Global Inventories of carbonaceous aerosols

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outline

1. estimating emissions
   a. particular challenges of carbonaceous aerosols
   b. inventory procedure & brief results
   c. major uncertainties
2. a brief history of inventories
   a. present dilemma
3. work on the future (from D. Streets)

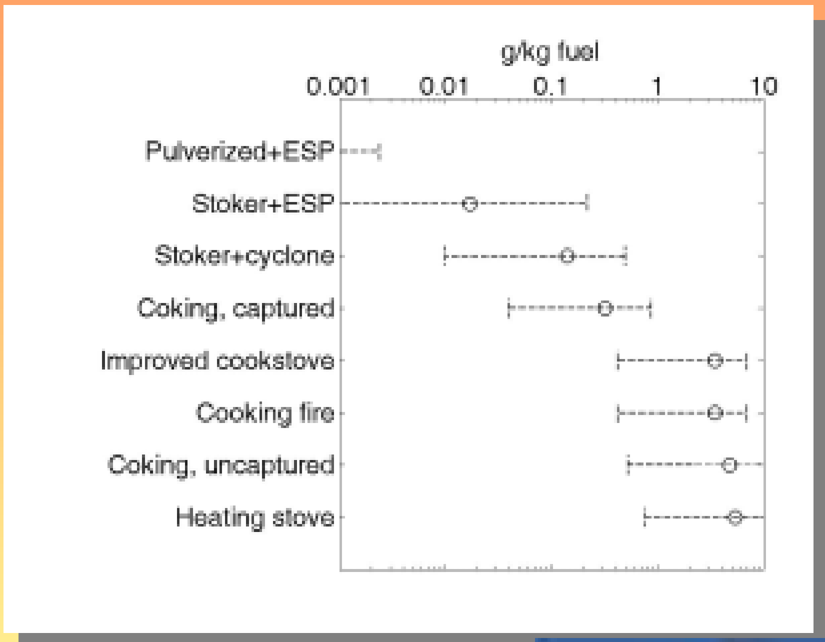
not here (and *needed*):

- *secondary anthropogenic* aerosol
- *biogenic* aerosol

BC/OC emission challenge

- Emission estimation
  - harder than species with bounded emissions (CO_2, SO_2)
  - similar to process-dependent species (NOx, CO)
- Model validation
  - harder than well-mixed species (CO_2, CH_4)
  - similar to species with short lifetimes ($SO_2/SO_4^=$, CO)
- Chemistry-optics connection
  - harder than single species (CO_2, CH_4, even $SO_4^=$)

Variability in different burning of the same fuel



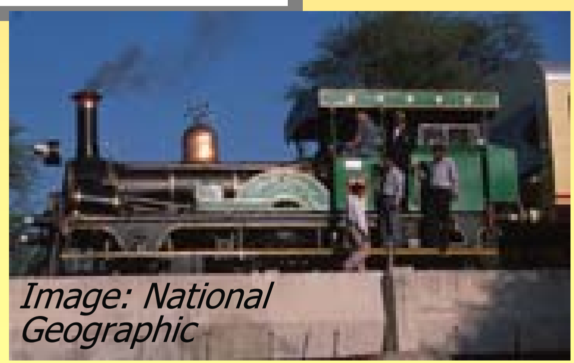
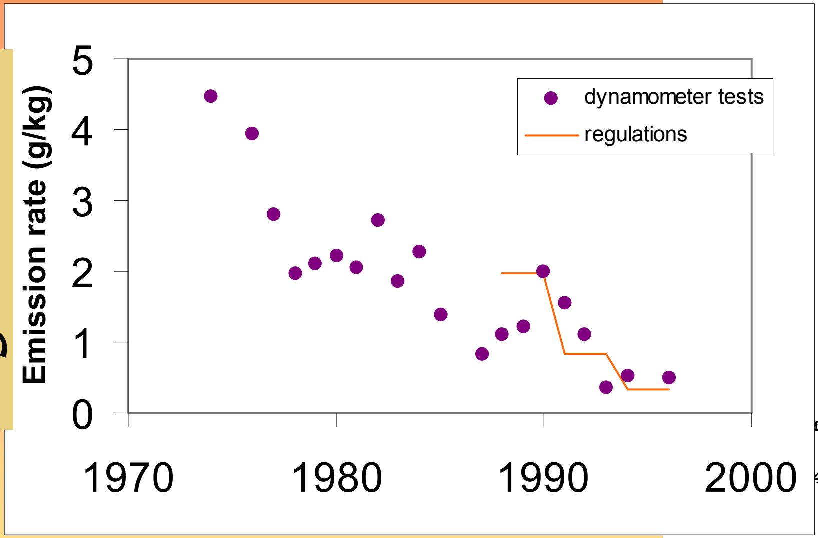


Image: National Geographic

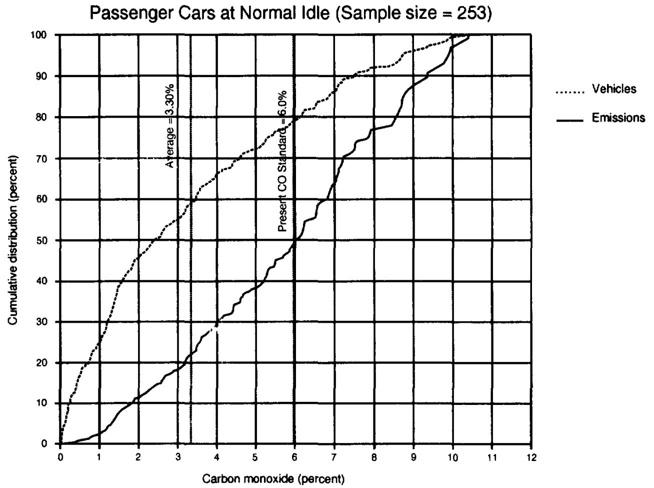
Variability betwe

Response to regulation



From *Yanowitz et al.*, 2000

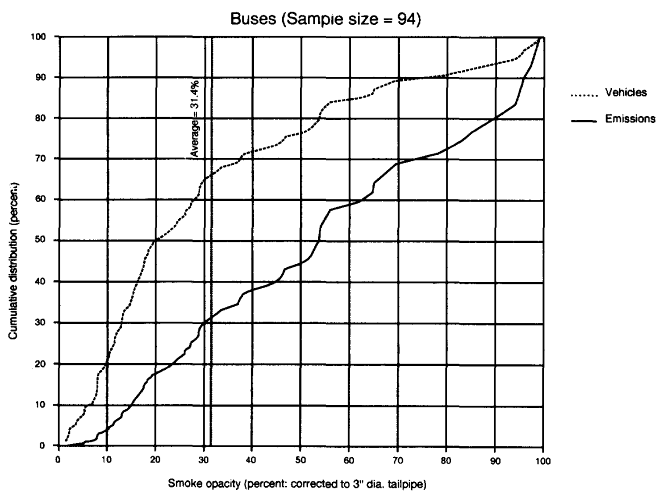
Figure 4.6 Cumulative Distribution of CO Emissions from Passenger Cars in Bangkok



