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

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Carbon dioxide is important

Do not think otherwise

The Methane Story: CH₄

Five subplots:

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

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Methane and global equity

Carbon dioxide

Methane and history

.....

What I am not speaking about

Particular methane reduction possibilities in California

Potential for runaway methane emissions as positive feedback in global warming



Only one-third of emissions from natural sources





Emissions expected to grow at ~1.5% per year until 2030 – similar to CO2



Warming in 2005 from emissions since 1750

Methane more than half of total from CO₂

IPCC, 2007

1. Methane and Global Warming

- A much more powerful greenhouse gas (GHG) than CO₂
- Partly due to its direct effect, but also because it creates ozone (O₃), another powerful GHG
- Nearly 100 times more per ton than CO₂ at any one time (73x from direct effects)
- Eventually turns to 2.75 times as much CO₂ by mass
- Methane has thus contributed a significant amount to global warming, more than half that of CO₂
- But has a much shorter atmospheric lifetime compared to CO₂

Math of GHG Decay (AR4)

- CO₂ 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



Natural CO2 and CH4 Depeletion - 100 years



Relative Warming from CO2 and CH4 emitted in 2008



Actually two types of methane

- Biogenic methane (ruminants, biomass combustion, landfills, etc.) – the CO₂ it creates is renewable, i.e., does not add to atmospheric load of CO₂
- Fossil methane (natural gas, coal mines, fossil fuel combustion) – the CO₂ it creates does add to the load

Global Anthropogenic Methane Emissions ~2005 Total ~ 305 million tons





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 CO₂ 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, including those for California.

Methane and Time

- The current official GWPs are based on 100-year time horizons
 - Methane is $21 \times CO_2$ 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% may now be too low.</p>
- The other GWP published by IPCC, has a 20-year time horizon
 - Methane is $72 \times CO_2$ 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



Methane GWPs and Discount Rates



Methane GWPs and Time Horizons





Time perspective makes a difference

horizon

IPCC, 2007

Methane #1: Summary

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- Methane has thus contributed a significant amount to global warming,
- But has a much shorter atmospheric lifetime compared to CO₂
- Thus, changes in emission rates will have a much faster impact to lower warming than changes in CO₂ emissions
- But there is also more variability in the system

2. Methane and Global Health

- Increases of wide-scale tropospheric (groundlevel) 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

Methane as a Global Ozone Precursor



Background Ozone is Growing ...



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

Mauzerall 2007

... 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



How Much Can Methane Be Reduced?



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



Effect of a reduction of 20% (~61 MT) in global methane emissions on tropospheric ozone

West et al., PNAS, 2006



Reduction in ozone mortality from 20% reduction in methane emissions

West et al, PNAS, 2006

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 Assessment, 2004



IPCC 2007, WGIII

National Household Solid Fuel Use, 2000



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



INDIA



Percent of Households Using Biomass Fuels

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



Smith, et al. 2000
Energy flows in a well-operating traditional wood-fired cookstove

Mood: 1 kg

A Toxic Waste Factory!!

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



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

Source: Smith, et al., 2000

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

- Small particles, CO, NO₂
- Hydrocarbons

Plus methane

- 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 $benzo(\alpha)pyrene$
- 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

Naeher, et al. 2007

 Chlorinated organics such as methylene chloride and dioxin ALRI/ Pneumonia (meningitis)

Low birth weight

Asthma?

Early infant death?

Birth defects?

Cognitive / Impairment?

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

Chronic obstructive lung disease

Tuberculosis

Blindness (cataracts, trachoma)

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

Heart disease?

Global Burden of Disease from Top 10 Risk Factors plus selected other risk factors



Indian Burden of Disease from Top 10 Risk Factors and Selected Other Risk Factors



