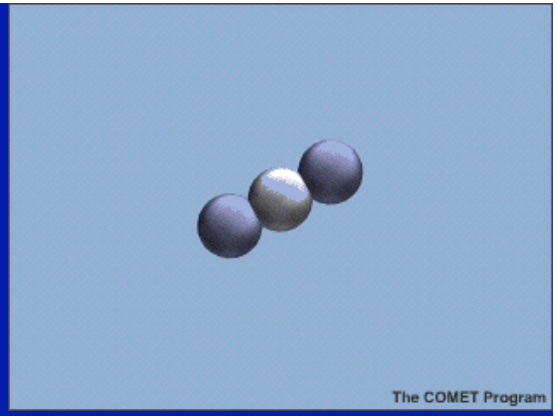

Our Climate: A Global Challenge

Academy for Lifelong Learning
Denver, CO
April 9, 2015
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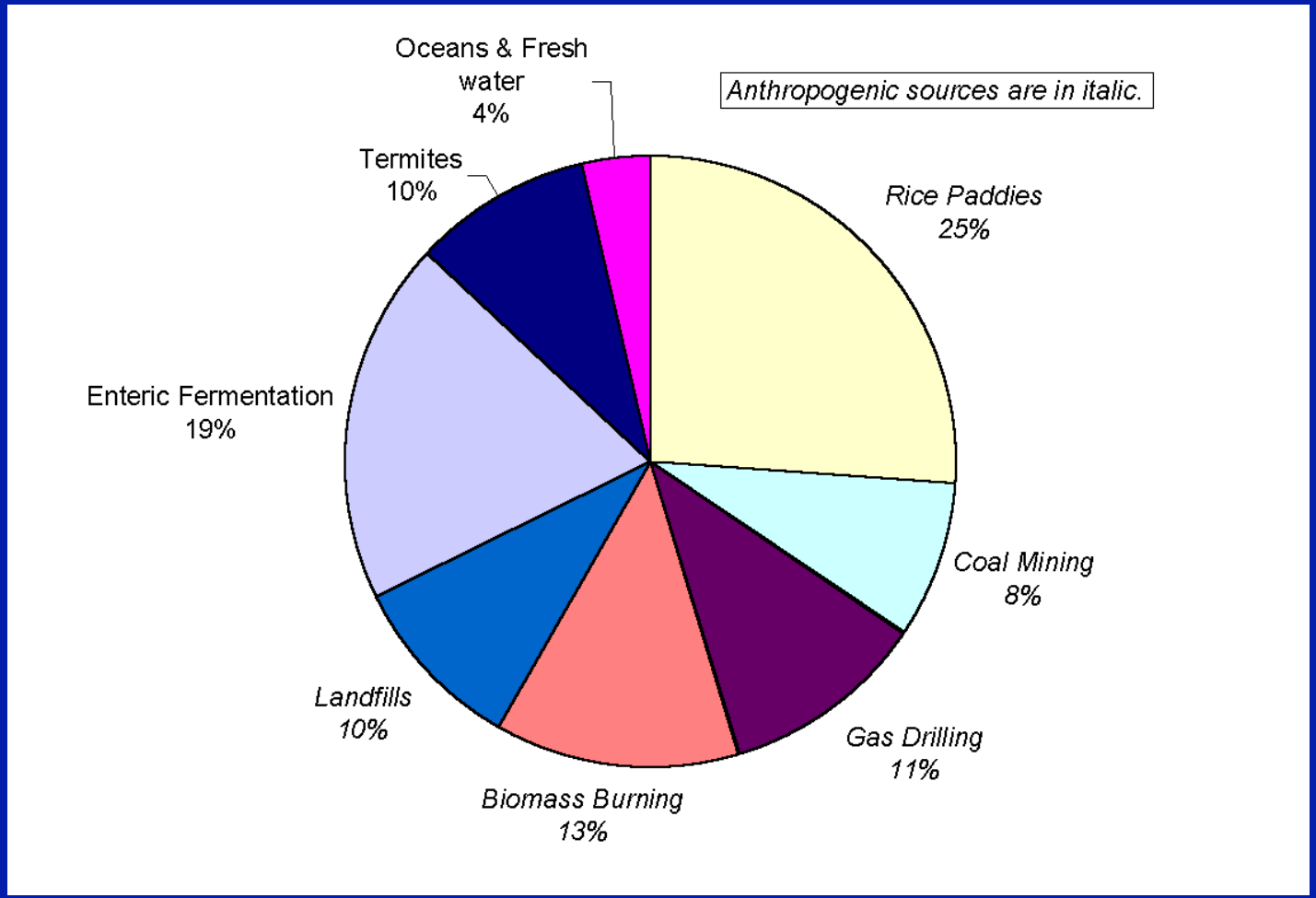
Greenhouse Effect: methane