lcGregor and others 1994

4.7 Cumulative Distribution of Smoke Opacity for Buses in Bangkok

Buses in one city



Source: McGregor and others 1994

From *Faiz et al.*, 1996

1a. some challenges

limit—the point at which "excessive soot" begins to form [8]. This limit is apparent in the figure for values of ϕ greater than about 0.6 when engine speed is about 600 RPM. At higher speeds, the acceptable ϕ is even lower, because the particles have less time to o… $m^2\ kg^{-1}$.

Variability of a single source

emission factor and aerosol type depends on burning conditions

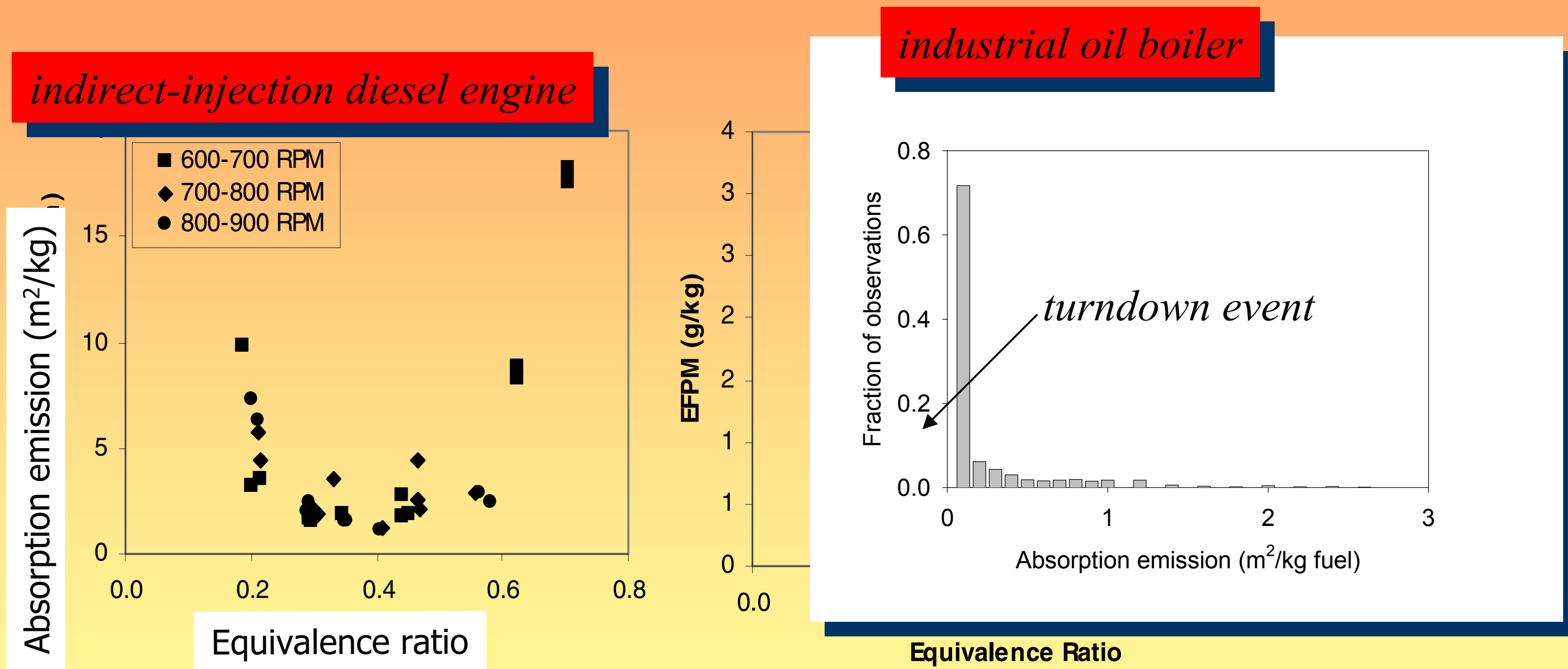


Figure 7- 1. Emission of absorption (left) and mass (right) from Caterpillar engine.

global inventory procedure

emission from one technology
= fuel use x PM emission factor x characteristics

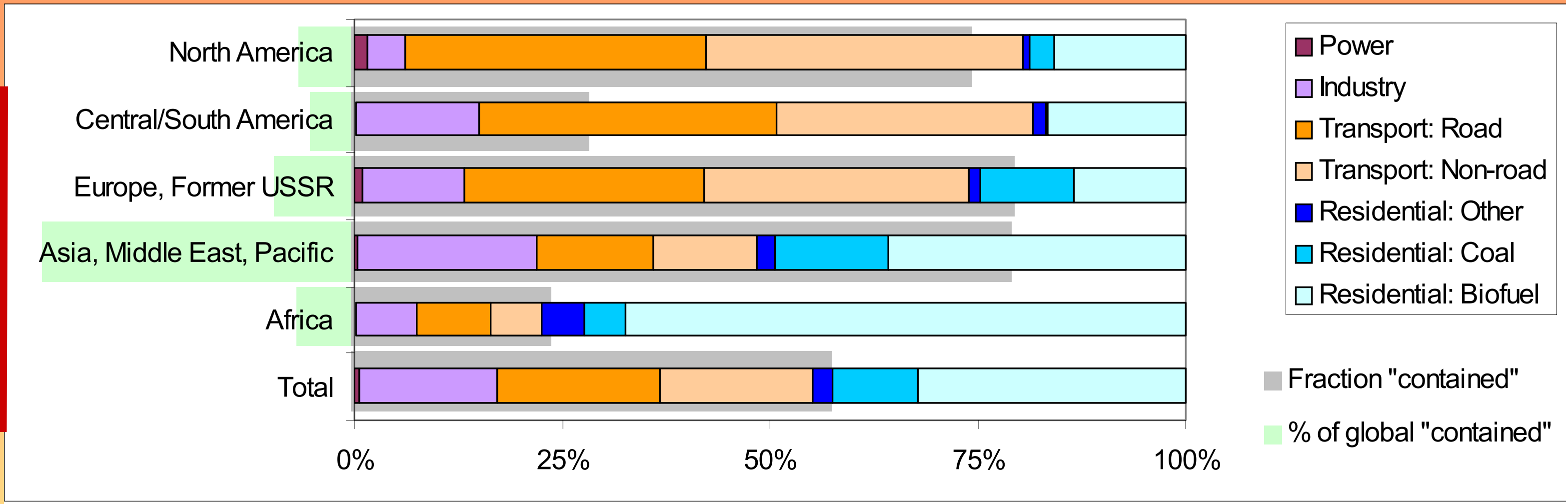
- activity levels (usually *fuel*)
  - International Energy Agency, United Nations, etc.
- emission factors (vary by fuel/technology)
- characteristics (also vary by fuel/technology)
  - BC fraction
  - Removal by control devices
  - Size (affects optical properties)
- technology divisions
  - division into >100 fuel+technology categories
  - regionally-distinct technology divisions

