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

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Nobel Laureate 2007

Energy and Resources Group
Colloquium
September 17, 2008

At the 0.02% level
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

**Anthropogenic Sources**

- $\text{CO}_2$
  - Fossil fuels
  - Land use change
  - Cement manufacturing

- Methane
  - Landfills
  - Rice
  - Livestock
  - Waste management
  - Fossil recovery

- $\text{N}_2\text{O}$
  - Fertilizer
  - Planted N-fixers
  - Combustion

Figure SPM.1
IPCC 2007
Only one-third of emissions from natural sources
"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 CO2

60% more by 2030
Current and Projected CH$_4$ and N$_2$O 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

- Carbon Dioxide
- Methane
Natural CO2 and CH4 Depletion - 100 years

Fraction Remaining of Gas Emitted in 2008

<table>
<thead>
<tr>
<th>Year</th>
<th>Carbon Dioxide</th>
<th>Methane</th>
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<tbody>
<tr>
<td>2008</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2028</td>
<td>0.90</td>
<td>0.80</td>
</tr>
<tr>
<td>2048</td>
<td>0.80</td>
<td>0.60</td>
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<td>2068</td>
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<td>2088</td>
<td>0.60</td>
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<tr>
<td>2108</td>
<td>0.50</td>
<td>0.20</td>
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Relative Warming from CO2 and CH4 emitted in 2008

- Not equal warming per year until 2075 (67 years)
- Not equal total warming until AD 7430 (5422 years)
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

Livestock 30%
Coal mining 6%
Biomass burn 3%
Oi/gas 18%
Fossil fuel burn 1%
Rice 10%
Landfills 12%
Waste water 9%
Other ag 7%
Manure 4%

Fossil methane ~25%

Expected to grow at ~1.5% per year

~47 kg/cap

USEPA, 2006
Future Warming of Fossil Methane and CO$_2$ from Equal Emissions in 2008

Future Annual Warming from One Ton of Each Pollutant Released in 2008

Includes CO$_2$ produced by the methane
Warming Contribution of Total ~2008 Emissions of Methane Compared to Total CO2 Emissions

Fraction of CO2 Warming from Methane

Year:
- 2008
- 2010
- 2012
- 2014
- 2016
- 2018
- 2020
- 2022
- 2024
- 2026
- 2028

Values:
- 1.20
- 1.00
- 0.80
- 0.60
- 0.40
- 0.20
- 0.00
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)

- 20 years – 72x
- 100 years – 25x

2. Graph showing the warming over time with a focus on 20 and 100 years.
3. Carbon Dioxide and Methane emissions differentiated.
4. Notably, more rapid warming within the first 20 years for CH4 compared to CO2.
Methane GWPs and Discount Rates

- Official GWP of 21, ~0.75% discount rate
- At GWP=25, ~1% DR
Methane GWPs and Time Horizons

A GWP of 48 (3% discount rate) ~ 40-year time horizon
Time perspective makes a difference
Methane #1: Summary

- 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
- Eventually turns to 2.75 times as much CO₂ by mass
- 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 (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\textsubscript{X} emissions (Wang et al., 1998; Prather et al., 2003).

Ozone trend at European mountain sites, 1870-1990 (Marenco et al., 1994).
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.
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
Modern Biomass 1.4%
Other Renewables 0.8%

Traditional Biomass 9.3%

Natural Gas 21.7%
Nuclear 6.9%
Hydro 2.3%

Coal 22.6%
Oil 35.1%

"Modern" Biomass Renewables 1.4%

Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 167 toe

World Energy – 2001

World Energy Assessment, 2004

3. Methane and the health of the poor
National Household Solid Fuel Use, 2000
Greenhouse warming commitment per meal for typical wood-fired cookstove in India

- Wood: 1.0 kg
  - Carbon: 454 g

- CO2 Carbon: 403 g

- Methane Carbon: 3.8 g

- Other GHG Carbon
  - Carbon Monoxide: 38 g
  - Hydrocarbons: 6.3 g

- Nitrous Oxide: 0.018 g

Global warming commitments of each of the gases as CO2 equivalents

Source: Smith, et al., 2000
Nearly 2 million tons methane per year of the ~ 305 Mt total global human emissions

Smith, et al. 2000

2001 Census
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: 2.8 MJ (18%)
- In PIC: 1.2 MJ (8%)
- Waste Heat: 11.3 MJ (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

- Small particles, CO, NO₂
- 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*

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

- Underweight
- Unsafe sex
- Blood pressure
- Tobacco
- Alcohol
- Unsafe water/sanitation
- Child cluster vaccination*
- Cholesterol
- Lack of Malaria control*
- Indoor smoke from solid fuels
- Overweight
- Occupational hazards (5 kinds)
- Road traffic accidents*
- Physical inactivity
- Lead (Pb) pollution
- Urban outdoor air pollution
- Climate change

Smith et al. 2005

4.9 million premature deaths/y
1.6 million premature deaths/y
two-thirds from ARI in children
0.15 million premature deaths/y
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

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
China: Solar PV

U.S. Solar PV

Smith & Haigler, 2008
Current Cost-effective Region In China

- China: Solar PV
- U.S. Solar PV
- U.S. Hybrid vehicles
- China: Wind
- U.S. Nuclear
- U.S. Wind
- India: Improved biomass stoves
- China: Household coal to biomass gasifier stoves
- China: Household coal to propane/LPG stoves

Relative Values ($Int)
- tCO2e offset
- DALYs avoided

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?
Ratio of largest to smallest emitting countries ~ 500x

This kind of calculation, however is based only on CO₂ emissions:

USA Anthropogenic Methane Emissions ~2005
Total ~ 25 million tons

- Landfills: 25%
- Oi/gas: 24%
- Livestock: 22%
- Waste water: 7%
- Coal mining: 11%
- Fossil fuel burn: 2%
- Manure: 8%
- Rice: 1%

~83 kg/cap
~8% of world

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

5.6 Mt ~2% of global total

~270 kg/cap

National GHG Inventory 2006,
Dept of Climate Change, 2008
Warming in 2005 from emissions since 1750
More than half due to methane

How much allocated to each living person from both GHGs --- our natural debts?
Ratio of largest to smallest emitters considering both CO₂ and methane ~ 40x

KR Smith and J Rogers, In preparation
THE ANTHROPOGENIC GREENHOUSE ERA BEGAN THOUSANDS OF YEARS AGO

WILLIAM F. RUDDIMAN
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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; Indermühle 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 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).
Early anthropogenic hypothesis

~150 GtC industrial "Hare"

~300 GtC pre-industrial "Tortoise"

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 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 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