Enteric: related to the intestines

Ruminant: mammals that use fermentation in the stomach cattle, goats, sheep, giraffes, yaks, deer, elk, camels, llamas, antelope, and yes, kangaroos, wallabies

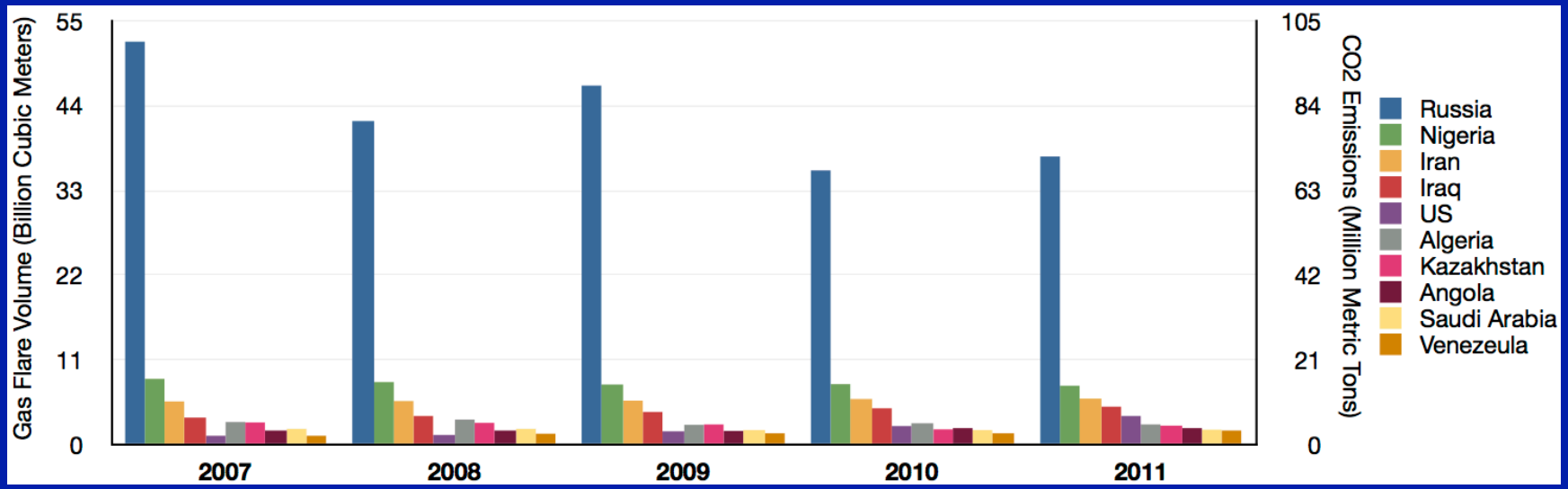


Methane compared to CO_2

as a greenhouse gas

Per pound: CH_4 is 20-25 times more powerful than CO_2

Per molecule: CH_4 is 7-9 times more powerful than CO_2



Biological formation of methane

Anaerobic decomposition of organic material by methanogenic bacteria (flooded soils, wetlands, landfills, digestive tracts).

