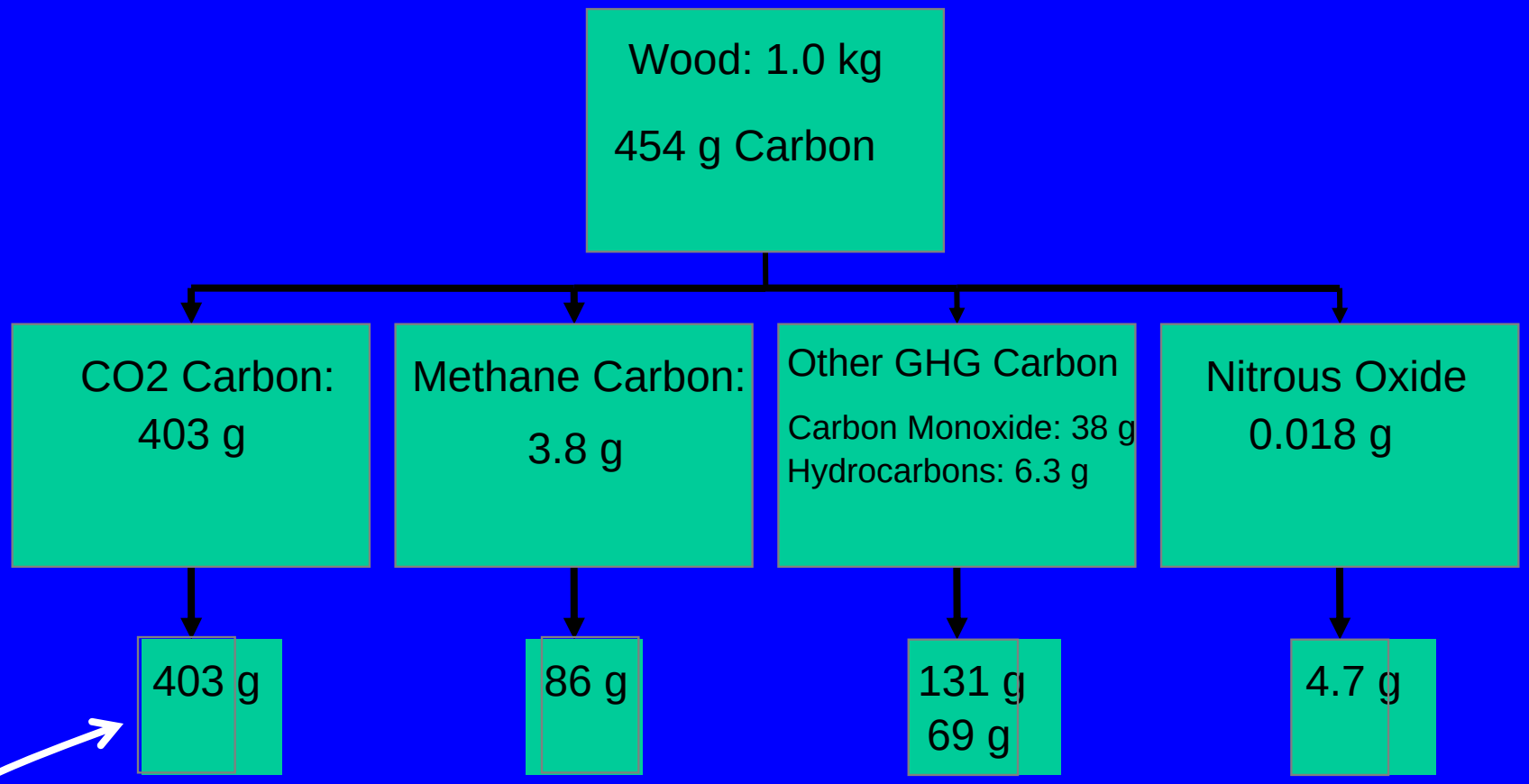
Guatemala house with open fire DustTrak vs UCB particle monitor



How to convince the Belgians to pay for improved stoves

- The PIC from a poorly operating stove are also greenhouse gases (GHG)
- Methane the most important one
- Pay for GHG reductions and get health improvements
- Co-benefits

