Carbon on Steroids: The Untold Story of Methane, Climate, and Health

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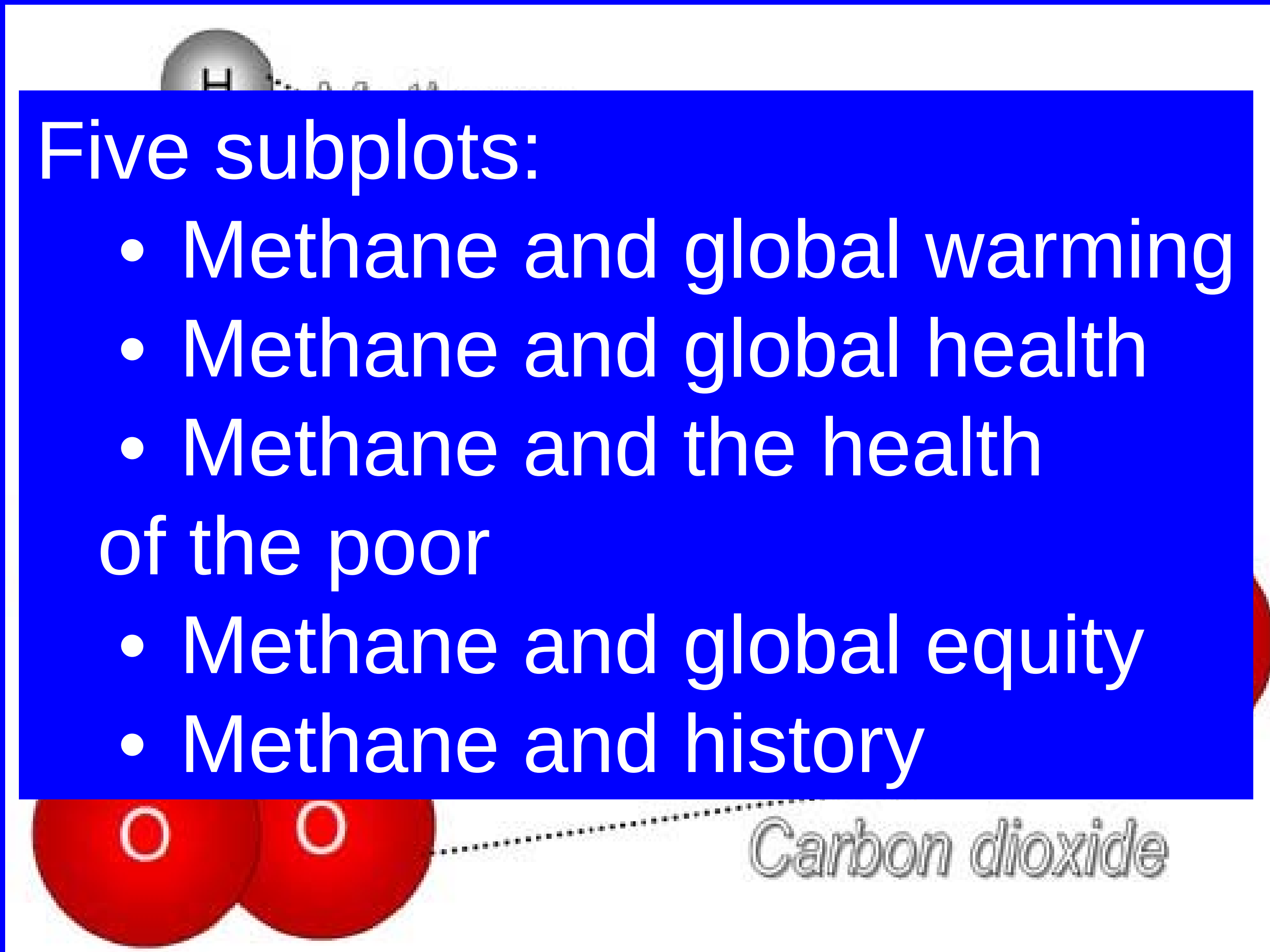
Nobel Laureate 2007 → At the 0.02% level

Energy and Resources Group Colloquium
September 17, 2008

Carbon dioxide is important

Do not think otherwise

The Methane Story: CH_4



Five subplots:

- Methane and global warming
- Methane and global health
- Methane and the health of the poor
- Methane and global equity
- Methane and history

Atmospheric Greenhouse gas concentrations

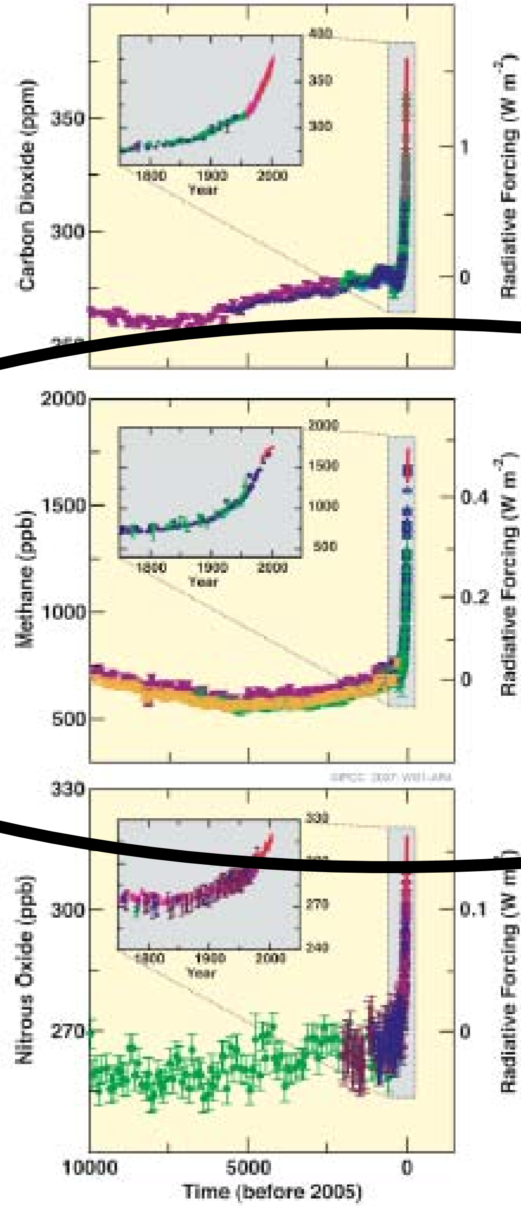


Figure SPM.1
IPCC 2007

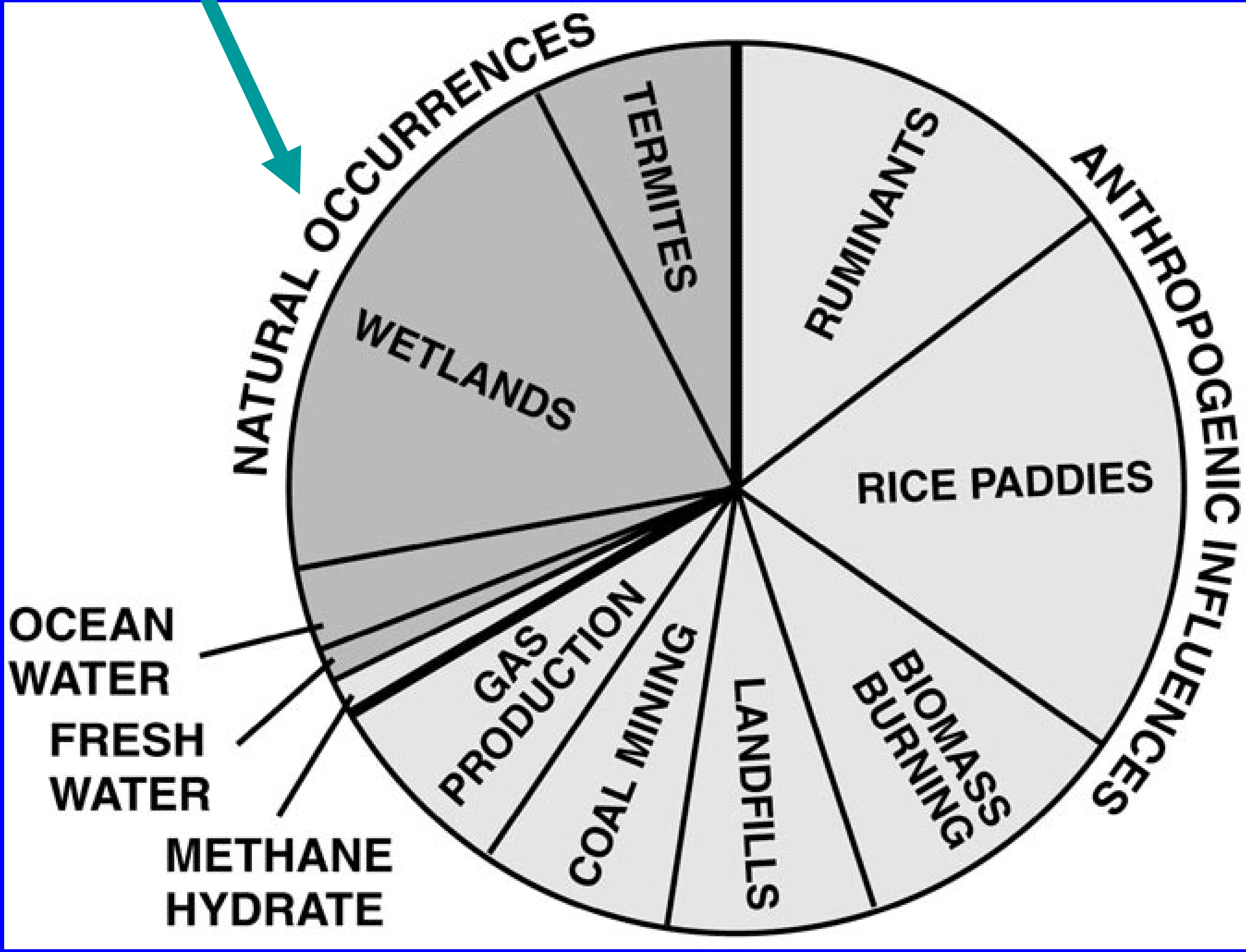
Anthropogenic Sources

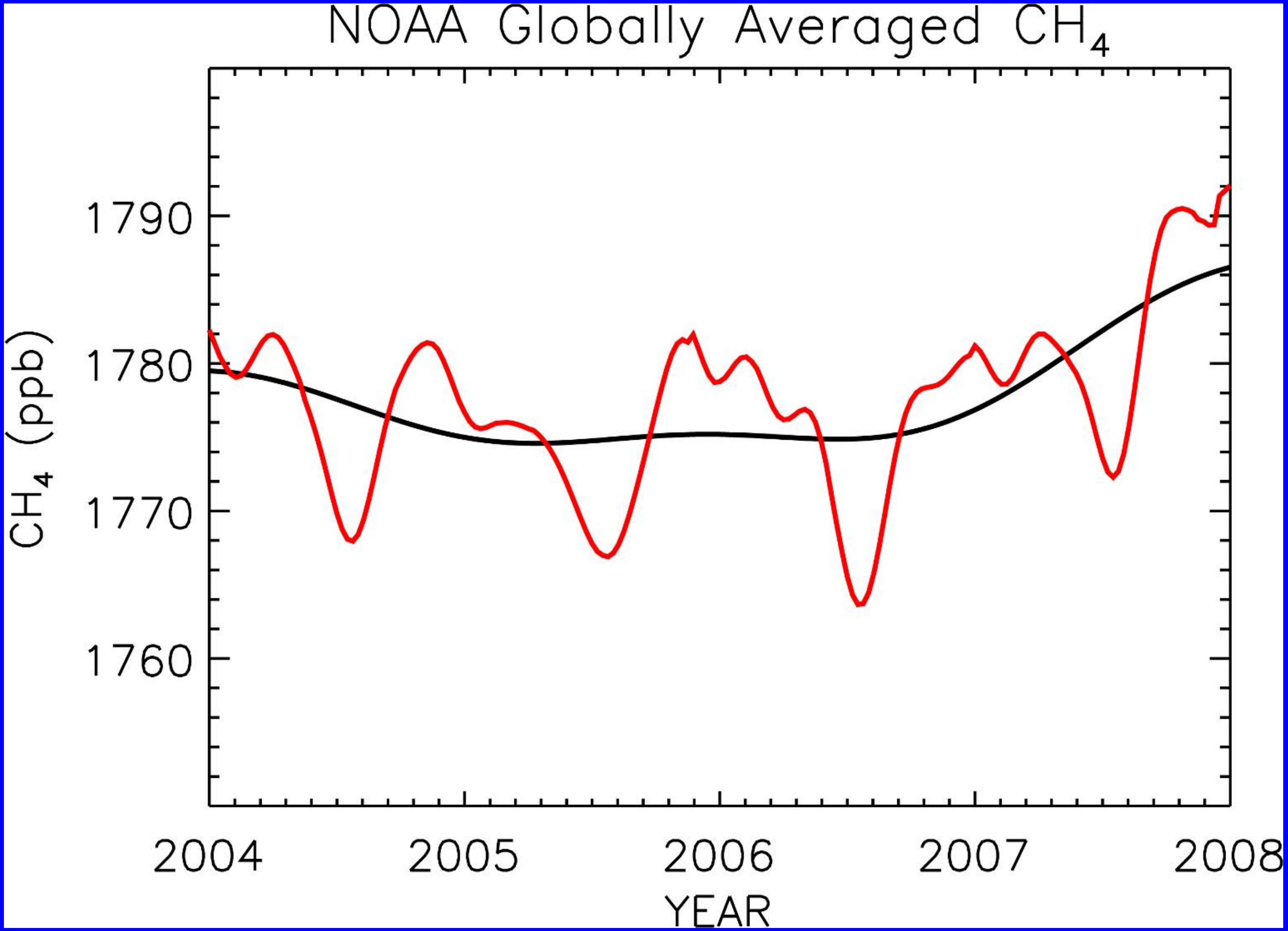
CO_2
Fossil fuels
Land use change
Cement manufacturing

Methane
Landfills
Rice
Livestock
Waste management
Fossil recovery

N_2O
Fertilizer
Planted N-fixers
Combustion

Only one-third of emissions from natural sources





NOAA Globally Averaged CH_4
CH_4 (ppb)
1790
1780
1770
1760
2004
2005
2006
2007
2008
YEAR

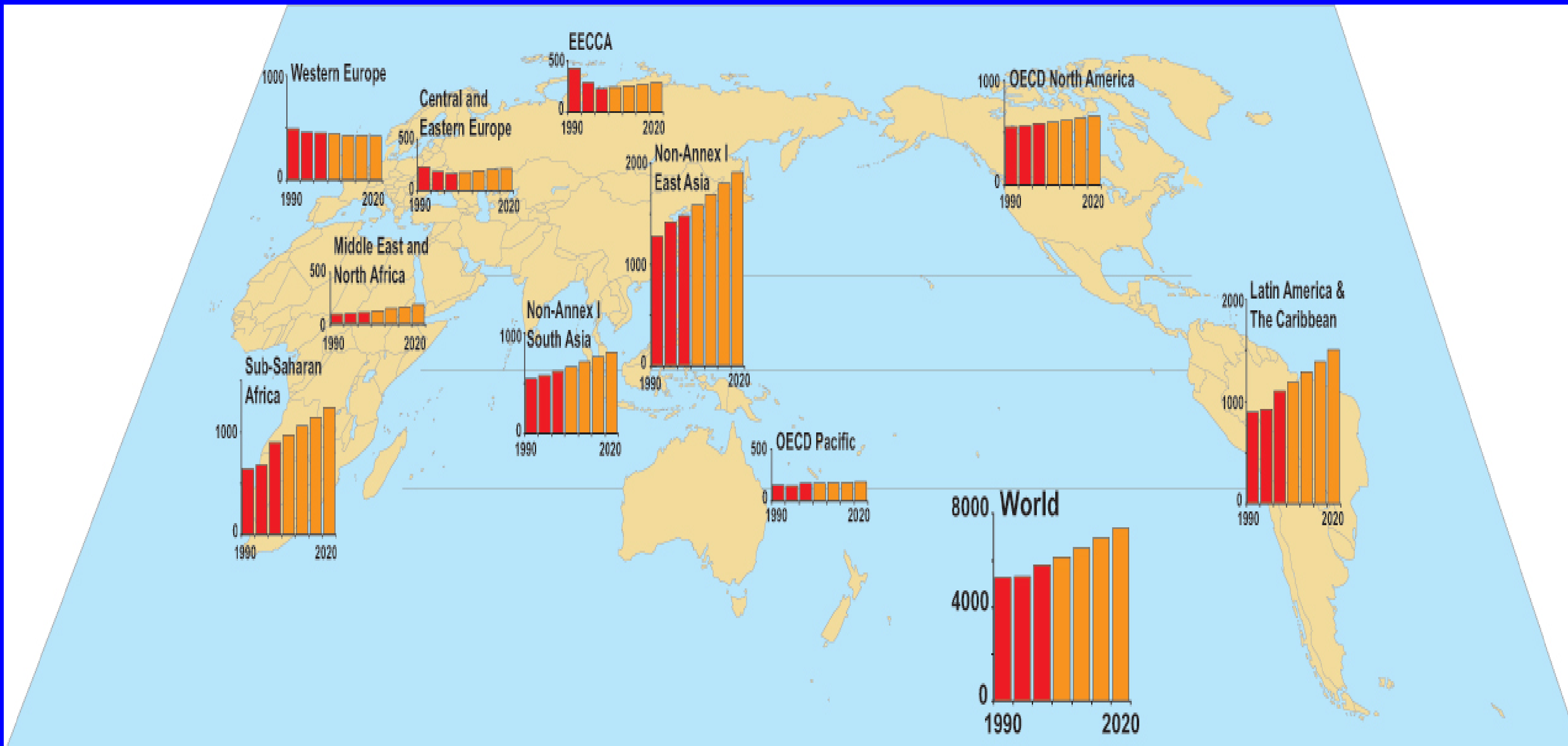
”We’re on the lookout for the first sign of a methane release from thawing Arctic permafrost. It’s too soon to tell whether last year’s spike in emissions includes the start of such a trend.”