$2CH_2O$ (formaldehyde) -> CH_4 (methane) + CO_2 (carbon dioxide)

Formaldehyde is ubiquitous in living organisms.

Methane production is temperature dependent, with a maximum reaction rate between 37 and 45 ^oC (98.6 & 113 ^oF).

Origin CH_4 Emission
Mass (M metric tons/yr)

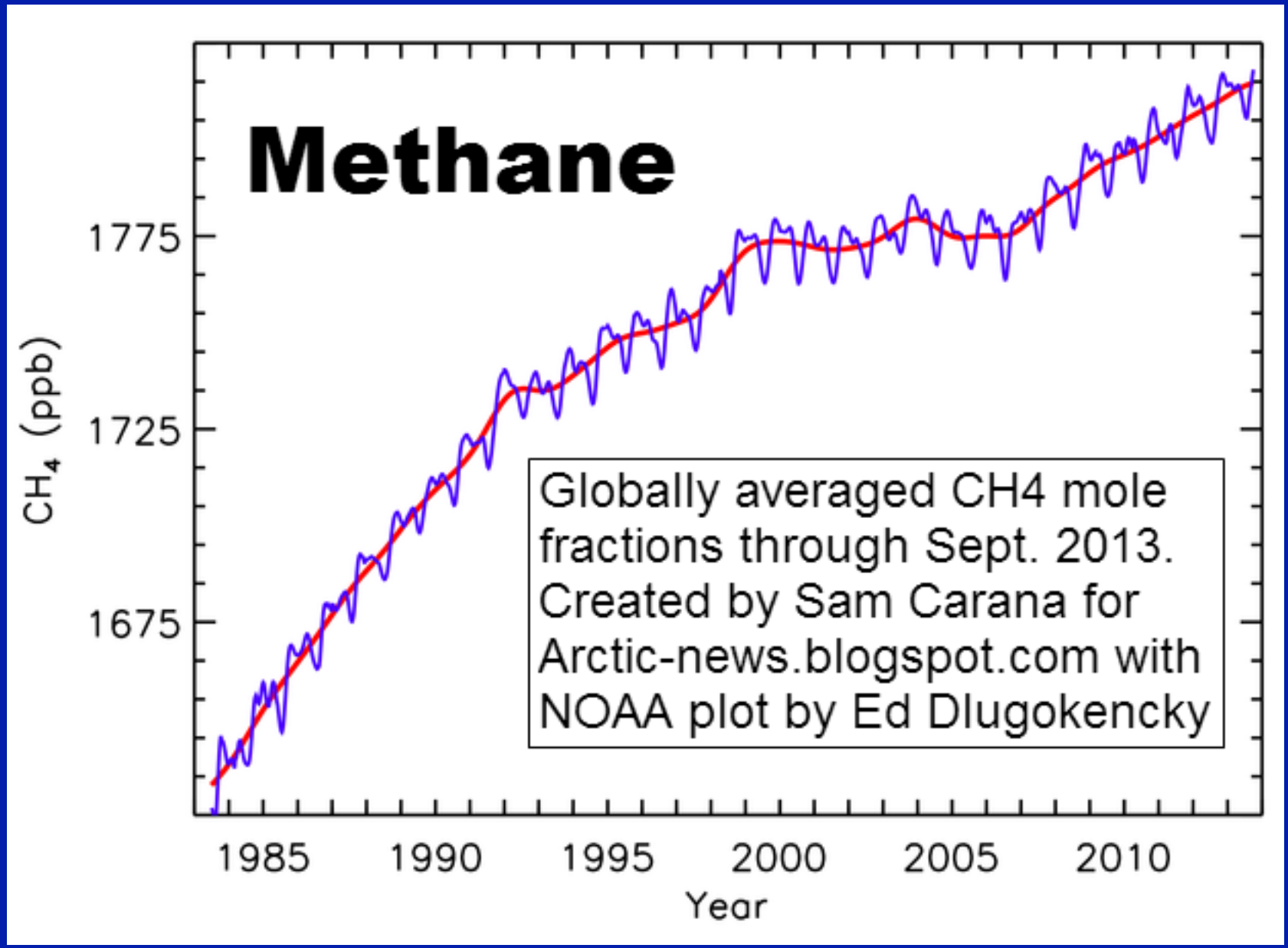
Sources	
Natural Emissions	
Wetlands (incl. rice agriculture)	225
Termites	20
Ocean	15
Hydrates	10
Natural Total	270
Anthropomorphic Emissions	
Energy	110
Landfills	40
Ruminates (Livestock)	115
Waste treatment	25
Biomass burning	40
Anthropogenic Total	330