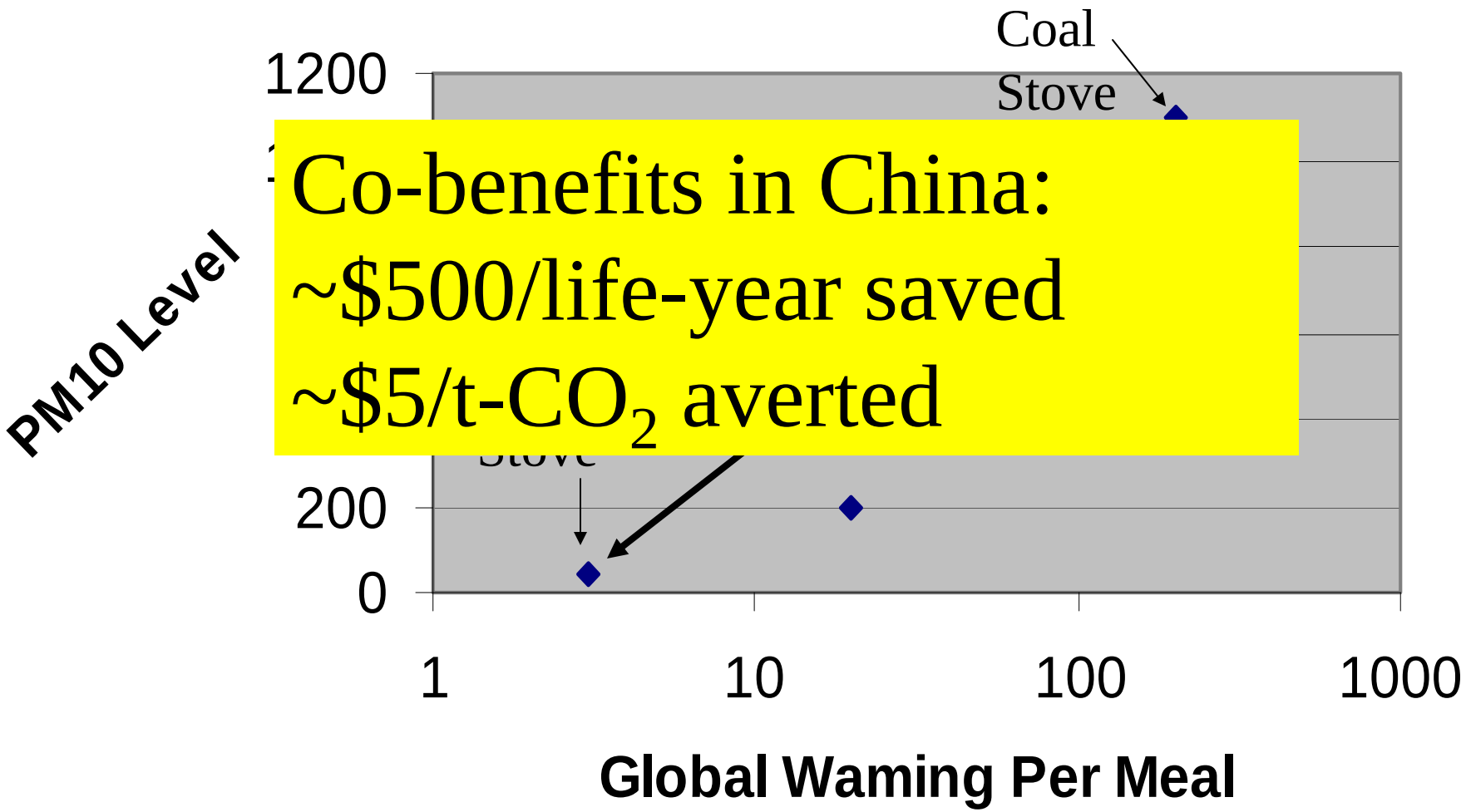
Greenhouse emissions from biomass stoves are not large in global terms, but are large per unit