total emissions = sum over technologies

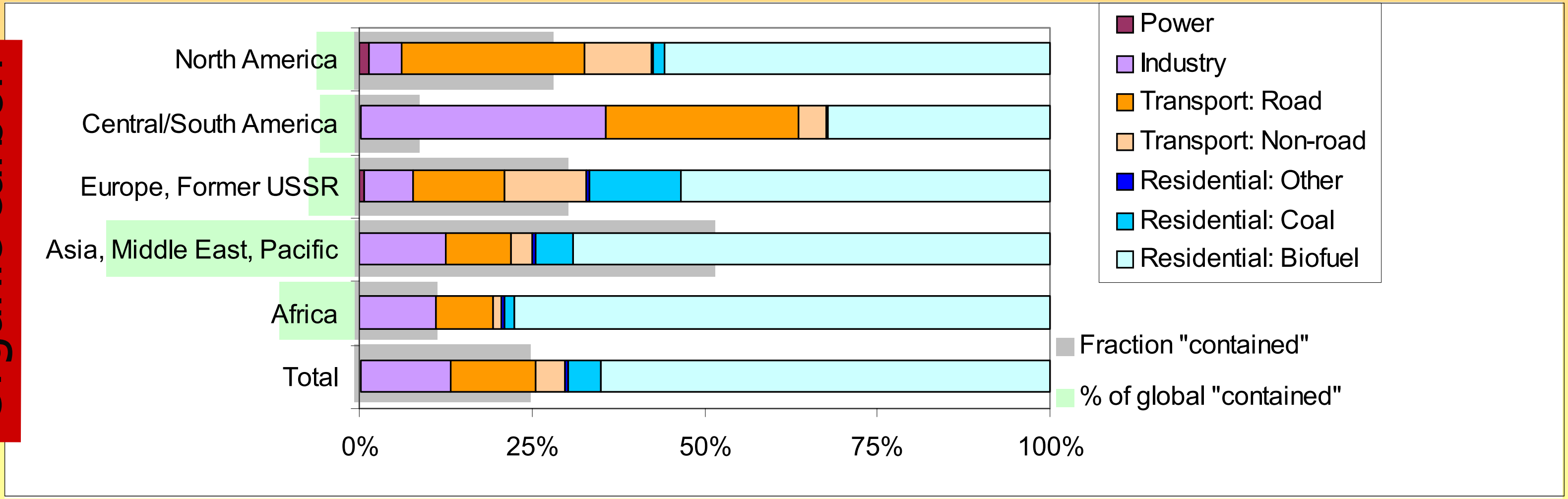
global sources

Bond, Streets et al., JGR 109, D14203, doi:10.1029/2003JD003697

Black carbon

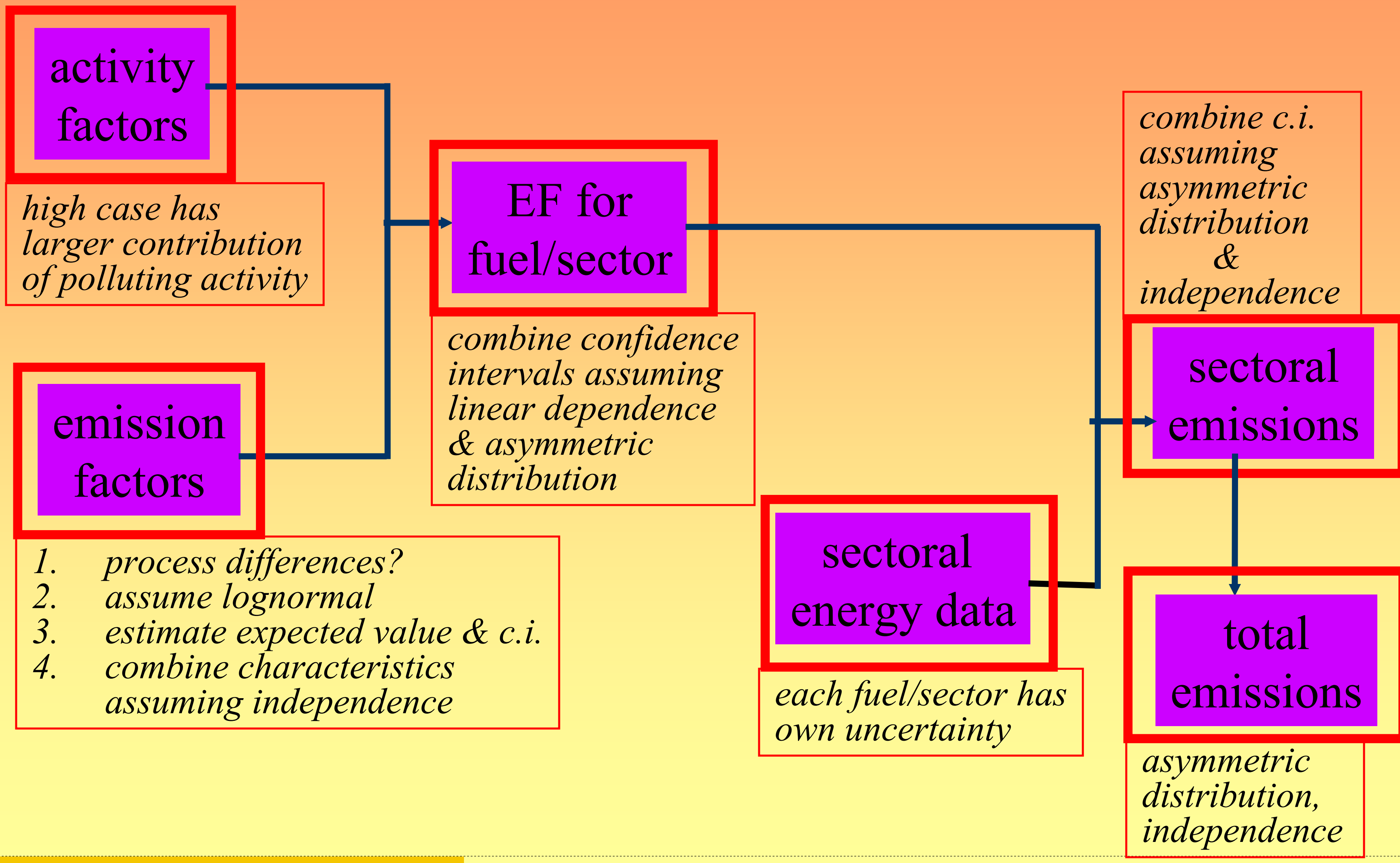


Organic carbon



1b. estimation procedure

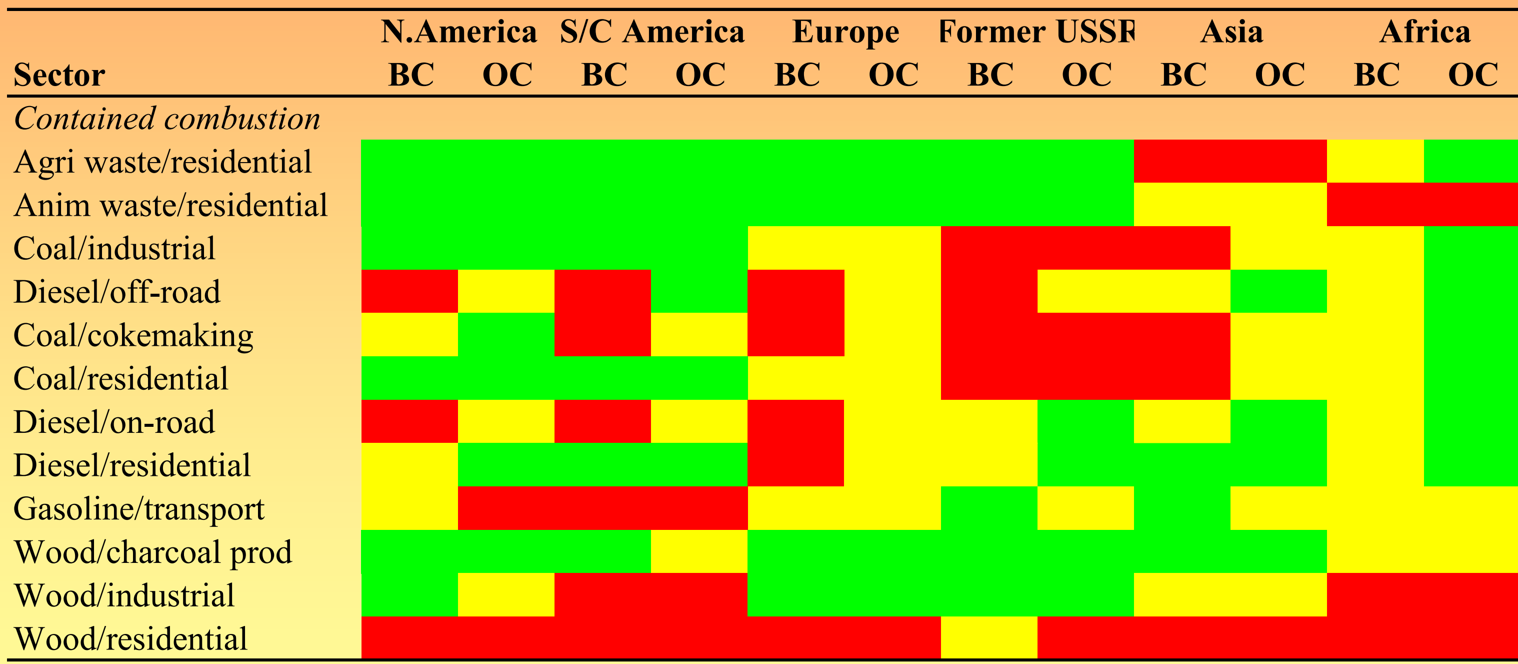
Estimating uncertainties



1b. estimation procedure

uncertainties

