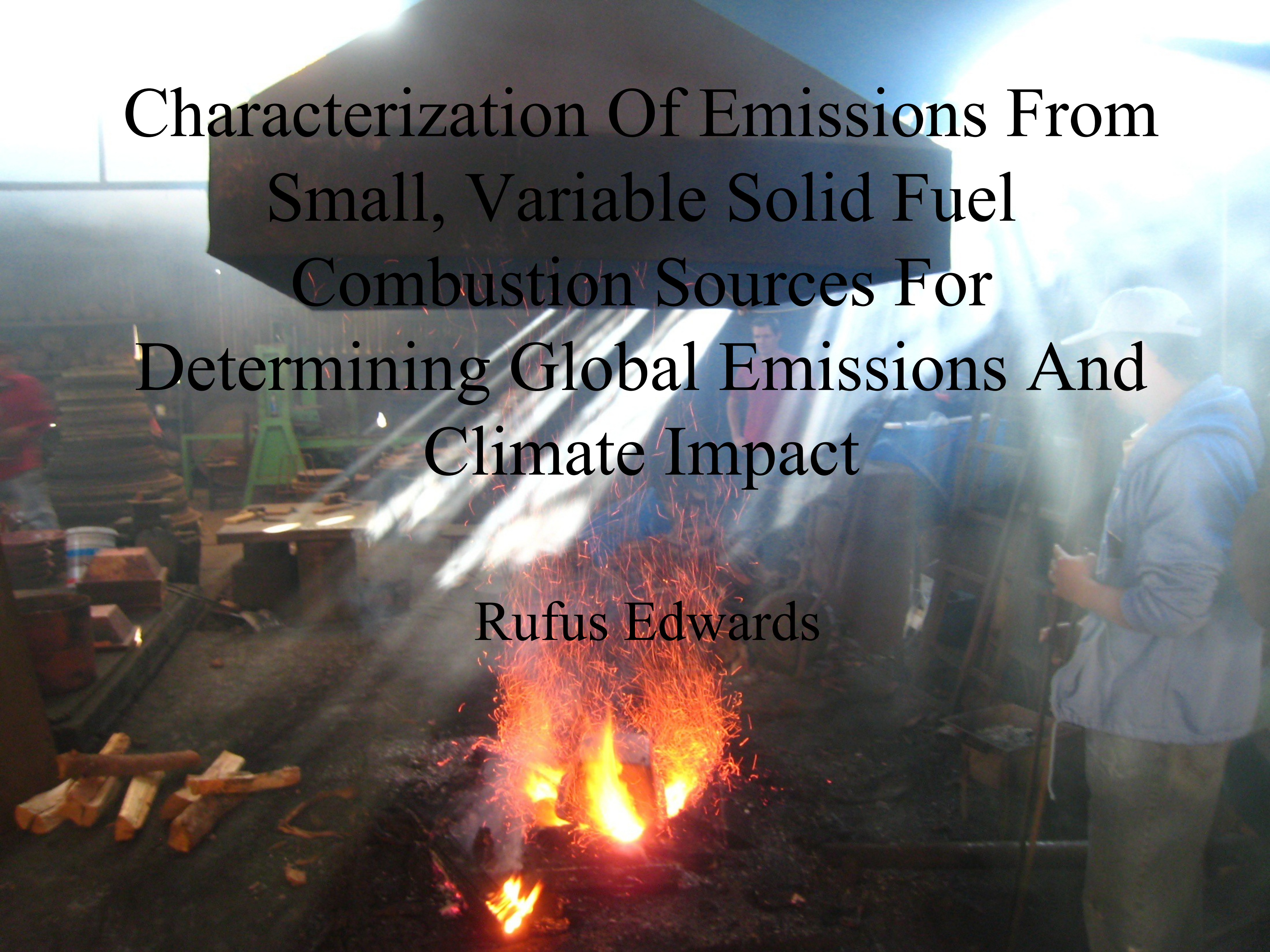
Characterization Of Emissions From Small, Variable Solid Fuel Combustion Sources For Determining Global Emissions And Climate Impact

Rufus Edwards



Rationale

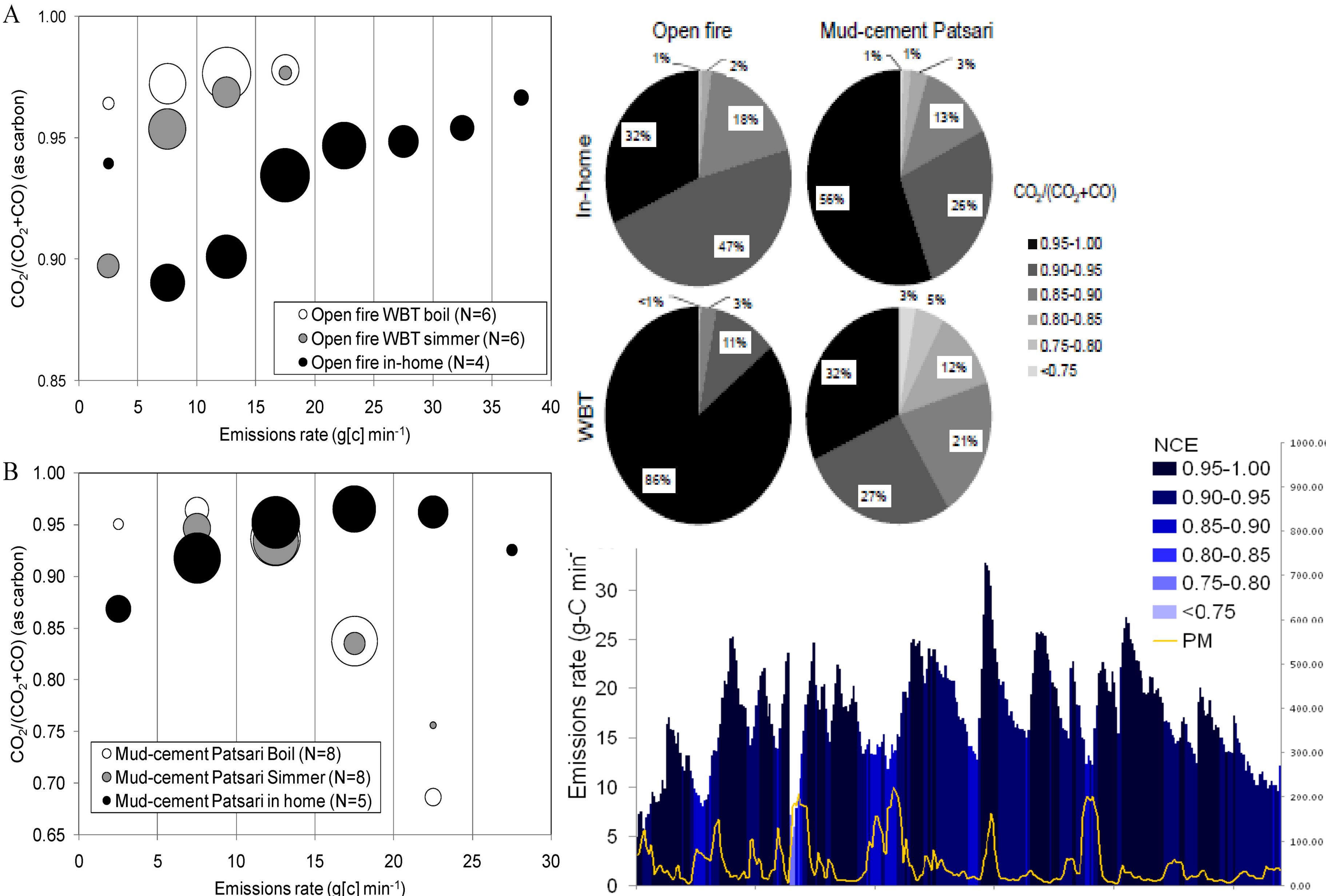
- Models indicate the large contribution of residential solid-fuel emissions to primary particle emissions and BC.
- The basis for these calculations is poor; emission factors and activity data remain uncertain.
- Residential sector emissions largely based on simulated tests in laboratories in an EPA study published in 2000.
- Few actual in field measurements during normal daily cooking activities.
- Lab measurements are quite poor at predicting actual emissions in the field - biases indicating that emissions could be significantly underestimated.