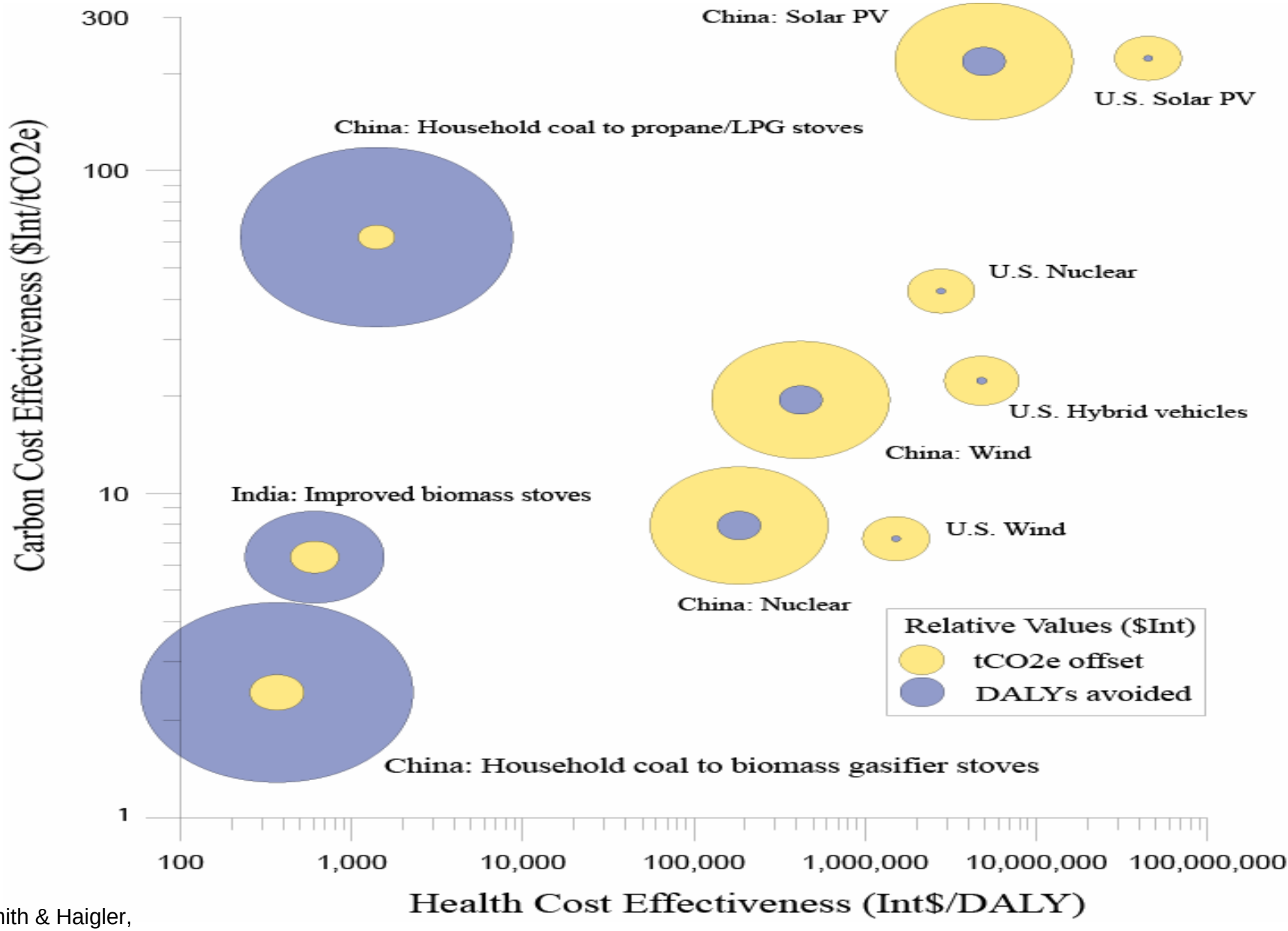
Global warming commitments of each of the gases as CO_2 equivalents