Sinks	
Soils	-30
Tropospheric OH	-510
Stratospheric loss	-40
Sink Total	-580

Emissions + Sinks Imbalance
(trend) +20 M tons/year

Recall C mass from CO_2 was 10 billion tons/yr

Methane trend



Methane Sinks: OH^-

Methane is rapidly converted to CO_2 in the atmosphere

production of OH radicals

$O^- + H_2O \rightarrow 2OH^-$
UV dissociation of H_2O_2
(H_2O_2 is hydrogen peroxide)

$CH_4 + OH^- \rightarrow CH_3^- + H_2O$

$CH_3 + OH^- \rightarrow CH_2O^- + H_2O$ 9.6 years

$CH_2O + 2OH^- \rightarrow CO^- + 2H_2O$

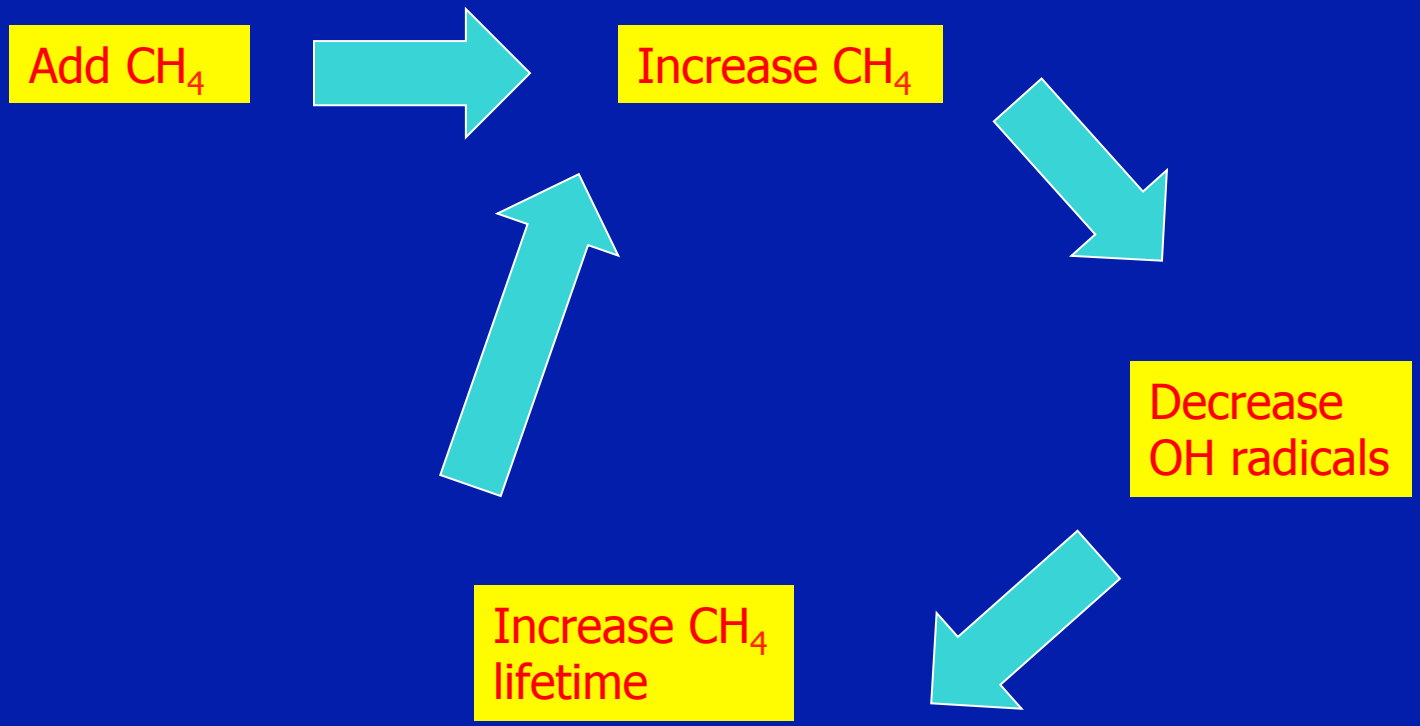
$CO + OH^- \rightarrow CO_2 + H^-$

OH comes from excited O and water. See *Methane and Carbon Monoxide in the Troposphere*