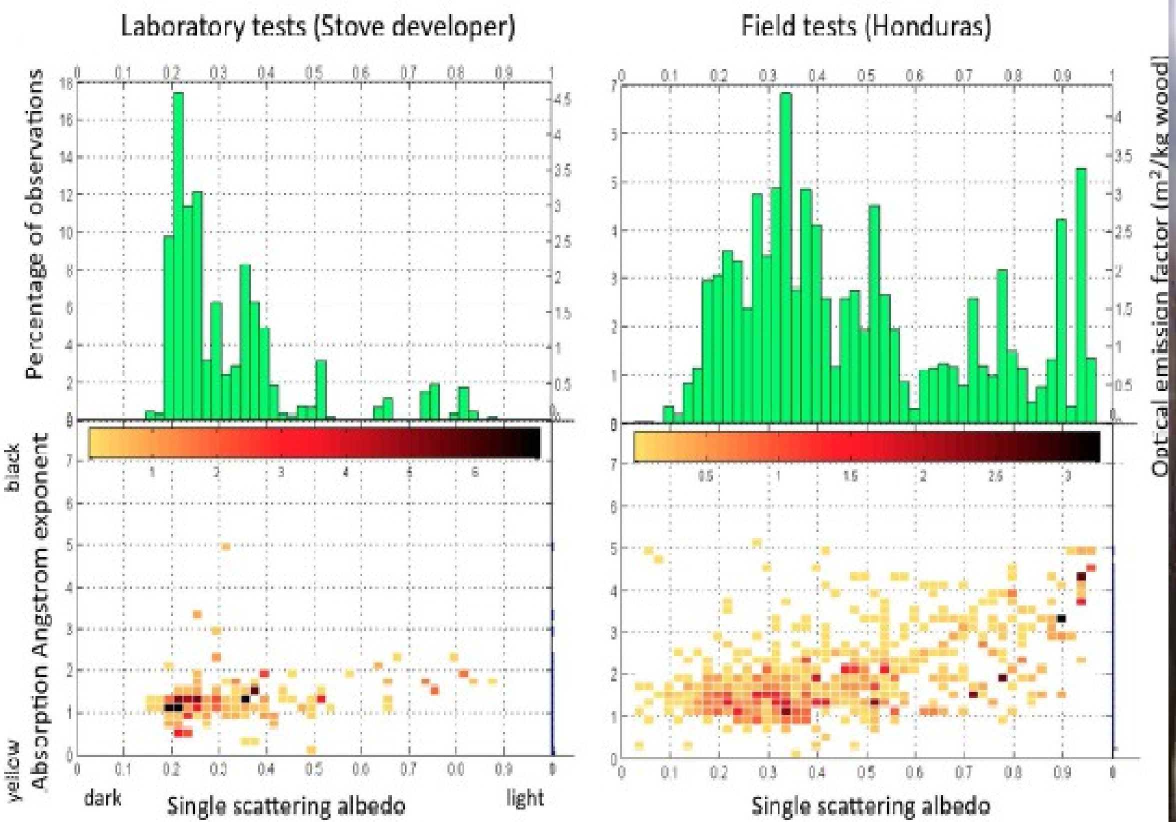
- # In Field

	Fuel	CO_2	CO	CH_4	NMHC	PM	%BC
Traditional stoves	Wood [42,21,40]	1592 (2)	98.2 (3)	6.4 (1)	4.8 (1)	8.44 (2)	10.5 (2)
		1533-1650	*81.7-112.6*			*8.09-8.80*	*3.4-17.5*
	Dung [21]	1610 (1)	84 (1)	-	-	-	-
	Crop res. [21]	1720 (1)	63 (1)	-	-	-	-
Improved stoves	Wood [42,40]	1558 (1)	68.3 (2)	2.4 (1)	1.4 (1)	4.61 (2)	12.3 (2)
			42.0-85.4			*3.50-6.31*	*0.4-25.9*
	Charcoal [40]	2982 (1)	350 (1)	15 (1)	53.4 (1)	15.9 (1)	