Ed Dlugokencky, NOAA, Apr 2008

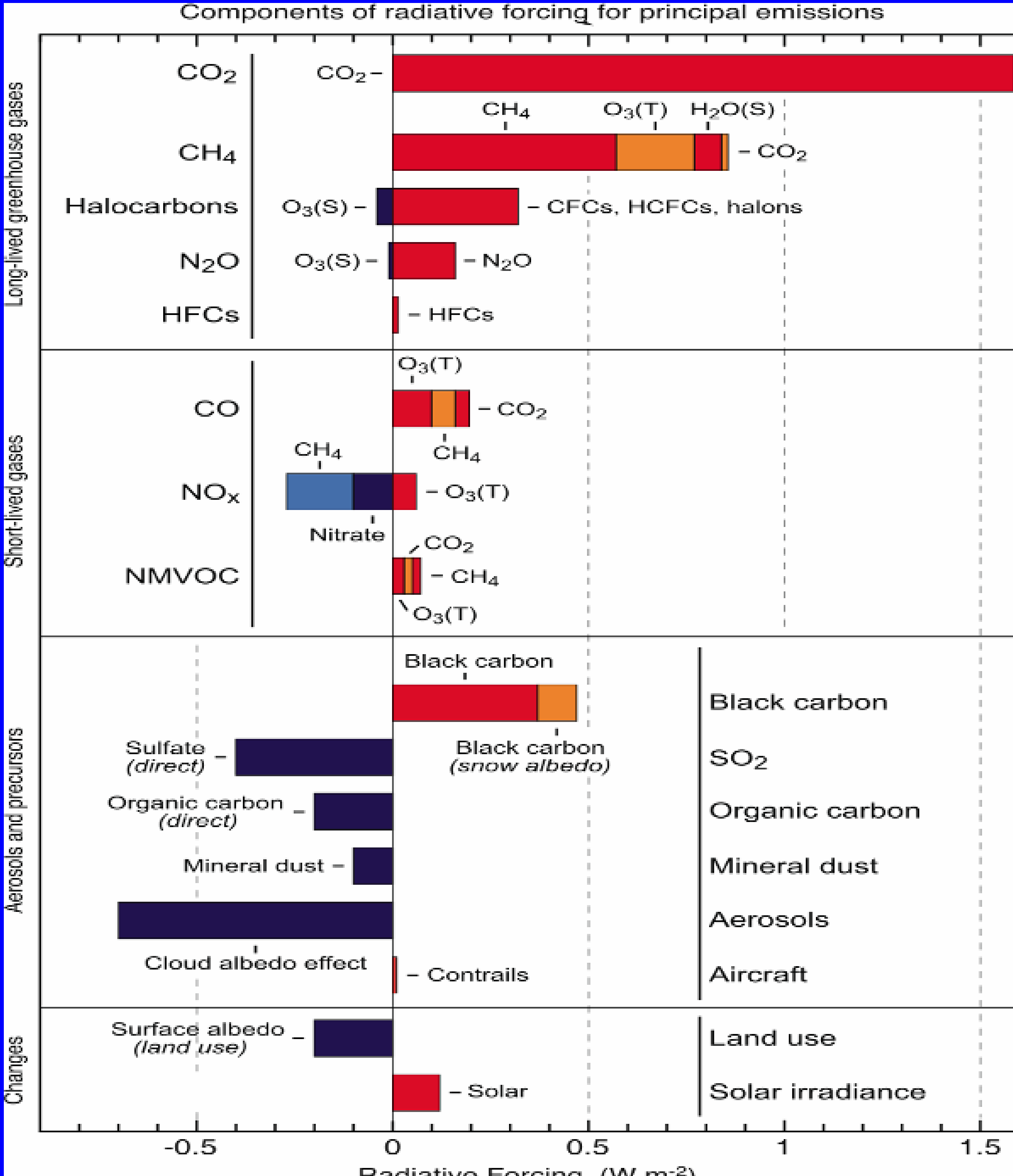
Projections of human emissions growth, however, put them at 1.5% per year, similar to CO_2

60% more by 2030

Current and Projected CH_4 and N_2O Emissions from Agriculture ($MtCo_2$-eq)



IPCC TS-III, 2007



Warming in 2005 from emissions since 1750

More than half due to methane

IPCC, 2007

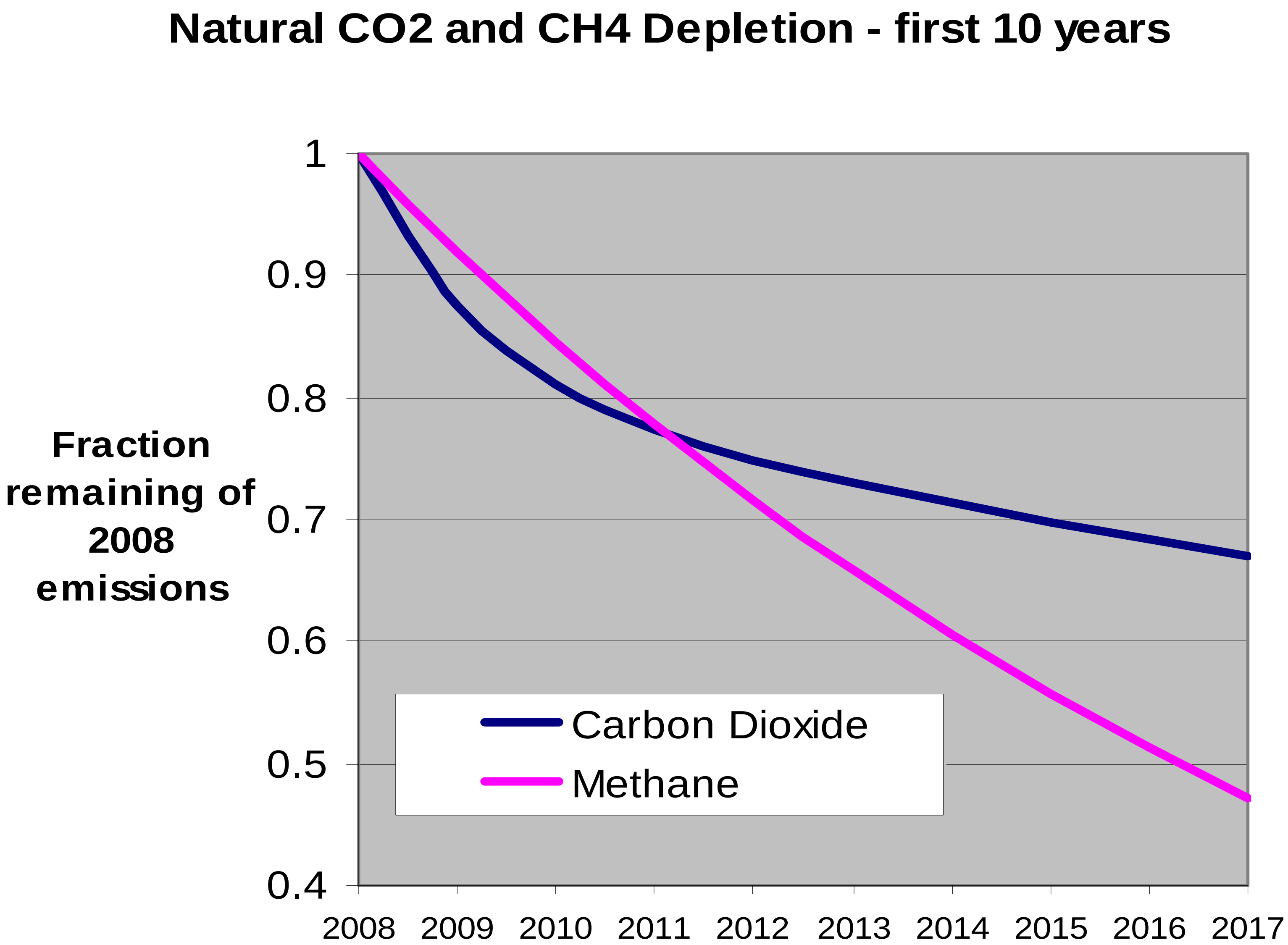
1. Methane and Global Warming

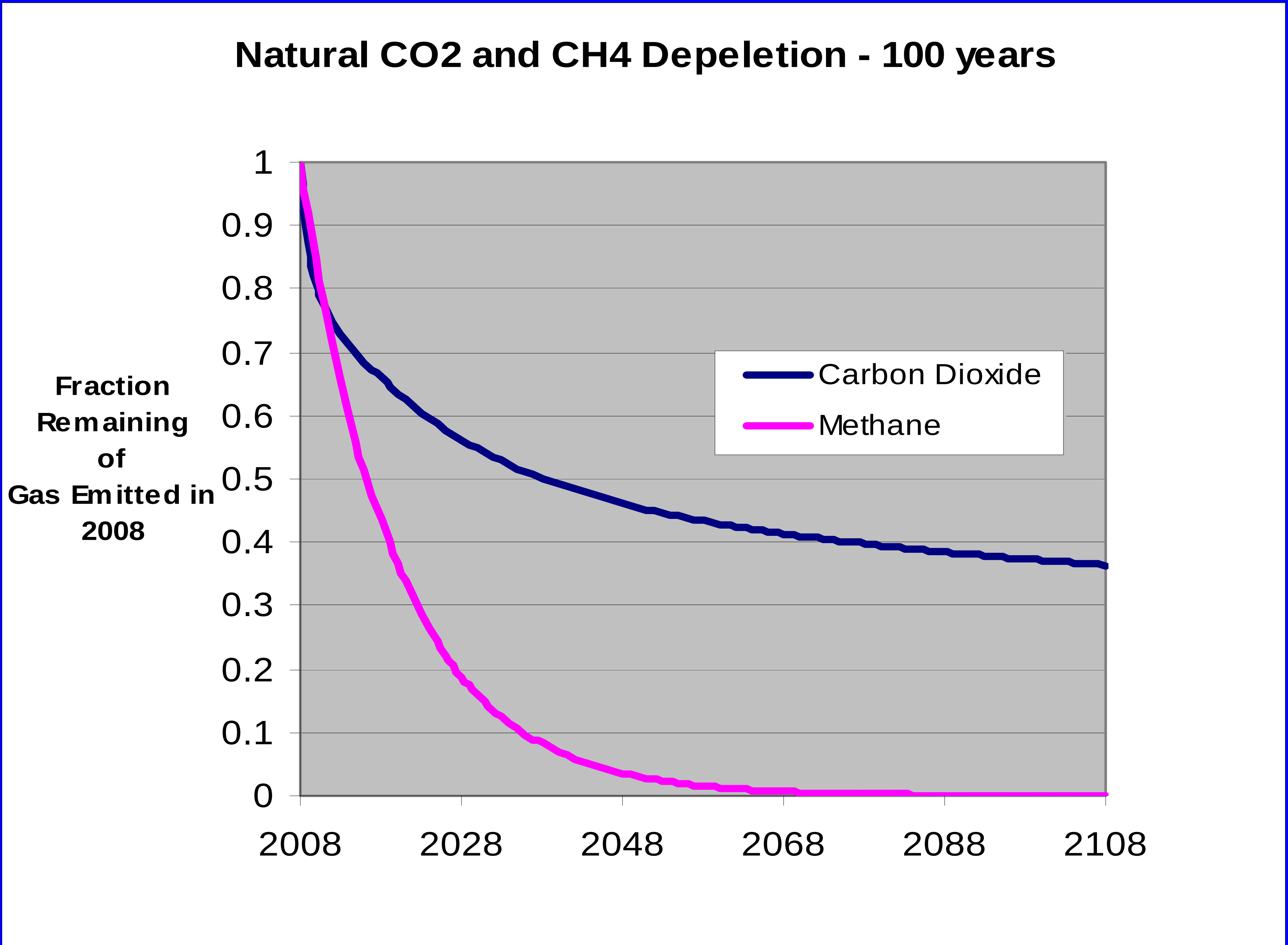
- A much more powerful greenhouse gas (GHG) than CO_2
- Partly due to its direct effect, but also because it creates ozone (O_3), another powerful GHG
- Nearly 100 times more per ton than CO_2 at any one time (73x from direct effects)
- Eventually turns to 2.75 times as much CO_2 by mass
- Methane has thus contributed a significant amount to global warming, more than half that of CO_2
- But has a much shorter atmospheric lifetime compared to CO_2

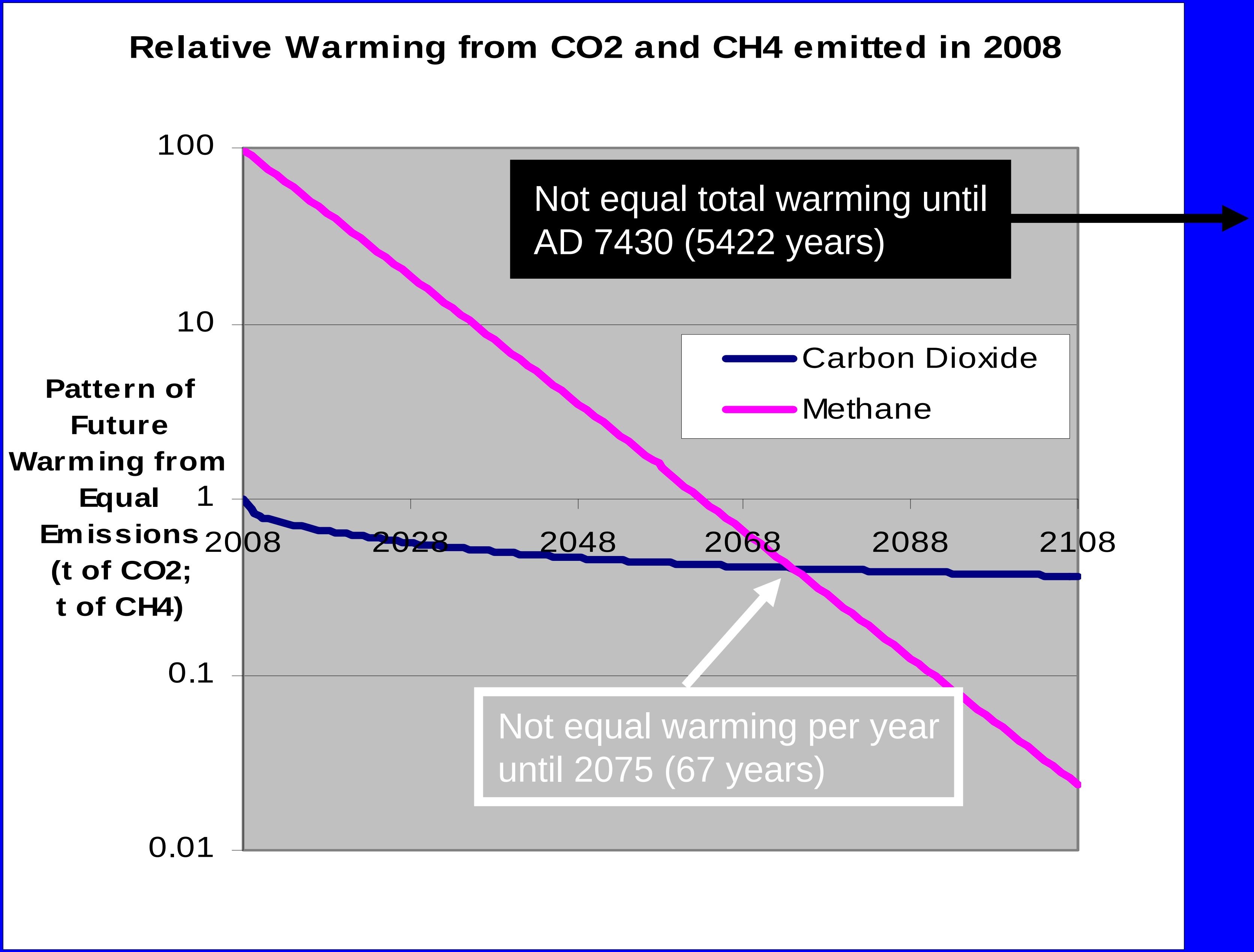
Math of GHG Decay (AR4)

- CO_2 goes into four compartments:
  - 19% of total with a lifetime* of 1.2 years
  - 34% at 18.5 y
  - 26% at 173 y
  - 21% with a lifetime of “many thousand years”
- Methane has a 12 y lifetime,
  - but contributes to ozone, a GHG
  - and eventually oxidizes to CO_2

*Lifetime refers to the time to reach 1/e (37%) of the original amount


Natural CO2 and CH4 Depletion - first 10 years
Fraction remaining of 2008 emissions
1
0.9
0.8
0.7
0.6
0.5
0.4
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Carbon Dioxide
Methane


Natural CO2 and CH4 Depeletion - 100 years
Fraction Remaining of Gas Emitted in 2008
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2008
2028
2048
2068
2088
2108
Carbon Dioxide
Methane

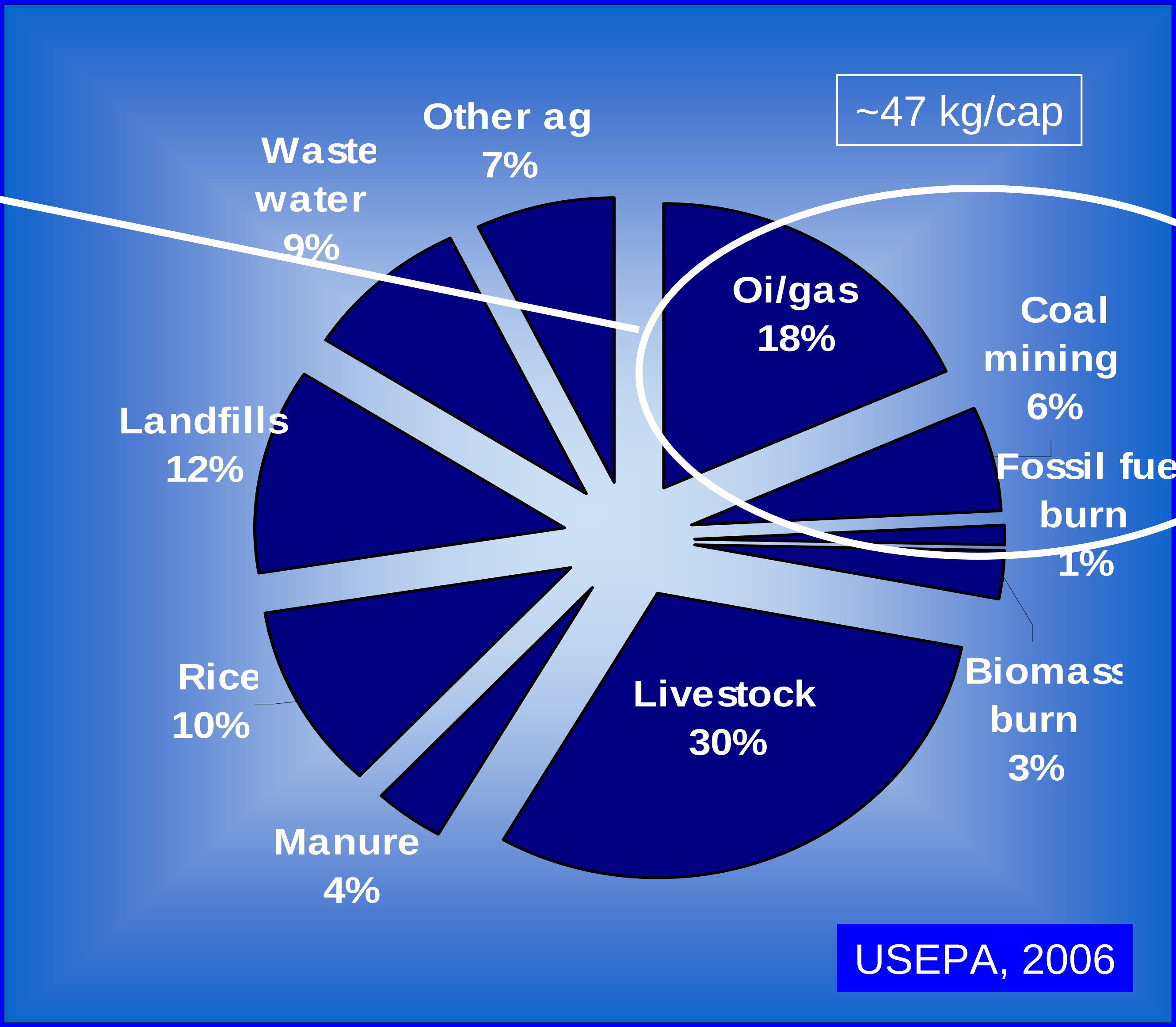

Relative Warming from CO2 and CH4 emitted in 2008
Not equal total warming until AD 7430 (5422 years)
Carbon Dioxide
Methane
Pattern of Future Warming from Equal Emissions (t of CO2; t of CH4)
100
10
1
0.1
0.01
2008
2028
2048
2068
2088
2108
Not equal warming per year until 2075 (67 years)

Actually two types of methane

- Biogenic methane (ruminants, biomass combustion, landfills, etc.) – the CO_2 it creates is renewable, i.e., does not add to atmospheric load of CO_2
- Fossil methane (natural gas, coal mines, fossil fuel combustion) – the CO_2 it creates does add to the load

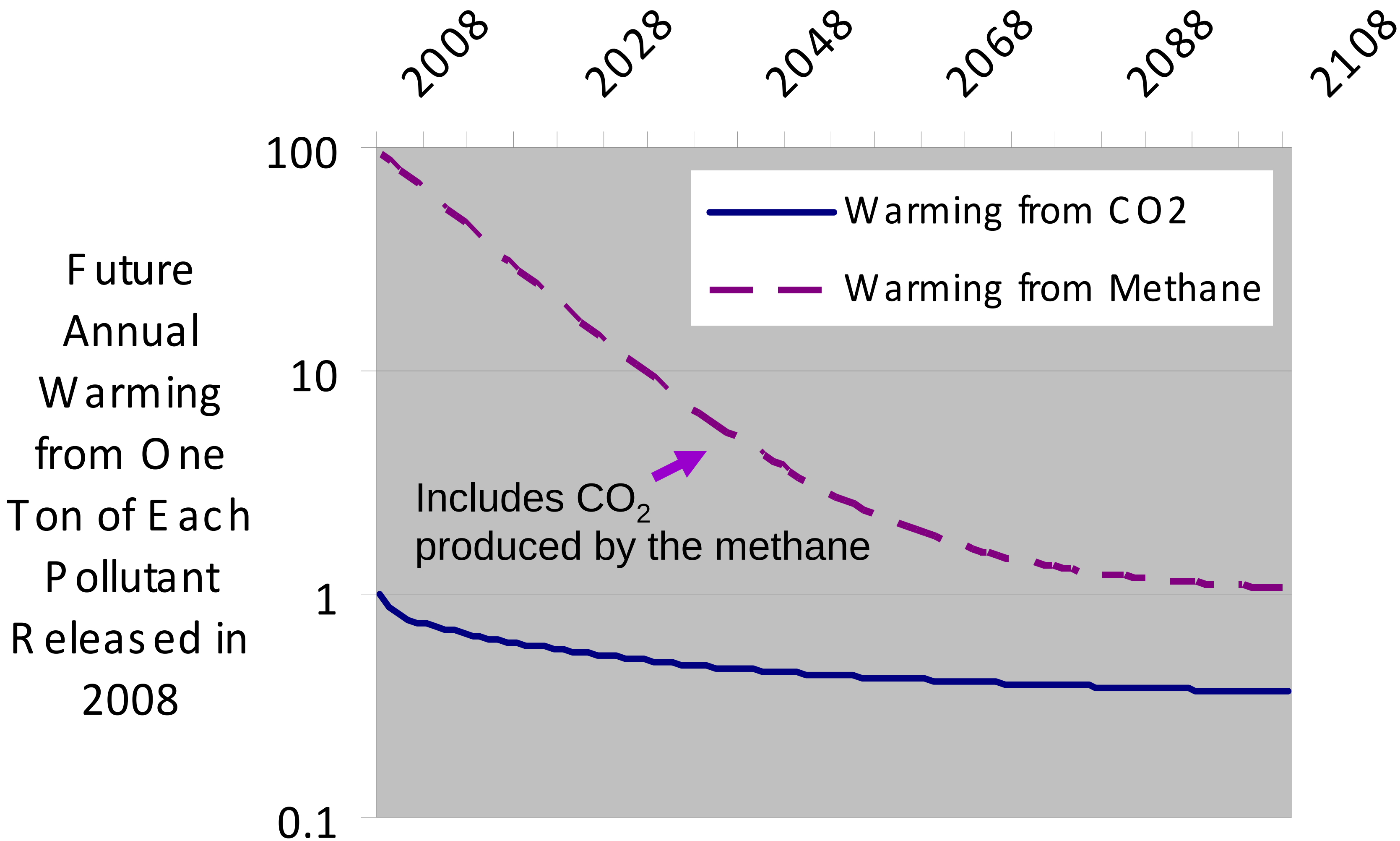
Global Anthropogenic Methane Emissions ~2005
Total ~ 305 million tons