http://www.atmosp.physics.utoronto.ca/people/loic/chemistry.html#2.4%20Oxidation%20of%20Carbon

Excessive methane can reduce the OH radical population in the atmosphere and live longer. See Houweling thesis. Berkeley

See also http://www.atmosp.physics.utoronto.ca/people/loic/chemistry.html#3.1

Positive Feedback methane



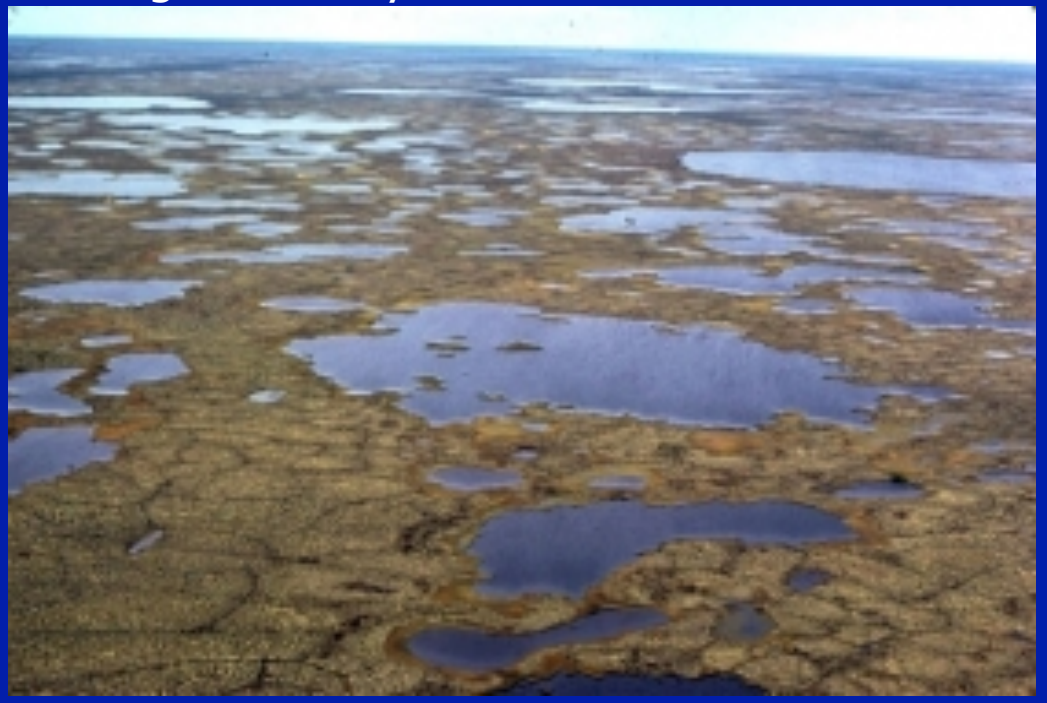
Methane lifetime

- Net of several reactions:
  - $CH_4 + OH^- \rightarrow CO_2 + H_2O$
  - 8-10 year lifetime
  - vicious cycle, positive feedback
- E.g. 1% increase in CH_4 -> 0.32% decrease in OH –> effective lifetime – 12-15 years

Permafrost melt releases CH_4 and CO_2.