- # Laboratory

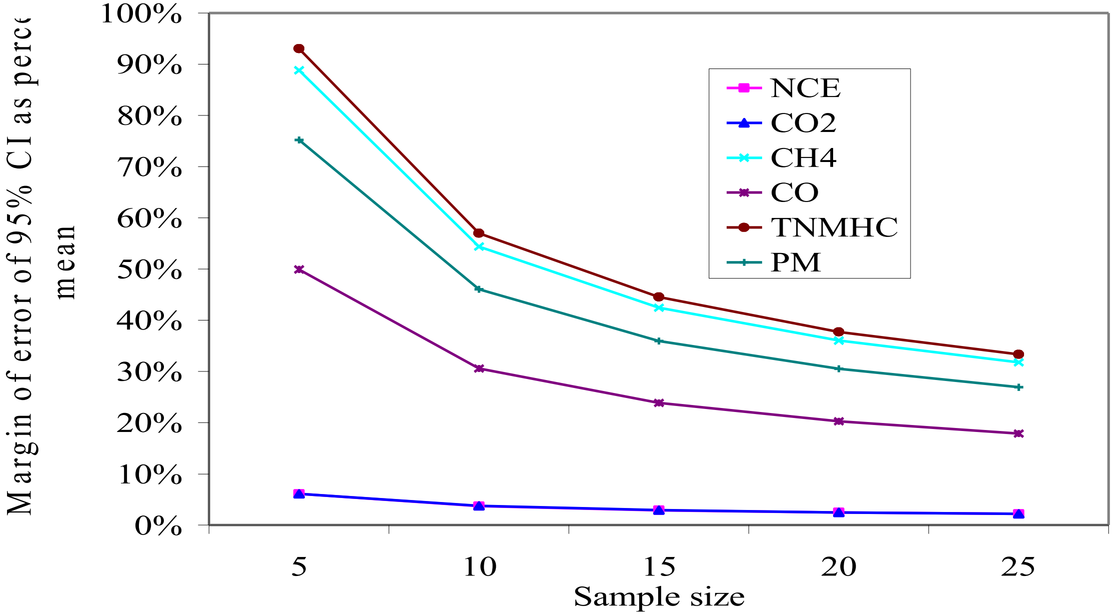
	CO_2	CO	CH_4	NMHC	N_2O	PM	%BC
Wood	1493	52.9	5.7	8.1	0.075	2.83	33.7
	1397-1590	*11.0-99.5*	*2.0-10.6*	*2.7-12.5*	*0.06-0.09*	*1.34-4.90*	*22.4-38.1*
	[42, 29-34]	[42, 40, 29-37]	[42, 29-34]	[42, 31-33,	[32, 34]	[40-42, 33, 34, 36, 37]	[38, 41, 42,
Charcoal	2440.5	169	6.3	5.8	0.04	-	-
	2226-2740	*105-230*	*2.4-8.0*	*4.0-7.5*			
	[29-32]	[29-32]	[29-32]	[31, 32]	[32]		
Dung	1027	33	6	18.8	0.31	3.9	4.7
		18.0-50.0				*2.21-4.90*	[11]
	[34]	[34, 36, 37]	[34]	[34]	[34]	[34, 36, 37]	
Crop residues	1302	46.5	7.6	8.5	0.05	2.17	20.6
		27.0-66.0				*1.34-3.0*	
	[34]	[34, 36]	[34]	[34]	[34]	[34, 36]	[34]
Wood	1434	49.7	6.9	10.5	0.2	2.48	35.5
	1276-1556	*12.0-108*	*4.0-12.9*	*2.9-14.8*		*1.00-4.80*	*20.8-44.8*
	[31, 33, 34,	[42, 40, 31, 33-37,	[42, 31, 33,	[42, 31, 33,	[34]	[33, 34, 36, 37, 40-43]	[42, 40, 41]
Charcoal	2452	228	10.3	15.8	0.24	6.06	12
	2402-2543	*135-275*	*8-14.3*	*7-29.9*		*1.74-14.1*	
	[28, 31, 34]	[28, 31, 34]	[28, 31, 34]	[28, 31, 34]	[34]	[28, 31, 34]	[41]
Dung	1015	41.3	10.7	26.9	0.31	3.1	-


A
CO2/(CO2+CO) (as carbon)
Emissions rate (g[c] min-1)
Open fire WBT boil (N=6)
Open fire WBT simmer (N=6)
Open fire in-home (N=4)
B
Mud-cement Patsari Boil (N=8)
Mud-cement Patsari Simmer (N=8)
Mud-cement Patsari in home (N=5)
Open fire
Mud-cement Patsari
In-home
WBT
CO2/(CO2+CO)
0.95-1.00
0.90-0.95
0.85-0.90
0.80-0.85
0.75-0.80
<0.75
NCE
PM
Emissions rate (g-C min



Courtesy Tami Bond

how broad in scope do our inventories need to be?



What are the major factors leading to variability in emissions quantities and properties? How can we group them and how many do we have to measure?

WHO Indoor air quality guidelines emissions assessment

Mitigation

National Cookstove Initiative in India

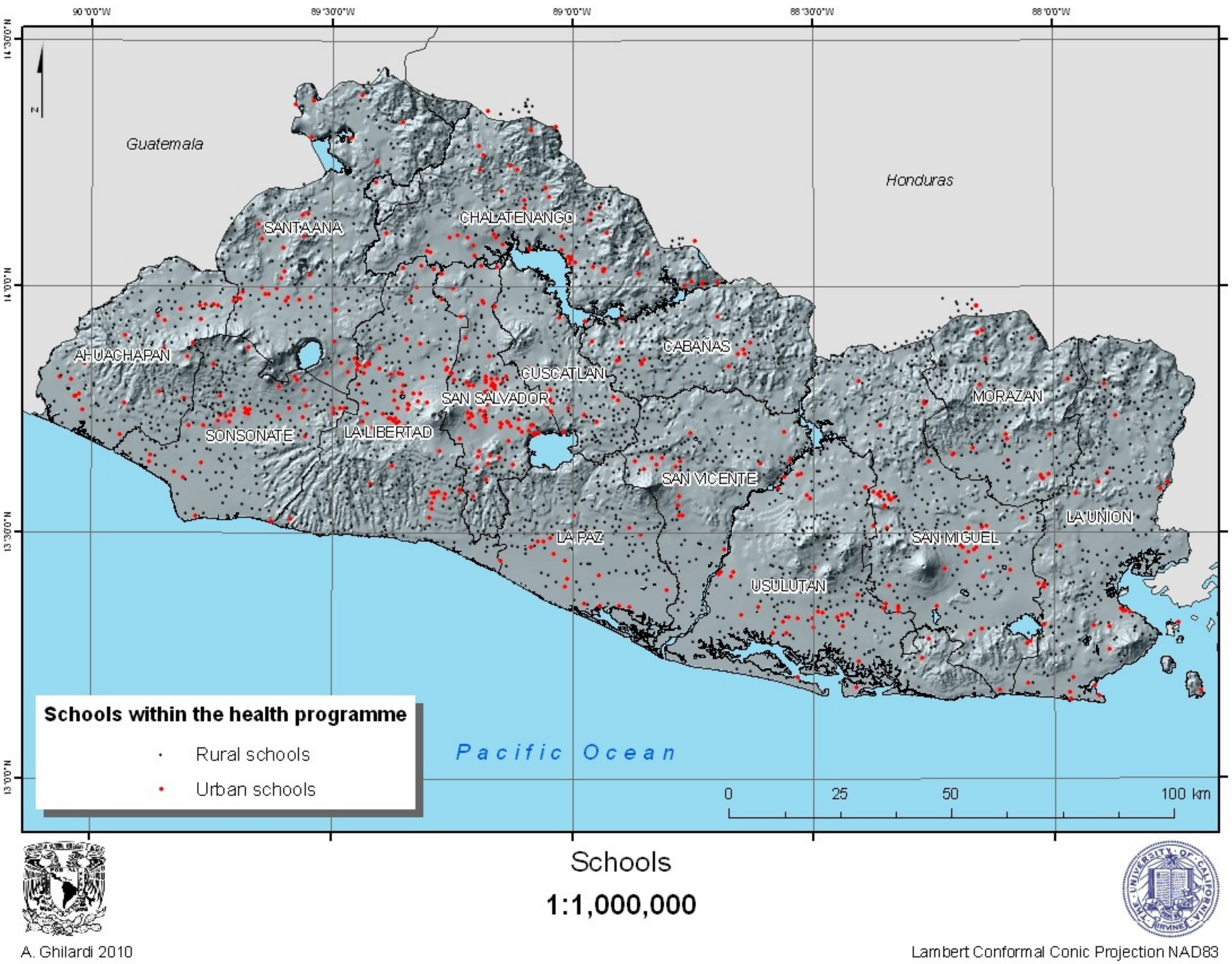
- Calculates the negative impacts today for climate, health, and energy of not having provided "LPG-like" combustion in all of India's households (so-called attributable risk).
- annually
  - >500k premature deaths avoided,
  - 4% of India's total estimated GHG emissions avoided - worth >US$1billion on international carbon markets for standard GHGs (CO2, methane, N20) using typical values of 13 Euro/tonne of CO2-e,
  - >one-third of India's black carbon emissions