Source: Smith, et al., 2000

Health and Greenhouse Gas Benefits of Biomass Stove Options



Co-benefits in China:
~$500/life-year saved
~$5/t-$CO_2$ averted

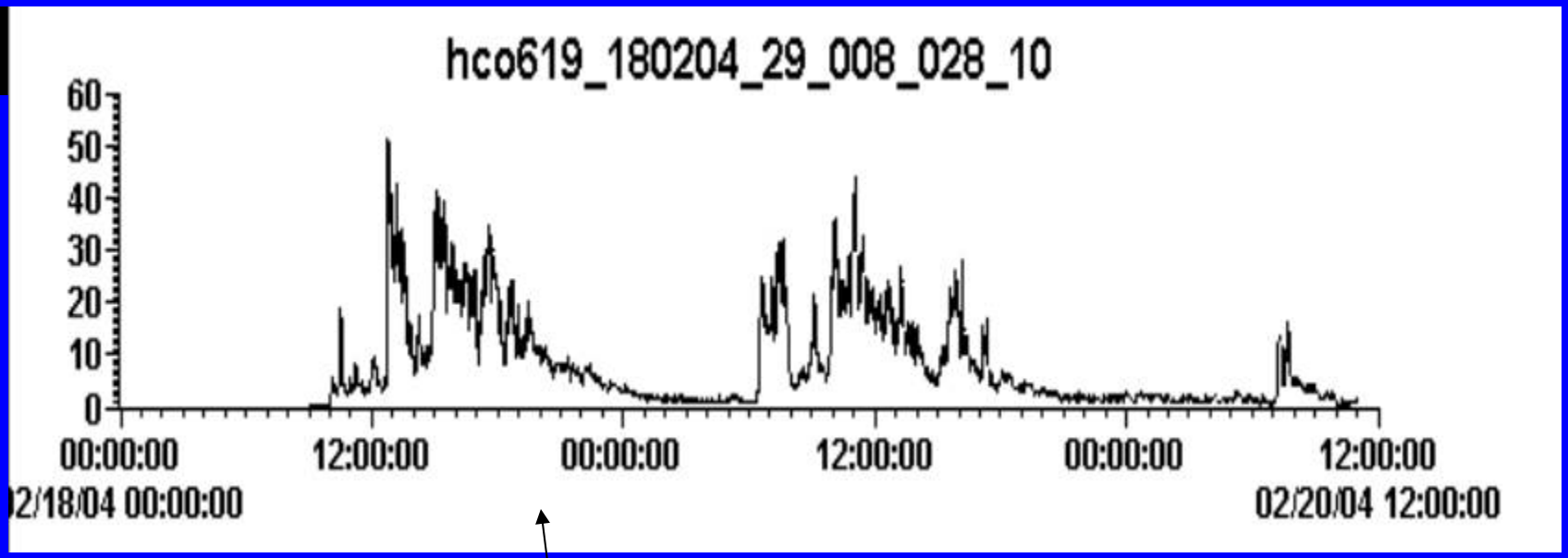


Smith & Haigler,
in press

Testing Combustion Efficiency

- CO/CO_2 ratio works pretty well
- But can lab measurement mimic field results?

48 Hours of Continuous Carbon Monoxide Monitoring in a Guatemalan Home Using an Open Fire for Cooking, (HOBO monitor, ppm)



Note that fire continues for much of day

A few relatively simple measurements do well in predicting total GHG emissions

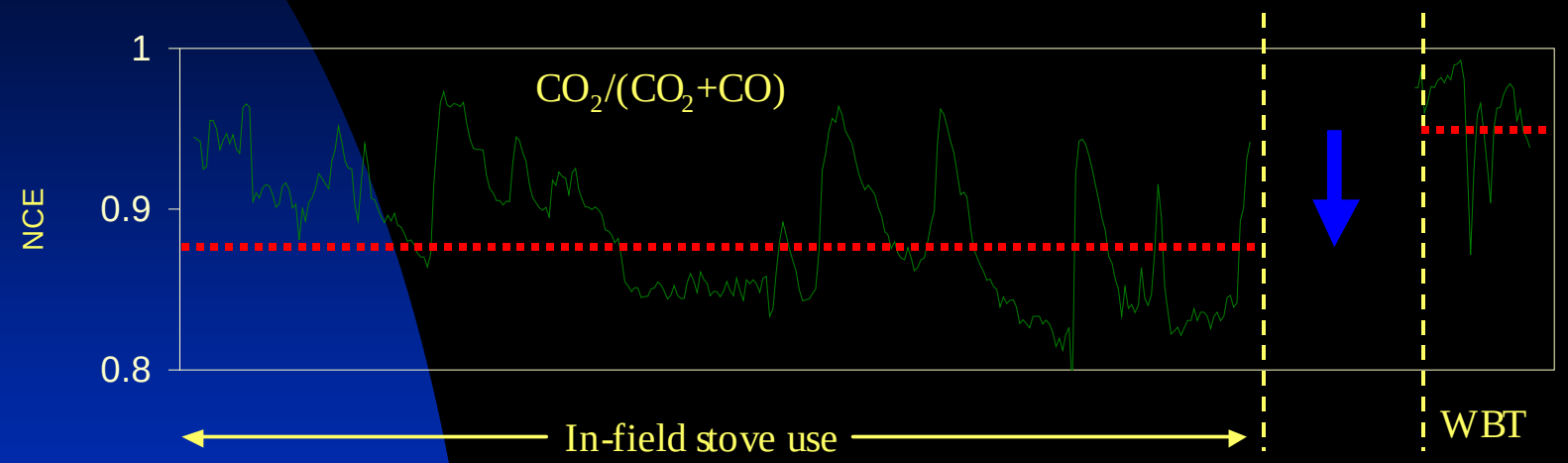
Predictors	Dependent variable	Adjusted r^2
Char, CO/CO_2	GWC (CO_2, CH_4, N_2O)	0.71
Char, NCE	GWC (CO_2, CH_4, N_2O)	0.73
Char, CO/CO_2	GWC (CO_2, CH_4, N_2O, CO, TNMHCa)	0.88
Char, NCE	GWC (CO_2, CH_4, N_2O, CO, TNMHCa)	0.90

a. Total non-methane hydrocarbons

Johnson et al., 2008

Laboratory results do not match field results:
Need to measure in real use in real households