- inventory contains full uncertainty propagation (activity estimates, emission factors, etc)
- of course, there are many guesses



Uncertainty > 25% of total "contained combustion" emission estimate *for region*

Uncertainty > 10%

Open biomass burning

Issues

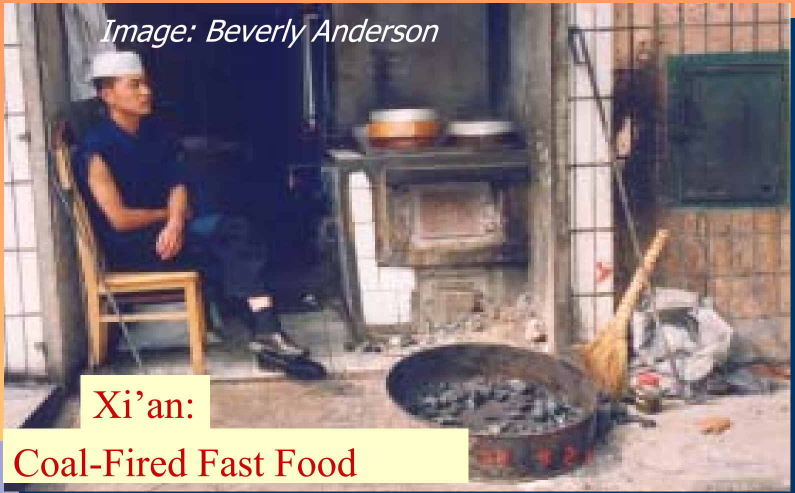
→ Quantities of vegetative matter burned
→ Emission factors variable with combustion conditions; not represented