Kirk Smith – The Lancet

Mitigation effectiveness

- Adoption rates are not 100% even when stoves are bought.
- growing recognition that even 70% over a long period may be pretty good
- Developing mechanisms to overcome adoption barriers increasingly important
    - linking stoves to prenatal care (India)
    - Linking to social welfare (Mexico)
    - providing lighting as a cogeneration

Urban and rural schools using fuelwood in governmental program Healthy Schools in El Salvador



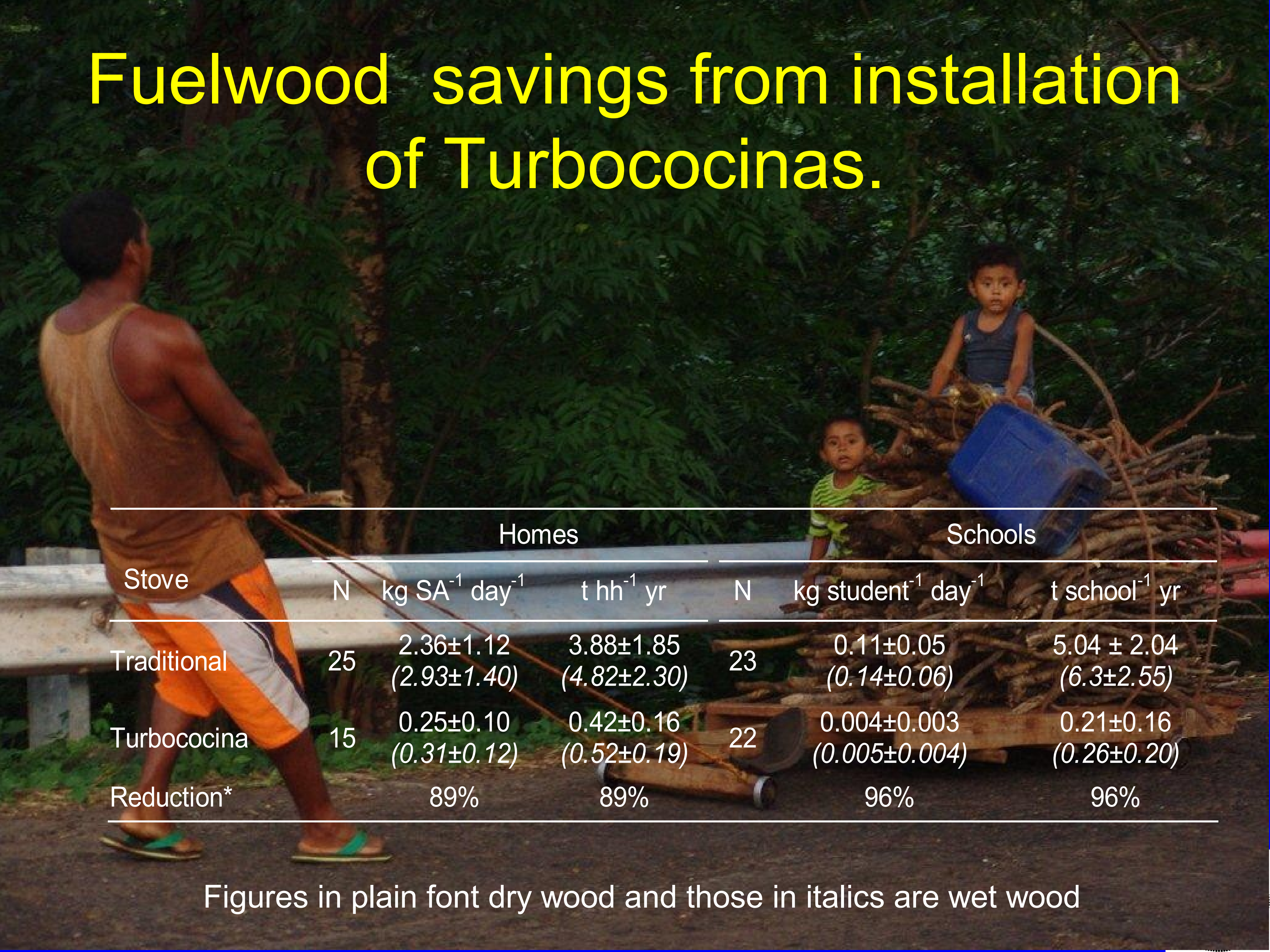
Difference in combustion efficiency and emissions for homes and schools using Turbococinas

(g emitted per kg dry fuelwood consumed).

	Stove	N	NCE (%)	CO_2 (g kg^{-1})	CH_4 (g kg^{-1})	CO (g kg^{-1})	TNMHC (g kg^{-1})	PM (g kg^{-1})
Homes	Traditional	25	86.4±4.6	1445±77	13.6±10.5	75.3±32.7	15.2±12.3	15.6±10.2
	Turbococina	15	97.2±1.3	1625±22	2.3±1.8	18.0±11.4	3.3±2.2	2.1±1.7
	Difference*		12%	12%	-83%	-76%	-78%	-87%
Schools	Traditional	25	87.1±6.1	1456±102	16.2±8.4	75.4±46.8	11.6±6.4	11.4±11.5
	Turbococina	25	98.1±1.1	1639±18	2.2±1.9	9.5±6.4	2.5±2.2	2.5±1.9
	Difference*		13%	13%	-86%	-87%	-79%	-78%