Fossil methane ~25%

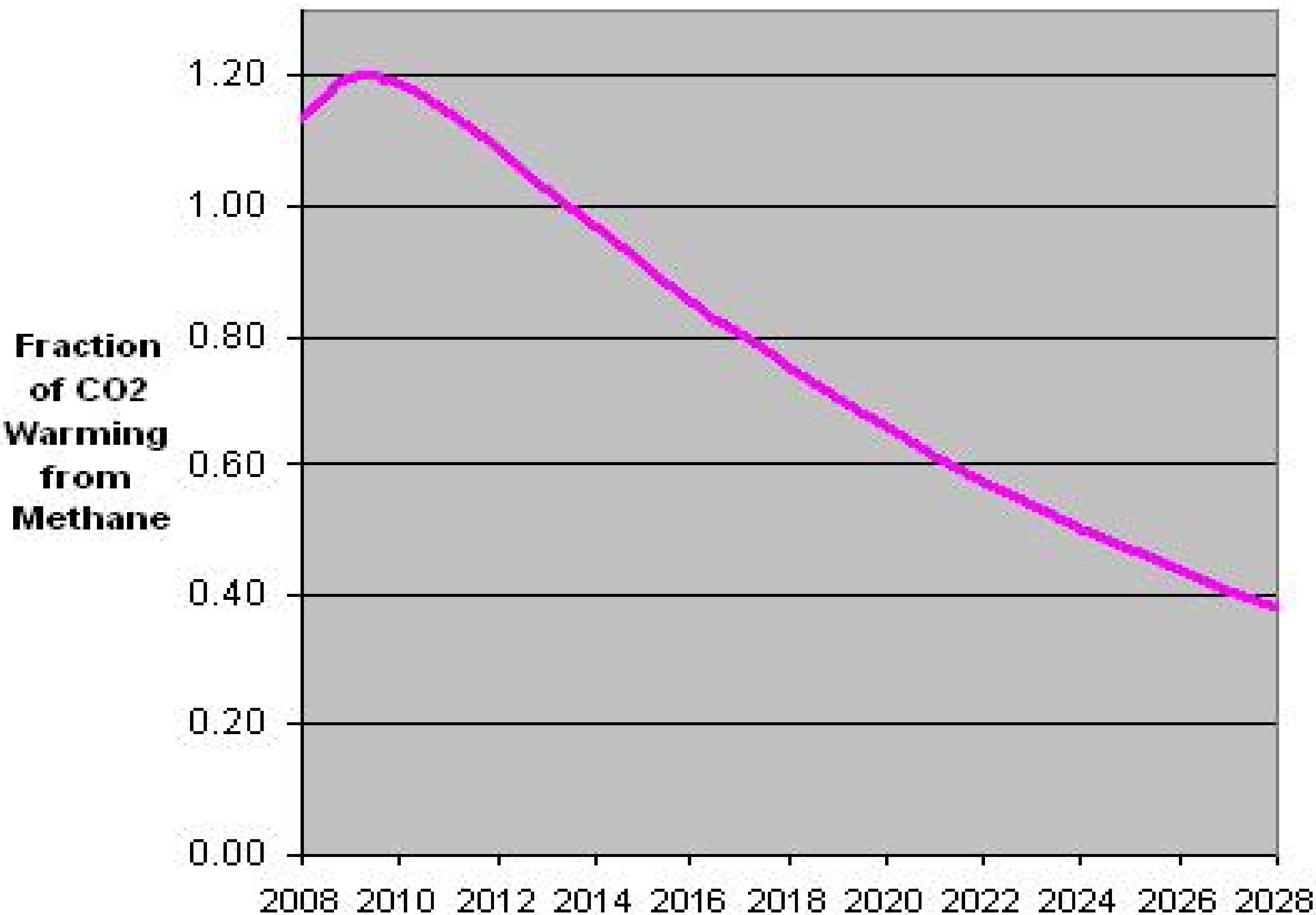


Expected to grow at ~1.5% per year

Future Warming of Fossil Methane and CO_2 from Equal Emissions in 2008



Warming Contribution of Total ~2008 Emissions of Methane Compared to Total CO2 Emissions

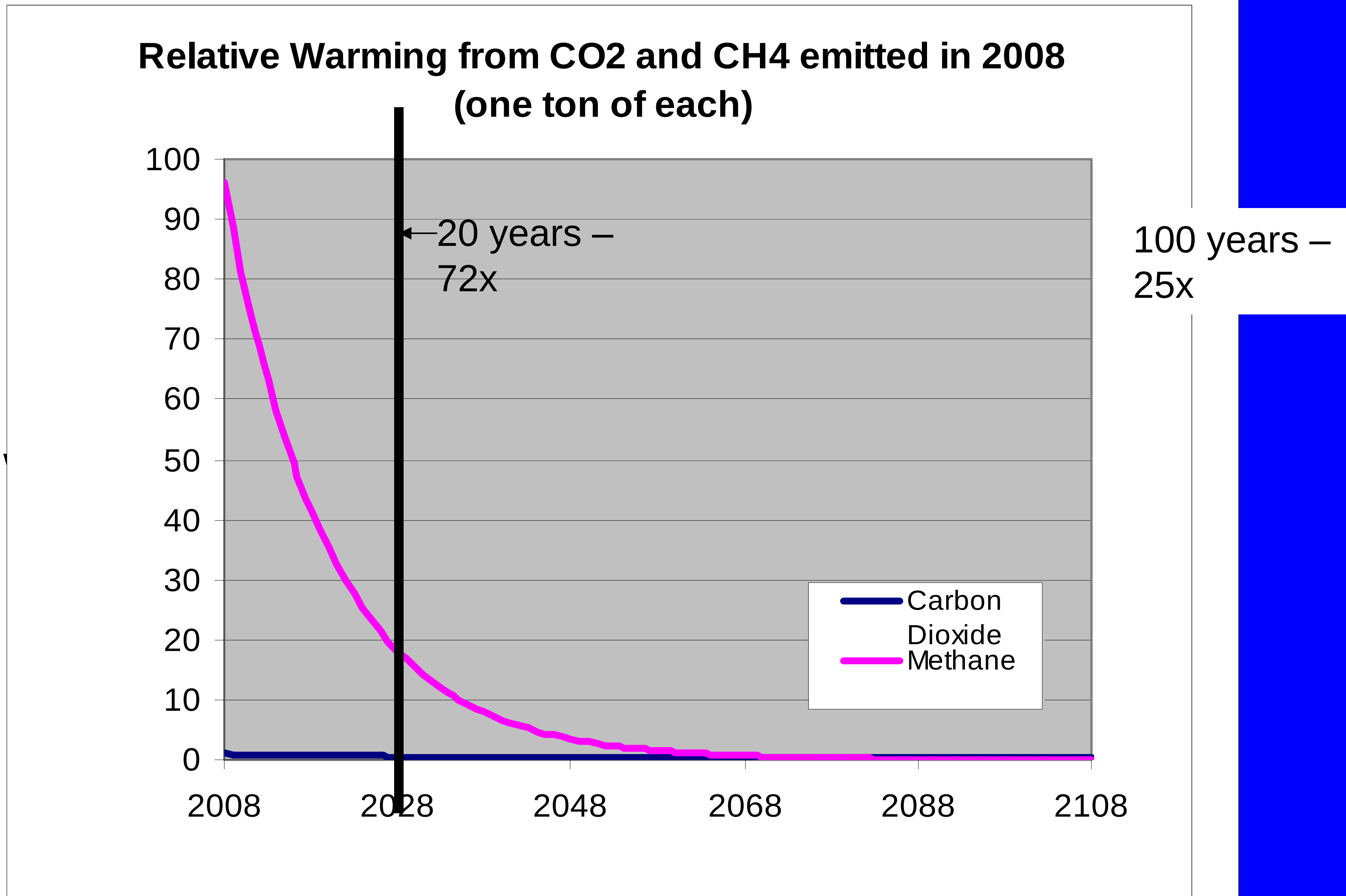


How can we compare projects to reduce different GHGs?

- Why not just take all future warming into account?
- This would mean that no effort would go into avoiding emissions of the shorter lived GHGs, such as methane, because CO_2 has such a long lifetime.
- It would result in spending most money to protect people thousands of years into the future and ignoring the needs of ourselves and our children.
- Thus, the IPCC established in 1996, official Global Warming Potentials (GWPs), which are weighting factors to compare the impact of different GHGs
- GWPs are built into the Kyoto Protocol, the Clean Development Mechanism, and nearly all national inventories and reduction plans.

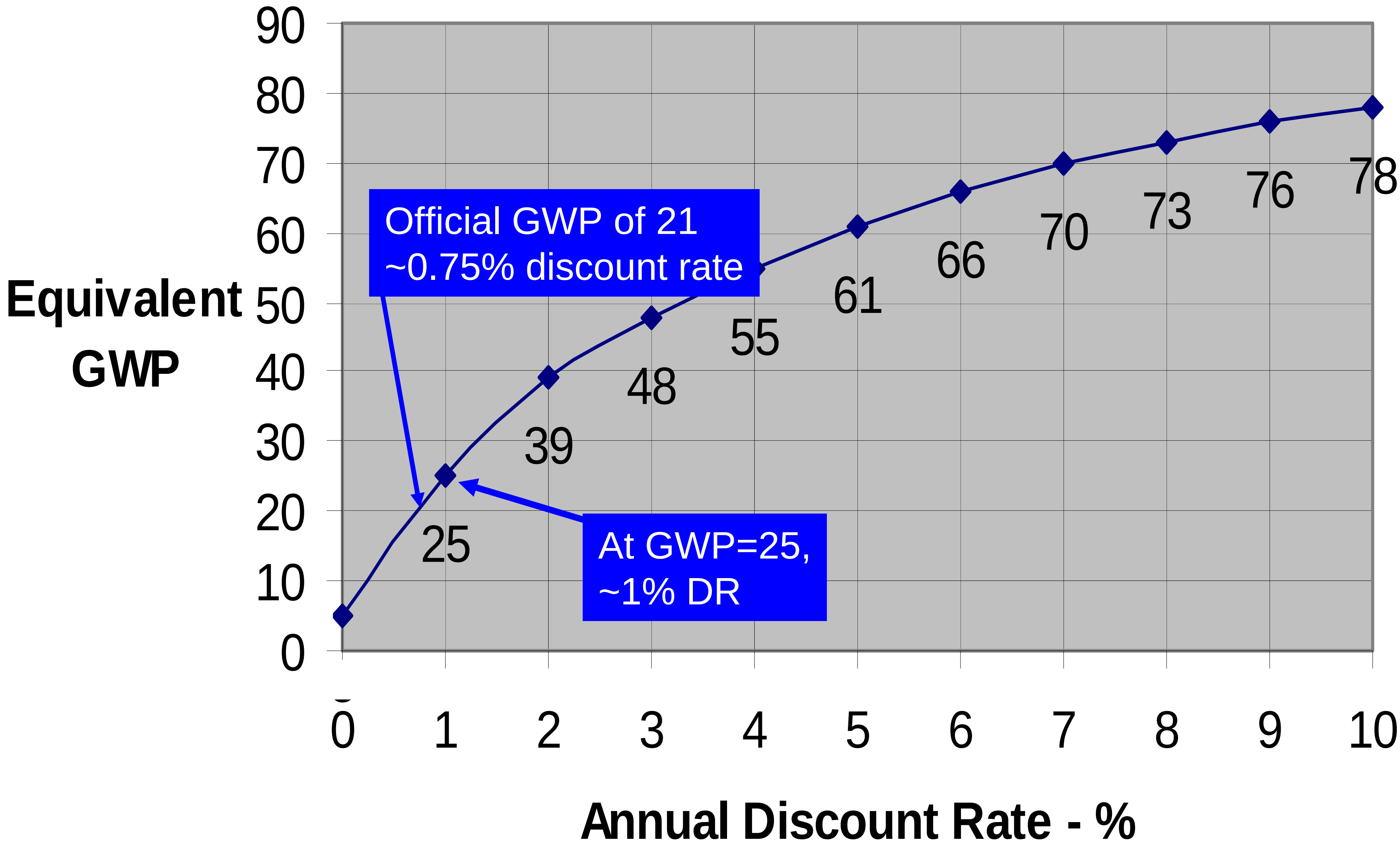
Methane and Time

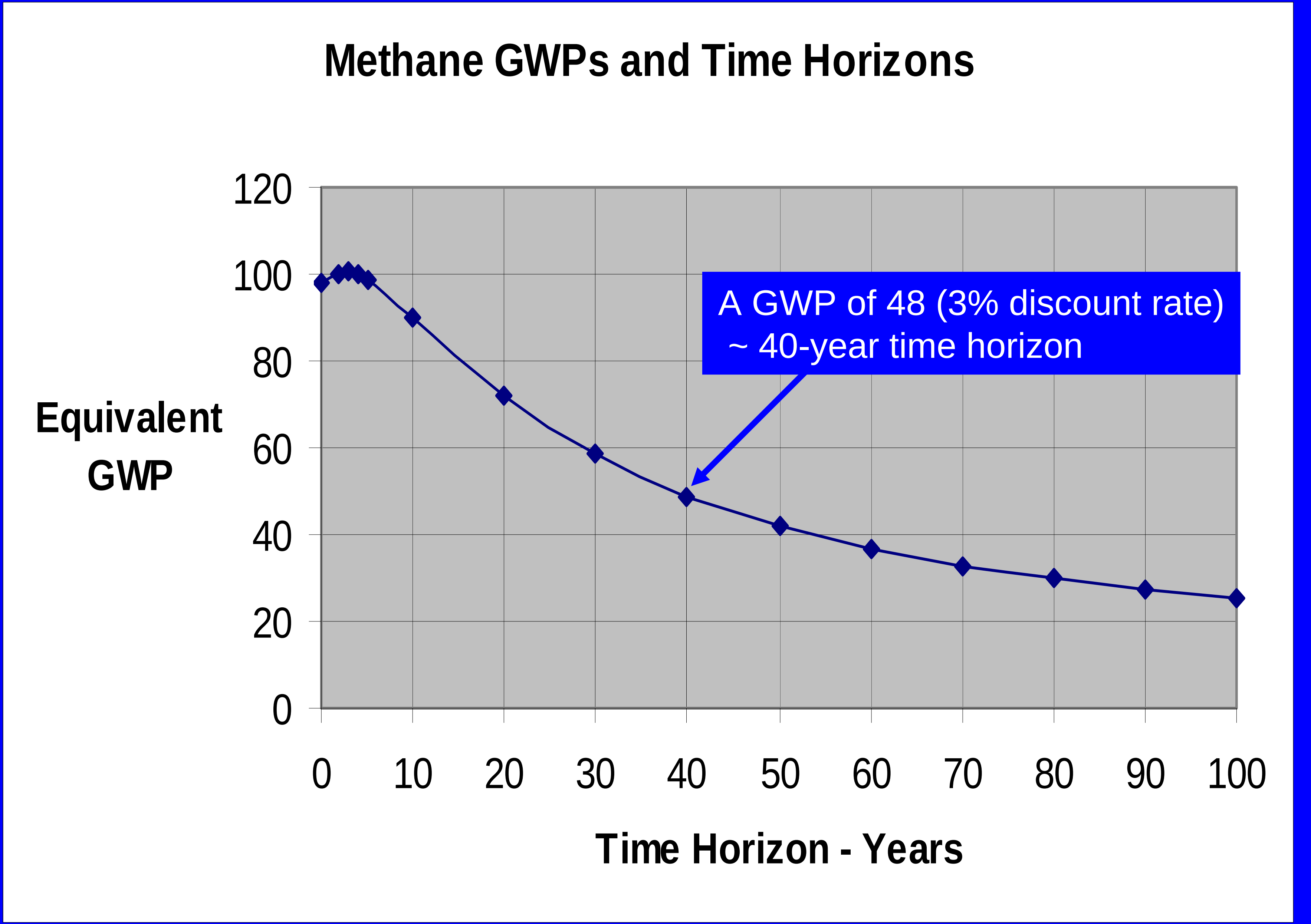
- The current official GWPs are based on 100-year time horizons
  - Methane is 21 x CO_2 by weight (25 in AR4)
  - Equivalent to ~0.75% discount rate
- For making decisions on how to spend resources when impacts are upon us, <1% is too low.
- The other GWP published by IPCC, has a 20-year time horizon
  - Methane is 72 x CO_2 by weight
  - Equivalent to ~ 8% discount rate
  - More compatible with financial investments
- International health investments use a 3% discount rate, which would be a GWP of ~48

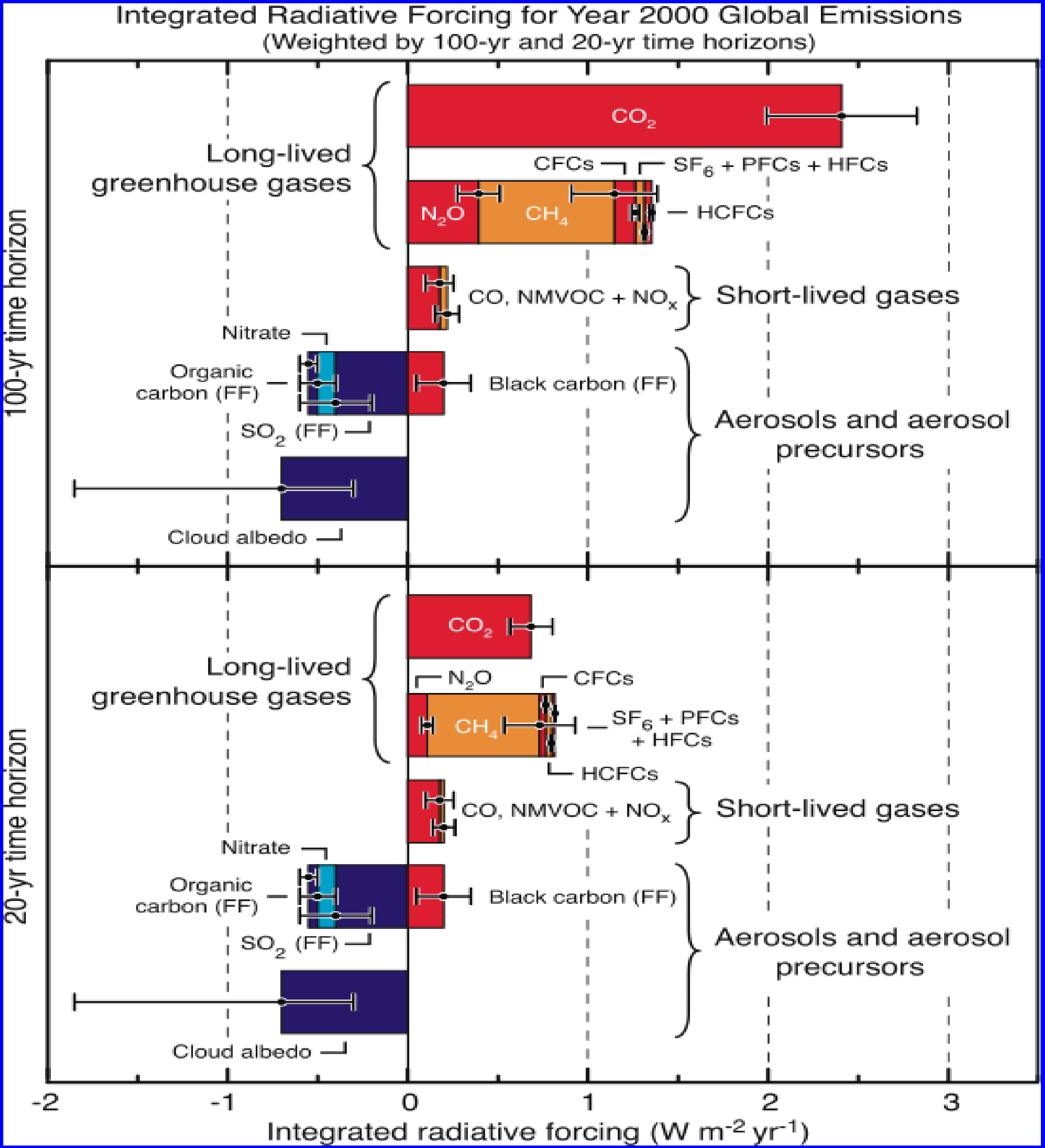


Relative Warming from CO2 and CH4 emitted in 2008
(one ton of each)
100
90
80
70
60
50
40
30
20
10
0
20 years –
72x
100 years –
25x
Carbon
Dioxide
Methane
2008
2028
2048
2068
2088
2108