Open fire real-time values



Johnson et al., 2008

No brainers

- Every house in the world deserves clean water and good sanitation for bad water
- Every household in the world deserves clean air and good ventilation for bad air
- The two (i.e., water and sanitation) are closely linked – need both, one is not enough
- Good engineering is necessary, but not sufficient to solutions
- The mundane is difficult, but rewarding

Gracias

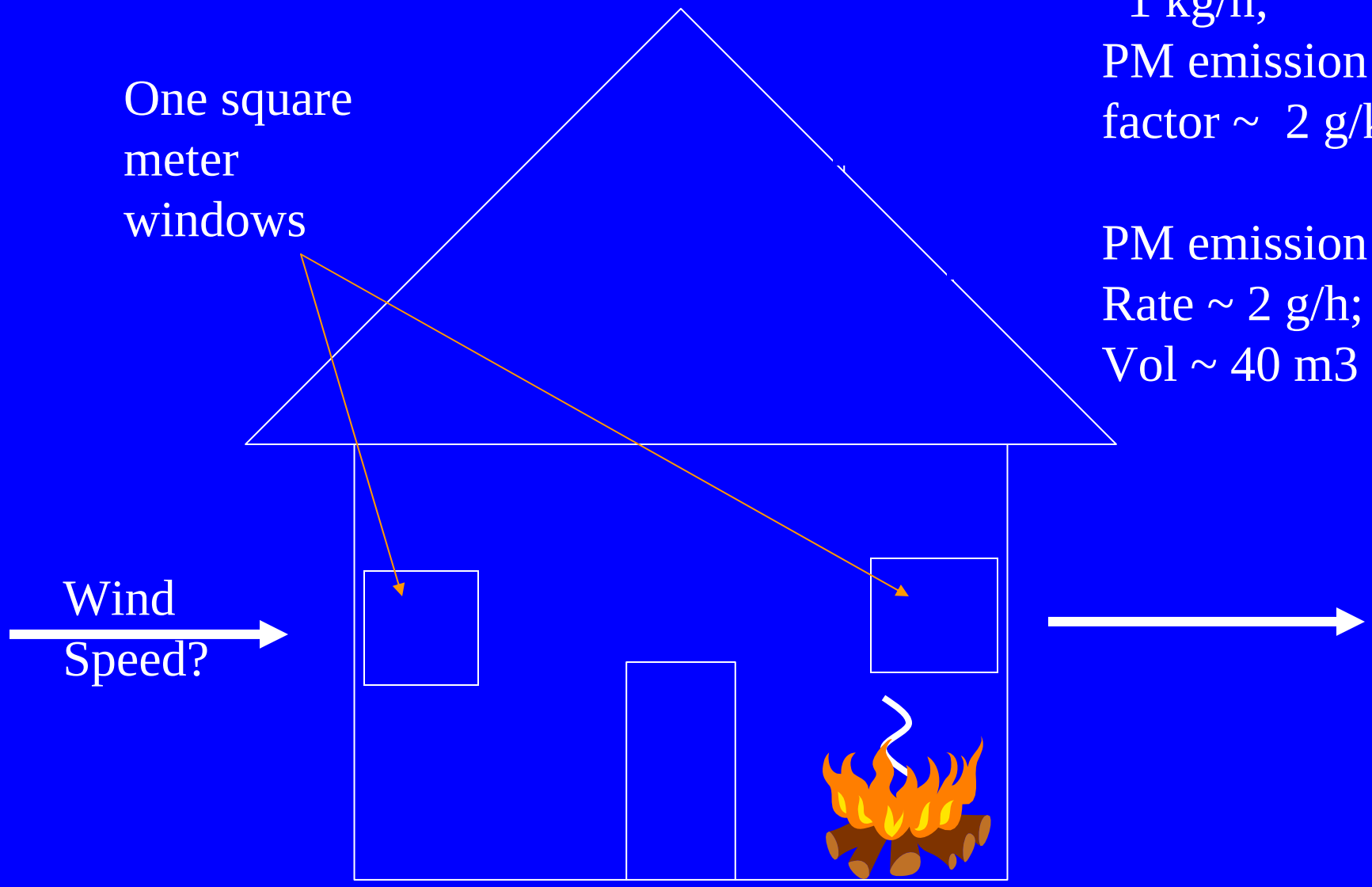
Publications at http://ehs.sph.berkeley.edu/krsmith/

Question for you to consider

(Wood use ~ 1 kg/h; PM emission factor ~ 2 g/kg);

PM emission Rate ~ 2 g/h; Vol ~ 40 m3

One square meter windows



What wind speed would be needed to reach 50 ug/m3 in hut?