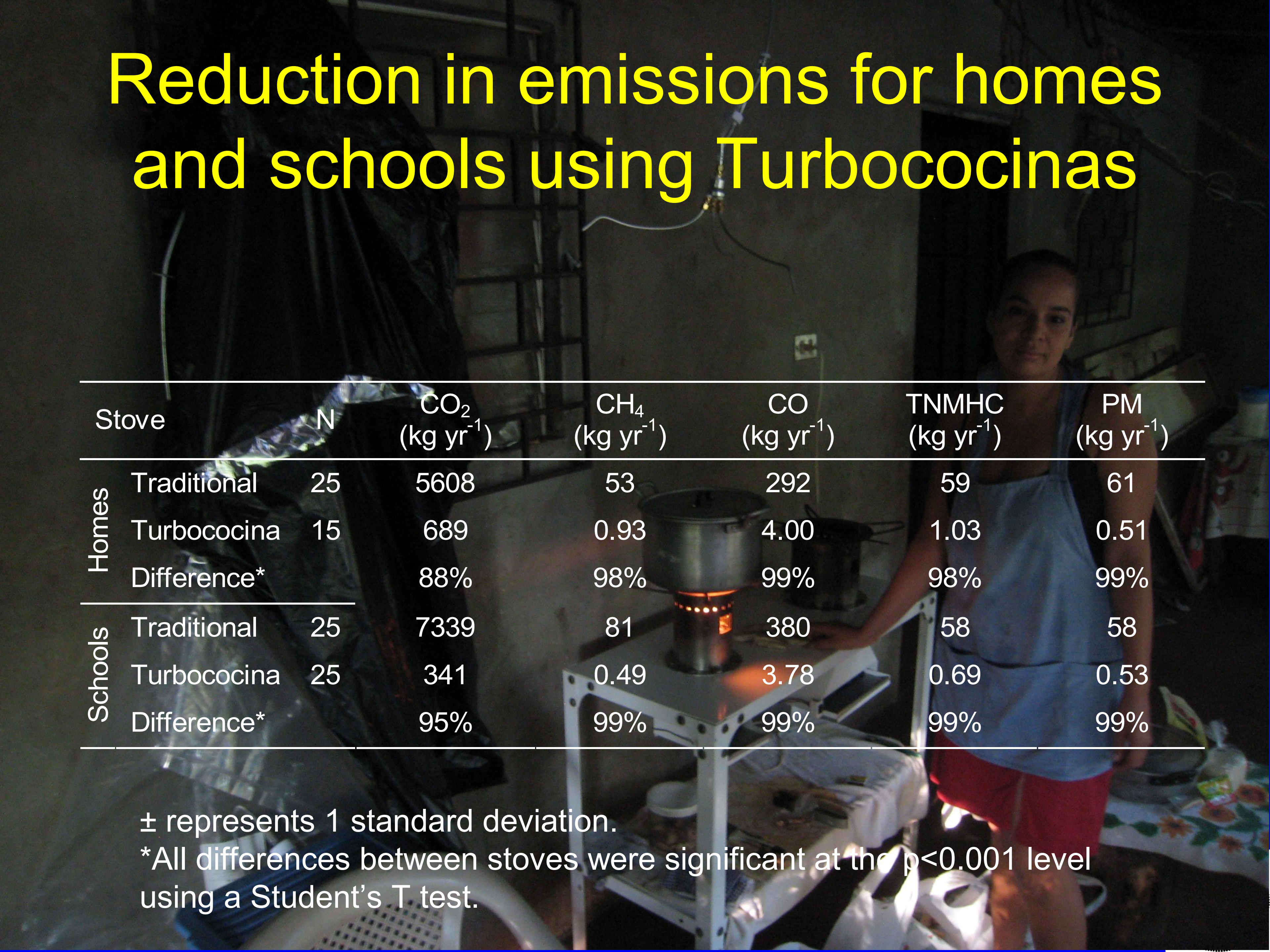
± represents 1 standard deviation.
*All differences between stoves were significant at the $p<0.001$ level using a Student's T test.

Fuelwood savings from installation of Turbococinas.



Stove	Homes			Schools		
	N	kg SA^{-1} day^{-1}	t hh^{-1} yr	N	kg student^{-1} day^{-1}	t school^{-1} yr
Traditional	25	2.36±1.12 *(2.93±1.40)*	3.88±1.85 *(4.82±2.30)*	23	0.11±0.05 *(0.14±0.06)*	5.04 ± 2.04 *(6.3±2.55)*
Turbococina	15	0.25±0.10 *(0.31±0.12)*	0.42±0.16 *(0.52±0.19)*	22	0.004±0.003 *(0.005±0.004)*	0.21±0.16 *(0.26±0.20)*
Reduction*		89%	89%		96%	96%

Figures in plain font dry wood and those in italics are wet wood



Reduction in emissions for homes and schools using Turbococinas

	Stove	N	CO_2 (kg yr^{-1})	CH_4 (kg yr^{-1})	CO (kg yr^{-1})	TNMHC (kg yr^{-1})	PM (kg yr^{-1})
Homes	Traditional	25	5608	53	292	59	61
	Turbococina	15	689	0.93	4.00	1.03	0.51
	Difference*		88%	98%	99%	98%	99%
Schools	Traditional	25	7339	81	380	58	58
	Turbococina	25	341	0.49	3.78	0.69	0.53
	Difference*		95%	99%	99%	99%	99%

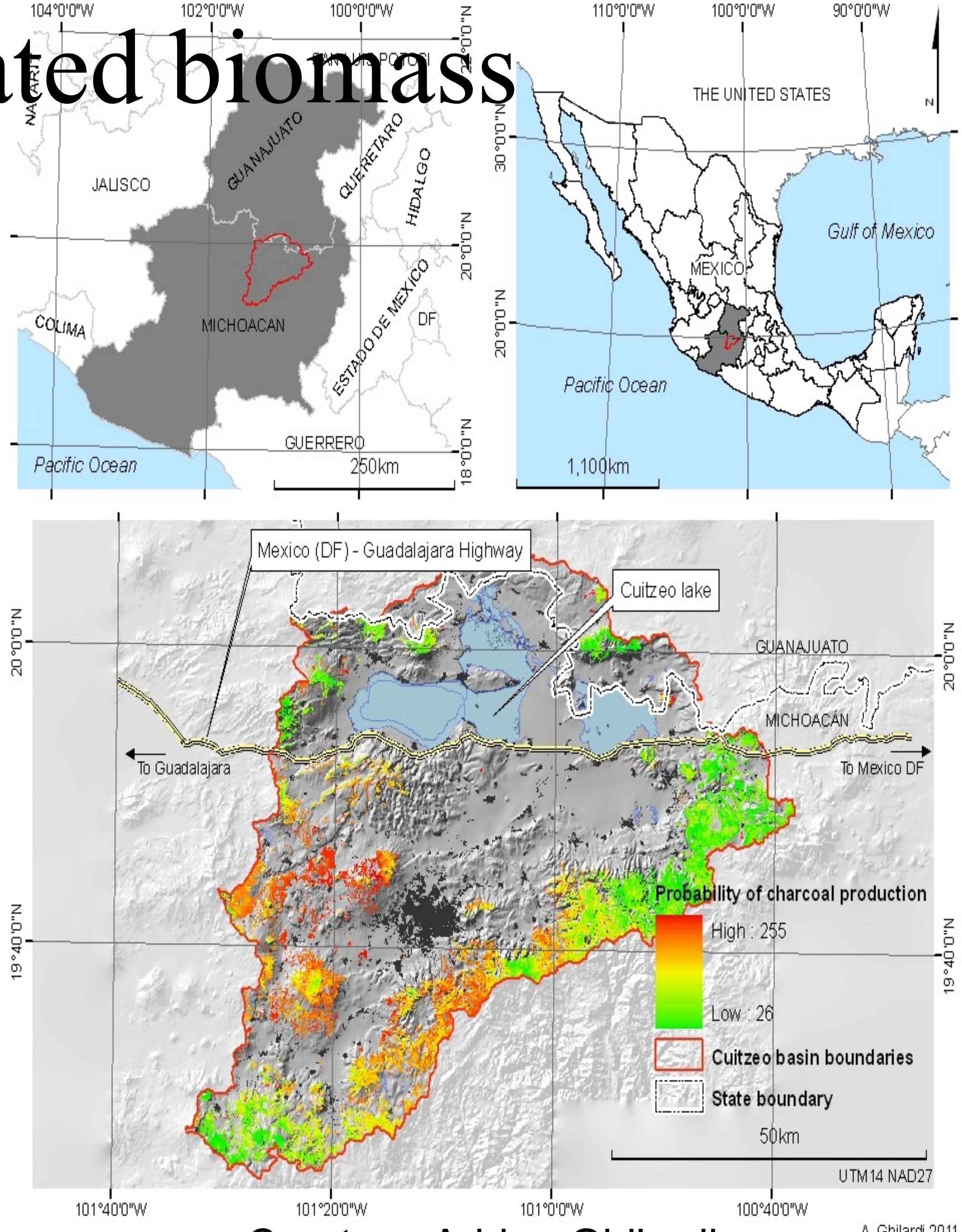
± represents 1 standard deviation.
*All differences between stoves were significant at the $p<0.001$ level using a Student's T test.