Methane GWPs and Discount Rates




Methane GWPs and Time Horizons
120
100
80
60
40
20
0
Equivalent GWP
A GWP of 48 (3% discount rate)
~ 40-year time horizon
0
10
20
30
40
50
60
70
80
90
100
Time Horizon - Years



100-y horizon

Time perspective makes a difference

20-y horizon

IPCC, 2007

Methane #1: Summary

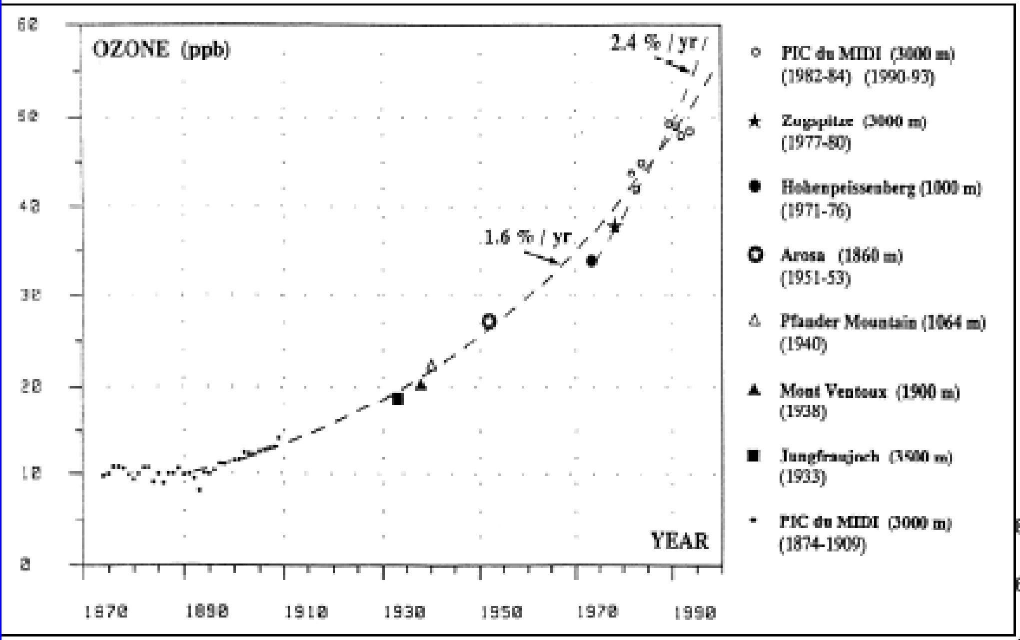
- A much more powerful greenhouse gas (GHG) than CO_2
- Partly due to its direct effect, but also because it creates ozone (O_3), another powerful GHG
- Nearly 100 times more per ton than CO_2 at any one time
- Eventually turns to 2.75 times as much CO_2 by mass
- Methane has thus contributed a significant amount to global warming,
- But has a much shorter atmospheric lifetime compared to CO_2
- Thus, changes in emission rates will have a much faster impact to lower warming than changes in CO_2 emissions
- But there is also more variability in the system

2. Methane and Global Health

- Increases of wide-scale tropospheric (ground-level) ozone is becoming a major world problem
- A significant health-damaging pollutant
- Damaging to ecosystems and agriculture
- Methane emissions are the main cause
- Reduction of methane emissions, therefore, will help protect health worldwide immediately

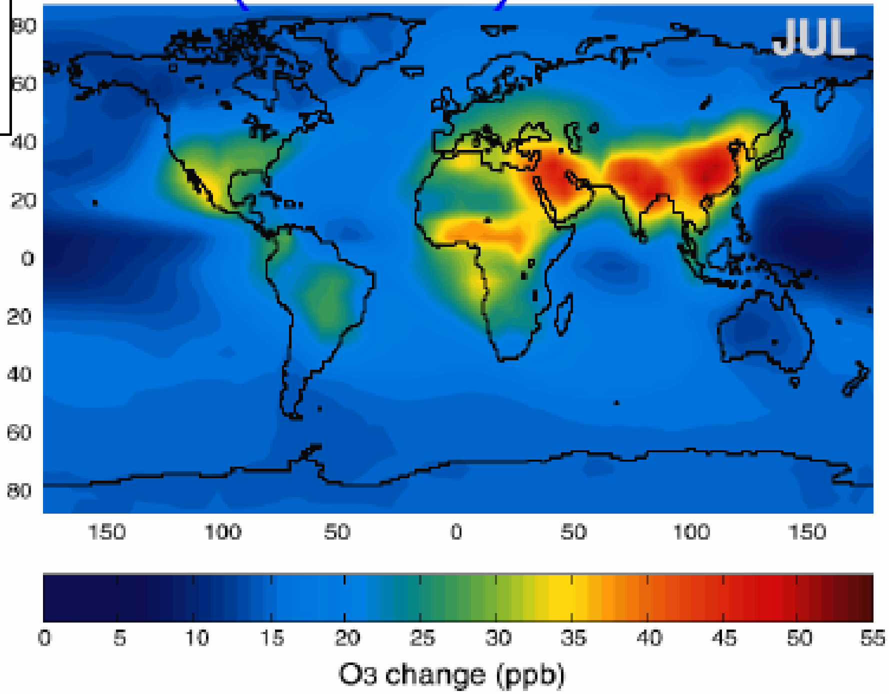
Background Ozone is Growing …

… and Will Continue to Grow!



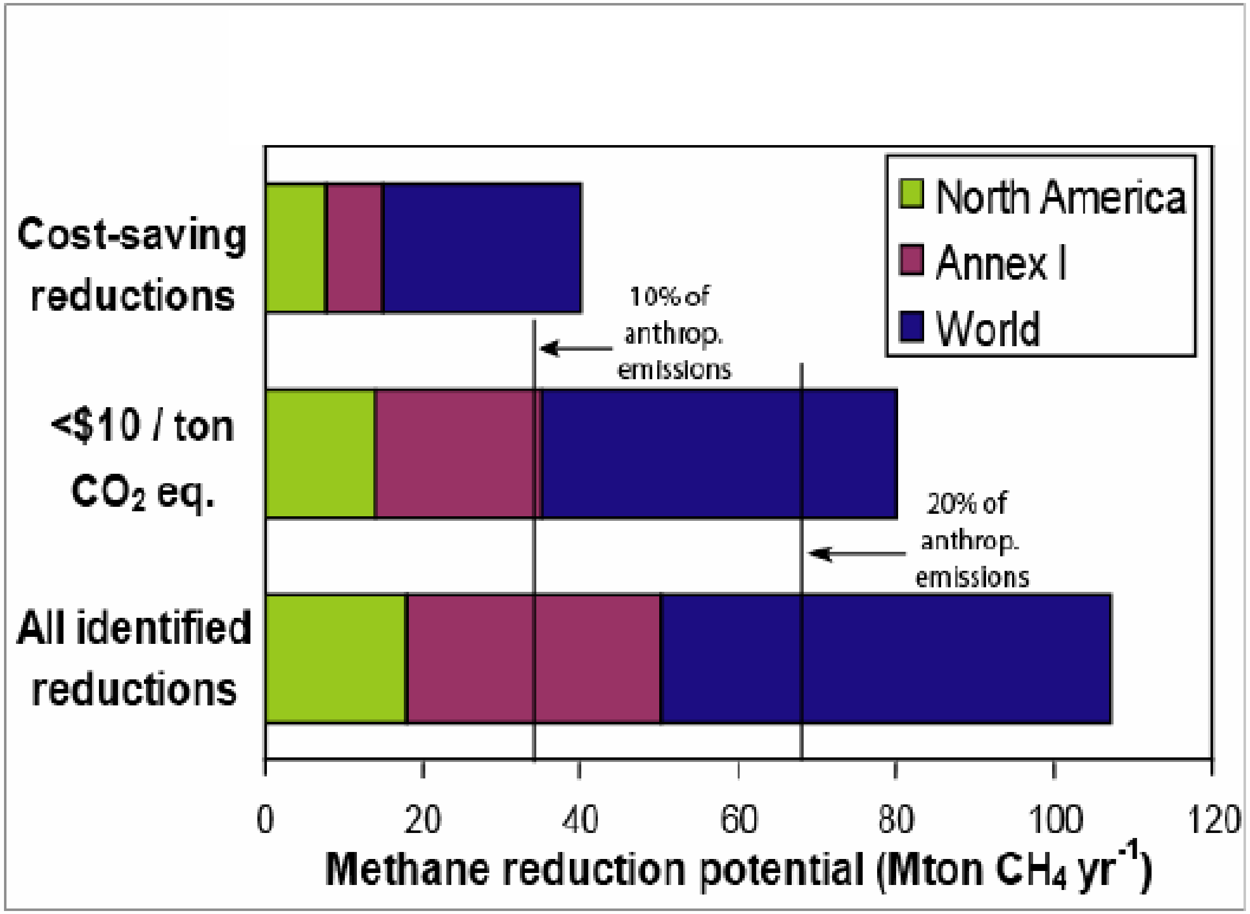
Historic and future increases in background ozone are due mainly to increased methane and NO_X emissions (Wang *et al.*, 1998; Prather et al., 2003).

2100 (IPCC A2) - 2000



Ozone trend at European mountain sites, 1870-1990 (Marenco et al., 1994).

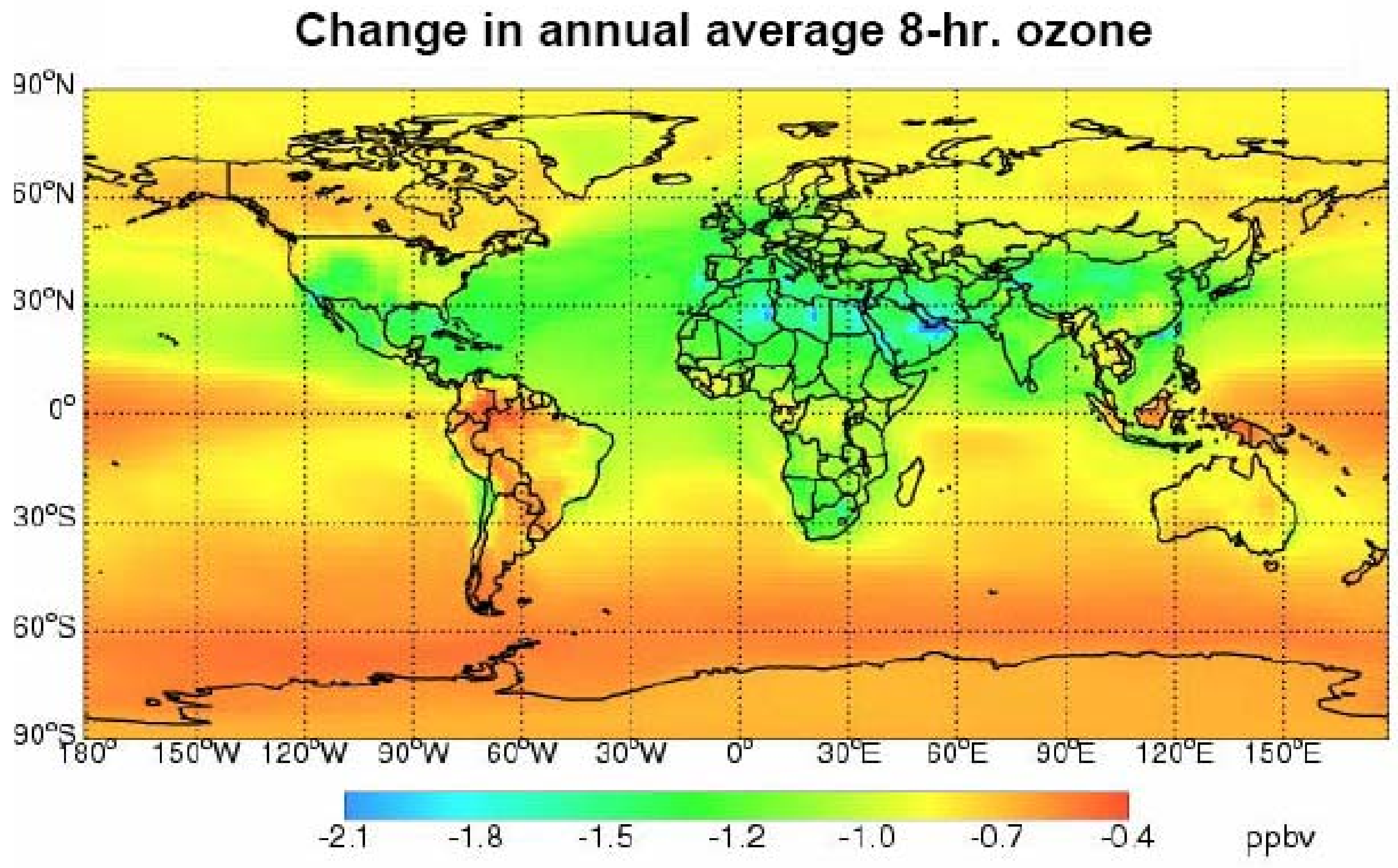
How Much Can Methane Be Reduced?



West & Fiore (2005)

Methane reduction potential from IEA (2003), for coal, oil and gas operations, wastewater, and landfills; maximum technically feasible in 2010.

- **A 20% decrease in global anthropogenic methane emissions decreases ozone globally by ~1 ppb.**



Multiple Benefits of Reducing Methane

Reducing ~20% of anthropogenic methane emissions will:

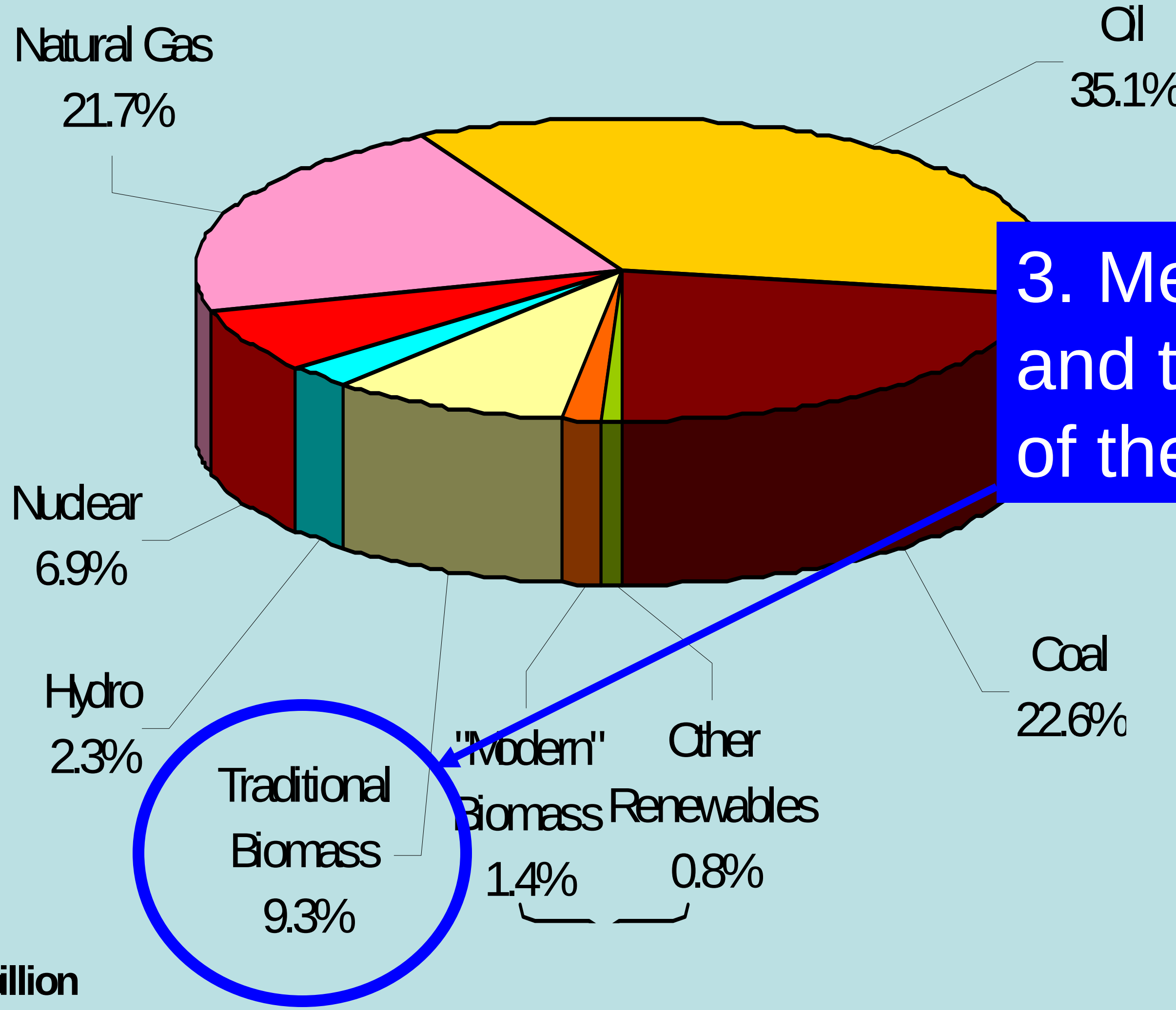
- Be possible at a net cost-savings.
- Reduce 8-hr. average ozone globally by ~1 ppb.
- Reduce global radiative forcing by ~0.14 W m^{-2}.
- Provide ~2% of global natural gas production.
- Prevent ~30,000 premature deaths globally in 2030, ~370,000 from 2010-2030.

Mauzerall, 2007

Methane #2: Summary

- Methane is precursor to tropospheric (ground level) ozone
- Tropospheric ozone rising around the world
- Significant impact on natural ecosystems and agriculture
- WHO and other agencies lowering ozone standards/guidelines because of new evidence on mortality and continued evidence of morbidity
- Standards suggested by health protection are now at the top end of regional levels in some parts of the world, e.g., Europe
- Nowhere to hide