Transport sector

Issues

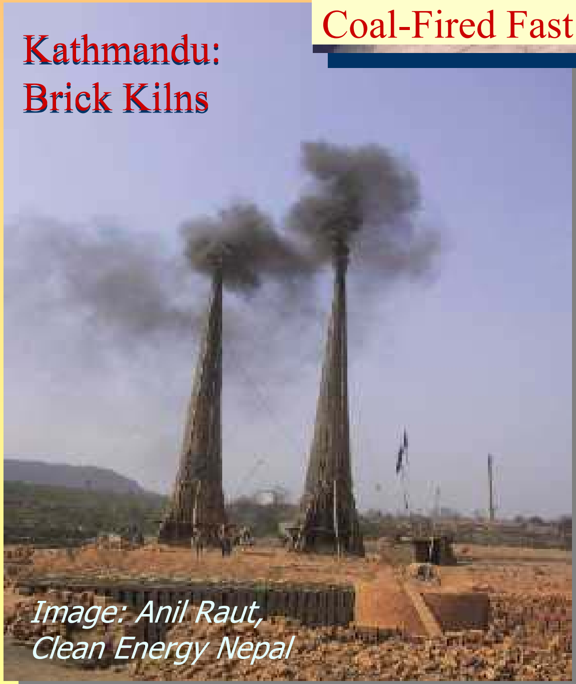
- on-road
  - estimated fleet emission factor (fleet information hard to find for many countries)
  - superemitters
  - difference between dynamometer measurements & real world
- off-road mobile/industrial
  - estimated from fraction of fuel used in various sectors
  - country treatment of reporting is inconsistent

Small industry



Xi'an:
Coal-Fired Fast Food

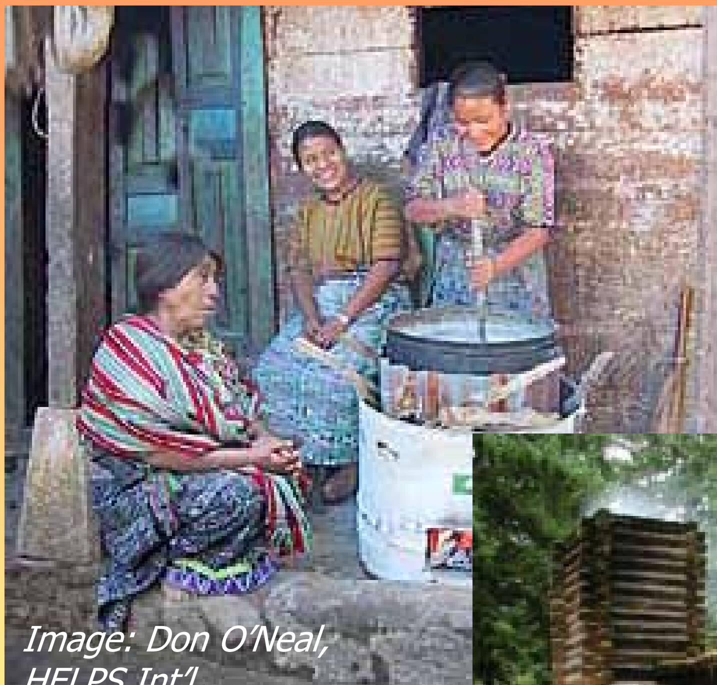
Kathmandu:
Brick Kilns



Issues

- limited measurements
  - emission factors/ characteristics
  - types of industrial use
  - willingness to be measured

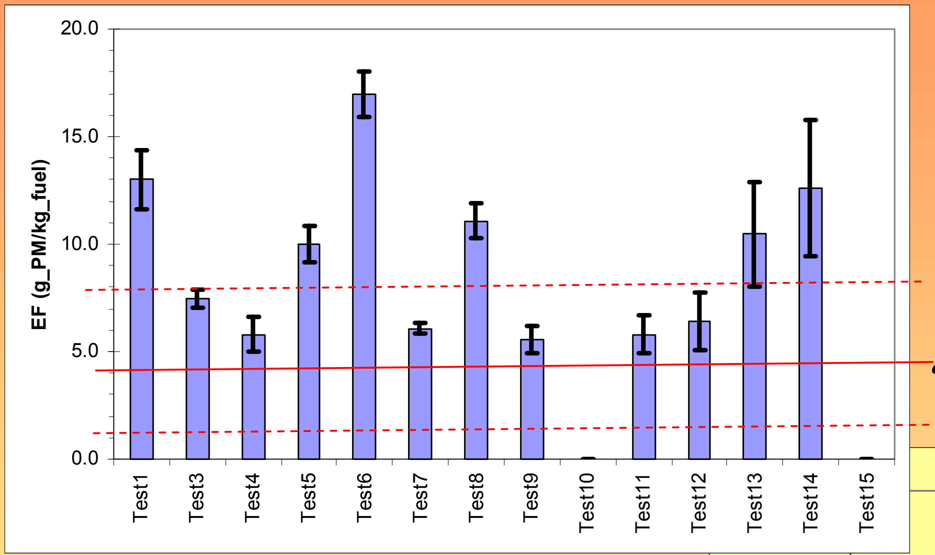
Domestic biofuel



Issues

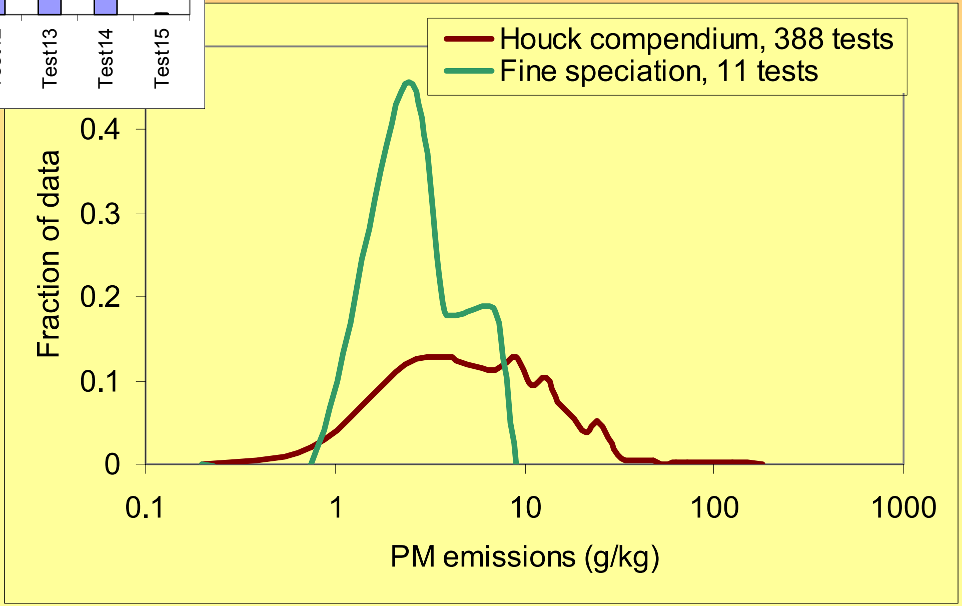
- fuel quantities
  - haven't been well estimated even by energy sector
  - not just a "developing" country issue (per-capita wood use in U.S. 50% of that in India)
- emission factors
  - many sources; difficult to estimate average
  - measurement of aerosol type (BC/OC) most uncertain