Small scale industries

- Rural small scale industries are practically uncharacterized, and we don't know a) how many there are, b) their emissions, or c) what fraction of biomass use they constitute.
- Even if we did know numbers and locations, application of industrialized country emission factors, such as those from the USEPA's AP-42 database, would almost certainly result in considerable errors in climate and pollution transport models, and would not be appropriate

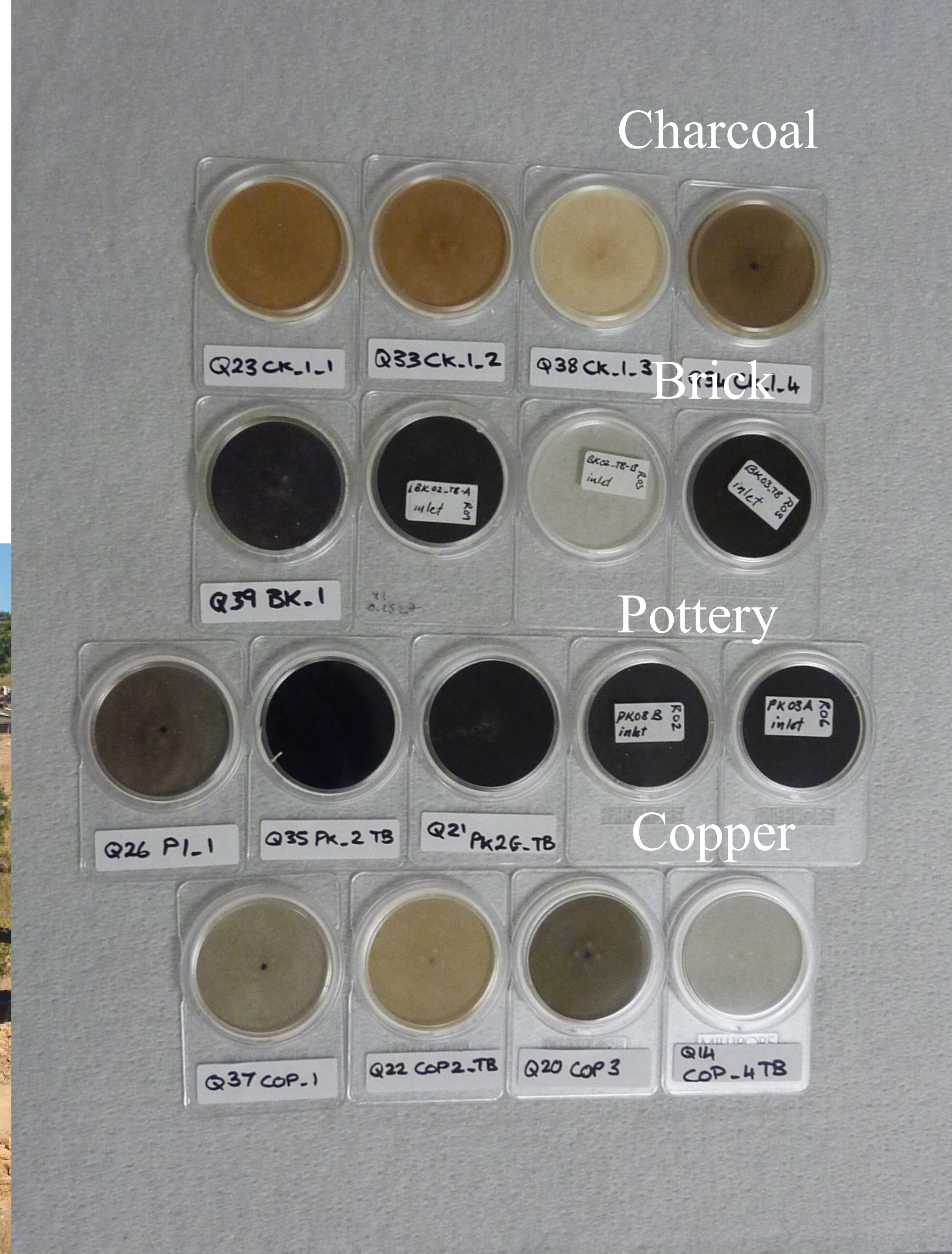
Combustion related biomass

Purepecha region	
brick	22%
copper	<1%
pottery	15%
bread	1%
domestic	61%



Courtesy Adrian Ghilardi

	EC/OC
Brick	0.44
Charcoal	0.01
Copper	0.08
Pottery	2.51

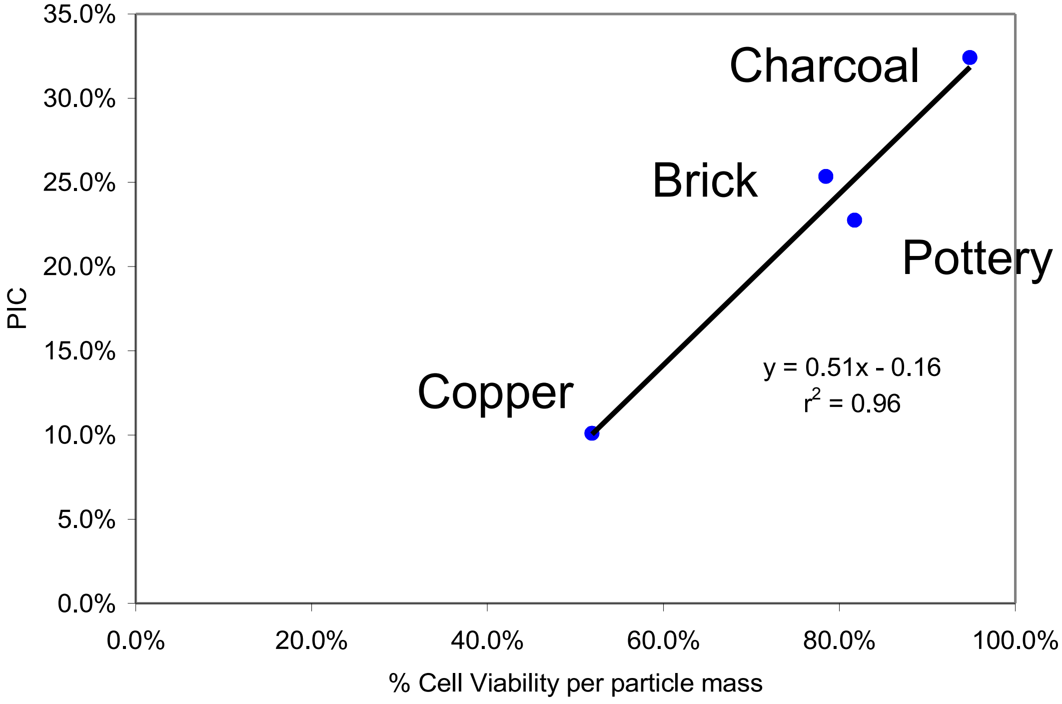


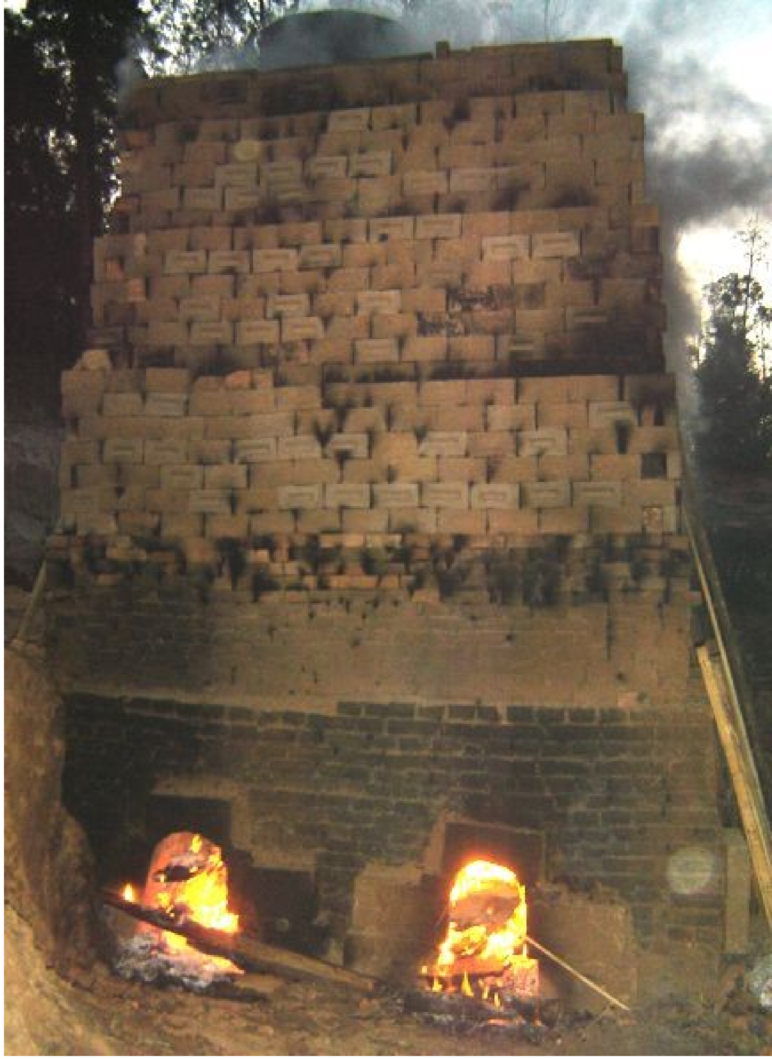
NCE and Emissions

	NCE	PIC	%CO	%CH4	%NMHC
Brick 1	87.7%	12.3%	11.1%	0.7%	0.5%
Brick 2	85.0%	15.0%	8.4%	4.0%	2.5%
Brick 3	64.3%	35.7%	30.7%	4.4%	0.6%