World Energy – 2001



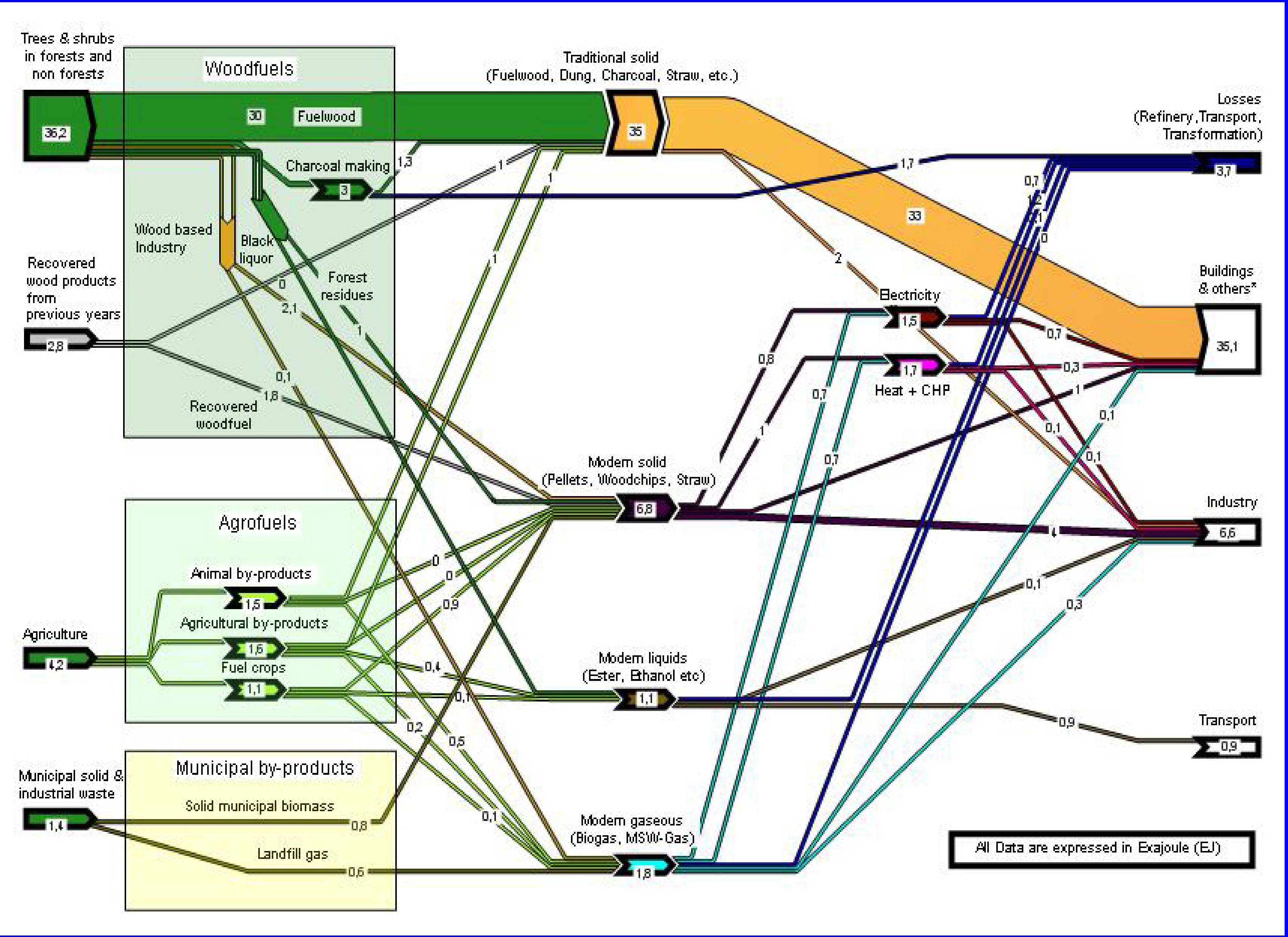
3. Methane and the health of the poor

Population: 6.102 billion

Total energy use: 10.2 Gtoe

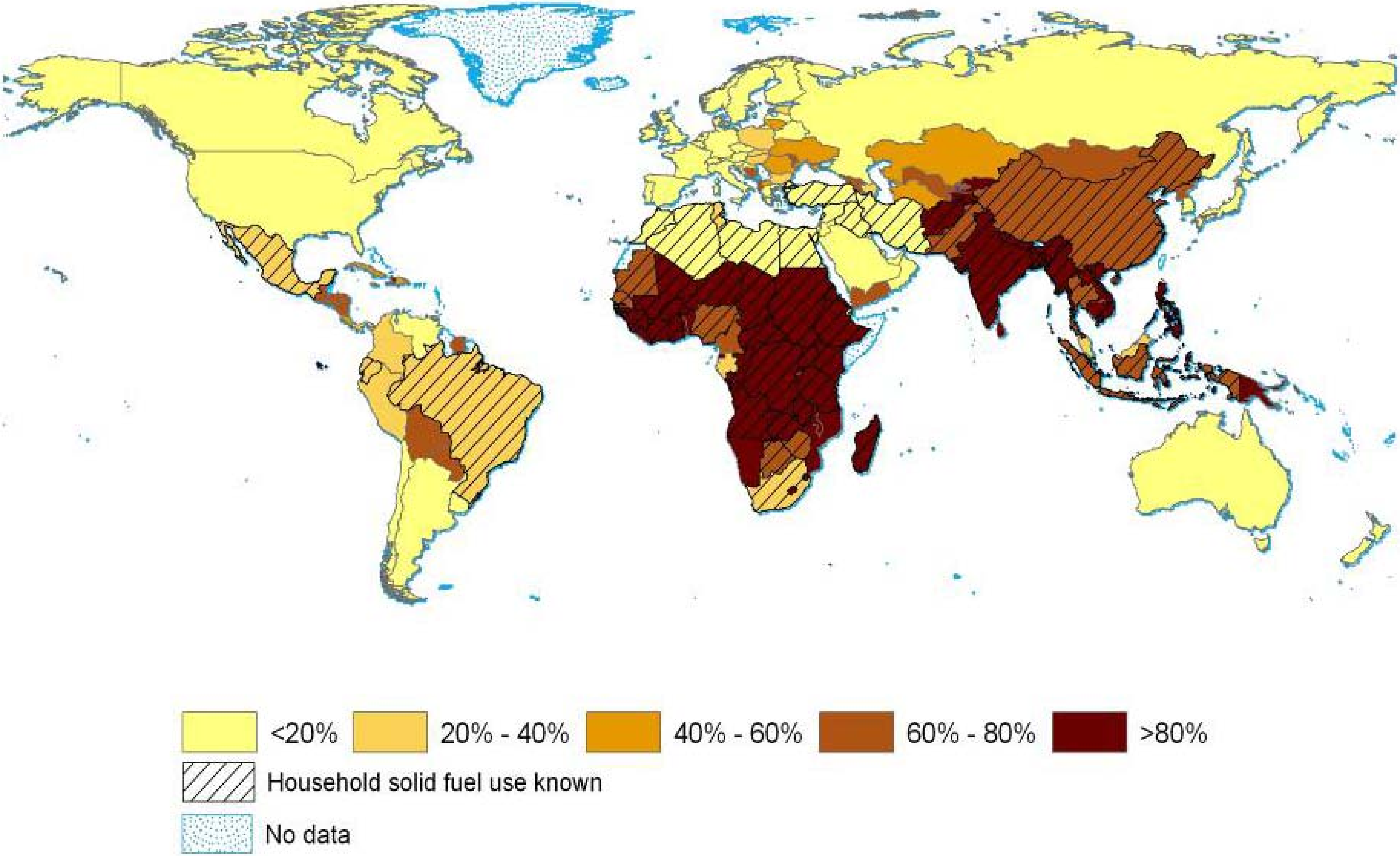
Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004

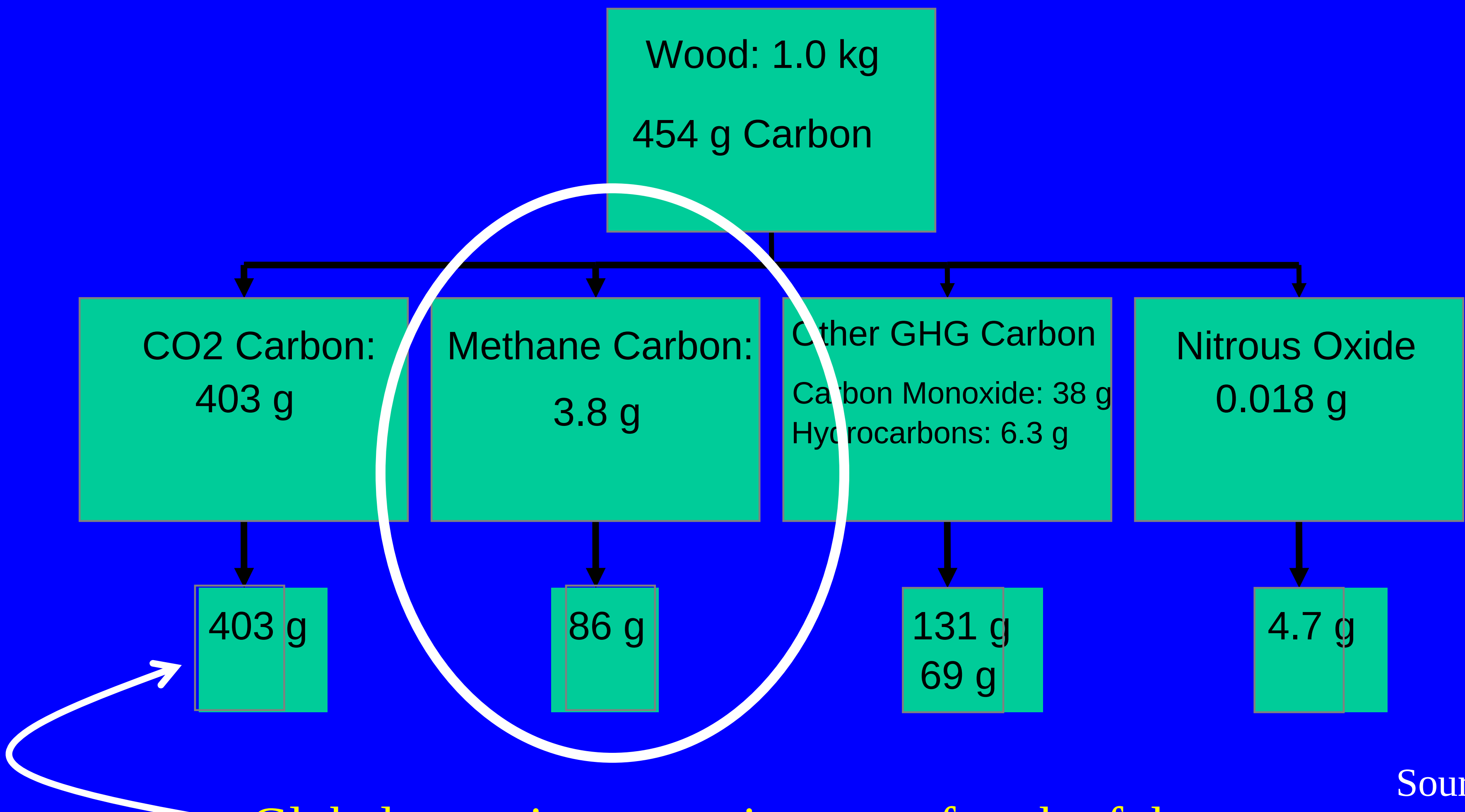


IPCC 2007, WGIII

National Household Solid Fuel Use, 2000



Greenhouse warming commitment per meal for typical wood-fired cookstove in India

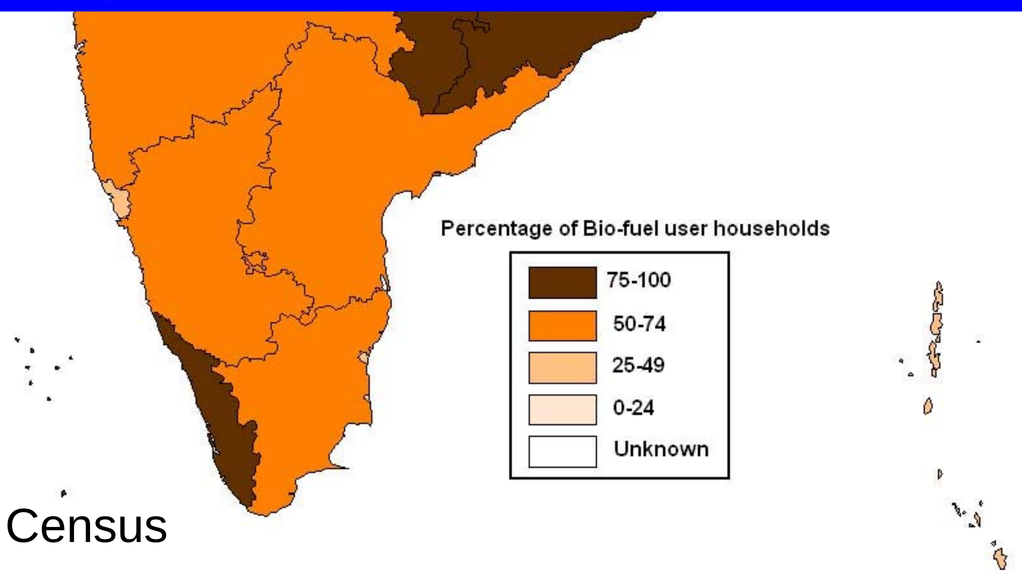


Global warming commitments of each of the gases as CO_2 equivalents

Source: Smith, et al., 2000

Percent of Households Using Biomass Fuels

Nearly 2 million tons methane per year of the ~ 305 Mt total global human emissions



2001 Census

Smith, et al. 2000

Energy flows in a well-operating traditional wood-fired cookstove

Wood: 1 kg

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

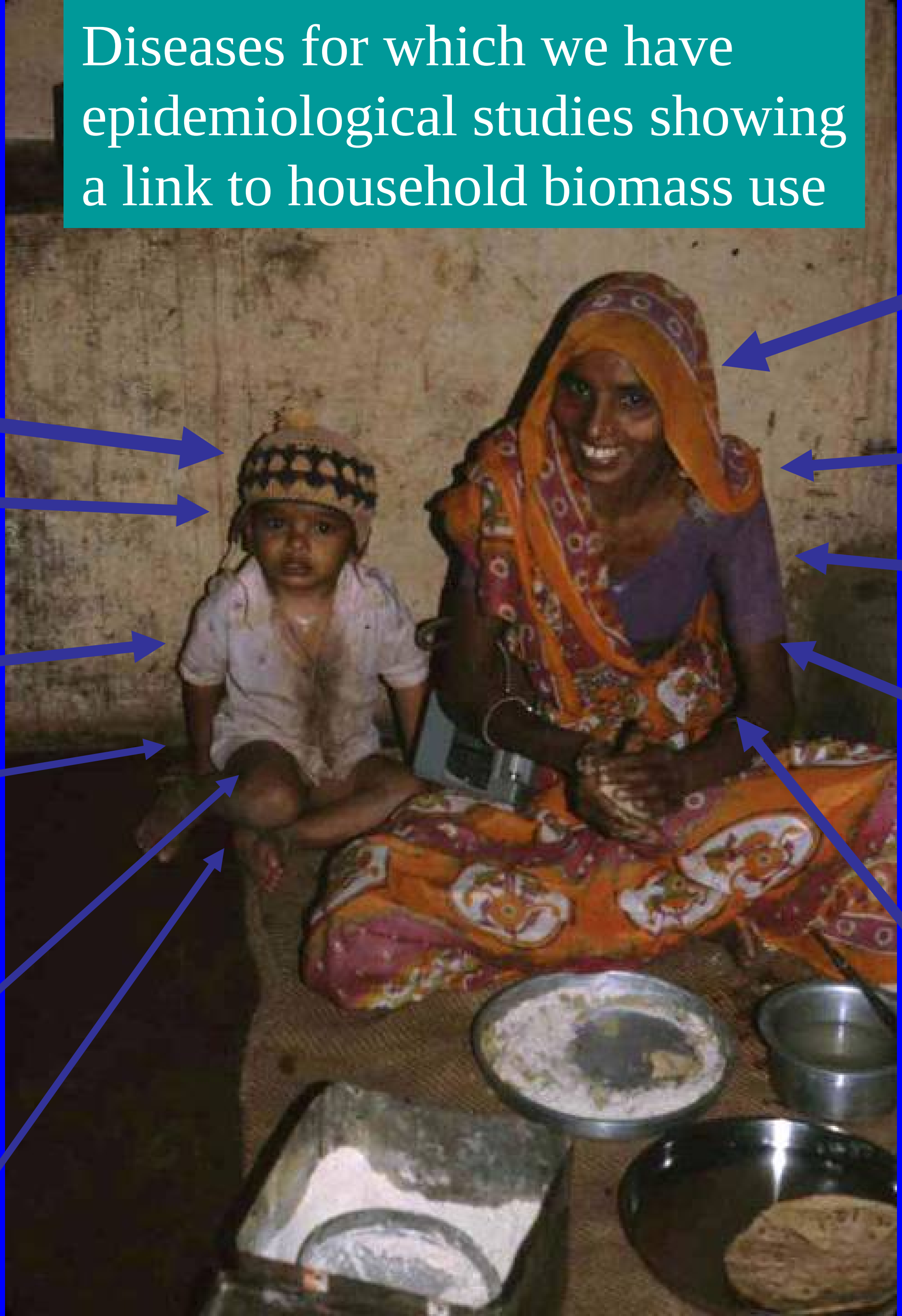
Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

Plus methane

- 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*

Naeher, et al. 2007

Diseases for which we have epidemiological studies showing a link to household biomass use



ALRI/
Pneumonia
(meningitis)

Low birth weight

Asthma?

Early infant death?

Birth defects?

Cognitive Impairment?

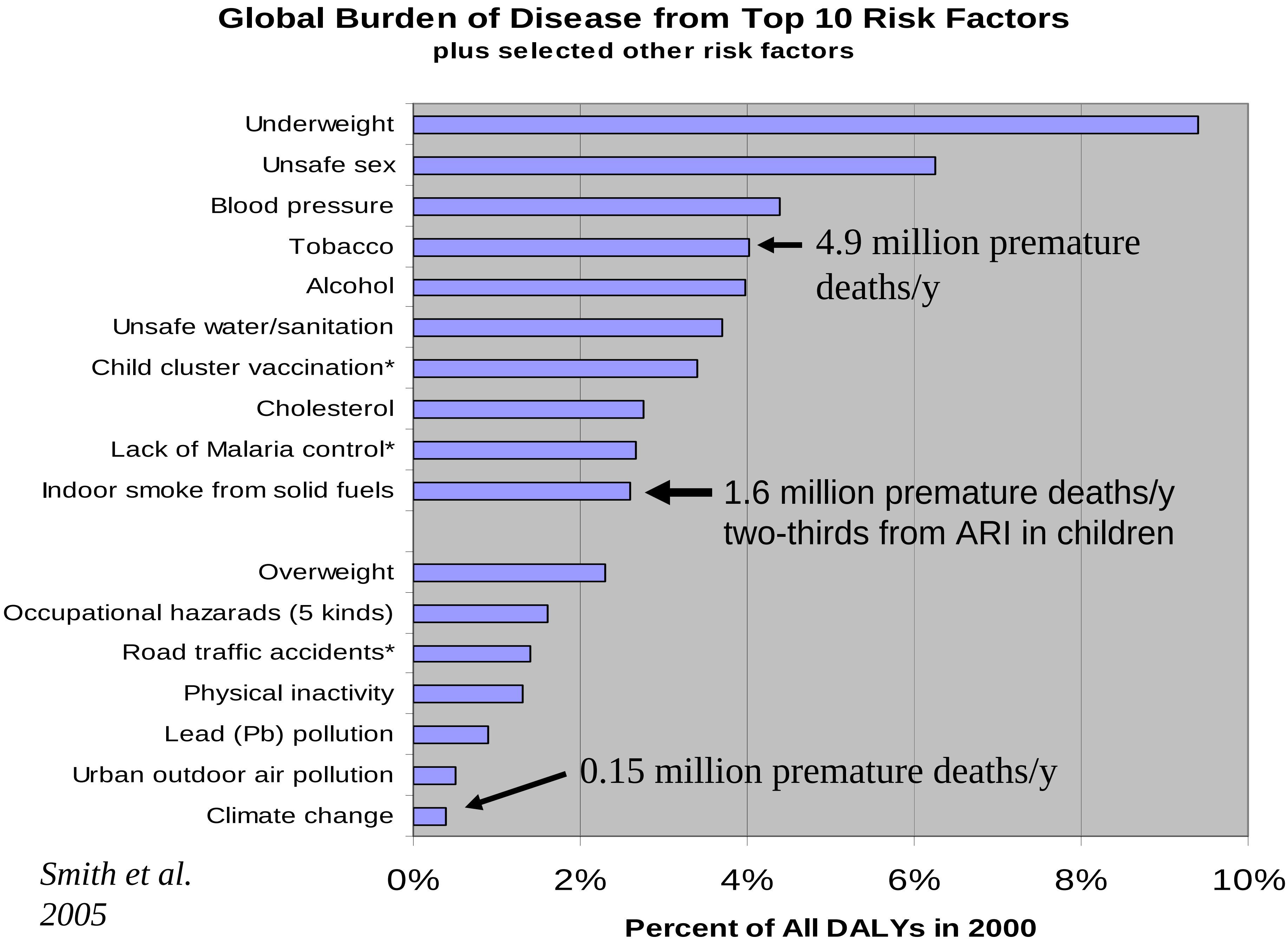
Chronic obstructive lung disease

Tuberculosis

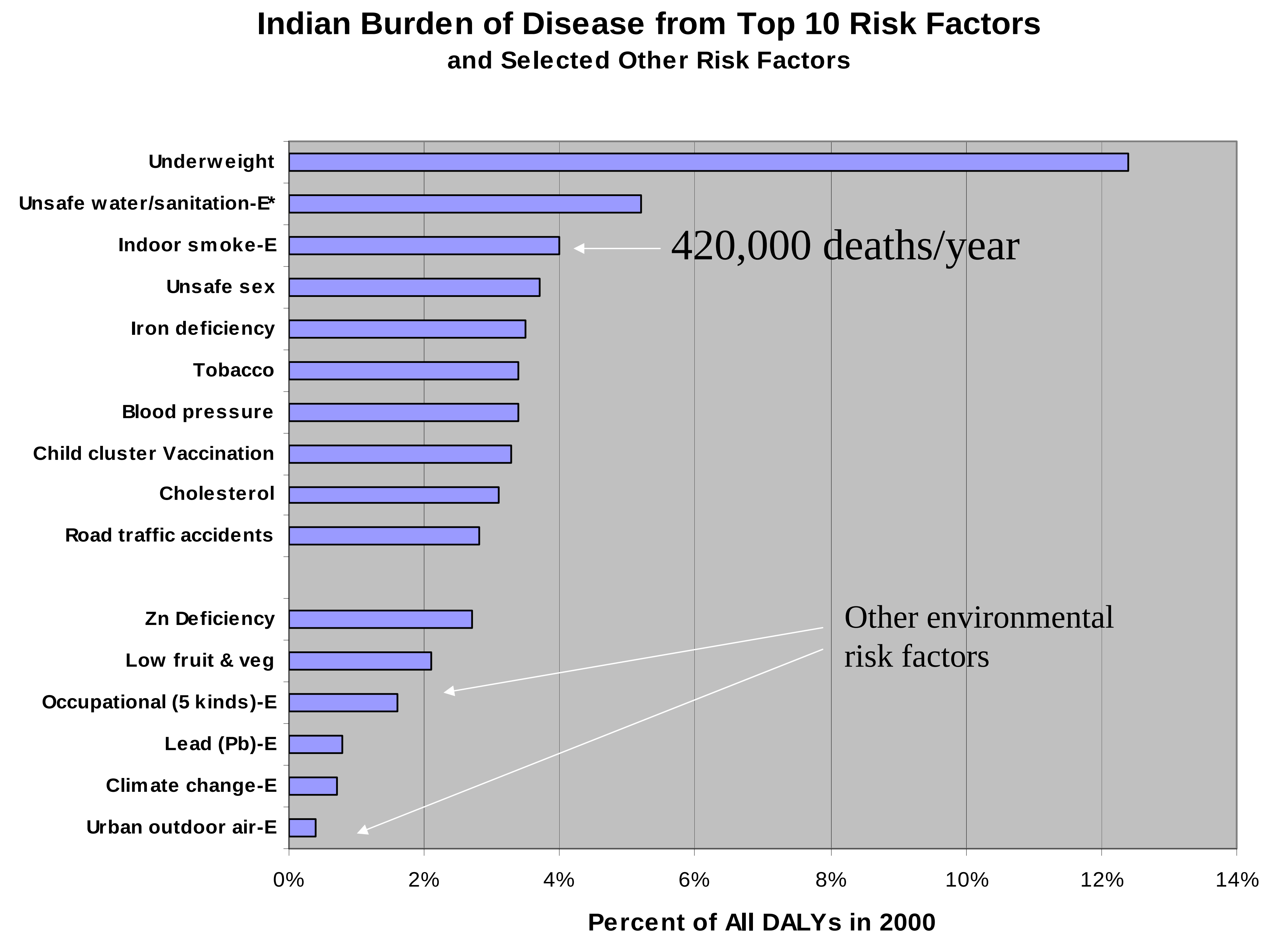
Blindness
(cataracts, trachoma)

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

Heart disease?