Percent of All DALYs in 2000

Child Pneumonia indoor air pollution

New Systematic Review and Meta-Analysis

Dherani et al. Bull WHO, 2008

Study	Odds Ratio (random)	Weight	Odds Ratio (random)		
or sub-category	95% CI	%	95% CI		
01 Intervention Studies					
Smith(2007)a		5.53	1.18 [0	0.88, 1.58]	
Smith(2007)b		5.73	1.35 []	1.05, 1.731	
Subtotal (95% CI)	•	11.26	1.28 []	1.06, 1.54]	
Test for heterogeneity: Chi ² = 0.48	3, df = 1 (P = 0.49), ² = 0%				
Test for overall effect: Z = 2.54 (P	P = 0.01)				
02 Cohort Studies					
Armstrong(1991)a		2.80	0.50 [0	0.20, 1.22]	
Armstrong(1991)b		3.65	1.90 [0).96, 3.75]	
Cambell(1989)		3.25	2.80 []	1.29, 6.08]	
Ezzati(2001)		3.86	2.33 [3	1.23, 4.40]	
Jin(1993)		5.69	0.80 [0	0.62, 1.03]	
Pandey(1989)a		4.34	2.45 []	1.43, 4.19)	
Pandey(1989)b		▶ 1.52	40.65 [9	9.79, 168.75	1
Subtotal (95% CI)		25.11	2.12 []	1.05, 4.25]	
Test for heterogeneity: Chi ² = 54.0)7, df = 6 (P < 0.00001), l² = 88.9%				
Test for overall effect: Z = 2.11 (P	' = 0.03)				
03 Case-Control Studies					
Azizi(1995)		3.97	1.20 [0).65, 2.21]	
Broor(2001)		4.49	2.51 []	1.51, 4.17]	
Collings(1990)		4.85	2.16 []	1.40, 3.33]	
De Francisco(1993)		→ 2.15	5.23 []	1.72, 15.91]	
Fonsecca(1996)		4.68	1.14 [0).71, 1.82]	
Johnson(1992)a		3.15	0.80 [0).36, 1.78)	
Kossove(1982)		→ 1.96	4.77 []	1.44, 15.74]	
Kumar(2004)		2.45	3.87 [3	L.42, 10.57]	
Mahalanabas(2002)		- 3.63	3.97 [2	2.00, 7.88]	
Morns(1990)		- 2.41	4.85 []	1.75, 13.40]	
O'Dempsey(1996)		- 2.59	2.55 [0).98, 6.64]	
Robin(1996)a		2.95	1.40 (0).60, 3.28)	
Victora(1994)a		4.08	1.10 (0	0.61, 1.98]	
Wayse(2004)		Z.90	1.39 [0).58, 3.30]	
Wesley(1996)		1.87	1.35 10	1.39, 4.63]	
Subtotal (95% CI)		48.15	1.97 [:	1.47, 2.64]	
Test for overall effect: Z = 4.53 (P	2, df = 14 (P = 0.003), P = 57.2% P < 0.00001)				
04 Cross-sectional Studies					
Michra(2003)		2 02	2 20 1	1 16 4 191	
Mishra(2005)		5.87	1 58 1	28 1 951	
Wichmann(2006)		5 79	1 29 11	02 1 631	
Subtatal (95% CD)		15 49	1 49 1	1 21 1 951	
Test for beterogeneity: Ch2 = 3.19	df = 2 (P = 0.20) P = 37.3%	10.40		4.001	
Test for overall effect: Z = 3.74 (P	2 = 0.0002)				
Total (95% CI)	•	100.00	1.78 []	1.45. 2.181	
Test for heterogeneity. Chi2 = 101	.74, df = 26 (P < 0.00001), P = 74.49	6			
Test for overall effect: Z = 5.61 (P	v < 0.00001)				
0.1	0.2 0.5 1 2 5	10			_
	Increased risk Decreased risk	c			



A Chinese Hybrid Gasifier Stove Winner of National Stove Contest

Efficiency 2x traditional stoves; Emissions 10-15x less: Low health risk and essentially no greenhouse emissions



Compared to Coal Stove

17% to 41% fuel efficiency0.12 to 0.02 CO/CO21.6 to 0.26 g PM/kg fuel

18 W blower

Health and Greenhouse Gas Benefits of Biomass Stove Options





Smith & Haigler, 2008



Smith & Haigler, 2008

Paying for Rural Energy Development



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 CO₂ 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 from $_{e}$ fossil fuels and cement: (billiö

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

Distribution of Global Natural Debt Among Top 10 Nations CO2 only in 2005



Nb. Land-use change emissions not are parsed out by country

Smith and Rogers, in preparation

USA Anthropogenic Methane Emissions ~2005 Total ~ 25 million tons



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



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

Chinese Methane Emissions in 2005 41 MT = 13% of world

31 kg/capita



USEPA, 2006

Distribution of Global Natural Debts in Top 10 Nations CH4 and CO2 in 2005

[compared to CO2 alone; note decrease for USA, increase for China, and large increases for India and Brazil]



Nb. National fossil fuel/cement emissions only for CO2, land-use change emissions are not parsed out by country

International Natural Debt Per Capita



Ratio of largest to smallest emitters considering both CO_2 and methane $\sim 40x$



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 CO₂ and methane in this period
- Excess GHGs are not just a feature of industrialization, although the rate has risen dramatically after the industrial revolution

THE ANTHROPOGENIC GREENHOUSE ERA BEGAN THOUSANDS OF YEARS AGO

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Climatic Change 61: 261–293, 2003. © 2003 Kluwer Academic Publishers. Printed in the Netherlands.



PLOWS, PLAGUES & PETROLEUM



How Humans Took Control of Climate

WILLIAM F. RUDDIMAN Princeton U Press, 2006



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).



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 CO₂ (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

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.



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 CO₂ on caffeine – several times worse
- Methane from any source (fossil, biologic, or incomplete combustion) is like CO₂ on steroids – dozens of times worse.
- Black carbon in particles from incomplete combustion is like CO₂ 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 CO₂
- 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 <u>rate</u> of warming is as important as the total amount
- Only way to slow the rate is to immediately reduce methane emissions (and other shortlived GH pollutants)
- While working to stop CO₂ in the long run

Carbon dioxide is still important

But, do you know your methane footprint?

California Methane Emissions 2004 – 1.2 MT



Publications and presentations available at

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