Brick	**79.0%**	**21.0%**	**16.8%**	**3.0%**	**1.2%**
Pottery 1	90.8%	9.2%	8.2%	0.7%	0.4%
Pottery 2	90.1%	9.9%	3.0%	1.7%	5.2%
Pottery 2 Glazing	83.5%	16.5%	5.3%	1.9%	9.4%
Pottery 3	71.0%	29.0%	18.5%	1.1%	9.4%
Pottery 3 Glazing	95.8%	4.2%	3.7%	0.4%	0.04%
Pottery	**86.2%**	**13.8%**	**7.7%**	**1.1%**	**4.9%**
Copper 1	96.2%	3.8%	2.3%	1.0%	0.5%
Copper 2	82.7%	17.3%	10.7%	5.2%	1.4%
Copper 3	97.1%	2.9%	0.6%	2.3%	0%
Copper 4	85.1%	14.9%	5.2%	9.8%	0%
Copper	**90.3%**	**9.7%**	**4.7%**	**4.6%**	**0.5%**
Charcoal 1 DAY1	74.8%	25.2%	17.1%	3.6%	4.4%
Charcoal 1 DAY2	75.5%	24.5%	20.2%	1.5%	2.8%
Charcoal 1 DAY3	72.0%	28.0%	13.9%	7.2%	7.0%
Charcoal 1 DAY4	66.0%	34.0%	14.2%	10.0%	9.7%
Charcoal 1	**72.1%**	**27.9%**	**16.4%**	**5.6%**	**6.0%**
Charcoal 2 DAY5	26.7%	73.3%	57.0%	0.9%	15.5%
Charcoal 2 DAY11	65.9%	34.1%	19.7%	0.2%	14.2%
Charcoal 2 DAY17	60.4%	39.6%	25.8%	0.4%	13.4%
Charcoal 2 DAY19	34.5%	65.5%	39.5%	0.9%	25.1%
Charcoal 2	**46.9%**	**53.1%**	**35.5%**	**0.6%**	**17.0%**