Smith et al. 2005

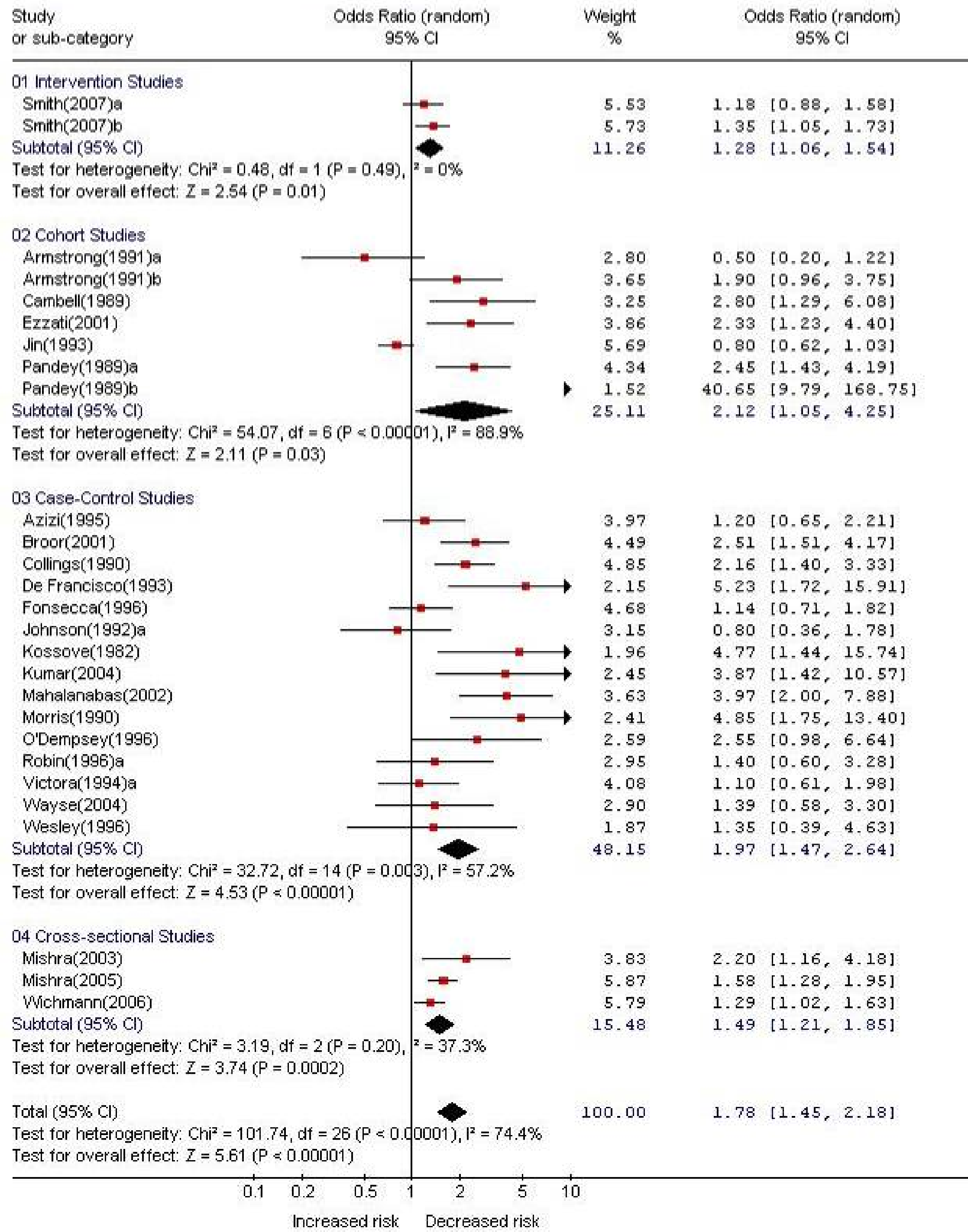


Indian Burden of Disease from Top 10 Risk Factors
and Selected Other Risk Factors
Underweight
Unsafe water/sanitation-E*
Indoor smoke-E
Unsafe sex
Iron deficiency
Tobacco
Blood pressure
Child cluster Vaccination
Cholesterol
Road traffic accidents
Zn Deficiency
Low fruit & veg
Occupational (5 kinds)-E
Lead (Pb)-E
Climate change-E
Urban outdoor air-E
420,000 deaths/year
Other environmental risk factors
0%
2%
4%
6%
8%
10%
12%
14%
Percent of All DALYs in 2000

Child Pneumonia - indoor air pollution

New Systematic Review and Meta-Analysis

Dherani et al.
Bull WHO, 2008

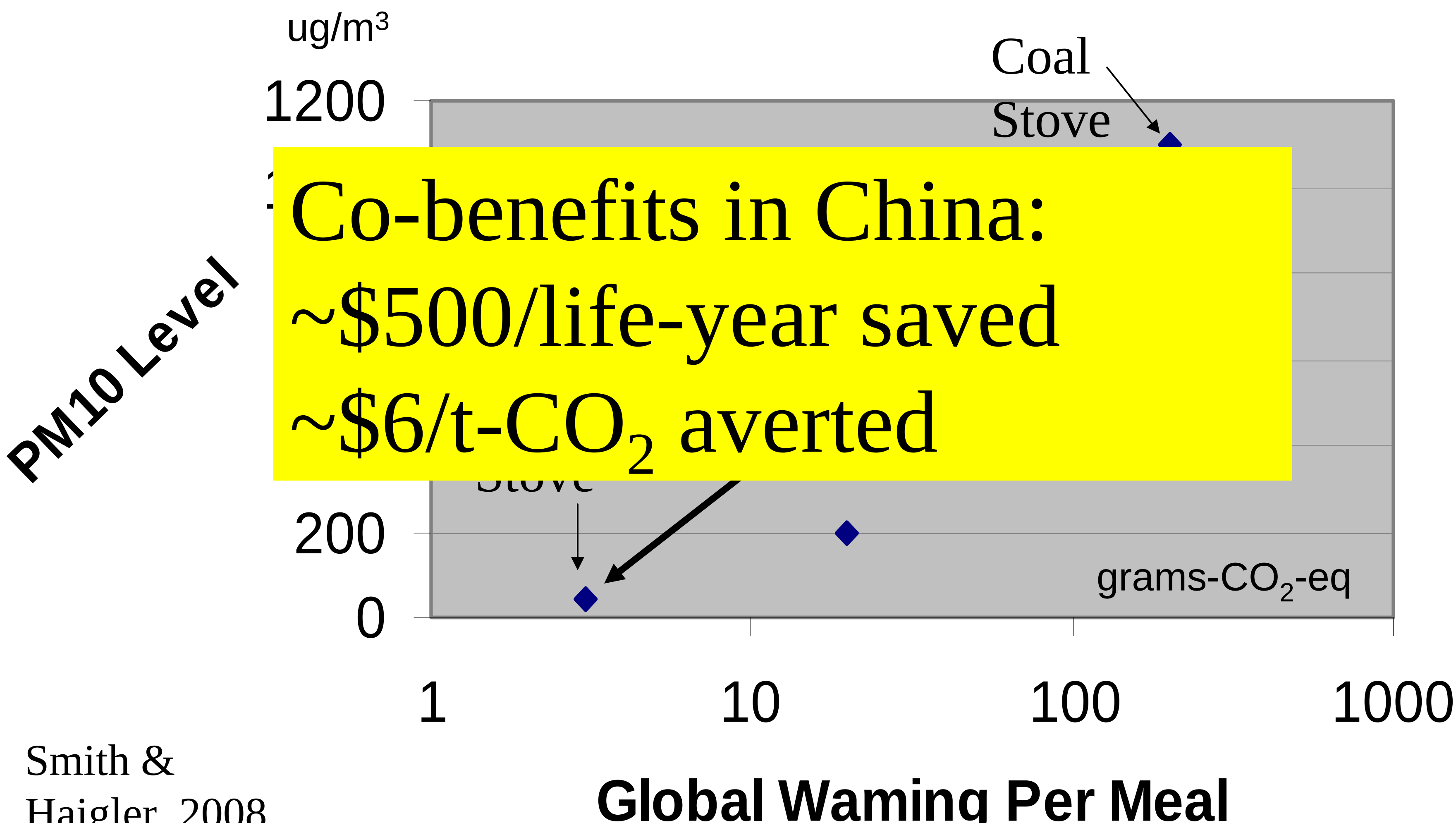


Chinese household rural energy:

A Chinese Biomass Gasifier Stove

Tests show emissions nearly at LPG levels:
Low health risk and essentially no greenhouse emissions

Health and Greenhouse Gas Benefits of Biomass Stove Options

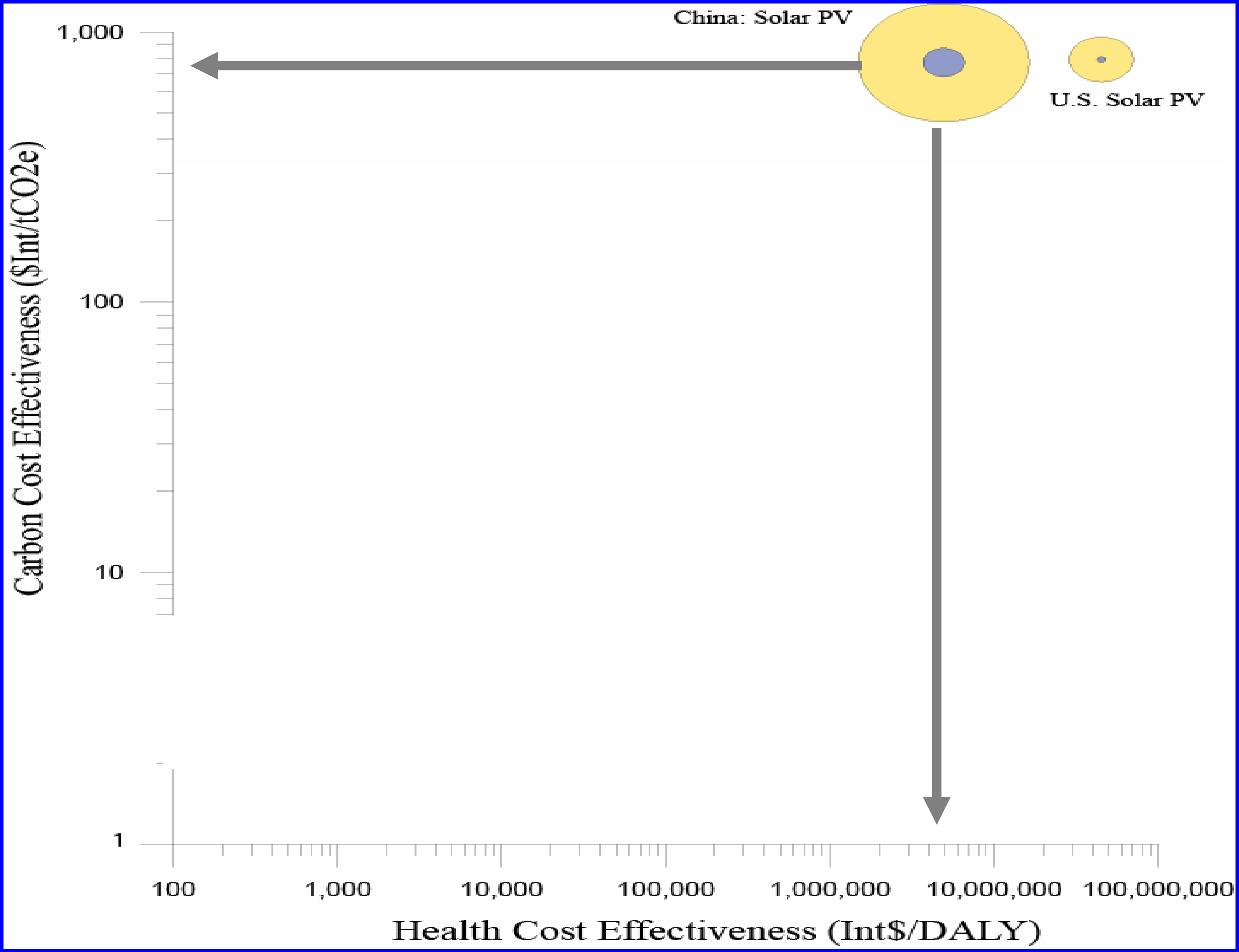


Co-benefits in China:

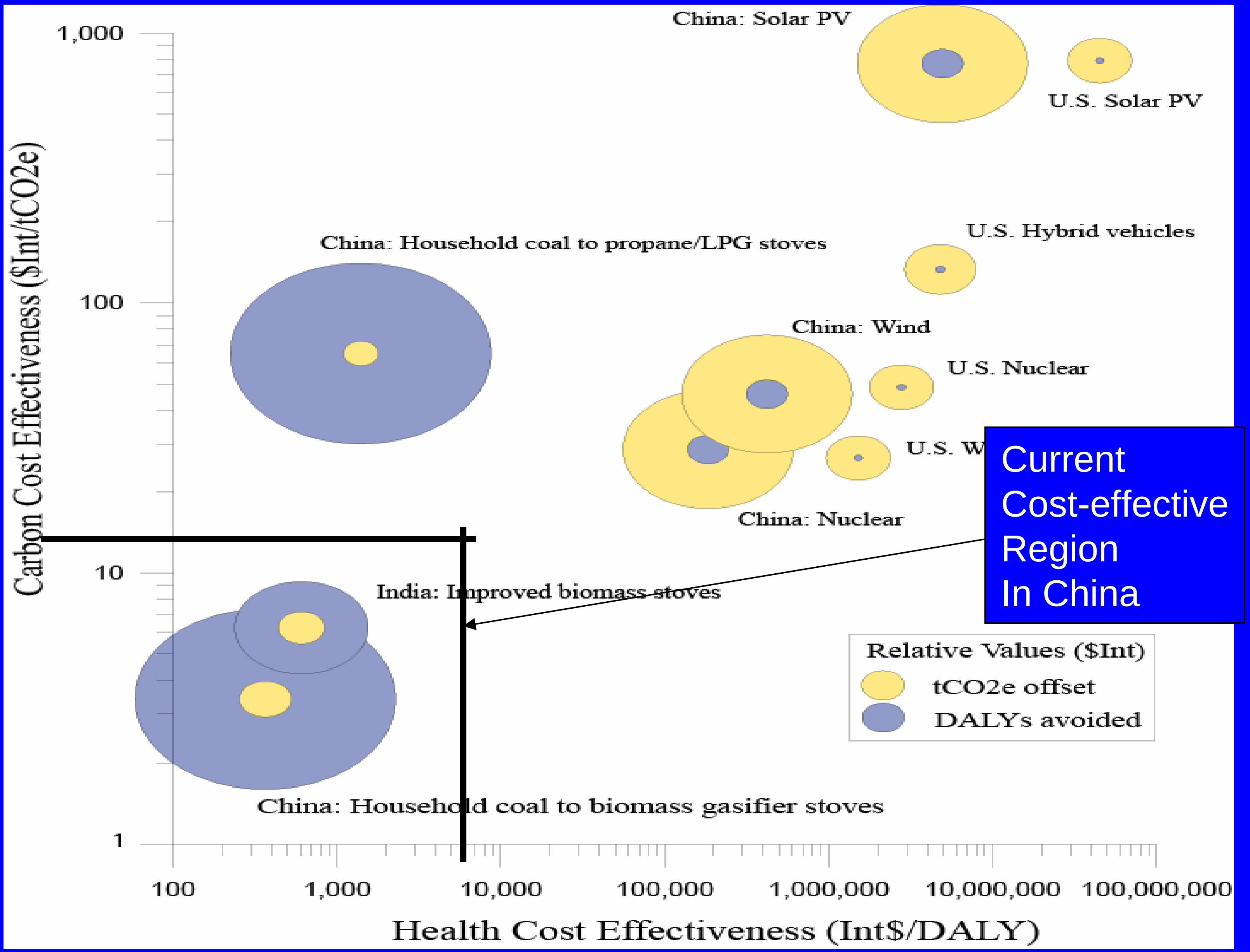
~$500/life-year saved

~$6/t-$CO_2$ averted

Smith & Haigler, 2008



Smith & Haigler, 2008



Smith & Haigler, 2008

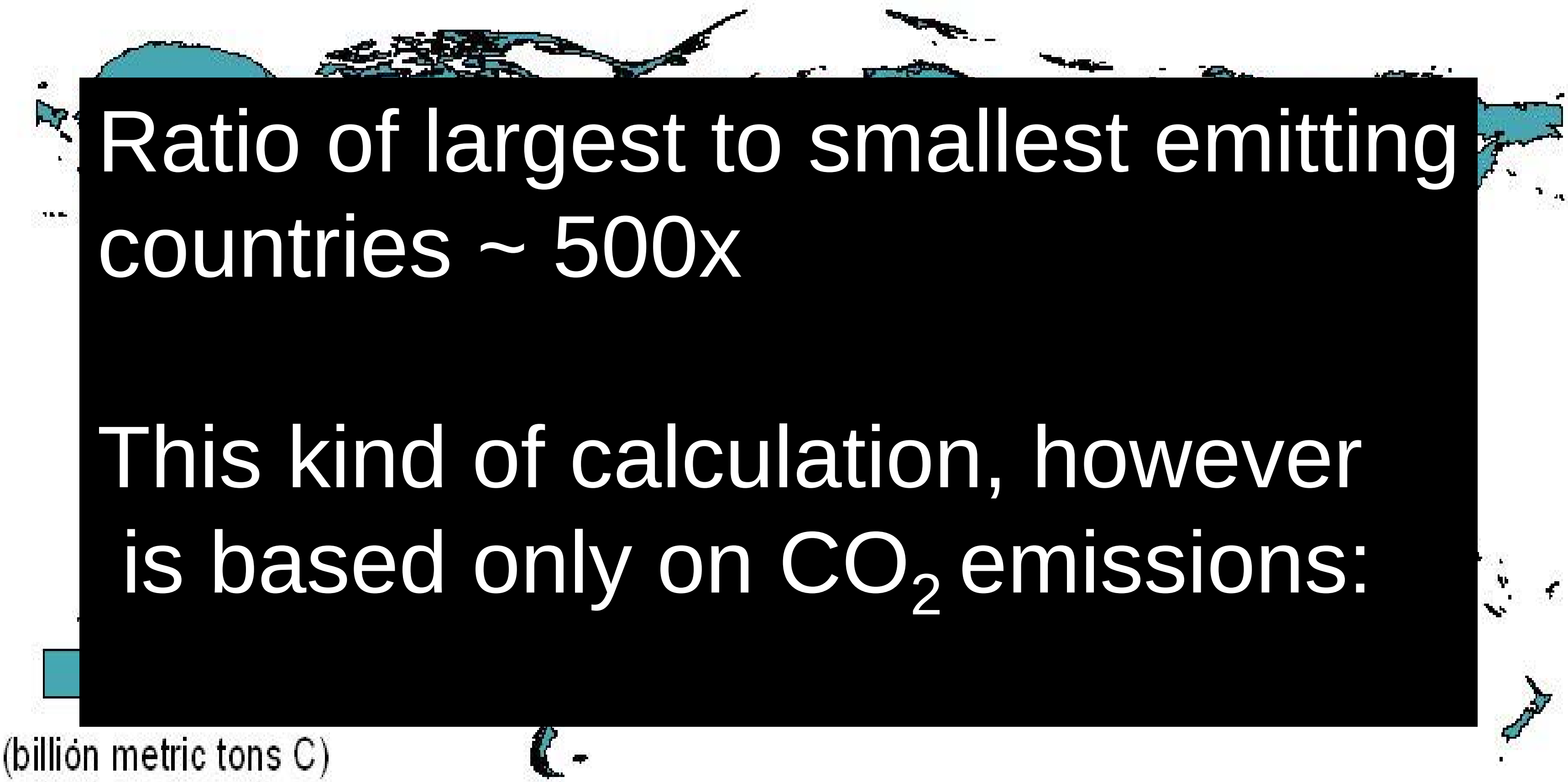
Methane #3: Summary

- Methane is one of the constituents of products of incomplete combustion (PIC) from fuel combustion
- PIC are responsible for much burden of disease in the world's poorest populations
- Controlling this PIC has a double benefit: health and climate
- Can potentially be done economically – low hanging fruit for both

4. Methane and Global Equity

- We have seen how methane’s health impacts, direct, indirect, and associated, mostly affect the poor
- What about methane emissions: how are they distributed?