Domestic biofuel (II)



Field measurements higher than lab measurements
(*Christoph Roden, UIUC, work in progress*)

Mass & speciation information from different sources



1c. major uncertainties

A brief history of global inventories

1983	Turco	order-of-magnitude estimate
1993	Penner	based on fuel use
1996	Cooke & Wilson	fossil fuel + biofuel
1996	Liousse	biomass/biofuel
1999	Cooke et al	emissions different by development level
2001	Andreae & Merlet	comprehensive tabulation of biomass emission factors
2004	Bond & Streets	emissions different by technology

A brief history of global inventories

	black carbon	organic carbon
1983 Turco	2.6-22	
1993 Penner	6.6 FF, 6 BB 24 (ratios w/sulfur)	
1996 Cooke & Wilson	8 FF, 6 BB	
1996 Liousse	5.6 BB	45 BB
1999 Cooke et al	5.1 FF	10 FF
2001 Andreae & Merlet	4.8 BB	36 BB
2004 Bond & Streets	3.0 FF, 5.0 BB/BF (4.3-22)	2.4 FF, 31 BB/BF (17-77)

Why the reduction in FF emissions?

Bond (2004) vs Cooke (1999)

Differences are easily explained.

Coal, power generation (difference 1.5 Tg/yr)

We rely on measured BC fractions (<1%) instead of guesses (25%)

On-road diesel (difference 1 Tg/yr)

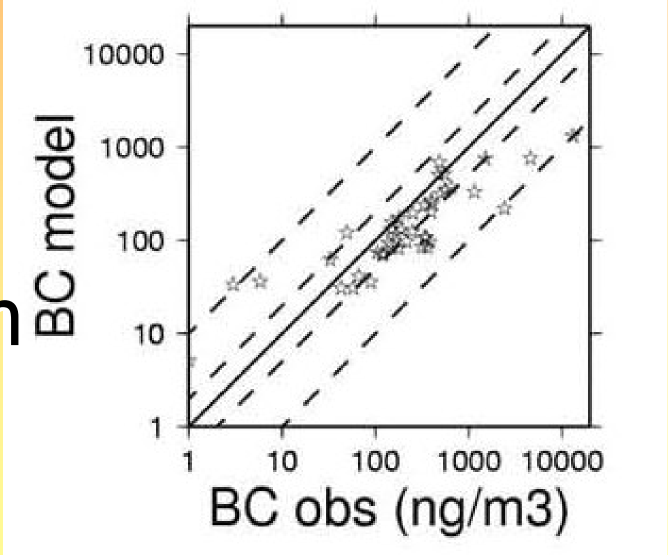
We use emission measurements and World Bank studies instead of assuming "developing countries have 5x higher emissions" (15 g/kg average PM emission factor)

Domestic diesel (difference 0.25 Tg/yr; large in Europe)

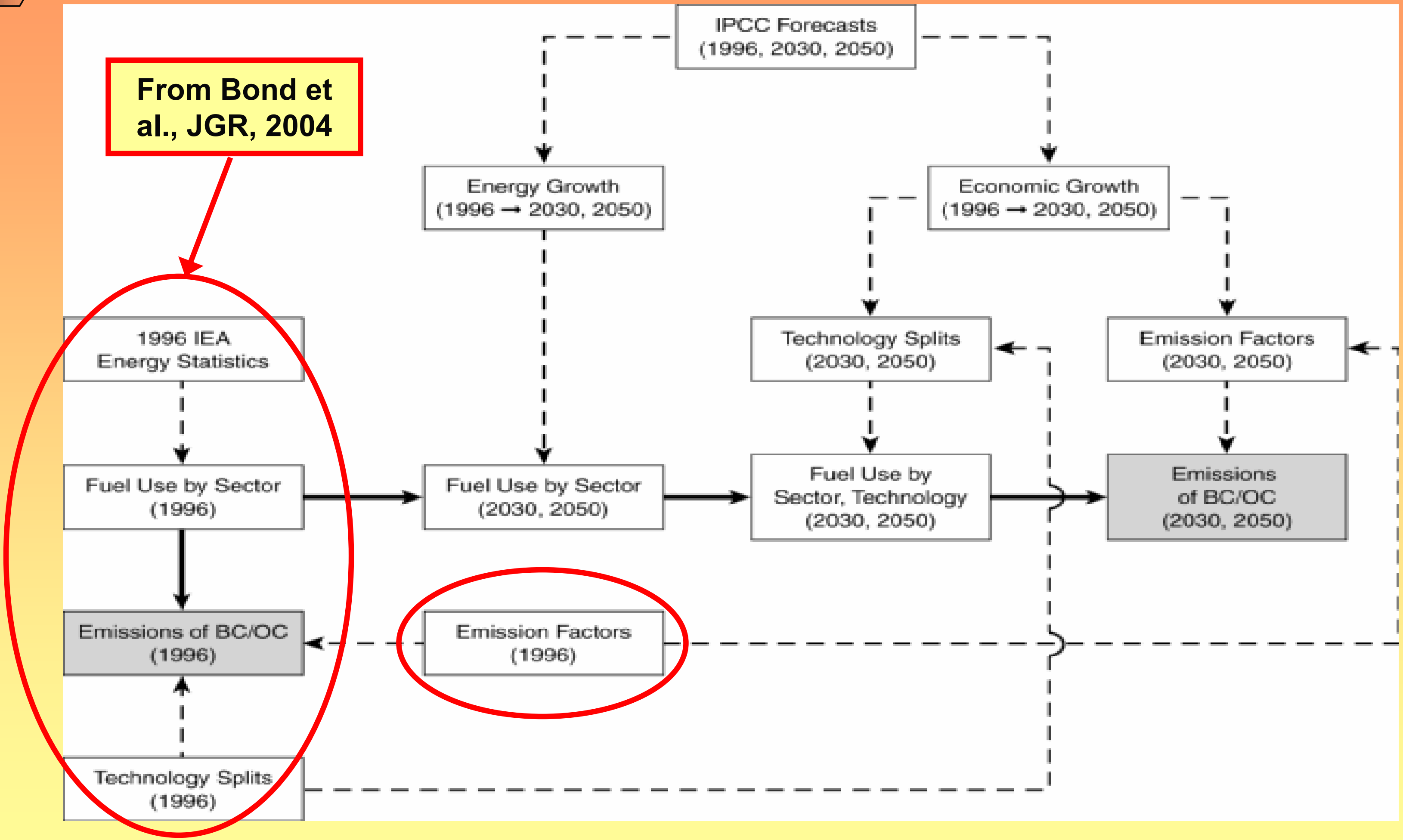
We do not apply emission factors for internal combustion engines to external-combustion boilers

The present dilemma

- “corrections” reduced emission estimates from 14 Tg/yr to 8 Tg/yr
- models typically need more BC to match observations… not less!
- measurement techniques may be uncertain…
- …but probably not enough to explain discrepancy.