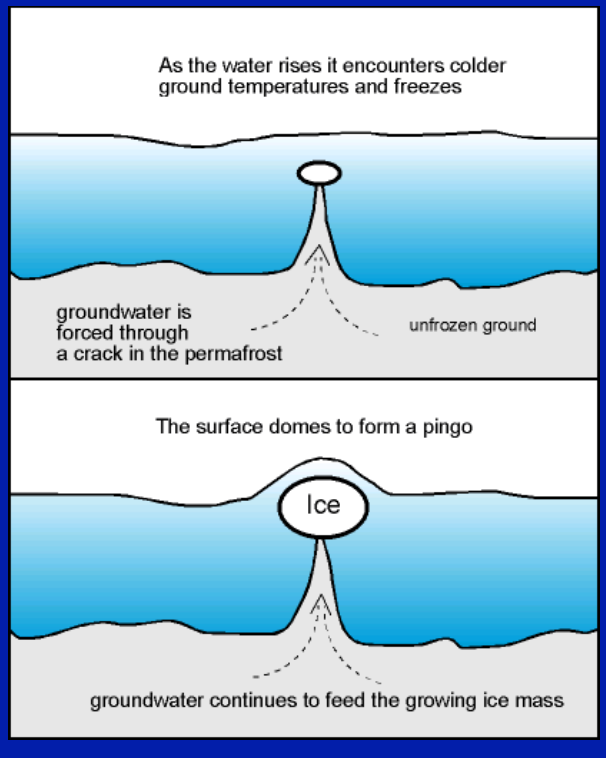
Changes in peat chemistry associated with permafrost thaw increase greenhouse gas production,
Hodgkins et al. 2014, doi: 10.1073/pnas.1314641111

On longer time scales, ~1000 years, the lakes formed, called thermokarst lakes, may absorb more carbon than is released. This absorption of CO_2 is the result of the slow development of biological activity in the lakes.
Anthony et al., Nature, 2014



A Pingo

A pingo, also called a hydrolaccolith, is a mound of earth-covered ice found in the Arctic and subarctic that can reach up to 70 metres (230 ft) in height and up to 600 m (2,000 ft) in diameter. The term originated as the Inuvialuktun word for a small hill. A pingo is a periglacial (nearby to glaciers) landform, which is defined as a nonglacial landform or process linked to colder climates.

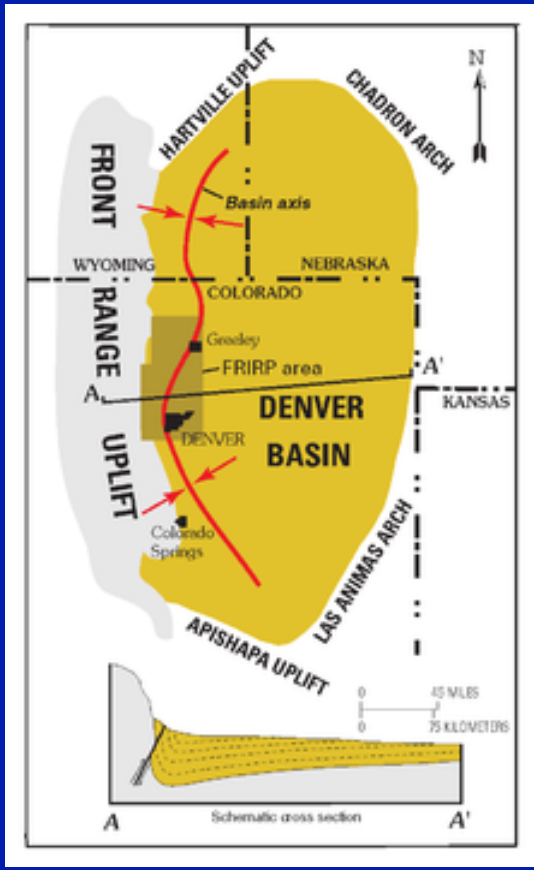


Natural gas: Gain lost via fracking?