National Natural Debts: Cumulative CO_2 emissions, depleted by natural processes

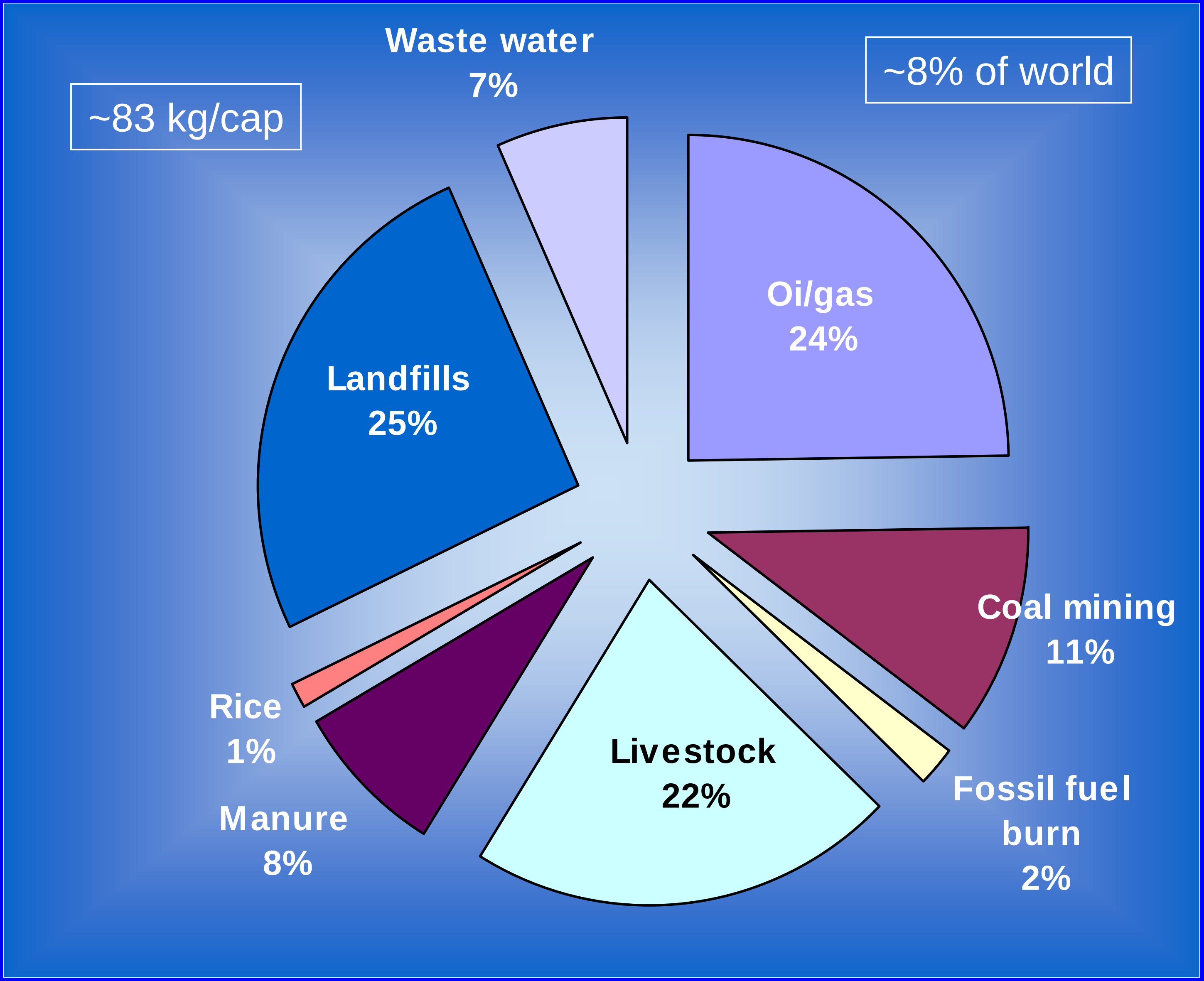


Ratio of largest to smallest emitting countries ~ 500x

This kind of calculation, however is based only on CO_2 emissions:

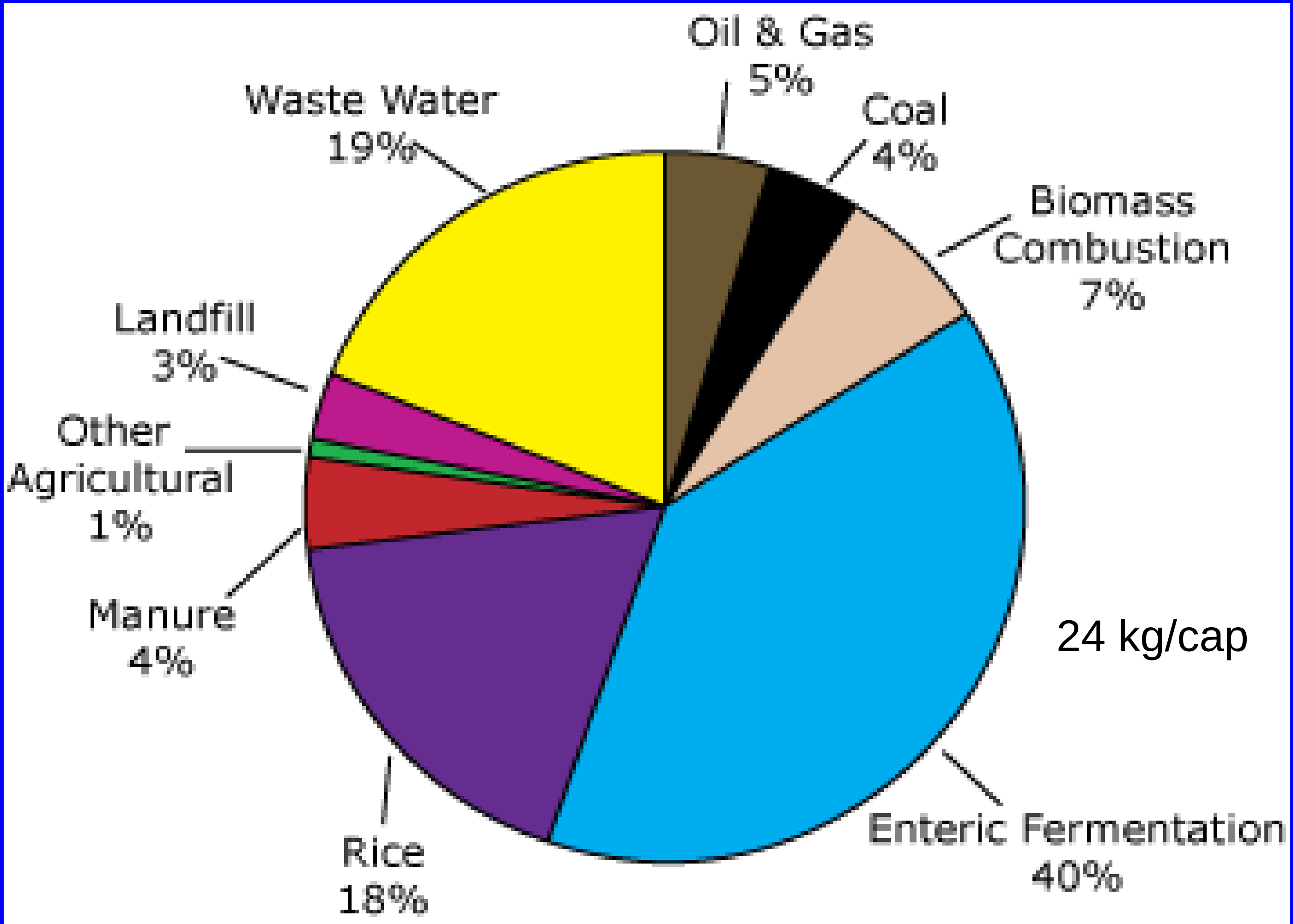
Patz JA, Gibbs HK, Foley JA, Rogers JV, Smith KR, 2007, **Climate change and global health: Quantifying a growing ethical crisis**, EcoHealth 4(4): 397–405, 2007.

USA Anthropogenic Methane Emissions ~2005
Total ~ 25 million tons



USEPA
2006

Methane Emissions from India in 2005
26.1 Mt (9% of world)

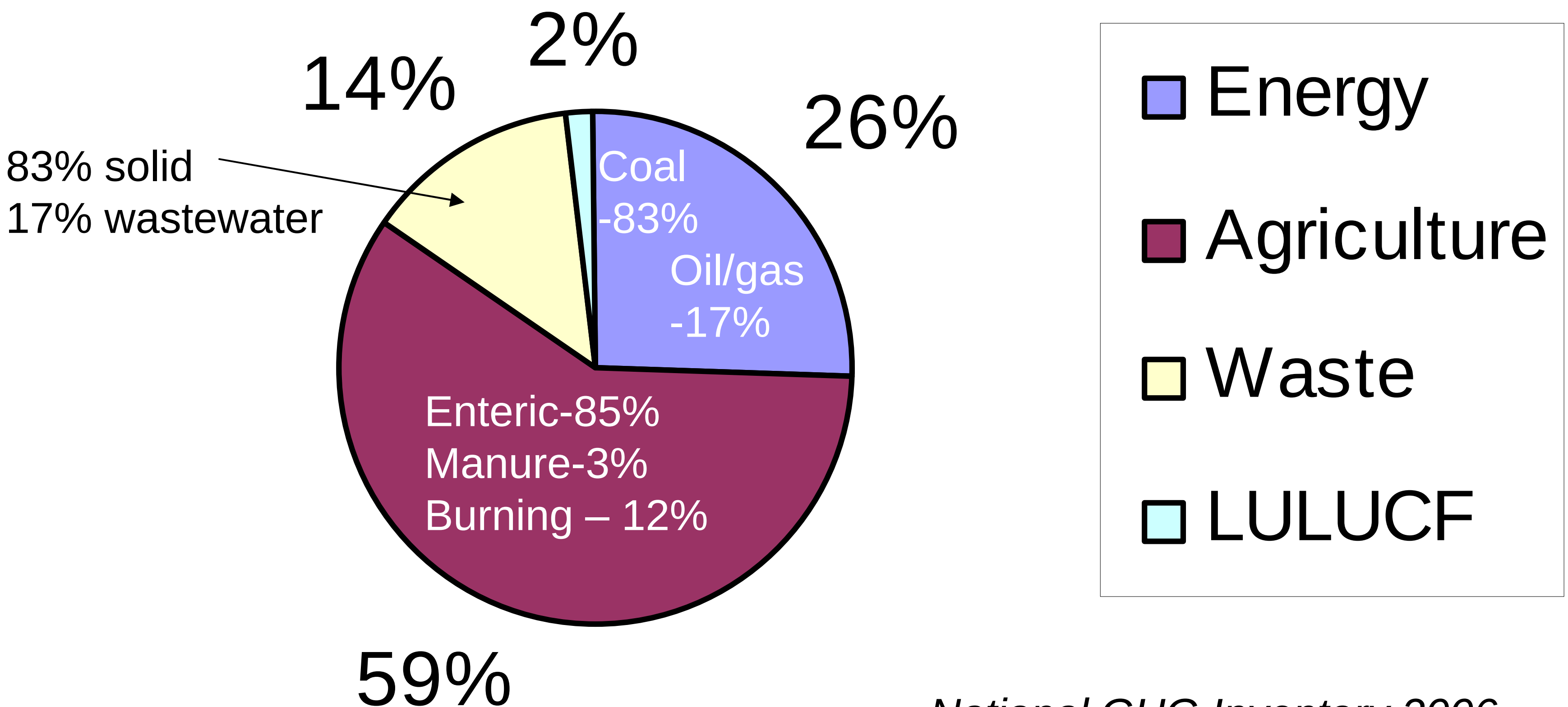


http://www.epa.gov/nonco2/econ-inv/international.html

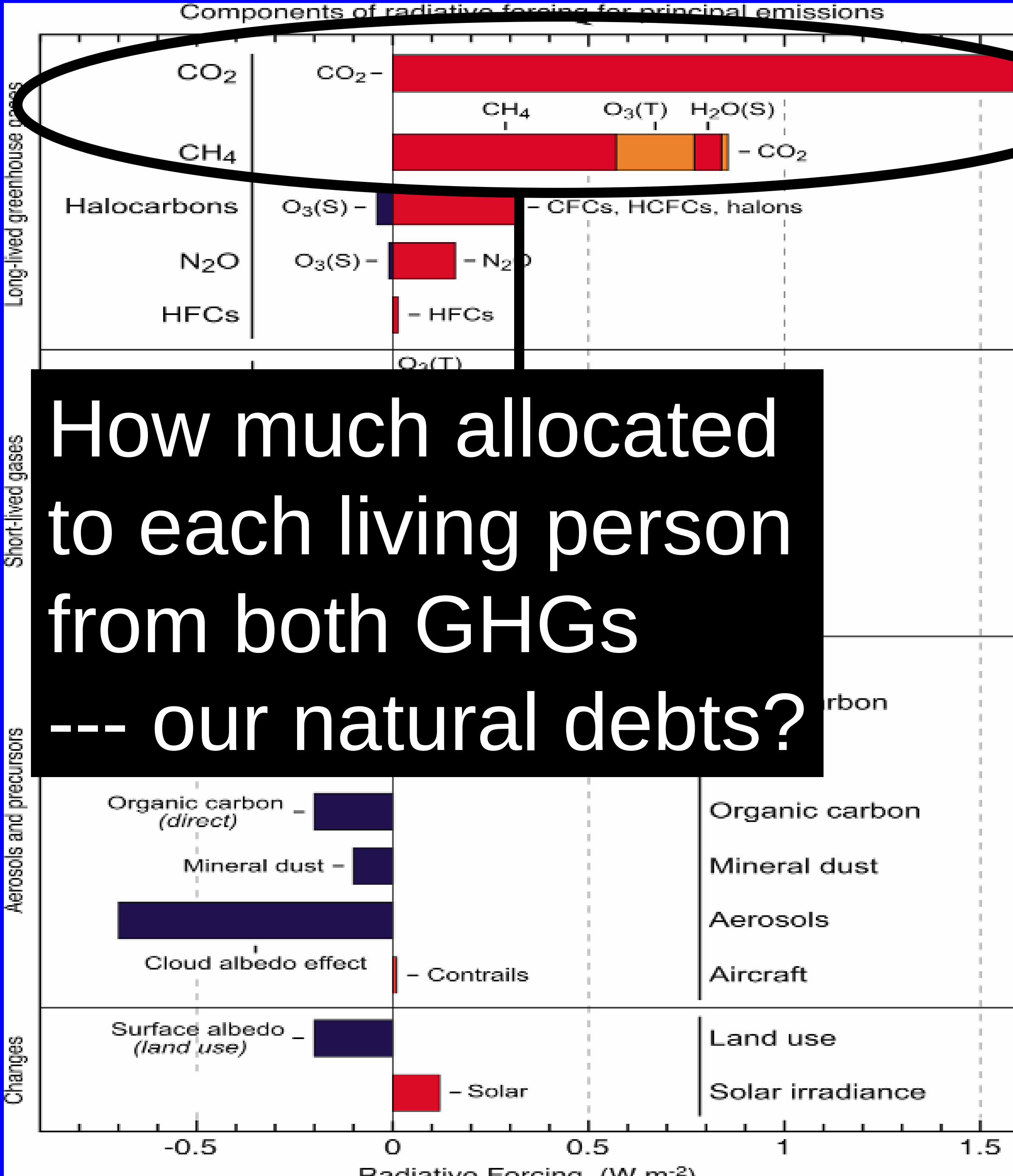
Australian Methane Emissions - 2006

~270 kg/cap

5.6 Mt ~2% of global total



National GHG Inventory 2006, Dept of Climate Change, 2008

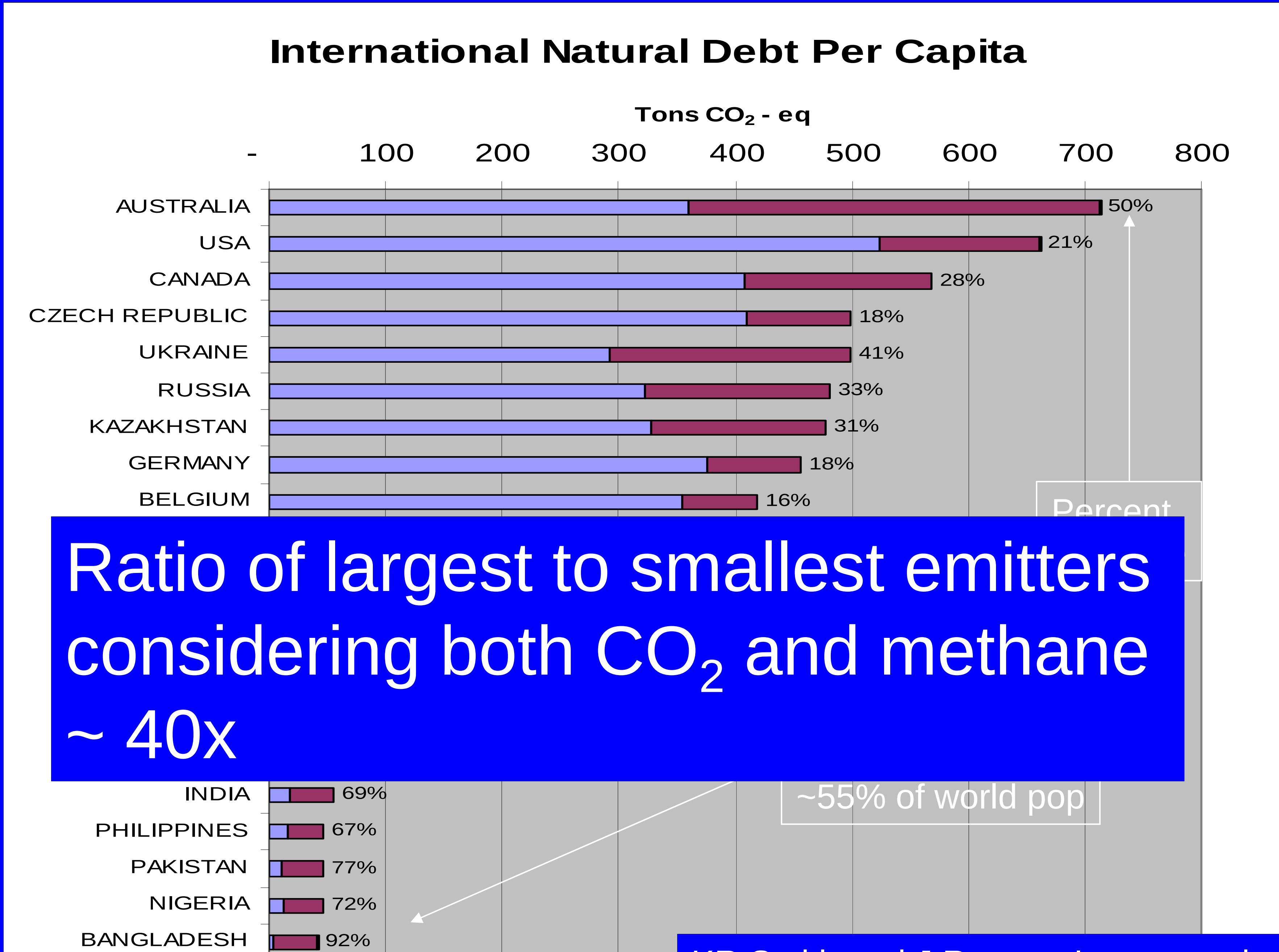


How much allocated to each living person from both GHGs --- our natural debts?