Forecasting BC and OC emissions

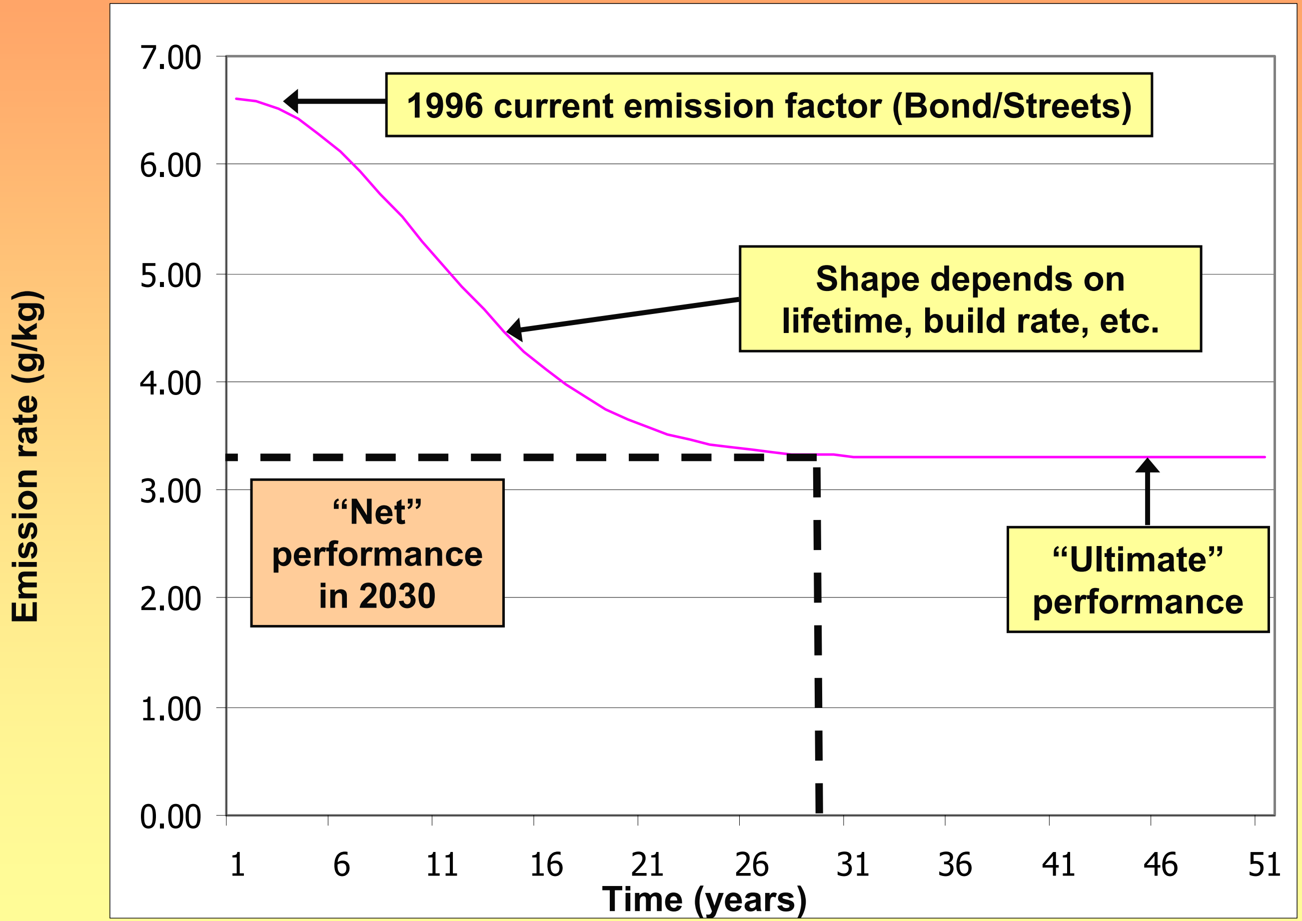


How fast will control technology improve?