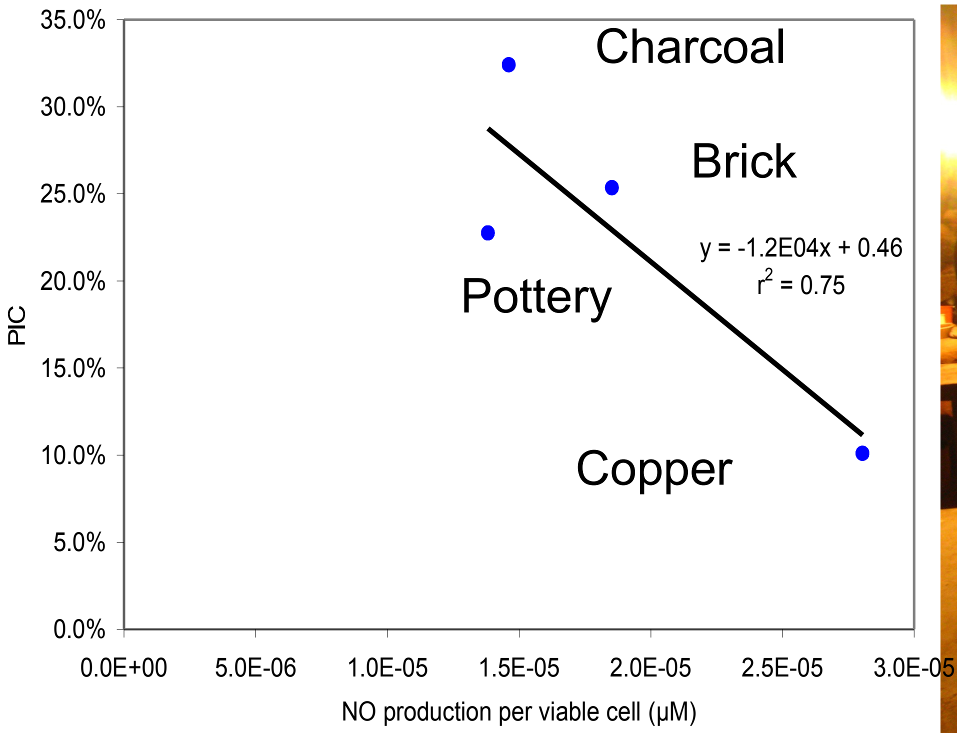
Charcoal kiln 1 was more efficient due to air entry

Cell viability vs PIC



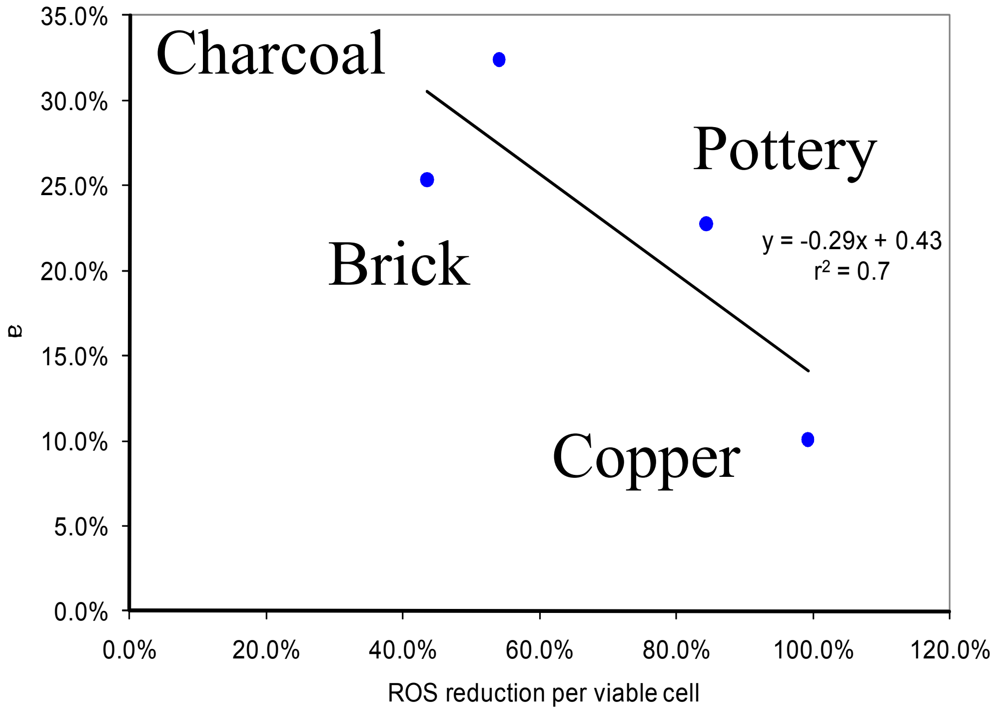


NO production vs PIC



Consistent with the cell viability - Peroxynitrite formed from NO attacks cell membranes leading to cell death

Inhibition of ROS production per viable cell and PIC



Focus on urban areas

Objective 1

Update emissions inventories with particulate (BC, OM, $PM_{2.5}$) and gaseous (CO_2, CO, CH_4, NMHC, SO_2) species from in field measurements of household stoves and rural small scale industries in 4 sites in a transect across the Himalayas:

- Nepal-Mid hills and plains
- China-Tibet
- China-Yunnan
- Haryana, India

Sample sites

Sampling site	Stoves	Fuel	Stove	Chimney	small scale industries	Kilns	Stack	Chimney
Northern Indi	15	Dung	traditional	no	brick	5	no	
	15	Crop residues	traditional	no	pottery	5	no	
	15	Wood	traditional	no	restaurants/bakeries	5		yes
	15	Wood	forced draft semi gasifie	no				
	15	LPG	gas	no				
Tibet	15	Yak dung	open fire	no	brick	5	yes	
	15	Wood	open fire	no	pottery	5	no	
	15	Honeycomb coal	Bucket stove	no	restaurants/bakeries	5		yes
	15	Yak dung	improved metal	yes				
	15	Wood	improved metal	yes				
Nepal	30	Dung	Traditional	no	brick	5	yes	
	30	Biomass and dung	Traditional	no	pottery	5	no	
	15	Kerosene	pressure	no	restaurants/bakeries	5		yes
China	15	Honeycomb coal	1st generation improve	yes	brick	5	yes	
	15	raw coal	1st generation improve	yes	pottery	5	no	
	15	Agricultural residue	1st generation improve	yes	restaurants/bakeries	5		yes
	15	biomass	1st generation improve	yes				
El Salvador	30	wood	traditional	no	brick	5	no	
	30	wood	Turbococina	no	pottery	5	no	
					roadside eateries (pupuserias)	5	no	no

Northern India; Concurrent project on impacts of household air pollution on birth outcomes. predominantly traditional cookstoves using dung, crop residues, and wood, advanced combustion biomass stoves (forced draft semi-gasifier stoves) In India 93% of total biomass fuel consumption occurs in households [54].

China-Tibet; local nomadic populations that primarily use yak dung and wood as fuel. In Tibet, dry dung cake and fuel wood contribute 95.2% of household energy consumption [55].

Nepal; Fuel use is predominantly wood 74%, dung 8%, and kerosene 3.5 % in Nepal [56]. Thus the fuel types measured as part of this proposal would represent 85% of fuel use.

China -Yunnan; Concurrent NCI group working on cancer, coal smoke and gene environment interactions.   Residential fuel use in China in 2000 was 22% wood 35% agricultural residues(straw) and 32% coal constituting 89% of rural household energy consumption [57]

El Salvador; evaluate an advanced combustion biomass cook stove used in homes, schools and in roadside food stalls (Pupuserías). Wood dominates residential energy consumption in El Salvador [58].

Objective 2

Identify major variability in emissions quantities and properties. Estimate sample sizes needed in future emissions measurements for updating global inventories, and determine how broad in scope our inventories need to be.

Objective 3

Estimate the potential of advanced combustion biomass stoves to mitigate emissions of greenhouse gases and particulate species in India and El Salvador.

Objective 4

Quantify the connection between light absorption, which is relevant to radiative forcing, and measurements of "elemental" carbon, the analytical quantity most frequently measured in emissions samples and in ambient air.


Thank you