Warming in 2005 from emissions since 1750

More than half due to methane

IPCC, 2007



Ratio of largest to smallest emitters considering both CO_2 and methane ~ 40x

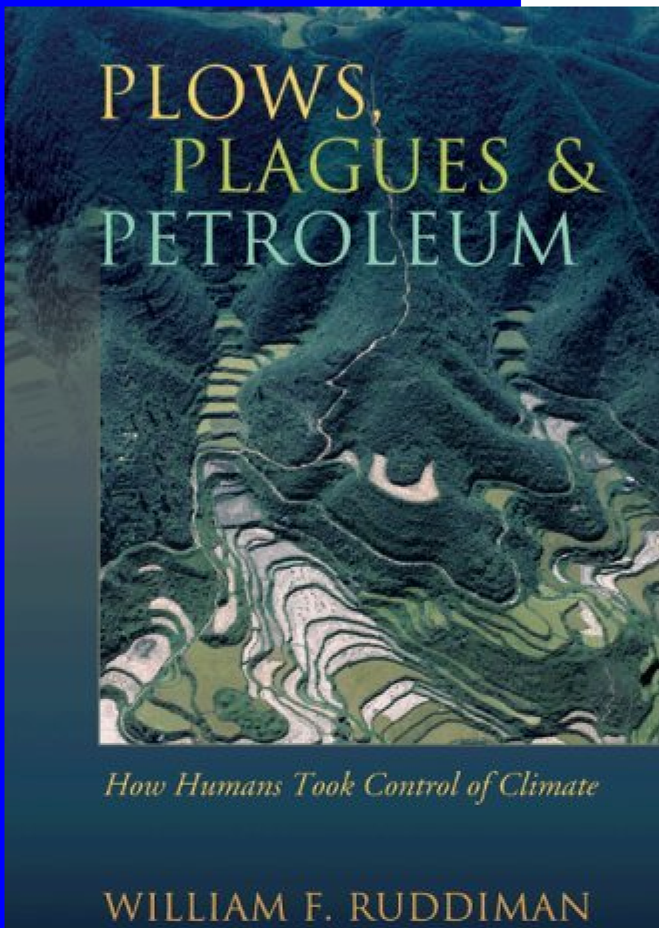
KR Smith and J Rogers, In preparation

THE ANTHROPOGENIC GREENHOUSE ERA
BEGAN THOUSANDS OF YEARS AGO

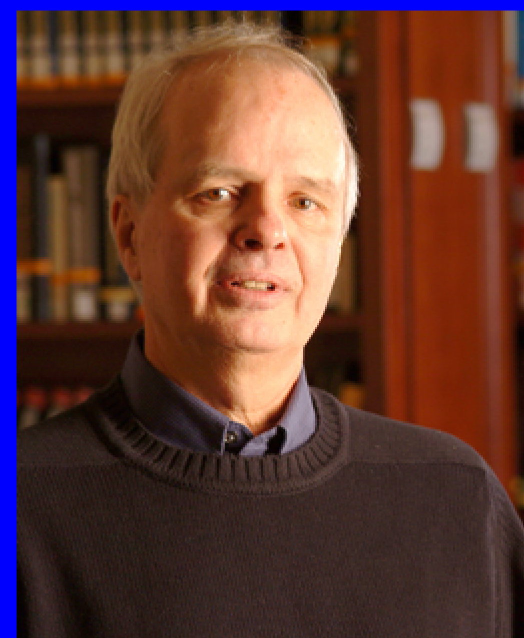
WILLIAM F. RUDDIMAN

Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22904, U.S.A.
E-mail: wfr5c@virginia.edu

Climatic Change **61:** 261–293, 2003.



Princeton U Press, 2006



5. A Different Historical Framework

- Agrarian societies have been contributing to incipient climate change for several millennia.
- Reversing what would have been a natural decline in CO_2 and methane in this period
- Excess GHGs are not just a feature of industrialization, although the rate has risen dramatically after the industrial revolution

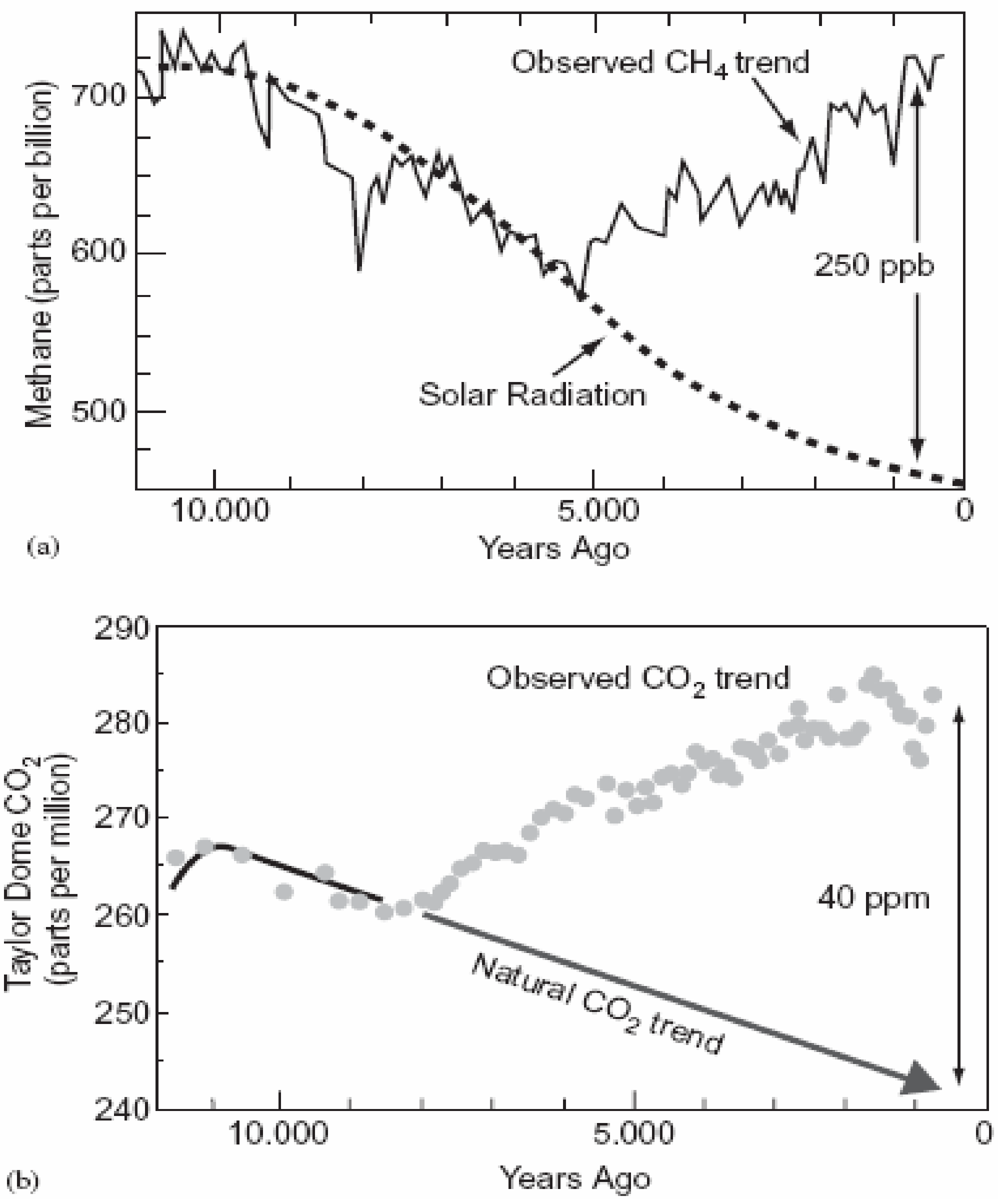


Fig. 1. Anthropogenic effects on (a) CH_4 and (b) CO_2 calculated as the difference between observed trends (Blunier et al., 1995; Indermuhle et al., 1999) and trends estimated from previous early interglacial intervals (Ruddiman, 2003).

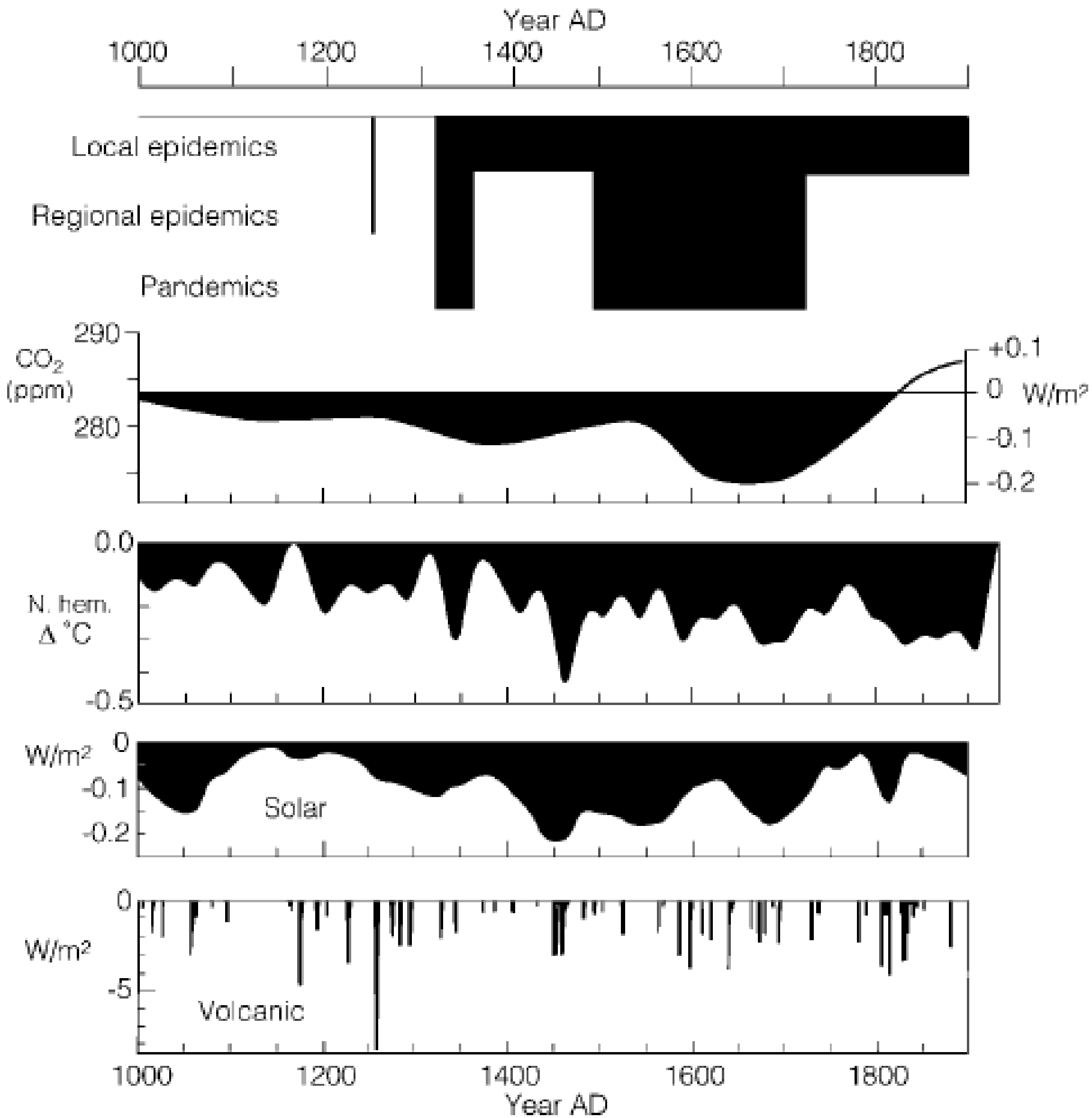
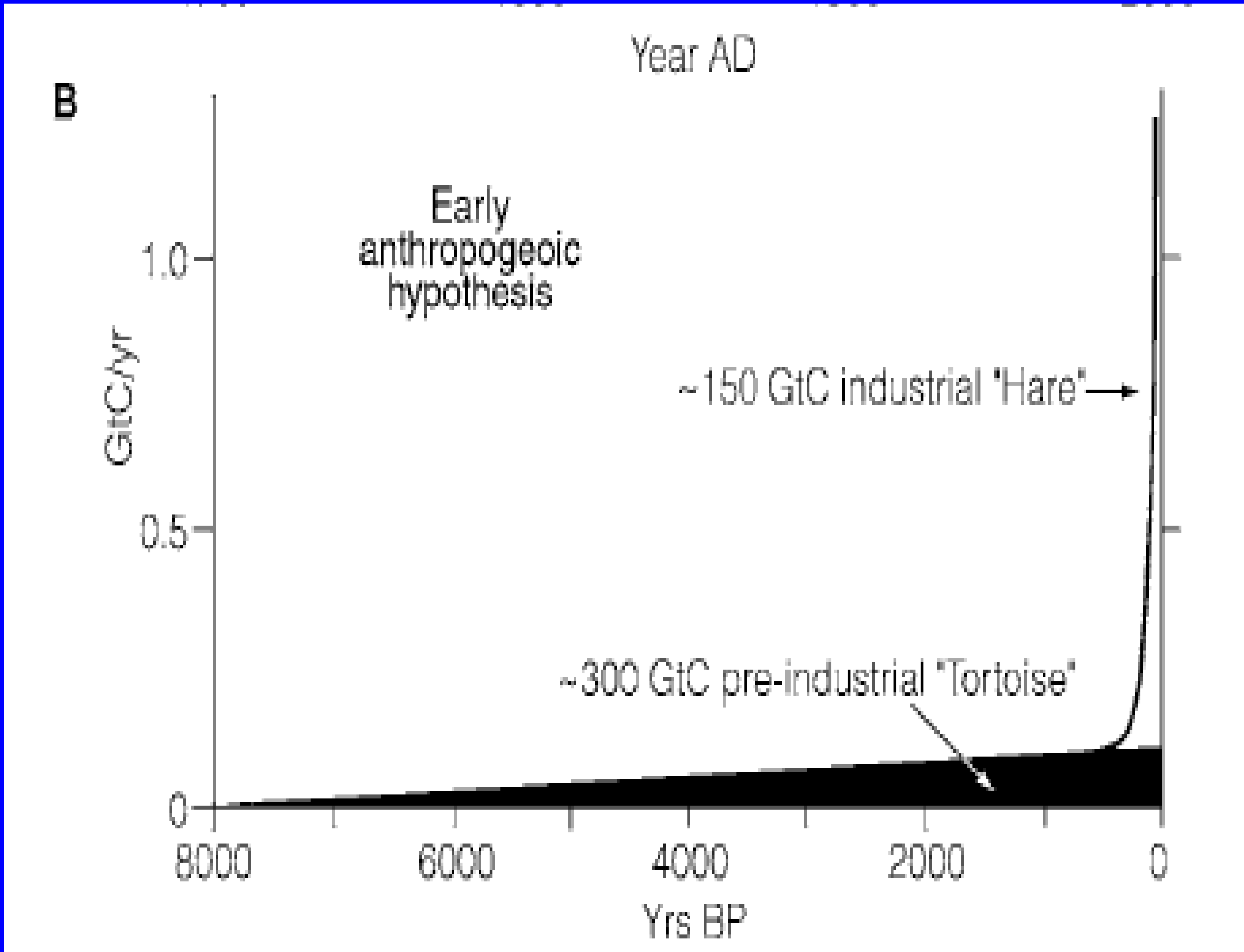


Figure 10. Estimated mean northern hemisphere temperature changes from 1000–1900 AD (Mann et al., 1999) compared to: plague epidemics and pandemics; ice-core CO_2 (average of changes at Taylor Dome and Law Dome shown in Figure 7); and solar and volcanic radiative forcing (from Bard et al., 2000; Crowley, 2000).

Ruddiman, 2003



Ruddiman 2003

Carbon dioxide is important

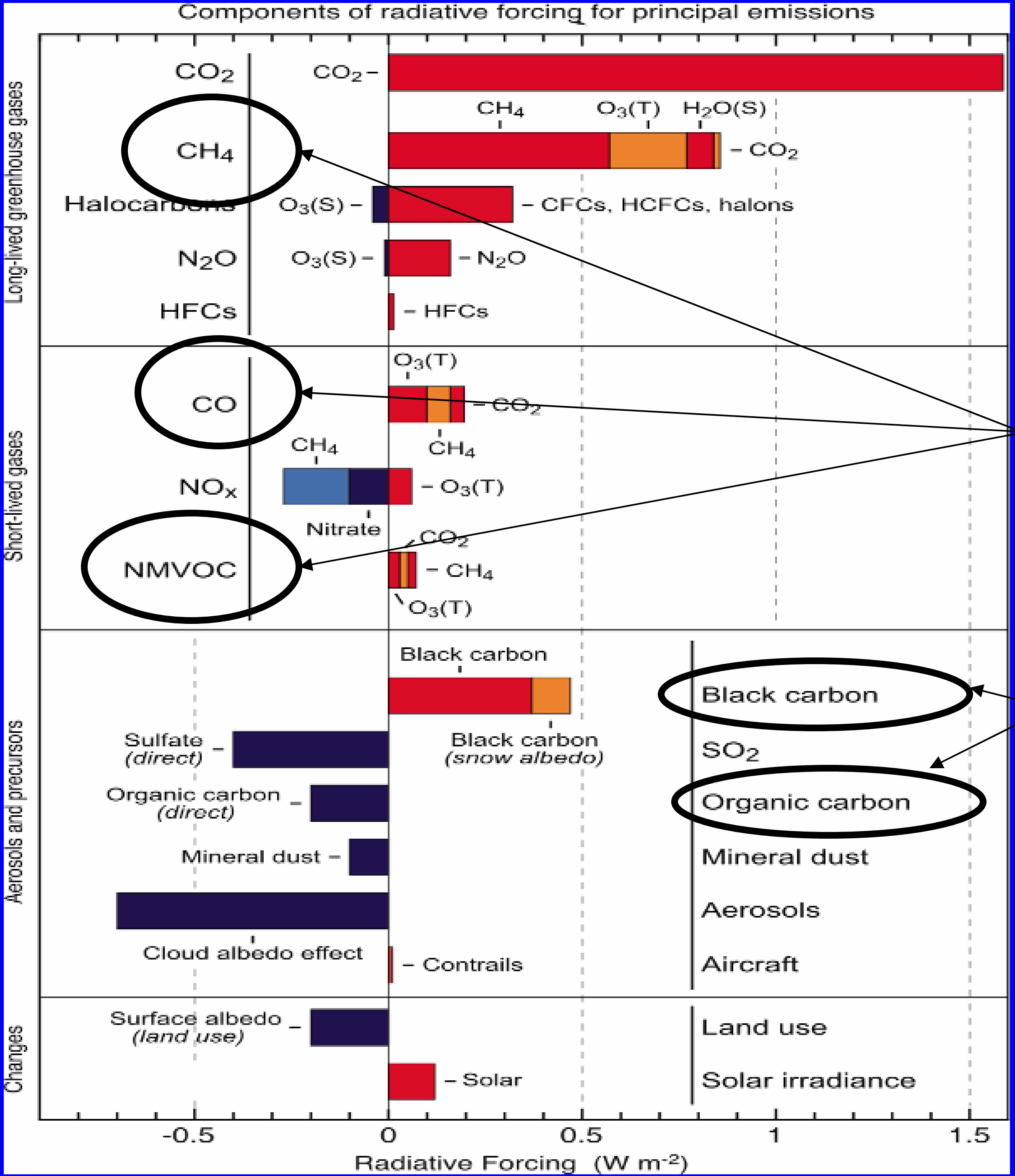
However, …

Laws of Carbon-thermodynamics

I. Keep all fossil and forest carbon out of the atmosphere

II. If you cannot do so, the least-damaging form to release is carbon dioxide because all other forms are worse for climate and health.

III. Even renewable (non-fossil) carbon is damaging for climate and health if not released as carbon dioxide.



Warming in 2005 from emissions since 1750

A large part from PIC: products of incomplete combustion

IPCC, 2007

Ranking of Carbon Emissions:
The Pharmaceutical Index

- Carbon dioxide is noxious if fossil or forest derived, but benign if from renewable sources
- Products of incomplete combustion (PIC) such as carbon monoxide and hydrocarbons are like CO_2 on caffeine – several times worse
- Methane from any source (fossil, biologic, or incomplete combustion) is like CO_2 on steroids – dozens of times worse.
- Black carbon in particles from incomplete combustion is like CO_2 on crack – hundreds of times worse.

Conclusion on Methane

- Methane emissions are more important than current official weighting factors indicate because of its large effect over the next generation
- May well increase in “value”, perhaps during the post-Kyoto deliberations now starting
- Developing countries have a bigger role
- Methane is emitted as part of the poor combustion process of solid fuels, which also produce much health-damaging pollution
- Contributes directly to global tropospheric ozone levels
- Improving this combustion offers substantial GHG as well as health benefits in a cost-effective manner
- Ways to control are quite different from CO_2
- And may be easier in the short term

Methane – bottom lines?

- Way to reduce warming in the next generation is to put more attention on methane (and other shorter lived GHGs)
- Once the heat enters Earth's systems, it does not matter where it came from
- For some impacts, the **rate** of warming is as important as the total amount
- Only way to slow the rate is to immediately reduce methane emissions (and other short-lived GH pollutants)
- While working to stop CO_2 in the long run

Carbon dioxide is still important

But, do you know your methane footprint?

Publications and presentations available at

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

Thank you