Electrostatic precipitator, high collection efficiency

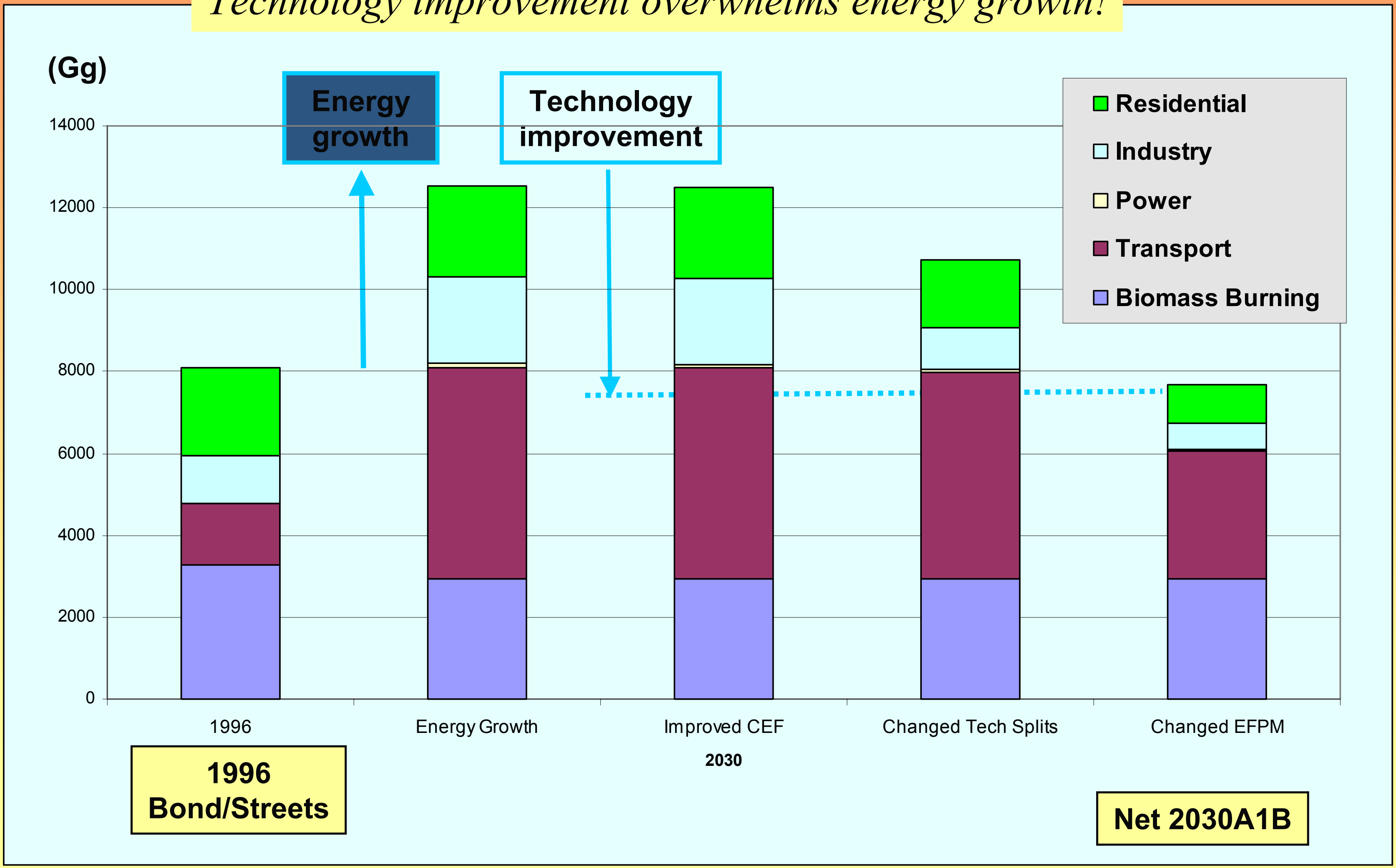
Cyclone, low collection efficiency

Representing time trends with S-shaped technology penetration curve



BC emission changes between 1996 & 2030A1B

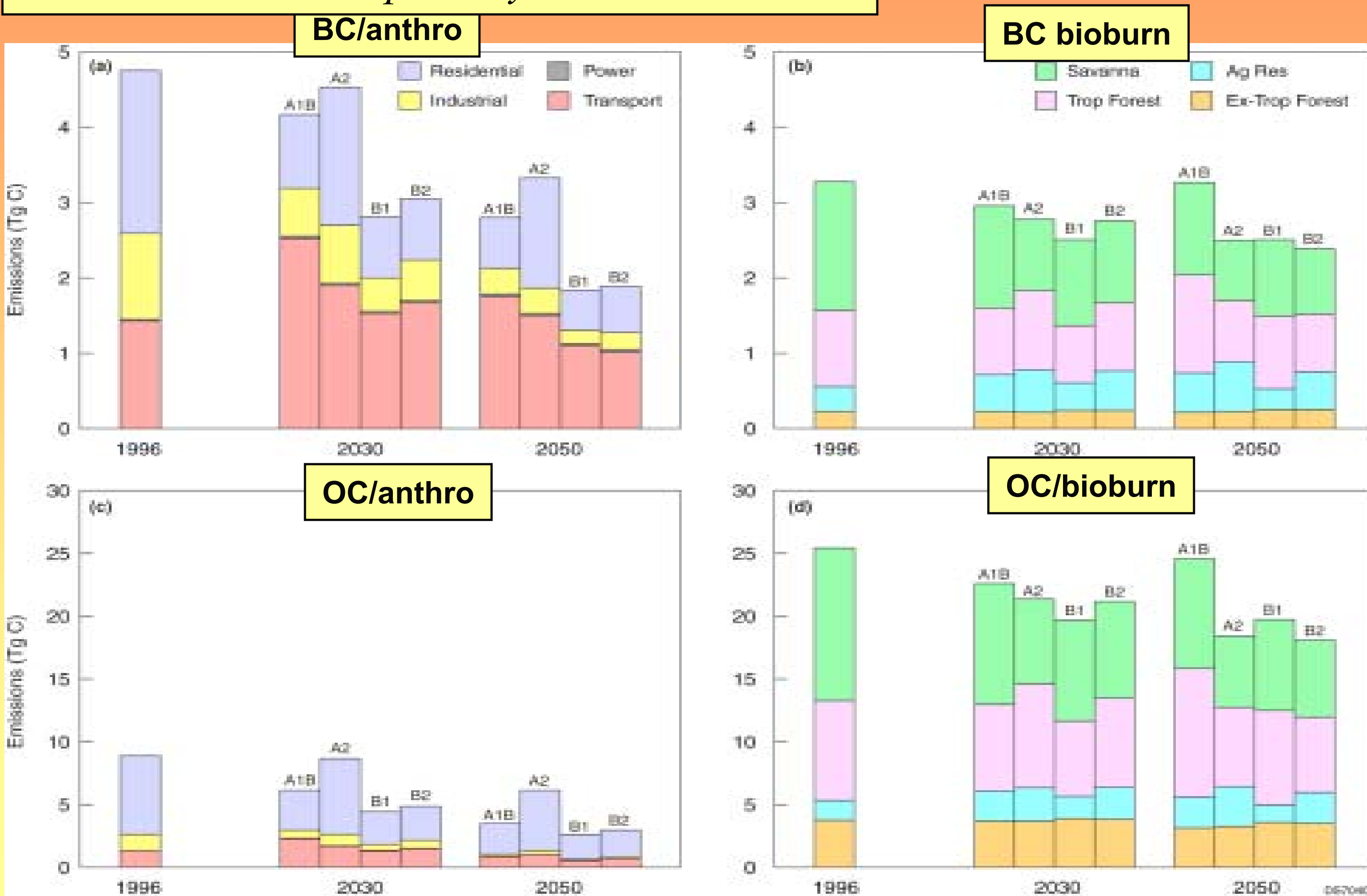
Technology improvement overwhelms energy growth!



3. future carbonaceous

General decline in all cases

Results suggest we are headed for a world with stable or lower primary aerosol emissions



Main message

- Estimating emissions of carbonaceous aerosols has challenges that may go beyond previous IPCC inventories.
- Technology & other practice are important.
- More *cooperation* and *information* from local knowledge is needed.