Natural gas (mostly CH_4) emits about half as much CO_2 as coal per unit of energy when burned, but the 4-8% losses of CH_4 to the atmosphere offsets most of the gain. (See "Methane and the greenhouse-gas footprint of natural gas from shale formations", Howarth, Santoro, and Ingraffea, 2011, Climatic Change, **106**, p 679)

Samples of air from a tower north of Denver, Colorado, showed that natural-gas producers in the Denver-Julesburg Basin are losing about 4% of their gas to the atmosphere — not including additional losses in the pipeline and distribution system. (See Tollefson, 2012, Nature, **482**, and Pétron et al., 2014, J. Geophysical Res, in press)

- CH_4 is not much better than coal unless this lost gas can be recaptured.
  - loss is more than double the official inventory
  - roughly in line with estimates made in 2011
  - challenged by industry



FRIRP: Front Range Infrastructure Resources Project

Methane

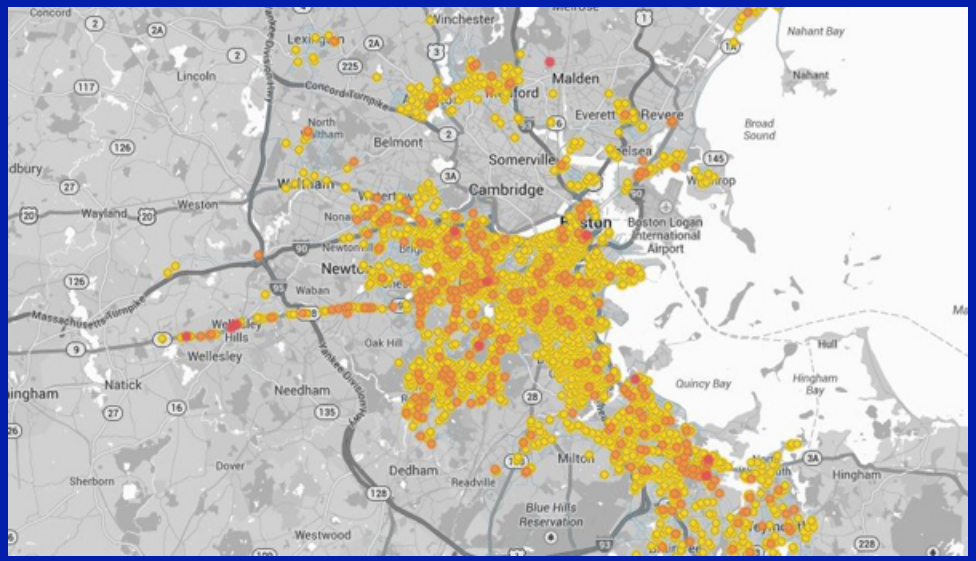
Recent study (Caulton et al., 2014, Proc. NAS, doi: 10.1073/pnas.1316546111) found sources of methane in southwestern Pennsylvania in June 2012 with emissions rates 1,000 times higher than those estimated by the EPA.

White House ordered the EPA to identify ways to cut methane from oil and gas production, with any new rules to be in place by the end of 2016. Why so long?

Google car detecting methane leaks

red dots indicate places where methane was leaking at a rate of more than 60,000 liters per day (sewer pipes)

also detects leaking natural gas vehicles



Katey Walter Antony, Univ. of Alaska, Fairbanks

https://www.youtube.com/watch?v=YegdEOSQotE

Conclusion

Methane is adding to the warming problem.